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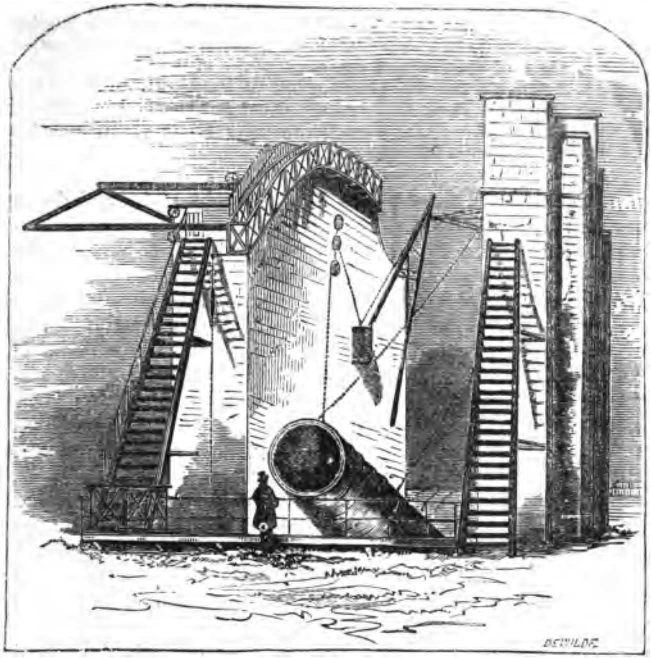

THE GREAT ROSSE TELESCOPE.

THE PLANETS:

ARE THEY INHABITED WORLDS?

CHAPTER I.

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1. When we walk abroad on a clear starlight night, and direct our view to the aspect of the heavens, there are certain reflections which will present themselves to every meditative mind. Are those shining orbs, which in such countless numbers decorate the firmament, peopled with creatures endowed like ourselves with reason to discover, with sense to love, and with imagination to expand to their boundless perfection the attributes of Him of "whose fingers the heavens are the work?" Has He, who "made man lower than the angels to crown him" with the glory of discovering that light in which He has "decked himself as with a garment," also made other creatures with like powers and like destinies, with dominion over the works of His hands, and having all things put in subjection under their feet? And are those resplendent globes which roll in silent majesty through the measureless abysses of space, the dwellings of such beings? These are inquiries against which neither the urgency of business nor the allurements of pleasure can block up the avenues of the mind.

2. Those whose information on topics of this nature is most superficial, would be prompted to look immediately for direct evidence on these questions; and consequently to appeal to the telescope. Such an appeal would, however, be fruitless. Vast as are the powers of that instrument it still falls infinitely short of the ability to give direct evidence on such inquiries. What will a telescope do for us in the examination of any of the heavenly bodies, or indeed of any distant object? It will accomplish this, and nothing more; it will enable us to behold it, as we should see it at a lesser distance. But, strictly speaking, it cannot accomplish even this: for to suppose it did, would be to ascribe to it all the admirable optical perfection of the eye; for that instrument, however nearly it approaches the organ of vision, is still deficient in some of the qualities which have been conferred upon the eye by its Maker.

3. Let us, however, assume that we resort to the use of a telescope having such a magnifying power, for example, as a thousand: what would such an instrument do for us? It would in fact place us a thousand times nearer to the object that we are desirous to examine, and thus enable us to see it as we should at

that diminished distance without a telescope. Such is the extent of the aid which we should derive from the instrument. Now, let us see what this aid would effect. Take, for example, the case of the moon, the nearest body in the universe to the earth. The distance of that object is about 240,000 miles; the telescope would then place us at 240 miles from it. Could we at the distance of 240 miles distinctly, or even indistinctly, see a man, a horse, an elephant, or any other natural object? Could we discern any artificial structure? Assuredly not! But take the case of one of the planets. When Mars is nearest to the earth, its distance is about 50,000000 of miles. Such a telescope would place us at a distance of 50,000 miles from it. What object could we expect to see at 50,000 miles' distance? The planet Venus, when nearest the earth, is at a distance something less than 30,000000 of miles, but at that distance her dark hemisphere is turned towards us; and when a considerable portion of her enlightened hemisphere is visible, her distance is not less than that of Mars. All the other planets, when nearest to the earth, are at much greater distances. As the stars lie infinitely more remote than the most remote planet, it is needless here to add anything respecting them.

4. It is plain, that the telescope cannot afford any direct evidence on the question whether the planets, like the earth, are inhabited globes. Yet, although science has not given direct answers to these questions, it has supplied a body of circumstantial evidence bearing upon them of an extremely interesting nature. Modern discovery has collected together a mass of facts connected with the position and motions, the physical character and conditions, and the parts played in the solar system by the several globes of which that system is composed, which forms a body of analogies bearing on this inquiry, even more cogent and convincing than the proofs on the strength of which we daily dispose of the property and lives of our fellow-citizens, and hazard our own.

5. We shall first consider this interesting question so far as relates to the group of planets, which from several striking analogies which they bear to our own, have been called the terrestrial planets. These planets, in number three, and by name Mercury, Venus, and Mars, revolve with the earth around the sun, at distances from that luminary less in a great proportion than the other members of the solar system. We shall next extend the same inquiries to the other bodies composing that system, as well as to those which are distributed through the more distant regions of the universe.

6. In considering the earth as a dwelling-place suited to man and to the creatures which it has pleased his Maker to place in

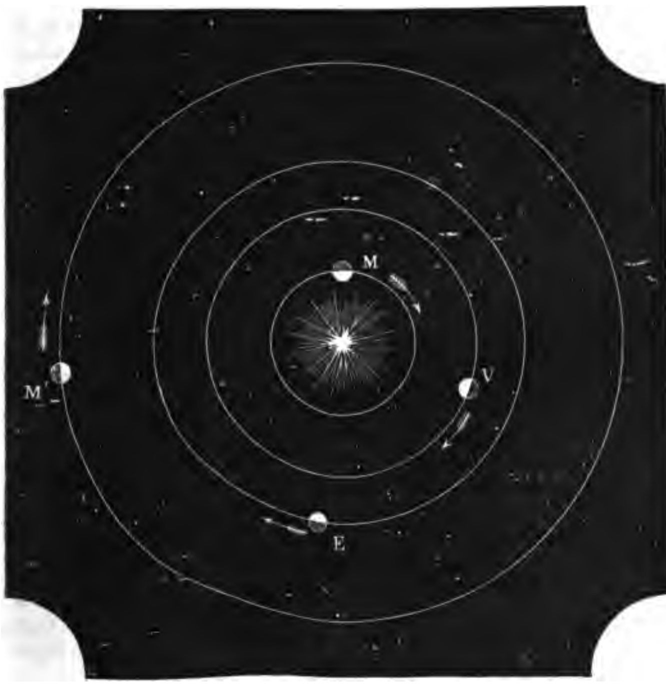
subjection to him, there is a mutual fitness and adaptation observable among a multitude of arrangements which cannot be traced to, and which indeed obviously cannot arise from, any general mechanical law by which the motions and changes of mere material masses are governed. It is in these conveniences and luxuries with which our dwelling has been so considerately furnished, that we see the beneficent intentions of its Creator more immediately manifested, than by any great physical or mechanical laws, however imposing or important. If—having a due knowledge of our natural necessities—of our appetites and passions—of our susceptibilities of pleasure and pain—in fine, of our physical organisation—we were for the first time introduced to this glorious earth with its balmy atmosphere—its pure and translucent waters—the life and beauty of its animal and vegetable kingdoms—with its attraction upon the matter of our own bodies just sufficient to give them the requisite stability, and yet not so great as to deprive them of the power of free and rapid motion—with its intervals of light and darkness, giving an alternation of labour and rest nicely corresponding wlth our muscular powers—with its grateful succession of seasons and its moderate variations of temperature so justly suited to our organisation: with all this fitness before us, could we hesitate to infer that such a place must have been provided expressly for our habitation?

7. If, then, the discoveries ot science disclose to us in each planet, which, like our own, rolls in regulated periods round the sun, provisions in all respects similar—if they are proved to be similarly built, ventilated, warmed, illuminated, and furnished—supplied with the same alternations of light and darkness by the same expedient—with the same pleasant succession of seasons—the same diversity of climates—the same agreeable distribution of land and water—can we doubt that such structures have been provided as the abodes of beings in all respects resembling ourselves? The strong presumption raised by such analogies is converted into a moral certainty, when it is shown from arguments of irresistible force that such bodies are the creation of the same Hand that raised the round world and launched it into space. Such, then, is the nature of the evidence which science offers on this interesting question. Let us endeavour to strip it of such technical forms of language and reasoning as are intelligible only to the scientific, and to present it so as to be easily and agreeably comprehended.

8. If we look at a plan of the solar system, but more especially of that part of it to which we desire now more particularly to call the attention of the reader, the first glance will impress us with

the idea that the earth is only an individual of a class of worlds of which the three other planets are members. Look at the annexed plan, fig. 1, which represents the relative positions of these planets in their courses round the sun. The position of Mercury is represented at M, that of Venus at V, that of the Earth at E, and that ot Mars at M′. The circles represent the paths in which they severally move in going round the sun, which is represented radiating its light and heat from the common centre.

Fig. 1.



These four bodies are globular in their forms, and not extremely different in their magnitudes. They move round the sun as a common centre in circular orbits, as indicated in the plan, and nearly in the same plane.

Now the impression is irresistible that these four globes are bodies of the same class; but let us see the purposes in the economy of nature which are fulfilled by this common character given to the motions of these planets and the position of the sun.

9. We find, upon considering the qualities of organised bodies, and especially of the species of the animals and vegetables upon the earth, that the maintenance of their physical well-being is essentially dependent on the uniformity and regularity with which hey are supplied with the two great physical principles of light and heat. Should these, or either of them, be subject to any extreme variations, such vicissitudes would be incompatible with the organisation of the species. There is a cold on one hand and a heat on the other, under which no organised body could continue to exist, and there are still narrower limits within which it is necessary to confine the temperatures they are exposed to, in order to secure the perfection of their physical health. There are also degrees of light, the intensity of which would be incompatible with the continued perfection of the organs of vision.

Seeing then how essential to the well-being of the creatures that people this globe an uniform supply of light and warmth is, we are naturally led to examine the expedient by which this necessary provision has been secured to them. If we had a fire in our neighbourhood which at once supplied light and heat, and that circumstances obliged us continually to shift our position in relation to it, how should we move so as to receive an uniform degree of illumination and warmth from it? Could we move in any other path than that of a circle around the fire as a centre, keeping thereby always at the same distance from it? Now this is exactly the path in which the earth moves, as represented in the plan; and we find that the three other planets severally also move in circles, each keeping continually at the same distance from the common fountain of light and heat.*

10. Since this motion in the case of the earth is an expedient whereby an important end is attained, analogy justifies the conclusion that it is to be regarded likewise as the expedient for the attainment of a similar end in each of the planets. But it will probably be said that the planets are at different distances from the sun: therefore, that although it must be admitted that each planet (considered *per se*) is supplied uniformly with light

* The paths of the planets in moving round the sun when submitted to extremely accurate examination prove to be oval in their form, but their departure from the circular form is so very minute, that if such an orbit were described in its proper proportions on paper, it would be indistinguishable from a circle. For all the purposes of the argument here advanced, the paths of the planets may, therefore, be taken to be concentric circles with the sun in the common centre.

and warmth by this circular motion; yet the intensity of these principles to which they severally are exposed, comparing one with another, is so extremely different as to destroy all analogy between them.

11. In answer to this, we are, however, to consider that the influence of light and heat upon a planet does not depend solely on its distance from the sun. The heat, as is well known, produced by the solar rays, depends on the density of the air which surrounds the objects affected by it. Thus we find the temperature, at great elevations in our own atmosphere, considerably lower than at the mean surface of our globe; because at these elevations the air becomes so thin as to be incapable of collecting and retaining the sun's heat. We can, therefore, easily imagine, provided the existence of planetary atmospheres be conceded, that their densities have been so regulated, that the nearest planets to the sun, which receive the greatest intensity of its rays, may not, after all, be subject to a greater temperature than the most remote ones, which are exposed to the least intensity of its rays: just as we find that the temperature of the summits of lofty mountains at the tropics is as low as the temperature of some of the polar latitudes. It is plain, then, how the effects of the various distances of the planet from the sun may be equalised and compensated. The means of accomplishing this are provided in the form of atmospheres, as we shall presently see.

12. But let us turn to the consideration of the solar light. The intensity of the sun's light varies with his distance exactly in the same proportion as that of his heat; and the brightness of the day in each of the planets would be in the exact proportion of the apparent magnitudes of the sun as seen from them severally. Now, it is evident, that as we approach any object, its visual magnitude increases, and, as we recede from it, its visual magnitude diminishes. A balloon seen at the place from which it makes its ascent appears of vast dimensions. Seen at a great height in the air, it is diminished to a mere spot. Looking from the summit of the cliffs of Dover, Edgar says to Kent—

Half way down
Hangs one that gathers samphire; dreadful trade!
Methinks, he seems no bigger than his head:
The fishermen, that walk upon the beach,
Appear like mice; and yon' tall anchoring bark,
Diminish'd to her cock; her cock, a buoy
Almost too small for sight.

Knowing the relative distances of Mercury, Venus, the Earth, and Mars from the sun, nothing is more easy than to ascertain by calculation the relative apparent magnitudes of the sun, as seen from them severally; since the apparent diameter must decrease in exactly the same proportion as the distance from the sun increases, and *vice versâ.* In this way we find that the sun, as seen from the four planets, has the relative magnitudes shown in fig. 2, where E being taken to represent the disc of the sun, as seen from the Earth, M will be its disc as seen from Mercury, V, as seen from Venus, and M′, as seen from Mars.

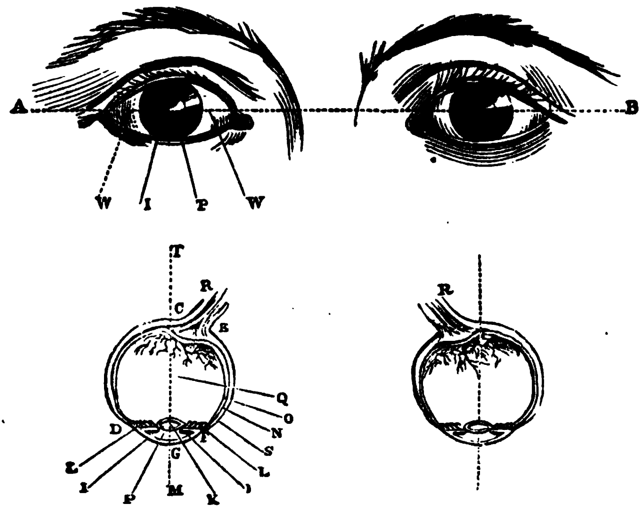
The brightness of the sun's light at Mercury will be greater than at the Earth, in the same proportion, as M is greater than E, and its light at Mars will be less bright than at the Earth, in the same ratio as that in which M′ is less than E. It might, therefore, be concluded that the light at Mars would be too feeble, and the light at Mercury too intense for vision.

Fig. 2.

13. A slight consideration of the structure and functions of the eye will, however, demonstrate how easily such difficulties may be removed. The perception of light which any creature possessing that organ acquires, depends (*cæteris paribus*) upon the magnitude of the circular aperture or *foramen*, in front of the eye, called the *pupil*, which has, externally, the appearance of a circular black spot; but which is, in reality, a circular hole through which the light is admitted to the interior of the chamber of vision, there to affect the membranous coating which transmits its influence to the brain and causes the sensation.

This will be better understood by reference to the annexed figures, 3 and 4, the former representing the external form and appearance of the eye, and the latter a section of the eye-ball, made in a horizontal plane through the dotted line A B. The line P (fig. 3), points to the pupil, I to the iris, a coloured ring surrounding the pupil; and W to the white of the eye. In fig. 4, P points to the pupil, I to the iris, and N and O to a membranous coat full of nerves and blood-vessels which lines the inside of the eye-ball. The light, entering from M G through the pupil, and passing through the internal humours of the eye, which are perfectly transparent, strikes on that membranous coating and acts upon it in such a manner as to produce a perception. The apparent brightness of the light will obviously depend on the quantity which enters the eye through the pupil, and the sensitiveness of the membranous coating on which it acts.

Fig. 2.



14. If, then, the pupils of eyes on Venus or Mercury were smaller, and those on Mars larger, in the same proportion as E is smaller than V and M (fig. 2), and larger than M′, the membranous coating having the same sensibility, the apparent brightness of the solar light would be the same to all of them. Or supposing the pupils of the eyes to have the same magnitude, a like effect would be produced by imparting to the membranous coatings different degrees of sensibility, the sensibility on Venus and Mercury being less, and on Mars greater, than those of the eyes upon the Earth.

15. In considering the powers of locomotion and strength conferred upon animals on the earth, we find that they have certain limitations; that animals are capable of exercising these powers for certain periods, varying, it is true, among individuals, but still in the main comprised within certain narrow limits. We find that after the lapse of certain intervals, bodily repose is wanted. But besides the disposition to activity and locomotion and the alternate want of rest, animals in general have also

other wants and capabilities of enjoyment which are periodical. Thus they are capable of wakefulness for certain periods, after which recurs the physical want of sleep. Now upon a general survey of the creation, it is found that the average period which must regulate the intervals of labour and rest, of wakefulness and sleep, corresponds in the main with that which regulates the alternations of light and darkness.

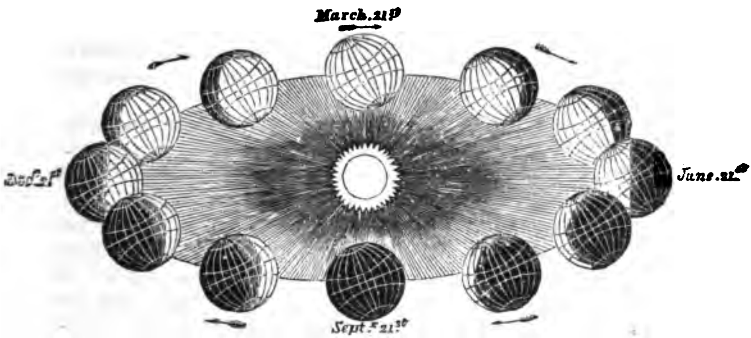
In the vegetable kingdom we find prevailing also periodical functions, certainly not so obvious and apparent, but not on that account the less interesting, which are ascertained to have the same close alliance with the period that regulates the returns of light and darkness. Plants undergo certain changes and suffer certain effects, in the presence of solar light, which are different from, and in some respects contrary to, those which they undergo in its absence. These changes are essential to the vegetable health of the creature; without them the tribes of plants would be extinct.

16. The duration of these operations is just as essential as their alternations. Light must be present a certain time, and neither more nor less; and its absence must be equally regulated by limits, otherwise the plant must perish. There is, then, it is evident, an essential relation between the functions and qualities of the vegetable kingdom—between the power of activity, the susceptibility of enjoyment and the physical wants of animals, and the periods which separate light from darkness; but what are those periods? What is the mechanical expedient to which He has resorted to accomplish His inscrutable purposes, who divided the light from the darkness, and "*saw that it was good*"? Nothing can be more simple. Nothing can be more beautiful. Nothing can be more admirably perfect. While the globe of the earth makes its annual course round the sun, it has at the same time a spinning motion, on a certain diameter, as an axis, in virtue of which it successively exposes all parts of its surface to the light and warmth of the sun. Each complete rotation is accomplished in the interval which we call twenty-four hours. All points on our earth are alternately exposed to and withdrawn from the solar light. The earth, in its annual movement round the sun, is represented in Fig. 5. It will be seen that one hemisphere is shone upon by the sun while the other is dark. But as the globe revolves on its axis once in twenty-four hours, each side is successively exposed to the sun's light and heat, for average intervals of twelve hours.

The culinary process of turning meat by a string or on a spit, successively exposing every side to the heat of the fire, is a homely illustration of this expedient.

Now when we reflect on the correspondence between these intervals and the indispensable wants of all organised creatures, can we for a moment doubt that the earth was made to turn upon its axis in that particular time rather than any other, because it was more conducive than otherwise to the well-being of the countless myriads of species, the production of the Divine

Fig. 5.



hand, for whose enjoyment the earth was made? Had the time of rotation been materially less than it is, our periods of activity and labour would be too short to prepare us for the return of darkness, and had the time of rotation been greater, we should have needed rest before the return of the natural epoch designed for it. As it is, the natural vicissitudes are nicely adapted to our wants; and yet our organisation is in no way connected physically with the rotation of the earth, by any relation of the nature of cause and effect, and to suppose such an adaptation fortuitous, would be an outrage upon all principles of probability. This mutual fitness is, then, another of the many proofs which offer themselves that the earth as a dwelling, and man as a dweller, have been expressly designed each for the other.

17. Many examples may be given of this correspondence between the time of rotation of the earth upon its axis and the periodical functions of the organised world. Linnæus proposed the use of what he termed a *floral clock*, which was to consist of plants which opened and closed their blossoms at particular hours of the day. Thus, the day-lily opens at five in the morning, the common dandelion at six, the hawk-weed at seven, the marigold at nine, and so on; the closing of the blossoms marking

corresponding hours in the afternoon. Nor can this be regarded as a specific effect of light upon the plants, for when the flowers are introduced into a dark chamber they are found to open and close their blossoms at the same times.

18. The necessity of maintaining a correspondence between the intervals of activity and repose, the taking of food, &c., and the period of light and darkness, was shown in the case of voyages made to the north pole, where navigators attained those latitudes in which the sun never rises for several weeks, in which cases it was found necessary to make the crews of the ships adhere to the habit of retiring at nine o'clock and rising at a quarter before six. Under these circumstances they enjoyed a state of salubrity very remarkable, notwithstanding the trying severity of climate to which they were exposed.

As an example of creative beneficence the rotation of the earth in twenty-four hours would lose none of its force if that particular period, like the time of its revolution round the sun, were a necessary consequence of an established physical law. It is interesting, nevertheless, to observe that such is not the case. No law of matter would have prevented the earth from receiving any other rate of rotation more or less rapid. It might have made a single rotation a month, in which case the average alternations of day and night would have been a fortnight, or it might have made a single rotation in an hour, in which case the alternations would have been thirty minutes. Such conditions though physically admissible, would be obviously incompatible with the continuance of the organised world. We are, then, to regard this period of diurnal rotation of the earth and its admirable adaptation to the wants and well-being of the creatures which inhabit it, not as the result of any law of physics, but as a provision directly emanating from divine beneficence, and as an example of the infinite skill of the hand which at the moment of its creation launched the earth into space.

19. Seeing then,—that the expedient of making the globe of the earth turn upon its axis in twenty-four hours is one productive of such multifarious benefits, and so intimately related to the organised species of our globe, that were it to turn otherwise than it does, in a greater or less time, an entire derangement of the animal or vegetable economy would ensue,—it becomes an interesting question to ascertain whether the other planets are provided with a similar expedient; and if so, to what extent the application of such expedient corresponds with the case of the earth. We accordingly find that all the planets without exception have a motion of rotation on certain diameters as

an axis, while they make their periodical revolutions round the sun, and that the diameter on which they so rotate has been selected in such a manner as to secure to each of them regular alternations of light and darkness in every part of their surfaces; in fact, they, like the earth, have days and nights. But are those days and nights regulated by the same intervals as ours? for that is an important question; such intervals being as we have shown, a key to the organisations and functions of the creatures upon them respectively.

Fig. 6.

20. When a telescope of adequate power is directed to the planet Mars, it is observed that the surface of his disc is diversified by certain features of light and shade like that of the moon. Some of these lights and shadows are shifting and variable, but most of them are permanent and unalterable. In fig. 6, a view of these permanent lineaments as they are presented in a certain aspect is given, taken from a telescopic drawing of the planet, made by M. Madler, the celebrated Prussian observer.

Now if these outlines of light and shade be watched for some hours, they will be observed to be carried slowly from one side of the disc to the other. Each of these will in succession disappear at one side, others coming into view at the other, and after an interval of about twelve hours, the marks which disappeared at one side will be found to re-appear at the other, and this goes on continually.

It is scarcely necessary to say that those are the effects of the rotation of the planet on its axis, and since the same features after disappearing at one side always return to the same precise position on the disc after an interval of 24h. 37m. 22s., it follows that the planet turns upon its axis in that interval.

21. By means very nearly similar strong reasons have been found for concluding that the globe of Venus turns on its axis in 23h. 21m. 21s., and that of Mercury in 24h. 5m.

22. Thus it appears that these three planets, not only have days and nights, but that these days and nights are for all practical purposes similar to those of the Earth. They are regulated by the same average duration; and He that gave them those alternations has seen it good to "divide the light from the darkness" after the same fashion.

If, then, the duration of our days and nights be evidently regulated with a view to the accommodation and well-being of the organised creatures to which the earth has been appropriated, we are surely warranted by all analogy in concluding that the adaptation of the same expedients in the planets Mercury, Venus, and Mars, has been directed to the same beneficent purposes, and that the creatures upon them, as upon the earth, are so organised as to require the same intervals of labour and rest, of activity and repose, of wakefulness and sleep.

23. In considering the expedient by which days and nights are secured to the planets, it is interesting to contemplate the particular position of the diameters on which they have been made to turn. There are a great variety of different diameters upon which the earth might have spun while it revolves round the sun. It might, for example, have turned on a diameter at right angles to its annual orbit. If such had been the case we should have had equal days and nights throughout the entire year, and at every part of the earth.

If its axis, as it might have been, had been in the plane of its annual orbit, the sun would have been constantly above the horizon for an interval of several weeks in summer, and constantly below it for a like interval in winter. The duration of these intervals of incessant light and incessant darkness would have varied in different parts of the earth, increasing with the latitude. No diurnal alternations of light and darkness would take place except for a short interval before and after the equinoxes.

It is not necessary to enlarge upon the consequences of such an arrangement, to render it apparent that they would be utterly incompatible with the well-being, and perhaps even with the maintenance, of the organised world.

In the first of the cases here supposed, we should have been deprived of the seasons and of the means of maintaining a convenient chronology, and in both cases we should be stripped of many of the benefits and utilities arising from the present arrangement.

24. But, between these extreme possible positions of the axis of rotation, there are an infinite variety which would have been nearly as unsuitable. Had the axis leaned down nearly to the ecliptic, consequences would have ensued almost as fatal as those which a position in the plane of the ecliptic would have inferred. We find, however, in fact, that a position has been given to this axis slightly inclined from the perpendicular, as represented in fig. 5. In virtue of this inclination the northern hemisphere leans toward the sun during one half of the year, and

the southern hemisphere during the other. We enjoy by this expedient the grateful succession of seasons; it is thus that spring, summer, autumn, and winter, follow each other with pleasant variety, marking in their progress by obvious phenomena the course of time. Yet this inclination or stooping of the axis is so regulated that the extremes of the seasons are confined within such moderate limits as are necessary and conducive to the physical well-being of the numerous tribes which people the earth.

It is true that this succession or seasons was not indispensably necessary to the continuance of the races that inhabit the earth, for had the axis been perpendicular to the orbit so as to render days and nights perpetually and everywhere equal, the organised world would still have continued to exist though subject to certain modifications.

25. Now, on observing the position of the axis on which Mars revolves, we find that it is inclined to the plane of the orbit of that planet, at an angle of 28° 27′, not very different from that at which the axis of the Earth is inclined to the ecliptic. The seasons and climates of Mars are therefore similar to those of the Earth.

Observation has not yet determined the position of the axes of rotation of Venus and Mercury, but it is probably not materially different from that of Mars and the Earth.

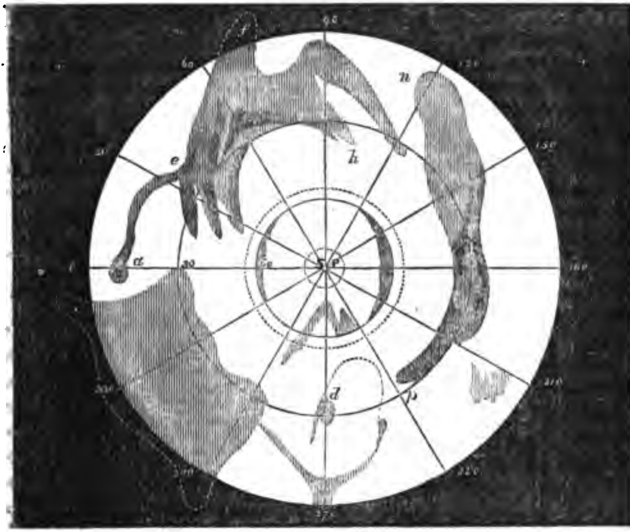
Thus we see that not only the same alternations of light and darkness but the same succession of seasons, regulated by nearly the same limits of temperature, the same diversity of climates, separated by nearly the same limits of latitude which prevail on Earth, have also been ordained for those three planets.

26. The atmosphere which surrounds the earth is an appendage which has an obvious and important relation to the animal and vegetable kingdoms. That respiratory beings depend on it for the maintenance of their vitality is obvious. The mechanical and chemical apparatus of the breathing organs is expressly adapted to it. Its relation to vegetable life is not less important.

But besides these qualities, without which life would become extinct on the surface of the globe, the atmosphere administers to our convenience and pleasures in other ways. It is the medium by which sound is transmitted; and as the apparatus of the lungs is adapted to operate chemically upon it, so as to impart to the blood the principle by which that fluid sustains life, so the exquisite mechanism of the ear is constituted to receive the effects of its pulsations and convey them to the *sensorium* to produce the perception of sound. Again, the mechanism of the organs of voice is adapted to impress on the atmosphere those pulsations, and thereby to convey its intonations to the correspondingly susceptible organisation of the ear. Without the atmosphere, therefore, even supposing we could live in its absence, however perfect might be our organs of speech and hearing, we should possess them in vain. Voice we might have, but no word could we utter; listeners we might be, but no sound could we hear; endowed with the full powers of hearing and speaking, we should nevertheless be deaf and dumb.

Another important manner in which the atmosphere administers to our convenience is, by diffusing in an agreeable manner the solar light, and mitigating its intensity. In this respect, the atmosphere may be considered as performing in regard to the sun what the imperfect transparency of a ground-glass shade performs for the glare of the lamp. In the absence of an atmosphere, the light of the sun would only illuminate objects on which its direct rays would fall; we should have no other degrees of light but the glare of intense sunshine, or the most impenetrable darkness. Shade, there would be none; the apartment whose casement did not face the sun, at the mid-day would be as at midnight. The presence of a mass of air extending from the surface of the earth upward to a height of more than forty miles, becomes strongly illuminated by the sun. This air reflects the solar light on every object exposed to it, and as it spreads over every part of the earth's surface, it conveys with it the reflected, but greatly mitigated light of the sun.

When the evening sun withdraws its light, the atmosphere continuing to be illuminated by its beams, supplies the gradual declining twilight which terminates in the shade of night. Before it rises, in like manner, the atmosphere is the herald of its coming, and prepares us for its splendour by the grey dawn and increasing intensity of morning twilight. In the absence of an atmosphere, the moment of sunset would be marked by an abrupt and instantaneous transition from the blaze of solar light to the most impenetrable darkness; and for the same reason, the morning would be characterised by an equally abrupt change from absolute darkness to broad, unmitigated sunshine.



MARS.

SKETCH OF THE OUTLINES OF CONTINENTS AND OCEANS, AND THE SNOW REGION OF THE POLAR CIRCLE ON THE SOUTHERN HEMISPHERE OF THE PLANET MARS, FROM THE OBSERVATIONS OF MÄDLER.

THE PLANETS:

ARE THEY INHABITED WORLDS?

CHAPTER II.

1.—Uses of an atmosphere—colour of sky.—2. Its effects on temperature.—3. Planetary atmospheres observable.—4. Clouds visible in them.—5. Hence rain, hail, and snow.—6. Winds manifested on the planets.—7. Clouds on Mercury, Venus, and Mars.—8. Continents and oceans.—9. Effect of gravity on planets.—10. Its relation to organised beings.—11. Adaptation of organised beings to the force of gravity.—12. Gravity on Mercury, Venus, and Mars.—13. Solar system—Planets.—14. Number of planets—groups.—15. Inner group—the twenty-five grouped round the sun.—16. The outer group—Jupiter, Saturn, Uranus, and Neptune.—17. Their distances from the sun, from each other, and from the earth.—18. Apparent diameters of Sun's disk as seen from these planets—Sun's light and heat.—

19. Question of habitability of these planets considered in reference to sun's light and heat.—20. Great comparative magnitude of these planets—Their volumes—Question of habitability continued.—21. Proportionate population, if inhabited.—22. Investigation of physical causes incompatible with their being habitable globes.—23. Application of such causes to Jupiter, and reasoning thereon—Necessity of organised world being different from that on the earth.—24. Comparative volume and density of the Earth and Jupiter.—25. Comparison of relative quantities of gravitating matter in Saturn, Uranus, and Neptune, and in the Earth—and of density.—26. Comparative weights of bodies placed upon such planets and on the Earth.—27. General results of inquiry as to the habitability of these planets.—28. Atmosphere of these planets.—29. Their diurnal revolution—General observations on rotation and their results—Position of axis of rotation.

1. In the absence of an atmosphere we could have no clouds; day would be one unvaried wearisome glare of the sun. The bright azure sky, so grateful to the sight, is nothing more than the natural colour of the air reflected to the eye. The air which fills a room is not perceived to be blue only because it is not present in sufficient quantity to excite in the eye any perception of its colour; just as a glass of sea-water seems translucent and colourless, while the same water viewed through a considerable depth, appears with its proper hue of green.

When we look up, therefore, through forty miles of air, we behold that fluid of its proper tint of blue. In the absence of the atmosphere the great vault of the heavens would present one unvaried and eternal black, the stars dimly twinkling here and there, the whole forming a most funereal contrast with the bright orb which would be seen holding its solitary course through this eternal expanse of darkness.

2. The atmosphere produces effects on the temperature of our habitation which are not less important. It retains and diffuses warmth, whether proceeding from the sun above, or from sources of internal heat within the globe itself. What situation with respect to temperature we should be placed in by its absence, or even by a considerable diminution of its quantity or density, may be easily inferred by considering the state of those parts of the earth which are placed at such an altitude as to leave below them a large portion of the atmosphere. The summits of lofty ridges, such as those of the Alps, the Andes, and the Himalayah, are examples of this. No intensity of direct solar heat can compensate for the absence of a sufficiently dense atmosphere, and even within the tropics, water cannot exist in a liquid form at elevations above 14,000 feet. The summits of the Andes are clothed in everlasting snow.

Had we, therefore, been unprovided with an atmosphere, or even had our atmosphere been so rare and attenuated as it is at an elevation of three miles (scarcely one-tenth of its whole height), the waters of our oceans would have been solid. Vegetation could never have existed, and in spite of the light and genial warmth of the sun—in spite of the grateful changes of season—in spite of the beautiful and simple provision by which spring succeeds winter, and is followed by summer and autumn, the earth would have been a barren and arid waste, enveloped in a shell of eternal ice, devoid of life, motion, form, and beauty.

Seeing, then, how necessary to the existence of an animal and vegetable world an atmosphere is—how indispensable its presence is to a society of creatures whose means of intercommunication is sound—and yet bearing in mind at the same time that this atmosphere is not essential to any of the great mechanical functions of the earth in the economy of the solar system—considering also that without its presence the part which that earth, as a whole, performs in the society of the planets, would be the same as it now is—can we come to any other conclusion than that this atmosphere was cast around the earth expressly with a view to the well-being of its occupants—to afford them a genial warmth—to give them diffused and gentle light—to convey the varieties of sound—to promote and facilitate social felicity, by supplying the means of intercommunication by language—to preserve the seas liquid—and supplying propitious winds to stimulate the intercourse of nations and knit together the races of beings who occupy its most distant points by the kindly bonds of reciprocal beneficence? If then such be admitted to be some among the many of the purposes and uses of our atmosphere, the question whether other planets, in situations resembling ours, are occupied by similar beings, must be materially influenced by the result of an investigation as to whether or not these planets are supplied with like atmospheres.

3. Telescopic observations have most clearly and satisfactorily answered this question. The atmospheres around the planets are as palpable to sight as the clouds which float on our own. Venus and Mercury are enveloped in thick atmospheres: in the former the air is especially conspicuous, nay, we can even see the morning and evening twilight in that distant world. The atmosphere of Mars is likewise apparent. We see the clouds floating on it.

4. The ascertained existence of clouds in the planets proves more than the mere presence of atmospheres upon them. An atmosphere is necessary to support clouds, but must not be

identified with them. Clouds are no more parts of the atmosphere than the mud and sand which float in a turbid river are parts of its waters. Water is converted into vapour by the agency of the sun and wind. This vapour, when it escapes from the surface of the liquid, is generally lighter, bulk for bulk, than that part of the atmosphere contiguous to it. It rises into more exalted regions, where, by the agency of cold, and by electricity, it is made to resume its liquid state, but in such minute particles that it floats and forms those semi-opaque masses called clouds. Clouds are, then, in fact, water existing in a very minute state of mechanical division, and affected in peculiar ways by electricity.

5. When these particles are caused to coalesce into drops or spherules of water—an effect which may arise from temperature or electricity, or both combined—their weight renders their further suspension impossible, and they descend to the surface in the form of rain: or if the cold be so great as to congeal the particles before they coalesce into globules, they descend in the form of snow; or, finally, if by the sudden evolution of heat caused by electrical influences their solidification is effected in drops, they come down in the form of hail.

Thus wherever the existence of clouds is made manifest, *there* WATER must exist; *there* EVAPORATION must go on; *there* ELECTRICITY, with its train of kindred phenomena, must reign; *there* RAINS must fall; *there* HAIL and SNOW must descend.

6. That healthful and refreshing winds agitate the atmospheres of the group of worlds in the centre of which our sun presides, and of which it is the common bond—that showers refresh their surfaces—that their climates and seasons are modified by evaporation—that their continents are bounded by seas and oceans—that intercourse is facilitated by winds which convert the surfaces of their waters into highroads for nations—these and a thousand other consequences of what has been here explained, all tending to one conclusion—that these various globes are placed in the system for the same purpose as the earth—that they are in fact, the dwellings of beings in all respects, even from their lowest physical wants to their highest social advantages, like ourselves, crowd upon the mind so thickly that we can scarcely give them expression in a clear and intelligible order.

It may be asked whether by immediate observation we may not perceive the geographical surfaces of the planets, so as to declare by direct survey their divisions of land and water, mountain and valley, and other varieties of surface.

Even the most superficial view of the subject will render apparent some great difficulties which must obstruct such an inquiry with respect to most of the planets. The very presence of those atmospheres and the clouds with which they are loaded, offers a serious obstruction to any observations having for their object to ascertain the geographical character of their surfaces. The great distance of some of them is a formidable obstacle to such an inquiry; still, where some peculiar circumstances favour the observation, something has been done in this investigation.

7. Venus and Mars, the two planets in the system which come nearest to the path of the Earth, are evidently the most eligible objects for such an inquiry, and sufficient has been ascertained, especially with regard to the latter planet, to draw very closely indeed the ties of analogy by which the planets are associated with the earth.

8. The existence of continents and oceans, and even the configuration of their outlines has been clearly traced on Mars. The snow which covers his polar regions during the winter, has been distinctly seen, and has even been observed partially to dissolve and disappear under the influence of the summer heat. The clouds with which Venus and Mercury are so constantly enveloped, combined with other obstructions peculiar to the positions of these planets, have rendered like observations respecting them impracticable. It has, nevertheless, been ascertained that their surface, like that of the Earth, is marked by mountain-chains of great elevation.

9. In tracing the analogies which prove the suitableness of the planets for habitable globes, and which connect them by ties of kindred with the earth, one of the most important and interesting is dependent upon the quantity of matter composing these planets, compared with their volumes or bulks. Let us see how this affects the condition of the organised creatures that dwell upon them.

10. All organised beings, whether animal or vegetable, are endowed with a certain limited amount of bodily strength. In the case of animals, which have powers of locomotion, this strength is regulated with reference to their weight, and the extent and quantity of motion necessary for their well-being on the surface of the globe. The structure of every animal is such, in the first place, as to give it strength to support and move its own body; but this is not enough; it must have a further amount of disposable force to enable it to supply its own wants by the pursuit of its prey; by the collection of its food; by the erection of its dwelling; and, in general, by its labour in the supply of its physical wants. In the case of vegetables, the strength must be sufficient to support its weight, and resist those external

disturbances to which it is exposed—such as the action of winds and other natural effects. But what, let us ask, regulates this necessary quantity of strength? What is the chief resistance which it has to overcome? We answer, mainly the weight of the creature itself. But again; what is this weight? It is a force produced by what? By the combined attractions of the whole mass of matter composing the globe of the earth, exercised upon the matter composing the creature itself; thus the weight of a man is merely the amount of the attraction of the globe of the earth exercised upon the matter composing the body of the man. The amount of this attraction, therefore, depends upon the quantity of matter in the earth; but not on that alone; it is a universal law of nature, that the energy of the attraction exerted by matter, is increased with the proximity of the attracted body to the centre of the attracted mass. Now, if the matter composing the globe of the earth were condensed into half its present bulk, all bodies placed upon the surface, being proportionally nearer the centre, would be attracted with greater energy; and, on the other hand, if the matter of the earth were swelled into a larger bulk, the distance of objects on the surface from the centre being proportionally increased, the energy of the attraction would be diminished. In the one case the weights of all bodies would be augmented, and in the other they would be diminished. The weights, then, of bodies placed on the surface of the earth depend conjointly on the mass of matter composing the earth, and on its density.

11. It is evident then, that the adaptation which we see usually to prevail between the strength of animals and plants and their weights, is, in reality, an exquisite harmony which is maintained between the strength of these infinitely various tribes of organised creatures, and the mass and density of the globe upon which they are placed; the slightest disturbance or change in this relation would utterly derange the fitness of things, and would render the globe and its occupants, whether animal or vegetable, unsuited to each other. The amount of attraction, or, to use the more familiar term, the weight of the body on the surface of the globe is, then, an index, so to speak, to the organisation of the creatures placed upon the globe. If we would, then, inquire respecting the probable organisation of the dwellers upon the planets, one of the means of our inquiry would be to ascertain what would be the weights of bodies upon their surfaces. Physical science enables us perfectly to accomplish this The masses of matter composing all the planets have been discovered with a great degree of precision. Their magnitudes have also been measured. Now, to ascertain the weights of bodies placed upon

the surface of any of them, it is only necessary to consider their masses and their magnitudes. The weight of a body placed upon any planet is greater or less, *cœteris paribus*, than the weight of a body placed upon the earth, just in proportion as the mass of matter in the planet is greater or less than the mass of matter in the earth. If the distance from the surface to the centre of the planet be double the corresponding distance in the case of the earth, then the weight of bodies upon its surface would, on that account alone, be four times less than in the case of the earth. But if, at the same time, the mass of matter in the planet were sixteen times greater than the mass of matter in the earth, then the weight of bodies on the planet, on that account alone, would be sixteen times greater. The weight, then, on the one score, would be sixteen times greater, and on the other, four times less; the result being that the actual weight under such circumstances would be four times greater than upon the earth. Such are the principles by which may be calculated the weights of bodies upon the surfaces of the different planets.

12. It has been found that the weights of bodies on the surface of Venus are nearly the same as on the Earth, but that on Mercury and Mars the weights of bodies are only half of those which they would have if placed on the Earth. The inference obviously is, that organised beings on Venus would require to be endowed with the same bodily strength exactly as upon the Earth, but that half the strength would suffice on Mars and Mercury. The numerous analogies which we have indicated give the highest degree of probability, not to say moral certainty, to the conclusion that the three planets, Mars, Venus, and Mercury, which, with the Earth, revolve nearest to the sun, are like the Earth appropriated by the Omnipotent Creator and Ruler of the Universe to races very closely resembling, if not absolutely identical with, those by which the Earth is peopled.

13. The solar system consists of the sun, a globe of stupendous magnitude, maintaining a position, relatively fixed in the centre, and thirty-three planets revolving round it in paths which do not differ sensibly from concentric circles.

14. These thirty-three planets are characterised by very striking differences in relative position and in magnitude, and have in relation to these differences been classed in three groups.

15. The inner group consists of four: Mercury, Venus, the Earth, and Mars. They are all included within a circle of 150,000000 of miles radius described round the sun as a centre, the distance of the earth being nearly 100,000000 of miles.

The circumstances attending these globes, their mutual analogies, and the probability, if not the moral certainty, that

Fig. 1.

they are the habitations of organised tribes similar to those which inhabit the earth having been very fully explained, we propose now to explain the circumstances which attend another of these groups.

The manner in which the thirty-three planets are distributed around the sun is represented in fig. 1. The relative distances are there represented as nearly as is practicable on their real scale. Twenty-five of the entire number of planets are crowded together at a distance from the sun about two-and-a-half times greater than that of the earth. These constitute a group apart, characterised by some very curious circumstances, which we shall explain hereafter.

16. The four outer planets, Jupiter, Saturn, Uranus, and Neptune, form the other group which we now propose to examine.

17. The relative distances of these bodies from the sun, from each other, and from the earth, are exhibited in the diagram (fig. 1), where the fifth part of an inch represents one hundred millions of miles. The distance of Jupiter from the sun on the plan being an inch, its real distance is, in round numbers, five hundred millions of miles. That of Saturn being $1\frac{8}{10}$ inch, that of Uranus $3\frac{6}{10}$ inches, and that of Neptune $5\frac{8}{10}$ inches; the actual distances of these three planets are 900, 1,800, and 2,800 millions of miles respectively, all the distances being, as before expressed, in round numbers.

18. When it is considered that the apparent magnitude of the sun and the intensity of its light and heat decrease in a very high proportion as its distance is augmented, it will be evident that that body, considered as the means of illumination and warmth, must minister to these several globes extremely different quantities of those necessary physical

principles. It has been already stated that the apparent diameter of the sun's disk is less in exactly the same proportion as the distance of the observer from that luminary is greater. Since, therefore, the distances of Jupiter, Saturn, Uranus, and Neptune are severally five, nine, eighteen, and twenty-eight times the earth's distance, the apparent diameters of the sun's disk, as seen from them, will be $\frac{1}{5}$, $\frac{1}{9}$, $\frac{1}{18}$, and $\frac{1}{28}$ of its diameter, as seen from the earth.

Fig. 2.

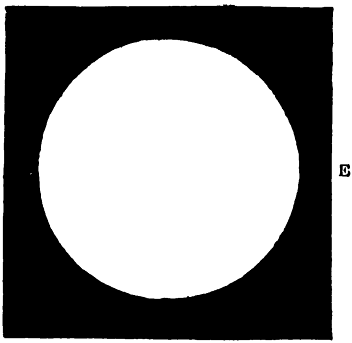
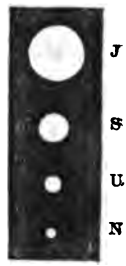


Fig. 3.



If the white circle E (fig. 2) be imagined to represent the apparent disk of the sun, as it is seen by an inhabitant of the earth, then J (fig. 3) will represent its appearance to an inhabitant of Jupiter, S its appearance to an inhabitant of Saturn, U to an inhabitant of Uranus, and N to an inhabitant of Neptune.

The light and heat which it would supply to each of these planets would be in the exact proportion of the apparent surface of the solar disk, and since the areas of circles are as the squares of their diameters, it would follow that the solar light and heat at Jupiter is 25 times, at Saturn 81 times, at Uranus 324 times, and at Neptune 784 times less than at the earth.*

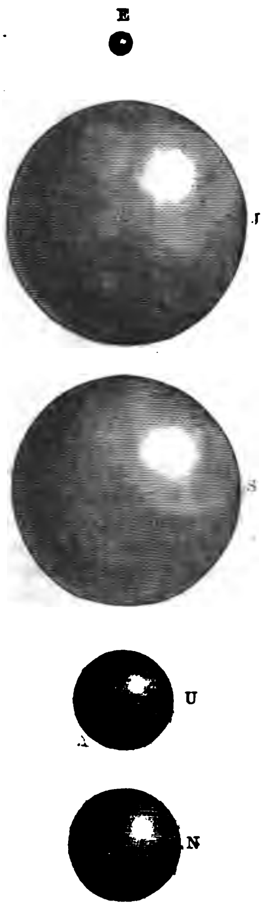
19. In considering the question of the habitability of these globes, it might appear from these numbers that the illuminating and heating power of the sun would be so diminished by distance as to be incompatible with the existence of organised races, at least on the more distant of those planets. It must, however, be considered that the illuminating power of the sun would be the same as at the earth, if only the pupils of the eyes were enlarged in the same ratio as the apparent superficial magnitude of the

* These numbers are not the exact ratios, but are near enough for the present illustration. For more precise results see "Handbook of Natural Philosophy and Astronomy" (2,994).

sun's disk is diminished, or that the same effect would be produced by a proportionally increased sensibility of the retina.

In like manner the diminished calorific power of the sun's rays proceeding from their diminished density, might be compensated by modified atmospheric conditions, just as we find with the same density of the solar rays all climates in ascending on tropical mountains to various altitudes from the level of the sea to the line of perpetual snow.

Fig. 4.



These points have been already so fully developed and explained, that we need not here further insist upon them.

It is apparent, therefore, that so far as the vastness of their distances from the sun compared with that of the earth affects the illumination and warmth supplied to them, there are no grounds for concluding that they may not be the habitations of races organised in a manner not differing in any important respect from those which inhabit the earth.

20. One of the most striking circumstances in which the group of planets now under consideration differ from the earth and the other three which form the terrestrial or inner group is their great comparative magnitude. The actual diameter of the earth is, in round numbers, 8000 miles. That of Jupiter is 88,000, that of Saturn 75,000, that of Uranus 35,000, and that of Neptune 37,500 miles. The diameter of Jupiter is therefore 11, that of Saturn $9\frac{1}{2}$, that of Uranus $4\frac{1}{3}$, and that of Neptune $4\frac{3}{4}$ times the diameter of the earth.

But the volumes or bulks of globes being in the proportion of the cubes of their diameters, it follows that the bulk of Jupiter is 1,330 times that of the earth; and that those of Saturn, Uranus, and Neptune are respectively 857, 88, and 107 times that of the earth.

To render these vast proportions more clearly perceptible, we have represented them in the annexed figures. If E (fig. 4) be imagined to represent the globe of the earth, the globe of Jupiter will be represented on the same scale by J, that of Saturn by S, that of Uranus by U, and that of Neptune by N.

21. If they be inhabited globes analogous to the earth, they will accommodate a population as many times greater than that to which the earth is adapted, as their surfaces are greater than the surface of the earth; and since the surfaces of globes are in the proportion of the squares of the diameters, Jupiter would afford space for habitation 121 times greater than the earth, and Saturn 90 times, Uranus 18 times, and Neptune 23 times greater.

22. It may, however, be asked whether this vast difference in the magnitude of these globes compared with that of the earth may not involve some physical consequences incompatible with the supposition of their being habitable globes at all analogous to the earth.

There is but one such consequence at all conceivable. It is that the effects of gravity upon them might be such as to be altogether unfitted for species organised like those of the earth. Thus, upon the earth the average strength of a man is adapted to support and give freedom of motion and action to a body whose average weight is an hundred and a half; that of a horse to one whose average weight is half a ton, and the like of other animals. The strength of the stalks and trunks of vegetables is in like manner adapted to their weights. In the same manner the materials of artificial structures have a strength which has like relation to their weights.

If these species, animal and vegetable, and these artificial structures were suddenly transferred to the surface of a planet, on which they would have several hundred times their present weight, the animals would not only be totally incapable of locomotion, but they, as well as the vegetables and artificial structures, would be crushed and crumbled to pieces under the enormous pressure of their own weights.

In discussing this question, it is therefore of the greatest importance to inquire whether the vast dimensions of this group of planets may not cause an increase of weight of bodies placed upon their surfaces so immense as to destroy all analogy to the earth considered as an inhabited globe.

In answer to this question, it may be replied that the weight of bodies placed upon the surface of a globe will depend conjointly on the quantity of matter in the globe, and on the distance of the body from its centre, which distance will be the radius or semi-diameter of the globe. The greater the quantity of matter composing the globe, the greater will be the attraction which it will exert upon a body at a given distance from its centre. But this attraction will be less as that distance is increased, in the proportion of the square of the distance.

23. Now let us apply these principles to the major planets;—to Jupiter for example.

The volume of Jupiter, as we have stated, is 1,330 times that of the earth. If it be composed of materials similar to those which compose the earth, its mass or quantity of matter will be 1,330 times greater than that of the earth, and it would consequently exert an attraction 1,330 times greater than terrestrial gravity upon a body *at the same distance from its centre.*

Now, the body of an average man placed on the surface of the earth, and therefore at a distance from its centre equal to half its diameter, is attracted towards that centre with a force of 150 lbs. The same body placed *at the same distance* from the centre of Jupiter would, on the above supposition, be attracted with a force of 1,330 times 150 lbs. But bodies placed on the surface of Jupiter are at a distance from its centre eleven times greater than the semi-diameter of the earth, because the semi-diameter of Jupiter is greater than that of the earth in the proportion of 11 to 1; and, consequently, if the body of the man were placed on the surface of Jupiter, it would be attracted with a less force in the ratio of the square of 11, that is of 121 to 1. The account would therefore stand thus:—

	lbs.
Weight of a man on the surface of the earth . .	150
Weight of do. placed at a distance from Jupiter's centre equal to the semi-diameter of the earth .	150×1330
Weight of do. removed to Jupiter's surface, the distance being thus increased 11 times . .	$\frac{150 \times 1330}{121}$

If we perform these arithmetical operations, multiplying 150 lbs. by 1,330, and dividing the product by 121 we shall obtain 1,648 lbs.

Thus it appears that if the materials of which the planet Jupiter is composed be similar to those of the earth, the weight of a man placed upon its surface would be greater than his weight upon the earth, in the ratio of 1,648 to 150, or about 11 to 1, and of course the weights of all bodies would be greater in the same proportion.

It is evident, that although such a physical condition would not at all exclude the possibility of Jupiter being an inhabited globe, it would require the admission, that the organised world upon it must be totally different from that which exists upon the earth.

But are the materials of which Jupiter is composed similar to those of the earth? If not, the conclusion at which we have arrived must be modified. The whole question resolves itself into the determination of the actual quantity of gravitating matter composing this stupendous planet compared with the quantity composing the earth. Now it will be apparent, that if we could ascertain the attractions which Jupiter and the earth would exert upon bodies placed at equal distances from them, these attractions would be the exact exponents of the quantities of gravitating matter composing these two globes.

This we are happily enabled to accomplish by a very simple and obvious arithmetical operation. The moon, as is well known, revolves in its monthly orbit round the earth, and is retained in that orbit by the attraction of the mass of gravitating matter composing the earth. If that mass were greater the moon would revolve faster, if less, slower. Its rate of motion is therefore an index to the quantity of gravitating matter composing the earth.

Jupiter like the earth is also attended, but by four and not by one moon. Each of these four moons is retained in its orbit round Jupiter by the attraction of the gravitating mass composing that planet. If it had happened that one of these four moons were at exactly the same distance from Jupiter's centre as the earth's moon is from its centre, then the motion of that moon would at once prove whether the quantity of matter composing Jupiter is greater or less than the quantity of matter composing the earth. If the moon of Jupiter being thus at the same distance moved faster than the earth's moon, the mass of Jupiter would be greater, and if it moved slower it would be less than the mass of the earth.

Although all the moons of Jupiter are more distant from its centre than the moon is from the earth's centre, the nearest of these moons to Jupiter is *not much* more distant. Yet this moon makes a complete revolution round Jupiter in forty-two hours, while the earth's moon, though *a little nearer* to the attracting mass, takes nearly 656 hours to make a revolution.

It is obvious, therefore, that the gravitating mass composing Jupiter must be vastly greater than that which composes the earth.

By allowing for the difference of distance of the two moons from the centres of the two planets, and by taking into account the exact proportion of their velocities, it has been found that the mass of gravitating matter composing Jupiter is 338½ times the mass of the earth.

The meaning of this is, that if 338½ masses of matter like the earth were placed in one scale of a colossal balance, and the single globe of Jupiter in the other, the beam would be exactly equipoised.

24. A very curious inference follows from this. It appears from what has been shown, that the volume or bulk of Jupiter is 1,330 times greater than that of the earth, so that it would require 1,330 globes like the earth to be moulded into a single globe to make such a globe as Jupiter, while 338½ such globes would be sufficient to make a globe as heavy as Jupiter. It is evident, therefore, that bulk for bulk, the matter composing Jupiter, is lighter than the matter composing the earth, in the ratio of 338½ to 1,330, or what is the same, of 4 to 1.

It has been proved that the earth is 5½ times the weight of an equal globe composed of water. It follows therefore that Jupiter is heavier than an equal globe of water in the far less proportion of 5½ to 4, or 1⅜ to 1.

It was shown that if Jupiter were composed of matter like the earth, the weight of bodies upon his surface would be 11 times greater than upon the earth. But since it appears that it is composed of matter 4 times lighter than that of the earth, it will follow that the weight of bodies upon its surface will be 4 times less than the weight previously computed, and that it will therefore be only 2¾ greater than upon the earth.

Thus it seems that owing to the comparative lightness of the matter composing this great globe, the attraction which it exerts upon bodies placed upon its surface, though greater than upon the earth, does not exceed terrestrial gravity in a proportion which requires the admission of any difference of organisation of the inhabitants, exceeding what may be imagined without removing Jupiter from the general analogy of the earth.

25. The other three planets of the exterior group, being attended by satellites, can be weighed against the earth by comparing, as in the case of Jupiter, the motions of their moons with that of the earth's moon, and after making due allowance for the difference of distance, the attractions which they would severally exert, compared with that exerted by the earth, becomes the expression of the relative quantities of gravitating matter compared with that of the earth.

It is thus found that the weight of Saturn is 101 times, that of Uranus 14¼, and that of Neptune 19 times the weight of the earth.

It appears, therefore, that while the bulk of Saturn is 857 times greater than that of the earth, its weight is only 101 times greater. It is therefore lighter, bulk for bulk, than the earth, in the proportion of 101 to 857, or 1 to 8½.

In like manner, while the bulk of Uranus is 82 times greater, its weight is only 14¼ times greater than that of the earth. It is therefore lighter, bulk for bulk, than the earth, in the proportion of 14¼ to 82, or 1 to 6 very nearly.

In fine, while the bulk of Neptune is 107 times greater, its weight is only 19 times greater than the earth, and it is therefore lighter, bulk for bulk, than the earth, in the proportion of 19 to 107, or nearly 1 to 6, the same as Uranus.

It has been proved that the earth is, bulk for bulk, 5½ times heavier than water. It follows therefore that Saturn being 8½ times lighter, bulk for bulk, than the earth, is lighter, bulk for bulk, than water in the proportion of 5½ to 8½, or 1 to 1½.

In like manner it appears that Uranus and Neptune, being nearly six times lighter, bulk for bulk, than the earth, must be composed of materials equal in weight, bulk for bulk, with water.

The weight of Jupiter is equal to that of some of the denser sorts of wood, such as lignum vitæ or ebony, and that of Saturn is equal to the weight of the lighter sorts, such as deal.

26. The weight of bodies placed upon the surfaces of Saturn, Uranus, and Neptune, are ascertained by comparing their masses with their magnitude, as in the case of Jupiter, and it is thus found that it does not differ much from their weights on the earth. On Saturn it is a very little more, and on Uranus and Neptune a little less.

27. It appears, therefore, that if these planets be inhabited, the same organisation which prevails on the earth would be sufficient to impart the same, or nearly the same, degree of stability and freedom of locomotion. A man, in fine, transferred from the earth to Saturn, Uranus, or Neptune, would not be sensible of much difference in his power of action and motion. Trees and other vegetables, with their present strength, would be equally stable, and artificial structures equally solid and durable.

28. The importance of the atmosphere to all the functions of animal and vegetable life, and its uses in the diffusion of light and the retention and diffusion of heat, have been fully explained. The existence of any atmosphere on a planet is, therefore, an essential condition necessary to bring it into analogy with the earth as an inhabited globe.

The atmospheres of Jupiter and Saturn are rendered conspicuously apparent by the telescope. We see the clouds floating in dense masses upon them; so dense indeed and so unbroken as to conceal from our view the characters of the surfaces of the planets themselves.

Uranus and Neptune are too remote for like observations in the present state of the telescope, but it is in the highest degree probable that with improved powers of that instrument, like appearances will be observed upon them.

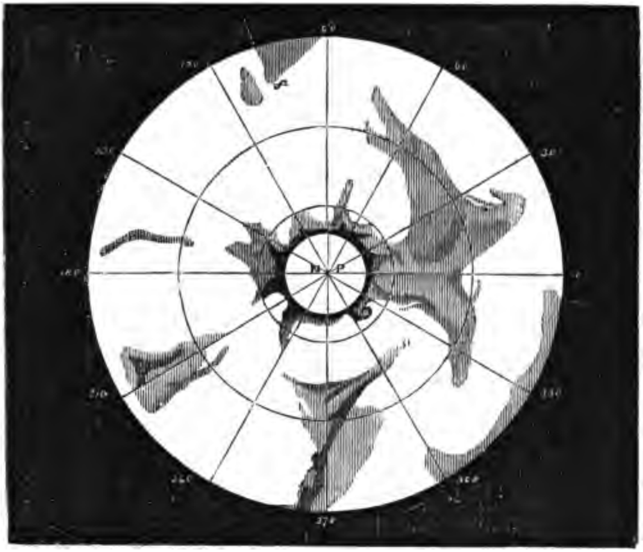
29. It might be imagined that the circumstance of being thus constantly enveloped in clouds would render it impossible to ascertain whether these planets, like the earth, turn upon an axis, and consequently have days and nights analogous to those of the earth.

It must be remembered, however, that the earth's atmosphere, and the clouds which float upon it, partake of the motion of diurnal rotation, and that if the atmosphere were perfectly calm for twenty-four hours, the various masses of clouds resting upon it being always suspended over the same parts of its surface, would be carried round with it, and would consequently make a complete rotation round the common axis in the same time exactly as the solid globe of the earth.

Now, if an observer placed upon any of the planets, not too remote, were in this case to direct a sufficiently powerful telescope to the earth, although he might not see the outlines of land and water, being enveloped by clouds, he would distinguish the masses of clouds themselves by their varieties of light and shade, and would see them carried round by the diurnal rotation—disappearing at one side and reappearing at the other; and he would thus not only ascertain the fact of the diurnal rotation of the earth, but also the time of rotation, that being the interval between two successive disappearances or reappearances of the same lineaments of light and shade, and the direction of the axis of rotation—that direction being at right angles to the apparent motion of rotation.

Circumstances, just such as these, have been observed to take place on Jupiter and Saturn. The masses of cloud, whose lights and shadows diversify their surfaces, though more or less shifting and variable, are at times found to remain fixed, as if the atmosphere were absolutely calm and quiescent for intervals sufficiently protracted to enable the telescopic observer to see the same lineaments disappear at one side of the disk, reappear at the other, and passing across the disk, again disappear. These are the obvious effects of the rotation of these planets upon an axis at right angles to the direction of this apparent motion.

Observations such as these, repeated and continued for long periods of time, have led to the discovery that Jupiter turns upon a certain diameter with a diurnal motion, making a complete revolution in 9^h 55^m 26^s terrestrial time, and that Saturn revolves in like manner, and what is more remarkable in a time not very different from that of the rotation of Jupiter. Saturn's rotation is completed in 10^h 29^m 17^s.



MARS.

SKETCH OF THE OUTLINES OF CONTINENTS AND OCEANS, AND THE SNOW REGION OF THE POLAR CIRCLE OF THE NORTHERN HEMISPHERE OF THE PLANET MARS, FROM THE OBSERVATIONS OF MÄDLER.

THE PLANETS:

ARE THEY INHABITED WORLDS?

CHAPTER III.

1. Diurnal rotation of Uranus.—2. Inclination of the axes and limitation of the seasons on the Major planets.—3. Jovian zones and climates. —4. Saturnian.—5. Short days and nights of Major planets.—6. Lightness of their materials.—7. Oceans and seas must consist of a liquid lighter than water.—8. Jovian, Saturnian, and Uranian years.—9. Effects of diurnal rotation on the distribution of clouds.—10. These effects more conspicuous in the Major planets.—11. Manifested by the belts.—12. Telescopic appearance of Jupiter.—13. Herschel and Mädler's telescopic views of Jupiter.—14. Jupiter elliptical in form.—15. Discovery of Jupiter's moons. —16. Short months.—17. Lunar eclipses.—18. Telescopic appearance of Jupiter's satellites.—19. As seen from Jupiter.—20. The Saturnian system.—21. Atmosphere and moons.

1. CONCLUSIVE and satisfactory observations of this kind have not yet been made on Uranus, but from the observations, imperfect as they are, which have been made, there are probable grounds for the inference that this planet also revolves on an axis in nine hours and a half.

Thus it appears that these vast globes, revolving at distances from the sun from five to thirty times that of the earth, have like the earth alternations of light and darkness; that they have days and nights; that all parts of their surfaces are in turn, like those of the earth, presented to the common centre of light and warmth, but that the intervals which regulate these alternations, "the division of the light from the darkness," which has been found good by Divine beneficence for the races which inhabit the earth, has not been found "good" for those which inhabit those more remote worlds. The average length of the day on them is about five hours, while it is twelve upon the earth.

The creatures placed upon these planets must, therefore, be so constituted as to require more frequent intervals for rest and sleep, and shorter periods of wakefulness, activity, and labour, than those which inhabit the earth.

2. The position of the axis of rotation has been ascertained in the cases of Jupiter and Saturn, but not as yet of the other two planets of this group.

The axis of Jupiter is inclined to the plane of its orbit at the very small angle of 3° 5′ 30″, while that of the earth, as is well known, has an inclination of 23° 28′ 30″.

As this inclination limits the temperature of the seasons, the extent of the zones and the varieties of the climates, it follows, that on Jupiter these phenomena must be very different from those of the earth. The extreme variation of the altitude of the sun at noon does not much exceed six degrees in any latitude, a change which cannot produce any very sensible variation in the temperature of the seasons. On this planet there is, therefore perpetual spring.

3. The tropics of Jupiter are only three degrees north and south of his equator, and the polar circles, which include the only parts of the planet at which the sun remains at any time below or above the horizon during a complete revolution, are limited to three degrees around the poles.

In fine, the diurnal phenomena on Jupiter are, at all times, nearly the same as they are upon the earth at the Equinoxes.

4. The case is very different with Saturn, which presents a closer analogy to the earth. The direction of the diurnal motion, in the case of that planet, makes an angle of 26° 48′ 40″, with the plane of the orbit differing little from the angle which the ecliptic

makes with the terrestrial equator. The Saturnian seasons, zones, and climates are, therefore, absolutely similar to those of the earth. The tropical and polar phenomena are the same.

It is to be hoped that the recent improvements effected by Lord Rosse, in the construction of reflecting telescopes, may place it within the power of observers to determine the position of the axes of Uranus and Neptune, and the line of rotation of the latter.

5. So far as discovery has hitherto proceeded, it would appear that a comparatively greater rapidity of rotation, and shorter intervals of light and darkness, is a characteristic by which the group of major planets are distinguished from the terrestrial group.

6. A second striking distinction between these two groups is the comparative lightness of the matter composing the former. It will be remembered that, in our notice of the terrestrial group, we showed that the density of the matter composing the earth, Venus, and Mars is nearly equal, and is five-and-a-half times that of water, and about the same as that of iron-stone, while the density of the planet Mercury is equal to that of gold. Now, it appears that, on the contrary, the density of Jupiter very little exceeds that of water, that of Uranus and Neptune is exactly that of water, while Saturn is so light that it would float in water like a globe of pine-wood.

It must be admitted to be not the least striking among the wondrous results of human sagacity, that these remote globes have been submitted to such an analysis as enables us thus to pronounce with certainty upon one, at least, of the physical characters of their constituent parts. In some instances science has even gone further, and has shown that the densities of Jupiter and Saturn cannot be uniform, but must increase gradually as that of the earth is known to do, from the surface to the centre, and from this it follows that the mean density of the matter of their surface must be much less than that of water.

7. It follows, therefore, that the seas and oceans of these planets must consist of a liquid far lighter than water. It is computed that a liquid on Jupiter, which would be analogous to the terrestrial oceans, would be three times lighter than sulphuric ether, the lightest known liquid, and would be such that cork would scarcely float in it.

8. The rapid rotation of these planets, combined with the great length of their revolution round the sun, gives them years consisting of a vast number of days. The year of Jupiter is nearly twelve terrestrial years, or, more exactly, $4332\frac{6}{10}$ terrestrial days. But as the Jovian days are shorter than the

terrestrial in the ratio of 1 to 2·42, it follows that in a Jovian year there are 10485 Jovian days.

The Saturnian year is equal to 29½ terrestrial years, or more exactly to 10,759 terrestrial days, and since the Saturnian day is shorter than the terrestrial in the ratio of 1 to 2·3, it will follow that the Saturnian year consists of 24746 Saturnian days.

Thus each of the Saturnian seasons, spring, summer, autumn, and winter is equal to seven-and-a-half terrestrial years.

The Uranian year is equal to 84 terrestrial years, or 30687 terrestrial days; and the Uranian day, according to the probable estimate, being shorter than the terrestrial day in the ratio of 1 to $2\frac{526}{1000}$, it follows that the Uranian year consists of 77336 Uranian days.

If the axis of Uranus be inclined to the plane of its orbit like that of Saturn, its seasons will be similar to those of the earth, but of very different duration, their length being 21 terrestrial years, or 19334 Uranian days.

9. One of the most remarkable meteorological consequences of the diurnal rotation of the earth is the system of atmospheric currents, which, in both hemispheres, are directed generally parallel to the equator, and which, from their great permanence and regularity in the lower latitudes, have, in all ages since the invention of ocean navigation, subserved the purposes of commerce so extensively as to have acquired the name of the trade-winds. These phenomena will be explained more fully, so far as relates to their physical causes, in another part of this series. What we now desire to direct attention to is their effects in the upper strata of the atmosphere.

It is evident that such currents must have a general tendency to distribute the strata of clouds in lines or streaks, more or less pronounced, according to their intensity and regularity, parallel to the equator. If these aërial currents were much more intense and much more permanent and regular, and if the clouds themselves were more voluminous and permanent than they are, this distribution of them in streaks or layers at right angles to the earth's axis would be in proportion more pronounced, more regular, and more permanent.

The causes of these atmospheric currents are traced to the combined effects of the velocity with which the atmosphere is carried round with the earth on its axis, and the influence of the solar heat produced upon the zone of atmosphere over those regions of the globe which extend to a certain distance north and south of the equator.

If the velocity with which the atmosphere is carried round were much greater than it is, and if the atmosphere were more constantly and heavily loaded with clouds, these effects would be much more striking.

The velocity with which the atmosphere is carried round would be greater if the earth's rotation were more rapid. It would also be greater, even with the present rate of rotation, if the earth were a larger globe, because then the atmosphere would be carried in the same time round a proportionately greater circumference. But if both these conditions were at the same time fulfilled—if the earth revolved more rapidly on its axis, and were at the same time a larger globe, the atmosphere would be not only carried round in a less time, but would revolve through a larger circumference.

10. Now this is exactly the case with the major planets. Jupiter, Saturn, and Uranus make each about five revolutions on their axes while the earth makes two, and the equatorial circumference of Jupiter is eleven times, that of Saturn above nine times, and that of Uranus more than four times greater than the equatorial circumference of the earth.

The speed with which the equatorial zone of air is whirled round on Jupiter is therefore about 27 times, on Saturn 23 times, and on Uranus about 7 times greater than on the earth.

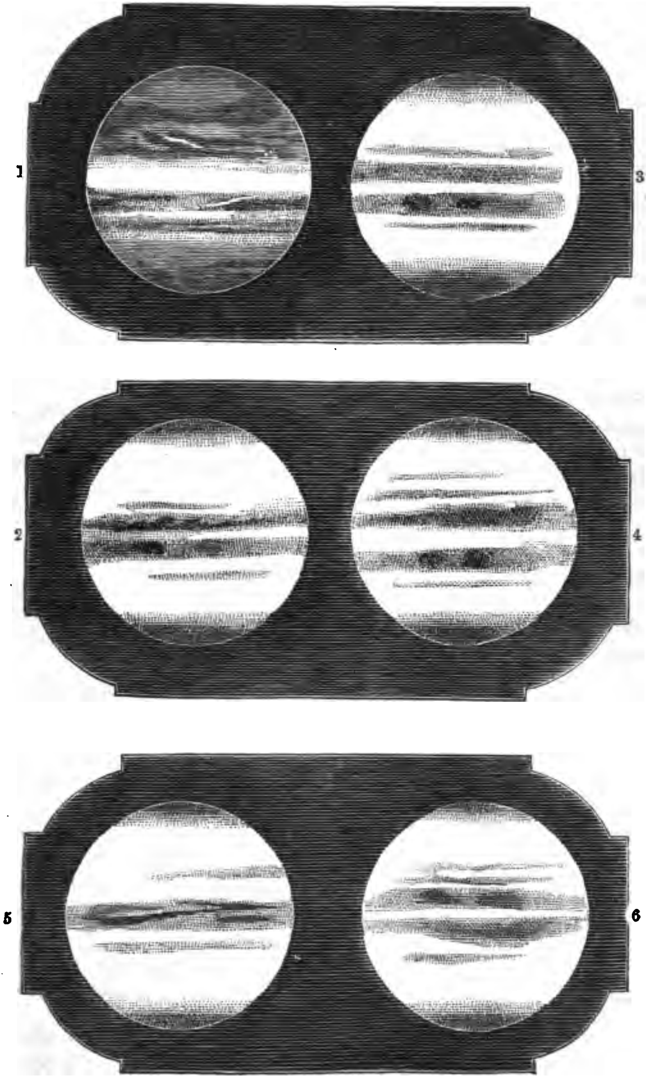
We find by telescopic observation also, as has been already stated, that the atmospheres of these planets are so thickly and constantly loaded with clouds that the surfaces of the solid globes are permanently concealed from us.

It may, therefore, be inferred that the prevalence of atmospheric currents on these planets parallel to their equators are far more constant and more strong than upon the earth; and since the masses of cloud with which they are loaded are greater and more permanent, the effects of such currents upon their distribution in equatorial strata or bands must be supposed to be far more conspicuous.

11. Observation has confirmed this in a most remarkable and interesting manner. Look at the six telescopic views of Jupiter, given in figures 1 to 6 (page 38), which are engraved after the telescopic drawings of Herschel and Mädler.

The streaks parallel to the Jovian equator are conspicuous. These streaks, which were seen not long after the invention of the telescope, are called "Jupiter's Belts."

Of all the bodies of the system, the moon perhaps alone excepted, Jupiter presents to the telescopic observer the most magnificent spectacle. Notwithstanding its vast distance, such is its stupendous magnitude that it is seen under a visual angle nearly twice that of Mars. A telescope of a given power, therefore, shows it with an apparent disc four times greater. It has



SIX TELESCOPIC VIEWS OF JUPITER.

1. Sept. 23, 1832. 2. Dec. 23, 1834. 3. Dec. 23, 1834.
4. Jan. 2, 1836. 5. Jan. 16, 1836. 6. Jan. 17, 1836.

consequently, been submitted to examination by the most eminent observers, and its appearances described with great minuteness of detail. The apparent diameter in opposition (when it is on the meridian at midnight) is about the fortieth part of that of the moon, and therefore a telescope with the very moderate magnifying power of forty, presents it to the observer with a disc equal to that with which the full moon is seen with the naked eye.

A power of four or five is sufficient to enable the observer to see the planet with a sensible disc; a power ot thirty shows the more prominent belts; a power of forty shows it with a disc as large as that which the full moon presents to the naked eye; but to be enabled to observe the finer streaks which prevail at greater distances from the planet's equator, it is not only necessary to see the planet under favourable circumstances of position and atmosphere, but to be aided by a well-defining telescope with magnifying powers varying from 200 to 300.

The planet, when thus viewed, appears to exhibit a disc, the ground of which is a light yellowish colour, brightest near its equator, and melting gradually into a leaden-coloured gray towards the poles, still retaining, nevertheless, somewhat of its yellowish hue. Upon this ground are seen a series of brownish-gray streaks, resembling in their form and arrangement the streaks of clouds which are often observed in the sky on a fine calm evening after sunset. The general direction of these streaks is parallel to the equator of the planet, though sometimes a departure from strict parallelism is observable. They are not all equally conspicuous or distinctly defined. Two are generally strikingly observable, north and south of the equator, separated by a bright yellow zone, a part of the general ground of the disc. These principal streaks commonly extend around the globe of the planet, being visible without much change of form during an entire revolution of Jupiter. This, however, is not always the case, for it has happened, though rarely, that one of these streaks, at a certain point, was broken sharply off, so as to present to the observer an extremity so well defined and unvarying for a considerable time as to supply the means of ascertaining, with a very close approximation, the time of the planet's rotation. The borders of these principal streaks are sometimes sharp and even, but, sometimes (those especially which are further from the equator), rugged and uneven, throwing out arms and offshoots.

On the parts of the disc more remote from the equator, the streaks are much more faint, narrower, and less regular in their parallelism, and can seldom be distinctly seen, except by practised observers, with good telescopes. With these, however, what appears near the poles, in instruments of inferior power, as a dim shading of a yellowish-gray hue, is resolved into a system of fine parallel streaks in close juxtaposition, which becoming closer in approaching the pole, finally coalesce.

In general, all the streaks become less and less distinct towards either the eastern or western limb, disappearing altogether at the limb itself.

Although these streaks have infinitely greater permanency than the arrangements of the clouds of our atmosphere, and are even more permanent than is necessary for the exact determination of the planet's rotation, they are nevertheless entirely destitute of that permanence which would characterise Zenographic features, such as are observed, for example, on Mars. The streaks, on the contrary, are subject to slow but evident variations, so that after the lapse of some months the appearance of the disc is totally changed.

12. These general observations on the appearance of Jupiter's disc will be rendered more clearly intelligible by reference to the telescopic drawings of the planet given in fig. 1 to 6. In fig. 1 is given a telescopic view of the disc by Sir John Herschel, as it appeared in the 20-feet reflector at Slough on the 23rd September, 1832. The other views were made by M. Mädler from observations taken in 1835 and 1836, at the dates indicated on the plate.

The two black spots represented in figs. 2, 3, and 4, were those by which the time of rotation was determined. They were first observed by Mädler, on the 3rd November, 1834. The effect of the rotation on these spots was so apparent that their change of position with relation to the centre of the disc, in the short interval of five minutes, was quite perceivable. A third spot, much more faint than these, was visible at the same time, the distances separating the spots being about 24° of the planet's surface. It was estimated that the diameter of each of the two spots represented in the diagrams was 3,680 miles, and the distance between them was sometimes observed to increase at the rate of half a degree, or 330 miles, in a month. The areas of these spots must therefore have been nearly equal to a fourth part of the entire surface of the earth. The two spots continued to be distinctly visible from the 3rd of November, 1834, when they were first observed, until the 18th of April, 1835; but during this interval the streak on which they were placed had entirely disappeared. It became gradually fainter in January (see fig. 4), and entirely vanished in February: the spots, however, retaining all their distinctness. The planet, after April, passing towards conjunction, was lost in the light of the sun;

and when it re-appeared in August, after conjunction, the spots had altogether vanished.

The observations being continued, the drawings (figs. 5 and 6), were made from observations on the 16th and 17th of January, 1836, when the entire aspect of the disc was changed. The two figures (5 and 6) represent opposite hemispheres of the planet.

It was remarked that the two spots, when carried round by the rotation, became invisible at 55° to 57° from the centre of the disc. This is an effect which would be produced if the spots were openings in the mass of clouds floating in the atmosphere of the planet. Their disappearance on moving from the centre of the disc would be caused by their deep sides intercepting the view of their bottom, just as we should lose sight of a railway in a deep cutting, if, being placed at the edge of the cutting, we were to withdraw to some distance from it.

A proper motion with a slow velocity, and in a direction contrary to the rotation of the planet, was observed to affect the spots, and this motion continued with greater uniformity in March and April, after the disappearance of the belt.

It was calculated that the velocity of their proper motion over the surface of the planet was at the rate of from three to four miles an hour.

Although the two black spots were not observed by Mädler until the first days of November, they had been previously seen and examined by Schwabe, who observed them to undergo several curious changes, in one of which one of them disappeared for a certain interval, its place being occupied by a mass of fine dots. It soon, however, re-appeared as before.

From all these circumstances, and many others developed in the course of his extensive and long-continued observations, Mädler considers it highly probable, if not absolutely certain, these vast masses of clouds have a permanence of form, position, and arrangement to which there is nothing analogous in the atmosphere of the earth, and that such permanence may in some degree be explained by the great length and very small variation of the seasons. He thinks it probable that the inhabitants of places in latitudes above 40° never behold the firmament at all, and those in lower latitudes only on rare occasions.

It is also probable that the bright yellowish general ground of Jupiter's disc consists of clouds, which reflect light much more strongly than the most dense masses which are seen illuminated by the sun in our atmosphere; and that the darker streaks and spots observed upon the disc are portions of the atmosphere, either free from clouds and through which the surface of the planet is visible more or less distinctly, or clouds of less density and less reflecting power than those which float over the general atmosphere and form the ground on which the belts and spots are seen.

That the atmosphere has not any very extraordinary height above the surface of the planet is proved by the sharply defined edge of the disc. If its height bore any considerable proportion to the diameter of the planet, the light towards the edges of the disc would become gradually fainter, and the edges would be nebulous and ill-defined. The reverse is the case.

13. One of the most remarkable consequences of the rotatory motion, which has been the means of giving to the inhabitants of the earth the alternations of day and night, is that its figure has been changed from that of a perfect sphere to an oblate spheroid; that is, a globe flattened at the poles. This has been already explained.

If the diurnal rotation of the earth were more rapid than it is, this polar flattening would be more considerable. In short, the degree of oblateness, or the proportion in which the polar axis is shorter than the equatorial diameter, depends on the time of rotation in such a manner, that this time being known, that proportion can be computed, or *vice versâ*.

Now, the rotation of these major planets being ascertained, and being much more rapid than that of the earth, it would follow that they must be oblate spheroids, and that their degree of oblateness must be much greater than that of the earth. Observation fully confirms this.

The disc of Jupiter, seen with magnifying powers as low as 30, is evidently oval, the lesser axis of the ellipse coinciding with the axis of rotation, and being perpendicular to the general direction of the belts; as in the case of the earth, the degree of oblateness of Jupiter is found to be that which would be produced upon a globe of the same magnitude, having a rotation such as the planet is observed to have.

At the mean distance from the earth, the apparent diameters of the disc are ascertained by exact micrometric measures to be—

	Miles.
Equatorial Diameter	38·4″=92080
Polar Diameter	35·6″=85210
Mean Diameter	=88645

The polar diameter is therefore less than the equatorial, in the ratio of 356 to 384, or 100 to 108 nearly. Other estimates give the ratio as 100 to 106.

This is just the proportion which would be produced by a rotation like that which Jupiter is ascertained to have.

14. However agreeable may be the light of the moon in the absence of the sun, that attendant is not indispensable to the well-being of the inhabitants of the earth; and of the inner group of planets the earth alone has been supplied with such a supplement to the solar illumination.

The planets constituting the outer group are, however, much more munificently provided with this convenience, each being supplied with so many moons that their nights must be perpetually moonlit.

When Galileo directed the first telescope to the examination of Jupiter, he observed four minute stars, which appeared in the line of the equator of the planet. He took these at first to be fixed stars, but was soon undeceived. He saw them alternately approach to and recede from the planet, observed them pass behind it and before it, and oscillate, as it were, to the right and left of it, to certain limited and equal distances. He soon arrived at the obvious conclusion that these were bodies which revolved round Jupiter in orbits, at limited distances, and that each successive body included the orbit of the others within it; in short, that they formed a miniature of the solar system, in which, however, Jupiter himself played the part of the sun. As the telescope improved, it became apparent that these bodies were small globes, related to Jupiter in the same manner exactly as the moon is related to the earth; that, in fine, they were a system of four moons, accompanying Jupiter round the sun.

15. But connected with these appendages there is perhaps nothing more remarkable than the period of their revolutions. That moon which is nearest to Jupiter completes its revolution in forty-two hours. In that brief space of time it goes through all its various phases; it is a thin crescent, halved, gibbous, and full. It must be remembered, however, that the day of Jupiter, instead of being twenty-four hours, is less than ten hours. This moon, therefore, has a month equal to a little more than four Jovian days. In each day it passes through one complete quarter; thus, on the first day of the month it passes from the thinnest crescent to the half moon; on the second, from the half moon to the full moon; on the third, from the full moon to the last quarter; and on the fourth returns to conjunction with the sun. So rapid are these changes that they must be actually visible as they proceed.

The apparent motion of this satellite in the firmament of Jupiter is at the rate of more than 8° per hour, and is the same as if our moon were to move over a space equal to her own apparent diameter in rather less than four minutes. Such an object would serve the purpose of the hand of a stupendous celestial clock.

The second satellite completes its revolution in about eighty-five terrestrial hours, or about eight and a half Jovian days. It passes, therefore, from quarter to quarter in twenty-one hours, or about two Jovian days, its apparent motion in the firmament being at the rate of about 4·25° per hour, which is as if our moon were to move over a space equal to nine times its own diameter per hour, or over its own diameter in less than seven minutes.

The movements and changes of phase of the other two moons are not so rapid. The third passes through its phases in about 170 hours, or seventeen Jovian days, and its apparent motion is at the rate of about 1° per hour. The fourth and last completes its changes in 400 hours, or forty Jovian days, and its apparent motion is at the rate of little less than 1° per hour, being double the apparent motion of our moon.

Thus the inhabitants of Jupiter have four different months, of four, eight, seventeen, and forty Jovian days respectively.

16. Jupiter's moons differ from that of the earth, inasmuch as all of them move in the plane of the planet's equator, from which plane the sun can never depart further than about 3°. At and for a considerable time before and after the Jovian equinoxes, the sun is so very near the planet's equator that each of the moons, which never leave that equator, must necessarily pass between the sun and the planet every revolution. It follows, therefore, that for a long interval before and after each of the equinoxes, solar eclipses will be produced by each of the four moons every revolution. These eclipses, however, will be visible only at certain low latitudes. The inhabitants of the higher latitudes in either hemisphere will be so far removed from the common direction of the moons and sun, or what is the same, from the plane of the Jovian equator, that the visual line directed to the sun will be clear of the moons.

The shadow of this vast globe is so prodigious in its dimensions that the three inner moons never pass behind Jupiter without passing through it. They are therefore invariably eclipsed every revolution; and since at the time these moons would appear full they are in direct opposition to the sun, they are then plunged in the shadow, and therefore eclipsed. The Jovians consequently never see any of these three moons when they are full.

The fourth or most remote of the moons is, like the others, generally eclipsed every revolution; but at the Jovian seasons of midsummer and midwinter, for a certain interval, the sun, and consequently the shadow of the planet, are sufficiently removed from the plane of the planet's equator to enable this moon to clear the boundary of the shadow, and to pass through opposition without entering it. This is the only case in which any of the moons can ever pass through opposition without also passing through the shadow of the planet, and consequently the only times the Jovians ever enjoy the spectacle of a full moon.

When these circumstances are combined with the rapid revolution of the moons, it will be easily understood that the celestial phenomena of the Jovians must offer great variety, and that their chronology must be curiously complicated. A total lunar eclipse of the first or nearest moon must take place every forty-two terrestrial hours, that is, every fourth Jovian day; and for a long interval before and after the equinoxes a total or partial solar eclipse must take place at like intervals, being alternated with the lunar eclipses, and separated from them by intervals of only twenty-one terrestrial hours, or two Jovian days.

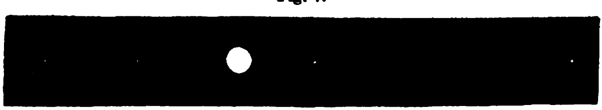
The same phenomena exactly take place with relation to the second satellite, at intervals of 3½ terrestrial, or about 8½ Jovian days; to the third at intervals of 7 terrestrial, or 17 Jovian days; and to the fourth at intervals of 16½ terrestrial, or 40 Jovian days, subject, nevertheless, with respect to the last, to an interruption at the Jovian summer and winter, from the cause already explained.

17. The appearance which the satellites of Jupiter present when viewed with a telescope of moderate power, is that of minute stars ranged in the direction of a line drawn through the centre of the planet's disc, nearly parallel to the direction of the belts, and therefore coinciding with that of the planet's equator.

The entire system is comprised within a visual area of about two-thirds of the apparent diameter of the moon. If, therefore, we conceive the moon's disc to be centrically superposed on that of Jupiter, not only would all the satellites be covered by it, but that which elongates itself most from the planet would not approach nearer to the moon's edge than one-sixth of its apparent diameter.

If all the satellites were at the same time at their greatest apparent distances from the planet, they would, relatively to

Fig. 7.



the apparent diameter of the planet, present the appearance represented in fig. 7.

By comparing their real diameters with their distances, the apparent diameters of the several satellites, as seen from Jupiter, may be easily ascertained.

18. The first satellite has an apparent diameter equal to that of the moon; the second and third are nearly equal and about half that diameter; and the apparent diameter of the other satellite is about the fourth part of that of the moon.

It may be easily imagined what various and interesting nocturnal phenomena are witnessed by the inhabitants of Jupiter, when the various magnitudes of these four moons are combined with the quick succession of their phases and the rapid apparent motions of the first and second.

The motions of the first three satellites are so related that they never can be at the same time on the same side of Jupiter; so that whenever any one of them is absent from the Jovian firmament at night, one at least of the others must be present. The nights are, therefore, always moonlit, except during eclipses, and often enlightened at once by three moons of different apparent magnitudes, and seen under different phases.

19. Of all the planets either of this or the terrestrial group, that which presents to the astronomical observer the most astonishing spectacle is Saturn—a stupendous globe, nearly 900 times greater in volume than the earth, surrounded by two, at least, and probably by several thin flat rings of solid matter, outside which revolve a group of eight moons; this entire system moving with a common motion so exactly maintained that no one part falls upon, overtakes, or is overtaken by another in their course around the sun.

Such is the SATURNIAN SYSTEM, the central body of which was known as a planet to the ancients, the annular appendages and satellites being the discovery of modern times.

The distance of Saturn from the sun is so enormous that if the whole earth's orbit, measuring nearly 200,000000 of miles in diameter, were filled with a sun, that sun seen from Saturn would be only about 24 times greater in its apparent diameter than is the actual sun seen from the earth. A cannon-ball moving at 500 miles an hour would take about 200 years; and a railway train moving 50 miles an hour would take about 2000 years to move from Saturn to the sun. Light, which moves at the rate of nearly 200000 miles per second, takes 1 hour 15 minutes to move over the same distance. Yet to this distance solar gravitation transmits its mandates, and is obeyed with the utmost promptitude and the most unerring precision.

Taking the diameter of Saturn's orbit at 1800,000000 of miles, its circumference is 5650,000000 of miles, over which it moves in 10759 days. Its daily motion is therefore 525140 miles, and its hourly 21880 miles.

20. All that has been said above respecting the atmosphere, the diurnal rotation, and their consequences, the clouds, atmospheric currents, trade-winds, and oblate figure in the case of Jupiter, may be applied without any important modification to Saturn.

This planet is attended by eight moons, four of which, like those of Jupiter, are remarkable for their proximity to the planet, three being at distances considerably less than that of the terrestrial moon from the earth, and the fourth at nearly the same distance. Of the four other moons, the most remote is ten times further from Saturn than the terrestrial moon is from the earth, and the nearest is about one half more distant.

The distances of moons are, however, more justly estimated relatively to the planets they attend, by expressing them in semi-diameters of the planet. If thus expressed, the moons of Saturn are on a scale ot distance very much less than that of the terrestrial moon. The distance of the most remote is 64 semi-diameters of Saturn, while that of the nearest is little more than 3 semi-diameters. The distance of the terrestrial moon from the earth is 60 semi-diameters.

Great, however, as these distances are, they are reduced to a very small apparent measure, owing to the remoteness of the Saturnian system from the earth. If the centre of the terrestrial moon were to come upon the centre of Saturn's disc, the most remote of his satellites could not approach nearer to the edge of the moon's disc than one-third of the moon's semi-diameter. Thus, although the Saturnian system fills a space measuring about 5,000000 of miles in its extreme breadth, this entire space would be covered by the moon's disc, even if that disc had a diameter one-third less than its actual diameter.

All that has been said of the phases and appearances of the moons of Jupiter, as presented to the inhabitants of that planet, is equally applicable to the satellites of Saturn, with this difference, that instead of four, there are eight moons continually revolving round the planet, and exhibiting all the monthly changes to which we are accustomed in the case of the solitary satellite of the earth.

The periods of Saturn's moons, like those of Jupiter, are short, with the exception of those most remote from the primary. The nearest passes through all its phases in 22½ hours, and the fourth, counting outwards, in less than 66 hours. The next three have months varying from 4 to 22 terrestrial days.

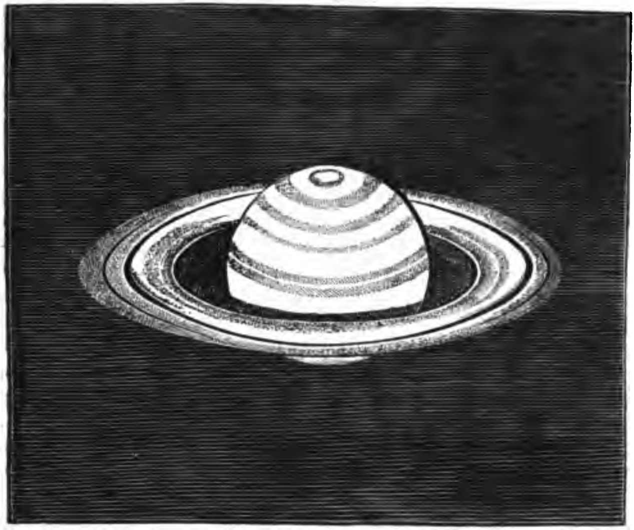
These seven moons move in orbits whose planes are nearly coincident with the plane of the Saturnian equator. The consequence of this arrangement is, that they are always visible by the inhabitants of both hemispheres when they are not eclipsed by the shadow of the planet.

The motion of the nearest moon is so rapid as to be perceivable by the Saturnians like that of the hour-hand of a colossal timepiece. It describes 360° in 22½ hours, being at the rate of 16° per hour, or 16′ per minute, so that in two minutes it moves over a space equal to the apparent diameter of the moon.

The eighth, or most remote satellite, is in many respects exceptional, and different from all the others. Unlike these, it moves in an orbit inclined at a considerable angle to the plane of the equator.

Owing to the great distance of Saturn, the dimensions of the satellites have not been ascertained. The sixth in order, proceeding outwards, called Titan, is, however, known to be the largest, and it appears certain that its volume is little less than that of the planet Mars. The three satellites immediately within this, Rhea, Dione, and Tethys, are smaller bodies, and can only be seen with telescopes of great power. The two nearest, Enceladus, and Mimas, require instruments of the very highest power and perfection, and atmospheric conditions of the most favourable nature, to be observable at all.

The real magnitudes of the satellites, the sixth excepted, being unascertained, nothing can be inferred with any certainty respecting their apparent magnitudes as seen from the surface of Saturn, except what may be reasonably conjectured upon analogies to other like bodies of the system. The satellites of Jupiter being all greater than the moon, while one of them exceeds Mercury in magnitude, and another is but little inferior in volume to that planet, it may be assumed with great probability of truth that the satellites of Saturn are at least severally greater in their actual dimensions than our moon.



SATURN,

AS SEEN IN NOVEMBER, 1852, WITH A REFRACTOR OF 6½ INCH APERTURE AT WATERINGBURY NEAR MAIDSTONE, BY W. R. DAWES.

THE PLANETS:

ARE THEY INHABITED WORLDS?

CHAPTER IV.

1. Apparent magnitudes of the moons as seen from Saturn.—2. Their phases—Short Saturnian months.—3. Solar and lunar eclipses.—4. Discovery of the rings.—5. Phases of the rings as seen from the earth.—6. Their appearance when seen edgeways in 1848—Schmidt's drawings of them.—7. Mountains upon them.—8. Their dimensions.—9. Discovery of the obscure semi-reflective rings.—10. Dawes' telescopic view of the planet and rings.—11. Appearance of the rings as seen from Saturn.—12. Errors committed on this subject by Bode, Herschel, Mädler, and others.—13. Correction of these errors.—14. Appearance of rings will vary with the latitude of the observer.—15. Illustrative diagrams.—16. Recapitulation.—17. No difficulty can arise in admitting the possibility of differently organised tribes on the different planets.—18. The sun, its physical character incompatible with habitability.—19. The moon not habitable.—20. Nor the satellites.—21. Comets not habitable.—22. The planetoids or asteroids.

1. If the estimate of the real magnitudes of the satellites, given at the conclusion of the last chapter, be admitted, their probable apparent magnitudes as seen from Saturn may be inferred from their distances. The distance of the first, Mimas, from the nearest part of the surface of the planet, is only 94,000 miles, or about 2½ times less than the distance of the moon; the distance of the second is about half that of the moon; that of the third about two-thirds, and that of the fourth about five-sixths, of the moon's distance. If these bodies, therefore, exceed the moon in their actual dimensions, their apparent magnitudes as seen from Saturn will exceed the apparent magnitude of the moon in a still greater ratio than that in which the distance of the moon from the earth exceeds their several distances from the surface of Saturn. Of the remaining satellites, little is as yet known of the seventh, Hyperion, which has only been recently discovered; and the great magnitude of the sixth, Titan, renders it probable that, notwithstanding its great distance, it may still appear to the Saturnians with a disc as great as that of the terrestrial moon.

2. All that has been observed respecting the remarkable appearances presented by the rapidly varying phases of Jupiter's moons is equally applicable to Saturn; the spectacle, however, being enriched and varied by twice the number of moons. Since the first satellite changes from the thinnest crescent to the half moon in five hours and a half (terrestrial), the gradual change of phase must be as visible as the motion of the hand of a timepiece. The second changes at a rate only one-half slower, that is, it passes from a thin crescent to the half moon in eight hours. The first passes from the state of the new to that of the full moon in eleven, and the second in sixteen hours. The interval between new and full moon for the third is twenty-two hours; for the fourth, thirty-two hours; for the fifth, fifty-three; for the sixth, eight terrestrial days; for the seventh, eleven; and for the eighth, forty.

3. The eclipses, solar and lunar, produced and suffered by these eight satellites are not so frequent and regular as those described as taking place in the Jovian system, because Saturn's equator is inclined to the sun's course at an angle of nearly 27°, considerably greater than the obliquity of the ecliptic, the consequence of which is that the sun, at and near the Saturnian midsummer and midwinter, departs to a great apparent distance from the equator, to which the motion of the satellites (except the eighth) is confined. For the same reason, the satellites depart further from the centre of the shadow, and all except the nearer ones generally move clear of the shadow in

opposition. The Saturnians, therefore, have the advantage over the Jovians of witnessing the frequently recurring spectacle of several full moons in their firmament.

4. The invention of the telescope having invested astronomers with the power of approaching, for optical purposes, hundreds of times closer to the objects of their observation, one of the earliest results of the exercise of this improved sense was the discovery that the disc of Saturn differed in a remarkable manner from those of the other planets in not being circular. It seemed at first to be a flattened oblong oval, approaching to the form of an elongated rectangle, rounded off at the corners. As the optical powers of the telescope were improved, it assumed the appearance of a great central disc, with two smaller discs, one at each side of it. These lateral discs, in fine, took the appearance of handles or ears, like the handles of a vase or jar, and they were accordingly called the ansæ of the disc, a name which they still retain. At length, in 1659, Huygens explained the true cause of this phenomenon, and showed that the planet is surrounded by a ring of opaque solid matter, in the centre of which it is suspended, and that what appear as ansæ are those parts of the ring beyond the disc of the planet at either side, which by projection are reduced to the form of the parts of an ellipse near the extremities of its greater axis, and that the open parts of the ansæ are produced by the dark sky visible through the space between the ring and the planet.

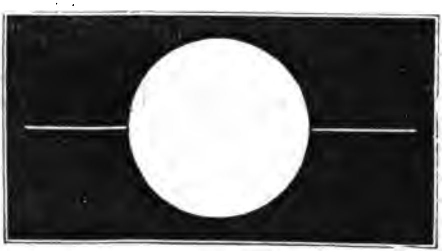
The improved telescopes, and greatly multiplied number and increased zeal and activity of observers, have supplied much more definite information as to the form, dimensions, structure, and position of this most extraordinary and unexampled appendage.

It has been ascertained that it consists of an annular plate of matter, the thickness of which is very inconsiderable compared with the superficies. It is nearly, but not precisely, concentric with the planet, and in the plane of its equator. This is proved by the coincidence of the plane of the ring with the general direction of the belts, and with that of the apparent motion of the spots by which the diurnal rotation of the planet has been ascertained.

When telescopes of adequate power are directed to the ring presented under a favourable aspect, dark streaks are seen upon its surface similar to the belts of the planet. One of these having been observed to have a permanence which seemed incompatible with the admission of the same atmospheric cause as that which has been assigned to the belts, it was conjectured that it arose from a real separation or division of the ring into two concentric rings placed one within the other. This conjecture was converted into certainty by the discovery that the same dark streak is seen in the same position on both sides of the ring. It has even been affirmed by some observers that stars have been seen in the space between the rings; but this requires confirmation. It is, however, considered as proved that the system consists of two concentric rings of unequal breadth, one placed outside the other, without any mutual contact.

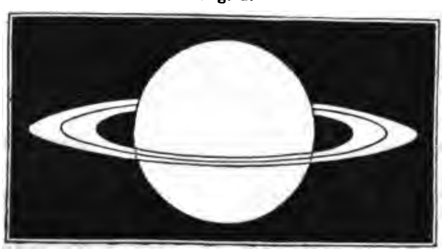
5. While the planet is carried round the sun in its orbital motion, the rings are presented to the view of observers situate on the earth under different aspects. In two positions of the planet at opposite points of its orbit the ring is seen edgeways, its plane then passing through the earth. It assumes these positions at intervals of about fifteen terrestrial years, or half a Saturnian year. If the ring were thick enough to be distinctly visible, and if its thickness were uniform, it would at these times have the appearance represented in fig. 1.

Fig. 1.



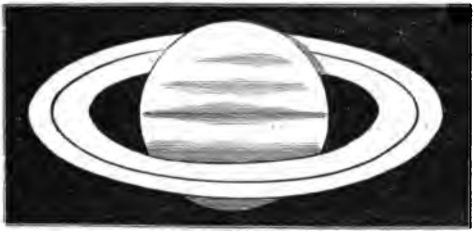
As it moves from these positions the rings become inclined at a sensible angle to the visual line, and this angle increasing

Fig. 2.



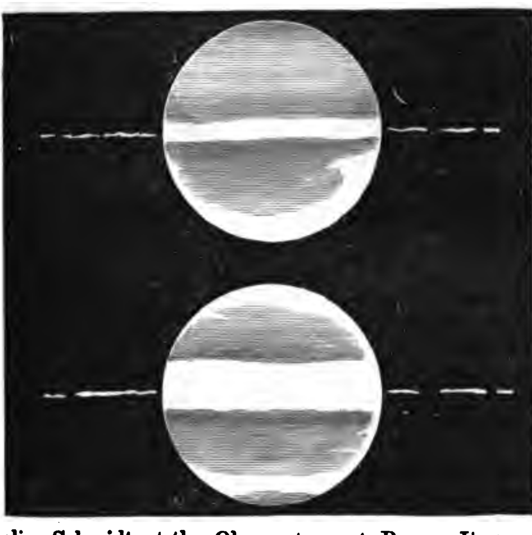
from year to year, they appear more and more open, as represented in fig. 2; until, after an interval of 7½ years, or a quarter of a Saturnian year, the plane of the rings forms the greatest possible angle, about 28°, with the visual line. At this time the appearance of the rings would be such as is represented in fig. 3.

Fig. 3.



The times at which the rings are presented edgeways to the earth are very nearly identical with those of the Saturnian equinoxes. The last which took place was in 1848, and the next will consequently be in 1863.

6. In 1848, the ring being presented edgeways, some very interesting and curious observations were made upon it by



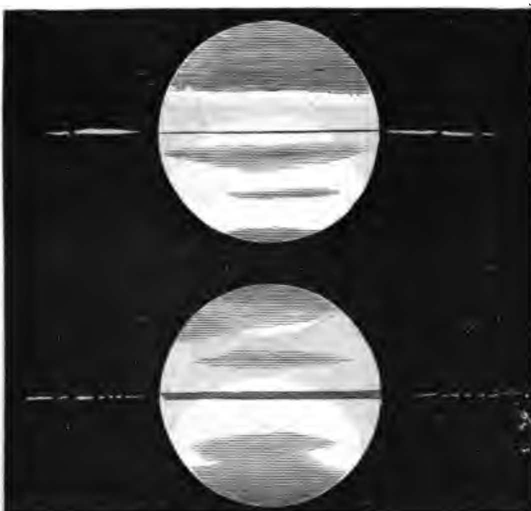
M. Julius Schmidt, at the Observatory at Bonn. It was found that the ring, instead of appearing as an even, thin line of light such as is represented in fig. 1, appeared as a broken and uneven line.

We have selected from the telescopic drawings made on that occasion by M. Schmidt, four, which are shown in Figs. 4, 5, 6, 7. These are intended only to represent the appearances of the edge of the rings, and not of the streaks on the disk of the planet.

Fig. 4	represents	the ring as	seen on the	26th June.
Fig. 5	,,	,,	,,	3rd Sept.
Fig. 6	,,	,,	,,	5th Sept.
Fig. 7	,,	,,	,,	11th Sept.

7. This singular appearance must arise from great mountainous inequalities on the surface of the ring, rendering it much thicker at some parts than at others. At some parts it is too thin to be visible at Saturn's distance, while at the parts rendered thicker by lofty mountains, it is apparent.

Figs. 6, 7.



8. The breadth of the rings, as well as of the intervals which separate them from each other and from the planet, have been submitted to very precise micrometric observations; and the results obtained by different observers do not differ from each other by a fortieth part of the whole quantity measured. In the

following table are given the results of the micrometric observations of Professor Struve, reduced to the mean distance.

		Apparent Magnitude at mean Distance.	In Semi-diameters of the Planet.	Miles.
Semi-diameter of the planet . . .	*r*	8″·995	1·000	39,580
Exterior semi-diameter of exterior ring .	*a*	20·047	2·229	88,209
Interior do. do. . .	*a′*	17·644	1·961	77,636
Breadth of exterior ring	*a—a′*	2·403	0·268	10,573
Exterior semi-diameter of interior ring .	*b*	17·237	1·916	75,845
Interior do. do. .	*b′*	13·334	1·482	58,669
Breadth of interior ring	*b—b′*	3·903	0·434	17,176
Width of interval between the rings .	*a′—b*	0·407	0·045	1,791
Width of interval between planet and interior ring	*b′—r*	4·339	0·482	19,089
Breadth of the double ring, including interval	*a—b′*	6·713	0·747	29,540

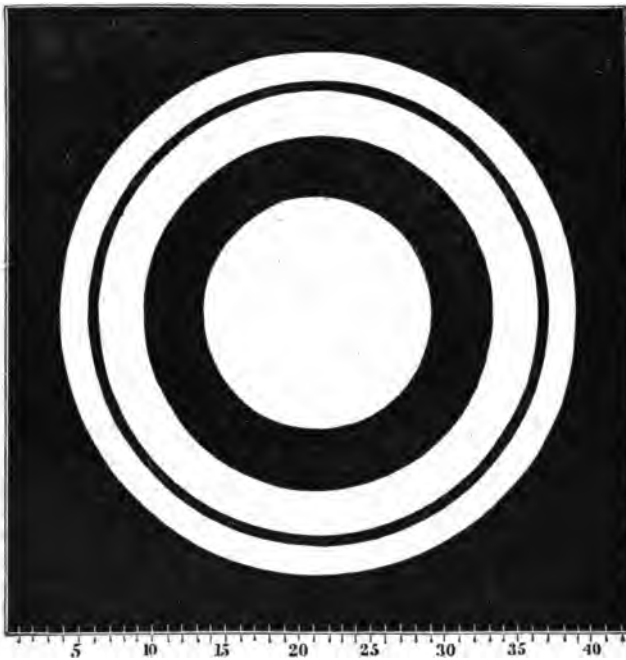
The relative dimensions of the two rings, and of the planet within them, are represented in fig. 8 projected upon the common plane of the rings and the planet's equator. Each division of the subjoined scale represents 5000 miles.

9. The most surprising result of recent telescopic observations of this planet has been the discovery of a ring, composed, as it would appear, of matter reflecting light much more imperfectly than the planet or rings already described; and, what is still more extraordinary, transparent to such a degree that the body of the planet can be seen through it.

In 1838, Dr. Galle, of the Berlin observatory, noticed a phenomenon, which he described as a gradual shading off of the inner ring towards the surface of the planet, as if the solid matter of the ring were continued beyond the limit of its illuminated surface, this continuation of the surface being rendered visible by a very feeble illumination, such as would attend a penumbra upon it; and measures of this obscure surface were published by him in the "Berlin Transactions" of that year.

The subject, however, attracted very little attention until towards the close of 1850, when Professor Bond, of Boston, and Mr. Dawes, in England, not only recognised the phenomenon noticed by Dr. Galle, but ascertained its character and features with great precision. The observations of Professor Bond were not known in England until the 4th of December; but the phenomenon was very fully and satisfactorily seen and described

Fig. 8.



by Mr. Dawes, on the 29th of November. That astronomer, on the 3rd of December, called the attention of Mr. Lassell to it, who also witnessed it on that evening at the observatory of Mr. Dawes; and both immediately published their observations and descriptions of it, which appeared in Europe simultaneously with those of Professor Bond.

It was not, however, until 1852 that the transparency was fully ascertained. From some observations made in September, Mr. Dawes strongly suspected its existence; and about the same time it was clearly seen at Madras by Captain Jacob, and in October by Mr. Lassell at Malta, whither he had removed his observatory to obtain the advantages of a lower latitude and more serene sky. The result of these observations has been the conclusive proof of the unique phenomenon of a semi-transparent annular appendage to this planet.

10. The planet surrounded by this compound system of rings is represented at the head of this chapter. The drawing is reduced from the original sketch, made by Mr. Dawes. The principal division of the bright rings is visible throughout its entire circumference. The black line, supposed to be a division of the outer ring, is visible in the drawing of Mr. Dawes; but was not at all seen by Mr. Lassell.

A remarkably bright thin line, at the inner edge of the inner bright ring, was distinctly seen by Mr. Dawes in 1851 and 1852.

The inner bright ring is always a little brighter than the planet. It is not, however, uniformly bright. Its illumination is most intense at the outer edge, and grows gradually fainter towards the inner edge, where it is so feeble as to render it somewhat difficult to ascertain its exact limit. It would seem as if the imperfectly reflective quality there approaches to that of the obscure ring recently discovered. The open space between the ring and the planet has the same colour as the surrounding sky.

11. The rings must obviously form a most remarkable object in the firmament of Saturnian observers, and must play an important part in their uranography. The problem to determine their apparent magnitude, form, and position, in relation to the fixed stars, the sun, and Saturnian moons, has, accordingly, more or less engaged the attention of astronomers. It is nevertheless a singular fact that, although the subject has been discussed and examined by various authorities for three quarters of a century, the conclusions at which they have arrived, and the views which have been generally expressed and adopted respecting it, are completely erroneous.

12. In the Berlin *Jahrbuch* for 1786, Professor Bode published an essay on this subject, which, subject to the imperfect knowledge of the dimensions of the rings which had then resulted from the observations made upon them, does not seem to differ materially in principle from the views adopted by the most eminent astronomers of the present day.

Sir John Herschel, in his "Outlines of Astronomy," edit. 1849, states that the rings as seen from Saturn appear as vast arches spanning the sky from horizon to horizon, holding an almost invariable situation among the stars; and that, in the hemisphere of the planet which is on their dark side, a solar eclipse of fifteen years' duration takes place.

This statement, which has been reproduced by almost all writers both in England and on the continent, is incorrect in both the particulars stated. *First*, the rings do not hold an almost invariable position among the stars. On the contrary, their position with relation to the fixed stars is subject to a change so rapid that it must be sensible to Saturnian observers, the stars seen on one side of the rings passing to the other side from hour to hour. *Secondly*, no such phenomenon as a solar eclipse of fifteen years' duration, or any phenomenon bearing the least analogy to it, can take place on any part of the globe of Saturn.

Among the continental astronomers who have recently reviewed this question, the most eminent is Dr. Mädler, to whose observations and researches science is so largely indebted for the information we possess respecting the physical character of the surface of the Moon and Mars.

This astronomer maintains, like Herschel, that the rings hold a fixed position in the firmament, their edges being projected on parallels of declination, and that, consequently, all celestial objects are carried by the diurnal motion in circles parallel to them, so that in the same latitude of Saturn the same stars are always covered by the rings, and the same stars are always seen at the same distance from them.

This is also incorrect. The zones of the firmament covered by the rings are not bounded by parallels of declination, but by curves which intersect these parallels at various angles.

Dr. Mädler enters into elaborate calculations of the solar eclipses which take place during the winter half of the Saturnian year. He computes the duration of these various eclipses in the different latitudes of Saturn, and gives a table, by which it would appear that the solar eclipses which take place behind the inner ring vary in length from three months to several years, that the duration of the eclipses produced by the outer ring is still greater, and that the duration of the appearance of the sun in the interval between the rings varies in different latitudes from ten days to seven and eight months.*

These various conclusions and computations of Bode, Herschel, Mädler, and others, and the reasoning on which they are based, are altogether erroneous; and the solar phenomena which they describe have no correspondence with, nor any resemblance to, the actual uranographical phenomena.

13. The problem of the appearance of the system of rings in the Saturnian firmament, and their effect in occulting and eclipsing occasionally and temporarily the sun, the eight moons, and other celestial objects, was fully discussed, and, for the first time, definitely solved in a memoir by the author of

* See Populäre Astronomie, von Dr. J. H. Mädler. Berlin, 1852.

these pages, read to the Royal Astronomical Society in 1853, and published in the twenty-second volume of their "Transactions."

It is there demonstrated that the infinite skill of the Great Architect of the Universe has not permitted that this stupendous annular appendage, the uses of which still remain undiscovered, should be the cause of such darkness and desolation to the inhabitants of the planet, and such an aggravation of the rigours of their fifteen years' winter, as it has been inferred to be from the reasoning of the eminent astronomers already named, as well as many others, who have either adopted their conclusions, or arrived at like inferences by other arguments.

It is shown, on the contrary, that, by the apparent motion of the heavens, produced by the diurnal rotation of Saturn, the celestial objects, including, of course, the sun and the eight moons, are not carried parallel to the edges of the rings, as has been hitherto supposed; that they are moved so as to pass alternately from side to side of each of these edges; that in general such objects as pass under the rings are only occulted by them for short intervals before and after their meridional culmination; that although under some rare and exceptional circumstances and conditions, certain objects, the sun being among the number, are occulted from rising to setting, the continuance of such phenomenon is not such as has been supposed, and the places of its occurrence are far more limited. In short, it has no such character as would deprive the planet of any essential condition of habitability.

Fig. 9.

14. The appearance which the ring presents to the Saturnians must vary very much with the latitude of the observer and the season of the year. In the summer half-year, the observer and the sun being on the same side of the ring, it will present the appearance of an arch in the heavens, bearing some resemblance in its form to a rainbow, the surface, however, having an appearance resembling that of the moon.

The vertex or highest point of this arch will be upon his meridian, and the two portions into which it will be divided by the meridian will be equal and similar, and will descend to the horizon at points equally distant from the meridian. The apparent breadth of this illuminated bow will be greatest upon the meridian, and it will decrease in descending on either side towards the horizon, where it will be least. The division between the two rings will be apparent, and, except at places within a very short distance of the equator, the firmament will be visible through it.

The distance of the edge of the bow from the celestial equator will not be everywhere the same, as it has been erroneously assumed to be. That part of the bow which is upon the meridian will be most remote from the celestial equator; and in descending from the meridian on either side towards the horizon, the declination of its edge will gradually decrease, so that those points which rest upon the horizon will be nearer to the equator than the other points.

15. Some idea may be formed of the varieties of appearance presented by the ring to observers in different latitudes of the planet, by imagining an observer starting from that Saturnian pole which is on the same side of the ring as the sun, to travel along a meridian towards the equator. At first the convexity of the planet will intercept all view whatever of the ring, and this, as has been shown in the memoir already referred to, will continue until he has descended below the latitude 63° 20′ 38″. At this latitude the ring will just touch his horizon, and will continue to be more and more seen until he descends to latitude 47° 33′ 51″, when both rings will be seen as represented in fig. 9.

Fig. 10

In descending to lower latitudes, more and more of the rings will rise above the horizon, and they will assume the form of a double bow, as represented in fig. 10.

As the observer descends lower and lower in latitude, the bow will take a higher and higher position, and will span a greater portion of the firmament, as represented in figs. 11, 12, 13.

It will be observed that, in all cases, the width of the bow decreases from the meridian to the horizon, and also decreases with the latitude of the observer.

Fig. 11.

Fig. 12.

Fig. 13.

In fig. 14 is represented a portion of the ring, with the satellites as they appear above, showing different lunar phases.

We must refer those who may desire to pursue the Uranography of Saturn into its details to the memoir already cited, published in the "Transactions of the Royal Astronomical Society;" and to Chapter XV. of Dr. Lardner's "Astronomy."

Fig. 14.

16. We have thus presented the reader with a brief and rapid sketch of the circumstances attending the two chief groups of globes which compose the solar system, and have explained the numerous and striking analogies which, taken together, amount to a demonstration that, in the economy of the material universe, these globes must subserve the same purposes as the earth, and must be the dwellings of tribes of organised creatures, having a corresponding analogy to those which inhabit the earth.

17. The differences of organisation and character which would be suggested as probable or necessary by the different distances of the several planets from the common source of light and heat, and the consequent differences of intensity of these physical agencies upon them, by the different weights of bodies on their surfaces, owing to the different intensities of their attractions on such bodies; by the different intervals which mark the alternations of light and darkness; are not more than are seen to prevail among the organised tribes, animal and vegetable, which inhabit different regions of the earth. The animals and plants of the tropical zones differ in general from those of the temperate and the polar zones; and even in the same zone we find different tribes of organised creatures flourish, at different elevations above the level of the sea. There is nothing more wonderful than this in the varieties of organisation suggested by the various physical conditions by which the planets are affected.

But these arguments and analogies will acquire great additional force, when it is shown that the other bodies composing the solar system are not furnished with like provisions, and exhibit none of the fitness, for the dwelling-places of such tribes.

18. The Sun, as will be shown in another part of this series, is a vast globe, invested with an ocean, or rather an atmosphere, of flame, in which the most astonishing convulsions and eruptions

are continually manifested. Here is no moderated and regulated temperature, no alternations of light and darkness, no succession of seasons, no varieties of climate, no divisions of land and water. The sun is, in fact, a vast globular furnace, the heat emitted from each square foot of which is seven times greater than the heat which issues from a square foot of the fiercest blast furnace. Such is the intensity of this heat, that although the distance of the earth from the sun is little less than 100,000000 of miles, and although the surface of the earth, by reason of its diurnal rotation, is withdrawn from the sun's direct influence during alternate intervals of twelve hours, yet the total quantity of heat received by the earth from the sun in a year is sufficient, if uniformly diffused over its surface, to liquefy a crust of ice covering it 100 feet thick!

It follows from this that the average heat received by each square foot of the earth's surface from the sun in a year would be sufficient to dissolve 5400 lbs. weight of ice.

How entirely removed from all analogy with the earth such a globe of fire must be, is apparent.

19. The moon, on the other hand, while it has nothing in common with the sun, is not the less destitute of all those analogies to the earth which suggest habitability. We shall, on another occasion, explain fully the circumstances attending our satellite. For the present, it will be sufficient to observe that it has no atmosphere, no clouds, no water or other liquids, no intervals of light and darkness, bearing any analogy to our days and nights; that its surface bristles with one unbroken continuity of rugged mountainous region more savage than the glaciers which crown the summits of the Alps, the Andes, or the Cordilleras, and that even in the valleys a temperature must prevail colder than that of our poles.

It will therefore be easily imagined how little analogy such a globe has to the earth, and how utterly unsuited it would be for the habitation of organised tribes.

20. Astronomical observation renders it probable that the satellites of the other planets are under physical conditions similar to that of the moon, and that, like the moon, they are deprived of the conditions of habitability.

21. A numerous class of bodies, called comets, have been proved by modern observation to be connected by gravitation with the solar system. These bodies appear generally to be divested of all solidity, and to be masses of vaporous matter floating through the system. It is obvious that these can have no analogy to the earth.

In the space between the two groups of planets which present such striking analogies to the earth, another group consisting of six or seven-and-twenty bodies, circulate round the sun, as represented in the plan of the system given in this tract, Chap. II., fig. 1. The number of these is augmented every year by the discovery of some which were not before seen.

22. These bodies, which have been called PLANETOIDS or ASTEROIDS, obey the law of gravitation in their motion round the sun. Their distances from that luminary are not only different one from another, but they differ from all the other planets in their extremely small magnitude. In the telescope they are seen as stars of the tenth or twelfth magnitude, and their real magnitudes are so minute that they have never yet been certainly ascertained, notwithstanding the number and power of the telescopes that have been directed to them.

As to their origin, and the parts they play in the economy of creation, nothing can be offered but the most vague and uncertain conjecture. According to the opinion of some, they are the minute fragments of a single planet, which has been smashed to pieces by collision with the solid nucleus of a comet, assuming the possible existence of such a body. According to others, the fracture may have been produced by internal explosion, arising from causes similar to those which produce earthquakes and volcanic phenomena. Others again reject altogether the hypothesis of the fracture of a formerly existing planet, and substitute for it the contrary hypothesis, that these numerous minute bodies are the germs or constituent elements of a future planet, which will be formed by these bodies gradually coalescing into one globe, some of them, perhaps, assuming the character of satellites to it.

These are speculations which, however ingenious and attractive, are beside our present purpose. It is plain that the planetoids, as they now actually exist, present none of the analogies to the earth which are so conspicuous in the other planets.

WEATHER PROGNOSTICS.

1.—Popular errors as to meteorological phenomena—2. Weather almanacks, their absurdities—Herschel's Weather Table—Murphy's Almanack. 3. Influence of the moon on the weather—Toaldo's theory—Pilgrim's observations—Horsley's observations and papers—Schübler's observations and calculations—Arago's examination of them—Observations of Flaugergués and Bouvard.—4. Metonic cycle—Arago's examination of it, and observations.—5. Arago's examples of the speculation and reasoning of meteorologists.—6. Changes of the moon have no influence on the weather.

1. The physical laws which govern the phenomena of our atmosphere, and regulate the changes of the weather, have always been a favourite topic of speculation. As the principles of astronomical science supplied means of predicting, with the highest possible degree of certainty and precision, the motions and appearances of the heavenly bodies, it was not unnaturally expected that atmospherical phenomena might be brought under equally clear and certain rules. The connection of the lunar motions with the tides was apparent, long before the influence by which the moon produced the rise and fall of the waters of the ocean was explained; and this gave countenance, at a very early period, to the idea that that body had an influence on the atmosphere, if not as certain and regular as on the waters, still

sufficiently so to furnish probable grounds for conjecture as to certain changes of the weather.

But even before analogies of this kind could have furnished much ground for reasoning, and when the heavenly bodies must have been regarded more as *signs* than *causes*, meteorological phenomena were connected with them by popular observation. The influence of climate on all the interests of a people in a pastoral, and subsequently in an agricultural state, is obvious; and accordingly we find weather prognostics coming down by tradition from the most remote antiquity. By a course, however, contrary to most other subjects of observation and inquiry, this was corrupted rather than improved with the progress of knowledge and civilisation; and what was once a mere system of *signs* of a certain present state of the atmosphere, indicating certain approaching changes, was, by the craving of philosophy after the relations of cause and effect, converted into the most absurd system of *rules*, having no foundation in nature, never fulfilled by the phenomena except fortuitously, and maintaining their ascendancy by the unbounded credulity of mankind.

The truth is, that the ancient prognostics, whether derived from the moon, from the sun, or from the stars, were, in the first instance, used legitimately as mere indications of the state of the atmosphere by persons too simple-minded and uneducated to trouble themselves much with the philosophy of cause and effect; but when these appearances came into the hands of philosophers, they were at once elevated to the rank of physical causes, and their dominion extended in proportion to the dignity and importance thus conferred upon them. Such notions were in keeping with a philosophy which made the moon the boundary between corruption, change, and passiveness, on the one hand, and the active powers of nature on the other. "Thus," says Horsley, "the uncertain conclusions of an ill-conducted analogy, and false metaphysics, were mixed with a few simple precepts, derived from observation, which probably made the whole of the science of prognostication in its earliest and purest state."

Although from age to age the particular circumstances and appearances connected with the moon, by which the atmospheric vicissitudes were prognosticated, were changed, still the faith of mankind in general in her influence on the weather has never been shaken; and even in the present day, when knowledge is so widely diffused, and physical science brought, as it were, to the doors of all who have the slightest pretension to education, this belief is almost universal. Many, it is true, may discard predictions which affect to define, from day to day, the state of the weather. There are few, however, who do not look for a change of the weather with a change of the moon. It is a belief nearly universal, that the epochs of a new and full moon are in the great majority of instances attended by a change of weather, and that the quarters, though not so certain, are still epochs when a change may be probably expected. Those who have least faith in the meteorological influence of the moon, extend their belief thus far.

It is worthy of remark, that this persuasion of the meteorological influence of the moon is never so strong and so undoubting as among those classes of persons who are at once most deeply interested to foreknow the weather, and have the best and most unceasing opportunities of observing the phenomena. No navigator, from the captain or master to the commonest seaman, no agriculturist or gardener, from the largest farmer to the commonest field-labourer, ever doubts for a single moment the influence of new and full moon on fair weather and foul.

Notwithstanding the general diffusion of scientific information and the multitude of encyclopædic compilations and elementary and popular digests of physical science that are accessible, it is astonishing how universal is the ignorance on this subject even among persons who might be supposed to spare no pains to inform themselves. Thus we find in the otherwise excellent compilations of the late Mr. Loudon on Agriculture and Gardening, a chapter on the means of prognosticating the weather, in which the supposed influences of the lunar phases have precedence over the indications of the barometer, the thermometer, the hydrometer, and the rain-gauge, the former being characterised by the author as "natural," and the latter as "artificial" data. Why the variations of the atmospheric pressure and temperature, and the quantities of water which are suspended in, or which fall from the atmosphere, should be regarded as less "natural" indications of the weather than the moon, the author does not inform us.

We find, however, in these popular works of reference, the lunar prognostics reproduced in their minutest details, and the fantastical theories of Toaldo, Lambert, and Cotte, referred to as though they were as sound as that of gravitation.

2. In some one of the numerous weather almanacks which have from time to time circulated, there appeared a table professing to indicate the relation between the changes of the weather and the lunar phases, entitled "Herschel's Weather Table." The general public have fallen into a natural and excusable mistake (from which Mr. Loudon does not seem to

have escaped), in supposing that this absurd affair has been sanctioned by the authority of one of the illustrious astronomers whose name it bears. Whether the table in question is really the production of any person bearing that celebrated name we cannot say; but the public may be assured that neither of the eminent astronomers who have rendered the name of Herschel for ever memorable, has had any concern with it.

It is astonishing, in this age of the diffusion of knowledge, how susceptible the public mind is of excitement on any topic, the principles of which do not lie absolutely on the surface of the most ordinary course of elementary education. It was only in the year 1832 that a general alarm spread throughout France, lest Biela's comet in its progress through the solar system, should strike the earth; and the authorities in that country, with a view to tranquillise the public, induced M. Arago, the astronomer royal, to publish an essay on comets, written in a familiar and intelligible style, to show the impossibility of such an event.

Several panics in England, connected with physical questions, have occurred within our memory. There prevailed in London a "water panic," during which the public was persuaded that the water supplied to the metropolis was destructive to health and life. While this lasted, the papers teemed with announcements of patent filtering machines; solar-microscope makers displayed to the terrified Londoners troops of thousand-legged animals disporting in their daily beverage; publishers were busy with popular treatises on entomology; and the public was seized with a general hydrophobia. It was in vain that Brande analysed the water at the Royal Institution, and Faraday attempted to reason London into its senses. Knowledge ceased to be power; philosophy lost its authority. Time was, however, more efficacious than science; and the paroxysms of the disease having passed through their appointed phases, the people were convalescent. There was at another time a panic against atmospheric air, during which the inhabitants of the great metropolis (in a literal sense) scarcely dared to breathe. The combustion of coal was denounced as the great evil in this case. Calculations were circulated of the number of cubic feet of sulphurous gas taken into the lungs of each adult inhabitant per annum; the properties of carbonic acid were discussed behind counters; patent furnaces were plentifully invented and advertised for sale; and parliament was urged to pass a bill for the purification of the atmosphere, and to compel all who used fires to consume their own smoke.

In 1838, the English public, who are especially excitable, were seized with a rage for weather prognostics, produced apparently by an unusually rigorous and long-continued frost, which took place in the months of January and February. In one of the numerous "weather almanacks" which were then circulated, a fortuitous coincidence occurred, by which it appeared that the coldest day had been predicted by the author, an adroit Hibernian named Patrick Murphy. The conductors of some of the leading journals, without waiting to obtain better information from any of the acknowledged scientific authorities, gravely descanted on the "great advantages which would accrue to the farmer, the manufacturer, the navigator, and others, from the certain prediction of the weather from week to week and from day to day," and admitted that they looked forward to the period not far distant, when

> "Careful observers might foretel the hour
> By sure prognostics when to dread a shower."

So extreme was the public excitement at the moment on this subject, that the book in which the so-called weather table was published was actually purchased, though its price was high, by the hundred thousand! So urgent was the demand for it, and so irrepressible the public impatience, that the shop of the publisher, like that of a baker in a famine, was obliged to be protected by the police, who, to keep the thoroughfare unobstructed, marshalled the expectant purchasers in a *queue* which extended to an incredible length. Yet will it be believed, that when this weather almanack was afterwards examined and compared with the actual changes of the weather by the author of these pages, its pretended predictions were found to fail in seventeen cases out of twenty-four!

3. The imputed influence of the moon upon the weather may he considered either as a question of theory or a question of fact.

Let us consider for a moment the theoretical question. If the moon act upon our atmosphere by attraction, as she acts upon the waters of the ocean, she will produce *atmospheric tides*. The greater mobility of air will cause those tides to be formed more rapidly than the water tides; and it may be, perhaps, assumed that they will always be placed, either exactly, or very nearly under the moon. Thus, as there is *high water* twice daily, so would there be *high air* twice daily; and the times of this air-tide would correspond with the moments of the transit of the moon over the meridian above and below the horizon.

The same causes, also, which at new and full moon produce spring tides, and at the quarters neap tides, would produce spring and neap atmospheric tides at the same epochs. At new and full moon, therefore, the air ought to be higher, daily, at noon and midnight than at any other times during the month ; and, on the other hand, at quarters it ought to be lower.

If, then, the barometer be observed twice daily, viz., at the times of the moon's transit over the meridian, above and below the horizon, it ought (so far as it will be affected by the sun and moon) to be the highest at new and full moon, and lowest at the quarters. Now as the rise of the barometer generally indicates fair weather, and its fall foul weather, the conclusion to which this would lead would be, that the epochs of new and full moon should be generally fair, while at the quarters bad weather would generally prevail.

This, however, is not the popular opinion. The traditional maxim is that a *change* may be looked for at new and full moon ; that is, if the weather be previously fair, it will become foul ; if previously foul, fair.

M. Arago submitted to rigorous investigations a series of barometric observations made in relation to the lunar phases at the Paris Observatory, and continued for twelve years, and found that the effect of the lunar attraction on the barometer at the epochs of the high and low atmospheric tides could not have exceeded the 1-600th of an inch,—a quantity such as could produce no conceivable effect upon the weather.

It is evident, then, that if the moon have any influence on our atmosphere, it cannot proceed from any cause analogous to that which produces the tides of the ocean.

But it may be said that although the moon may not affect the atmosphere by her gravitation, yet she may influence it by her light, or by electrical or magnetical emanations, or, in fine, by some occult physical causes not yet discovered by astronomers. This is an objection that, from its vagueness and indefiniteness, is difficult to be rebutted by any means which theory can furnish. It is known that the light of the moon concentrated in a point by the most powerful burning lenses, is incapable of producing the slightest sensible effect on the most susceptible thermometer. Neither is it found to produce any effects of an electrical or magnetical kind. It may be assumed generally, that the effects commonly imputed to the moon, in producing change of weather at her principal phases, are so contradictory, that it is impossible to imagine any physical causes which could account for them. If the new and full moon and the quarters are attended by changes of the weather, the cause producing this effect, under the same circumstances, must have incompatible influences; if fair weather precede the phase, the supposed physical cause must be such as to be capable of converting it into foul weather; and if foul weather precede the phase, the same cause must convert it into fair weather. It will be admitted that it is hard to imagine any physical agent whatever, which under precisely the same circumstances, shall produce upon the same body effects so opposite.

But let us dismiss the theoretical view of the question, and inquire as to the facts. Has it been found, *as a matter of fact*, that the epochs which mark the principal phases of the moon have been, in the majority of cases, attended with a change of weather? Before this question can be satisfactorily answered, it will be indispensable that the meaning of the phrase, *change of weather*, be distinctly understood. An observer who is predisposed to a belief in the influence of the lunar phases, will consider himself warranted in classing as a change of weather every transition from a calm to a wind, whether feeble or forcible—every change from a clear and serene firmament to one ever so little clouded—from a firmament a little clouded to one quite covered over. He will consider the change from a day absolutely free from rain to one in which a few drops may chance to fall, as well entitled to be recorded as a change of weather as if the transition had been from a day absolutely fair to one of incessant rain. On the other hand, a disbeliever in the lunar influences will class all very slight changes as settled weather, and will only register as changes those of a very decisive character. These are difficulties hard to remove, but unless they be removed, how is it possible to compare together, with any probability of arriving at the truth, the records of different observers? What value or importance are we to attach to the results of any such observations, unless the prejudices of the observer are admitted into our estimate?

Toaldo has given the result of a comparison of observations continued for forty-five years at Padua, in which changes of weather are recorded in juxta-position with the lunar phases. Without detailing the particulars of these calculations, we may state at once the following results of them. He found that for every seven new moons the weather changed at six, and was settled only at one; for every six full moons, the weather changed at five, and was settled at one; for every three epochs of the quarters, there were two changes of weather.

He also examined the state of the weather in reference to the moon's distance from the earth, which is subject to some variation. The position of the moon when most distant from the earth is called *apogee*, and her position when nearest is called *perigee*. He found that of every six passages of the moon through *perigee* there were five changes of weather; and of every five through *apogee* there were four changes of weather. It is clear that if these results would bear the test of rigid examination, they would be decisive in favour of the popular notion of the lunar influence. But let us see in what manner Toaldo conducted his inquiry.

He was himself an avowed believer in the lunar influence, not merely upon the atmosphere, but even on the state of organised matter. In his memoir he has not informed us what atmospherical changes he has taken as changes of weather; and it is fair to presume that the bias of his mind would lead him to class the slightest vicissitudes under this head. But, further, Toaldo, in recording the changes of weather coinciding with the epochs of the phases, did not confine himself to changes which took place upon the particular day of the phase. On the pretext that time must be allowed for the physical cause to produce its effect, he took the results of several days. At the new and full moon he included in his enumeration all changes which took place two or three days before or two or three days after the day of new or full moon; while for the quarters he only included the day preceding and the day following the phases; and for epochs not coincident with the lunar phases, he only counted the changes of weather which took place on the particular day in question.

It appears, then, that by the changes coinciding with a new and full moon recorded by Toaldo are understood any changes occurring within the space of from four to six days; for the changes recorded at the quarters are to be understood those which occurred within the space of three days; and for those not coinciding with the phases the changes which occurred on a single day. It will not, we presume, require much mathematical sagacity to perceive that the results of such an inquiry must have been just what Toaldo found them to be; and that, if instead of taking the epochs of the lunar phases, he had taken any other periods whatsoever, and tried them by the same test, he would have arrived at the same results. Five days at the new and full moon would include a third of the entire lunar month; and thus a third of all the changes of weather which occurred in that period were ascribed by Toaldo to the lunar influence.

Professor Pilgrim has examined a series of observations on the lunar phases as connected with the changes of weather, made at Vienna, and continued from 1763 to 1787—a period of twenty-five years—and he has found that, of every hundred cases of the phases, the proportion of the occurrence of changes to that of the settled state of the weather was as follows :—

	Changes.	Settled Weather.
New moon	58	42
Full moon	63	37
Quarter	63	37
Perigee	72	28
Apogee	64	36
New moon at perigee	80	20
New moon at apogee	64	36
Full moon at perigee	81	19
Full moon at apogee	68	32

Admitting these results, it would follow, contrary to popular belief and to the observations of Toaldo, that the new moon is the least active of the phases; and that the full moon and quarters are equally active; also that the influence of *perigee*, or the nearest position of the moon, is greater than that of any of the phases, while the influence of *apogee*, or its greatest distance, is equal to that of the quarters and full moon, and greater than that of the new moon.

But Pilgrim's calculations are liable to objections similar to those to which Toaldo's are obnoxious. Like Toaldo, he included in his enumerations of changes corresponding to the phases, changes which occurred the days preceding and following the phases: this being the case, the only wonder is that the proportion which he has found, especially for the new moon, is not more favourable to his hypothesis. But independently of this, Pilgrim's results are not entitled to any confidence: they bear internal evidence of their inaccuracy; and besides, the observations were not continued for a sufficient length of time to give a safe and certain conclusion.

In the years 1774 and 1775, Dr. Horsley directed his attention to the question, and published two papers in the "Philosophical Transactions," with a view to dispel the popular prejudice on the subject of lunar influences. Horsley's observations, however, were confined to so short a period of time (two years), that they could not be expected to afford any satisfactory results. He found that in the year 1774 there were only two changes of weather which corresponded with the new moon, and none with the full moon; and that in the year 1775 there were only four changes which corresponded with the new moon, and three with the full moon.

Dismissing, then, this popular notion of the correspondence of changes of the weather with the lunar phases, let us consider the question of lunar influences in a more general point of view, and see whether observation has supplied any ground for the supposition of any relation whatever of periodicity between the moon and the weather. M. Schübler examined this question with considerable care so recently as 1830, and published the results of his observations, which, shortly after, were re-examined by M. Arago.

Schübler's calculations were founded on meteorological observations made at Munich, Stutgard, and Augsburg, for twenty-eight years.* His object was to ascertain whether any correspondence existed between the lunar phases and the quantity of rain which fell in different parts of the month. He defined a rainy day to be one in which a fall of rain or snow was recorded in the meteorological journals, provided it affected the rain-gauge to an extent exceeding the six-hundredth part of an inch.

So far as his observations may be relied upon, it would follow, that in the places where they were made, out of 10,000 rainy days the following are the number of those days which would happen at the different lunar phases.

New moon	306
First octant.	306
First quarter	325
Second octant	341
Full moon	337
Third octant	313
Last quarter	284
Fourth octant	290

Now, as there are twenty-nine days and a half in the lunar month, if we suppose the fall of rain to be distributed equally through every part of the month, the total number of these 10,000 days which should happen on the eight days of the phases, would be found by a simple proportion; since it would bear to 10,000 the same proportion that 8 bears to 29½: the number would therefore be 27·12. Whereas, it appears from the above table, that the actual number which fell upon these days were 25·02: it appears, therefore, that less than the proportional amount occurred upon them.

Pilgrim had already, in 1788, attempted to ascertain the influence of the lunar phases on the fall of rain; and he found that in every hundred cases there were 29 days of rain on the full moon, 26 at the new moon, and 25 at the quarters.

The preceding observations refer only to the number of wet days. Schübler, however, also directed his inquiries to the

* At Munich, from 1781 to 1788 inclusive: at Stutgard, from 1809 to 1812 inclusive; and at Augsburg, from 1813 to 1828 inclusive.

influence of the lunar phases on the *quantity* of rain and on the clearness of the atmosphere. From observations continued for sixteen years at Augsburg, including 199 lunations, he obtained the following results:—

Epochs.	Number of clear days in 16 years.	Number of overcast days in 16 years.	Quantity of rain in 16 years in inches.
New Moon .	31	61	26·551
First quarter	38	57	24·597
Second octant	25	65	26·728
Full moon .	26	61	24·686
Last quarter	41	53	19·536

In this table, by a clear day, is meant such days as exhibited a cloudless sky at seven in the morning, and at two and nine o'clock in the afternoon; those that were not clear at these hours, were counted as cloudy days. These results are in accordance with the former. It appears that the number of clear days is more frequent in the last quarter, which is an epoch at which, by the former method of inquiry, the number of rainy days was least; also the number of cloudy days is greatest at the second octant, which is a period at which the number of rainy days are found to be greatest; the depth of rain also agrees with this, being the greatest about the second octant, and least at the last quarter. Schübler extended his inquiries to the influence of the moon's distance on rain; and he found that, on examining 371 passages of the moon through the positions of her extreme limits of distance, during the seven days nearest to *perigee* it rained 1,169 times; and during the seven days nearest *apogee* it rained 1,096 times. Thus, *cæteris paribus*, the nearer is the moon to the earth the greater would be the chances for rain.

From all that has been stated, it can scarcely be denied that there exists some correspondence between the prevalence of rain and the phases of the moon. What that exact correspondence is, remains for more extended and accurate observations to inform us; but meanwhile it may be safely affirmed that it is not such as to constitute a prognostic in any sense approaching to that in which it has been popularly adopted. That some extremely small excess of rain falls during the four days which precede the day of full moon, and a correspondingly small defect during the four days which precede the day of new moon, seems to be to a certain degree probable. But this pluvial variation is so minute in its amount, even supposing it real and general, as to be utterly imperceptible by any means of popular observation, and therefore practically inapplicable as a prognostic.

Schübler also examined the question of a correspondence between the direction of the wind and the lunar phases, and found that winds from the south and south-west became more and more frequent at those periods of the month at which rain was also observed to increase; and that such winds were more and more rare, while winds in the contrary direction occurred oftener, towards those epochs of the month when least rain was observed to prevail. These results, it will be seen, are quite in accordance; and the question respecting the mode of action by which the periods of rain are produced, would be reduced to the question of the physical action by which the moon affects the currents of the atmosphere.

The connection of barometric indications with atmospheric phenomena is so obvious, that the inquiry as to a correspondence between the lunar phases and the variations of the barometer, could scarcely escape the attention of meteorologists. M. Flaugergués accordingly made a series of observations at Viviers (in the department of Ardêche), in France, which were continued from 1808 to 1828, a period of twenty years, on the heights of the barometer in relation to the lunar phases: that the influence of the sun might be always the same, the observations were made at noon, and the heights of the barometer were reduced to what they would be at the temperature of melting ice. The following are the mean heights of the barometer, deduced from these observations:—

New moon	29·743
First octant	29·761
First quarter	29·740
Second octant	29·716
Full moon	29·736
Third octant	29·751
Last quarter	29·772
Fourth octant	29·744

Hence it appears that the height of the barometer is least about four days before full moon, and greatest six or seven before new moon. Now these are about the times at which the investigations of Schübler give the greatest and least quantity of rain: and, since the fall of the barometer generally indicates a tendency to rain, these results are in accordance. Although it must be admitted that the variation of the barometer is in this case so minute, that a sensible effect could hardly be expected from it, still, though minute, it is quite distinct and decided.

M. Flaugergués also observed the mean height of the barometer when the moon was at her greatest and least distance from the earth, and found that at perigee it was 29·713, and at apogee 29·753.

So far, therefore, as this small difference can be supposed to indicate anything, it would indicate a prevalence to rain at perigee and at apogee, which is in accordance with the observations of Schübler.

We have shown that the theory of the moon's attraction, applied to explain atmospheric tides similar to those of the ocean, would lead to the conclusion that the height of the barometer observed at noon, when the moon is in her quarters, would be less than its height at noon at new and full moon. Observation, however, shows the very reverse as a matter of fact. The observation of M. Flaugergués gives the mean height of the barometer at quadratures 29·756, and at new and full moon 29·739 ; the height at quadratures being in excess to the amount of 0·017. This result has been further confirmed by the more recent observations of M. Bouvard, at the Paris Observatory ; he has found the mean height of the barometer at the quarters 29·786, and at new and full moon 29·759 ; the excess at the quarters being 0·027.

4. Although, therefore, it cannot be denied that there exists a certain relation between the barometric column and the lunar phases, yet it is not the relation which the theory of atmospheric tides would indicate ; and by whatever physical influence the effect may be produced, it is certainly not the gravitation of the moon affecting our atmosphere in a manner analogous to that by which she affects the waters of the ocean. Any physical effects which depend on the relative positions of the sun and moon, as seen from the earth, would necessarily occur in the same order throughout the year, when these two luminaries themselves have corresponding positions in the heavens on the same days of the year.

At a very early period in the history of astronomical discovery, it was known that, after the lapse of nineteen years, the sun and moon assume on successive days of the year relative positions.

Thus, for example, if the moon were 90° behind the sun on a certain day of a certain month in the year 1800, it would be 90° behind the sun on the same day of the same month in the year 1819, and again in the year 1838, and so on ; but on the same day of the same month in any intermediate year it would have a different relative position with respect to the sun. This cycle of nineteen years was known to the Greeks, and was called *the Metonic cycle*, from Meton, its reputed discoverer ; and it has always been used as a convenient method of calculating eclipses and other phenomena depending on the relative positions of the sun and moon. In a solar eclipse, the sun and moon must occupy nearly the same position in the heavens; and in a lunar eclipse, nearly opposite positions: it is evident, therefore, that if an eclipse occur on any day in any given year, an eclipse of the same kind must occur on the corresponding day in every nineteenth succeeding year. The tides, depending as they do on the relative positions of the sun and moon, would be calculated with facility by means of the same cycle; and meteorologists who hold the doctrine that atmospheric vicissitudes depend solely or chiefly upon the relative aspects of the sun and moon, have favoured the doctrines, that there is a general cycle of weather, the period of which corresponds with that which we have noticed. Thus they hold, that the general changes of weather succeed each other in the same, or almost the same order, throughout every successive period of nineteen years.

We shall not here object, on theoretical grounds, to the doctrine that the true amount of the Metonic cycle is not precisely nineteen years. But it is subject to a stronger objection, founded on the principles which its supporters themselves rely upon. The attraction of bodies in virtue of their gravitation increases in the same proportion as the square of the distance diminishes; and as we have already stated that the moon's distance from the earth is variable to an extent not inconsiderable, it is evident that her influence on the atmosphere ought to be expected to depend much more on that variation of distance, than on her relative position with respect to the sun. Now, although the cycle of nineteen years corresponds with the changes of her relative position to the sun as *seen* from the earth, yet it has no correspondence whatever with the variation of her distance; and although, on each day of each succeeding period of nineteen years, she will have the same apparent position relatively to the sun, she will not have the same distance from the earth, and, therefore, will not exert the same attraction on our atmosphere. M. Arago (to whom we are indebted for the most complete investigation of this question, and for the collection of the labours of others upon it) has successfully shown that observation affords no countenance or confirmation whatever to this hypothesis.

The variation of the moon's distances from the earth (to which we have more than once adverted) is occasioned by the fact that her path round the earth is not circular, but oval—the position of the earth being nearer to the one end than the other. As the moon, therefore, approaches the furthermost extremity of her oval orbit, her distance from the earth continually increases until, arriving at that point, it becomes greatest; as she moves from that extremity of the orbit to the other end of the oval, her distance continually diminishes until arriving at the other end, it becomes least. These variations of distance are produced every revolution of the moon round the earth. Now, owing to a certain change of position, to which the moon's orbit is subject, the points which mark her greatest and least distances are subject to a slow, gradual, and regular change; so that the points in the heavens at which she reaches her greatest and least distances are different every revolution. After the lapse, however, of eight years and ten months, these points having traversed the whole circumference of the heavens, resume their former position very nearly; so that the actual times at which the moon is observed at the same distances from the earth, and also at the same points in the heavens, recur in a cycle, the length of which is about eight years and ten months.

So far, therefore, as the vicissitudes of the weather can be supposed to be influenced by this cause, their period should be such that, after the lapse of nine years, the corresponding states of the weather would be as it were, two months in advance: thus the effect produced in December, 1800, would again be produced in October, 1809, in August, 1818, and so on.

If the purpose be to determine the cycle in which the lunar influence so far as it depends on distance, would produce the same effects upon the same days of the year, the duration of the cycle would be six times eight years and ten months: for in six successive intervals of that period, there are exactly fifty-three years; but any less number of periods of eight years and ten months do not make a complete number of years. Therefore after a cycle of fifty-three years, the moon being on the same day of each successive year at the same distance from the earth, her influence, so far as depends on distances, will be the same, and will produce the same effect upon the weather.

5. Now we cannot better illustrate the loose and inaccurate manner in which scientific principles are applied by some meteorologists than by stating that this cycle of eight years and ten months has formed the theoretical grounds for a reputed meteorological period of nine years. It has been maintained that, through every successive interval of nine years, the changes of weather have a general correspondence: thus, if the state of the weather throughout the year 1800 be examined, it has been said to correspond with the weather throughout the years 1809, and 1818, &c.

6. From all that has been stated, it follows, then, that the popular notions concerning the influence of the lunar phases on the weather have no foundation in theory, and no

correspondence with observed facts. That the moon, by her gravitation, exerts an attraction on our atmosphere cannot be doubted; but the effects which that attraction would produce upon the weather are not in accordance with observed phenomena; and, therefore, these effects are either too small in amount to be appreciable in the actual state of meteorological instruments, or they are obliterated by other more powerful causes, from which hitherto they have not been eliminated. It appears, however, by some series of observations, not yet confirmed or continued through a sufficient period of time, that a slight correspondence may be discovered between the periods of rain and the phases of the moon, indicating a very feeble influence, depending on the relative position of that luminary to the sun, but having no discoverable relation to the lunar attraction. This is not without interest as a subject of scientific inquiry, and is entitled to the attention of meteorologists; but its influence is so feeble that it is altogether destitute of popular interest as a weather prognostic. It may, therefore, be stated that as far as observation combined with theory has afforded any means of knowledge, there are no grounds for the prognostications of weather erroneously supposed to be derived from the influence of the sun and moon.

Those who are impressed with the feeling that an opinion so universally entertained even in countries remote from each other, as that which presumes an influence of the moon over the weather, must have some foundation, will do well to remember that against that opinion we have not here opposed mere theory. Nay, we have abandoned for the occasion the support that science might afford, and the light it might shed on the negative of this question, and have dealt with it as a mere question of fact. It matters little, so far as this question is concerned, in what manner the moon and sun may produce an effect on the weather, nor even whether they be active causes in producing such effects at all. The point, and the only point of importance is, whether regarded as a mere *matter of fact*, any such correspondence between the changes of the moon and those of the weather exists as is popularly supposed? And a short examination of the recorded facts proves that IT DOES NOT.

POPULAR FALLACIES.

1. Fallacy of the evidence of the senses.—2. Fallacies of vision.—3. As applied to the sun and moon.—4. Mechanism of the eye—its uses.—5. Perceptions of colour—6. Fallacies of smell, taste, and touch.—7. Fallacies as to number—8. Impressions retained by the eye.—9. Fallacies as to distance—10. Fallacies of touch—of apparent temperature.—11. Explained by reference to temperature of the human body.—12. Cause of apparent coldness of glass and porcelain.—13. Explanations of the feats of mountebanks exposing their bodies to a fierce temperature.

1. Nothing can be more common or frequent than to appeal to the evidence of the senses as the most unerring test of physical effects. It is by the organs of sense, and by these alone that we can acquire any knowledge of the qualities of external objects, and of their mutual effects when brought to act one upon another, whether mechanically, physically, or chemically, and it might, therefore, not unreasonably be supposed, that what is called the evidence of the senses must be admitted to be conclusive as to all the phenomena developed by such reciprocal action.

Nevertheless, the fallacies are numberless into which those are led who take what they consider the immediate results of sensible impressions, without submitting them to the severe control and disciplined analysis of the understanding.

These fallacies arise partly from mistaking the true character and functions of the organs of sense. These organs were never designed by their Maker to be the instruments of scientific inquiry. If they had been so constructed, they would most probably have been unfit for the ordinary purposes of life. It is observed somewhere, by Locke, we believe, that an eye adapted to perceive the constituent atoms of the metal which forms the hands of a clock might be, from the very nature of its structure, incapable of informing its owner of the hour of the day indicated by the same hands; and it may be added, that a pair of telescopic eyes, which would discover the population of a distant planet, would ill requite the observer for the loss of that ruder power of vision necessary to guide his steps through the city he inhabits, and to recognise the friends which surround him. The comparison of instruments adapted for the use of commerce and domestic economy, and those designed for domestic purposes, furnishes a not less appropriate illustration of the same fact. The highly delicate balance used by the philosopher in his inquiries respecting the relative weights and proportions of the constituent elements of bodies, would, by reason of its very perfection and sensibility, be utterly useless in the hands of the merchant or the housewife. Each class of instruments, has, however, its peculiar uses; and is adapted to give indications with that degree of accuracy which is necessary and sufficient for the purpose to which it is applied.

2. Of all the organs, that which would seem to be most exact and unerring in its indications is the eye; and, although in a certain sense this is true, yet there are no impressions which more imperiously require the exercise of the judgment to adjust and rectify them than those of vision. By this sense we receive the perception, subject, however, to many qualifying conditions, of form, magnitude, brightness, and colour. There is not one of these qualities, however, which is not frequently mistaken or wrongly estimated.

3. Every one, for example, is familiar with the appearance of the sun and moon when rising and setting. The apparently large orb which they present to the senses is an object of familiar notice. Is not every one impressed with a conviction that the apparent magnitude of the sun when it rises, glowing with a redness acquired from the depth of air through which its rays then pass, is much greater than the apparent magnitude of the same object at noonday? and is not the same impression admitted with respect to the rising or setting full moon, compared with the same object seen on the meridian? Yet nothing is more easy than to prove, as a matter of fact, that these

impressions are fallacious. Let any one adopt any convenient method which may occur to him, to measure the apparent magnitude of the sun on the horizon, and again on the meridian, and he will find them the same. This may be accomplished by extending two threads of fine silk parallel to each other in a frame, and placing them in such a position, and at such a distance from the eye, that when presented to the sun or moon, on the horizon, they will, exactly, touch its upper and lower limb, so that their apparent distance asunder will be equal to the apparent diameter of the lunar or solar disk. If this arrangement be preserved, and the sun or moon be viewed in the same manner when at, or near, the meridian, it will be found that the threads will equally touch its upper and lower limbs, and that their interval will still measure its apparent diameter. It will, therefore, be evident that whatever be the cause of the illusion, the apparent magnitude of the sun or moon is not greater at rising or setting than in the meridian. Whence, then, it may be asked, arises an impression so universally entertained?

The explanation of this singular effect, in which all astronomers appear to concur, refers it to mental, and not optical causes; strictly speaking, it is not an optical illusion. The error is one of the mind and not one of the senses. The estimate which we form of the actual magnitude of any visible object depends on a comparison of the apparent magnitude which that object presents to the eye, with the distance at which we imagine it to be. Thus if there be two objects—buildings, for example, which have to the eye the same apparent height, but which we know or believe to be at different distances from us, we instinctively, and without any operation of the judgment of which we are conscious, conceive that which is more distant to be the largest.

To apply this reasoning to the case of the sun or moon, we are to consider that when either of these objects is in the horizon, a portion, at least, of the space between the eye and it is occupied by a series of objects with the magnitudes and relative positions of which we are familiar. We are, therefore enabled to make some estimate of a portion of the space that intervenes between the eye and the object. But when the object is in a more elevated position in the firmament, no part of the intervening distance is thus spaced out, and we are accustomed to consider the object nearer to the eye.

Conceding this, then, it will be asked how it explains the universal impression of the enormously large disk of the sun or moon when rising or setting; the answer is, that when in or near the horizon the mind is impressed with the idea that the distance of these objects is much greater than when on the meridian, and that their apparent magnitude being the same, the real magnitude is judged to be greater in the same proportion as the distance is supposed to be greater. Thus, if we are impressed with the notion that the sun seen in the horizon is twice as distant as the sun seen in the meridian, we shall infer its diameter to be twice as great, since it appears the same; and if its diameter is twice as great, its apparent superficial magnitude will be four times as great.

The operations of the judgment in such cases are so rapid, and the effect of habit is such, that we are altogether unconscious of them. A thousand examples might be given of bodily actions and motions performed by the dictates of the will, of which we retain no consciousness. It is difficult in the case we have just explained, for minds unaccustomed to metaphysical inquiries, to satisfy themselves of the validity of the explanations we have given. Yet, if it be remembered that it is capable of unequivocal proof that the illusion is not optical, and that, in fact the apparent magnitudes of the moon on the horizon and the meridian are not different, it will easily follow that the error must be mental, and the only explanation which has ever been given of it is that which we have here offered.

There is perhaps no sense which more requires the vigilant exercise of the understanding to rectify its impressions, than that of sight. The susceptibility of the organ of vision itself is liable to frequent and rapid change, and the same objects at different times produce upon it extremely different impressions. A situation in which, in one condition of the eye, we shall appear to be in absolute darkness, will present to us, in another state of the organ, sufficient light to render visible the objects around us. If we are suddenly deprived of the illumination of any strong artificial light, we appear to be for the moment in absolute darkness; but when the organ of vision has had time to recover itself, we often find that there is sufficient light to guide us.

> "Thus when the lamp that lighted
> The traveller at first goes out,
> He feels awhile benighted,
> And lingers on in fear and doubt.
>
> "But soon, the prospect clearing,
> In cloudless starlight on he treads,
> And finds no lamp so cheering
> As that light which heaven sheds."—MOORE.

4. The mechanism which the all-wise Creator that made the eye

has contrived to meet these contingencies is marked by the same perfection that prevails through all His works. The opening in the front of the eye, called the pupil, through which light is admitted to produce vision, is surrounded by an elastic ring, called the iris, which is capable of being contracted or enlarged by the action of certain muscles with which it is connected. It is the magnitude of this opening that determines the quantity of light transmitted to the retina. If, then, we are in a room illuminated with a strong lamp, the muscles which govern the opening of the pupil contract its dimensions until so much light only is admitted as is consistent with the healthful condition of the eye. If the lamp be suddenly extinguished, and the room be left dependent only on the light admitted by the windows, from the nocturnal firmament, we shall at first appear to be in profound darkness, but immediately the pupil will begin to expand, and will presently become so enlarged that enough of light will be received into the eye to render the objects around us faintly visible.

If in this condition of the organ the lamp again be suddenly brought into the room, the eye will be pained by its light, and the eyelid will immediately drop to give it relief; for the enlargement of the pupil which has taken place to accommodate it to the faint light to which it was previously exposed, will admit so great a quantity of the strong light of the lamp as to hurt the retina, and the contraction of the pupil cannot be effected with sufficient rapidity to protect the organ from this injury. But the beneficent Maker of the eye has provided for this purpose the eyelid, which is capable of closing instantaneously, and which gives the pupil time to contract, and to accommodate its dimensions to the new condition to which it is exposed.

5. The perception we receive of the colour of an object depends often as much on the condition of the eye when the object is seen as upon the object itself. By the action of lights of different colours, the sensibility of the retina may be so modified that the same object will appear at different times to have different colours, and unreal objects will often be perceived. These are called spectra. If we place on a sheet of white paper a red wafer, and, illuminating it strongly, direct the eye steadily to it for a short time, and then look at the paper close beside it, we shall there see a blue wafer of the same size. This object is an optical spectrum. The cause of its appearance is easily explained. By the action of the strong red light proceeding from the wafer, the retina is rendered for the moment insensible to the operation of a more feeble red light upon it, for the same reason as the ear would be insensible to the ticking

of a clock immediately after being affected by a discharge of artillery. Accordingly, when the eye, after viewing the red wafer, looks at a white paper beside it, the action of that portion of the compound white light reflected from the paper which is red fails to produce any perception, and the remaining constituents alone are perceived, which accordingly present a bluish tint. To comprehend this, and other similar illusions, it is very necessary to remember that white light is a compound of reds, yellows, and blues, and that if we deprive it of any one of these elements it will assume the tint produced by the others. Thus, if the eye be insensible to red light, all white objects will appear to it with a tint composed of yellow and blue. If it be insensible to blue light, then white objects will appear orange.

Instances have more than once occurred, and are recorded in the works on optics, of individuals incapable, from original defects of vision, of perceiving particular colours. The late Dr. Dalton, of Manchester, was a conspicuous example of this.

But, as we have above stated, even a healthy and perfect eye will be rendered temporarily insensible to the impression of particular colours by being exposed for a short time to the strong action of coloured lights. Optical illusions are produced in this way in the exhibition of fireworks. When luminous balls, some red and some white, are thrown up into the air, the white appear blue beside the red, and are generally imagined to be really blue. The effect, however, is a visual illusion, ascribable to the cause just explained.

In the sky towards sunset, when reddish clouds are arranged with openings between them, the sky at such openings appears green, although it be really blue.

In astronomical observations on the stars there is a curious case, in which it has never been settled whether the appearance is real or illusive. Many of the stars, which to the eye appear individual objects, prove to be double when examined with powerful telescopes. The two stars, thus composing a double star, are frequently of different colours, and it is found that when one is red the other is of a bluish tint. Now we know that it would appear of this tint, even though it were a white object, by reason of the presence of the red star. Whether, in these cases of double stars, the blue one would be really blue, or is rendered so by the optical effect adverted to, has not been decided, it being impossible to view it except in juxtaposition with its red companion.

If the eye be directed to the sun for a few seconds, and the eyelids then be closed, a blue spectrum of the sun will be seen, and will continue to be visible until the retina recover its state of repose.

If we write a page or two with red ink, and then commence to write with black ink, the writing will appear of a light blue colour, and will continue to appear so until the retina loses the impression made by the red ink upon it. In passing, however, from the black to the red, no illusion is produced, the black not acting on the retina so as to excite it.

If small holes be made in a red curtain, so as to admit the rays of the sun through them, the light which will be thrown upon a sheet of white paper will be the general redness produced by the semi-transparency of the curtain, with the white spots produced by the lights passing through the holes; but these white spots will appear to the eyes blue.

It will appear, from these observations, that effects are produced by the juxtaposition of colours in objects of art independent of the separate properties of the colours themselves. Two colours, when seen in juxtaposition, do each of them appear to the eye different from what either would appear to be if seen separately from the other.

6. The senses of smelling, tasting, and even of feeling or touch, are liable to innumerable causes of deception. If the organ at the time it receives an impression be in any unusual condition, or even out of its usual position, the indication of the impression will be fallacious.

If two fingers of the same hand, being crossed, be placed upon a table, and a marble or a pea is rolled between them, the impression will be, if the eyes are closed, that two marbles or two peas are touched.

If the nose be pinched, and cinnamon be tasted, it will taste like a common stick of deal. This is not a solitary instance. Many substances lose their flavour when the nostrils are stopped. Nurses, therefore, upon right and scientific principles stop the noses of children when they give them doses of disagreeable medicine.

If things having different or opposite flavours be tasted alternately, in such rapid succession as not to allow the nerves of tasting to recover their state of repose, the power of distinguishing flavour will be lost for the moment, and the substances, however different, will be undistinguishable from one another. Thus, if the eyes be blindfolded, and buttermilk and claret be alternately tasted, the person tasting them, after a few repetitions of the process, will be unable to distinguish one from the other.

Tastes, like colours, in order to produce agreeable effects, should succeed each other in a certain order. Eating, considered as one of the fine arts in the most refined state of society, is regulated by principles, and nothing can shock the habits and rules of epicureanism more than the violation of certain rules in the succession and combination of dishes. It is maintained that perfection in the art of cookery and the observance of its principles at table is the surest mark of a nation's attainment of the highest state of civilisation.

Of all the organs of sense, that whose nervous mechanism appears to be most easily deadened by excessive action is that of smelling. The most delightful odours can only be enjoyed occasionally, and for short intervals. The scent of the rose, or still more delicate odour of the magnolia, can be but fleeting pleasures, and are destined only for occasional enjoyment. He who lives in the garden connot smell the rose, and the wood-cutter in the southern forests of America is insensible to the odour of the magnolia.

Persons who indulge in the use of artificial scents soon cease to be conscious of their presence, and can only stimulate their jaded organs by continually changing the objects of their enjoyment.

7. One of the most curious and most incomprehensible illusions of the senses is the singularly erroneous estimate which we make of the number of objects of any kind that are presented to us. A striking example of this is presented by the impression made upon the eye by the view of the firmament on a clear starlight night. The number of visible stars is always immensely over-estimated. Although it be true that the stars are, strictly speaking, countless in number, yet the number distinctly seen by the naked eye at any one time, unaided by the telescope, is not great. Any one can satisfy himself of this by examining any good map of the stars ; yet when we look at the firmament on a clear night, these objects appear to be inconceivably numerous. This illusion is dispelled by examining the heavens through the most ordinary telescope, or even by looking through a long tube, which will limit the view at any one moment to a small portion of the firmament. On the entire sphere of the heavens there are not above twenty stars of the first magnitude, and it is seldom that as many as six or eight of these can be seen at once. The number of stars of the second magnitude does not exceed fifty, and of these twenty are seldom seen at any one time. The stars of the third magnitude may amount to about two hundred, half of which only can be at the same time above the horizon. The small stars are much more numerous, but they are dis-

cernible with difficulty, and do not produce upon the mind the impression of multitude that we conceive.

8. It has been ascertained that the membrane of the eye, which is affected by light, retains the impression it has received for about the tenth of a second after the cause which produced the impression has been removed. When a lighted stick is whirled in a circle, the circle will appear to be one continuous line of light, because the eye retains the impression which the light produces upon it at any point in the circle until the stick returns to that point. The light is, therefore, visible at the same time at every point of the circle.

Ingenious optical toys are constructed, the effects of which are explicable on these principles. The same object is painted on the several divisions of the circumference of a circle in a succession of different attitudes, and while the eye is directed to the highest point of the circle, through an opening made for that purpose, the circle is made to revolve, and the object passes before the eye in a succession of different attitudes. If the velocity with which the circle turns be such that the eye shall retain the impression of the object in one attitude until its picture in another attitude comes into view, it will have all the effect of a moving object. Waltzing figures and other similar devices are painted on circular cards and mounted, so as to give these effects.

9. If the eye is supplied with no external means of knowing the distance of a visible object, it estimates that distance by its apparent magnitude, and if there be any means of causing the magnitude of the same object to undergo a gradual change, the impression on the spectator is as if the object advanced to or receded from him. It is upon this principle that the exhibitions of phantasmagoria are made. The image of an object is formed on some surface prepared to receive it, the apartment being elsewhere in complete darkness, so that the observer has no means of knowing where the image is placed. The magic lantern has a power, by advancing it gradually toward the surface, to diminish the size of the image indefinitely, and by drawing it from the surface to augment it. The spectators, therefore, seeing the images gradually increase and diminish imagine they gradually approach to and recede from them.

10. Although the eye, by its direct as well as its indirect indications, supplies the greatest variety of impressions, of which many admit of exact numerical estimation, the touch, according to popular notions, is regarded as a more sure test of reality. The incredulous apostle, who refused to believe the evidence of his eyes, yielded to that of his touch. This sense is, never-

theless, confined within narrow and vague limits in most of its indications.

If we take two heavy bodies in the hand, we shall, in many cases, be able to declare that one is heavier than the other; but if we are asked whether one be exactly twice as heavy, or thrice as heavy as the other, we shall be utterly unable to decide. In like manner, if the weights be nearly equal, we shall be unable to declare whether they are exactly equal or not.

If we look at two objects, differently illuminated, we shall in the same way be in some cases able to declare which is the more splendid; but if their splendour be nearly equal, the eye will be incapable of determining whether the equality of illumination be exact or not. It is the same with heat. If two bodies be very different in temperature, the touch will sometimes inform us which is the hotter; but if they be nearly equal, we shall be unable to decide which has the greater or which the less temperature.

The sense of touch, however, totally fails in informing us of the comparative quantities of heat in bodies. It cannot be at all affected by that part of the heat of a body which is latent. Ice-cold water, and ice itself, feel to have the same temperature, and to contain the same quantity of heat; and yet it is proved that ice-cold water contains a great deal more heat than ice; nay, that it can be compelled to part with its redundant heat, and to become ice; and that this redundant heat, when so dismissed, may be made to boil a considerable quantity of water. But it is not only in the case of latent heat, which cannot be felt at all, that the touch fails to inform us of the quantities of heat in a body. Different bodies are raised to the same temperature by very different quantities of heat. If water and mercury, both at the temperature of 32°, be touched, they will be felt to be both equally cold; and if they be both raised to 100° and then touched, they will be felt to be both equally warm; and the inference would be, that equal quantities of heat must have been in the meanwhile communicated to them. Now, on the contrary, it has been proved that, in this case, the quantity of heat which has been communicated to the water is not less than thirty times the quantity which has been imparted to the mercury. In fact, to cause the same change of temperature, and, therefore, the same feeling of heat, in different bodies, requires very different quantities of heat to be imparted to them. It is plain, therefore, that the sense of touch totally fails in the discovery of the quantities of heat which must be added to different bodies, in order to produce in them the same change of temperature.

The thermometer, the scientific measure of temperature, is here, however, in the same predicament as the sense of feeling, since the unequal additions of heat given to the water and the mercury produce precisely the same effects upon it. But even though we omit the consideration of the relative quantities of heat that produce equal changes of temperature in different bodies, the sense of feeling will still be found most fallacious in the indications which it gives of temperature itself; and here, indeed, the error and confusion into which it is apt to lead, when unaided by the results of science, are very conspicuous. The air of a cave, if it be sufficiently deep, will feel cold in summer, and warm in winter. If a thermometer be suspended in it, it will prove that its temperature is always the same. In summer, that temperature being below that of the general atmosphere, the cave feels cold; in winter, being above it, the cave feels warm. The same thermometer which has been kept for sixty years in the vaults of the Observatory at Paris, at the depth of eighty-eight feet below the surface, has shown, during that interval, the temperature of 11°·82 Cent., which is equal to 53¼° Fahr., without varying more than half a degree of Fahr., and even this variation, small as it is, has been explained by the effects of currents of air produced by the quarrying operations in the neighbourhood of the Observatory.

It appears, therefore, that our perception of heat or cold depends not alone on the thermal state of the bodies which affect us, but also on the state of our own bodies at the moment. These perceptions are, in effect, relative, and not absolute. One body feels cold because it is below, and another warm because it is above, the temperature of our own bodies.

It follows, therefore, that if we reduce, by any expedient, different members of our bodies to different states of warmth, any external object which has one intermediate temperature will feel warm to the colder, and cold to the warmer member. This experiment may be easily tried. If we hold the hand in water which has a temperature of about 90°, after the agitation of the liquid has ceased, we shall become wholly insensible of its presence, and shall be unconscious that the hand is in contact with any body whatever. We shall, of course, be altogether unconscious of the temperature of the water. Having held both hands in this water, let us now remove the one to water at a temperature of 200°, and the other to water at the temperature of 32°. After holding the hands for some time in this manner, let them be both removed, and again immersed in the water at 90°; immediately we shall become sensible of warmth in the one hand, and cold in the other. To the hand which had been immersed in the cold water, the water at 90° will feel hot, and to the hand which had been immersed in the water at 200°, the water at 90° will feel cold. If, therefore, the touch be in this case taken as the evidence of temperature, the same water will be judged to be hot and cold at the same time.

I have elsewhere indicated several curious examples of the fallacies of the senses of feeling in relation to the temperature of bodies.*

Even when the state of our bodies is the same, and the temperature of external objects the same, different objects will feel to us to have different degrees of heat. If we immerse the naked body in a bath of water at the temperature of 120°, and, after remaining for some time immersed, pass into a room in which the air and every object is raised to the same temperature, we shall experience, on passing from the water into the air, a sensation of coldness. If we touch different objects in the room, all of which are at the temperature of 120°, we shall nevertheless acquire very different perceptions of heat. When the naked foot rests on a mat or carpet, a sense of gentle warmth is felt; but if it be removed to the tiles of the floor, heat is felt sufficient to produce inconvenience. If the hand be laid on a marble chimney-piece, a strong heat is likewise felt, and a still greater heat on any metallic object in the room. Walls and woodwork will be felt warmer than the matting, or the clothes which are put on the person. Now, all these objects are, nevertheless, at the same temperature. From this chamber let us suppose that we pass into one at a low temperature; the relative heats of all the objects will now be found to be reversed—the matting, carpeting, and woollen objects, will feel the most warm; the woodwork and furniture will feel colder; the marble colder still; and metallic objects the coldest of all. Nevertheless here, again, all the objects are exactly at the same temperature, as may be in like manner ascertained by the thermometer.

In the ordinary state of an apartment, at any season of the year, the objects which are in it all have the same temperature, and yet to the touch they will feel warm or cold in different degrees: the metallic objects will be coldest; stone and marble less so; wood still less so; and carpeting and woollen objects will feel warm.

When we bathe in the sea, or in a cold bath, we are accustomed to consider the water as colder than the air, and the air colder than the clothes which surround us. Now all these objects are, in fact, at the same temperature. A thermometer, surrounded by the cloth of our coat, or suspended in the atmosphere, or immersed in the sea, will stand at the same temperature.

* Treatise on Heat, p. 372.

A linen shirt when first put on will feel colder than a cotton one, and a flannel shirt will actually feel warm; yet all these have the same temperature.

The sheets of the bed feel cold, and blankets warm; the blankets and sheets, however, are equally warm. A still, calm atmosphere, in summer, feels warm; but if a wind arises, the same atmosphere feels cold. Now a thermometer, suspended under shelter, and in a calm place, will indicate exactly the same temperature as a thermometer on which the wind blows.

11. These circumstance may be satisfactorily explained, when it is considered that the human body maintains itself almost invariably, in all situations, and at all parts of the globe, at the temperature of 96°; that a sensation of cold is produced when heat is withdrawn from any part of the body faster than it is generated in the animal system; and, on the other hand, warmth is felt when either the natural escape of the heat generated is intercepted, or when some object is placed in contact with the body which has a higher temperature than that of the body, and consequently imparts heat to it. The transition of heat from the body to any object when that object has a lower temperature, or from the object to the body when it has a higher temperature, depends, in a certain degree, on the conducting power of the objects severally, and the transition will be slow or rapid, according to that conducting power. An object, therefore, which is a good conductor of heat, if it has a lower temperature than the body, carries off heat quickly, and feels cold; if it has a higher temperature than the body, it communicates heat quickly, and feels hot.

A bad conductor, on the other hand, carries off and communicates heat very slowly, and therefore, though at a lower temperature than the body, is not felt to be colder, and, though at a higher temperature, not felt to be warm.

Most of the apparent contradictions which have been already adduced in the results of sensation, compared with thermometric indications, may be easily understood by these principles.

When we pass from a hot bath into a room of the same temperature, the air, though at a higher temperature than our body, communicates heat to it more slowly than the water because, being a more rare and attenuated substance, a less number of its particles are in actual contact with the body; and also such particles as are in contact with the body take almost the same temperature as the body, and adhere to it, forming a sort of coating or shield, by which the body is defended from the effects of the hotter part of the surrounding atmosphere. A carpet, being a bad conductor of heat, fails to transmit heat to the foot, and therefore, though at a higher temperature than the body, creates no sensation of warmth. The tiles and marble, being better conductors of heat, and at a higher temperature than the body, transmit heat readily, and metallic objects still more so: these, therefore, feel hot. On passing into a cold room, the very contrary effects ensue. Here all the objects have a temperature below that of the body; the carpet and other bad conductors, not being capable of receiving heat when touched, produce no sensation of cold; wood, being a better conductor, feels cooler; marble, being a better conductor, gives a still stronger sensation of cold; and metal, the best of all conductors, produces that sensation in a still greater degree.

In cold temperatures, the particles of water which carry off the heat from the body are far more numerous than those of air, and therefore carry the heat off more rapidly; and, besides, they are constantly changing their position; the particles warmed by the body immediately ascend by their levity, and cold particles come into contact with the skin. Thus water, although a bad conductor of heat, has the same effect as a good conductor, by the effect of its currents.

Sheets feel colder than the blankets, because they are better conductors of heat, and carry off the heat more rapidly from the body; but when, by the continuance of the body between them, they acquire the same temperature, they will then feel even warmer than the blanket itself. Hence it may be understood why flannel, worn next the skin, forms a warm clothing in cold climates, and a cool covering in hot climates.

To explain the apparent contradiction implied in the fact that the use of a fan produces a sensation of coldness, even though the air which it agitates is not in any degree altered in temperature, it is necessary to consider that the air which surrounds us is generally at a lower temperature than that of the body. If the air be calm and still, the particles which are in immediate contact with the skin acquire the temperature of the skin itself, and, having a sort of molecular attraction, they adhere to the skin in the same manner as particles of air are found to adhere to the surface of glass in philosophical experiments. Thus sticking to the skin, they form a sort of warm covering for it, and speedily acquire its temperature. The fan, however, by the agitation which it produces, continually expels the particles thus in contact with the skin, and brings new particles into that situation. Each particle of air, as it strikes the skin, takes heat from it by contact, and, being driven off, carries that heat with it, thus producing a constant sensation of refreshing coolness.

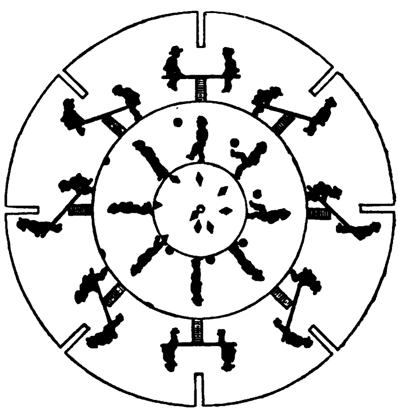
Now from this reasoning it would follow that, if we were placed in a room in which the atmosphere has a higher tempera-than 96°, the use of a fan would have exactly opposite effects, and, instead of cooling, would aggravate the effects of heat; and such would, in fact, take place. A succession of hot particles would, therefore, be driven against the skin, while the particles which would be cooled by the skin itself would be constantly removed.

12. It may be objected to some of the preceding reasonings, that glass and porcelain, though among the worst conductors of heat, generally feel cold. This, however, is easily explained. When the surface of glass is first touched, in consequence of its density and extreme smoothness, a great number of particles come into contact with the skin; each of these particles, having a tendency to an equilibrium of temperature, takes heat from the skin, until they acquire the same temperature as the body which is in contact with them. When the surface of the glass, or perhaps the particles to some very small depth within it, have acquired the temperature of the skin, then the glass will cease to feel cold, because its bad conducting power does not enable it to attract more heat from the body. In fact, the glass will only feel cold to the touch for a short space of time after it is first touched. The same observation will apply to porcelain and other bodies which are bad conductors, and yet which are dense and smooth. On the other hand, a mass of metal, when touched, will continue to be felt cold for any length of time, and the hand will be inca-pable of warming it, as was the case with the glass.

A silver or metallic tea-pot is never constructed with a handle of the same metal, while a porcelain teapot always has a porcelain handle. The reason of this is, that metal being a good conductor of heat, the handle of the silver or other metallic teapot would speedily acquire the same temperature as the water which the vessel contains, and it would be impossible to apply the hand to it without pain. On the other hand, it is usual to place a wooden or ivory handle on a metal teapot. These substances being bad conductors of heat, the handle will be slow to take the temperature of the metal, and even if it does take it, will not produce the same sensation of heat in the hand. A handle, apparently silver, is sometimes put on a silver teapot, but, it examined, it will be found that the covering only is silver; and that at the points where the handle joins the vessel, there is a small interruption between the metallic covering and the metal of the teapot itself, which space is sufficient to interrupt the communication of heat to the silver which covers the handle. In a porcelain teapot, the heat is slowly transmitted from the vessel to its handle; and even when it is transmitted, the handle, being a bad conductor, may be touched without inconvenience.

A kettle which has a metal handle cannot be touched, when filled with boiling water, without a covering of some non-conducting substance, such as cloth, or paper, while one with a wooden handle may be touched without inconvenience.

13. The feats sometimes performed by quacks and mountebanks, in exposing their bodies to fierce temperatures, may be easily explained on the principle here laid down. When a man goes into an oven, raised to a very high temperature, he takes care to have under his feet a thick mat of straw, wool, or other non-conducting substance, upon which he may stand with impunity at the proposed temperature. His body is surrounded with air, raised, it is true, to a high temperature, but the extreme tenuity of this fluid causes all that portion of it in contact with the body, at any given time, to produce but a slight effect in communicating heat. The exhibitor always takes care to be out of contact with any good conducting substance; and when he exhibits the effect produced by the oven in which he is enclosed, upon other objects, he takes equal care to place *them* in a condition very different from that in which he, himself, is placed; he exposes them to the effect of metal or other good conductors. Meat has been exhibited, dressed in the apartment with the exhibitor; a metal surface is, in such a case provided, and probably heated to a much higher temperature than the atmosphere which surrounds the exhibitor.



THAUMATROPE.

VIEW OF GREENWICH OBSERVATORY, SHOWING THE SIGNAL-BALL AT THE TOP OF THE DOME.

LATITUDES AND LONGITUDES.

1. Necessary to know our position on the earth.—2. Poles and equator.—3. Parallel of latitude.—4. Meridian of Greenwich.—5. Latitude and longitude.—6. Methods of determining the latitude.—7. By the sun.—8. By stars.—9. Hadley's sextant.—10. Latitude at sea.—11. To find the longitude.—12. Lunar method.—13. Ball signal at Greenwich.

1. Before it is possible to acquire a distinct knowledge of the position or distances of any bodies in the universe outside the surface of the earth, it is first indispensable that we, who have to make these calculations, should distinctly ascertain our own position in reference to the bodies we observe. But as our position is subject to continual change, as well by reason of the diurnal rotation of the earth upon its axis, on the surface of which we are carried round, as by the annual motion of the globe in its orbit round the sun, we are obliged as a necessary preliminary to analyse with accuracy all the circumstances of these

motions. But even before we are in a condition to accomplish this, there is another preliminary step not less indispensable, which is to ascertain our own position on the surface of the globe we inhabit.

This is not so easy a matter as at the first view it might seem to be. The earth we dwell on is a globe which compared with any familiar standards of measure has a stupendous magnitude. The range of our vision around any situation which we may occupy upon the surface of this globe is small. In the most unobstructed situation we can obtain—that which is presented us at sea, when out of sight of land, on the clearest day—our observation is circumscribed by a radius of a few miles. The portion of the surface which we see at one and the same time, forms in reality so small a patch of the globe of the earth, that it is only by indirect reasoning that we can recognise upon it any character save that of a flat plane. How, then, are we to know in what part of the terrestrial globe that small patch of surface is situated?

2. To answer this question, it is evidently necessary first to settle some fixed points or lines to which we may refer various places, and by which we may express their positions. The points which have been usually selected for this purpose are the POLES and the EQUATOR. The poles are those points on the surface of the earth where the axis on which it performs its diurnal rotation terminates, and they are distinguished, as is well known, by the names of the NORTH and SOUTH poles.

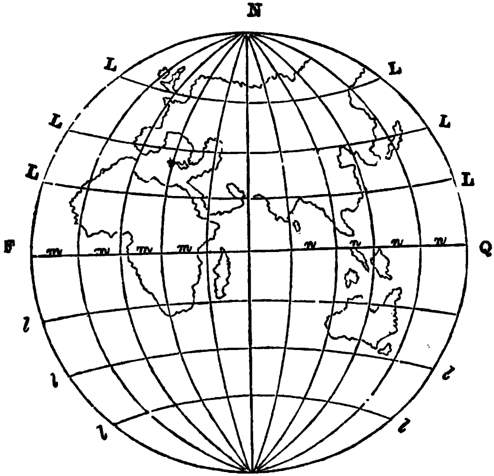
If we imagine a circle drawn round the globe in such a manner as to divide it into two hemispheres, having in the midst of one the north pole, and in the midst of the other the south pole, such a circle is called the EQUATOR, from equally dividing the globe. Every point in this circle will be at the same distance from the poles, and if we imagine the globe to be cut by a plane through the poles, that plane will be at right angles to this circle, and the section it forms will be what is called a TERRESTRIAL MERIDIAN. The arc of this meridian between either pole and the equator will be one quarter of its entire circumference, and will therefore be 90°. The equator is, therefore, everywhere 90° from each of the poles.

In fig. 1, N is the north and S the south pole, and EQ is the equator.

The hemispheres into which the equator divides the earth are called the NORTHERN and SOUTHERN HEMISPHERES. That which includes the north pole, being the northern, and that which includes the south pole, the southern.

The position of a place in either hemisphere with reference to the equator is expressed by stating the number of degrees of a terrestrial meridian included between the place and the equator. This is called the LATITUDE of the place; which is the distance of the place from the equator expressed in degrees of the meridian. Thus, if a place be midway between the pole and the equator, its latitude is 45°. If it be distant from the equator by two-thirds of the entire distance from the equator to the pole, its latitude will be 60°, and so on.

Fig. 1.



3. The latitude is said to be northern and southern, according as the place is in the northern or southern hemisphere.

But it is evident that the latitude alone will be insufficient for the determination of the position of a place. If we state that a certain place is 45° north of the equator, it will be impossible to ascertain certainly the place in question, inasmuch as there is a circle of points on the earth, all of which are 45° north of the equator. If we suppose a circle drawn round the surface of the northern hemisphere parallel to the equator, at the distance from the equator of 45°, every point of such circle will be equally characterised by the latitude of 45° north.

Such a circle is called a PARALLEL OF LATITUDE, and it is therefore apparent that wherever such a parallel may be drawn upon the earth, all the places upon it will have the same latitude.

In the figure E N Q is the northern and E S Q the southern hemisphere. The circles L L, are northern and *l l*, southern parallels of latitude. All places situate upon any one of these circles have the same latitude. The distances of N and S from E Q, being 90° that is the latitude of the poles. The circles N *m* S and N *n* S, drawn upon the earth from pole to pole intersect the equator E Q, and all the parallels L L, *l l*, at right angles. These are TERRESTRIAL meridians.

The latitude is, then, insufficient to determine the position of any place. How, then, it may be asked, can the exact position of any place be expressed?

4. Let us suppose that a meridian is arbitrarily selected, passing through some particular place, such as the Greenwich Observatory. We may conceive another meridian drawn upon the earth east or west of that, so that the two meridians shall include between them an arc of the equator, consisting of a definite number of degrees; say, for example, that it shall consist of 20°; then such a meridian will be defined by stating that it is 20° east or west of the meridian of Greenwich. All that can be settled by such a statement is the position of the meridian in which the place lies with reference to the arbitrarily chosen meridian of Greenwich. This relative position of the two meridians is called the LONGITUDE OF THE PLACE. As the meridian from which the longitude is measured is altogether arbitrary, there being no physical or geographical reason why one meridian should be chosen rather than another, each nation has naturally selected as the zero of longitude the meridian of some noted place in its precincts. In England the Royal Observatory at Greenwich has been the place selected, and accordingly in all English works on geography, political and physical, longitudes are invariably expressed in reference to the meridian of Greenwich. It will, therefore, be most convenient for us here to refer to that meridian.

When these explanations are clearly understood, we shall be in a condition, distinctly and definitely, to express the position of a place upon the surface of the globe of the earth. If we state its latitude and its longitude, we can fix at once, and unequivocally, the position of a place. Thus, let us suppose that its latitude is 50° north, its longitude 30° east of Greenwich; its position will be found by imagining a circle parallel to the equator drawn upon the northern hemisphere at a distance of 50° from the equator; then, supposing a meridian drawn through Greenwich, intersecting this parallel, and another drawn so as to cross the equator at a point 30° east of the former; the place in question will be upon the line parallel to the equator first drawn, inasmuch as it will be 50° north of the equator, and it will be also in the meridian last drawn, inasmuch as it will be 30° east of Greenwich. Since, then, it will be at the same time on both these lines, it will necessarily be at the point where they cross each other at the east of the standard meridian of Greenwich.

5. Thus, then, we have succeeded at least in establishing standards of position and a nomenclature by which the exact position of a place on the surface of the globe can be expressed. But we have still another much more important and difficult question to settle. How are we to discover in what part of the globe any place is which we may occupy at a given time; in other words, how are we to discover its latitude and its longitude? These are questions, especially the latter, attended with some difficulty, and which have been solved by different methods, applicable in different cases, according to the circumstances under which the position of the place is sought, and the purpose for which such position is to be determined.

At any place on land where the geographical position is once determined, it may be recorded, so as to be permanently known for the future without a repetition of the process for determining it; but it is otherwise at sea. On the trackless surface of the deep all marks of events and operations are immediately obliterated, and a new investigation must be instituted in every case when the position of any point is to be determined. The mariner must, therefore, be supplied not only with the means of determining the position of his ship at all times, but with means the application of which is practicable under the peculiar circumstances in which he is placed. The instruments he uses must not only be portable, but must be such as may admit of being manipulated, subject to the disturbances and the vicissitudes of the sea. The objects of his observations must be such as are almost always in his view. It is evident, then, that the problem, as applicable on land, is wholly different in its circumstances and conditions from that which is applied on the deep. But even on land the problem presents itself under various circumstances and conditions. In the fixed observatory, where the observer is supplied with instruments of the greatest magnitude, of the most refined accuracy, and the most absolute stability, methods have been used which are susceptible of the last conceivable degree of accuracy, and accordingly the position of those points on the globe where such observatories have been erected are usually determined with the greatest degree of precision. Such points on the globe serve, therefore, as a sort of landmarks, relative to which the position of all surrounding places may be determined.

The circumstances under which the scientific traveller and geographer makes his observations, with a view to the general determination of the points of a country, are less favourable to accuracy than those available to the astronomer, but still are more susceptible of precision than those which can be placed at the disposal of the mariner. It is, however, the business and the duty of those who devote their lives to the advancement of the sciences, to supply to each class of observers those instruments and methods of inquiry which are capable, respectively of giving results which, in the circumstances of the case, have the greatest attainable accuracy.

TO FIND THE LATITUDE.

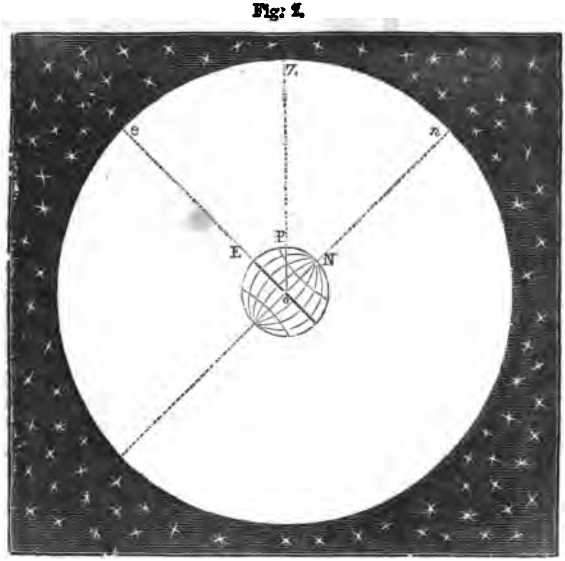
6. Let us suppose the globe of the earth to be represented at O, and let N be its north pole, and E its equator; let P be a place upon it, whose latitude, that is, whose distance from the equator is to be determined. Let *n* Z *e* represent the firmament surrounding the globe at an indefinite distance. The point *n*, immediately over the north pole, and which is in fact the continuation of the line O N, will be the place of the north pole in the heavens, very near to which is a star, called the Polar star. The point *e*, in the continuation of the line O E, will be that which is directly over the equator, and will be that point in the heavens representing the position of the equator; and the point Z, in the continuation of the line O P, the point of the heavens which is directly over the observer at the place P, will be that which is called his zenith. This point is that to which a plumb line would direct itself.

Now the points *n*, Z, and *e* are the points in the firmament which correspond with the points N, P, and E, upon the earth, and it is evident that whatever arcs of the terrestrial meridian N P E are included between these points, similar arcs of the celestial meridian must be included between the points *n* Z *e*. If, then, P E were 40°, Z *e* must also be 40°, just as *n e* is 90°, while N E is also 90°.

In short, the zenith of any place in the heavens is the point in the firmament which corresponds with the position of the place on the globe, and the distance of the zenith in the heavens of one place from the zenith of another, must necessarily be the same in degrees as the distance between two places on earth. Thus Z is the zenith of P; *e* is the zenith of E; Z is the same number of degrees from *e* as P is from E. This being clearly understood, it is evident that if we can, by any means ascertain by observations, the distance from Z to *n*, we can infer at once the distance from P to E, and hence can discover the latitude of the place.

It is apparent, then, if we can observe the distance of the zenith of any place from the celestial pole, that will give us the distance in degrees of the place itself from the terrestrial pole, and by subtracting that from 90°, we shall obtain the distance of the place itself from the equator, or what is the same, its latitude. As an example of this, let us suppose that in measuring

Fig: 2.



the distance from Z to *n* we find it to be 50°, we infer, therefore, that since the distance of the zenith from the pole is 50°, the distance of the place from the terrestrial pole is also 50°.

But since the terrestrial pole is 90° from the equator, it follows that the distance of the place from the equator must be 40°, and it is north or south, according as the zenith of the place is in the northern or southern hemsiphere of the firmament.

Thus, then, it appears that the latitude of a place can always be found, provided we can measure the distance of its zenith from the celestial pole; and this, of course, can always be done by the use of proper instruments, provided that the zenith and the pole can be distinctly seen. Now the direction of the zenith can always be determined by the plumb line; but although the pole star is very near the pole, it is not exactly at it; there is, in fact, no star exactly at the pole, and there being no visible object there, it is impossible to measure directly its distance from the zenith. This difficulty is eluded by measuring the distance of the zenith from some star, or other celestial object, whose distance from the pole happens to be known: for example, suppose that there were a star directly between the zenith and pole, whose distance from the pole was known to be 10°. Then if we find the distance of the zenith from this star to be 40°, we should immediately infer the distance of the zenith from the pole to be 50°.

It is in fact, then, by this device that the latitude is always ascertained. By various observations made by astronomers, the positions of most of the stars and other celestial objects, with respect to the poles, are known and recorded; and when we desire to determine the latitude of any place, we measure the distance of the zenith of that place from some celestial object whose position with respect to the pole is known, and thence infer the position of the place with respect to the terrestrial pole; and from that deduce at once the latitude.

7. But our purpose would be equally served if we were supplied with the position of any visible object with reference to the celestial equator. Thus, if we know the distance of the centre ot the sun from the celestial equator, we shall readily be able to find the latitude; for it would only be necessary when the sun is in or very near the meridian, that is, at or near noon, to measure the distance of the zenith of the place from the centre of the sun. This would be done by measuring the distance of the zenith, first from the upper, and then from the lower limb of the sun. The distance from the centre would be the mean between these.

Let us suppose, for example, that the sun being between the zenith and the equator, we find that the distance from the zenith to the centre of the sun is 20°, and that we also ascertain from the table of the position of the sun, that the distance of the centre of the sun at that time from the equator, is also 20°, we should infer at once that the distance of the zenith from the equator must be 40°, and that such, therefore, must be the latitude of the place.

This method of ascertaining the latitude is, perhaps, the most easily practicable. The observations may be performed daily, at noon, when the sun is visible: and in all almanacs, the distance of the centre of the sun from the equator, which is called the sun's declination, is registered. The instrument by which the observations are executed on land is, usually, a quadrant furnished with a telescope moving upon its centre. One radius of the quadrant is placed in the direction of the plumb line, and therefore points to the zenith. The telescope moves round the centre until it is directed to the object whose distance from the zenith is to be observed. The angle between the telescope and the vertical radius of the quadrant will then be the same as the distance of the object from the zenith.

8. In astronomical observatories methods of observation have been applied susceptible of much greater accuracy. Stars upon the meridian can there be used with great advantage. The distances of these stars from the pole are accurately known, and the astronomer selects for his observation those conspicuous stars which pass near to his zenith. He observes the arc of the celestial meridian between his zenith and these stars. And from the magnitude of the arc and the distance of the star of the celestial pole, he discovers the distance of the zenith from the pole and thence the latitude.

The principal source of accuracy in this method is, that the distance between the zenith and the star being very small, is capable of more exact measurement, for reasons connected with the structure of the astronomical instrument, than could be attained in the measurement of greater angles.

9. In observations made at sea, it is not practicable, however, to use the plumb line, and indeed, even for the purposes of geographers it is not always convenient. An admirable instrument has been invented equally applicable to observations by land or by water, called Hadley's sextant, by means of which the observations can be made with reference to the horizon, independent of the zenith, and therefore independent of the plumb line.

It is not our purpose here to enter into a description of the principles and structure of this celebrated and most useful instrument. It will be sufficient for the present purpose to state that it is capable of being applied to the measurement of the angular distances between any two visible objects with a very great degree of precision, and that it may be used with facility even when the position of the observer is subject to all the unsteadiness incidental to the condition of the mariner.

When this instrument is used, instead of observing the distance of any object from the zenith, we observe its distance from the horizon, which will answer the same purpose, inasmuch as that whenever the distance of an object from the horizon is known, its distance from the zenith can be found, since the distance from the zenith to the horizon being 90°, if we subtract the distance of the object from that, the remainder will be the distance of the object from the zenith.

At sea we have generally, indeed almost always, a well-defined horizon. If the mariner desires to measure the altitude of an object, he has only to measure the distance of the object from the horizon in a direction perpendicular to it, and this he is enabled to do with a little practice, with admirable facility and precision, with Hadley's sextant.

10. Let us see, then, how the mariner is thus enabled daily to determine the latitude of his ship.

As noon approaches, the sky being sufficiently clear to render the disc of the sun visible, he applies the instrument and finds the altitude of the lower limb which he continues to observe until it ceases to increase. He then adds to it the apparent semi-diameter of the sun which is given by the tables, and thus obtains the altitude of the sun's centre. If this altitude be taken from 90°, the remainder will be the distance of the sun's centre from the zenith. He finds in his almanac the distance of the centre of the sun on that day from the equator, and hence he at once, as already explained, obtains the distance of his zenith from the equator; that is the latitude of the ship.

There are several minute circumstances observed in the practice of this problem, which do not affect its general spirit, and the introduction of which here would be unsuitable to our object; we therefore omit them.

Thus we see that, whether by sea or by land—whether in the observatory of the astronomer, traversing the sands of the desert or the forests of America, or voyaging over the trackless and unimpressible surface of the ocean—we are in every case by science supplied with suitable and practicable means by which we can ascertain the distance of the place where we are, north or south, on the globe.

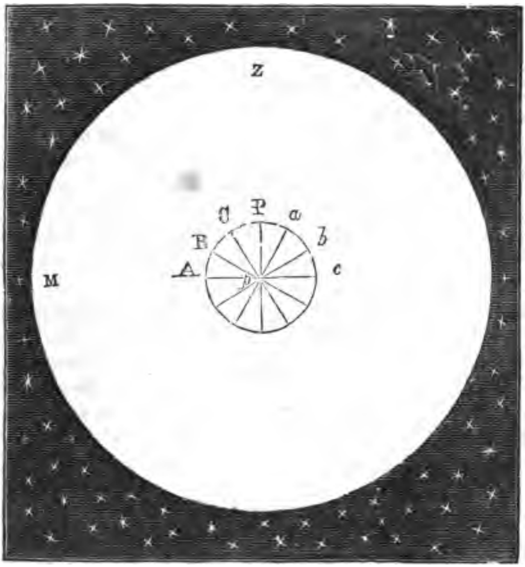
TO DETERMINE THE LONGITUDE.

11. In expressing and determining the latitude of a place, we have fixed points and lines on the firmament to refer to—such as the celestial pole and equator; and to find it, nothing more is necessary than to ascertain the position of the zenith of the place with reference to these. But with respect to the longitude, the case is very different; it is impossible even to express the longitude without involving a reference to two places at least—that of which we wish to determine the longitude, and that which is selected as the starting point from which all longitudes are to be measured. If we could observe in the firmament the two points which at the same time form the zeniths of the two places, then the difference of their longitudes could be found by

noting the times at which these two points would cross the meridian of the place whose longitude is to be determined.

To comprehend fully the spirit of the celebrated problem of finding the longitude, we must imagine the globe of the earth turning on its axis, having around it the starry firmament. Let us suppose A B C, *a b c*, to be the parallel of latitude of the place P, whose longitude is to be determined, *p* being the pole, and let M Z N represent the firmament. Let the zenith be the point on

Fig. 8.



the firmament marked by Z. If we suppose the globe to turn upon its axis in the direction of A B C, *a b c*, the place P will, by its rotation be carried to the right of Z, and the same point Z will become successively the zenith of the points C B and A; and, in fact, every point in the parallel of latitude will successively come under the point Z, which will be, therefore, in regular succession, their zenith points. In twenty-four hours, or, more accurately, in twenty-three hours and fifty-six minutes, the globe will make its complete revolution; therefore three hundred and sixty degrees of the parallel will successively pass under the same point of the firmament.

By knowing exactly the time of rotation of the earth, and having ascertained that its diurnal motion is uniform, we can determine by simple arithmetic what extent of its surface will pass, in a given time, under any point of the firmament. Thus if we say in round numbers that the whole circumference corresponds to twenty-four hours, it will follow that fifteen degrees will move under the point Z each hour, or one degree in four minutes.

If we suppose Z to represent the place of the sun, then it will be noon, or twelve o'clock, at the place which is immediately under Z; that is, at P. If O be fifteen degrees west of P, then it will arrive under Z one hour after P; consequently, when it is noon at P it is eleven o'clock at a place fifteen degrees to the west of P; and, for the same reason, it is ten o'clock at a place thirty degrees to the west of P, and so on.

Again: if *a* be a place fifteen degrees to the east of P, *a* must have been under Z an hour before P reached it. It will be noon, therefore, at *a*, an hour before it is noon at P; therefore, when it is noon at P it is one o'clock at *a*. In the same manner, and for like reasons, if *b* be a place thirty degrees east of P, *b* will pass under Z two hours before P; and therefore when P passes under Z it will be two o'clock at *b*.

It will be apparent from these explanations, that in general, the hour of the day at different places upon the earth, at the same time, will depend upon their relative position east or west of each other. If one place be east of another, the hour at that place will be later with respect to noon than the hour at the other; and the extent to which it is later will depend on the distance which one place is east of the other. In calculating this difference of time from the difference of position east or west, we may take fifteen degrees to correspond with an hour, as already explained.

But this distance of one place east or west of another, expressed in degrees, is, in fact, the difference of their longitudes; and if one of the two places in question be that from which the longitudes are measured, the determination of the longitude of a place would resolve itself into the discovery of the hour of the day in the place whose longitude we want to find, and also at the place from which the longitudes are measured.

Thus, for example, let us suppose that we ascertain the hour of the day in New York, and find that it is two o'clock in the afternoon, and that we have a means by which we can discover, at the same time, what the hour of the day is at Greenwich, and that by these means we know that it is 56 minutes past 6 o'clock. We know, then, that the time is 4 hours 56 minutes earlier at

New York than at Greenwich, and consequently we infer that New York must be west of Greenwich by a longitude which corresponds to 4 hours 56 minutes. Now 4 hours correspond to 60°, and 56 minutes correspond to 14°; therefore it follows, that the longitude of New York must be 74° west of Greenwich. We can, then, always discover the longitude of any place, provided we can ascertain, at any moment, the hour of the day at the place in question, and know, at the same time, what the hour of the day is in that place from which the longitude is measured.*

There are simple methods of observation and calculation by which the hour of the day in the place where we are can be determined, with more or less accuracy, according to the circumstances of our position. If we are on land, and supplied with a proper transit instrument, we can, by its means, observe the moment at which the centre of the sun's disc passes the meridian. Thus, as the moment of noon arrives, by observing it, we can set a good clock, which will inform us of every other hour of the day. But even in the absence of a clock, we can determine the hour of the day at any moment at which the sun is visible, by observing its altitude, having previously ascertained the latitude of the place at which we are.

If we are at sea, where we cannot command a transit instrument, nor use it if we could, the latitude of the place of the ship is first determined, and then the hour is found by observing the altitude of the sun at any convenient time in the afternoon or forenoon. The hour being once found, the time can be kept by a chronometer for any number of hours afterward. Thus it appears, under all circumstances, whether at sea or on land, there is no practical difficulty in determining what o'clock it is where we are. This at once reduces the problem of the longitude to the simple discovery of the hour of the day, at any given time, at the place from which the longitudes are reckoned.

The first and most obvious method of accomplishing this which would occur to the mind, would be to carry a good chronometer from the place from which the longitude is reckoned. Supposing this chronometer subject to no error, it will continue to inform you of the hour of the day at that place. Thus, suppose that on leaving London the mariner takes with him a chronometer set according to the time at Greenwich, and with it makes his voyage to New York; the chronometer will

* There are several corrections to be attended to in the practical working of the methods of determining latitude and longitude which we have purposely omitted, as they do not affect the spirit of the method, which is all we would here convey.

continue to inform him what the time is from hour to hour at Greenwich. When he arrives at New York, he will find that when the chronometer points to 12 o'clock, or noon, it will be early in the morning; and if he ascertains the hour exactly, he will find that it will be 4 minutes after 7 o'clock. He will therefore know that the time at New York is 4 hours 56 minutes earlier than at Greenwich, and, consequently, that New York must be 74° west of Greenwich. It is for these reasons that the perfection of chronometers has always been considered so essential to the progress of navigation. Every ship that makes a long voyage ought to be supplied with one, at least, of these instruments; but as they are liable to accident, and as even the best of them cannot be rendered perfect, it is usual with ships that are well provided for long voyages to carry more than one chronometer.

Although the art of constructing time-keepers has been brought to a high degree of perfection by the skill of modern artisans, these instruments are even yet, and probably will ever continue to be, too imperfect to be implicitly and exclusively relied upon. If we only required their indications for short spaces of time, such as a few days, or even weeks, we might perhaps place a secure reliance upon them; especially if the voyager were provided with more than one instrument of this kind. But in voyages or journeys which occupy months, we cannot rely on the indications of these instruments, even when most liberally provided and most perfectly constructed.

In the absence, then, of a chronometer, how, it will be asked, can the longitude of a place be ascertained at all? The first method that will occur to the mind, will be that of some conspicuous signal which can be seen at the same time at the two places, whose difference of longitude is to be determined. For this we require two observers; but it is perhaps the method of all others susceptible of the greatest accuracy. Let us suppose that on some elevated position, between two distant places, such as London and Birmingham, a conspicuous light is produced, such as the celebrated electric light, which might be exhibited on the top of a high mountain so as to be visible at once from both places. Let this signal light be suddenly extinguished, and let the observers stationed at London and Birmingham note the exact moment at which this extinction takes place. By comparing afterwards these times the exact difference of longitude of the two places will be found.

12. But this method is evidently applicable only on a limited scale, and under peculiar circumstances; it is altogether unavailable to the mariner. Now the astronomer supplies him with a chronometer of unerring precision; a chronometer which can

never go down, nor fall into disrepair; a chronometer which is exempt from the accidents of the deep; which is undisturbed by the agitation of the vessel; which will at all times be present and available to him wherever he may wander over the trackless and unexplored regions of the ocean. Such a chronometer has been found; made by an Artisan who cannot err, and into whose works imperfection can never enter. Such a chronometer is supplied by the firmament itself. The unwearied labours of modern astronomers have converted the face of the heavens into a clock, and have taught the mariner to read its complicated but infallible indications. We may regard for this purpose the firmament as the dial-plate of a chronometer on an immense scale. The constellations and the fixed stars upon it, which, for countless ages, are subject to no change in position, serve as the hour and minute-marks. The sun, the moon, and the planets, which move continually over the surface of this splendid piece of mechanism, play the parts of the hands of the clock. The positions of these bodies from day to day and from hour to hour, and every change of their positions, are accurately foreknown and exactly registered in a book published some two or three years in advance, called the "Nautical Almanac," and circulated for the benefit of mariners. In this work the navigator is told what the hour is or will be at Greenwich for every variety of position which the sun, moon, and planets shall have from time to time upon the heavens. But of all objects in the heavens, that which is best suited for this species of observation is the moon, and hence this method of determining the longitude at sea has been distinguished by the appellation of the *lunar method*. By the use of Hadley's sextant, which we have already alluded to, it is easy, whenever the heavens are clear, to observe the angular distance of the moon either from the sun or from the most conspicuous stars or planets. The motion of the moon in the firmament is so rapid that its change of position is perceptible, even by such observations as can be made on board a ship from hour to hour.

How, then, it may be asked, can such observations be made subservient to the discovery of the longitude of a ship? Nothing can be more simple. The navigator requires only to know what is the hour at Greenwich at the time he makes his observation. This he discovers in the following manner: He observes with the sextant the distance of the moon from the sun, or from some of the most conspicuous stars; he then, after certain preliminary calculations not necessary to detail here, examines the "Nautical Almanac," where he learns what the hour is at Greenwich, when it has these particular distances from the sun or the stars. Knowing this, and knowing the hour where he is, the difference of the longitude of a ship and the observatory at Greenwich is known to him.

13. To supply ships leaving the Thames on long voyages with the exact Greenwich time, the following expedient is adopted:

The Royal Observatory, built on an elevated ridge, forms a conspicuous object from the river. It was, therefore, decided that a signal should be given at the instant of one o'clock in the afternoon of each day; by observing which, navigators within view of the observatory could correct their chronometers. The signal adopted for this purpose was the sudden fall of a large black ball, placed upon a pole raised from the top of one of the towers of the observatory.

Before elevating the ball, at five minutes before one o'clock, a signal is made of the intention to do so by raising it half-mast high. Observers are then instructed to prepare their chronometers; and as the descent of the ball occupies several seconds, they should confine their attention to observing the moment when the ball leaves the top, as it is that alone which indicates the hour.

The use of this signal is not merely confined to the indication of the mean time at Greenwich for navigators going down the river. By observing the drop of the ball, repeated day after day, mariners who are in the river will be enabled to ascertain the daily rate of their chronometers.

LUNAR INFLUENCES.

1. Popular opinions on Lunar Influences.—2. Red moon.—3. Time for felling timber.—4. Supposed Lunar Influences on vegetables.—5. On the complexion.—6. On putrefaction.—7. On shell-fish.—8. On the marrow of animals.—9. On the weight of the human body.—10. On births.—11. On incubation.—12. On mental derangement and other human maladies—Instances of this supposed influence during eclipse given by Faber and Ramazzini—Amusing anecdote of a village curé near Paris—Examples of Vallisnieri and Bacon—Observations and examples of Menuret, Hoffmann, Dr. Mead, Pyson, and Dr. Gall.—13. Difficulty of showing fallacy of these opinions by reasoning or proof—Dr. Olbers' partial refutation of them—Arago's opinion on them.—14. General conclusion that few of these influences have any foundation in fact.

1. Astronomers have demonstrated that the effects of the moon's gravitation are manifested by various phenomena upon the surface of the earth, among which the most conspicuous are the tides of the ocean. But popular opinion, advancing further, has in all nations, and in all ages, claimed for our satellite a vast number of other influences which do not seem to appertain to its mere physical attraction. The vicissitudes of the weather which have been supposed to follow the course of the lunar phases might be imagined, if they could be shown to have any reality, to be produced by atmospheric tides or currents arising from the

moon's attraction, like the tides of the ocean. We have shown, however, in another number of this series, that there are no grounds whatever, either in theory or in observation, for imputing to the moon any such meteorological influence, and that, as a matter of fact, there is no such accordance or correspondence whatever between the lunar phases and the changes of the weather.

There are, however, a numerous class of other influences which popular opinion has imputed to our satellite, which we propose to examine, and which, however absurd some of them may appear in a scientific point of view, claim to be seriously considered, inasmuch as they have prevailed among mankind in almost all countries and throughout all ages.

According to these popular opinions and traditions, our satellite is responsible for a vast variety of influences on the organised world. The circulation of the sap in vegetables, the qualities of grain, the goodness of the vintage, are severally laid to its account; and timber must be planted, transplanted, and felled, the harvest cut down and gathered in, the juice of the grape expressed, and its subsequent treatment regulated at times and under circumstances having determined relations to the aspects of the moon, if excellence be looked for in these products of the soil. According to popular belief, our satellite also presides over human maladies, and the phenomena of the sick chamber are governed by the lunar phases; nay, the very marrow of our bones and the weight of our bodies suffer increase or diminution under its influence. Nor is its influence limited to mere physical and organic effects; it extends its sway into the region of intellectual phenomena, and notoriously governs mental derangement.

If such doctrines and opinions were limited to particular nations, or prevailed only at particular epochs, they would be less entitled to serious consideration. But it is a curious fact, and one which it is extremely difficult to account for, that many of these doctrines prevail and have prevailed among nations and people so distant and unconnected, that it is impossible to imagine the same errors to have had the same origin. At all events the extent and long continuance of their prevalence entitles them to grave investigation. We propose, therefore, at present to state some of the principal facts and arguments bearing on these points, for the collection of most of which we are indebted to the labours and research of M. Arago.

To analyse all the popular opinions which relate to lunar influences would require a volume. We shall confine ourselves therefore to the principal of them, and shortly examine how far they can be reconciled with the established principles of astronomy and physics.

2. *The Red Moon.*—It is believed generally, especially in the neighbourhood of Paris, that in certain months of the year, the moon exerts a great influence upon the phenomena of vegetation. Gardeners give the name of *Red Moon* to that moon which is full between the middle of April and the close of May. According to them the light of the moon at that season exercises an injurious influence upon the young shoots of plants. They say that when the sky is clear the leaves and buds exposed to the lunar light redden and are killed as if by frost, at a time when the thermometer exposed to the atmosphere stands at many degrees above the freezing point. They say, also, that if a clouded sky intercept the moon's light it prevents these injurious consequences to the plants, although the circumstances of temperature are the same in both cases.

According to the notions of these agriculturists the rays of lunar light are endowed with a certain frigorific property, in the same manner as those of solar light are endowed with a calorific virtue; and that as the latter raise the temperature of objects upon which they are directed, the former, on the contrary, lower their temperature.

Now this question has been submitted to the test of direct experiment, and the result has been directly opposite to such a notion. The bulb of a thermometer sufficiently sensitive to render apparent a change of temperature amounting to the thousandth part of a degree, was placed in the focus of a concave reflector of vast dimensions, which being directed to the moon, the lunar rays were collected with great power upon it. Not the slightest change, however, was produced in the thermometric column, proving that a concentration of rays sufficient to fuse gold, if they proceeded from the sun, does not produce a change of temperature so great as the thousandth part of a degree when they proceed from the moon.

Nevertheless, the fact observed by the gardeners and agriculturists is real, subject only to the objection that their observation of it has not been sufficiently extended. Had they observed the effects produced on clear and clouded nights which are not moonlit, they would have discovered the moon's innocence of the offence they charge against her.

That these phenomena are wrongly ascribed to the influence of the moon, will be easily comprehended by any one who is familiar with the physical principles which govern the radiation and reflection of heat.

All bodies, whatever be the matter of which they are formed, and whatever be their temperature, emit continually rays of heat, just as the sun or any luminous body emits rays of light. The intensity with which this radiation takes place, depends partly on the temperature, partly on the sort of matter, partly on the state of the surface of the body. The higher the temperature, other things being the same, the more intense will be the radiation. Certain sorts of bodies are strong, while others are feeble, radiators. Metallic bodies are examples of the latter, and charcoal of the former. Polished surfaces are unfavourable, rough surfaces favourable to radiation.

All bodies are likewise capable of reflecting from their surfaces the rays of heat which fall upon them. But different bodies possess this quality of reflection in different degrees, according to the state of their surfaces; those which have the greatest power of radiation having the least power of reflection.

A clear and unclouded sky, being in fact empty space, cannot reflect back to the earth any of the heat which is radiated by bodies on the earth; but if the sky be clouded, the heat thus radiated will be reflected back to the earth in a greater or less degree.

If, therefore, the firmament at night be clear and unclouded, all bodies on the surface of the earth radiating heat towards it, and receiving back no part of that heat by reflection, will lose temperature, will become colder; and this fall of temperature will be greater with bodies which are strong radiators than with those which are feeble radiators.

But if the firmament be covered with clouds, the heat which all bodies on the surface of the earth radiate will be reflected back to them by the clouds, and receiving as much or nearly as much as they emit, their temperature will be maintained.

So powerful is the cooling effect of an unclouded sky, that in hot climates water is frozen by such exposure. It is placed in porous earthen pots, under the clear sky. It loses heat at the same time by radiation from its surface, by radiation from the surface of the earthen pan, and by evaporation, especially from the latter surface. The result of these combined effects is, that the water in the pans is congealed, although the temperature of the air and surrounding objects may be considerably above the point of congelation.

The leaves and flowers of plants are always strong radiators of heat, and on a clear and unclouded night they lose temperature continually by this radiation, not receiving at the same time any return by reflection. But if, as has been explained above, the sky be clouded, they will receive as much as they give, and their temperature will not fall.

The moon, therefore, has no connexion whatever with this effect; and it is certain that plants would suffer under the same circumstances whether the moon is above or below the horizon. It equally is quite true that if the moon be above the horizon, the plants cannot suffer unless it be visible; because a *clear sky* is indispensable as much to the production of the injury to the plants as to the visibility of the moon; and, on the other hand, the same clouds which veil the moon and intercept her light, give back to the plants that warmth which prevents the injury here adverted to. The popular opinion is therefore right as to the *effect*, but wrong as to the *cause;* and its error will be at once discovered by showing that on a clear night, when the moon is new, and, therefore, not visible, the plants will be similarly affected.

3. *Time for felling Timber.*—An opinion is generally entertained that timber should be felled only during the decline of the moon; for if it be cut down during its increase, it will not be of good or durable quality. This impression prevails in various countries. It is acted upon in England, and is made the ground of legislation in France. The forest laws of the latter country interdict the cutting of timber during the increase of the moon. M. Auguste de Saint Hilaire states that he found the same opinion prevalent in Brazil. Signor Francisco Pinto, an eminent agriculturist in the province of Espirito Santo, assured him as the result of his experience, that the wood which was not felled at the full of the moon was immediately attacked by worms and very soon rotted.

In the extensive forests of Germany, the same opinion is entertained and acted upon with the most undoubting confidence in its truth. Sauer, a superintendent of some of these districts, assigns what he believes to be its physical cause. According to him, the ascensional force of the sap is much greater during the increase than during the decrease of the moon, and he infers, therefore, that timber which is felled in the first or second quarter of the moon, when the vessels are more filled with sap, will be spongy and more easily attacked by worms; that it will be more difficult to season, and that it will warp and split by exposure to very slight variations of temperature; but that, on the contrary, timber felled in the third or fourth quarter, when the sap ascends with diminished force, will be more dense and durable, and fitter for the purposes of structure.

Can there be imagined in the whole range of natural science a physical relation more extraordinary and unaccountable than this supposed correspondence between the movement of the sap and the phases of the moon? Assuredly theory affords not the slightest countenance to such a supposition: but let us inquire as to the fact, whether it be really the case that the quality of timber depends upon the state of the moon at the time it is felled.

M. Duhamel du Monceau, a celebrated French agriculturist, made direct experiments for the purpose of testing this question; and clearly and conclusively showed that the qualities of timber felled in different parts of the lunar month are the same. M. Duhamel felled a great many trees of the same age, growing from the same soil, and exposed to the same aspect, and never found any difference in the quality of the timber when he compared those which were felled in the decline of the moon with those which were felled during its increase; in general they have afforded timber of the same quality. He adds, however, that by a circumstance, which was doubtless fortuitous, a slight difference was manifested in favour of timber which had been felled between the new and full moon—contrary to popular opinion.

4. *Supposed Lunar Influence on Vegetables.*—It is a maxim among gardeners, that cabbages and lettuces which are desired to shoot forth early, flowers which are to be double, trees which it is desired should produce early ripe fruit, should severally be sown, planted, and pruned during the decrease of the moon; and that, on the contrary, trees which are expected to grow with vigour should be sown, planted, grafted, and pruned during the increase of the moon. These opinions are altogether erroneous. The increase or decrease of the moon has no appreciable influence on the phenomena of vegetation; and the experiments and observations of several French agriculturists, and especially of M. Duhamel du Monceau (already alluded to) have clearly established this.

Montanari has attempted, like M. Sauer, to assign the physical cause for this imaginary effect. During the day, he says, the solar heat augments the quantity of sap which circulates in plants, by increasing the magnitude of the tubes through which the sap moves; while the cold of the night produces the opposite effect by contracting these tubes. Now, at the moment of sunset, if the moon be increasing, it will be above the horizon, and the warmth of its light would prolong the circulation of the sap; but, during its decline, it will not rise for a considerable time after sunset, and the plants will be suddenly exposed to the unmitigated cold of the night, by which a sudden contraction of leaves and tubes will be produced, and the circulation of the sap as suddenly obstructed.

If we admit the lunar rays to possess any sensible calorific power, this reasoning might be allowed; but it will have very little force when it is considered that the extreme change of temperature which can be produced by the lunar light, does not amount to the thousandth part of a degree of the thermometer.

It is a curious circumstance that this erroneous prejudice prevails on the American continent. M. Auguste de Saint Hilaire states, that in Brazil cultivators plant, during the decline of the moon, all vegetables whose roots are used as food, and, on the contrary, they plant during the increasing moon, the sugar-cane, maize, rice, beans, &c., and, in general, those which bear the food upon their stocks and branches. Experiments, however, were made and reported by M. de Chanvalon, at Martinique, on vegetables of both kinds planted at different times in the lunar month, and no appreciable difference in their qualities was discovered.

There are some traces of a principle in the rule adopted by the South American agronomes, according to which they treat the two classes of plants distinguished by the production of fruit on their roots or on their branches differently; but there are none in the European aphorisms. The directions of Pliny are still more specific: he prescribes the time of the full moon for sowing beans, and that of the new moon for lentils. "Truly," says M. Arago, "we have need of a robust faith to admit without proof that the moon, at the distance of 240,000 miles, shall in one position act advantageously upon the vegetation of beans, and that in the opposite position, and at the same distance, she shall be propitious to lentils."

Supposed Lunar Influence on Grain.—Pliny states that if we would collect grain for the purpose of immediate sale, we should do so at the full of the moon; because, during the moon's increase the grain augments remarkably in magnitude: but if we would collect the grain to preserve it, we should choose the new moon, or the decline of the moon.

So far as it is consistent with observations that more rain falls during the increase of the moon than during its decline, there may be some reason for this maxim; but Pliny, or those from whom we receive the maxim, can scarcely have credit for grounds so rational: besides which, the difference in the quantity of rain which falls during the two periods is so utterly insignificant as to be totally incapable of producing the effects here adverted to.

Supposed Lunar Influence on Wine-making.—It is a maxim of wine-growers, that wine which has been made in two moons is never of a good quality, and cannot be clear. Toaldo, the celebrated Italian meteorologist, whose mind appears to have been predisposed for the reception of lunar prejudice, attempts to justify this maxim. "The vinous fermentation," he says, "can only be carried on in two moons when it begins immediately before the new moon: and, consequently, that this being a time when the enlightened side of the moon is turned for the most part from the earth, our atmosphere is deprived of the heat of the lunar rays; that therefore the temperature of the earth is lowered, and the fermentation is less active."

To this we need only answer, that the moon's rays do not affect the temperature of the air to the extent of one thousandth part of a degree of the thermometer, and that the difference of temperatures of any two neighbouring places in which the process of making the wine of the same soil and vintage might be conducted, must be many times greater at any given moment of time, and yet no one ever imagines that such a circumstance can affect the quality of the wine.

According to the meteorological maxims of the ancients, the fate of the vintage was even more powerfully affected by the influence of a particular star, and moreover one scarcely so bright as to be classed among those of the first magnitude, than by that of the moon. This stellar enemy of the grape was the star called Procyon, in the constellation of the little dog. Pliny records the opinion prevailing in his time that Procyon decided the fate of the vintage, and that its malign influence burnt the grape.

Now it might fairly be demanded by what means the grape was protected from this malignant star in some years, though exposed to it in others? Procyon, a fixed star, held and still holds constantly the same place in the firmament; and whatever be the physical influence which it radiates to the earth, that influence cannot change from year to year. If it be replied that the number of unclouded nights at a certain season is greater or less in different years, we shall then fall back upon the explanation already given in the case of the red moon, and show that Procyon is in this case a mere witness, and not a malefactor.

As this ancient error does not, however, appear to prevail in our times, it will not be necessary to enlarge further on this point.

It is a maxim of Italian wine merchants, that wine ought never to be transferred from one vessel to another in the month of January or March, unless in the decline of the moon, under penalty of seeing it spoiled.

Toaldo has not favoured us with any physical reason for this maxim; but it is remarkable that Pliny, on the authority of Hyginus, recommends precisely the opposite course. We may presume that from such contrary rules, it may reasonably be inferred that the moon has no influence whatever in this case.

Among the maxims of Pliny we find that grapes should be dried by night at new moon, and by day at full moon.

When the moon is new it is below the horizon during the night, and above it during the day; and when it is full it is above the horizon during the night, and below it during the day. The maxim of Pliny, therefore, is equivalent to a condition requiring that the grapes should be dried when the moon is below the horizon. It is evident that the absence of the moon is not required in this case in consequence of any effect which her light might produce if she were present; for when the moon is new she affords no light, even when in the firmament, the illuminated side being turned from the earth. If the maxim be founded upon any reason, it must, therefore, either be on some influence which the moon is supposed to produce when present, independent of her light (the absence of which influence is desired), or it may be that she may be supposed to transmit some effect through the solid mass of the earth when on the other side of it which she is incapable of producing without its intervention. The maxim is probably as absurd and groundless as the other effects imputed to the moon.

5. *Supposed Lunar Influence on the Complexion.*—It is a prevalent popular notion in some parts of Europe, that the moon's light is attended with the effect of darkening the complexion.

That light has an effect upon the colour of material substances is a fact well known in physics and in the arts. The process of bleaching by exposure to the sun is an obvious example of this class of facts. Vegetables and flowers which grow in a situation excluded from the light of the sun are different in colour from those which have been exposed to its influence. The most striking instance, however, of the effect of certain rays of solar light in blackening a light-coloured substance, is afforded by chloride of silver, which is a white substance, but which immediately becomes black when acted upon by the rays near the violet extremity of the spectrum. This substance, however, highly susceptible as it is of having its colour affected by light, is, nevertheless, found not to be changed in any sensible degree when exposed to the light of the moon, even when that light is condensed by the most powerful burning lenses. It would seem, therefore, that as far as any analogy can be derived from the qualities of this substance, the popular impression of the influence of the moon's rays in blackening the skin receives no support.

M. Arago (who generally inclined to favour rather than oppose prevailing popular opinions), thought it possible that some effect may be produced upon the skin exposed on clear nights, explicable on the same principle as that by which we have explained the effects erroneously imputed to what is called the *red moon*. The skin being, in common with the leaves and flowers of vegetables, a good radiator of heat, will, when exposed on a clear night, for the same reasons, sustain a loss of temperature. Although this will be to a certain extent restored by the sources of animal heat, still it may be contended that the cooling produced by radiation is not altogether without effect. It is well known that a person who sleeps exposed in the open air on a night when the dew falls, is liable to suffer from severe cold, although the atmosphere around him never falls below a moderate temperature; and although no actual deposition of dew may take place upon his skin. This effect must arise from the constant lowering of temperature of the skin by radiation.

The *Hâle du bivouack* is a term familiar to all French soldiers who have taken much part in campaigns. Hâle is a term which expresses a certain supposed quality of the atmosphere, by which it produces the effect of tanning or darkening the skin. It is well known to the soldier that it takes place only on unclouded nights when the face is exposed to the sky. That it is not a mere quality of the atmosphere is proved by the fact that any screen which will intercépt the view of the sky will protect the face, however much it be otherwise exposed to the air.

In the south of France mothers warn their daughters against nocturnal promenades by the old proverb :—

> " Que lou sol y la sereine
> Fan veni la gent mouraine."

It is remarkable that this proverb is current in places where the moon is not noticed as concerned in the effect produced.

6. *Supposed Lunar Influence on Putrefaction.*—Pliny and Plutarch have transmitted it as a maxim, that the light of the moon facilitates the putrefaction of animal substances, and covers them with moisture. The same opinion prevails in the West Indies, and in South America. An impression is prevalent, also, that certain kinds of fish exposed to moonlight lose their flavour and become soft and flabby ; and that if a wounded mule be exposed to the light of the moon during the night, the wound will become irritated, and frequently become incurable.

Such effects, if real, may be explained upon the same principles as those by which we have already explained the effects imputed to the red moon. Animal substances exposed to a clear sky at night, are liable to receive a deposition of dew, which humidity has a tendency to accelerate putrefaction. But this effect will be produced if the sky be clear, whether the moon be above the horizon or not. The moon, therefore, in this case, is a witness and not an agent; and we must acquit her of the misdeeds imputed to her.

7. *Supposed Lunar Influence on Shell-fish.*—It is a very ancient remark, that oysters and other shell-fish become larger during the increase than during the decline of the moon. This maxim is mentioned by the poet Lucilius, by Aulus Gellius, and others: and the members of the academy *del Cimento* appear to have tacitly admitted it, since they endeavour to give an explanation of it. The fact, however, has been carefully examined by Rohault, who has compared shell-fish taken at all periods of the lunar month, and found that they exhibit no difference of quality.

8. *Supposed Lunar Influence on the Marrow of Animals.*—An opinion is prevalent among butchers that the marrow found in the bones of animals varies in quantity according to the phase of the moon in which they are slaughtered. This question has also been examined by Rohault, who made a series of observations which were continued for twenty years with a view to test it; and the result was that it was proved completely destitute of foundation.

9. *Supposed Lunar Influence on the Weight of the Human Body.*—Sanctorius, whose name is celebrated in physics for the invention of the thermometer, held it as a principle that a healthy man gained two pounds weight at the beginning of every lunar month, which he lost towards its completion. This opinion appears to be founded on experiments made upon himself; and affords another instance of a fortuitous coincidence hastily generalised. The error would have been corrected if he had continued his observations a sufficient length of time.

10. *Supposed Lunar Influence on Births.*—It is a prevalent opinion that births occur more frequently in the decline of the moon than in her increase. This opinion has been tested by comparing the number of births with the periods of the lunar phases; but the attention directed to statistics as well in this country as abroad, will soon lead to the decision of this question. Other sexual phenomena, vulgarly supposed to have some relation to the lunar month, have no relation whatever to that period.

11. *Supposed Lunar Influence on Incubation.*—It is a maxim handed down by Pliny, that eggs should be put to hatch when the moon is new. In France it is a maxim generally adopted, that the fowls are better and more successfully reared when

they break the shell at the full of the moon. The experiments and observations of M. Girou de Buzareingues have given countenance to this opinion. But such observations require to be multiplied before the maxim can be considered as established. M. Girou inclines to the opinion that during the dark nights about new moon the hens sit so undisturbed that they either kill their young or check their development by too much heat; while in moonlight nights, being more restless, this effect is not produced.

12. *Supposed Lunar Influence on Mental Derangement and other Human Maladies.*—The influence on the phenomena of human maladies imputed to the moon is very ancient. Hippocrates had so strong a faith in the influence of celestial objects upon animated beings, that he expressly recommends no physician to be trusted who is ignorant of astronomy. Galen, following Hippocrates, maintained the same opinion, especially of the influence of the moon. Hence in diseases the lunar periods were said to correspond with the succession of the sufferings of the patients. The critical days or *crises* (as they were afterwards called), were the seventh, fourteenth, and twenty-first of the disease, corresponding to the intervals between the moon's principal phases. While the doctrine of alchymists prevailed, the human body was considered as a microcosm; the heart, representing the vital principle, was placed under the influence of the sun; the brain was regulated and controlled by the moon. The planets had each its proper influence; Jupiter presided over the lungs, Mars over the liver, Saturn over the spleen, Venus over the kidneys, and Mercury over the organs of generation. Of these grotesque notions there is now no relic, except the term *lunacy*, which still designates unsoundness of mind. But even this term may in some degree be said to be banished from the terminology of medicine, and it has taken refuge in that receptacle of all antiquated absurdities of phraseology—the law. Lunatic, we believe, is still the term for the subject who is incapable of managing his own affairs.

Although the ancient faith in the connexion between the phases of the moon and the phenomena of insanity appears in a great degree to be abandoned, yet it is not altogether without its votaries; nor have we been able to ascertain that any series of observations conducted on scientific principles, has ever been made on the phenomena of insanity, with a view to disprove this connexion. We have even met with intelligent and well-educated physicians who still maintain that the paroxysms of insane patients are more violent when the moon is full than at other times.

Mathiolus Faber gives an instance of a maniac who at the very moment of an eclipse of the moon, became furious, seized upon a sword, and fell upon every one around him. Since it was observed that as the day of the eclipse approached, the patient became more and more sombre and melancholy, it may be inferred that in this case imagination, excited by the apprehension of the approaching phenomenon, had more to do with the paroxysm than the moon.

Ramazzini relates that, in the epidemic fever which spread over Italy in the year 1693, patients died in an unusual number on the 21st of January, at the moment of a lunar eclipse. Without disputing this fact (to ascertain which, however, it would be necessary to have statistical returns of the daily deaths), it may be objected that the patients who thus died in such numbers at the moment of the eclipse, might have had their imaginations highly excited, and their fears wrought upon by the approach of that event, if popular opinion invested it with danger. That such an impression was not unlikely to prevail is evident from the facts which have been recorded.

At no very distant period from that time, in August, 1654, it is related that patients in considerable numbers were by order of the physicians shut up in chambers well closed, warmed, and perfumed, with a view to escape the injurious influence of the solar eclipse, which happened at that time; and such was the consternation of persons of all classes, that the numbers who flocked to confession were so great, that the ecclesiastics found it impossible to administer that rite. An amusing anecdote is related of a village curate near Paris, who, with a view to ease the minds of his flock, and to gain the necessary time to get through his business, seriously assured them that the eclipse was postponed for a fortnight.

Two of the most remarkable examples recorded of the supposed influence of the moon on the human body, are those of Vallisnieri and Bacon. Vallisnieri declares that being at Padua recovering from a tedious illness, he suffered on the 12th of May, 1706, during the eclipse of the sun, unusual weakness and shivering. Lunar eclipses never happened without making Bacon faint; and he did not recover his senses till the moon recovered her light.

That these two striking examples should be admitted in proof of the existence of lunar influence, it would be necessary, says M. Arago, to establish the fact that feebleness and pusillanimity of character are never connected with high qualities of mind.

Menuret considers that cutaneous maladies have a manifest connexion with the lunar phases. He says that he himself observed in the year 1760, a patient afflicted with a scald head (*teigne*), who, during the decline of the moon, suffered from a gradual increase of the malady, which continued until the epoch of the new moon, when it had covered the face and breast, and produced insufferable itching. As the moon increased, these symptoms disappeared by degrees; the face became free from the eruption; but the same effects were reproduced after the full of the moon. These periods of the disease continued for three months.

Menuret also stated that he witnessed a similar correspondence between the lunar phases and the distemper of the itch; but the circumstances were the reverse of those in the former case; the malady attaining its maximum at the full of the moon, and its minimum at the new moon.

Without disputing the accuracy of these statements, or throwing any suspicion on the good faith of the physician who has made them, we may observe that such facts prove nothing except the fortuitous coincidence. If the relation of cause and effect had existed between the lunar phases and the phenomena of these distempers, the same cause would have continued to produce the same effect in like circumstances; and we should not be left to depend for the proof of lunar influence on the statements of isolated cases, occurring under the observation of a physician who was himself a believer.

Maurice Hoffman relates a case which came under his own practice, of a young woman, the daughter of an epileptic patient. The abdomen of this girl became inflated every month as the moon increased, and regularly resumed its natural form with the decline of the moon.

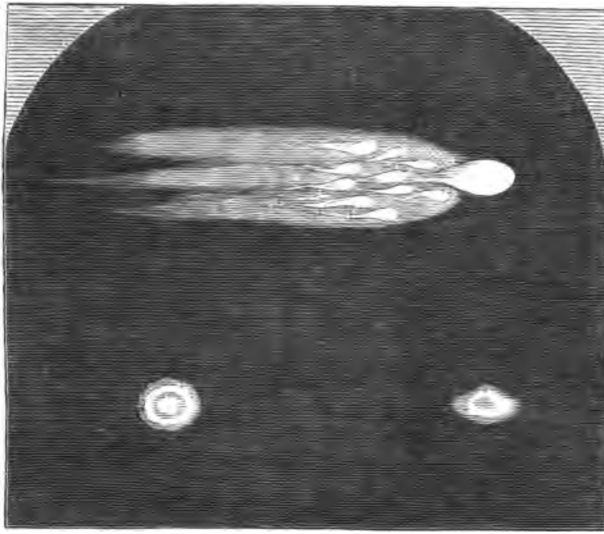
Now, if this statement of Hoffman were accompanied by all the necessary details, and if, also, we were assured that this strange effect continued to be produced for any considerable length of time, the relation of cause and effect between the phases of the moon and the malady of the girl could not legitimately be denied; but receiving the statement in so vague a form, and not being assured that the effect continued to be produced beyond a few months, the legitimate conclusion at which we must arrive is, that this is another example of fortuitous coincidence, and may be classed with the fulfilment of dreams, prodigies, &c., &c.

As may naturally be expected, nervous diseases are those which have presented the most frequent indications of a relation with the lunar phases. The celebrated Mead was a strong believer, not only in the lunar influence, but in the influence of all the heavenly bodies on all the human. He cites the case of a child who always went into convulsions at the moment of full moon. Pyson, another believer, cites another case of a paralytic patient whose disease was brought on by the new moon. Menuret records the case of an epileptic patient whose fits returned with the full moon. The transactions of learned societies abound with examples of giddiness, malignant fever, somnambulism, &c., having in their paroxysms more or less corresponded with the lunar phases. Gall states, as a matter having fallen under his own observation, that patients suffering under weakness of intellect, had two periods in the month of peculiar excitement ; and in a work published in London so recently as 1829, we are assured that these epochs are between the new and full moon.

13. Against all these instances of the supposed effect of lunar influence, we have little direct proof to offer. To establish a negative is not easy. Yet it were to be wished that in some of our great asylums for insane patients, a register should be preserved of the exact times of the access of all the remarkable paroxysms ; a subsequent comparison of this with the age of the moon at the time of their occurrence would furnish the ground for legitimate and safe conclusions. We are not aware of any scientific physician who has expressly directed his attention to this subject, except Dr. Olbers of Bremen, celebrated for his discovery of the planets Pallas and Vesta. He states that in the course of a long medical practice, he was never able to discover the slightest trace of any connexion between the phenomena of disease and the phases of the moon. In the spirit of true philosophy, M. Arago, nevertheless, recommends caution in deciding against this influence. The nervous system, says he, is in many instances an instrument infinitely more delicate than the most subtle apparatus of modern physics. Who does not know that the olfactory nerves inform us of the presence of odoriferous matter in air, the traces of which the most refined physical analysis would fail to detect ? The mechanism of the eye is highly affected by that lunar light which, even condensed with all the power of the largest burning lenses, fails to affect by its heat the most susceptible thermometers, or, by its chemical influence, the chloride of silver ; yet a small portion of this light introduced through a pin-hole will be sufficient to produce an instantaneous contraction of the pupil ; nevertheless the integuments of this membrane, so sensible to light, appear to be completely inert when otherwise affected. The pupil remains unmoved, whether we scrape it with the point of a needle, moisten it with liquid acids, or impart to its surface electric

sparks. The retina itself, which sympathises with the pupil, is insensible to the influence of the most active mechanical agents. Phenomena so mysterious should teach us with what reserve we should reason on analogies drawn from experiments made upon inanimate substances, to the far different and more difficult case of organised matter endowed with life.

14. In conclusion, then, it appears that of all the various influences popularly supposed to be exerted on the surface of the earth, few have any foundation in fact.



METEOR OF 18TH OF AUGUST, 1783, AS SEEN FROM WINDSOR. THE TWO LOWER FIGURES REPRESENT IT A FEW SECONDS BEFORE ITS EXPLOSION.

METEORIC STONES & SHOOTING STARS.

CHAPTER I.

1.—Necessity of following out the true spirit of the inductive philosophy in the investigation of physical phenomena.—2. Circumstances attending appearance of meteorites supplied by past observation—Ball-lightning—Explosive clouds—Chladni's catalogue of meteoric stones.—3. Remarkable falls of aerolites.—4. Physical condition and analysis of aerolites.—5. Crust of meteorites, their internal mass.—6. Their magnitude and velocity.—7. The different hypotheses or theories proposed to explain them.—8. Luminous appearance explained.—9. Hypothesis of Poisson.—10. Atmospheric origin impossible.—11. Volcanic origin inadmissible.—12. Lunar origin rejected.—13. Planetary origin generally admitted.—14. Remarkable appearances of shooting-stars recorded in history.—15. Shower of stars seen in 1788 and 1799.—16. Also in 1822 and 1831.—17. Remarkable shower in 1833.—18. Vast number of shooting-stars seen on that occasion.—19. Their magnitude.

1. When we reflect upon the length of time which has elapsed since just methods of investigating nature were first formally taught by Bacon, we cannot fail to be struck with surprise at witnessing the frequency with which these inestimable precepts

are neglected and overlooked. There appears to be a disposition inherent in the mind—springing probably from that arrogance and vanity, which are invariably the offspring of ignorance—that induces us precipitately to rush to the formation of theories and the assumption of causes, omitting or postponing the far more important though less ambitious duty of analysing phenomena. It is true that these observations are less applicable to that order of minds which have been disciplined in the severe schools of the old and long-established universities, where the works of BACON, and the mathematical classics of NEWTON and LAPLACE, are studied with a zeal and perseverance which do not fail to infuse their spirit into the minds of their aspiring successors. But in the much larger class of half-disciplined or self-taught aspirants to scientific rank, the disposition we refer to frequently exists, and to a proportionate extent retards their progress, and impairs the value of their labours.

The public teacher should, therefore, omit no proper opportunity of inculcating the true spirit of the inductive philosophy, which, in our day, has afforded so rich a harvest of discovery. We shall avail ourselves of the opportunity which the consideration of aerolites offers, to give an example of the rigorous observance of the canons of Bacon's philosophy in the investigation of nature.

Every one possessed of the smallest amount of the current information of the day, imagines that he knows what meteoric stones are. He knows that they fall from the air. and that they are accompanied by fire and noise. With this amount of information he unhesitatingly sets about to conjecture their origin, and to get up a theory to explain them. As might be expected, the theory produced under such circumstances is always crude and absurd, and falls to pieces upon the slightest comparison with the phenomena.

When any new and unexplained phenomenon offers itself to our inquiry, the first duty of the investigator is to inform himself, with the most scrupulous accuracy, of all the circumstances, however minute, which accompany it; and if past observation cannot answer all circumstantial inquiries which his understanding may suggest as necessary, he must patiently wait the recurrence of a like phenomenon, and diligently observe it. When he shall have thus collected all the circumstances that can be imagined to throw light on its origin, he will then, and not until then, be in a condition to justify an inquiry into its cause.

2. Let us see, then, what circumstances attending the appearance of meteorites past observation has supplied.

These meteors manifest themselves in various ways. Their fall is often preceded by the appearance of a stream of light passing with great velocity across a part of the firmament more or less extensive, which terminates with an explosion,—sometimes so loud, that windows and doors, and even buildings themselves, are shaken by it as if by an earthquake. This phenomenon is sometimes called *ball-lightning*, a term which is liable to the objection that it implies an analogy, or identity of origin, between these meteors and common lightning, which not only is not proved, but is attended with no probability.

Sometimes a small and dark cloud is observed to be suddenly formed in a perfectly clear sky, which explodes with a noise resembling a succession of discharges of artillery, and stones are hurled from it in a shower. Such a cloud moving over an extensive tract of country has sometimes thrown down thousands of meteoric stones of various magnitudes, but alike in their constituents and external appearance.

The luminous appearance and subsequent explosion attending these meteors were long known; the fact, however, that heavy substances, now called meteoric stones, were projected upon the surface of the earth at the same time, was not clearly proved or generally admitted until the present century. Abundant evidence, however, has been supplied, by the vigilance and zeal of contemporaneous philosophers, of the reality of these deposits. Chladni, in his work on this subject, has given an extensive chronological catalogue of the meteoric stones, which supplies examples of these phenomena occurring in various parts of the world several times in each year of the last century.

3. Remarkable falls of aerolites were observed at Barbotan, in the department of the Landes, in France, on the 24th July, 1790; at Sienna, in Italy, on the 16th June, 1794; at Weston, in Connecticut, U. S., on the 14th December, 1807; and at Juvenas, in the department of Ardèche, in France, on the 15th June, 1821.

The phenomenon sometimes occurs under a perfectly clear and unclouded sky. On the 16th September, 1843, a large aerolite fell at Kleinwenden, near Mulhausen, attended with a thundering noise, the sky being at the time entirely free from clouds.

The fact, then, may be regarded as conclusively established, that masses of stony matter, of various magnitudes, and often of very considerable weight, are frequently seen passing athwart the heavens, with great apparent velocity, which are afterwards precipitated upon the earth with extraordinary force.

The second circumstance worthy of attention is, that these bodies rarely strike the surface of the earth in a direction either vertical or nearly so. They generally come in a direction very oblique to the plane of the horizon. It may be asked, how the direction in which they strike the earth can be ascertained unless they are seen, which rarely happens, at the moment of their fall. Their direction is rendered manifest by the manner in which they penetrate the surface of the ground—which they always do, and to a depth more or less considerable.

The velocity of their motion when they encounter the earth is another circumstance of much importance. This velocity is discoverable by observation on their movement while visible, as well as by inferring the force with which they struck the ground from the depth to which they penetrate it.

It is accordingly found by means of such observations that their velocities belong to the kind of motions which characterise the bodies of the solar system, and such as are never witnessed in the motions of terrestrial bodies. They are velocities which could not be imagined to be imparted by the earth's gravitation to any masses attracted from points within the limits of the atmosphere.

4. On examining the physical condition, and analysing the constituents of the masses thus precipitated, several circumstances worthy of notice are presented. In whatever way they fall, whether from fire-balls visible at night, from a cloud in the day, or from a clear and serene sky, they exhibit a general and striking resemblance in their form, their external crust, and their constituents. When recently fallen, they have always a temperature more or less elevated. They exhibit a shining black and apparently burnt surface, and their constituents are generally iron, nickel, cobalt, manganese, chromium, copper, arsenic, tin, potash, soda, sulphur, phosphorus, and carbon, being in all about a third of the elementary substances to which terrestrial bodies have been reduced by chemical analysis. These constituents are found with some exceptions to be the same at whatever epochs and at whatever parts of the earth these bodies may have fallen.

It is important to observe here, that the iron and nickel are almost always in the metallic form—a state in which they are never known to exist naturally on the surface of the earth. These metals, when found in the earth, are invariably combined with oxygen, and it is their oxydes only which have a place among natural terrestrial substances. The iron and nickel used in the arts are obtained by the decomposition of the ores in the processes of metallurgy.

In some exceptional cases the iron contained in these masses differs extremely in its proportion and quality. The meteorites which fell at Agram, in India—those which were found at Sisim, in the Jeniseisk government—and those brought by Humboldt from Mexico,—contained so much as 96 per cent. of very malleable iron, while the aerolite of Sienna did not contain above 2 per cent., and those of Jonzac and Juvenas contained no metallic iron at all.

5. The crust by which meteorites are almost invariably invested is only a few hundredths of an inch in thickness, and is described by Humboldt as being highly characteristic. It has often a pitchy lustre, and is sometimes veined. This black crust is separated from the light gray mass within it by a line as sharply defined as that of the dark leaden-coloured crust of the white granite blocks brought by Humboldt from the cataracts of the Orinoco, and which are also found by the side of many cataracts in other parts of the world, as those of the Nile and the Congo. It is observed by Humboldt that the greatest heat of porcelain furnaces can produce nothing similar to the crust of the aerolites, so distinctly and sharply separated from the unaltered mass within. Appearances which might seem to indicate a softening of the fragments have been occasionally recognised, but in general the condition of the greater part of the mass—the absence of all flattening which might be produced by the fall—and the moderate degree of heat perceived on touching the newly-fallen aerolite,—are far from indicating a state of internal fusion during its rapid passage through the atmosphere.

6. Observations and measurements made on the magnitude and velocity of these meteoric bodies supply many surprising results.

Fire-balls have been observed whose computed diameters vary from 500 to 2,600 feet. The fire-ball seen at Weston, in Connecticut, U.S., on the 14th December, 1807, measured 500 feet. Le Roi observed one on the 10th July, 1771, which measured about 1000 feet; and Sir Charles Blagden estimated the diameter of one observed by him on the 18th January, 1713, at 2,600 feet. These measurements include, however, not only the solid mass, but the igneous matter by which it may have been surrounded.

Of the meteoric masses found on the surface of the earth, the largest known are those of Bahia in Brazil, and of Otumpa, described by Ruben de Celis. These are from seven to seven and a half feet in diameter. The meteoric stone of Ægos Potamos, celebrated in antiquity, mentioned in the "Chronicle ot the Parian Marbles," and which fell about the year of the birth of Socrates, has been described as being of the size of two mill-stones, and equal in weight to a full waggon load. In the beginning of the tenth century an enormous meteoric mass fell into the river near Narni, the magnitude of which was so great, that when resting on the bottom, it projected four feet above the surface.

According to a popular tradition in Mongol, there is, in a plain near the sources of the Yellow River in Western China, a fragment of black rock forty feet high, which fell from heaven.

It is observed by Humboldt, that great as these masses are they can only be regarded as fragments of the mass which exploded in the fire-ball, or was hurled from the cloud.

The heights at which these objects have been visible, and the actual velocities of their motion, will be presently noticed.

7. Such are the circumstances attending the exhibition of these meteors, which have been collected from careful and accurate information. Let us now turn our attention to the different methods by which it has been attempted to explain them. Four different hypotheses, or theories, have been proposed for this purpose.

First.—It is supposed that the matter composing them has been drawn up from the surface of the earth in a state of infinitely minute subdivision, as vapour is drawn from liquids; that, being collected in clouds in the higher regions of the atmosphere, it is there agglomerated and consolidated in masses, and falls by its gravity to the surface of the earth; being occasionally drawn from the vertical direction which would be imparted to it by gravity, by the effect of atmospheric currents and thus occasionally striking the earth obliquely. We shall call this the *atmospheric hypothesis.*

Secondly.—It is supposed that meteoric stones are ejected from volcanoes, with sufficient force to carry them to great elevations in the atmosphere, in falling from which they acquire the velocity and force with which they strike the earth. The oblique direction with which they strike the ground is explained by the supposition that they may be projected from the volcanoes at corresponding obliquities, and that, by the principles of projectiles, they must strike the earth at nearly the same inclination as that with which they have been ejected. This we shall call the *volcanic hypothesis.*

Thirdly.—It has been suggested that meteorites may be bodies which have been ejected from lunar volcanoes, with such a force that they may have departed from the moon to a distance so great, as to come within such a distance of the earth, that the terrestrial attraction exerted upon them predominating over that of the moon, they may have either fallen down directly upon the earth, or may have revolved round it in a curvilinear orbit, with a motion constantly retarded by the earth's atmosphere, the consequence of which would be that they would continually approach the earth, and at length fall upon its surface. We shall call this the *lunar hypothesis.*

Fourthly.—It has been supposed that meteorites are planetary bodies; that they revolve in orbits round the sun; that these orbits intersect the annual path of the earth; that when the earth passes through the point of intersection of its path with their orbits they either encounter it directly, and fall upon its surface, or entering its atmosphere, are rapidly retarded by the resistance of that fluid, and are then drawn to the surface by the terrestrial attraction.

To render this supposition sufficient to explain the large numbers of meteorites which sometimes appear simultaneously and fall down upon the surface, it is assumed that these planetary bodies circulate round the sun in groups consisting of numerous individuals which move together with equal, or nearly equal, velocities in parallel paths, thus maintaining for long periods of time their relative position, and passing through the celestial space like a flock of gregarious birds. Now, if we suppose the parallel paths of a number of such bodies to be represented at A A, (fig. 7), and that the earth's path, E E′, passes across them,

it is clear that it, while the earth is passing from *e* to *e′*, these bodies happen to be at that point of their orbit, an encounter must ensue, and they must, in greater or less number, pass through the terrestrial atmosphere and be drawn down upon the surface by the earth's attraction.

By admitting the possible existence of a swarm of such bodies consisting of many hundreds, or even thousands, against which there is no physical impossibility, not to say improbability, a satisfactory explanation is afforded of the most extraordinary phenomena of meteoric showers that have ever been witnessed or recorded.

8. Such are the various theories which have been offered to explain the phenomena attending meteoric stones and shooting stars. The evolution of light which attends their rapid progress through space has been accounted for in all of them in the same manner. It is supposed that, in the rapid motion with which the body proceeds, the air which lies in its path is so extremely condensed, as either to become itself luminous, or to acquire so intense a heat as to render the stone incandescent, or, perhaps, to produce upon it a superficial combustion, the signs of which are exhibited in the blackness and elevated temperature of its surface. This reasoning is supported by the well-known experiment of the fire-syringe. In that instrument a solid piston is fitted in a cylinder, so as to be air-tight, carrying a piece of amadou or other easily combustible matter, at its end. When the piston is suddenly forced down, so as to produce an instantaneous and severe compression of the air under it, the amadou takes fire, and, if the cylinder be glass, a flash of light is visible through it. It has therefore been contended, that in this experiment the air under the piston has acquired, by compression, such a temperature as renders it luminous.

More recent experiments, however, made in France, throw doubt upon the validity of this inference. It is said that the unctuous matter commonly used to lubricate the piston in the fire-syringe is, in fact, the source of the ignition; for that, when experiments were made with pistons not so lubricated, the flash of light was not produced. It is, therefore, considered not to be satisfactorily proved, that air by such mechanical compression has become luminous. Still, however, it may be contended that, even though the air were not to become luminous, it may, nevertheless, be raised to such a temperature by compression as, by contact with the meteorite, may render the latter luminous.

Admitting the possibility of this supposition, as applied to the air contiguous to the earth, or at any moderate elevation, a difficulty has been raised from the vast height at which meteorites have been visible. By barometric experiments and observations made on the duration of the morning and evening twilight, it may be considered as proved, that beyond the elevation of thirty miles there exists no atmosphere possessing any sensible mechanical properties. We may safely conclude that at such elevations the air must be so infinitely attenuated as to be divested of all sensible resistance or inertia. The space there must, for example, be more nearly a vacuum than any which could be produced under the receiver of the most perfect air-pump; how, then, can we imagine such a compression of air so rarefied to be produced, as would be necessary to evolve the enormous temperature requisite to render luminous the matter composing meteoric stones?

To this objection the following very plausible answer has been made. It is known that the quantity of latent heat contained in any proposed volume of air is greater the more rare and attenuated the air is. This is easily proved. Every one knows that when a volume of air at a given temperature expands into a larger volume, its temperature falls, although no heat has been abstracted from it. Since, therefore, it contains the same absolute quantity of heat as it did before it expanded, and since, nevertheless, its sensible heat is less, as is proved by its fall of temperature, it follows that the portion of sensible heat which has disappeared must have become latent, that is to say, the air has augmented its latent at the expense of its sensible heat.

Since then highly rarefied air contains much more latent heat than air of greater density, and since this excess of latent heat is greater and greater as the rarefaction is greater and greater, it follows that the latent heat of the air in the highest strata of the atmosphere must be immeasurably greater than in the inferior strata, and that the same degree of sudden compression applied to it would develop a much greater amount of this latent heat, and consequently produce a much greater elevation of temperature than in the lower regions.

It is, therefore, contended that not only notwithstanding the rarefaction of the air in the higher strata, but *because* of that rarefaction, a meteorite rushing through it with a planetary velocity, would, by the sudden compression of the air driven before it, produce an elevation of temperature sufficient not only to cause a superficial combustion of the meteorite, but to cause its explosion by the sudden expansion and combustion of any volatile or combustible matter which might form part of its constituents.

9. There is yet another supposition extremely plausible and ingenious which was suggested by Poisson, the eminent French geometer, to explain the evolution of light and heat observed

in the passage of areolites through the firmament. He affirmed the probability of an atmosphere of electricity surrounding the earth and lying above the atmosphere of air. He supposed that the meteorite rushing through this electric atmosphere would decompose the electric fluid exactly as the friction of an electric machine decomposes it between the cushion and the glass, and that by such electric decomposition light and heat would be evolved.

It may then be admitted that all of the hypotheses above mentioned will equally afford an explanation of the evolution of light and heat; and that, on the other hand, so far as regards these effects, all the hypotheses are subject to the same objections and the same difficulties.

Let us, however, examine them severally, and see how far in other respects they will supply an explanation of the phenomena.

10. The atmospheric hypothesis is subject to objections so unanswerable, that it may be considered as altogether set aside. In order to suppose it probable that aerolites could be formed in the atmosphere, we must show that their constituent elements can exist there. We know that hail and snow can be formed in the air, because it can be proved that aqueous vapour is suspended there, and that a temperature is sometimes produced there so low as to convert that vapour, first, into the liquid, and then into the solid form of snow or hail. But the most rigorous analysis has never detected in the atmosphere any of the constituents of meteoric stones, nor is there any proof that the constituent principles of the air could dissolve, evaporate, or sublimate such substances. Nor can it be said that, although the atmosphere which immediately surrounds us may not have such properties, yet, that at the great elevations in which meteorites are formed, the air may consist of different constituents; for, besides the fact that it has been ascertained by direct analysis that the atmosphere, at all elevations to which man has ever yet attained, consists of exactly the same constituents, in exactly the same proportions, there is a general law, which prevails among all gaseous substances, that when different gases are superposed they will, notwithstanding their different degrees of levity, ultimately mingle so as to form a uniform mass; thus, if we could imagine for a moment a stratum of air to exist near the top of the atmosphere, having constituents different from those around us, such stratum would gradually intermingle with the strata below it, until the whole would acquire a uniform quality. It is, therefore, physically impossible that there can exist in any elevated region of the air any

substances capable of discharging or sublimating the matter of meteoric stones.

To these objections we may add others. Although it may be admitted, as Arago argues, that the constituent principles of aerolites should really exist in the atmosphere, and that they only escape analysis because of their extreme minuteness, it would still be necessary to explain with such feeble and such dispersed elements a sudden precipitation, yielding stones of several hundred weight, such as those preserved at Ensenheim, in Alsace, or 3000 or 4000 stones of various dimensions, like those which were separated and shot off by the l'Aigle meteor, which we shall presently notice. It would be necessary to assign the cause that combines the scattered molecules, and forms them into a single mass. It is not affinity, for the elements composing aerolites are not generally in a state of combination, but simply agglomerated and held together in juxta-position. And yet, if they are not subjected to any mutually attractive force, these little globules ought to fall separately as they are formed. It is in vain to object that they might be suspended, for a greater or less time, by a cause analogous to that which, according to the ingenious hypothesis of Volta, balances the particles of hail between two clouds, so as to give them time to enlarge by the addition of new layers of ice. The fact still remains, that these latter have never been seen to amount to several hundred weight, though the elements that form hail are much more abundant in the air than those of which aerolites are supposed to be formed. Besides, in Volta's theory, the suspension of hail in the atmosphere is attributed to the reciprocal action of electric clouds, a cause which cannot be in like manner adapted to the formation of aerolites, since the meteors that carry them sometimes burst in the clearest weather.

But even granting all this, and admitting the formation of aerolites in the atmosphere by some unknown agency, how shall we account for the circumstances attending their collision with the surface of the earth? According to this theory, they would move to the surface of the earth by the operation of terrestrial gravity alone, and would meet the earth with a velocity due to the height from which they fell. Now the actual velocities with which they are known to strike the earth could never be acquired under the mere agency of terrestrial gravity, through any height within the ordinary limits of the air.

But if the velocity of the meteorites be incompatible with this theory, their direction is still more so. Their obliquity could never be produced by any conceivable atmospheric current.

We may, therefore, safely pronounce the atmospheric theory to be incompatible with the ascertained circumstances of the phenomena, and to require admissions inconsistent with the established principles of physics.

11. The volcanic theory is subject to objections as decisive. The nature of the substances ejected from terrestrial volcanoes is well known, and we do not find among them the substances which form the constituents of meteorites; besides this, it is found that meteoric stones fall on parts of the earth so remote from volcanoes, and at times so distant from any known extensive eruptions, that it is impossible to admit the supposition that they have proceeded from this cause. For these and other reasons, needless to dwell on, the volcanic hypothesis is set aside.

12. The lunar hypothesis has been seriously entertained by many of the most eminent geometers of the last century. Chladni states that the possibility of such an origin of the aerolites was first suggested by Paolo Maria Terzago, an Italian philosopher, in 1660. Unaware of this ancient conjecture, the hypothesis was revived by Dr. Olbers on the occasion of the great fall of meteorites at Sienna, on the 16th of June, 1794. That astronomer in the following year undertook to investigate the force with which such bodies should be projected from a lunar crater, in order to enable them to pass from the sphere of the moon's attraction into that of the earth. The same problem subsequently engaged the attention of Laplace, Biot, Brandes, and Poisson for many years. It was then supposed that, notwithstanding the absence of air and water, active lunar volcanoes existed.

Some countenance to this idea was derived from a remarkable phenomenon, which several observers affirmed that they had witnessed on the dark disc of the moon in lunar eclipses. They saw, or imagined they saw, vividly bright luminous spots at distances not inconsiderable within the moon's limb. Now such appearances, if real, could only be explained by active lunar volcanoes, or by the very improbable supposition of the existence of holes through the moon through which the sun's light passed. The supposition of any such origin as an aurora borealis was removed by the admitted absence of an atmosphere.

Laplace, Biot, and Poisson, agreed in their calculations of the velocity with which such bodies must be projected from the moon to reach the earth. This velocity would be about 8000 feet per second. But Olbers showed, that although such a force of projection might bring them to the earth, it would not impart to them, on arriving there, a speed greater than 35,000 feet per second, a velocity three or four times less than that with which meteorites have been ascertained to strike the ground.

Laplace, though not without much doubt, inclined rather to the lunar than the planetary hypothesis. But at that time the prodigious velocity with which aerolites traverse the terrestrial atmosphere was not so well ascertained as it has been more recently.

In fine, the consideration of these great velocities, combined with the great improbability of the existence of active volcanoes on the moon, an improbability which has been greatly increased if indeed it be not converted into an impossibility by the extensive selenographic researches and observations of Messrs. Beer and Madler, has decided the opinion of the scientific world on this long-vexed question, and the lunar hypothesis like the others has been by common consent set aside.

13. It is, then, agreed generally, that the planetary hypothesis must be taken as the true solution of the problem of the aerolites.

Taking it then to be established on satisfactory grounds that aerolites are planetary bodies which the earth encounters in its annual course round the sun, it remains to examine more closely the peculiar circumstances which have attended their appearance, so as to obtain some more exact and special knowledge of them.

We shall at once assume, what in the sequel will be abundantly evident, the identity of these bodies with shooting stars. Among the numerous records, ancient and modern, of remarkable exhibitions of these objects, we select the following as worthy of attention.

14. According to Arabian historians, on the night of the death of King Ibrahim-ben-Ahmed, in October, 902, a great fall of shooting stars took place, which were described as resembling "a rain of fire."

On the night of 25th April 1095, it was recorded that in France the stars were seen "falling from heaven as thick as hail" by innumerable witnesses, and the terrific phenomenon was mentioned at the Council of Clermont as foreboding the great movement in Christendom.

On 19th October, 1202, stars were recorded as falling during the whole night like a "shower of locusts."

In the "Chronicon Ecclesiæ Pragensis," page 389, it is recorded that on 21st October, O. S., 1366, for several hours during the morning, stars were seen continually falling in such numbers that no person could count them.

15. Humboldt relates that a friend of his accustomed to exact

trigonometrical measurements, saw, in 1788, at Papayana, a town situate in 2° 26′ N. lat., and at an elevation of 5,880 feet, at noonday, with the sun shining brightly in an unclouded sky, his whole room illuminated by a ball of fire. He was standing at the moment with his back to the window, and, on turning round, a great part of the track left by the meteor was still visible and brilliantly marked.

After midnight, on 12th November, 1799, Humboldt and Bonpland saw a prodigious shower of shooting stars at Cumana. This phenomenon was not local, being seen over a great part of the earth.

16. On the night 12th November, 1822, shooting stars, mingled with balls of fire, were seen in vast numbers at Potsdam by Klöden.

On the night of 13th November, 1831, Captain Berard, of the French navy, commanding the brig Le Loiret, off the Spanish coast near Carthagena del Levante, saw in a perfectly cloudless sky, at four in the morning, a considerable number of shooting stars and luminous meteors of great dimensions. During more than three hours they continued to shoot at the average rate of three per minute, and consequently 540 must have appeared in that interval. One of these meteors which passed through the zenith was especially remarkable, exhibiting a luminous train half the breadth of the moon, in which were plainly distinguished all the colours of the rainbow. This train continued visible during more than six minutes.

17. One of the most interesting descriptions of these phenomena is that published by D. Olmsted of Newhaven, Massachusetts, U.S., in which a detailed account is given of the magnificent showers of stars which took place in the United States on the night of 12-13th November, 1833.

The meteors began to attract notice by their frequency as early as 9 o'clock on the evening of 12 Nov., the exhibition became strikingly brilliant about 11 o'clock, but most splendid of all about 4 o'clock, and continued with but little intermission until darkness merged in the light of day. A few large fire-balls were seen even after the sun had risen. The entire extent of the exhibition is not ascertained, but it covered no inconsiderable portion of the earth's surface. It has been traced from the longitude of 61° in the Atlantic ocean, to longitude of 100° in central Mexico, and from the North American lakes to the southern side of the island of Jamaica. Everywhere within these limits, the first appearance was that of fire-works of the most imposing grandeur, covering the entire vault of heaven with myriads of fire-balls resembling sky-rockets.

On more attentive inspection, it was seen that the meteors exhibited three distinct varieties; the first consisting of *phosphoric lines,* apparently described by a point; the second of *large fire-balls,* that at intervals darted along the sky, leaving numerous trains, which occasionally remained in view for a number of minutes, and in some cases for half an hour or more; the third, of undefined, *luminous bodies,* which remained nearly stationary for a long time.

One of the most remarkable circumstances attending this display was, that the meteors all seemed to emanate from one and the same point. They set out at different distances from this point, and proceeded with immense velocity, describing, in some instances, an arc of 30° or 40° in less than four seconds. At Poland, on the Ohio, a meteor (of the third variety) was distinctly visible in the north-east for more than an hour. At Charleston, South Carolina, another of extraordinary size was seen to course the heavens for a great length of time, and then was heard to explode with the noise of a cannon. The point from which the meteors seemed to emanate, was observed by those who fixed its position among the stars to be in the constellation Leo; and what is very remarkable, this point was *stationary* among the stars during the whole period of observation; that is to say, it did not move along with the earth in its diurnal rotation eastward, but accompanied the stars in their apparent progress westward. It is not certain whether the meteors were in general accompanied by any peculiar sound. A few observers reported that they heard a hissing noise, like the rushing of a sky-rocket, and slight explosions, like the bursting of the same bodies. Nor does it appear that any substance reached the ground which could be clearly established to be a residuum or deposit from the meteors.

18. Attempts were made to obtain at least some approximation to the number of shooting stars which appeared on this occasion. At the time when they were presented in the greatest number, an observer at Boston estimated them at about half the number of the flakes which would be presented by a dense snow-storm. When they became considerably less dense, so as to allow being distinctly observed, he counted in a vertical zone having the breadth of 36° of azimuth, 650 in fifteen minutes; but he estimated this as not above two-thirds of the total number which actually appeared in that interval, so that the total number would have been 1000, and supposing them to prevail uniformly throughout the entire hemisphere, the number exhibited every quarter of an hour would be 10,000, being at the rate of 40,000 per hour, and as the phenomenon

continued for seven hours, the total number must have greatly exceeded 280,000, inasmuch as this estimate was based on observations when the density of the stars was much less than its maximum.

It may, therefore, be inferred that on this memorable night of the 12-13th November, 1833, 300,000 masses forming part of the solar system, and foreign to the earth, passed through that part of the terrestrial atmosphere, which was visible at Boston.

19. From the apparent magnitude of many of the meteors, and their probable distance, it was conjectured that they were bodies of a very large size, although it was impossible to ascertain their magnitude with any certainty. It was supposed that they were only stopped in the atmosphere, and prevented from reaching the earth by transferring their motion to columns of air, large volumes of which they would suddenly and violently displace. It was remarked that the state of the weather, and the condition of the seasons following this meteoric shower, were just such as might have been anticipated from these disturbing circumstances of the atmospheric equilibrium. Such were the speculations to which this remarkable phenomenon gave rise.

METEOR OF THE EVENING OF SUNDAY, NOV. 13, 1803. SMALLER BALLS TINGED WITH YELLOW, ORANGE, AND PURPLE. ABOUT A SECOND AND A HALF PREVIOUS TO ITS DISAPPEARANCE IT ASSUMED THE SHAPE OF AN EGG.—*Phil. Mag.*, vol. xvii.

METEORIC STONES & SHOOTING STARS.

CHAPTER II.

1. Encke's calculation of the direction of the shooting-stars seen from 1833 to 1838.—2. Apparent magnitudes of those objects.—3. The luminous train which follows them not an optical illusion.—4. Hypotheses to explain them.—5. Heights, directions, and velocity of shooting-stars, calculated by Brandes.—6. A like calculation by Quetelet.—7. A like calculation by Wartmann.—8. Shooting-stars and fire-balls identical.—9. Lunar origin rejected.—10. Received explanation of the phenomena.—11. Difficulties and objections.—12. Description of great shower of stars witnessed in 1799 by Humboldt and Bonpland.—13. Description of like showers in 1833-40.—14. August meteors.—15. Halley suggests the use of these meteors to determine the longitude.—16. Table of shooting-stars from 763 to 1837.—17. Inferences from this.—18. Observation of Sir J. Herschel in 1836.—19. Of Wartmann in 1837.—20. Of Tharand in 1832.—21. Annual epochs of the prevalence of these meteors.—22. Why those masses are not visible like the moon and planets by the reflected light of the sun.—23. Zodiacal light.—24. The nebulous matter producing it may cause shooting-stars.—25. Shooting-stars may become satellites to the earth.—26. M. Petit claims to have discovered one.—27. Sun-stones.

1. Professor Encke made a computation founded on the whole collection of observations made on the meteors which appeared in November, 1833, in the United States, over an extent of country included between the latitudes 35° and 42°, from which he inferred that all these meteoric bodies had a common direction, and that their motion was exactly contrary to that which the earth had at the moment of their appearance. In the great showers of shooting-stars which were afterwards observed in November, 1834, 1837, and 1838, the same general parallelism of the directions of their motion was ascertained, and as before, they were observed to move from a certain point in the constellation of Leo.

A similar parallelism of direction has been observed in the showers of shooting-stars which appear at other times of the year, and it is ascertained that those which reappear in the same month have always the same direction.

On the 13th November, 1834, a like shower of shooting-stars was witnessed in North America, but much less considerable in point of numbers.

On the 13th November, 1835, a meteorite fell in France in the department De l'Ain, which set fire to a barn.

On the same night a shooting-star, larger and brighter than Jupiter, was seen at Lille. It left behind it a train of sparks like those which issue from a rocket.

2. Whatever be the origin of the phenomena of shooting-stars, it cannot fail to be interesting to learn the principal circumstances which observation has collected respecting them.

Their apparent magnitudes are very various. Sometimes they are not brighter or larger than the smallest star visible to the naked eye, and at other times they surpass in splendour the most brilliant of the planets. Sometimes the globular form can be distinctly recognised upon them, and they are not distinguishable from the meteors called fire-balls.

3. Shooting-stars seem to prevail equally in every climate and in every state of the weather. They are occasionally seen at all seasons of the year, but more frequently in summer or at the end of the autumn. They appear usually to be followed by a luminous train of intensely white light.

A question will immediately arise, whether this be a real continued physical line of light, or whether it must not rather be ascribed to the same cause which makes us see a complete circle of light when a lighted stick revolves rapidly in a circle In that case the circle of light is not real, the effect being an optical illusion. The membrane of the eye which is affected by light has been ascertained to preserve the impression made upon it for about one-tenth of a second after the cause which produced that impression has ceased to act. We, consequently, continue to see a visible object in any position for a tenth of a second after it has left that position. If a luminous object move over a certain space in one-tenth of a second, the eye will, therefore, see it at the same time in every part of that space, and consequently that space will appear one continuous line of light.

If, then, the luminous train which is visible after a shooting star, extends through a space over which the star has moved in one-tenth of a second, it is then possible that such luminous train may be illusory, being a mere optical effect of the rapid motion of the star. But if it be longer than this, or if it be visible in any one place for more than the tenth of a second after the star has moved from that place, then it cannot be explained on this principle, and must be admitted to be an actual train of light. Now it is stated by observers of these meteors that the trains are sometimes seen for several minutes. In the case of actual fire-balls, Dr. Olbers observed trains which continued visible for six or seven minutes, and Brandes in one instance estimated that fifteen minutes elapsed between the extinction of the fire-ball and the disappearance of the luminous train. Admiral Krusenstern, in a voyage round the world, saw the train of a fire-ball, which continued to shine for the space of an hour after the ball itself had disappeared, during which interval the train appeared almost stationary.

In general, the trains have the same hollow, cylindrical appearance as the tails of comets, their inner part appearing to be void of luminous matter, and a further resemblance to comets is exhibited in the curved form, which they sometimes assume.

4. Various and discordant have been the explanations offered of these luminous trains. Some have ascribed them to an oily sulphurous vapour existing in the atmosphere, which, being disposed in thin layers, and becoming inflamed, would exhibit the appearance of a brilliant spark passing rapidly from point to point. Beccaria and Vassali considered them to be lines of electrical sparks; an hypothesis, however, which has been abandoned. Lavoisier, Volta, and others explained these meteors by supposing that hydrogen gas, accumulated, by its lightness, in the higher regions of the atmosphere, was inflamed. But the general law of gases, which gives them a tendency to mingle, notwithstanding the effect of their specific gravities, puts aside this hypothesis.

5. In the year 1798, an investigation of the heights of shooting-stars was undertaken by Brandes, at Leipsig, and Benzenberg, at Dusseldorf. Having selected a base line (about

nine miles in length), they placed themselves at its extremities, on appointed nights, and observed all the shooting-stars which appeared, tracing their courses through the heavens on a celestial map, and noting the instants of their appearances and extinctions by chronometers previously compared. The difference of the paths traced on the heavens afforded data for the determination of the parallaxes, and consequently the heights and the lengths of the orbits. On six evenings, between September and November, the whole number of shooting-stars seen by both observers was 402: of these, 22 were identified as having been observed by each in such a manner that the altitude of the meteor above the ground at the instant of extinction could be computed. The least of the altitudes was about 6 English miles. Of the whole, there were 7 under 45 miles: 9 between 45 and 90; 6 above 90; and the highest was above 140 miles. There were only two observed so completely as to afford data for determining the velocity. The first gave 25 miles, and the second from 17 to 21 miles, in a second. The most remarkable result was, that one of them, certainly, was observed not to *fall* but to move in a direction away from the earth.

By these observations, a precise idea was first obtained of the altitudes, distances, and velocities, of these singular meteors. A similar but more extended plan of observation was organised by Brandes, in 1823, and carried into effect at Breslau and the neighbouring towns, by a considerable number of persons, observing at the same time on concerted nights. Between April and October, about 1800 shooting-stars were noted at the different places—out of which number 62 were found which had been observed simultaneously at more than one station, in such a manner that their respective altitudes could be determined, and 36 others of which the observations furnished data for estimating the entire orbits. Of these 98, the heights (at the time of extinction) of 4 were computed to be under 15 English miles; of 15, between 15 and 30 miles; of 22, between 30 and 45; of 33, between 45 and 70; of 13, between 70 and 90; and of 11, above 90 miles. Of these last, 2 had an altitude of about 140 miles, 1 of 220 miles, 1 of 280, and there was 1 of which the height was estimated to exceed 460 miles.

On the 36 computed orbits, in 26 instances the motion was downward, in 1 case horizontal, and in the remaining 9 more or less upward. The velocities were between 18 and 36 miles in a second. The trajectories were frequently not straight lines, but incurvated, sometimes in the horizontal and sometimes in the vertical direction, and sometimes they were of a serpentine form. The predominating direction of the motion of the meteors from north-east to south-west, contrary to that of the earth in its orbit, was very remarkable, and is important in reference to their physical theory.

6. A similar set of observations was made in Belgium, in 1834, under the direction of M. Quetelet, the results of which are published in the "Annuaire de Bruxelles for 1837." M. Quetelet was chiefly solicitous to determine the velocity of the meteors. He obtained six corresponding observations, from which this element could be deduced, and the result varied from 10 to 25 English miles in a second. The mean of the six results gave a velocity of nearly 17 miles per second, a little less than that of the earth in its orbit.

7. Another set of corresponding observations was made in Switzerland, on the 10th of August, 1838, a circumstantial account of which is given by M. Wartmann in "Quetelet's Correspondence Mathematique for July, 1839." M. Wartmann and five other observers, provided with celestial charts, stationed themselves at the observatory of Geneva, and the corresponding observations were made at Planchettes, a village about sixty miles to the north-east of that city.

In the space of seven and a half hours, the number of meteors observed by the six observers at Geneva was 381, and during five and a half hours the number observed at Planchettes by two observers, was 104. All the circumstances of the phenomena—the place of the apparition and disappearance of each meteor the time it continued visible, its brightness relatively to the fixed stars, whether accompanied with a train, &c. — were carefully noted. The trajectories described by the meteors were very different, varying from 8° to 70° of angular space. The apparent velocities also differed considerably; but the average velocity was supposed by M. Wartmann to be 25° per second. It was found, from the comparison of the simultaneous observations, that the average height above the ground was about 550 miles; and hence the relative velocity was computed to be about 240 miles in a second. But as the greater number moved in a direction opposite to that of the earth in its orbit, the relative velocity must be diminished by the earth's velocity (about 19 miles in a second); this still leaves upward of 220 miles per second for the absolute velocity of the meteor, which is more than 11 times the orbital velocity of the earth, seven and a half times that of the planet Mercury, and probably greater than that of many of the comets at their perihelion.

8. Such are the principal facts which have yet been established respecting the heights, velocities, and orbits of the shooting-stars; and it is from these, chiefly, that we are enabled to form

any probable conjectures respecting their origin. And since it is now established that no difference is observable between the larger shooting-stars and small fire-balls, both having similar altitudes and velocities, and presenting absolutely the same appearances, we may assume them to be of the same nature, and that whatever has been proved respecting fire-balls will apply equally to the larger shooting-stars. Whether the meteoric appearances to which the latter term is applied may not include objects of totally different natures, is a question admitting a doubt. It is possible that among the shooting-stars there may be objects which are merely electric sparks, or which have their origin in spontaneously-inflammable gases, known or unknown, existing in the atmosphere; but the greater part of them must be considered as identical with fire-balls.

9. The lunar hypothesis advanced by Laplace, Berzelius, and others, to explain meteoric stones, appears to be attended with serious difficulties, if, indeed, it be not altogether incompatible with the phenomena of shooting-stars. In order to enter our atmosphere with a velocity of 20 miles in a second, it may be shown that, if they come from the moon, they must have been projected from the lunar surface with a velocity of about 120,000 feet in a second, which may be regarded as almost impossible.

It thus appears that those shooting-stars and fire-balls which have the planetary velocity of from 20 to 40 miles in a second, cannot, with any probability, be regarded as having their origin in the moon. Whether any individual bodies, moving with a smaller velocity, may have a lunar origin, is a question which cannot be decisively answered. "To me," says Dr. Olbers, "it does not appear at all probable; and I regard the moon, in its present circumstances, as an extremely peaceable neighbour, which, from its want of water and atmosphere, is no longer capable of any strong explosions."

10. The hypothesis first suggested by Chladni is that which appears to have met with most favour, having been adopted by the most eminent astronomers of the present day to explain these phenomena. It consists in supposing that, independently of the great planets, there exist in the planetary regions myriads of small bodies which circulate about the sun, generally in zones, and that some of these zones intersect the ecliptic, and are, consequently, encountered by the earth in its annual revolution. The principal difficulties attending this theory are the following:—

11. First, that bodies moving in groups in the circumstances supposed, must necessarily move in the same direction, and consequently they must become visible from one point and move

toward the opposite. Now, although the observations seem to show that the predominating direction is from north-east to south-west, yet shooting-stars are observed on the same nights to emanate from all points of the heavens, and to move in all possible directions.

Secondly, their average velocity (especially as determined by Wartmann) greatly exceeds that which any body circulating about the sun can have at the distance of the earth.

Thirdly, from their appearance, and the luminous train which they generally leave behind them, and which often remains visible for several seconds, sometimes for whole minutes, and also from their being situated within the earth's shadow, and at heights far exceeding those at which the atmosphere can be supposed capable of supporting combustion, it is manifest that their light is not reflected from the sun ; they must therefore be self-luminous, which is contrary to every analogy of the solar system.

Fourthly, if masses of solid matter approached so near the earth as many of the shooting-stars do, some of them would inevitably be attracted to it ; but of the thousands of shooting-stars which have been observed, there is no authenticated instance of any one having actually reached the earth.

Fifthly, instead of the meteors being attracted to the earth, some of them are observed actually to rise upward, and to describe orbits which are convex toward the earth, a circumstance of which, on the present hypothesis, it seems difficult to give any rational explanation.

From the difficulties attending every hypothesis which has hitherto been proposed, it may be inferred how very little real knowledge has yet been obtained respecting the nature of the shooting-stars. It is certain that they appear at great altitudes above the earth, and that they move with prodigious velocity, but everything else respecting them is involved in profound mystery. From the whole of the facts, M. Wartmann thinks that the most rational conclusion we can adopt is, that the meteors probably owe their origin to the disengagement of electricity, or of some analogous matter, which takes place in the celestial regions on every occasion in which the conditions necessary for the production of the phenomena are renewed.

The presumption in favour of the cosmical origin of the shooting-stars is chiefly founded on their periodical recurrence at certain epochs of the year, and the extraordinary displays of the phenomena in various years on the nights of the 12th or 13th of November.

We shall here state the principal circumstances accompanying those of 1799, which put the notion of a *lunar* origin entirely out of the question.

12. On the morning of the 12th of November, 1799, before sunrise, Humboldt and Bonpland, then on the coast of Mexico, were witnesses to a remarkable exhibition of shooting-stars and fireballs. They filled the part of the heavens extending from due east to about 30° toward the north and south. They rose from the horizon between the east and north-east points, described arcs of unequal magnitude, and fell toward the south; some of them rose to the height of 40°, all above 25° or 30°. Many of them appeared to explode, but the larger number disappeared without emitting sparks; some had a nucleus apparently equal to Jupiter. This most remarkable spectacle was seen at the same time in Cumana, on the borders of Brazil, in French Guiana, in the channel of Bahama, on the continent of North America, in Labrador, and in Greenland; and even at Carlsruhe, Halle, and other places in Germany, many shooting-stars were seen on the same day. At Nain and Hoffenthal in Labrador, and at Neuernhut and Lichtenau in Greenland, the meteors seem to have appeared the nearest to the earth. At Nain they fell toward all points of the horizon, and some of them had a diameter which the spectators estimated at half an ell. See Humboldt's "Recueil des Voyages," &c., vol. ii.

13. A not less stupendous exhibition took place in North America on the night of the 12th of November, 1833. In 1834 similar phenomena occurred on the night of the 13th of November; but on this occasion the meteors were of a smaller size. In 1835, 1836, and 1838, shooting-stars were observed on the night of November 13th, in different parts of the world, but though diligently looked for on the same nights in 1839 and 1840, they do not appear to have been more numerous than on other nights about the same season of the year.

14. The second great meteoric epoch is the 10th of August, first pointed out by M. Quetelet, and although no displays similar to those of the November period have been witnessed on this night, there are more instances of the recurrence of the phenomena. In 1838, 1839, 1840, shooting-stars were observed in great numbers both on the 9th and 10th; but they appear in general to be unusually abundant during the first two weeks of August. The other periods which have been remarked, are the 18th of October, the 23rd or 24th of April, the 6th and 7th of December, the nights from the 15th to the 20th of June, and the 2nd of January.

15. Halley first suggested the idea that the shooting-stars

may be observed as signals for determining differences of longitude by simultaneous observations, and Maskelyne in 1783 published a paper on the subject, in which he calls the attention of astronomers to the phenomena, and distinctly points out this application. The idea was revived by Benzenberg in 1802, but so long as they were regarded merely as casual phenomena, it could scarcely be hoped that they would be of much use in this respect to practical astronomy. As soon, however, as their periodicity became probable, the phenomena acquired a new interest, and some recent attempts to determine longitudes in this manner have proved that the method is not to be disregarded.

The probability of the conjecture that the causes of the meteoric phenomena observed in the months of August and November is to be found in the fact that the particular regions of the solar system through which the earth passes at these seasons, are the seats of an unusual quantity of the matter composing these meteors, must in a great degree depend on the extent to which it can be proved by observation that such meteors do really prevail at each of those periods of the year.

16. With a view of testing this, we have collected together, from various sources, the dates of the most remarkable atmospheric appearances of this class from the eighth century to the present time. In the table in the following page, the day of the month when it has been recorded, is placed in the column under the month, and in the line with the year of the occurrence. Where an asterisk occurs under the month, the particular night has not been recorded, but the appearance has merely been mentioned as having occurred.

17. There are here recorded fifty-two nights on which these appearances prevail to such a degree as to attract particular notice. Of these, twenty-six occurred between the 8th and 15th of August, and thirteen the 6th and 19th of November. Thus three-fourths of the nights recorded correspond to the epochs to which we have referred.

Some disappointment was produced in 1837, by the circumstance of an unusually small number being seen on the night between the 12th and 13th, arising from an erroneous impression that that was the night on which their periodical return should be expected. It will be seen, however, from the preceding table, that these appearances have not at all been confined to the night of the 12th; but independently of this, the night of the 12th at Paris was so bright, that stars of the second magnitude were not visible, and consequently meteors—even supposing them to have existed of similar or of inferior brightness—could not have been observed. It should also be considered, that their non-appearance at any particular place is no proof of their non-existence in our atmosphere. They may be produced during the day, or they may be produced in a part of the atmosphere not visible from the place in question. Thus, in 1833, when they were a general object of terror to the people of America, they attracted but little attention in Europe. On the other hand, they sometimes appear contemporaneously in the atmosphere on opposite sides

Years.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
763	..	..	*									
902	..	..	..	..	..	..	..	..	..	*		
1029	..	..	..	..	..	..	..	*				
1092	..	..	..	25								
1202	..	..	..	..	..	..	..	..	..	19		
1741	..	..	..	..	..	..	..	..	..	..	..	25
1777	..	..	..	..	..	17						
1779	..	..	..	..	..	..	..	9				
1781	..	..	..	..	..	..	..	8				
1784	..	..	..	..	..	..	27	9				
1785	..	..	..	..	..	..	27					
1798	..	..	..	..	..	..	..	..	..	..	..	7
1799	..	..	..	..	..	..	..	9	..	..	11	
1803	..	..	..	22								
1805	..	..	..	..	..	..	..	..	..	23		
1806	..	..	..	..	..	..	..	10				
1811	..	..	18	..	..	..	..	10				
1812	..	..	..	..	..	..	..	..	..	..	?	
1813	..	..	..	..	..	..	..	11	..	..	8	
1815	..	..	..	..	..	..	..	10				
1818	..	..	..	..	..	..	..	14	..	..	19	
1819	..	..	..	..	..	..	..	6				
1819	..	..	..	..	..	..	..	13				
1820	..	..	..	..	..	..	..	9	2	..	12	
1822	..	..	..	..	..	..	..	..	10	..	12	
1823	..	..	..	..	..	..	..	15				
—	..	..	..	..	..	..	..	10				
1824	..	..	..	..	..	..	..	14				
1826	..	..	..	..	..	..	..	14	..	..	6	
—	..	..	..	..	..	..	..	10				
1827	..	..	..	..	..	..	..	14				
1828	..	..	..	..	..	..	..	10				
1829	..	..	..	..	..	..	..	14				
1830	..	..	..	..	..	..	..	..	..	..	12	
1831	..	..	..	..	..	..	..	..	..	..	13	
1832	..	..	..	..	..	..	..	..	..	..	13	
1833	..	..	..	..	..	..	..	10	..	..	13	
1834	..	..	..	..	..	..	..	10	..	..	13	
1835	..	..	..	..	..	..	..	10	..	..	13	
1836	..	..	..	..	..	..	..	8	..	..	13	
—	..	..	..	..	..	..	..	10				
1837	..	..	..	..	..	..	..	10				

of the globe. In 1837, they were observed from the French ship *Bonite*, on the other side of the globe, while on the same day in Europe a vast number appeared.

18. On the night of the 12th of November, 1836, Sir. John Herschel observed these phenomena at the Cape of Good Hope. Their number was not very considerable, but their motion had a

marked regularity; they appeared to diverge from a centre or focus, which preserved a fixed position with respect to the horizon, but had no such fixed relation to the objects on the firmament. This point, or centre, to which their common directions converged, was a point of about thirty degrees above the horizon, and sixty degrees west of north.

19. On the night of the 9th of August, 1837, M. Wartmann observed these phenomena at Geneva; between nine o'clock, P.M., and midnight, eighty-two were seen in different parts of the heavens. They were most frequent about ten o'clock, and then appeared to emanate from a centre or focus situated between the star *B*, in the constellation of Bootes, and the star *A*, in the constellation of the Dragon. At a quarter past ten, twenty-seven were seen, and were remarkable for their bright bluish light. Other observers in the same neighbourhood, and on the same night, counted one hundred and forty-nine in one part of the heavens, between a quarter before nine and half-past eleven o'clock.

Of these hundred and forty-nine meteors, three had the appearance of round disks, or globes, of a ruddy red colour, measuring from four to five minutes in diameter, being about one-sixth part of the moon's diameter. Twenty-six were more brilliant than the planet Venus, and of resplendent whiteness; the remainder had the appearance of stars from the first to the third magnitude, their colours varying between blue, yellow, and orange.

20. On the night of the 11th of November, 1832, M. Tharand, a retired officer at Limoges, stated that workmen who were employed in laying the foundation of the bridge over the river Vienne, observed the firmament brilliant with meteors, which at first only amused them, but after some hours the number and splendour of these luminous appearances were so greatly augmented, that the people were seized with panics, and so great was their terror, that they abandoned their labour, and flew to their families, exclaiming that the end of the world had arrived. On the next day these people were interrogated on the subject, and their accounts varied according to the different impressions which had been produced on their imaginations. Some declared that they saw streams of blue fire; others that they beheld bars of red iron crossing each other in all directions; others, that they beheld an immense quantity of flying rockets. All agreed that the phenomena were diffused over every part of the firmament; that they commenced at eleven o'clock, and continued till four the next morning.

21. There appears some reason for supposing that November and August are not the only times of the annual recurrence of these

meteors. Arago has suggested the probability of their periodical recurrence between the 22nd and 25th April. Humboldt thinks that other annual periods may be assigned—to the 6-12th December, and Capocci has assigned the 17th July, and the 27-29th November as the dates also of their probable periodic occurrence.

On the night of the 6th December, Brandt observed and counted 2000 shooting-stars; and on the 11th December, 1836, according to Humboldt, an immense fall of aërolites took place in Brazil, near the village of Macao, on the banks of the river Assu.

In the interval between 1809 and 1839, Capocci shows that twelve falls of aërolites took place between the 27th and 29th November, besides others on the 13th November, 10th August, and 17th July.

On the whole, the following appear to be the dates at which the recurrence of these meteors may be looked for:—

22-25th April.
17th July.
10th August.
12-14th November.
27-29th November.
6-12th December.

From all this it must be inferred that those parts of its annual orbit through which the earth passes at these dates severally, are intersected by the orbits of those groups of bodies, which, when passing near the earth, present the appearance of shooting-stars, or aërolites.

22. From all that has been stated it may be considered then as demonstrated with the highest degree of probability, if not with moral certainty, that the phenomena called shooting-stars, fire-balls, and meteoric stones are identical; that these latter bodies belong not to the earth, but are masses of matter moving like the planets in the celestial spaces, subject to the gravitating attraction of the sun; that the earth encounters them occasionally, either striking directly upon them, or approaching so close to them that they are drawn by the terrestrial attraction, first within the atmosphere, and afterwards to the surface; that the shooting-stars, which rush athwart the heavens without falling on the earth, are the same class of bodies which do not either directly strike the earth or come so close to it as to be drawn to its surface by its attraction.

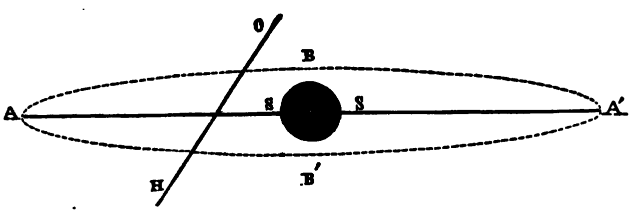
Since it is supposed that these bodies become visible only after they enter the atmosphere, being there rendered luminous by the heat which they develop by the sudden and violent compression of that fluid, it is probable that they may be passing around us in countless numbers, outside the atmosphere, without the possibility of being seen or observed. It may be objected that they would be illuminated by the sun's light, as the moon and planets are, and must thus be rendered visible. Their extreme minuteness, however, affords a satisfactory explanation why they are not visible by the light which they reflect. Compared with the planets, as Sir J. Herschel observes, which are visible in our most powerful telescopes, rocks and stony masses of great magnitude and weight would be but as the impalpable dust which a sunbeam renders visible as a sheet of light, when streaming through a narrow chink into a dark chamber. It has nevertheless been affirmed that occasions have been recorded on which the sun's light, at noon-day and in an unclouded sky, has become sensibly obscured during certain intervals of time, which has been explained by the supposition that at such times a flight of meteoric stones were passing between the sun and the earth, so as partially to intercept the sun's light.

A stony mass which would weigh an hundred tons, however strongly illuminated by the sun's light, would not be visible at the distance of eight hundred or a thousand miles.

23. Sir John Herschel supposes it probable that the sun is surrounded by a mass of nebulous matter of greater or less extent, such as is seen around many of the stars, and that the phenomenon called the zodiacal light, as well as meteoric stones and shooting-stars, are mere manifestations of this nebulous matter.

The zodiacal light is explained by the supposition of an oval spheroid of nebulous matter surrounding the sun, the larger diameter of which coincides with the solar equator.

In fig. 2, S S represents the sun's equator, and A B A′ B′ the



oval mass of surrounding nebulous matter shown by its section made by a plane through the axis of the sun, the section by a plane through the sun's equator being a circle whose diameter is A A′.

The semi-diameter C A of this lenticular mass is nearly equal to that of the earth's orbit, so that at certain times the earth grazes its edges at A and A′, and probably may pass through a portion of the nebulous matter.

24. If this matter consist to any extent of solid masses of small dimensions, they may pass through the earth's atmosphere, on these occasions producing the phenomena of shooting-stars, or they may strike the surface or be drawn down upon it by terrestrial gravitation, and produce the phenomena of meteoric stones.

The appearance of the zodiacal light is easily explained. Let H O represent the line in which the plane of the horizon intersects the lenticular nebula after sunset. In that case, O A′ H will be below, and O A H above the horizon. The matter composing O A H being illuminated by the sun will, so far as it may have reflective power, be visible. In fact it is seen in certain positions of the earth in relation to the sun. It presents the appearance of a faint and ill-defined comet, and is usually seen soon after sunset about the months of March, April, and May, and before sunrise about the months of September, October, and November. It appears as a luminous cone extending from the horizon obliquely upwards as has been already stated in the direction of the solar equator, and therefore nearly in that of the ecliptic, or the zodiac, and hence has been called "zodiacal light." The semi-diameter A C subtends an angle at the earth, which varies with the position of the earth from 40° to 90°. In some cases, therefore, the vertex A is near the zenith, when the sun is below the horizon. The breadth B B′, of the base of the sun subtends an angle which varies from 8° to 30°.

The zodiacal light is very faint and ill-defined when seen in the higher latitudes, but is much brighter and clearer within the tropics.

The matter composing this nebulous envelope of the sun may, according to Sir J. Herschel, be conjectured to be no other than the denser part of that medium, which, we have some reason to believe, resists the motion of the comets, loaded perhaps with the actual materials of the tails of millions of those bodies, of which they have been stripped in their successive visits to the sun. An atmosphere of the sun the zodiacal light cannot be, in any proper sense of that term, since the existence of a gaseous envelope propagating pressure from part to part, subject to mutual friction in its strata, and therefore rotating in the same or nearly the same time with the central body, and of such dimensions, and ellipticity, is utterly incompatible with dynamical laws. If its particles have inertia they must necessarily stand, with respect to the sun, in the relation of separate and independent minute planets, each having its own orbit, place of motion, and periodic time. The total mass being almost nothing compared with that of the sun, mutual perturbations are impossible, though collisions between such as may cross each other's paths, may operate in the course of indefinite ages to effect a subsidence of at least some fraction of it into the body of the sun or those of the planets.*

25. There are certain supposable circumstances under which the earth might pass near to one of these masses, the consequence of which would be that it would become a satellite of the earth, and would accompany it as the moon does in its course round the sun, and would, if it were large enough, be visible by reflected light like the moon. But since, so far as is yet known, these bodies are far too small to be seen thus at any distance, at which they could possibly revolve without being speedily arrested by the resistance of the atmosphere, and brought down to the surface by terrestrial gravitation, it follows that the earth may actually be attended by hundreds of such invisible moons. Sir J. Herschel is even of opinion that these not only exist, but that some of them may be so large, and of such texture and solidity, as to shine by reflected light, and become visible (such at least as are very near to the earth) for a brief moment, suffering extinction by plunging into the earth's shadow, in other words undergoing total eclipse.† Sir John Lubbock is of opinion that such is the case, and has supplied rules and mathematical formulæ for calculating their distances from observations of this kind.‡

26. M. Petit, Director of the Observatory of Toulouse, has made observations and calculations of this kind, which induces him to conclude that there is at least one meteoric stone of considerable magnitude, which is attached as a satellite to the earth. Its orbit is at about 5,000 miles from the surface, and therefore 9,000 miles from the centre, or about twenty-six times nearer than the moon. It makes a complete revolution in three hours and twenty minutes, and therefore revolves round the earth about seven times per day. §

27. In enumerating the hypotheses which have been proposed to explain the phenomena of aërolites, we have omitted to notice one, which, if for no other reason, may be regarded as entitled at least to be mentioned on account of its antiquity. As the

* Herschel's Astron., p. 616. † Ibid., p. 521.
‡ Phil. Mag., 1848, p. 80.
§ Comptes rendus, Acad. Sc., Oct. 12th, 1846, and Aug. 9th, 1847.

supposed lunar origin of these bodies gave them the name of "MOON-STONES," the hypothesis we refer to conferred upon them that of "SUN-STONES." Diogenes Laertius records an opinion which prevailed in Greece, that the meteoric mass of Ægos potamos fell from the sun! Pliny, deriding the supposition, charges Anaxagoras with having predicted the fall of aërolites from the sun. Humboldt suggests the probability that the fall of aërolites during bright sunshine, and when the moon was not visible, may have led to the idea and name of sun-stones.

RAILWAY ACCIDENTS.

CHAPTER I.

1 All travelling attended with danger.—2. Awful disasters incidental to railway travelling.—3. Is railway travelling, however, really more dangerous?—4. Not practically so considered.—5. The real amount of danger may be calculated.—6. Utility of such a calculation.—7. Imperfections of official reports.—8. Necessary to compare accidents with total amount of travelling.—9. Example illustrating this.—10. Necessary data given in official reports.—11. Reports of 1847-8 and 1850-1.—12. Total mileage of passengers in these intervals.—13. Computation of the risk to life and limb in a journey of given length.—14. Tabular statement.—15. Analysis of its results.—16. Classification of accidents in relation to their causes.—17. The greatest disasters arise from imprudence.—18. Accidents to railway servants.—19. No progress observable in railway safety.—20. Accidents on foreign railways—Risk on Belgian lines.—21. Accidents on French railways.—22. Contrasted with accidents by stage coaches in and near Paris.—23. Frequent departures, great expedition, and numerous stoppages create danger of collision.—24. Liability to collision with express trains.—25. Accidents by escaping rails.—26. Neglect of points and switches.—27. Analytical table of proportion of causes of accident in 100 cases.—28. Number of brakes.—29. Greater number of brakes necessary with fast trains.—30. Danger of bringing trains to rest too suddenly.—31. Danger of reversing action of engine.—32. Fog signals.—33. Consequences of collision aggravated by manner of connecting vehicles.—34. Derailment of carriages.

1. WHATEVER may be the agency by which personal locomotion is produced, it has always been attended with more or less danger to life and limb. If one age or country be compared

with another, the result will only amount to a difference in the degree of the danger, or in the gravity of the catastrophe produced by an accident. So universal and so ancient is this danger, that in the form of prayer ordained by the Church, travellers by land and water are included among the classes more especially and emphatically entitled to the supplications of the people.

2. The progress of civilisation, the development of commerce, the increase of population, and the discoveries of science, have stimulated and increased personal locomotion on an immense scale. The risk attendant upon it, and the character of the danger incident to it, have varied with every change in the physical or mechanical expedients by which this locomotion has been effected. The spectacle exhibited on the occasion of some great railway collisions would have been deemed by our forefathers too extravagant even to be allowed a place in the wildest fictions. Colossal vehicles, weighing several tons, shivered to pieces; rods of iron, thick and strong enough to sustain a vast building, bent, twisted, and doubled up as though they were rods of wax; massive bars of metal snapped and broken like glass; bodies of the killed dispersed here and there, amongst the wrecks of vehicles and machinery, so mangled as to render identification impossible—limbs, and even heads, severed from the trunks, and scattered right and left, so as to render it impossible to re-combine the *disjecta membra* of the same body—the countenances of the dead, where countenances remain at all, having a ghastly expression of the mingled astonishment and horror with which the sufferer was filled in the brief instants which elapsed between the catastrophe and death; the survivors, maimed and wounded, lying under the ponderous ruins, groaning in agony and supplicating for relief and extrication! These are incidents with which the vast improvements introduced by science into the art of locomotion have unhappily rendered us familiar, and which assuredly have had no parallel in the days of waggons and stage-coaches, to say nothing of those of pack-horses and saddle-bags.

3. Are we thence to infer that the great mechanical inventions which have signalised this age of ours, are attended with the serious drawback of exposing us to greater risk and more terrible dangers than any which were known in less advanced and enlightened times? Is the traveller at fifty miles an hour by steam, on railway, in the nineteenth century, really exposed to greater risks, and does he really need the prayers of the Church more urgently than the wayfarer of the beginning of the eighteenth? That disasters do occasionally occur, which were

never known in former times, is undeniable; but that the risk to life and limb has been augmented, is a conclusion which we should only be justified in assuming after a much more rigorous examination of the question.

4. Meanwhile, it may be observed that, notwithstanding the degree to which imaginations may be excited, and fears aroused by such recitals as we have described, still the public instinct, independent of any rigorous statistical analysis of the point, has resisted all exaggerated estimate of the danger, and it is incontestable that travelling over land was formerly regarded with greater apprehension of danger than at present. A century has not elapsed since no prudent person would start upon a journey, say from Exeter to London, without a solemn farewell of his kindred and the deposition of his last will and testament in trustworthy hands.

5. To prevent exaggerated apprehensions of danger, and reduce the fears of the timid within reasonable limits, it will only be necessary to investigate the actual extent of the danger, by comparing the number of casualties with the number of persons who travel, taking into account the distances over which they are transported. By this means the real risk of life and limb incurred by a railway traveller can be determined with as much arithmetical precision as that with which the average duration of life is computed from the tabular reports of births and deaths; and we know that the latter has been determined with all the exactitude and certainty necessary to render it the basis of the operations of commercial institutions for life insurance, involving many millions of capital.

6. To do justice at once to the public who are the victims of these casualties, and to the railway administration to whose negligence and mismanagement they are generally ascribed, it will be only necessary to ascertain the causes which in each case have produced them. So far as they may prove to arise from the imperfections which are incidental even to the most efficient and best constructed machinery, they must be submitted to as inevitable. Happily, however, the proportion of casualties which admit only of this explanation, is infinitesimally minute. So far as they shall appear to arise from maladministration, as from overcrowding the lines with traffic, overloading the engines, or what is the same, providing an insufficient stock of locomotive power, or from the negligence or insufficiency of the railway servants, the executive bodies of the railway companies must be held accountable, and the prevailing character of the accidents will indicate the direction in which administrative reform may be required. So far, in fine, as they may appear to arise from

imprudence or want of due care and precaution on the part of the traveller himself,—a case of frequent occurrence,—the railway managers and the railway machinery must stand acquitted, and the character of the casualty will indicate the nature of the precautions which are necessary on the part of passengers, to guarantee them from its recurrence.

7. To estimate the chances of accident fatal to life or limb, it is not enough to compare the number of passengers killed or injured with the total number booked at the stations. This is an error which is very apparent, yet it has been committed year after year without correction by the government railway commissioners in their reports. Such an estimate is based upon the implied assumption that all passengers run the same risk, whatever be the distances they travel. Thus, a passenger booked from London to Aberdeen is assumed to incur no more risk than one who travels from London to Greenwich.

It is evident, on the contrary, that the risk incurred, other circumstances being alike, is in the exact proportion of the distance travelled. A passenger who travels an hundred miles is exposed to ten times as much risk of accident as one who travels only ten miles. The premium upon insurance against railway accident should obviously be a *mileage*.

8. To ascertain the extent of the danger incurred in travelling on any proposed system of railways, it would, therefore, be necessary to compare the number of accidents which take place in any given time, a year, for example, with the total *mileage* of the passengers in the same interval. This *mileage* may always be determined with great precision. It is the sum total of the distances travelled by all the passengers booked in that interval. Now, since the fares paid by the passengers of each class bear a fixed average proportion to the distances to which they travel, their total *mileage* will be found with all the necessary exactitude by dividing the gross receipts arising from each class by the average fare per mile.

9. To render this method of investigation more clear, let us suppose, that in a given time the quantity of passenger traffic which has taken place on a given system of railways, is represented by an hundred millions of miles, that is to say, that all the distances travelled by all the passengers booked, when summed up, will make an hundred millions of miles. This would then be the same as if a million of passengers were transported over a distance of an hundred miles.

Now, let us suppose that in the same interval ten passengers were killed, and an hundred wounded by accidents occurring in their transport. It would then follow, that of a million of passengers travelling an hundred miles ten would be killed and an hundred wounded. The risk of life in such a journey would, therefore, be 1 to 100,000, and the risk of personal injury, not causing death, would be 1 to 10,000. That is to say, when a traveller undertakes a railway trip of an hundred miles on that system of railways, the chances against his being killed are 100,000 to 1, and the chances against his being injured, without loss of life, are 10,000 to 1.*

10. The official returns, published annually by the Board of Trade, supply all the data which are necessary to ascertain the actual amount of danger incurred in railway travelling in the United Kingdom. We propose, in the present tract, to apply to the data thus supplied the principles of calculation explained above, so as to ascertain what is, under the existing system of railway management, the actual risk to life and limb incurred by a railway traveller.

By applying the same calculation to different intervals, we shall see whether the disasters which have from time to time been reported, have caused such improved management as to diminish the risk in any sensible degree.

11. The following is the classified summary of the accidents reported as having taken place on the railways of the United Kingdom in 1847-8:—

Analysis of the Railway Accidents for the Two Years ending December 31, 1848.

	Killed.	Injured
Passengers suffering from causes beyond their own control	28	215
Passengers suffering from causes which they might have prevented	23	13
Railway servants suffering from causes beyond their own control	30	57
Railway servants suffering from causes which they might have prevented	232	85
Trespassers and strangers suffering from crossing or standing on the railway	96	22
Persons suffering from misconduct of railway servants .	2	1
Suicides	2	0
	413	393

* More exactly the chances would be 99,999 to 1 in the former case, and 9,999 to 1 in the latter. We have preferred the round numbers as being more simple, and sufficiently exact for all practical purposes.

It is easy to see how from these data the risks attending other distances would be calculated, since the risk would vary in the exact ratio of the

The following is a like summary for 1850-1 :—

Analysis of Railway Accidents for the Two Years ending December 31, 1851.

	Killed.	Injured.
Passengers suffering from causes beyond their own control	31	526
Passengers suffering from causes which they might have prevented	37	32
Railway servants suffering from causes beyond their own control	129	69
Railway servants suffering from causes which they might have prevented	116	42
Trespassers or strangers suffering from crossing or standing on the railway	113	24
Persons suffering from misconduct of railway servants .	0	0
Suicides	8	0
	434	693

12. To deduce from these reports any certain conclusions, either as to the danger incurred by the railway traveller or the efficiency of the railway management, it will be necessary to ascertain in each case the total *mileage* of the passengers transported, and to compare with this *mileage* the accidents.

By means of the returns of the passenger traffic, compared with the average fares in proportion to distance, it appears that the total *mileage* of the passengers of all classes in each of the intervals to which the above returns refer, was as follows :—

	Mileage of Passengers.
In two years ending 31st Dec., 1848 . .	1830,184617
In two years ending 31st Dec., 1851 . .	2282,752756

The meaning of these numbers is, that the total movement of passengers on the railways was the same as if 1830,184617 had been carried one mile in 1847-8, and 2282,752756 had been carried one mile in 1850-1.

By comparing the number of killed and wounded with these numbers, it will be easy to determine the number of persons of each class which were killed and wounded in the transport of a given number of passengers over a given length of railway.

13. Let it be required, for example, to determine the numbers

distances travelled. Thus, if the risk in travelling 100 miles be 100,000 to 1, the risk in travelling 200 miles will be 100,000 to 2, or 50,000 to 1, and the risk in travelling 50 miles will be 100,000 to ½, or 200,000 to 1, and so on.

of each class of persons who were killed and injured in the transport of a million of passengers over an hundred miles of railway, in each of the intervals of two years to which the preceding returns refer.

This is effected by a simple proportion, and is, in fact, nothing more than a question in the rule of three. As the total *mileage* divided by an hundred is to the number of accidents reported, so is a million to the number of accidents produced in the transport of a million of passengers an hundred miles.

The following are the results of such a calculation :—

14. *Table showing the mean numbers and classes of persons killed and injured in the transport of a million of passengers over an hundred miles on the Railways of the United Kingdom.*

	1847-8.				1850-1.			
	Killed.		Injured.		Killed.		Injured.	
Passengers from causes beyond their control .	1·53	...	11·75	...	1·36	...	23·04	...
Passengers from causes within their control .	1·26	...	0·71	...	1·62	...	1·40	...
Total . .	...	2·79	...	12·46	...	2·98	...	24·44
Railway servants from causes beyond their control . . .	1·64	...	3·11	...	5·65	...	3·02	...
Railway servants from causes within their control . . .	12·68	...	4·64	...	5·08	...	1·84	...
Total .	...	14·32	...	7·75	...	10·73	...	4·86
Trespassers & strangers	5·25	5·25	1·20	1·20	4·95	4·95	1·04	1·05
Grand total . .		23·36	...	21·41	...	18·66	...	30·35

15. The numerical results consigned to this small table, when clearly comprehended, are full of interest and importance ; of interest and importance not merely to the travelling public who are exposed to these dangers, but to the railway directors, as indicating the real proportion which such disasters bear to the total amount of personal locomotion, and to the government authorities whose duty it is to see that the greatest practicable precautions are adopted for the public safety.

For the benefit of those who are less accustomed to deal with such arithmetical results, we shall here examine some of the consequences deducible from this table.

It appears that in 1850-1, 2·98, or very nearly three passengers in every million who travelled one hundred miles were killed.

The chances therefore of safety for life in the case of any individual traveller were 1,000,000 to 3, or 333,333 to 1.

In like manner, 24·44 in every million were wounded, maimed, or more or less injured. The chances against personal injury in the case of each individual were therefore 1,000,000 to 24·44, or very nearly 40,000 to 1.

Notwithstanding the gravity of some of the accidents which are recorded, it must therefore be acknowledged that there is no very great amount of danger in railway travelling.

16. The classification of accidents to passengers into such as arise from causes beyond their control, and which proceed from their own imprudence and want of due caution, merits especial attention. It appears that in 1850-1, more than half the accidents fatal to life belonged to this class. But the most remarkable feature of these accidents is the immense proportion of the entire number which are fatal. Of the accidents which arise from causes beyond the control of the passenger, only 1 in 18 results in loss of life, while more than the half of those arising from imprudence are fatal.

17. These remarkable proportions are equally manifested in 1847-8, and 1850-1, and as we have found them also to prevail in other periods, they may be regarded as a fixed *law* of personal locomotion by railway.

The railway traveller will therefore do well to remember that small as is the amount of risk he incurs, one-half of it depends on his own incaution, and may be altogether eliminated by his own prudence and vigilance, and further that the part of the risk which arises from his imprudence is for the most part the *risk of his life*, and not merely the risk of personal injury.

18. It appears further that the transport of a million of passengers 100 miles, costs the lives of eleven railway servants and five strangers who chance to be on the road, and produces more or less bodily injury to five of the former and one of the latter class.

In the gravity of the accidents from which these latter classes suffer, nothing is more remarkable than the large proportion of them which are fatal to life, and which arise from imprudence on the part of the sufferer.

Thus, of fifteen railway servants who incurred accidents, eleven were killed, one-half of whom suffered through their own want of due caution.

Of six strangers and trespassers who suffered from accidents, five were killed.

19. In fine, it appears from the table that in 1847-8, the transport of a million of passengers 100 miles, cost the lives of

23 and the injury of 22 persons of all classes, and that the same amount of passenger traffic in 1850-1, cost the lives of 19 and the injury of 30 persons. The total number of sufferers being 45 in the former and 49 in the latter period.

So far therefore as the aggregate of the sufferers from accidents can be taken as exponents of the efficiency of railway management, no very sensible improvement seems to have taken place in the five years over which these reports extend.

20. On the foreign railways it might be expected that the prevalence of accidents would be less, owing to the less crowded state of the lines. On the Belgian railways, during the three years ending 1st December, 1846, there were but three passengers killed by causes beyond their control. The total mileage of the passengers was 239,629541, from which it follows that in the transport of a million of passengers an hundred miles, the number of passengers killed by causes beyond their control, was 1·25, being very little less than on the English railways.

21. On the French railways, accidents have been still more rare. One fatal accident occurred many years ago on the Paris and Versailles Railway, on which occasion a train took fire, and appalling consequences followed. Another serious accident occurred on the Fampoux embankment of the Northern Railway in 1846. These however stand almost alone.

In the two years ending 31st December, 1848, there was not a single fatal accident to a passenger reported on any French railway.

22. It may not be uninteresting to put in juxtaposition with this the returns of accidents produced by ordinary horse-coaches travelling in Paris and its environs :—

Year.	Killed.	Wounded.
1834	4	134
1835	12	214
1836	5	220
1837	11	361
1839	19	366
1839	9	384
1840	14	394
Total	74	2073

23. However insignificant may be the proportion of the number of persons injured to the total amount of passenger traffic, it may not be without interest or utility to inquire into the causes which produced these accidents.

The causes which are not dependent on the imprudence of the sufferers are, generally, either collision of the passenger train with some other carriages or waggons, or the escape of the train, or some part of it, from the rails.

The English railways are in general constructed with double lines, the train observing the common rule of the road, and keeping always on the left-hand line. The consequence of this is, that, in regular work, all trains upon the same line move in the same direction. The collision of one train with another, therefore, can only take place by a faster train overtaking a slower, or a train running into one which is at rest.

It is evident, therefore, that, if all trains moved with the same speed, and all stopped at the same stations, no collisions could ever happen, except when a train should be retarded or stopped by accident, or in the case of a vehicle being improperly left standing on the line.

The probabilities of collision will therefore depend on the differences between the speed with which the several trains travel, and the differences between the number of stations at which they stop.

But, on railways as worked at present, it is impracticable to maintain uniformity of speed. Passenger and goods traffic being necessarily worked on the same lines of rails, and the latter being carried at less speed than the former, a source of danger is produced. If the present enormous amount of transport had been foreseen when railways were in an early stage of their progress, it might have been a question for consideration whether it would not have been advantageous to construct the trunk railways with three lines of rails, reserving one line exclusively for the goods traffic. This would have been infinitely more politic than augmenting the capacity of the railway by increasing the width of the rails, and, consequently, the magnitude and weight of the engines and vehicles of transport. But the railways being constructed, it is now too late, and nothing remains to be done but to adopt the most efficient precautions against those collisions, the probability of which is augmented with the frequency of the trains, and the differences of their average speed.

24. The accommodation of the public requires frequent departures, great expedition, and means of arriving at numerous intermediate points of lines. These demands cannot be satisfied without calling into existence all the conditions which are productive of the danger of collision.

To satisfy the urgent call for great expedition, express trains are despatched at extraordinary speed, stopping only at chief stations. To satisfy the want of intercommunication with the intermediate stations, trains are despatched which stop at all the stations; and as the stations, on the average, are not four miles asunder, these trains must be almost continually in a state either of retarded or accelerated motion. They scarcely get up their speed after starting from one station, before they are obliged to slacken their pace, in order to stop at the next. The average speed of such trains is therefore comparatively small.

Between these and the express trains, which present the extremes of speed, there are several which move at intermediate average rates, stopping less frequently than the one, and more so than the other, and, when at full speed, proceeding with a less velocity than the express trains.

When all these circumstances are taken into account, and when it is also considered that, on some of the great trunk lines, such as the North-Western, as many as fifty trains pass over the same rails every twenty-four hours, much more than the half of which are worked during the day, and therefore succeed each other at very short intervals, the wonder is, not that collisions occasionally occur, but that a movement so crowded and complicated can be conducted at all, without most imminent danger.

The most frequent source of accidents from collision, arises from single waggons or trucks being left standing upon the rails.

When express trains have to be stopped, the steam must be cut off, and the brakes applied at a considerable distance from the place where they come to rest. Hence arises the greater liability of accidents by collision with these trains. If an obstacle is observed upon the railway by the engine-driver, it must be noticed at a distance so great as to render it possible to stop the train, otherwise collision must take place.

One railway accident is often the cause of another, and collisions frequently arise in this way. When an accident occurs to a train, by which it, or part of it, is detained upon the line for any length of time at a place where, in the regular course of the railway traffic, it ought not to be found, trains following on the same line of rails, not expecting to encounter such an obstacle, are liable to a collision with it. In all such cases, the guards or conductors run back upon the line, and if the accident take place at night, make signals with their lamps to warn the approaching train of the obstacle.

In certain classes of accident, both lines are obstructed, and such precautions must be taken in both directions—as, for example, when a train or part of it running off the rails, the engine, carriages, or waggons are thrown some on one line of rails and some on the other. In this case, one messenger is sent along the *up* and another along the *down* line to warn approaching trains to stop.

25. Next in frequency to accidents from collision, are those which arise from the engine or the vehicles escaping from the rails. The causes which produce this class of accidents are very various.

The most frequent are impediments left on the rails, such as blocks of wood, bars of iron, spare sleepers or rails. The engine encountering obstacles of this kind is generally thrown off, dragging with it one or more of the carriages.

Cattle from adjacent fields, through deficient fences, have sometimes got upon the road, and the engine encountering them has run over them, and been thrown off.

A wheel or axle of the engine, tender, or any of the carriages breaking, is sometimes the cause of escape from the rails. A defect in the rails themselves is not unfrequently the cause of this class of accidents. This is especially liable to occur at a ioint chair, that is to say, a chair where the ends of two successive rails are united. It frequently happens that one of these rails is considerably above or below the other, or that the rails are not sufficiently fastened in the chair. The impact of the wheel of the engine on such a defective joint may either immediately break the rail, or so weaken it that one of the succeeding carriage-wheels will break it, and the carriages thus escape from the rails.

26. Another not unfrequent cause of accidents is the neglect of the points and switches, a name given to a part of the mechanism by which trains are enabled to pass from one line of rails to another, or from either line into the sidings.

When such passage is intended, a certain change is made in the position of the points and switches by a person employed for this purpose on the line, and after the train passes from the line the switches are restored to their usual position. If any neglect take place in this operation, considerable danger will ensue to the trains which next pass.

27. In order to ascertain the proportion in which these causes of accident respectively operate, we have taken indiscriminately, from the returns of accidents, 100 cases, of which the following is the analysis :—

Accidents from	collision	56
,,	broken wheel or axle	18
,,	defective rail	14
,,	by switches	5
,,	impediments lying on road	3
,,	off rails by cattle on line	3
,,	bursting boiler	1
		100

Hence it appears that 56 per cent. of these accidents arise from collision. Next to these comes the escape from the rails by the breaking of a wheel or axle, or by defective rails, which together make up 32 per cent., the remaining causes operating in small proportions.

Since more than half the total number of fatal accidents which occur upon railways arise from collision, it is important that the attention of railway companies be more specially directed to precautions against this source of danger.

Before a collision takes place, the engine-driver and others in management of the following train have, or ought to have, the means of observing the object in advance of them, with which the collision is about to take place. If it be possible to bring the train to rest before it can pass over the length of road between the point where the obstacle has been observed, and the point where such obstacle would be overtaken, the collision will be prevented. This possibility will depend upon the proportion which the number of brakes and brakesmen upon the train bears to its weight and speed. It is clear, therefore, that in all cases the number of brakes provided should have reference to the magnitude and speed of the train.

It is found by experience that the distance within which a train of given weight can be brought to rest by a given number of brakes, will be in proportion to the square of its speed, that is to say, with a double speed it will require four times the number of brakes; with a treble speed, nine times the number of brakes; and so on.

In the case of an accident which occurred near Wolverton on the 5th of June, 1847, it was found impossible to bring a train of 19 carriages to rest within a distance of 540 yards, the speed of the train being about 25 miles an hour. In this case a collision took place by which seven persons were killed: on an inquiry it was found that this train was provided with three brakes, one upon the tender and two upon the carriages.

28. Inquiries suggested by this and other similar accidents, induced the Board of Trade to propose a rule to be observed by railway companies, that a brake should be attached to every fourth carriage.

A similar rule was imposed by the French government, in February, 1848, on the trains working on the railways of that country.

29. Since, however, the brake power necessary to stop a train is increased in so large a ratio with the speed, a still greater number of brakes would be necessary with a fast train, such as the express trains, each carriage of which ought to be provided

with an independent brake and brakesman. This would certainly cause a considerable increase in the working expenses of the faster class of trains, but the public safety is a matter of too great importance to be postponed to considerations of this kind.

30. In attempting to avoid one source of danger another is often produced. When an obstacle is seen on the rails before a train moving with great speed, all means must of course be used to bring the train suddenly to rest. But if this be not done with great caution and skill, danger may be produced even more serious than that from which it is attempted to escape. The means of stopping a train are, the brake on the tender, the brakes on the vehicles composing it, and, in fine, *reversing the action of the engine.* This process consists in so changing the motion of the slides, that the steam shall obstruct instead of accelerating the pistons. In this way the whole force of the steam is suddenly made to resist the progressive motion of the train.

31. This is a dangerous process. The progress of the engine is arrested by an agent which does not act on the vehicles which follow it. The latter are consequently urged against the engine and against each other with all the force of which the engine is deprived by the back action of the steam. The effect is nearly the same as if an engine acting behind the train suddenly pushed the train against the engine in front. The effect of this is an obvious tendency to drive the intermediate carriages off the rails by *doubling up the train.*

Before reversing the engine, or even applying the brake to the tender, it is therefore always advisable to warn the brakesmen to apply the brakes to the vehicles composing the train. This being done, and the brake being then applied to the tender, there is less danger in reversing the steam on the engine.

But it unfortunately happens that in the emergencies in which these extreme measures are demanded, there is rarely time to observe these precautions. The prudence of providing a signal on the tender which shall be within view of the brakesmen, and seats for the latter from which they can always see such signal, is so obvious that it need not here be enlarged on.

32. We must not dismiss this subject without noticing the ingenious application of detonating substances, now called *fog signals.*

These are detonating balls, which on being crushed explode with the report of a pistol. When a train is stopped on the line by an accident, or in general when an obstacle is found upon the railway from any unexpected cause, and which cannot be immediately removed, if there be a fog at the time, or any other cause which may prevent the driver of a following train from seeing the obstacle, the guard or policeman runs back along the line and places these balls on the rails at certain distances, so that when a train approaches it causes them successively to explode in rolling over them, and the driver thus receives warning to stop.

33. The evil consequences resulting from collision are frequently aggravated by the manner in which the carriages or waggons composing the trains are connected with or adapted to each other. The mode of connecting the successive carriages forming a train is as follows. From the end of the frame supporting each carriage project two strong iron rods, which rest against spiral springs, and which are terminated by circular cushions, about a foot in diameter, called buffers. When two successive coaches are brought into contact, these buffers ought to meet each other so that their centres should coincide. This requires that the buffers of all the carriages should have the same gauge, that is to say, that there should be the same distance between their centres; and, secondly, that they should be at the same height above the rails. If this be not the case, a collision would have the effect of causing one carriage to push the other either aside or upwards, as the case might be: aside if the centre of the buffer deviated horizontally, and upwards if it deviated vertically.

In any case there would be a tendency of the coaches to throw each other off the rails.

The successive coaches forming a train were originally held together by a chain, which was necessarily always a little slack, so that when the power of the engine was driving the train, the buffers were not in close contact, and whenever the train stopped, or even slackened its speed, the hinder carriages ran against the foremost ones with a collision, the force of which was proportional to the difference of their speeds.

This mode of connection was replaced by a coupling screw, by means of which the carriages are drawn together, so that the buffers are pressed into close contact, and their springs a little compressed.

In this manner the train is formed into one complete column, and the change of speed to which it is subject does not produce the partial collision just mentioned.

One of the means, therefore, of diminishing the chances of injuries resulting from collision is to provide against the occurrence of eccentric buffers, and to ensure the proper coupling of the trains.

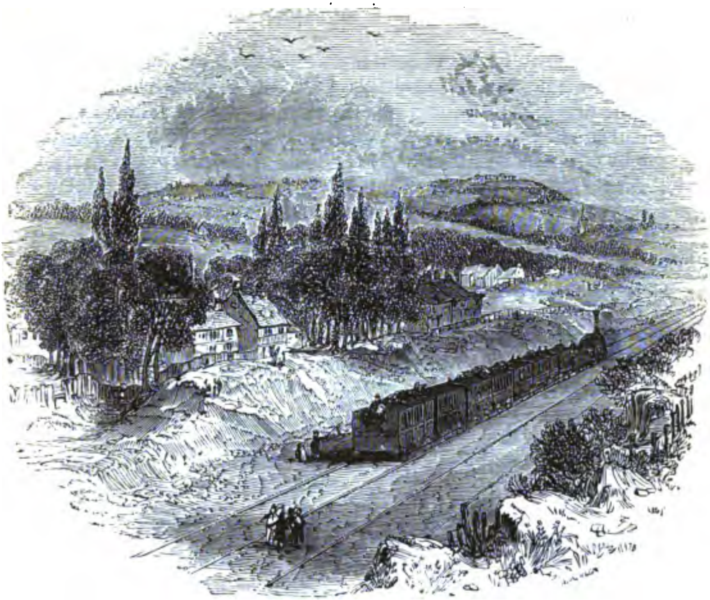
34. Although, in most cases of derailment,* it is the engine which escapes from the rails, yet it occasionally happens that while the engine maintains its position, one or more of the carriages forming the train are derailed.

This happens frequently when an axle or wheel breaks, but it sometimes happens that a defect of the rail throws a carriage off after the engine and preceding carriages have passed over it.

On the 16th September, 1847, on the Manchester and Liverpool Railway, the last carriage of the express train, having two passengers in it, was derailed, the other carriages being undisturbed, and was dragged a considerable distance before the engine-driver was made aware of the accident. The two passengers it contained were killed.

This accident was ascribed to a defect in the rails. It was supposed that the weight of the engine being too great for the strength of the road, it had deranged the rails in passing over them, and that the succeeding carriages increasing the injury, the displacement only became great enough to derail the wheels on the arrival of the last coach at the point.

* We have adopted this word from the French: it expresses an effect which is often necessary to mention, but for which we have not yet had any term in our railway nomenclature. By *deraillement* is meant the escape of the wheels of the engine or carriage from the rails; and the verb *to derail* or *to be derailed* may be used in a corresponding sense.



RAILWAY ACCIDENTS.

CHAPTER II.

1. Necessity of adopting means of watching trains.—2. Proposals of Great Western. — 3. Of the North-Western.— 4. Merit of engine-drivers. —5. Example in the accident on the Dee.—6. Investigation of circumstances producing accidents arising from imprudence or want of vigilance or care.—7. Instances from reports of railway commissioners.—8. Analysis of 100 accidents produced by imprudence of passengers.—9. Precautions against accidents.—10. Plain rules for railway travellers to avoid accidents.—11. Not to get in or out while moving.—12. Not to take an unusual position.—13. Stay in your place.—14. Don't get out on wrong side.—15. Don't cross the line.—16. Avoid going in express trains.—17. Avoid special and excursion trains.—18. In case of accident, get out.—19. Don't attempt to recover a falling article.—20. Take the middle carriage.—21. Don't hand an article into a train in motion.—22. Don't sit in your private carriage.—23. Anecdote of Lady Zetland.—24. Beware of level crossings.—25. Avoid night railway travelling.

1. Such accidents have suggested to the railway authorities the expediency of adopting some method by which a com-

munication can be made between the several carriages forming the train and the engine-driver. If, in the last instance, the engine-driver had been made aware of the accident at the moment of the derailment, it is probable such fatal results might not have occurred.

A case will be mentioned hereafter, in which a private carriage caught fire by a cinder projected from the funnel of the engine falling on its roof. The carriage continued to burn until the arrival of the train at the next station, the engine-driver and conductor being ignorant of the accident.

Previously to this, the necessity of some means of watching a train, and of notifying promptly to the engine-driver the occurrence of any accident, had attracted the attention of the government commissioners, and they consulted some of the principal railway companies on the most desirable means of remedying the evil.

2. The Great Western Company proposed to fix at the back of the tender a seat for a conductor, in a sufficiently high position to see along the roofs of the carriages, so as to have a perfect view of the entire side length of the train, and a means of passing from side to side of the tender, so as to get a view of each side of the train. Such a conductor, from his proximity to the engine, could immediately communicate with the driver, and each guard upon the coaches of the train could communicate with such conductor by signals.

3. The North-Western Company proposed that the under guard should always stand in his van next to the engine, with his face to the train, so as to observe any signal of distress, irregularity, or derangement among the carriages which the chief guard, stationed at the rear of the train, might make. A communication between the under guard and the engineman was only necessary to complete this arrangement, and the company accordingly ordered that means should be provided by which the under guard should be enabled at pleasure to open the whistle of the engine.

The late Colonel Brandreth had interviews with some of the most eminent railway engineers, with a view to obtain some additional protection for the travelling public, by contriving a method not only for securing the constant watching of the trains while on their journey, but also to provide the passengers with means, in case of accident or sudden illness, of communicating with a guard, and of enabling the guard to communicate with the engineman, for the purpose, when necessary, of stopping the train.

There could be no difficulty in providing means by which any passenger could at his pleasure sound the whistle of the engine so as to give the engine-driver notice to stop; but the government commissioners considered that it would be objectionable to give a passenger a power to stop the train at will, though it was admitted that it would be extremely desirable to establish a practicable and sure communication between the passengers in each coach with a guard, and to provide the latter with means of communicating with the engine-driver.

The great improvements which are made in the application of the electric telegraph justify the expectation that that admirable invention may supply the most effectual means of attaining these objects. Each train might be provided with a portable telegraph, by means of which the passengers in each carriage might have the power of communicating with the principal conductor in case of any accident; while the conductors themselves might be enabled to communicate with each other and with the engine-driver.

4. While noticing the subject of railway accidents arising from causes beyond the control of the passengers, or those who have the management of the trains, it would be an injustice to a most meritorious and generally intelligent class of persons not to acknowledge the zeal, courage, skill, and good conduct of the engine-drivers, conductors, and stokers, as a body. All who have had opportunities of experience in railway transport will feel the justice of such a tribute in the exact proportion of the extent of their experience. Innumerable instances might be offered of admirable judgment and presence of mind exhibited by this class of men in the emergencies which arise in railway travelling.

An incident which occurred on the Chester and Holyhead Railway may be mentioned as one among numbers in attestation of this, and in which, although the promptness and presence of mind of the engineer were not successful in effecting the safety of the passengers, they were not the less admirable.

5. On the 24th of May, 1847, a fatal accident occurred to a train in crossing the bridge over the Dee. The train consisted of the engine and tender, weighing 30 tons, followed by three passenger carriages, a luggage-van, and another passenger carriage, containing in all 25 passengers, the gross weight of the train being 60 tons.

The train proceeded safely over the first and second arches, and the engine reached the middle of the third arch to a point about 50 feet from the abutments of the bridge. At that point the engine-driver felt the railway sinking under him. With admirable promptitude he instantly opened the steam valve to the fullest extent of its power, giving to the train a sudden pull, so as to endeavour to clear the bridge before the catastrophe, of the imminence of which he was instantly conscious, should occur.

His purpose was but partially successful. The engine cleared the bridge as the railway sunk under it, and dragged the tender with it. The fireman, who was upon the tender, was thrown off upon the side of the railway beyond the end of the bridge, and killed. The passenger coaches had not cleared the bridge when it sunk under them, and their connection with the tender was broken. The carriages which had the passengers were precipitated into the river from a height of 36 feet above the surface of the water, the depth of which was 10 feet.

It appeared afterwards that the tender in following the engine had been derailed, and was dragged along, rubbing hard against the parapet wall at the end of the bridge. It was left standing apart at 50 feet from the water's edge and 3 feet off the rails, the engine having broken away from it, and proceeded with the driver, the only individual who escaped, to the adjacent station.

6. Having investigated the circumstances which produce that class of accidents against which the sufferer cannot effectually protect himself by measures of precaution, it remains now to notice those which arise from imprudence, or from the want of that vigilance and care on the part of the traveller, which the very nature of railway transport renders necessary.

7. The railway commissioners publish periodically reports of all accidents attended with personal injury which take place on railways. The most certain method of ascertaining the manner in which imprudence or negligence operates in the production of these disasters, will be to take from the reports those accidents which have occurred to passengers, and to classify them according to their causes. We have accordingly taken indiscriminately a hundred such occurrences, and have classified them in the following table:—

8. *Analysis of* 100 *Accidents produced by Imprudence of Passengers.*

CAUSES.	RESULTS.		
	Killed.	Injured.	Total.
Sitting or standing in improper place, attitude, or position	17	11	28
Getting out of carriage while train in motion .	17	7	24
Getting into carriage while train in motion . .	10	6	16
Jumping out to recover hat blown off or parcel dropped	8	5	13
Crossing the railway incautiously	11	1	12
Getting out on wrong side.	3	3	6
Handing an article into a train in motion .	1	0	1
	67	33	100

9. From what has been stated and explained, it will be evident that of all the means of locomotion which human invention has as yet devised, railway travelling is the safest in an almost infinite degree. Indeed, the risk to life and limb, when reduced to a numerical statement, seems to be evanescent. Nevertheless the apprehension of danger in this mode of travelling entertained by timid persons, and even by some who scarcely merit that appellation, is not inconsiderable.

This may arise partly from the circumstance of the public not being generally aware of the smallness of the amount of the danger which has been here described, but in a greater degree from the terrific results of some of the rare accidents which have occurred.

In the modes of travelling used before the prevalence of railways, accidents to life and limb were frequent, but in general they were individually so unimportant as not to attract notice, or to find a place in the public journals. In the case of railways, however, where large numbers are carried in the same train, and simultaneously exposed to danger, accidents, though more rare, are sometimes attended with appalling results. Much notice is therefore drawn to them. They are commented on in the journals, and public alarm is excited.

Notwithstanding the smallness of the amount of risk, yet, as in many cases the danger of accident beyond the control of the passenger may be diminished by the adoption of proper precautions, and in all cases the causes of danger arising from his own ignorance or neglect may be wholly removed, it may be beneficial to give in a succinct form short rules, by the observance of which the traveller will render still less the amount of that risk already so small.

With this view we have put together the following series of plain intelligible rules, founded partly upon rather a large personal experience in railway travelling in every quarter of the globe where this species of locomotion has been adopted.

10. PLAIN RULES FOR RAILWAY TRAVELLERS.

11. *Rule* I.—NEVER ATTEMPT TO GET INTO OR OUT OF A RAILWAY CARRIAGE WHILE IT IS MOVING, NO MATTER HOW SLOWLY.

Self-preservation imperiously commands the observance of this rule, since forty in an hundred of the accidents which occur to passengers through their own imprudence, arise from this cause, and of these forty, twenty-seven are fatal.

It is a peculiarity of railway locomotion, that the speed, when not very rapid, always appears to the unpractised passenger much less than it is. A railway train moving at the rate of a fast stage-coach seems to go scarcely as fast as a person might walk. To this circumstance (which is explained by the extreme smoothness of the motion) is to be ascribed the great frequency of accidents arising from passengers attempting to descend from trains while still in motion.

On the 4th of July, 1844, on the Dublin and Drogheda Railway, a passenger jumped out before the train stopped, fell with his hand on the rail, over which the carriage-wheels passed.

On the 26th of August, 1844, on the Liverpool and Manchester Railway, a passenger, jumping out before the train stopped, was killed.

Similar accidents fatal to life occurred on the Grand Junction Railway on the 7th of August, 1846; on the Edinburgh and Glasgow, on the 16th of February, 1846; on the South-Western, on the 9th of January, 1847; on the East-Lancaster, on the 29th of May, 1847; on the North-Western, on the 1st of February, 1847; on the Great North of England, on the 17th of February, 1845; on the Midland, on the 27th and 31st of October, 1845.

The reports supply an interminable list of like casualties, from which we have taken the preceding indiscriminately.

12. *Rule* II.—Never sit in any unusual place or posture.

Twenty-eight in every hundred of the accidents to travellers resulting from incaution, arise from this cause, and of these twenty-eight, seventeen are fatal.

On some lines of railway seats are provided on the roofs of the carriages. These are to be avoided. Those who occupy them sometimes inadvertently stand up, and when the train passes under a bridge they are struck by the arch. Guards and brakesmen whose duty brings them to these positions, and who are disciplined to exercise caution, are nevertheless frequent sufferers.

Passengers should beware of leaning out of carriage windows, or of putting out their arm, or if a second-class carriage, as sometimes happens, has no door, they should take care not to put out their leg.

The reports supply frequent examples of fatal accidents from these causes. Outside passengers placed on the roof of the carriages of a train, happening to stand up, were struck on the head by the arches of bridges, at the dates given below on the following railways:—

Newcastle and Carlisle	2 Sept.	1846.
Manchester and Sheffield	5 Nov.,	1847.
North Union	6 Jan.	—
South Eastern	30 Jan.	1846.
Bristol and Birmingham . . .	11 July.	—
Glasgow and Ayr	16 May,	1844.
Manchester and Birmingham . .	31 May,	—

These examples are only a few taken indiscriminately from the reports.

The injuries and deaths from leaning out of doors and windows are very numerous, and produced by various causes.

On the Preston and Wyre line, on the 18th of April, 1844, a passenger leaning out of a window was struck by the signal board and wounded.

On the Bolton and Bury line, on the 26th of July, 1846, a passenger leaning out was struck by the iron column of a bridge, and killed.

On the Hull and Selby line, on the 17th of April, 1846, a passenger reaching over to recover his coat had his arm broken.

On the Edinburgh and Glasgow line, a passenger, climbing from one compartment of a second class carriage to another, fell and was killed.

On the Manchester and Leeds line, a passenger, getting over the side of a carriage instead of going out by the door, fell and was killed.

On the Bodmin and Wadebridge line, on the 3rd of August, 1844, a passenger, jumping from one carriage to another, fell between, and was killed.

On the Midland line, on the 15th of July, 1846, two passengers, imprudently standing on the seat, were thrown off, and both killed.

On the Liverpool and Manchester line, on the 15th of June, 1845, a passenger fell, attempting to pass from one carriage to another, and was injured.

On the Grand Junction line, on the 8th of August, 1845, a passenger fell off the buffer of a waggon, and was injured.

On the Preston and Wyre line, on the 8th of August, 1845, a passenger, improperly sitting on the side of a carriage, fell off, and was killed.

On the York and North Midland line, on the 2nd of November, 1845, a passenger fell from the foot-board of a carriage in motion, and was killed.

On the Dublin and Kingstown line, on the 25th of November, 1845, a passenger, over-reaching herself, fell from a train in motion, and was injured.

On the Eastern Counties line, on the 1st of March, 1845, a passenger struck his head against a signal-post while leaning over, and was killed.

On the Stockton and Darlington line, on the 14th of April, 1845, a passenger leaning over, struck a waggon, and was injured.

On the Dundee and Perth line, on the 24th of July, 1847, a passenger on the roof was struck by a bridge, and killed.

On the North-Western line, on the 26th of December, 1847, a passenger was standing upon the step of the tender, after the train got into motion; and jumping off, was killed.

On the Newcastle and Carlisle line, on the 22nd of August, 1847, a passenger got upon the step of a carriage before the train stopped; fell, and was injured.

On the Lancashire and Yorkshire line, June 19, 1848, a passenger riding on the roof, contrary to orders, came in contact with a bridge, and was killed.

On the South Staffordshire line, on the 8th of July, 1848, a passenger, sitting on the bar of the window, fell out, fracturing leg and head.

On the York and North Midland line, on the 28th of August, 1848, a passenger, seated on the edge of an open carriage, lost his balance, and fell between the carriages; arm broken.

13. *Rule* III.—IT IS AN EXCELLENT GENERAL MAXIM IN RAILWAY TRAVELLING TO REMAIN IN YOUR PLACE WITHOUT GOING OUT AT ALL UNTIL YOU ARRIVE AT YOUR DESTINATION. WHEN THIS CANNOT BE DONE, GO OUT AS SELDOM AS POSSIBLE.

14. *Rule* IV.—NEVER GET OUT AT THE WRONG SIDE OF A RAILWAY CARRIAGE.

All who are accustomed to railway travelling know that the English railways in general consist of two lines of rails, one commonly called the *up line*, and the other the *down line*. The rule of the road is the same as on common roads. The trains always keep the line of rails on the left of the engine-driver as he looks forward. The consequence of this is, that trains moving in opposite directions are never on the same line, and between these there can never be a collision.

The doors of the carriages which are on your right as you look towards the engine open upon the space in the middle of the railway between the two lines of rails. The passenger should never attempt to leave the carriage by these doors; if he do, he is liable to be struck down or un over by trains passing on the adjacent line of rails. If he leave the carriage by the left-hand door, he descends on the side of the railway out of danger.

On quitting a train under such circumstances, immediately retire to the distance of several feet from the edge of the line, so as to avoid being struck by the steps or other projecting parts of carriages passing.

On the North-Western Railway, on the 12th of January, 1847, a passenger got out at the wrong side, and was run over and killed by a train which was passing at the moment.

A like accident happened on the 25th of December, 1848, on the South-Eastern line.

The reports abound in like accidents, resulting either in death or broken limbs.

15. *Rule* V.—NEVER PASS FROM ONE SIDE OF THE RAILWAY TO THE OTHER, EXCEPT WHEN IT IS INDISPENSABLY NECESSARY TO DO SO, AND THEN NOT WITHOUT THE UTMOST PRECAUTION.

Care should be taken before crossing the line to look *both ways*, to see that no train is approaching. The risk is not merely that of the train coming upon you before you can pass to the other side. You slip or trip, or otherwise accidentally fall, and a train may be upon you before you can raise yourself and get out of its way.

Precaution in this case is especially necessary at a point where the line is curved, and where you cannot command a view to any considerable distance. It is true that the noise of the train generally gives notice of its approach, but this cannot always be depended on, as the wind sometimes renders it inaudible.

In crossing a railway at a place where there are sidings and numerous points (which is always the case at and near stations), the feet are liable to be caught between the rails and points, and in such cases it has happened very frequently that the person thus impeded is run over by a train before he is able to disengage himself.

Passengers waiting at stations for the arrival of a train, or having descended from a train which has stopped and waiting to remount, stand in need of the greatest caution. The refreshment-room is sometimes on the side of the road, opposite to that on which the train stops, in which case it can only be arrived at by crossing the line.

The reports abound in cases showing the necessity of observing this rule. On the 29th of June, 1846, a female passenger on the

Brighton Railway waiting for a train, was crossing the railway, and fell, it is supposed with fright, on seeing the train approaching. The station-clerk, on perceiving her situation, hurried to her assistance, and while endeavouring to remove her, the train went over and killed both.

On the 26th of March, 1847, a passenger on the York and Newcastle railway, in crossing the line, had his foot caught between the points, and was held fast there, until a train arriving passed over and killed him.

On the 8th of May, 1846, a lady, on the Eastern Counties railway, attempting to cross the line, in order to prevent one of her children getting upon it from the opposite side, was run over and killed.

On the Darlington Railway, on the 15th of June, 1846, a passenger, waiting for a train, fell asleep on the edge of the platform, and was struck by a goods train passing and killed.

It frequently happens that while the attention of a person crossing a line is directed to a train approaching from one direction which he thinks there is time to avoid, he is run over by a train, from which his attention has been withdrawn, coming from the opposite direction.

This occurred for example on the Caledonian railway, on the 15th of March, 1847, when a passenger was run over by a train while his attention was directed to another train coming from the opposite direction.

Similar accidents, attended with a like result, are recorded of numerous other lines. On the 30th of December, 1847, a passenger, on the Midland line, having left the train and attempted to cross the line, was crushed by the step of the brake-van against the platform and killed.

16. *Rule* VI.—EXPRESS-TRAINS ARE ATTENDED WITH MORE DANGER THAN ORDINARY TRAINS. THOSE WHO DESIRE THE GREATEST DEGREE OF SECURITY SHOULD USE THEM ONLY WHEN GREAT SPEED IS INDISPENSABLE.

The principal source of danger for express-trains arises not so much from their extreme speed as from their rate of progress being *different* from that of the general traffic of the line. If all trains without exception moved with exactly the same speed, no collision by one overtaking another could occur. The more they depart from this uniformity the more likely are collisions. Now the speed of express-trains is both exceptional and extreme. Inasmuch as it is exceptional, they are likely to overtake the slower and regular trains, if these be retarded even in the least degree by any accidental cause; and inasmuch as it is extreme, they are more difficult to be stopped in time to prevent a collision in such a contingency. If a collision occur, the effects are disastrous, in the direct ratio of the relative speed of the trains, one of which overtakes the other. The momentum of the shock, other things being the same, will be proportional to the excess of the speed of the faster over that of the slower train.

The probability of a collision will also be increased in the same ratio.

To work express trains with safety, an additional line of rails should be laid down and appropriated to them.

Their number per day being necessarily small, and the duration of their trips short, the same line of rails might, without inconvenience or danger, serve for the traffic in both directions as on single lines of railway.

Examples illustrative of the danger attending express-trains abound in the reports. The following may be mentioned:—

On the Great-Western, on the 10th of May, 1848, six passengers were killed, and thirteen injured, in consequence of a train coming in collision with a horse-box at the Shrivenham station.

On the Lancaster and Preston, on the 21st of August, 1848, one passenger was killed, and two seriously injured, in consequence of a collision at the Bay Horse station between a Lancaster and Carlisle Company's express-train, and a local train belonging to the Lancaster and Preston Company.

On the North-Western, on the 2nd of September, 1848, an express-train ran off the rails near the Newton Road station, causing severe injury to two passengers, Mr. Shuard and Colonel Baird, both of whom died afterwards.

On the South-Western, on the 17th of November, 1848, an express-train ran into a ballast-engine on the Richmond line, causing death to one servant of the company and injury to four others, all of whom were riding on the engine; also injury to eight passengers in the express-train.

17. *Rule* VII.—SPECIAL TRAINS, EXCURSION TRAINS, AND ALL OTHER EXCEPTIONAL TRAINS ON RAILWAYS ARE TO BE AVOIDED, BEING MORE UNSAFE THAN THE ORDINARY AND REGULAR TRAINS.

There is always more or less danger of collision when any object on a railway is out of its customary place. The engine-drivers of the regular trains are always informed of the course of other regular trains, and, except in cases of accidental stoppage or delay, they know where they are liable to be encountered. Special trains are supplied on sudden and unforeseen occasions, and although their drivers are informed of the movement of the regular trains, and may therefore provide against collisions, this information is not reciprocal.

Excursion trains are exceptional but not unforeseen, and are not therefore as unsafe as special trains. They are, nevertheless, to be avoided by those who scrupulously consult their safety. An examination of the statistics of accidents would conclusively prove the prudence of such a course.

On the Maryport and Carlisle, on the 10th of November, 1846, a collision between a special train and a coal-train took place in consequence of neglect on the part of the signal-man at the Wigton station, and of the agent and superintendent of locomotives at Carlisle, in not informing the driver of the coal-train that a special train was expected, and that he was not to start until it arrived. Engine-driver and sole passenger injured.

18. *Rule* VIII.—IF THE TRAIN IN WHICH YOU TRAVEL MEET WITH AN ACCIDENT, BY WHICH IT IS STOPPED AT A PART OF THE LINE, OR AT A TIME, WHERE SUCH STOPPAGE IS NOT REGULAR, IT IS MORE ADVISABLE TO QUIT THE CARRIAGE THAN TO STAY IN IT, BUT IN QUITTING IT REMEMBER RULES I., IV., AND V.

It may be affirmed generally that there is always more or less danger on a railway when carriages or waggons are found at a place, where in the regular working of the line, they ought not to be. In such cases a train following them, not expecting to find them there, is likely to run upon them and produce a collision. We have personally witnessed more than one example of this, and the reports of the railway commissioners supply several. We should therefore recommend the above rule for general observance; but in leaving the train passengers should beware of crossing the line, or standing on it, or of getting out of the carriages at the wrong side.

On the South-Western, on the 14th of January, 1848, the engine of a passenger train having been partially disabled, the engine-driver got under it to repair the damage. While thus employed, a goods train overtook and ran into the passenger train, causing the instant death of the driver, and injury to the fireman and eleven passengers; also injury to one of the guards of the goods train.

On the Manchester and Leeds, on the 9th of March, 1847, a passenger train was stopped by a broken axle; another train belonging to the Manchester and Leeds Railway Company, notwithstanding signals were made, ran into and injured the two hindmost carriages.

On the Midland, on the 20th of October, 1845, a pilot-engine, sent after a disabled passenger train to assist it, overtook and ran into it. Two passengers killed.

19. *Rule* IX.—BEWARE OF YIELDING TO THE SUDDEN IMPULSE TO SPRING FROM THE CARRIAGE TO RECOVER YOUR HAT WHICH HAS BLOWN OFF, OR A PARCEL DROPPED.

It would appear that there is an impulse, which in some individuals is almost irresistible, to leap from a train to recover their hats when blown off or accidentally dropped. The reports of railway accidents supply numerous examples of this.

On the Edinburgh and Glasgow, on the 2nd of December, 1846, a passenger fell between carriages in motion, while attempting to recover his cap, which had been blown off into the next carriage, and was killed.

On the Manchester and Birmingham, on the 16th of October, 1845, a passenger was struck by a bridge while getting on the roof of one of the carriages to recover his hat which had been blown off, and was killed.

On the Manchester and Leeds, on the 23rd of January, 1845, a passenger, attempting to recover his hat, fell off the train and was killed.

On the North-Western, on 26th of June, 1847, a passenger, jumping after his hat from a train in motion, was killed.

On the same line, on the 10th of May, 1847, a passenger, jumping after his hat from a train in motion, fell upon a block of stone, and was killed on the spot.

20. *Rule* X.—WHEN YOU START ON YOUR JOURNEY, SELECT, IF YOU CAN, A CARRIAGE AT OR AS NEAR AS POSSIBLE TO THE CENTRE OF THE TRAIN.

In case of collision, the first and the last carriages of a train are the most liable to damage. If the train run into another, the foremost carriages suffer. If it be run into by a train overtaking it, the hindmost carriages suffer. Almost every case of collision affords an example illustrating this rule.

In case of the engine running off the rails, the carriages most likely to suffer are the foremost.

21. *Rule* XI.—DO NOT ATTEMPT TO HAND AN ARTICLE INTO A TRAIN IN MOTION.

On the London and Brighton railway, on the 15th of February, 1847, a passenger, while handing a basket to the guard of a passing train, had his coat caught by one of the carriages, and was dragged under the wheels and killed.

22. *Rule* XII.—IF YOU TRAVEL WITH YOUR PRIVATE CARRIAGE, DO NOT SIT IN IT ON THE RAILWAY. TAKE YOUR PLACE BY PREFERENCE IN ONE OF THE REGULAR RAILWAY CARRIAGES.

The regular railway carriages are safer in case of accident than a private carriage placed on a truck. They are stronger and heavier. They are less liable to be thrown off the rails, or to be crushed or overthrown in case of a collision. The cinders ejected from the smoke funnel of the engine are generally in a state of vivid ignition, and if they happen to fall on any combustible object, are liable to set fire to it. The railway carriages are constructed so as to be secured from such an accident, but private carriages are not so, and, moreover, from their greater elevation, when placed on a truck, are more exposed. Serious accidents have sometimes occurred from this cause.

The trucks which carry private carriages are also often placed at the end of the train, the least safe position. (See Rule X.)

23. On the 8th Dec., 1847, an accident happened to the Countess of Zetland, while travelling in her private carriage on the Midland Railway, of which Lady Zetland herself gave the following narrative. The accident occurred about 5 o'clock in the afternoon, as the train was approaching Rugby from Derby, *en route* to London, and at about six miles from Rugby.

"Aske, Richmond, Yorkshire.

"On the 8th of December, I left Darlington by the 9h. 25m. train for London. I travelled in my chariot with my maid. The carriage was strapped on to a truck, and placed with its back to the engine, about the centre of the train, which was a long one. Soon after leaving Leicester, I thought I smelt something burning, and told my maid to look out of the window on her side to see if anything was on fire. She let down the window, and so many lumps of red-hot coal or coke were showering down that she put it up again immediately. I still thought I smelt something burning; she put down the window again, and exclaimed that the carriage was on fire. We then put down the side-windows, and waved our handkerchiefs, screaming 'fire' as loud as we could. No one took any notice of us. I then pulled up the windows, lest the current of air through the carriage should cause the fire to burn more rapidly into the carriage, and determined to sit in as long as possible. After some time, seeing that no assistance was likely to be afforded us, my maid became terrified, and without telling me her intention, opened the door, let down the step, and scrambled out on to the truck. I followed her, but having unluckily let myself down towards the back part of the carriage, which was on fire, was obliged to put up the step and close the door as well as I could, to enable me to pass to the front part of the carriage, furthest from the fire, and where my maid was standing. We clung on by the front springs of the carriage, screaming 'fire' incessantly, and waving our handkerchiefs. We passed several policemen on the road, none of whom took any notice of us. No guard appeared. A gentleman in the carriage behind mine saw us, but could render no assistance. My maid seemed in an agony of terror, and I saw her sit down on the side of the truck and gather her cloak tightly about her. I think I told her to hold fast to the carriage. I turned away for a moment to wave my handkerchief, and when I looked round again my poor maid was gone. The train went on, the fire of course increasing, and the wind blowing it towards me. A man (a passenger) crept along the ledge of the railway carriages, and came as near as possible to the truck on which I stood, but it was impossible for him to help me. At last the train stopped at the Rugby station. An engine was sent back to find my maid. She was found on the road, and taken to the Leicester Hospital, where she now lies in an almost hopeless state; her skull fractured; three of her fingers have been amputated. I am told the train was going at the rate of fifty miles an hour.

(Signed) "S. Y. ZETLAND."

The train, consisting of seven passenger carriages, two brake-vans, and four private carriages on trucks, altogether thirteen separate carriages, was drawn by an engine with driver and fireman, and was under the charge of one guard, who was placed in the rear of the entire train, and within a luggage-van, from which it was impossible for him to see the burning carriage, which was the eighth from the engine.

24. *Rule* XIII.—BEWARE OF PROCEEDING ON A COACH ROAD ACROSS A RAILWAY AT A LEVEL CROSSING. NEVER DO SO WITHOUT THE EXPRESS SANCTION OF THE GATEKEEPER.

On the English railways, common roads are usually carried over or under the railway, which is crossed by or crosses them on bridges. This, however, is not invariable, and the greatest caution should be observed in passing such level crossings. A restive horse has frequently produced injurious or fatal accidents in such cases.

25. *Rule* XIV.—WHEN YOU CAN CHOOSE YOUR TIME, TRAVEL BY DAY RATHER THAN BY NIGHT; AND IF NOT URGENTLY PRESSED, DO NOT TRAVEL IN FOGGY WEATHER.

Accidents from collision and from encountering impediments accidentally placed on the road happen more frequently at night and in foggy weather, than by day and in elear weather.

Persons on or near railways appear to be sometimes seized with a delirium or fascination which determines their will by an irresistible impulse to throw themselves under an approaching train. Cases of this kind occur so frequently, and under such circumstances, as cannot be adequately explained by predisposition to suicide.

Examples.

On the Midland railway, on June 20, 1845, a plate-layer jumped suddenly in front of a train in motion; no cause can be assigned.

On June 25, 1845, a trespasser ran from behind a bridge, and laid himself across the rails in front of an approaching train.

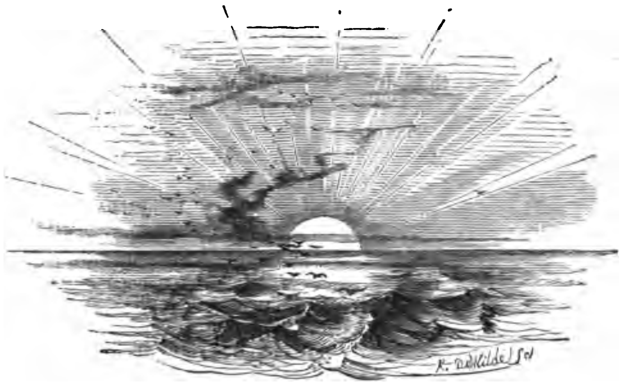
On September 18, 1845, a trespasser laid his neck on the rail in front of an approaching train; supposed to be insane.

On the South-Western railway, on June 9, 1847, Frances Arney threw herself under the wheels of a train; killed.

On the Glasgow and Paisley railway, on November 19, 1847, a woman of dissipated habits rushed from the side of the railway, and throwing herself in front of an approaching train, was run over and killed.

On the South-Western railway, on February 19, 1848, a person committed suicide by placing himself before an approaching train.

On the Sheffield and Manchester railway, on May 4, 1846, a person committed suicide by laying himself across the rails in front of an approaching train.



LIGHT.

1. Description of eye, and mode in which light is transmitted to it—Ways in which objects are rendered visible.—2. Analogy between the eye and the organ of smelling.—3. Analogy between the eye and the ear.—4. Luminiferous ether.—5. Corpuscular theory—Undulatory theory.—6. Undulatory theory explained and examined—Roemer's discovery of the velocity of light—Newton's solution of the amplitude or breadth of the luminous waves—Altitude of luminous waves—Table of the magnitudes of the luminous waves of each colour.—7. Consideration of the two theories of light.—8. The idea of the undulatory theory entertained by Descartes, Hooke, and others—The honour of having reduced the hypothesis to a definite shape attributable to Huygens—Dr. Young's mechanical reasoning thereon.—9. Malus discovers the polarisation of light by reflection—The theory greatly extended by Fresnel, Arago, Poisson, Herschel, and others.—10. Relation of light and heat—Herschel's discovery apparently establishing the independence of the heating and illuminating effects of the solar rays—Berard's experiments.—11. Bodies luminous and non-luminous.—12. Transparency and opacity.

1. Among the many marvellous results of the labours of the human mind directed to the discovery of the laws of the physical creation, there is perhaps none which strikes us with more astonishment than the knowledge which has been obtained relating to the qualities and laws of Light. I propose for the present to bring forward the facts which have been disclosed regarding its physical nature and its motion through space, as

well as the manner in which it affects the organ of vision, so as to produce the perception of external and distinct objects.

Between the eye and any distant object, there intervenes a space of greater or less extent, and often, as in the case of the stars, so great as to be incapable of being clearly and adequately expressed by any standard or modulus of magnitude with which we are familiar. Yet objects, at these immense distances, are rendered visible to us by some physical effects which they produce upon our organs of vision.

It has been ascertained that the interior of the eye-ball is lined with a membrane highly susceptible of mechanical vibration and connected by a continuity of nerves with the brain; and to this membrane admission is given to light by an opening in front of the eye called the *pupil*. The light then proceeding from any distant object must be supposed to pass over the space intervening between the object and the eye, to enter the pupil and to produce upon the membrane within the eye a specific mechanical effect, which being propagated to the brain, is the means of producing in the mind a perception of the distant object.

How then are we to conceive that an object placed at any distance, for example, say one hundred millions of miles, from the eye, can transmit over and through that space a mechanical effect on the eye? We answer that there are two, and only two, ways in which it is possible to conceive such an action to take place. These two are the following:—

First.—The distant object thus visible to us, may emit particles of matter from its surface, which particles of matter may pass over the intervening space, may enter the pupil of the eye, may strike upon the nervous membrane, and so affect it as to produce vision.

Secondly.—There may be in the space between the distant visible object and the eye, *a medium possessing elasticity*, so as to be capable of receiving and transmitting pulsations or undulations like those imparted to the air by a sounding body. If this be admitted, the distant visible object may, without emitting any particles of matter from its surface, affect such a medium surrounding it with pulsations or undulations, in the same manner as a bell affects the air around it. These pulsations or undulations may pass along the space intervening between the visible object and the eye, in the same manner as the pulsations or undulations produced by a bell pass along the air between the bell and the ear. In this manner, the pulsations transmitted from the visible object, and propagated by the medium we have referred to, may reach the eye and affect the membrane which lines it, in the same manner exactly as the pulsations in the air affect the tympanum of the ear.

These are the two, and the only two modes, in which it was ever imagined that a distant object could become visible to the eye.

2. In the first, there is an analogy between the eye and the organs of smelling. Odorous objects do actually emit material effluvia, which form part of their own substance. These effluvia reach the organ of smelling, and produce upon it a specific effect, which impresses the mind with a corresponding perception. According to the first supposition, a visible object at any distance would act in the same way, and would eject continual particles of light, which particles of light would move to the eye and produce vision, acting mechanically on its membrane in the same manner as the effluvia of a rose produce a sensible effect upon the organs of smelling.

3. The second method places the eye in analogy with the ear So close is this analogy, that all the mathematical formulæ by which the effects of sound are expressed in acoustics, will, with very slight changes, be capable of expressing the effects of vision, according to the latter hypothesis.

4. It is evident, however, that as the first hypothesis requires us to admit that distant visible objects are continually ejecting matter from their surfaces to produce vision; so the second hypothesis as peremptorily requires the admission of the existence of some physical medium pervading the universe,—some subtle ethereal fluid endowed with a property of propagating the pulsations or undulations of distant visible objects, and transmitting them to the eye. This hypothetical fluid has been called the *luminiferous ether*.

5. The first of these two celebrated theories of light has been called the CORPUSCULAR THEORY, and the second the UNDULATORY THEORY.

Newton, although he did not identify his investigations in optics with any hypothesis, but in the spirit of the inductive philosophy founded by Bacon based his conclusions on experiments and observations only, adopted nevertheless the nomenclature and language of the corpuscular theory, and, probably, from veneration for his authority, English philosophers, until recently, have very generally given the preference to that theory.

The undulatory theory, on the other hand, was adopted by Huygens, and after him by most continental philosophers.

Optical researches within the last hundred years have been prosecuted with singular diligence and success. A vast variety of phenomena previously unknown, have been accurately investigated, new laws have been developed, and the general result has been that the undulatory theory has prevailed over the corpuscular. It is perhaps not an unfair statement of the actual condition of these two celebrated hypotheses, to say that while the corpuscular system is found sufficient to explain most of the common and obvious phenomena of optics, it totally fails in explaining many of the most remarkable effects brought to light by modern observations and experiments. On the other hand, the undulatory theory in general offers a satisfactory explanation for all. This circumstance has very properly and legitimately enlisted under that hypothesis almost all the leading scientific men of the present day.

Although the principal facts which we shall have now to explain are in fact independent of either of these two hypotheses, and incontestably true, whichever may be adopted, yet in their exposition it will be necessary to adopt the language of one or the other of these theories. We shall, for the reason just stated, use the nomenclature of the undulatory theory.

We are then to imagine light to consist of undulations propagated through the universal ether, in the same manner as the waves or undulations of sound are propagated through the air.

6. The first question then that arises is, what is the velocity with which these waves move? At what rate does light come from a distant star to the eye? Is it propagated instantaneously? Would a fire suddenly lighted at a point one hundred millions of miles from the eye be seen at the moment the light was produced?—or would an interval of time be necessary to allow the light to reach the eye? and if so, what would be the interval of time in relation to the distance of the luminous object?

In tracing the progress of human knowledge, we frequently have occasion to behold with surprise, and not without a due sense of humility, the important part which accident plays in the advancement of science. Often are we with diligent zeal in search of things, which, if found, would be of trifling or no value, when we stumble on inestimable treasures of truth. The frequency of this strongly impresses the mind with the persuasion that there is in secret operation a power whose will it is that knowledge and the human mind should be constantly progressive. It is in physics as in morals. We ignorantly seek that which is worthless, and find what is inestimable.

In the pursuit of knowledge we might well say that which we are taught to express in the pursuit of what is moral and good. We might say that the power which governs its progress knows better than we do "our necessities before we ask, and our ignorance in asking." We shall see a striking example of this in the narrative of the celebrated discovery of the motion of light.

Soon after the invention of the telescope, and the consequent discovery of Jupiter's satellites, Roemer, an eminent Danish astronomer, engaged in a series of observations, the object of which was the discovery of the exact time of the revolution of one of these bodies around Jupiter. The mode in which he proposed to investigate this, was by observing the successive eclipses of the satellite, and noticing the time between them.

Fig. 1.

Let S (fig. 1) represent the sun, and A B C D E F G H the successive relative positions of the earth. Let J be Jupiter projecting behind him his conical shadow, and let M N represent the orbit of one of his satellites. After each revolution the satellite will enter the shadow at M, and emerge from it at N.

Now if it were possible to observe accurately the moment at which the satellite would, after each revolution, either enter the shadow, or emerge from it, the interval of time between these events would enable us to calculate exactly the velocity and motion of the satellite. But by attentively watching the satellite we can note the time it enters the shadow, for at that moment it is deprived of the sun's light, and becomes invisible. We can also note the moment of its emergence, because then escaping from the edge of the shadow, it comes into the sun's light, and becomes visible. It was in this manner that Roemer proposed to ascertain the motion of the satellite. But in order to obtain the estimate with the greatest possible precision, he proposed to continue his observations for several months.

Let us, then, suppose that we have observed the time which has elapsed between two successive eclipses, and that this time is, for example, forty-three hours. We ought to expect that the eclipse would recur after the lapse of every successive period of forty-three hours.

Imagine a table to be computed in which we shall calculate and register beforehand the moment at which every successive eclipse of the satellite for twelve months to come shall occur, we shall then, as Roemer did, observe the moments at which the eclipses occur and compare them with the moments registered in the table.

Let the earth be supposed at A, at the commencement of these observations, where it is nearest to Jupiter. When the earth has moved to B, which it will do in about six weeks, it will be found that the occurrence of the eclipse is *a little later* than the time registered in the table. When the earth arrives at C, which it will do at the end of three months, it will occur *still later* than the registered time. In fact, at C the eclipses will occur about eight minutes later than the registered time. At D they will be twelve minutes later, and at E sixteen minutes later.

By observations such as these, Roemer was struck with the fact that his predictions of the eclipses proved in every case to be wrong. It would at first occur to him that this discrepancy might arise from some errors of his observations; but if such were the case, it might be expected that the result would betray that kind of irregularity which is always the character of such errors. Thus it would be expected that the predicted time would sometimes be later, and sometimes earlier than the observed time, and that it would be later and earlier to an irregular extent. On the contrary, it was observed during an interval of little more than six months which the earth took to move from A to E, that the observed time was continually later than the predicted time, and moreover, that the interval by which it was later continually and regularly increased. This was an effect too regular and consistent to be supposed to arise from the casual errors of observation; it must have its origin in some physical cause of a regular kind.

The attention of Roemer being thus attracted to the question, he determined to pursue the investigation by continuing to observe the eclipses for another half year. Time accordingly rolled on, and the earth transporting the astronomer with it, moved from E to F. On arriving at F, and comparing the observed with the predicted eclipse, it was found that the observed time was now only twelve minutes later than the predicted time. Soon after the expiration of the ninth month when the earth arrived at G, the observed time was found to be only eight minutes later; at H it was only four minutes later, and finally, when the earth returned to its first relative position with the planet, the observed time corresponded precisely with the predicted time.*

From this course of observation and inquiry it became

* The exact interval is 398 days, the synodic period of Jupiter.

apparent that the lateness of the eclipse depended altogether on the increased distance of the earth from Jupiter. The greater that distance, the later was the occurrence of the eclipse as apparent to the observers, and on calculating the change of distance, it was found that the delay of the eclipse was exactly proportional to the increase of the earth's distance from the place where the eclipse occurred. Thus when the earth was at E, the eclipse was observed 16 minutes, or about 960 seconds later than when the earth was at A. The diameter of the orbit of the earth, A E, measuring about 190 millions of miles, it appeared that that distance produced a delay of 960 seconds, which was at the rate of 198,000 miles per second. It appeared, then, that for every 198,000 miles that the earth's distance from Jupiter was in creased, the observation of the eclipse was delayed one second.

Such were the facts which presented themselves to Roemer How were they to be explained? It would be absurd to suppose that the actual occurrence of the eclipses was delayed by the increased distance of the earth from Jupiter. These phenomena depend only on the motion of the satellite and the position of Jupiter's shadow, and have nothing to do with, and can have no dependence on the position or motion of the earth, yet unquestionably the time they *appear* to occur to an observer upon the earth, has a dependence on the distance of the earth from Jupiter.

To solve this difficulty, the happy idea occurred to Roemer that the moment at which we see the extinction of the satellite by its entrance into the shadow is not, in any case, the very moment at which that event takes place, but sometime afterward, viz.: such an interval as is sufficient for the light which left the satellite just before its extinction to reach the eye. Viewing the matter thus, it will be apparent that the more distant the earth is from the satellite, the longer will be the interval between the extinction of the satellite and the arrival of the last portion of light which left it, at the earth; but the moment of the extinction of the satellite is that of the commencement of the eclipse, and the moment of the arrival of the light at the earth is the moment the commencement of the eclipse is observed.

Thus Roemer with the greatest felicity and success explained the discrepancy between the calculated and the observed times of the eclipses; but he saw that these circumstances placed a great discovery at his hand. In short, it was apparent that light is propagated through space with a certain definite speed, and that the circumstances we have just explained supply the means of measuring that velocity.

We have shown that the eclipse of the satellite is delayed one second more for every 198,000 miles that the earth's distance from Jupiter is increased, the reason of which obviously is, that light takes one second to move over that space; hence it is apparent that the velocity of light is at the rate, in round numbers, of 200,000 miles per second.

Such was the discovery which has conferred immortality upon the name of Roemer; a discovery to which, as we have shown, he was accidentally led when seeking to determine the velocity of one of the moons ot Jupiter. The velocity of light thus determined would, in the corpuscular theory, be regarded as that with which the particles of light issuing from the surface of a visible object move through space. In the undulatory theory, however, which is more generally receied, this velocity is that with which the waves are propagated through space, in the same sense as waves appear to move on the surface of water if a pebble be dropped in to form a centre round which they are propagated.

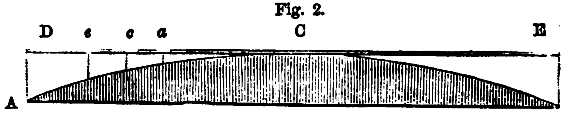
It is necessary to remember when considering any system of undulations, no matter through what medium they may be propagated, that the progressive motion which belongs to them is a motion of form merely, and not of matter. The waves which are propagated round a centre when a pebble is dropped into calm water, present an appearance to the eye as though the water which formed the wave really moved outward from the centre of the undulations. Such is, however, not the case. No particle of the fluid has any progressive motion whatever, of which many proofs may be offered. It any floating body be placed on the surface of the water, it will not be carried along by the waves, and if similar waves be formed, as they might be, by giving a peculiar motion to a sheet or cloth, they would have the same appearance of progressive motion, although the parts of the sheet or cloth, as is evident, would have no other motion than the up-and-down motion that would form the apparent undulations. The waves of the sea appear to the eye to be endowed with a progressive motion. A slight reflection, however, on the consequences of such a motion, will soon convince us that it can have no reality. The ship which floats upon the waves is not carried forward with them; they pass beneath her, now lifting her on their summits, and now letting her sink into the abyss between them. Observe a sea-fowl, or a nautilus floating on the water, and the same effect will be presented. If, however, the water itself partook of the motion as well as its waves, the ship and the fowl would be carried forward in the direction of that motion. Once on the summit of a wave, there they would continually remain, and their motion would be as smooth as if they were propelled on the calm surface of a lake.

We are then to remember that when light is propagated through space with the astonishing velocity of 200,000 miles per second, there is no material substance which really has this progressive velocity; it belongs merely to the form of the pulsations, or undulations. The same observations, exactly, are applicable to the transmission of the waves of sound through the air.

In order to submit the phenomena of light to a strict physical analysis, it is not enough to measure the motion of its waves. We require also to know their amplitude or breadth, just as, in the case of the waves of the sea, we should require to know not only the rate at which they are propagated over the surface of the water, but also the space which intervenes between the hollow or crest of each and the hollow or crest of the succeeding one.

For the solution of this problem we are indebted to Newton himself. To render intelligible the mode in which he solved it, let us imagine a flat plate of glass, such as D E (fig. 2), placed upon a convex lens of glass, the surface of which is represented by A B, but which must be supposed to have infinitely less curvature than that which appears in the figure.

Fig. 2.



The under surface of the flat plate will touch the vertex of the convexity at C, and the further any point on the under surface is from C, the greater will be the distance between the surfaces of the two glasses. Thus the distance between them at *a* is less than at *c*, and the distance at *c* is less than at *e*, and so on. The distance at the surfaces gradually increasing, in fact, from C outward.

If, looking down on the plate D E, we consider the point C as a centre, and a circle be described round it, at all points of that circle the surfaces of the glasses will have the same distances between them, and the greater that circle is, the greater will be the distance between the surfaces of glass.

Having the glasses thus arranged, Newton let a beam of light of some particular colour, produced by a prism, as red, for example, fall on the surface of the glass D E. He found that the effect produced was that a black spot appeared at the centre C, where the glasses touched; that immediately around this spot there appeared a circle of red light; that beyond that circle appeared a dark ring; that outside of that dark ring there was another circle of red light, still having the point C as its centre. Outside this second circle appeared another dark ring, beyond which there was another circle of red light, and so on, a series of circles of red light, alternated with dark rings being formed, all having the point C as their common centre.

The distances between the surfaces of glass at which the successive circles of red light were found, were too minute to be directly measured, but they were easily calculated by measuring the diameters of the circles of light; and, knowing the diameters of the convex surface A C B, this was a simple problem in geometry, easily solved, and admitting the greatest accuracy.

On making these calculations, Newton found that the distance between the glass surfaces where the second red circle was formed was double the distance corresponding to the first; that at the third red circle the distance was triple that of the first, and so on. It followed, of course, that wherever the dark rings were formed, the distances between the glass surfaces were not an exact number of times the space corresponding to the first red circle.

Thus if we express the space between the glasses at the first red circle by 1, the space between them within that circle, toward the centre C, would be a fraction. The space corresponding to the first dark ring outside the first red circle, would be expressed by 1 and a fraction; the space at the second red circle would be expressed by 2; the space at the second dark ring would be expressed by 2 and a fraction, and so on.

Newton was not slow to see that these phenomena were the direct manifestation of those effects which, in the corpuscular theory, whose nomenclature he used, corresponded to the amplitude of the waves of light in the undulatory theory. The space between the surfaces of glass at the first red ring was the amplitude of a single wave, the space at the second red circle the amplitude of two waves, and so on. Within the first red circle, the space between the glasses being less than the amplitude of a wave, the propagation of the undulation was stopped, and darkness ensued; in like manner, in the space corresponding to the second dark ring, the distance between the glasses being greater than the amplitude of one wave, but less than the amplitude of two, the propagation was again stopped, and darkness produced. But at the second red circle, the space being equal to the amplitude of two waves, the undulations were reflected and the red ring produced, and so on.

It was evident, then, that to measure the amplitude of the luminous waves, it was only necessary to calculate the distance between the glasses at the first red ring.

When light of other colours was thrown upon the glass, a similar system of luminous rings was produced, but it was found in each case that the first ring varied in its diameter according to the colour of the light, and consequently that the amplitude of the waves of lights of different colours is different. It appeared that the waves of red light were the largest; orange came next to them; then yellow, green, blue, indigo, and violet, succeeded each other, the waves of each being less than those of the preceding. But the most astonishing part of this most celebrated investigation was the minuteness of these waves. It appeared that the waves of red light were so minute, that 40,000 of them would be comprised within an inch, while the waves of violet light, forming the other extreme of the series, were so small, that 60,000 spread over an inch, and the waves of light of other colours were of intermediate magnitudes.

Thus was discovered the physical cause of the splendour and variety of colours, and a singular and mysterious alliance was developed between colour and sound. Lights are of various hues, according to the magnitude of the pulsations that produce them, exactly as musical sounds vary their tone and pitch according to the magnitude of the aerial pulsations from which they result.

But this is not all. The alliance between sound and light does not terminate here. We have only spoken of the amplitude of the luminous waves, and have shown that it determines the tints of colours. What are we to say for the altitudes of the waves? Here, again, is another link of kindred between the eye and the ear. As the altitude of sonorous waves determines the loudness of the sounds, so the altitude of luminous waves determines the intensity or brightness of the colour.

There is one step more in the series of wondrous results which these memorable investigations have unfolded. As the perception of sound is produced by the tympanum of the ear vibrating in sympathetic accordance with the pulsations of the air produced by the sounding body, so the perception of light and colour is produced by similar pulsations of the membrane of the eye vibrating in accordance with ethereal pulsations propagated from the visible object. As in the case of the ear, the rigour of scientific investigation requires us to estimate the rate of the pulsation of the tympanum corresponding to each particular note, so in the case of light are we required to count the vibrations of the retina corresponding to every tint and colour. It may well be asked, in some spirit of incredulity, how the solution of such a problem could be hoped for; yet, as we shall now see, nothing can be more simple and obvious.

Let us suppose an object of any particular colour, a red star, for example, looked at from a distance. From the star to the eye there proceeds a continuous line of waves; these waves enter the pupil and impinge upon the retina; for each wave which thus strikes the retina, there will be a separate pulsation of that membrane. Its rate of pulsation, or the number of pulsations which it makes per second, will therefore be known, if we can ascertain how many luminous waves enter the eye per second.

It has been already shown that light moves at the rate of about 200,000 miles per second; it follows, therefore, that a length of ray amounting to 200,000 miles must enter the pupil each second; the number of times, therefore, per second, which the retina will vibrate, will be the same as the number of the luminous waves contained in a ray 200,000 miles long.

Let us take the case of red light. In 200,000 miles there are in round numbers 1000,000000 feet, and therefore 12000,000000 inches. In each of these 12000,000000 of inches there are 40000 waves of red light. In the whole length of the ray, therefore, there are 480,000000,000000 waves. Since this ray, however, enters the eye in one second, and the retina must pulsate once for each of these waves, we arrive at the astounding conclusion, that when we behold a red object, the membrane of the eye trembles at the rate of 480,000000,000000 of times between every two ticks of a common clock!

In the same manner, the rate of pulsation of the retina corresponding to other tints of colours is determined; and it is found that when violet light is perceived, it trembles at the rate of 720,000000,000000 of times per second.

In the annexed table are given the magnitudes of the luminous waves of each colour, the number of them which measure an inch, and the number of undulations per second which strike the eye:—

Colours.	Length of undulation in parts of an inch.	Number of undulations in an inch.	Number of undulations per second.
Extreme Red	0·0000266	37,640	458,000000,000000
Red	0·0000256	39,180	477,000000,000000
Orange	0·0000240	41,610	506,000000,000000
Yellow	0·0000227	44,000	535,000000,000000
Green	0·0000211	47,460	577,000000,000000
Blue	0·0000196	51,110	622,000000,000000
Indigo	0·0000185	54,070	658,000000,000000
Violet	0·0000174	57,490	699,000000,000000
Extreme Violet	0·0000167	59,750	727,000000,000000

The preceding calculations are, as will be easily perceived, made only in round numbers, with a view of rendering the principles of the investigation intelligible. In the table the exact results of the physical investigations which have been carried on, on this subject, are given.

7. Whichever theory we adopt to explain the phenomena of light we are led to conclusions that strike the mind with astonishment. According to the corpuscular theory, the molecules of light are supposed to be endowed with attractive and repulsive forces, to have poles to balance themselves about their centres of gravity, and to possess other physical properties which we can only ascribe to ponderable matter. In speaking of these properties, it is difficult to divest oneself of the idea of sensible magnitude, or by any strain of the imagination to conceive that particles to which they belong can be so amazingly small as those of light demonstrably are. If a molecule of light weighed a single grain, its momentum (by reason of the enormous velocity with which it moves) would be such that its effect would be equal to that of a cannon-ball of one hundred and fifty pounds, projected with a velocity of one thousand feet per second. How inconceivably small must they therefore be, when millions of molecules, collected by lenses or mirrors, have never been found to produce the slightest effect on the most delicate apparatus contrived expressly for the purpose of rendering their materiality sensible!

If the corpuscular theory astonishes us by the extreme minuteness and prodigious velocity of the luminous molecules, the numerical results deduced from the undulatory theory are not less overwhelming. The extreme smallness of the amplitude of the vibrations, and the almost inconceivable but still measurable rapidity with which they succeed each other, were computed by Dr. Young, and are exhibited in the above table.

8. That the sensation of light is produced by the vibrations of an extremely rare and subtle fluid, is an idea that was maintained by Descartes, Hooke, and some others; but it is to Huygens that the honour solely belongs of having reduced the hypothesis to a definite shape, and rendered it available to the purposes of mechanical explanation. Owing to the great success of Newton in applying the corpuscular theory to his splendid discoveries, the speculations of Huygens were long neglected; indeed, the theory remained in the same state in which it was left by him till it was taken up by our countryman, the late Dr. Young. By a train of mechanical reasoning, which in point of ingenuity has seldom been equalled, Dr. Young was conducted to some very remarkable numerical relations among some of the apparently most dissimilar phenomena of optics to the general laws of diffraction, and to the two principles of coloration of crystallised substances.

9. Malus, so late as 1810, made the important discovery of the polarisation of light by reflection, and successfully explained the phenomenon by the hypothesis of an undulatory propagation. The theory subsequently received a great extension from the ingenious labours of Fresnel ; and the still more recent researches of Arago, Poisson, Herschel, Airy, and others, have conferred on it so great a degree of probability, that it may almost be regarded as ranking in the class of demonstrated truths. "It is a theory," says Herschel, "which, if not founded in nature, is certainly one of the happiest fictions that the genius of man has yet invented to group together natural phenomena, as well as the most fortunate in the support it has received from all classes of new phenomena, which at their discovery seemed in irreconcileable opposition to it. It is, in fact, in all its applications and details, one succession of *felicities ;* inasmuch as that we may almost be induced to say, if it be not true, it deserves to be."

10. Light and heat are so intimately related to each other, that philosophers have doubted whether they are identical principles, or merely co-existent in the luminous rays. They possess numerous properties in common : being reflected, refracted, and polarised, according to the same laws, and even exhibit the same phenomena of interference. Most substances during combustion give out both light and heat ; and all bodies, except the gases, when heated to a high temperature, become incandescent. Nevertheless, there are many circumstances in which they appear to differ.

A thin plate of transparent glass interposed between the face and a blazing fire intercepts no sensible portion of the light, but most sensibly diminishes the heat. Light and heat are therefore not intercepted alike by the same substances. Heat is also combined in different degrees with the different rays of the solar spectrum. A very remarkable discovery on this subject was made by Sir William Herschel, which would seem to establish the independence of the heating and illuminating effects of the solar rays. Having placed thermometers in the several prismatic colours of the solar spectrum, he found the heating power of the rays gradually increased from the violet (where it was least) to the extreme red, and that the maximum temperature existed some distance beyond the red, out of the visible part of the spectrum. The experiment was soon after repeated with great care by Berard, who confirmed Herschel's conclusions relative to the augmentation of the calorific power from the violet to the red, and even beyond the spectrum. This discovery of the inequality of the heating power of the different rays led to the inquiry whether the chemical action produced by light upon certain bodies was merely the effect of the heat accompanying it, or owing to some other cause. By a series of delicate experiments, Berard found that this action is not only independent of the heating power, but follows entirely a different law; its intensity being greater in the violet ray, where the heating power is the least, and least in the red ray, where the heating power is the greatest. We are thus led to the conclusion that the solar rays possess at least three distinct powers—those of heating, illuminating, and effecting chemical combinations and decompositions; and these powers are distributed among the different refrangible rays in such a manner as to show their complete independence of each other.

11. In relation to the production of light, bodies are considered as luminous and non-luminous.

Luminous bodies, or luminaries, are those which are original sources of light, such, for example, as the sun, the flame of a lamp or candle, metal rendered red-hot, the electric spark, lightning, and so forth.

Luminaries are necessarily always visible when present, provided the light they emit be strong enough to excite the eye.

Non-luminous bodies are those which themselves produce no light, but which may be rendered temporarily luminous when placed in the presence of luminous bodies. These cease, however, to be luminous, and therefore visible, the moment the luminary from which they borrow their light is removed. Thus the sun, placed in the midst of the planets, satellites, and comets, renders these bodies luminous and visible; but when any of them is removed from the solar influence by the interposition of any object not pervious by light, they cease to be visible, as is manifest in the case of lunar eclipses, when the globe of the earth is interposed between the sun and moon, and the latter object is therefore deprived of light. A candle or lamp placed in the room renders the walls, furniture, and surrounding objects temporarily luminous, and therefore visible; but if the candle be screened by any object not pervious to light, those parts of the room from which light is intercepted would become invisible, did they not receive some light from the other parts of the room still illuminated. If, however, the candle or lamp be completely covered, all the objects in the room become invisible.

12. In relation to the propagation of light, bodies are considered as transparent and opaque. Bodies through which light passes freely are called transparent, because the eye placed behind them will see such light through them. Bodies, on the contrary, which do not admit light to pass through them, are

called opaque; and such bodies consequently render a luminary invisible if interposed between it and the eye.

Transparency and opacity exist in various bodies in different degrees. Glass, air, and water are examples of very transparent bodies. The metals, stone, earth, wood, &c. are examples of opaque bodies.

Correctly speaking, no body is perfectly transparent or perfectly opaque.

There is no substance, however transparent, which does not intercept some portion of light, however small. The light is thus intercepted in two ways; first, when the light falls upon the surface of any body or medium, a portion of it is arrested, and either absorbed upon the surface, or reflected back from it; the remainder passes through the body or medium, but in so passing more or less of it is absorbed, and this increases according to the extent of the medium through which the light passes. Analogy, therefore, justifies the conclusion that there is no transparent medium which, if sufficiently extensive, would not absorb all the light which passes into it.

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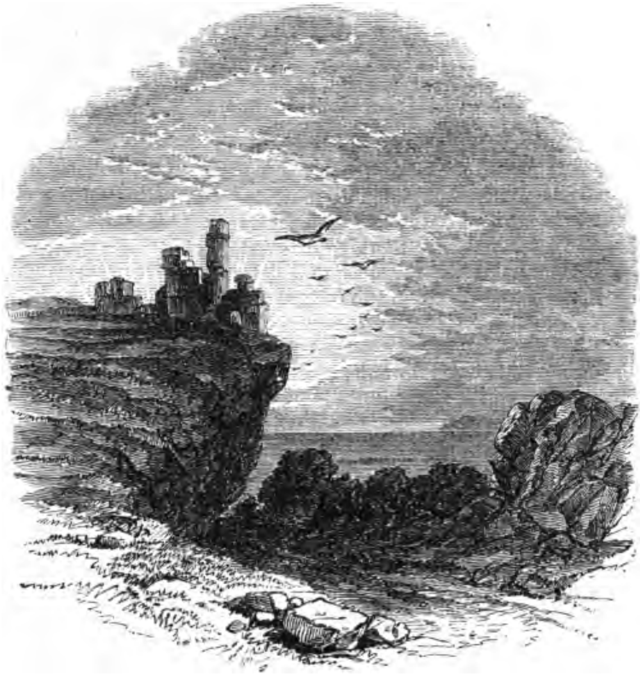

COMMON THINGS.

AIR.

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1. Of all common things, air is the most common. No space or place is accessible to us that is not filled with it. It is of all material wants that which is most incessantly indispensable to our existence. Food is an occasional want, an intermitting supply is all that is needed. Clothing may in certain cases be dispensed with, and habit may inure us to a deficiency of it. The want of warmth must be extreme to become fatal. But the privation of air, even for a brief interval, is attended with instant and certain death.

Unlike other natural wants, our consumption of air is not voluntary. The action of the lungs is like the oscillations of a pendulum. It is incessant, sleeping or waking, in sickness or in health; sitting, standing, or moving, it is maintained with a regularity and continuity quite independent of the will. Its suspension is the suspension of life.

Must we not then be prompted by a natural and irresistible curiosity to obtain some acquaintance with a physical agent so universal, so omnipresent, and so indispensable to our vitality?

2. Air is the transparent, colourless, invisible, light, and attenuated fluid with which we are always surrounded. It is drawn into our lungs by the action called suction, and after remaining a moment there, is forced out through the mouth and nose by the muscular compression of the chest. This alternate action, by which the air enters and leaves the lungs, is called respiration. During the moment it remains in the lungs, it undergoes a certain change, which we shall presently explain, in consequence of which, when expired, it is not the same as that which was inspired. The effect produced on the blood by this change is essential to the maintenance of life.

The air which, thus changed, is expired, is unfit for respiration. If, therefore, the same air be taken several times successively into the lungs, death must ensue.

3. The air around us, therefore, requires to be continually changed, that which we expire being carried away and replaced by fresh and pure air.

4. The apparent lightness of air, the freedom with which we move through it, and its invisibility, led the ancients to imagine that it was unsubstantial and immaterial, and hence the disembodied souls of the dead came to be called *spirits*, from the word *spiritus*, which signifies *air*.

5. It is a great mistake, however, to imagine that air is destitute of weight, that quality which is inseparable from whatever is material. Light it undoubtedly is, but only by comparison. Bulk for bulk, it is lighter than stone, earth, or water, or any other substance in the solid or liquid state. But light as it is, it has a certain definite weight, and a quantity of it can be assigned which will weigh many tons. The pressure produced by its weight is under certain assignable circumstances quite enormous, and when it is moved with a certain velocity its force is so irresistible that trees are torn by it from their roots, the most solid buildings overturned and reduced to ruins, and devastation spread over vast tracts of country.

Nothing can be easier than to show practically that air has weight, and what that weight is.

6. If a glass flask, having the capacity of a cubic foot, be provided with a proper neck, furnished with a stop-cock, we shall be able, by means of a well-constructed syringe, to extract from it the air which it contains, and by closing the stop-cock, and detaching the syringe, we shall have the flask void of air. Let it be weighed in that state in a good balance. Let the stop-cock be then opened so as to admit the air to fill the flask, and let it then be weighed again. It will be found to weigh 1·291 oz. or 564·8 grains more than it did when void of air.

It follows therefore that a cubic foot of air weighs 564·8 grains.

Since the weight of a cubic foot of water is 997·125 oz., it follows that, bulk for bulk, water is heavier than air in the proportion of 997·125 to 1·291, that is, of 772½ to 1.

Since thirty-six cubic feet of water weighs a ton, it follows that 772½ times thirty-six cubic feet of air also weighs a ton.

It appears, therefore, that 27810 cubic feet of air will weigh a ton.

7. When it is considered that the mass of air which taken collectively is called the ATMOSPHERE, extends above us to the height of more than fifty miles, it will easily be imagined that the weight with which it presses on the surface of every object exposed to it, must be very considerable. If, for example, we take a square inch of level surface, it is clear that that square inch must bear the weight of a column of air extending from that surface to the top of the atmosphere. It has been ascertained by experiments, susceptible of the greatest precision, (which we shall explain on another occasion) that this pressure or weight amounts to about 15lbs., and that it is subject, from time to time, to a variation not exceeding three quarters of a pound.

8. It is a well known property of fluids, that any pressure which

they exert, acts equally in all possible directions. Thus, if any body be let down into the sea, the weight of the water, which is above it, will press equally on its top, bottom, and sides. It is very easy to demonstrate this by a simple experiment.

Let several empty bottles be carefully corked, and being loaded with weights so as to sink in the water, the neck of one being presented upwards, that of another downwards, another horizontal, and the others oblique in various degrees, it will be found that when they have been sunk to a certain depth, the corks will be all forced into the bottles by the pressure of the surrounding water, with which the bottles will be immediately filled, and this will take place equally, and at the same time, with all the bottles, in whatever directions the corks may be presented to the water.

It is evident, therefore, that the pressure produced by the weight of the incumbent column of water at any given depth is equally propagated in all directions, and that a body, a fish for example, or the body of a diver, sustains that pressure, not downwards only, or on the upper surface of the body as might be at first imagined, but equally on the under surface, the sides, and, in a word, on every part of the body in contact with the water.

Now this equal transmission or propagation of pressure in all directions, is not an exclusive property of water, but is common to all substances whatever in the fluid state. Air possesses fluidity in even a greater degree, if possible, than water, being more freely mobile, and air accordingly transmits freely and without diminution in all directions whatever any pressure which it receives. The stratum of air in which we live is under the pressure, as has just been stated, of the incumbent column of air extending upwards to the limits of the atmosphere, this pressure amounting to 15 lbs. on each square inch. A body, therefore, exposed to the contact of this air is subject at all parts of its surface, upper, under, and lateral, to this pressure; and the total amount of the pressure by which it is affected will be expressed in pounds weight by the number obtained by multiplying the number of square inches in its entire surface by 15.

The body of a man of average size has a surface of about 2000 square inches. The total pressure which it sustains from the surrounding air is therefore 15 × 2000, or 30000 lbs., or nearly fourteen tons!

9. It may seem wonderful that a force so enormous, acting on all parts of the surface of the body, should not crush it and actually destroy its delicately constructed organs. This, however, is prevented by the perfect equilibrium of pressure outwards and inwards, produced by the property of fluids just explained, in

virtue of which they transmit freely, and undiminished, the pressure in all directions. The fluids which fill the entire vascular system are exposed, as well as the surface of the body, to the pressure of the atmosphere, which enters the lungs and all the cavities and open parts of the organs. These fluids transmit that pressure to all the inner parts of the body, so that the skin and integuments are pressed by them outwards by a force exactly equal to that with which the air presses the external surface of the skin inwards. These outward and inward pressures are necessarily always equal, because, in fact, they are one and the same pressure, *i.e.*, that of the air, the pressure on the external surface acting inwards, being the immediate action of the air, and the pressure of the internal fluids acting outwards being the same pressure of the air transmitted by those fluids to the inside of the skin and integuments.

10. That this outward pressure, transmitted by the fluids which fill the organs under the skin, is really at all times in operation, and that it is only counteracted by the immediate pressure of the external air upon the skin, is rendered conspicuously manifest in the well-known surgical operation of cupping. In that process the open mouth of the cupping-glass being pressed upon the skin so as to exclude all communication with the external air, the air within the cup is withdrawn, or partially withdrawn, by means of a syringe attached to the glass. The moment the skin within the glass is relieved from even a small part of the pressure of the external air by this means, the outward pressure of the fluids under the skin begins to take effect, being no longer resisted; it swells up the skin within the glass, and when the skin thus dilated is punctured with the lancet, the blood is propelled from it by the force of the pressure of the fluids under the skin acting outwards.

11. The free transmission of pressure in all directions is a property which air has in common with water and other liquids. It has, however, another quality eminently characteristic, which is not found in liquids, or any other form of matter. The property we refer to is unlimited compressibility.

Let a tube A B (fig. 1) be provided, open at one end A, and closed at the other B, and let a solid plug P be made to fit it air-tight. Let an opening, governed by a stop-cock, be provided at C. When the plug is inserted at A, the air inclosed by it in the tube will be in its natural state, provided the stop-cock be open, and the plug will be pressed upon it by the amount of the atmospheric pressure. If we suppose the plug to have the magnitude of a square inch, this pressure will be fifteen pounds.

The stop-cock C being closed, let the plug P be pressed down with a force of fifteen pounds. If the tube were filled with water instead of air, the plug would in that case maintain its position, for the water would not yield in any degree to the pressure.

Fig. 1.

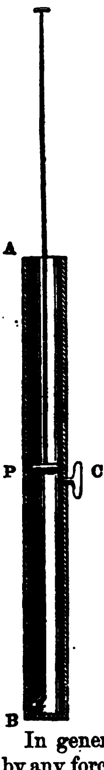
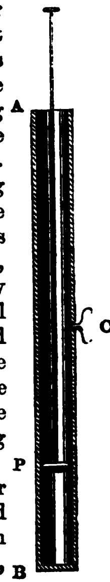


Fig. 2.



But the case is quite otherwise with air. The moment the pressure is applied, the plug will descend in the tube, squeezing or compressing the air into a less space, and it will continue to descend until the air is compressed half its original bulk. There the compression will cease, and the plug will remain at half its original distance from the bottom B of the tube, as in fig. 2.

Thus, if the original height of the plug P above the bottom of the tube were twelve inches, the plug being pressed downwards only by the atmospheric pressure, that is, by 15 lbs., its height, when pressed by 15 lbs. more, that is, by 30 lbs. in all, will be six inches. The air, which is compressed into twelve inches by 15 lbs., is therefore compressed into six inches by 30 lbs., the volume of the air being diminished in the exact proportion in which this compressing force is augmented.

This experiment may be carried farther with a like result. If the piston be forced down with a weight of 30 lbs., in addition to the atmospheric pressure, which is 15 lbs., the whole compressing force will be 45 lbs. In this case, the compressing force being augmented in the proportion of three to one, the space into which the air is compressed will be decreased in the same ratio, and the plug P will descend to four inches from the bottom B.

In general, therefore, the space into which air will be squeezed by any force will be less in exactly the proportion in which the compressing force is increased, it being well understood, nevertheless, that the original pressure of the external air, amounting to 15 lbs. per square inch, is to be included in the compressing force.

This property of unlimited and uniformly regular compressibility is one of the essential and characteristic properties of air, being one in which no other form of matter participates. Liquids are in general, for all practical purposes, absolutely incompressible. Some solids are compressible in a certain slight degree, but not at all in the general and regular way in which air is compressible.

12. Air has another characteristic and highly important quality, called ELASTICITY, which, like its compressibility, is unlimited and uniform.

Fig. 3.

Let us suppose that the plug P in the tube A B, fig. 1, instead of being pressed down, is drawn upwards, the tube being long enough to allow it all the necessary play, as in fig. 3. If, in that case, water had filled the tube under the plug, a void space would remain between the surface of the water and the plug. In short, the elevation of the plug would be followed by no sensible change in the space occupied by the water. But when the tube contains air, the result is quite otherwise. In that case, when the plug is drawn upwards, the air which before filled the tube between the plug and the bottom now expands, and swells so as still to fill the increased space left open to it by the elevation of the plug, and this expansion will go on without any practical limit to whatever height the plug may be elevated.

This capability of swelling without limit into augmented dimensions when relieved from the conditions which confine it is called ELASTICITY. Like COMPRESSIBILITY, it is a characteristic property in which no other form of matter participates. Liquids are for all practical purposes inelastic. Some solid bodies possess a certain elasticity, but not at all identical in its character or laws with the elasticity of air above described.

13. It has been explained that air in its common state exercises a pressure of 15 lbs. on each square inch of surface with which it is in contact. It exercises this pressure equally whether it is in communication with the external atmosphere or not. In the case of the tube A B and plug P, the air in the tube, before the introduction of the plug, pressed on the surface of the tube with a force of 15 lbs. per square inch, because it sustained that pressure from the incumbent weight of the atmosphere, and transmitted that pressure freely and undiminished to the inner surface of the tube. But when the plug is introduced, all communication with the external air is cut off, and nevertheless the included air still presses on the surface of the tube with the same force. As this pressure cannot arise from the incumbent weight of the external air, all communication with which is intercepted by the piston, it is due altogether to the elasticity of the air confined within the tube.

The piston inserted in the tube in this case is therefore subject to the action of two equal forces. The WEIGHT of the external air presses it *downwards* with a force of 15 lbs., and the ELASTICITY of the air confined within the tube presses it *upwards* with an equal force of 15 lbs. The piston is thus held in equilibrium, having no tendency either to rise or fall in the tube.

Indeed, the very fact that the piston inserted in the tube A B has no tendency to descend into it, and to compress the air under it, although it is urged downwards by the air above it with a force of 15 lbs., proves that the air below it must urge it upwards by a force exactly equal; since, if it were urged upwards by any less force, it would be pressed down by this excess of the force of the external air, and if it were urged upwards by any greater force than 15 lbs., it would ascend with the excess of this upward force.

Air, therefore, in its natural and usual state, has an elastic force of 15 lbs. per square inch, so that when it is shut up in any vessel or other envelope, and cut off from all communication with the external air, it will press on every square inch of the inner surface of such envelope with a force of 15 lbs.

14. This elastic force increases in the same proportion as the space in which the air is confined is diminished by compression, and it decreases in the same proportion as the space into which it is allowed to expand is increased. Thus, if we suppose that when the air fills twelve inches of the tube A B, fig. 1, it has an elastic force of 15 lbs., it will have an elastic force of 30 lbs. when it fills six inches of the tube; 45 lbs. when it fills four inches; 60 lbs. when it fills three inches, and so on. And in like manner when it is allowed to expand so as to fill twenty-four inches, its elastic force will be reduced to 7½ lbs.; when it expands to thirty-six inches, the elastic force will only be 5 lbs., and so on.

15. The stratum of air which rests on the surface of the earth, and in which the organised tribes that inhabit the earth live, derives its pressure, elasticity, and density from the weight of the whole mass of the atmosphere which rests upon it. It must, therefore, be evident, that if we ascend to greater elevations, leaving below us a certain stratum of the atmosphere, and having above us a proportionally less quantity of air, the weight of the incumbent air being less, the pressure, elasticity, and density of the stratum which surrounds us will be proportionally less. And we find this actually to be the case. At great heights on mountain chains, such as the Pyrenees or the Alps, the air is very sensibly rarefied. It is lighter, and exercises a much less pressure. In like manner, persons who ascend to great elevations in balloons find much inconvenience from the thinness of the air. The fluids confined within the body are much less resisted, certain organs become dilated, and the effect of a cupping-glass is occasionally produced, attended with bleeding at the nose, and singing in the ears.

16. The ancients imagined that air was a simple substance which entered more or less into the composition of bodies in general, and hence they called it one of the elements; the others being in their theory of physics, water, earth, and fire. Better informed now, we know that neither air, water, nor earth, are simple or elementary substances, and that fire is not a substance at all, but a physical effect due to the sudden and large production of heat which attends the chemical combination of certain substances. Thus the ancient elements are not elements at all.

But to return to air, the more immediate object of our attention at present.

17. Air—meaning by that term the air of the atmosphere, the air we breathe, the air through which we behold the firmament, the air whose currents carry our commerce over the ocean from land to land—is a compound or mixture made up of two extremely different kinds of air.

18. As there are many sorts of air having extremely different qualities and properties, although they are alike in appearance, being all invisible, transparent, colourless, light, compressible, and elastic, it has been found convenient to call them by the general name *gas* (derived from the Saxon word *gast*), and to limit the application of the term "air" to that particular compound or mixture of gases which constitutes the atmosphere.

19. The erroneous notion that air was a simple and elementary substance prevailed until the close of the last century, when Lavoisier, the celebrated French philosopher, who was one of the most illustrious of the founders of modern chemistry, showed that it was a mixture of two different gases in definite proportions, called oxygen, and azote or nitrogen.

A hundred cubic inches of air is a mixture consisting of 80 cubic inches of azote, and 20 of oxygen. The result of the most exact analyses differs from this proportion by a minute fraction, which, though not unimportant in certain respects, need not here embarrass the reader, who will do well to fix in his memory this proportion of 80 to 20.

There are many ways in which this constitution of atmospheric air may be made manifest, some of which, however, involve principles which would not be comprehended without a more extensive knowledge of chemistry than is expected from our readers in general. The following demonstration will, however, it is hoped, be understood without difficulty.

Let 100 cubic inches of common air, and 40 cubic inches of the gas called hydrogen, be introduced into a closed flask. If an electric spark be transmitted through this mixture, which may be easily done, an explosion will take place with a considerable development of heat. When the flask has been cooled, and its contents examined, it will be found to contain eighty cubic inches of azote and a quantity of water, whose weight is exactly equal to the combined weights of twenty cubic inches of oxygen and forty cubic inches of hydrogen.

The inference from this experiment is, that, under the influence of the electric spark, one of the constituents of the air has entered into combination with the hydrogen, and that their compound is water; and since the air has lost twenty cubic inches, it follows that this portion of it is a gas which has the property of combining with twice its own measure of hydrogen, and thus forming water. The gas which possesses this property is called oxygen.

The experiment here described is attended with two results, both of which have high importance. It proves first that 100 cubic inches of common air consists of eighty cubic inches of azote, and twenty of oxygen; and, secondly, that twenty cubic inches of oxygen mixed with forty of hydrogen will be converted into water by passing through them the electric spark.

It now remains to explain the chief properties of the two gases, by the mixture of which, in the proportion of eighty to twenty, or four to one, common air is formed.

20. Azote, or nitrogen, which thus forms four-fifths of the air we respire, is characterised by negative rather than positive qualities. It has neither colour, taste, nor odour. A candle or lamp is immediately extinguished when introduced into it. No animal which requires respiration can live in it.

Although this inability to support life by respiration is not peculiar to this particular gas, it has nevertheless given to it the name azote, from two Greek words signifying the negation of life.

This gas is not inflammable.

The destructive influence of this gas on animal life does not arise from any poisonous or injurious quality in the gas itself, but altogether from the absence of oxygen.

This gas, when compressed by the same force, is very little different in weight from common air. A hundred cubic inches of it weigh $30\frac{1}{8}$ grains, while 100 cubic inches of common air weigh 31 grains.

21. The other constituent of atmospheric air, called oxygen, is characterised by many very remarkable properties.

Like azote, this gas has neither colour, taste, nor odour. Bulk for bulk, and under equal pressure, it is a little heavier than common air, 100 cubic inches weighing $34\frac{1}{8}$ grains.

The properties which are most conspicuously characteristic of this gas are those which relate to combustion and respiration.

22. Combustion, or burning, is a phenomenon which consists of

the large and sudden evolution of heat and light arising from the combination of a class of bodies, called combustibles, with oxygen.

If a piece of charcoal be heated to redness, it will immediately begin to combine chemically with the oxygen of the atmosphere. A great heat and a vivid light are produced in this combination, and the product of it is a compound gas, composed of oxygen and carbon, and called carbonic acid.

In like manner, if sulphur or phosphorus be similarly heated, similar effects will ensue.

But since it is evident that these phenomena thus produced in common air arise exclusively from the presence of oxygen, which nevertheless forms only a fifth part of that air, it may naturally be inferred that if the same combustibles were placed in an atmosphere containing a greater portion of oxygen, and still more if they were placed in an atmosphere of pure oxygen, the phenomena would be far more vivid.

And this is accordingly found to be the case.

All substances, which are capable of burning in common air, burn with far greater intensity and splendour in an atmosphere of pure oxygen. A piece of wood on which the least spark of light is visible, which would be spontaneously extinguished in common air, will burst into flame the moment it is plunged in a jar of pure oxygen. A piece of charcoal, heated to redness at its point, will in like circumstances enter into vivid combustion, emitting the most brilliant scintillations, until it altogether disappears. Phosphorus similarly treated burns with a light too splendid to be looked at without pain. If the extremity of a coil of steel wire be heated to redness, and plunged in such a jar, the wire will be rapidly burnt, emitting in like manner streams of brilliant sparks.

These substances severally disappear in the process of combustion, and before science had attained to its present state of advancement it was supposed that they were destroyed. It is now known that the destruction of matter, in any form, and by any natural process, is as impossible as its creation. It is a physical maxim of high generality and undoubted truth that nothing but the immediate operation of the Divine will can either augment or diminish the quantity of matter composing the world. Whenever ponderable matter, therefore, seems to disappear, we are called upon to trace it, to discover its hiding-place, and to explain the nature and the cause of the change which produces its disappearance. In the present case nothing is easier.

23. Let us suppose, for example, that a piece of lighted charcoal of sufficient magnitude is plunged in a closed glass jar filled with

pure oxygen gas. The vivid combustion of the charcoal will take place, and will be continued for a certain time, when it will cease, becoming continually less vivid until it is extinguished. If the gas now contained in the jar be examined by the usual chemical test, it will be found that it is no longer oxygen. A taper plunged in it will be instantly extinguished. An animal placed in it will die. Its weight will be greater than that which it had previously to the experiment, and if the unburnt residue of the charcoal be weighed it will be found to have lost precisely the weight which the gas has gained.

In a word, the oxygen gas has been converted into another and heavier gas, called carbonic acid, and this has been accomplished by a portion of the charcoal entering into chemical combination with it, that combination being attended with the evolution of heat and light, which characterises the phenomenon of combustion or burning.

24. Now it is most desirable to become familiar with the character and properties of this gas, for it plays a most important part in numberless processes and phenomena natural and artificial, which we encounter daily and hourly in the common experience of life.

Like all other gases, carbonic acid in its ordinary state is invisible, colourless, compressible, and elastic. It has a pungent smell and acidulous taste. If reduced to the temperature of melting ice and compressed with a force of 36 atmospheres, that is of 36 × 15, or 540 lbs. per square inch, it is reduced to a liquid, and when reduced to 180° below zero of Fahrenheit's thermometer, it is frozen and becomes solid.

25. This gas is altogether unfit for respiration. When breathed pure it produces a violent spasm of the organ of the throat called the glottis, which prevents the gas from entering the lungs. If, however, it be mixed with so much common air as to prevent it from producing this spasm, it may enter the lungs, and in that case it acts on the system as a narcotic poison.

26. All substances used for warming rooms, such as coal, coke and wood, and all such as are used for lighting them, such as oil, tallow, wax, consist chiefly of carbon combined in small proportions with other constituents. The chief product of the combustion of all such substances is therefore carbonic acid. When coal, or other fuel, is burnt in a grate or stove, the carbonic acid is carried away by the chimney or flue, and therefore does not pollute the air of the room. But this is not the case with the carbonic acid produced by the candles and lamps used to illuminate the room. All the carbonic acid produced by them mixes with the atmosphere of the room and poisons it to

a proportionate degree. As this gas is evolved in the flame of the lamps and candles in a heated and highly expanded state, it will ascend to the ceiling of the room, and will float in a stratum there for a certain time. If means are not provided for its escape it will soon descend into, mix with, and poison the air of the room, and render it injurious to the health of those who breathe it.

27. In theatres and other large buildings, which are sometimes illuminated by a central chandelier suspended from the ceiling, an opening is provided over the chandelier, which permits the escape of the carbonic acid, exactly as the chimney of a fireplace or the flue of a stove receives that which is produced by the combustion of the fuel. In all cases whatever, the healthiness of apartments would be greatly increased if similar openings were provided for the escape of the carbonic acid produced by lamps, candles, and other causes.

28. The effervescence of soda water, champagne, ale, beer, and other similar drinks is produced by carbonic acid, which is fixed in them, and suddenly liberated when relieved from the confining pressure by the withdrawal of the cork. The agreeable pungency of these liquors is in a great degree due to the presence of this carbonic acid, which being allowed to escape by exposure in the air, or by leaving the bottle uncorked, the drink becomes stale and flat.

Water commonly contains more or less carbonic acid fixed in it. This being expelled by the process of boiling, cold boiled water acquires a peculiarly insipid taste, owing to the absence of the acid gas.

It appears that the reception of carbonic acid gas into the stomach is not attended with the same deleterious effects as are produced by its introduction into the lungs. There are few forms of food or drink which do not include more or less of it.

In general, fermentation is attended with the evolution of carbonic acid. The gas ejected from dyspeptic stomachs affected by flatulency is carbonic acid.

29. This gas is abundantly generated in all the spontaneous changes which attend the corruption of dead animal and vegetable matter. In autumn, after the fall of the leaf in woods, forests, and gardens, and in all places where dead leaves are allowed to accumulate, the air is more or less impregnated with carbonic acid, which, by reason of its weight, remains long collected in the lower strata of the air, rendering it unhealthy.

30. This gas is often collected and retained in the bottom of old wells, where it is known under the name of *choke-damp*. An animal which descends in such a well dies.

It sometimes issues from the earth, being evolved in some subterraneous process. Examples of this are presented in the case of the celebrated Grotto del Cane in Italy, and at Pyrmont, in Westphalia. The former place takes its name from the cruel and now useless experiment of showing that a dog let down into it dies.

31. Carbonic acid is so much heavier than air, that it may be decanted like a liquid from one vessel to another. It is, however, a mistake to suppose that in consequence of its relative weight, it will permanently sink to the lowest strata of the atmosphere on which it happens to be placed, on the same principle that water would sink to the bottom of oil. Gases in general are subject to a physical law, in virtue of which they mingle one with another when they are in contact, and become at length uniformly diffused through each other, notwithstanding these differences of weight.

A small proportion of this gas is always diffused through the atmosphere, being the produce of innumerable natural processes which take place on the surface of the earth. This is not to be regarded, however, as a constituent of common air, any more than the mud of the Mississippi or the Tiber, or the salt of the ocean, is to be considered as a constituent part of pure water.

32. Carbonic acid is evolved in large quantities by respiration. The oxygen, which forms one-fifth part of the common air which is inspired in respiration, is absorbed by the blood before it enters the arterial system, and the same blood on issuing from the venous system dismisses a corresponding quantity of carbonic acid, which is expired at the mouth and nostrils. Thus, while the air inspired is a mixture of azote and oxygen, the air expired is a mixture of azote and carbonic acid.

The effect, therefore, of respiration on the surrounding air is precisely the same as that of a lamp or candle. In both cases the oxygen constituent disappears, and is replaced by carbonic acid.

It is evident, therefore, that it is the oxygen constituent of common air which is the means of supporting animal life by a specific effect which it produces upon the blood which absorbs it, and which carries it through the arterial and venous systems, where it is converted into carbonic acid, and discharges a variety of functions necessary to the maintenance of life.

33. It is for this reason that oxygen is often called VITAL AIR.

34. In apartments or buildings where persons are crowded together in large numbers, more especially when they are illuminated by artificial light, there is therefore an enormous and rapid production of this noxious gas, as well by respiration as by the lamps, candles, or gas-burners used for illumination.

Although in large public buildings which are habitually thus filled, proper means of ventilation are often provided, this is not the case in general in private residences, where such assemblies are only occasional. Hence it happens that large parties, balls, and other social entertainments given in private houses are extremely injurious to the health. Multitudes are crowded together in brilliantly-lighted rooms. The respiration, the exhalation from the skin produced by an elevated temperature and by the exercise of dancing, and the combustion of vast numbers of candles, lamps, and gas-lights, evolve carbonic acid in large quantities, which, having no means of escape, accumulates until the company becomes painfully sensible of its ill-effects on respiration. Relief is then sought by opening one or more windows or doors, by which currents of fresh air are let in, and the foul air drawn out. If the air thus admitted were of a proper temperature, this palliative of the evil might be admitted to be partially efficient; but the air thus introduced is usually of a temperature from twenty to forty degrees lower than that of the room. The persons exposed to these sudden cold currents, more especially females, having their highly heated skins and open pores extensively uncovered, receive a chill, by which the integument contracting drives back into the blood the fluids which ought to have been permitted to escape by cuticular transpiration. Hence arise numberless diseases, rheumatisms, colds, fevers, and in more cases than is ever known or acknowledged, premature and ultimate death.

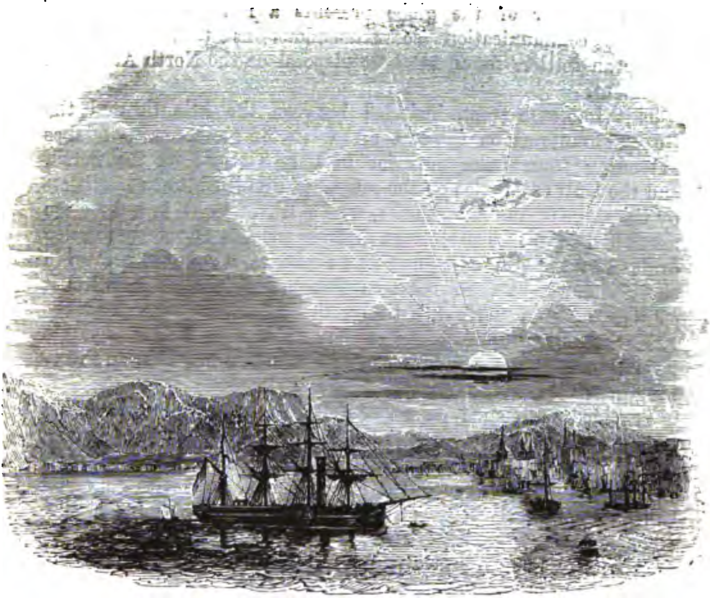
35. It will be apparent from these considerations how much it behoves architects, builders, and proprietors to provide proper expedients in the erection of private residences for the efficient ventilation of rooms.

36. We have stated that air is colourless and transparent, and this is practically true not only of common air, but of gases generally, when they are exhibited in such moderate quantities as are usually submitted to observation or experiment. Strictly speaking, however, air is not absolutely transparent or absolutely free from colour.

When a fluid is very faintly coloured, its peculiar hue is only perceptible when a considerable depth or thickness of it is submitted to view. If a tapering glass, such as those used for champagne, be filled with pale sherry or other liquor of a like colour, the peculiar colour of the liquid will be distinctly enough perceived at the top of the glass, when the eye views a certain thickness of it; but the colour becomes fainter and fainter towards the point of the cone, where it is scarcely perceptible. If a glass tube of small bore be dipped in the liquid, and, the finger being applied at the upper end to stop it, it be raised, the liquid which will be suspended in the tube will appear as transparent and colourless as water. It cannot be doubted, nevertheless, that the liquid in the tube has the same colour as the liquid in the glass. The colour is not perceived only because the quantity in the tube is too small to reflect sufficient colour to produce a sensible effect on the eye.

The atmosphere is in the same circumstances. The colour reflected even from a considerable volume of it is too faint to be perceptible. Thus the air which fills a room, or which intervenes between the eye and the buildings, trees, and other objects around us, appears quite transparent and colourless, and we see all such objects distinctly through it in their proper colours. But when, in the daytime, we look up through fifty or sixty miles height of air, illuminated by solar light, we find that a strong and decided tint of blue is perceived. This azure, which in the absence of clouds forms the celestial vault, belongs not to anything which occupies the regions of the universe in which the heavenly bodies are placed, but to the vast mass of air through which these bodies are seen.

To perceive this peculiar colour of air, however, it is not necessary that so vast a mass should be presented to the eye. Distant mountains appear bluish, not because that is their colour, but because it is the hue of the aërial medium through which we look at them. As we approach them, the quantity of the intervening air being diminished, this bluish tint is no longer perceived, and they appear with their proper colours.



NEW YORK HARBOUR.

LOCOMOTION BY RIVER AND RAILWAY

IN THE UNITED STATES.

CHAPTER I.

1. Natural apparatus of internal communication in United States.—2. Canal navigation.—3. Erie Canal.—4. Extent of canals.—5. Total cost, and cost per mile.—6. Extent of canals as compared with population.—7. River and coast navigation in United States.—8. Steam navigation on Hudson.—9. Tables of Hudson steamers.—10. Beautifully finished machinery and structure.—11. Their great speed.—12. Application of expansive principle.—13. Explosions on eastern rivers rare.—14. Description of paddle-boards and mode of working steam in steamers of eastern rivers.—15. Power of engines.—16. Fares reduced with increased size of vessels—Form and structure of Hudson steamers.—17. Description of the navigation of that river.—18. Steam navigation of other American rivers.—19. Mississippi steam-boats.—20. Cause of explosions.—21. Magnitude and splendour of boats.—22. Extent of the navigation of the Mississippi valley.

1. No quarter of the globe presents a natural apparatus of internal communication so stupendous as that which the European settlers found at their disposal on the North American continent.

This immense tract, included between the Atlantic and the Rocky Mountains on the east and west, the great chain of lakes extending from Lake Superior to Lake Ontario on the north, and the Gulf of Mexico on the south, is divided into two districts by the ridge of the Alleghanies, which traverses it in a direction north and south. The western division consists of the vast valley drained by the Mississippi and its tributaries, a territory greater in superficial extent than Western Europe. The eastern district consists of that portion between the Alleghany ridge and the Atlantic, falling towards the ocean and drained by innumerable rivers, navigable for vessels of greater or less burthen, and running generally eastward.

Provided with such means of water communication, it might have been expected that a population thinly scattered over an area so extensive, and engrossed by the exigencies of incipient agriculture, would have continued for ages contented with means of transport afforded them on so vast a scale, without having recourse to the resources of art.

It is, however, the character of man, and more especially of Anglo-Saxon man, never to rest satisfied until he renders the gifts of nature, however munificent, ten times more fruitful by his industry and skill; and it will be presently seen to what a prodigious extent the enterprise of the population of the United States has improved these means of inland transport.

I. Canal Navigation.

2. The spectacle of a machinery of commerce so imposing in magnitude and power, and so remarkably co-extensive with the vastness, the fertility, and the mineral wealth of the territory of which this emigrant people found themselves possessors, only provoked their ambition to rival the enterprise of the parent country, and to import and naturalise its improvements and its arts. Their independence was scarcely established before the same resources of art and science which ages had not been more than sufficient to develop in Britain were invoked; and a system of artificial communication was undertaken, and finally executed, on the new continent, for which, all things considered, there is no parallel in the history of civilisation.

Immediately after the acknowledgment of the independence of the American colonies by England in 1783, several companies were formed in the two principal states of the Union, those of

New York and Pennsylvania, for the purpose of constructing a system of canals. These enterprises were accordingly commenced, but on a scale too limited for the attainment of the ultimate objects; and as the United States advanced in commercial prosperity, more extensive plans were adopted. In 1807, the senate charged the Secretary of State, Mr. Galatin, to prepare a project for a general system of intercommunication by canals, based upon the geographical character of the territory of the Union.

A system of artificial water-communication was accordingly projected, which, with some modifications, was at a later period adopted and carried into execution.

These projects, however, suffered an interruption from the renewal of the war in 1812; and it was not until five years later that the vast works were commenced, the result of which has been a system of inland navigation which is without a rival in any country in the world.

3. On the anniversary of the declaration of independence celebrated the 4th July, 1817, the commencement of the great line of canal connecting the Hudson with Lake Erie was inaugurated. The river Hudson presented a navigable communication for vessels of a large class from New York to Albany. The object of this line of canal was to open a water-communication between Albany and the northern lakes, so as to connect, by continuous water-communication, the North-Western States with the Atlantic.

In less than eight years this work was accomplished by the state of New York, with its exclusive resources.

That state alone executed and brought into operation the largest canal in the world. As first constructed, the Erie canal, with its branches, cost 2,600000*l*. sterling; but its magnitude and proportions being still found inadequate to the exigencies of a continually increasing traffic, its enlargement was decided upon in 1835, and it was finally completed, at a cost of upwards of 5,000000*l*. sterling. The total length of this canal is 363 miles, and its cost of construction per mile was therefore about 13700*l*.

Meanwhile, the other states of the Union did not remain inactive. Pennsylvania especially rivalled New York in these enterprises, and became intersected with canals in all directions. In short, these works were undertaken to a greater or less extent in most of the Atlantic and some of the Western States; and the American Union now possesses a system of internal artificial water-communication amounting to nearly 4500 miles, executed with a degree of skill and perfection rarely surpassed by any similar works constructed in the states of Europe.

4. According to M. Michel Chevalier, whose work on this

subject supplies most voluminous and valuable details,* the extent of canals which were in operation in the United States on January, 1, 1843, was 4333 miles. There was a further extent projected, but not executed, amounting to 2359 miles.

5. The total cost of executing the canals which were completed was, according to M. Chevalier, 27,870964*l*., being at the average rate of 6432*l*. per mile.

Since the date of these returns considerable extension has been given to the system of canal navigation by the opening of new lines and the increased length of former ones, and it is probable that the actual extent of artificial water-communication now in use in the United States considerably exceeds 5000 miles. The average cost of executing this prodigious system of water-roads was at the rate of 6432*l*. per mile, so that 5000 miles would have absorbed a capital of above 32,000000*l*.

6. This extent of canal transport, compared with the population, exhibits in a striking point of view the activity and enterprise which characterise the American people. In the United States there is a mile of canal navigation for every 5000 inhabitants, while in England the proportion is a mile to every 9000 inhabitants, and in France a mile to every 13000. The ratio, therefore, of this instrument of intercommunication in the United States is greater than in the United Kingdom, in proportion to the population, as 9 to 5, and greater than in France in the ratio of 13 to 5.

II. River Navigation.

7. The river navigation of the United States is on a scale commensurate with the extent of their territory. The division of the country east of the Alleghanies, forming the Atlantic States, is drained by a vast number of rivers, of the first and second class, all navigable for vessels of considerable burthen, the principal of which are the Hudson, the Delaware, the Susquehanna, the Connecticut, the Potomac, the James, the Roanoke, the Savannah, and, to the southwards, the Atamala and the Alabama.

The western division is drained by the Mississippi and its hundred tributaries, navigable for vessels of great tonnage for several thousands of miles.

Besides the internal communication supplied by rivers, properly so called, a vast apparatus of water transport is derived from the geographical character of the extensive coast, stretching for about four thousand miles, from the Gulf of St. Lawrence to the

* "Histoire et Description des Voies de Communication aux États Unis, et des Travaux d'Art qui en dépendent," par Michel Chevalier. Paris, 1840—1843.

delta of the Mississippi, indented and serrated in every part with natural harbours and sheltered bays, fringed with islands, forming sounds, throwing out capes and promontories, which inclose arms of the sea, in which the waters are free from the roll of the ocean, and which, for all the purposes of internal navigation, have the character of rivers and lakes. The lines of communication, formed by the vast and numerous rivers, are completed in the interior by chains of lakes, presenting the most extensive bodies of fresh water in the known world.

8. Whatever may be the dispute maintained among the historians of art as to the conflicting claims for the invention of steam navigation, it is an incontestable fact that the first steam-boat practically exhibited for any useful purpose, was placed on the Hudson to ply between New York and Albany in the beginning of the year 1808. From that time to the present, this river has been the theatre of the most remarkable series of experiments on locomotion on water ever recorded in the history of man.

The Hudson rises near Lake Champlain, the easternmost of the great chain of lakes or inland seas which extend from east to west across the northern boundary of the United States. The river follows nearly a straight course southwards for two hundred and fifty miles, and empties itself into the sea at New York. The influence of the tide is felt as far as Albany, above which the stream begins to contract. Although this river, in magnitude and extent, is by no means equal to several others which intersect the States, it is nevertheless rendered an object of great interest by reason of the importance and extent of its trade. The produce of the state of New York, and that of the banks of the lakes Ontario and Erie, are transported by it to the city; and one of the most extensive and populous districts of the United States is supplied with the necessary imports by its waters. A large fleet of vessels is constantly engaged in its navigation; nor is the tardy but picturesque sailing vessel as yet excluded by the more rapid steamer. The current of the Hudson is said to average nearly three miles an hour; but as the ebb and flow of the tide are felt as far as Albany, the passage of the steamers between that place and New York may be regarded as equally affected by currents in both directions. The passage, therefore, whether in ascending or descending the river, is made in the same time.

This river is navigable by steamers of a large class as far as Albany, nearly one hundred and fifty miles above New York.

Attempts have been made, but hitherto without much success, to push the navigation a few miles higher, as far as the important town of Troy. The impediments arising however from the shallowness of the river appear to be so serious, that Albany has continued, and probably will continue, to be the limit of steam navigation in this direction.

The steam navigation of the Hudson is entitled to attention, not only because of the immense traffic of which it is the vehicle, but because it forms a sort of model for most of the rivers of the Atlantic States. This navigation is conducted, as will be seen, in a manner and on a principle altogether different from that which prevails on the Mississippi and its tributaries.

In the steam-vessels used on these rivers, no other strength or stability is required than is sufficient to enable them to float and bear a progressive motion through the water. Not having to encounter the agitated surface of an open sea, they are supplied with neither rigging nor sails, and are built exclusively with a view to speed. Compared with sea-going steamers, they are slender and weak in their structure, with great length in proportion to their beam, and a very small draft of water.

The position and form of the machinery are affected by these circumstances. Without the necessity of being protected from a rough sea, the engines are placed on the deck in a comparatively elevated situation. The cylinders of large diameter and short stroke, almost invariably used in sea-going ships, are rejected in these river boats, and the proportions are reversed,—a comparatively small diameter and a stroke of great length being adopted. It is but rarely that two engines are used. A single engine, placed in the centre of the deck, drives a crank placed on the axle of the enormous paddle-wheels. The great magnitude of these latter, and the velocity imparted to them, enable them to perform the office of fly-wheels, and to carry the engine through its dead points with but little perceptible inequality of motion. The length of stroke adopted in these engines supplies the means of using the expansive principle with great effect.

The steamers which navigate the Hudson are vessels of great magnitude, splendidly fitted up for the accommodation of passengers; and this magnitude and splendour of accommodation have been continually augmented from year to year to the present time.

9. In the following table (p. 23) we have given the dimensions of nine steamers which were worked on the Hudson previously to 1838.

Since the date of these returns, considerable changes have been made in the proportion and dimensions of the vessels navigating this river; all these changes having a tendency to augment their magnitude and power, to diminish their draft of water, and to increase the play of the expansive principle. Increased length and beam have been resorted to with great success. Vessels of the largest class now draw only as much water as the smallest drew a few years ago: 4ft. 6in. is now regarded as the maximum.

Names.	Length of Deck.	Breadth of Beam.	Draft.	Diameter of Wheel.	Length of Paddles.	Depth of Paddles.	Number of Engines.	Diameter of Cylinder.	Length of Stroke.	Number of Revolutions.	Part of Stroke at which Steam is cut off.
	ft.	ft.	ft.	ft.	ft.	in.		in.	ft.		
Dewit Clinton .	230	28	5·5	21	13·7	36	1	65	10	29	¾
Champlain .	180	27	5·5	22	15	34	2	44	10	27·5	½
Erie . . .	180	27	5·5	22	15	34	2	44	10	27·5	½
North America .	200	30	5	21	13	30	2	44·5	8	24	½
Independence .	148	26	—	—	—	—	1	44	10	—	
Albany . .	212	26	—	24·5	14	30	1	65	—	19	
Swallow . .	233	22·5	3·75	24	11	30	1	46	—	27	
Rochester .	200	25	3·75	23·5	10	24	1	43	10	28	
Utica . . .	200	21	3·5	22	9·5	24	1	39	10	—	
Providence .	180	27	9	—	—	—	1	65	10	—	
Lexington . .	207	21	—	23	9	30	1	48	11	24	
Narragansett .	210	26	5	25	11	30	1	60	12	—	½
Massachusetts .	200	29·5	8·5	22	10	28	2	44	8	26	
Rhode Island .	210	26	6·5	24	11	30	1	60	11	21	

In the following table we have exhibited the dimensions and other particulars of nine of the most efficient of the more recently built steamers plying on the Hudson and its collateral streams; and by a comparison of this with the former table, it will be seen to what an extent the dimensions and efficiency of these vessels have been increased.

Name of Vessel.	DIMENSIONS OF VESSEL.				ENGINE.			PADDLE-WHEEL.		
	Length.	Beam.	Depth of Hold.	Tonnage	Diameter of Cylinder.	Length of Stroke.	Number of Strokes.	Diameter.	Length of Bucket.	Depth of Bucket.
	ft.	ft. in.	ft. in.		in.	ft.		ft. in.	ft in.	in.
Isaac Newton .	333	40 4	10 0	—	81	12	18½	39 0	12 4	32
Bay State . .	300	39 0	13 2	—	76	12	21½	38 0	10 3	32
Empire State .	304	39 0	13 6	—	76	12	21½	38 0	10 3	32
Oregon . .	305	35 0	—	—	72	11	18	34 0	11 0	28
Hendrik Hudson	320	35 0	9 6	1050	72	11	22	33 0	11 0	33
C. Vanderbilt .	300	35 0	11 0	1075	72	12	21	35 0	9 0	33
Connecticut . .	300	37 0	11 0	—	72	13	21	35 0	11 6	36
Commodore .	280	33 0	10 6	—	65	11	22	31 6	9 0	33
New World . .	376	35 0	10 0	—	76	15	18	44 6	12 0	36
Alida . .	286	28 0	9 6	—	56	12	24½	32 0	10 0	32

10. It is not only in dimensions that these vessels have undergone improvements. The exhibition of the beautifully finished machinery of the English Atlantic steamers did not fail to excite the emulation of the American engineers and steam-boat proprietors, who ceased to be content with the comparatively rude though efficient structure of the mechanism of their steam-boats. All the vessels more recently constructed are accordingly finished and even decorated in the most luxurious manner. In respect of the accommodations which they afford to passengers, no water-communication in any country in the world can compare with them. Nothing can exceed the splendour and luxury of the furniture. Silk, velvet, and the most expensive carpeting, mirrors of immense magnitude, gilding and carving, are used profusely in their decorations. Even the engine-room in some of them is lined with mirrors. In the Alida, for example, the end of the room containing the engine is composed of one large mirror, in which the movements of the highly-finished machinery are reflected.

11. The new and largest class of steamers are capable of running from twenty to twenty-two miles an hour, and make, on an average, eighteen miles an hour. These extraordinary speeds are obtained usually by rendering the boilers capable of carrying steam from forty to fifty pounds pressure above the atmosphere, and by urging the fires with fanners, worked by an independent engine, by which the furnaces can be forced to any desired extent.

It is right to observe here that this extreme increase of speed is obtained at a disproportionately increased consumption of fuel. When the speed is increased, the space through which the vessel must be propelled per minute is increased in the same proportion: and, at the same time, the resistance which the moving power has to overcome is augmented in the proportion of the square of the speed. Hence, the effect to be produced by the moving power per minute, is increased by two causes: first, the actual resistance which it has to overcome is augmented in the ratio of the square of the speed; and, secondly, the space through which the moving power has to act against this resistance in each minute is increased in the ratio of the speed. Thus, the total expenditure of moving power per minute will be augmented in the proportion of the cube of the speed.

Let us suppose the speed to be increased, for example, from eighteen to twenty-one miles an hour: the power to be expended per minute to produce this effect must be increased in the ratio of the cube of 18 to the cube of 21; or, what is the same, in the ratio of the cube of 6 to the cube of 7, that is, in the ratio of 216 to 343, or as 3 to 5 very nearly.

Hence, if the furnaces could be worked with equal economy, an increased consumption of fuel per hour would be necessary in the proportion of 3 to 5; but the waste incurred by urging the blowers so as to produce a sufficiently vivid combustion is so great, that it is practically found that the consumption of fuel is increased in a much higher ratio than that which results from the increased resistance, and indeed in some cases that the increase of three or four miles an hour on eighteen miles will cause nearly triple the consumption of fuel.

12. Much of the efficiency of these engines arises from the application of the expansive principle; but to this there has been hitherto a limit, owing to the inequality of the action of the piston when urged by expanding steam on the crank. When the steam is cut off at less than half-stroke, the force of the piston is diminished before the termination of the stroke to less than one half its original amount. This inequality is aggravated by the relative position of the crank and connecting rod, the leverage diminishing in nearly the same proportion as the power of the piston diminishes. On this account it has not been found generally practicable to cut off the steam at less than half-stroke.

13. It must be observed, in relation to the navigation of these eastern rivers, that the occurrence of explosions is almost unheard-of. During the last ten years, not a single catastrophe of that kind has occurred on them, although cylindrical boilers ten feet in diameter, and composed of plating $\frac{5}{16}$ths of an inch thick, are commonly used with steam of fifty pounds pressure above the atmosphere.

14. It will be seen by the table given above, that the paddle-wheels used on these rivers have extraordinary magnitude. There is nothing particular in their construction. The split paddle-board, which was adopted about ten years since, has been discontinued, and has given way to the simple and continuous paddle-board. These boards, however, are generally placed alternately at greater and less distances from the centre, somewhat like a break-joint. Wooden spokes, with cast-iron centre pieces, are generally adopted.

The steam is universally worked with expansion, the valves for its admission and emission being moved independently of each other. A separate engine is generally provided for driving the blowers, and a cylindrical fan-blower is employed for each boiler. Some of these blowers are ten feet in diameter, being driven by a crank placed on their axle, which receives its motion from the small independent engine.

15. The great power developed by these river engines is due, not so much to the magnitude of their cylinders, as the pressure of steam used in them. Some of the most recently constructed

boats have cylinders seventy-six inches in diameter, and fifteen feet stroke. The steam has forty pounds pressure in the boiler, and is cut off at half-stroke. The wheels, which are forty-five feet in diameter, make sixteen revolutions per minute. The speed of the circumference of the wheel will therefore be twenty-five miles an hour; so that, if the speed of the boat be twenty miles an hour, we have the difference, five miles, giving the relative movement of the edge of the paddle-boards through the water.

To ascertain the power developed by these engines, let us suppose the mean effective pressure on the piston, taking into account the degree of vacuum produced by the condenser, and supposing the steam to be cut off at half-stroke, to be 40 lbs. per square inch, the area of the piston 4536 square inches, and the stroke 15 feet; the piston moves through 30 feet during each revolution of the wheels; and since 16 revolutions take place per minute, we shall find the effective force developed by the piston by multiplying its area, 4536, by twice the length of the stroke, which is 30, and by 16, which is the number of revolutions per minute. This product multiplied by 40, the number of pounds effective pressure per square inch, gives 87,091200 lbs. raised one foot high per minute as the power developed by the engine. This is equivalent, according to the ordinary mode of expressing steam power, to 2,640 horse power.

Whatever allowance, therefore, may be made for friction, &c., it is clear that the effective power thus obtained must be greater than anything hitherto executed on water.

The increase of the dimensions of these vessels and their machinery has been attended with a greatly augmented economy of fuel.

On comparing the Hendrik Hudson, for example, with the Troy, a vessel formerly well known, plying between New York and Albany, it has been found that when the speed of the former is reduced to an equality with that of the latter, the trip between New York and Albany being performed in the same time, the former consumed thirteen tons of coal while the latter consumed twenty; yet the displacement of the Hendrik Hudson, owing to its increased dimensions, is nearly twice that of the Troy.

The ease with which these vessels of extraordinary length and beam and small draft move through the water is very remarkable. The results of their performance show that the resistance per square foot of immersed midship section is not perceptibly increased by the increased length of the vessel, and the consequently augmented surface and friction. This anomaly has not been explained, but it is certain that the increased length does not diminish the effect of the moving power in any perceptible degree.

16. Practical evidence of the economy arising from this increase of power and dimensions is supplied by the fact that the proprietors of the Hudson steam-boats reduced their tariff for passengers, as well as for freight, as they increased the size of their vessels.

Previously to 1844 the lowest fare from New York to Albany, a distance of 145 miles, was 4*s.* 4*d.*; at present the fare is 2*s.* 2*d.*; and for an additional sum of the same amount the passenger can command the luxury of a separate cabin. When the splendour and magnitude of the accommodation is considered, the magnificence of the furniture and accessories, and the luxuriousness of the table, it will be admitted that no similar example of cheap locomotion can be found in any part of the globe. Passengers may there be transported in a floating palace, surrounded with all the conveniences and luxuries of the most splendid hotel, at the average rate of twenty miles an hour, for less than *one-sixth of a penny per mile!*

It is not an uncommon occurrence during the warm season to meet persons on board these boats who have lodged themselves there permanently, in preference to hotels on the banks of the river. Their daily expenses in the boat are as follow:—

	s.	*d.*
Fare	2	2
Separate bed-room	2	2
Breakfast, dinner, and supper	6	6
Total daily expense for board, lodging, attendance, and travelling 150 miles at 20 miles an hour	10	10

Such accommodation is, on the whole, more economical than an hotel. The bed-room is as luxuriously furnished as the handsomest chamber in an hotel or private house, and is much more spacious than the room similarly designated in the largest packet ships.

To obtain an adequate notion of the form and structure of one of the first-class steam-boats on the Hudson, let it be supposed that a boat is constructed similar in form to a Thames wherry, but above 300 feet long and 25 or 30 feet wide. Upon this, let a platform of carpentry be laid, projecting several feet upon either side of the boat, and at stem and stern. The appearance to the eye will then be that of an immense raft, from 250 to 350 feet long, and some 30 or 40 feet wide. Upon this flooring let us imagine an oblong rectangular wooden erection, two stories high to be raised. In the lower part of the boat, and under the flooring just mentioned, a long narrow room is constructed, having a series of berths at either side, three or four tiers high. In the centre of this flooring is usually, but not always, enclosed an oblong, rectangular space, within which the steam machinery is placed, and this enclosed space is continued upwards through the structure raised on the platform, and is intersected at a certain height above the platform by the shaft or axle of the paddle-wheels.

These wheels are propelled, generally, by a single engine, but occasionally, as in European states, by two. The paddle-wheels are usually of great diameter, varying from 30 to 40 feet, according to the magnitude of the boat. In the wooden building raised upon the platform, already mentioned, is contained a magnificent saloon devoted to ladies, and to those gentlemen who accompany them. Over this, in the upper story, is constructed a row of small bed-rooms, each handsomely furnished, which those passengers can have who desire seclusion, by paying a small additional fare.

The lower apartment is commonly used as a dining or breakfast-room.

In some boats, the wheels are propelled by two engines, which are placed on the platform which overhangs the boat at either side, each wheel being propelled by an independent engine; the wheels, in this case, acting independently of each other, and without a common shaft or axle. This leaves the entire space in the boat, from stem to stern, free from machinery. It is impossible to describe the magnificent *coup d'œil* which is presented by the immense apparent length when the communication between them is thrown open. Some of these boats, as has been already stated, are upwards of three hundred feet long, and the uninterrupted length of the saloons corresponds with this.

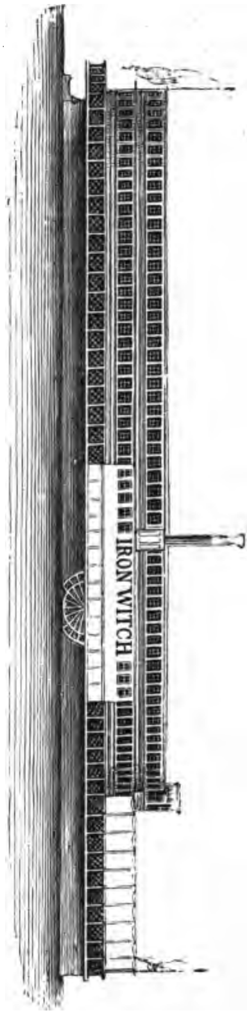
This arrangement of machinery is attended with some practical advantages, one of which is a facility of turning, as the wheels, acting independently of each other, may be driven in opposite directions, one propelling forwards and the other backwards, so that the boat may be made to turn, as it were, on its centre. Although, from the great width of the Hudson, no great difficulty is encountered in turning the longest boat, yet cases occur in which this power of revolution is found extremely advantageous.

Another advantage of this system is, that when one of the two engines becomes accidentally disabled, the boat can be propelled by the other.

The general appearance of the Hudson steamers is represented in the annexed engraving of the "Iron Witch."

17. No spectacle can be more remarkable than that which the Hudson presents for several miles above New York. The skill with which these enormous vessels, measuring from three to four hundred feet in length, are made to thread their way through the crowd of shipping, of every description, moving over the face

of this spacious river, and the rare occurrence of accidents from collision, are truly admirable. In a dark night these boats run at the top of their speed through fleets of sailing vessels. The bells through which the steersman speaks to the engineer scarcely ever cease. Of these bells there are several of different tones, indicating the different operations which the engineer is commanded to make, such as stopping, starting, reversing, slackening, accelerating, &c. At the slightest tap of one of these bells, these enormous engines are stopped, or started, or reversed by the engineer, as though they were the plaything of a child. These vessels, proceeding at sixteen or eighteen miles an hour, are propelled among the crowded shipping with so much skill as almost to graze the sides, bows, or sterns of the vessels among which they pass.



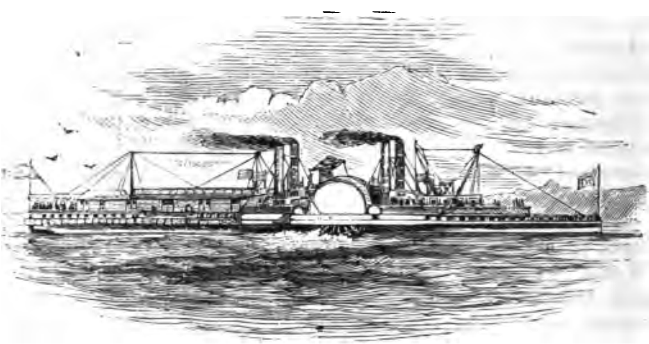
The difficulty attending the evolutions by a vessel such as the New World, for example, one hundred and twenty-five yards long and twelve yards wide, may be easily imagined; and the promptitude and certainty with which an engine whose pistons are seventy-six inches in diameter, and whose stroke is five yards in length, is governed must be truly surprising.

18. The navigation of the other rivers of the Atlantic States differs in nothing from that of the Hudson and its collateral branches, except in the extent of their traffic and the magnitude and power of the steamers. The engines, in all cases, are constructed on the condensing principle; and although steam of forty or fifty pounds above the pressure of the atmosphere is frequently used, it is worked expansively, and

a good vacuum is always sustained behind the piston by means of the condenser.

19. The steam navigation of the Mississippi is conducted in a manner entirely different from that of the Hudson and the eastern rivers. Every one must be familiar with the lamentable accidents which happen from time to time, and the loss of life from explosion which continually takes place in those regions.

These accidents, instead of diminishing with the improvements of art, appear rather to have increased. Engineers, disregarding the heart-rending narratives continually published, have done literally nothing to check the evil; and it may be almost said to be a disgrace to humanity, that the legislature of the Union has not ere this interposed its authority to check abuses, which are productive of such calamities.



MISSISSIPPI STEAMBOAT.

In a Mississippi steam-boat the cabins and saloons provided for the accommodation of the passengers, though less magnificently furnished, are as spacious as those already described in the boats on the Hudson. They are, however, erected on a flooring or platform, six or eight feet above the deck of the vessel. Upon this deck, and in the space under the cabins and saloons allotted to the passengers, are placed the engines, which are of the coarsest structure. They are invariably worked with high-pressure steam without condensation; and in order to obtain that effect, which, in the boats on the Hudson, is due to the vacuum, the steam is worked at an extraordinary pressure. I have myself frequently witnessed boilers of the most inartificial construction worked with steam of the full pressure of 120 lbs. per square inch; but more recently this pressure has been increased, the ordinary working pressure being now 150 lbs., and I am assured, on good authority, that it is not unfrequently raised to even 200 lbs. The boilers are cylindrical, of large diameter, and of the rudest kind. When returning flues are constructed in them, the space left is so small, that the slightest variation in the quantity of water they contain, or in the trim of the vessel, causes the upper flues to be uncovered, and the intense action of the furnace in this case soon renders them red-hot, when a frightful collapse is almost inevitable. The red-hot iron, no longer able to resist the intense pressure, gives way, the boiler explodes, and the scalding water is scattered in all directions, often producing more terrible effects than even the fragments of the boiler which are projected around with destructive force.

20. Another frequent cause of explosion in these boilers is the quantity of mud held in suspension in the waters of the Mississippi below the mouth of the Missouri. As the water in the boiler is evaporated, the earthy matter which it held in suspension remains behind, and accumulates in the boiler, in the bottom of which it is at length collected in a thick stratum. This produces effects similar to those which take place in marine boilers, in consequence of the deposition of salt. This earthy stratum collected within the boiler being a non-conductor, the heat proceeding from the furnace is interrupted, and, instead of being absorbed by the water, is accumulated in the boiler-plates, which it ultimately renders red-hot. Being thus softened, they give way, and the boiler bursts. The only preventive remedy of this catastrophe is, to blow the water out of the boiler from time to time, before a dangerous accumulation of mud takes place, in the same manner as marine boilers are blown out to prevent the accumulation of salt. The engine-drivers and captains, however, rarely attend to this process. They are too intent upon obtaining speed, and, to use their own phrase, "going a-head." They do not hesitate to endanger their own lives and those of the passengers, rather than allow themselves to be outrun by a rival boat.

Not only the Mississippi, but the Ohio, the Missouri, the Illinois, the Red River, and, in a word, all the tributaries of the Father of Rivers, are navigated for many thousands of miles by this description of boats, worked with the same reckless disregard of human life.

21. The magnitude and splendour of these boats is little, if at all, inferior to those of the Hudson. They are, however, constructed more with a view to the accommodation of freight, as they carry down the river large quantities of cotton and other produce, as well as passengers, to the port of New Orleans. Many of these vessels are three hundred feet and upwards in length, and are capable of carrying a thousand tons freight, and three or four

hundred deck passengers, besides the cabin passengers. The traffic in goods and passengers of the entire extent of the immense valley of the Mississippi is carried by these vessels, except that portion which is floated down by the stream in a species of raft called flat-boats.

22. This line of steam-navigation is continued up the Mississippi, branching east and west along its great tributaries. The Ohio carries it eastwards as far as Pittsburgh, in Pennsylvania. A canal connects the Ohio at Cincinnati with Lake Erie. The navigation of the Upper Mississippi is continued by the Illinois river to a port near Lake Michigan, with which it is connected by a canal extending to Chicago, on the western shore of that lake. Here commences the great chain of lake steam-navigation, which extends across the northern division of the States, traversing Lakes Michigan, Huron, Erie, and Ontario, and being continued along the St. Lawrence, to Montreal and Quebec. The lakes are connected by canals.

By the Erie canal, connecting the lake of that name with the head of the Hudson navigation at Albany, the circuit of navigation round the United States is completed.

LOCOMOTION BY RIVER AND RAILWAY

IN THE UNITED STATES.

CHAPTER II.

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1. Notwithstanding the facilities for coast navigation which are offered along the Atlantic shores from New York southwards, successful efforts have been directed to establish a parallel inland

communication by the Potomac and the Hudson. A line of inland steamers is established between the Potomac and New York by Chesapeake Bay, the Delaware, the Chesapeake and Delaware canal, the Delaware and Rariton canal, and the Rariton river, and by these means the same line of communication is extended to the shores of New England and Long Island Sound.

A project is introduced, and likely to be carried into effect, for enlarging the Great Erie canal, so as to admit of steamers. When this shall be effected, the entire extent of the States, from Washington, by New York, Albany, the great Northern Lakes, and the Mississippi, to New Orleans, will be surrounded by a continuous chain of inland steam-navigation. The importance of this internal communication in the event of a war must be apparent.

The form and structure of these river-steamers, as described in general terms in the last chapter, will be more easily understood

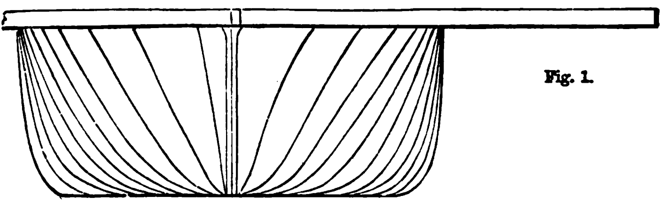
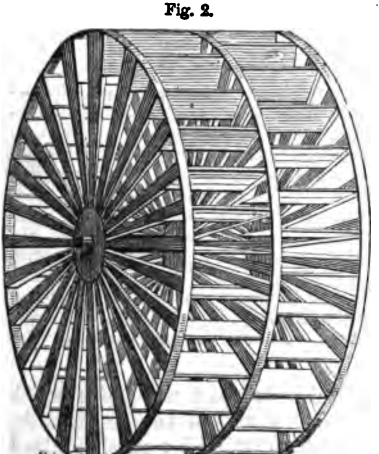


Fig. 1.

by figure 1, which represents a cross section of the hull with one-half of the platform, which is placed upon it, and which supports the upper cabins and saloons. This hull is constructed with a perfectly flat bottom and perpendicular sides, and is rounded at the angles. At the bow or cutwater they are made very sharp.

Fig. 2.



The split paddle-wheel, which until very lately was exclusively used in these boats, is represented in fig. 2, and is formed as if by the combination of two or more common paddle-wheels, placed one outside the other, on the same axle, but so that the paddle-boards of each may have an intermediate position between those of the adjacent one, as represented in fig. 2.

The spokes, which are bolted to cast-iron flanges, are of wood. These flanges, to which they are so bolted, are keyed upon the paddle-shaft. The outer extremities of the spokes are attached to circular bands or hoops of iron, surrounding the wheel; and the paddle-boards, which are formed of hard wood, are bolted to the spokes. The wheels thus constructed, sometimes consist of three, and not unfrequently four, independent circles of paddle-boards, placed one beside the other, and so adjusted in their position that the boards of no two divisions shall correspond.

2. Although the subject of this tract is limited to inland transport, it will not be without interest to exhibit here some particulars of the progress made in the United States in sea steam-navigation. With this view we have given, in the following table, (p. 36), the dimensions and power of some of the principal sea-going steamers which had been constructed and brought into operation at the date of the last reports accessible to us. It must, however, be always remembered, that the progress of enterprise, more especially in this department, in the United States is so rapid, that probably before these pages come into the hands of the reader many other and more magnificent vessels will have been launched.

3. The other class of steamers used for towing the commerce of the rivers corresponds to the goods trains on railways. No spectacle can be more remarkable than these locomotive machines, dragging their enormous load up the Hudson. They may be seen in the midst of this vast stream, surrounded by a cluster of twenty or thirty loaded craft of various magnitudes. Three or four tiers are lashed to them at each side, and as many more at their bow and at their stern. The steamer is almost lost to the eye in the midst of this crowd of vessels which cling around it, and the moving mass is seen to proceed up the river, no apparent agent of propulsion being visible, for the steamer and its propellers are literally buried in the midst of the cluster which clings to it and floats round and near it.

4. As this *water goods train*, for so it may be called, ascends the Hudson, it drops off its load, vessel by vessel, at the towns which it passes. One or two are left at Newburgh, another at Powkeepsie, two or three more at Hudson, one or two at Fishkill, and, in fine, the tug arrives with a residuum of some half-dozen vessels at Albany.

Name and Route of Vessel.	DIMENSIONS OF VESSEL. Length.	Beam.	Depth of Hold.	Tonnage.	ENGINE. Diam. of Cylinder.	Length of Strokes.	Number of Strokes.	PADDLE-WHEEL. Diam.	Length of Bucket.	Depth of Bucket.
	ft.	ft. in.	ft. in.		in.	ft. in.		ft. in.	ft. in.	in.
Panama, Panama and San Francisco	200	33 6	20 0	..	70	8 0	17	26 0	8 9	30
Pacific, New York and Liverpool	280	45 6	24 0	..	95	9 0	$16\frac{1}{2}$	35 0	11 6	34
Antarctic, ditto	280	45 6	24 0	..	96	10 0	$16\frac{1}{2}$	35 6	12 0	32
Washington, New York, Southampton, and Bremen	230	39 0	32 0	1750	72	10 0	12	35 0	7 6	36
Hermann, Do.	235	40 0	32 0	1850	72	10 0	12	36 0	8 0	36
Southerner, New York and Charleston	196	32 0	22 0	850	67	8 0	14	31 0	7 6	30
Northerner, Do.	206	33 0	22 0	1000	70	8 0	14	31 0	7 6	30
Cherokee, New York and Savannah	212	35 0	22 0	1250	75	8 0	14	31 0	8 0	30
Tennessee, Do.	212	35 0	22 0	1250	75	8 0	14	31 0	8 6	30
Oregon, Panama and Oregon................	200	34 0	20 0	1100	70	8 0	15	26 0	9 0	30
California, Do.	200	33 0	20 0	1050	70	8 0	15	26 0	9 0	30
Franklin, New York and Havre	260	42 0	26 0	2300	94	8 0	..	34 0	12 0	30
Atlantic, New York and Liverpool	280	46 0	32 0	2800	95	9 0	..	35 0	12 0	32
United States, New York, New Orleans, and Chagres	250	40 0	34 6	..	80	9 0	16	35 0	9 0	36
Crescent City, Do.	220	34 0	17 0	..	80	9 0	16	32 0	8 0	30
Empire City, Do.	230	33 0	17 6	..	83	9 0	..	32 0	8 0	30
Georgia, Do.	260	45 0	34 6	..	90	8 0	..	36 0	10 6	30
Ohio, Do.	260	47 0	34 6	..	90	8 0	..	36 0	10 6	30
Falcon, Do., touching at Havannah..........	206	32 0	22 0	..	60	5 0	16	30 0	7 8	13
Powhatan .... } Government vessels.	254	45 0	26 6	$2419\frac{32}{95}$	70	10 0	..	31 0	10 0	30
Susquehanna .... } Government vessels.	252	45 0	26 6	$2398\frac{2}{95}$	70	10 0	..	31 0	9 6	34
Saranac .... } Government vessels.	215	33 0	23 6	$1459\frac{21}{95}$	60	9 0	..	27 0	9 0	30
								Screw Propellers.		No. of Blades.
San Jacinto ...... } Government vessels.	215	38 0	23 6	..	$62\frac{1}{2}$	4 2	..	14 0	5 0	6
Carolinian, Philadelphia and Charleston......	175	28 0	18 0	660	44	8 0	..	11 0	..	
Philadelphia, Do.	192	33 0	18 6	..	56	6 9	19	27 0	8 9	
Isabel, Charleston and Havannah	222	23 0	21 6	1115	72	8 0	16	31 0	8 0	
Republic, Baltimore and Charleston	200	30 0	18 6	800	54	6 0	..	25 6	8 9	

III. Railways.

5. The phenomena of transport so unexpectedly developed on the opening of the Liverpool and Manchester Railway, and the miracles of swift locomotion there exhibited, had no sooner been announced, than the Americans, with their usual ardour, resolved to import this great improvement; and projects of passenger railways, on the vast scale which characterises all their enterprises, were immediately set forth.

Some lines of railway in isolated positions, around coal-works and manufactories, had been, as in England, already for some years in operation. It was not, however, until after 1830 that the railway system began to assume in America the character which it had already taken in England. A few years were sufficient to bring it into practical operation in several parts of New England and in the State of New York; and, once commenced, its progress was extremely rapid.

As might naturally be expected, the chief theatre of railway enterprise is the Atlantic States. The Mississippi and its tributaries have hitherto served the purposes of commerce and intercommunication to the comparatively thinly scattered population of the Western States so efficiently, that notwithstanding the extraordinary enterprise of the people, the railway system has hitherto made comparatively small progress in these vast forest-covered plains and open prairies. Nevertheless they have not altogether escaped the operations of the engineer; and the traveller already feels the benefit, even in these remote regions, of the new art of transport. These railways consist as yet of detached and single lines, unconnected with the vast network which we shall presently notice.

To the traveller in these wild regions, the aspect of such artificial agents of transport in the midst of a country, a great portion of which is still in the state of native forest, is most remarkable, and strongly characteristic of the irrepressible spirit of enterprise of its people. Travelling in the backwoods of Mississippi, through native forests, where, till within a few years, human foot never trod, through solitudes, the silence of which was never broken, even by the red man, we have been sometimes filled with wonder to find ourselves transported by an engine constructed at Newcastle-on-Tyne, and driven by an artisan from Liverpool, at the rate of twenty miles an hour. It is not easy to describe the impression produced by the juxtaposition of these refinements of art and science with the wildness of the country, where one sees the frightened deer start from its lair at the snorting of the ponderous machine and the appearance of the snake-like train which follows it.

6. The first American railway was opened for passengers on the last day of 1829. It appears that in 1849, after an interval of just twenty years, there were in actual operation 6565 miles of railway in the States. The cost of construction and plant of this system of railways, according to official reports, was 53,386885*l.*, being at the average rate of 8129*l.* per mile.

7. We have, however, before us documents which supply data to a more recent period, and have computed from them the following table, exhibiting the number of miles of railway which were in actual operation in the United States, the capital expended in their construction and plant, and the length of the lines in process of construction, but not yet completed in 1851:—

	Railways in operation.	Cost of Construction and Plant.	Railways projected and in progress.	Cost per mile.
	Miles.	£	Miles.	£
Eastern States, including Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut	2845	23,100987	567	8120
Atlantic States, including New York, the Jerseys, Pennsylvania, Delaware, and Maryland . .	3503	27,952500	2020	7979
Southern States, including Virginia, the Carolinas, Georgia, Florida, and Alabama	2106	8,253130	1283	3919
Western States, including Mississippi, Louisiana, Texas, Tennessee, Kentucky, Ohio, Michigan, Indiana, Illinois, Missouri, Iowa, and Wisconsin	1835	7,338290	5762	3999
Totals and averages . . .	10289	66,644907	9632	6478

8. Of the total length of railways which overspread the territory of the Union, more than the half are constructed in the States of Pennsylvania, New York, and those of New England. The principal centres from which these lines of communication diverge are Boston, New York, and Philadelphia.

A considerable extent, though of less importance, diverges from Baltimore; and recently lines of communication of great length have been constructed, from Charleston in South Carolina, and from Savannah in Georgia.

9. From Boston three trunk-lines issue; the chief of which passes through the State of Massachusetts to Albany, on the Hudson. This line of railway is 200 miles in length, and appears destined to carry a considerable traffic. Its ramifications southward, through the smaller states of New England, are numerous, chiefly leading to the ports upon Long Island Sound, which communicate by steam-boats with New York. The first branch is carried from Worcester, in Massachusetts, to New London on the Sound, where it meets a short steam-ferry which communicates with Greenport, at the eastern extremity of Long Island, from which another railway, nearly fifty miles long, is carried to Brooklyn, which occupies the shore of that island immediately opposite New York, and communicates with the latter city by a steam-ferry.

Thus there is a continued railway communication from Boston to New York, interrupted only by two ferries.

Another branch of the great Massachusetts line is carried south from Springfield, through Hartford to Newhaven; and a third from Pittsfield to Bridgeport, both the latter places being on the Sound, and communicating with New York by steamboats.

The second trunk-line from Boston proceeds southwards to Providence, and thence to Stonington, from which it communicates by a ferry with the Long Island Railway. This trunk-line throws off a branch from Foxburgh to New Bedford, where it communicates by ferries with the group of islands and promontories clustered round Cape Cod.

A third trunk-line proceeds from Boston through the State of Maine.

10. Notwithstanding the speed and perfection of the steam navigation of the Hudson, a railway is constructed on the east side of that river to Albany.

From Albany an extensive line of railway communication, 323 miles in length, is carried across the entire State of New York to Buffalo, at the head of Lake Erie, with branches to some important places on the one side and on the other. This line forms the continuation of the western railway, carried from Boston to Albany, and, combined with this latter, completes the continuous railway communication from the harbour of Boston to that of Buffalo on Lake Erie, making an entire length of railway communication, from Boston to Buffalo, of 523 miles.

The branches constructed from this trunk-line are not numerous. There is one from Schenectady to Troy, on the Hudson, and another from Schenectady to Saratoga; another from Syracuse to Oswego, on Lake Ontario; and another from Buffalo to the falls of Niagara, and from thence to Lockport.

Not content with this fine line of communication to the Western Lakes, the commercial interests of New York have projected, and in part constructed, a more direct route from New York to Buffalo, independent of the Hudson.

The disadvantage of this river as a sole means of communication is, that, during a certain portion of the winter, all traffic upon it is suspended by frost. In this case, the line of railway communicating already from Bridgeport and Newhaven to Albany has been resorted to by travellers. However, it may be regarded as certain, that the intermediate traffic of the State of New York along the direct line of railway now in progress from that city to Buffalo, will very speedily be sufficient for the support of an independent line of railway.

The immediate environs of New York are served by several short railways, as is usual indeed in all great capitals where the railway system of transport prevails.

The line connecting that city with Haarlem is analogous in many respects to the Greenwich and Blackwall lines at London, and the Versailles and St. Germain lines at Paris. It is supported by a like description of traffic. The New York line, however, has this peculiarity, that it is conducted through the streets of the capital upon their natural level, without either cutting, tunnel, or embankment. The carriages, on entering the town, are drawn by horses, four horses being allowed to each coach; each coach carrying from sixty to eighty persons, and being constructed like the railway coaches in general in the United States.

The rails along the streets are laid down in a manner similar to that which is customary at places where lines of railway in England cross turnpike roads on a level. The surface of the rail is flush with the pavement, and a cavity is left for the flange to sink in.

Other short railways, from New York to Paterson, Morristown, and Somerville, require no particular note.

11. The great line of railway already described, from Boston to New York, is continued southwards from that capital to Philadelphia. There are here two rival lines; one of which, commencing from Jersey city on the Hudson, opposite the southern part of New York, is carried to Bordentown, on the left bank of the Delaware, whence the traffic is carried by steamboats a few miles further to Philadelphia. The rival line commences from South Amboy in New Jersey, to which the traffic is brought from New York by steamers plying on the Rariton river, which separates New Jersey from Staten Island. From Amboy, the railway is continued to Camden, on the left bank of the Delaware, opposite Philadelphia.

By far the greater part of the traffic between New York and Philadelphia is carried by the former line.

12. Philadelphia is the next great centre from which railways diverge. One line is carried westward through the state of Pennsylvania, passing through Reading, and terminating at Pottsville, in the midst of the great Pennsylvanian coal-field. There it connects with a network of small railways, serving the coal and iron mines of this locality. This line of railway is a descending line towards Philadelphia, and serves the purposes of the mining districts better than a level. The loaded trains descend usually with but little effort to the moving power, while the empty waggons are drawn back.

The passenger traffic is chiefly between Reading and Philadelphia.

Another line of railway is carried westward through the state of Pennsylvania, passing through Lancaster, Harrisburg, the seat of the legislature, Carlisle, and Chambersburg, where it approaches the Baltimore and Ohio Railway. The length of this railway from Philadelphia to Chambersburg is 154 miles. The former, to Pottsville and Mount Carbon, is 108 miles, the section to Reading being 64.

13. The rate at which this prodigious extent of public works has been executed will appear by the following table:—

Year.	Miles in operation.
1830	167
1832	213
1835	787
1840	2380
1845	3659
1846	4144
1847	4249
1848	5258
1849	7000
1850	8797
1851	10289

14. It appears from returns still more recent that on the 1st of January, 1853, the number of miles of railway in operation was 13315, and the number of miles in process of construction was 12029; so that in the two years ending the first of January, 1853, a total extent of railway measuring 3026 miles was brought under traffic, and the construction of 2397 miles of new railway was commenced.

15. The proportion in which this enormous extent of overland communication is distributed among the confederated States, and the proportion of its extent in each State to the superficial area and to the population, are exhibited in the following table:—

TABLE showing the Area, Population, Length of Railway, and the Ratio of the Railway to the Area and Population in each of the States of the American Union in 1853.

STATES.	AREA SQ. MILES.	POPULATION.	MILES OF RAILWAY.			MILES PER 100 SQUARE MILES OF SURFACE.			MILES PER 1000 INHABITANTS.		
			In operation.	In progress.	Total.	In operation.	In progress.	Total.	In operation.	In progress.	Total.
Maine	30280	583188	395	111	506	1·30	0·67	1·67	0·68	0·19	0·87
New Hampshire	9000	317964	500	42	542	5·55	0·47	6·02	1·57	0·13	1·70
Vermont	10212	314120	439	..	439	4·30	..	4·30	1·40	..	1·40
Massachusetts	7800	994499	1140	66	1206	14·61	0·85	15·46	1·15	0·07	1·22
Rhode Island	1306	147544	50	32	82	3·85	2·46	6·31	0·34	0·22	0·56
Connecticut	4674	370791	630	198	828	13·48	4·24	17·73	1·70	0·53	2·23
New York	46000	3,097349	2150	1004	3154	4·67	2·18	6·85	0·69	0·32	1·01
New Jersey	8320	480553	254	85	339	3·06	1·00	4·06	0·53	0·18	0·71
Pennsylvania	46000	2,311786	1211	914	2125	2·63	2·00	4·63	0·52	0·40	0·92
Delaware	2120	91535	16	11	27	0·76	0·50	1·26	0·17	0·12	0·29
Maryland	9356	583035	521	..	521	0·56	..	0·56	0·89	..	0·89
Virginia	6352	1,421661	624	610	1234	9·82	9·60	19·42	0·44	0·43	0·87
North Carolina	45000	868903	249	248	497	0·55	0·55	1·10	0·29	0·29	0·58
South Carolina	24500	668507	599	296	895	2·45	1·21	3·66	0·90	0·44	1·34
Georgia	58000	905999	857	203	1060	1·48	0·35	1·83	0·95	0·22	1·17
Florida	59268	87401	23	..	23	0·04	..	0·04	0·26	..	0·26
Alabama	50722	771671	236	666½	902½	0·47	1·31	1·78	0·31	0·86	1·17
Mississippi	47156	600555	95	875	970	0·20	1·86	2·06	0·16	1·46	1·62
Louisiana	46431	517739	63	200	263	0·14	0·43	0·57	0·12	0·39	0·51
Texas	237321	212592	32	..	32	0·01	..	0·01	0·15	..	0·15
Tennessee	45608	1,002625	185	509½	694½	0·41	1·12	1·53	0·18	0·51	0·69
Kentucky	37680	982405	94	659	753	0·25	1·75	2·00	0·09	0·67	0·76
Ohio	39964	1,980408	1418	1736	3154	3·54	4·34	7·88	0·72	0·88	1·60
Michigan	56243	397654	427	..	427	0·76	..	0·76	1·07	..	1·07
Indiana	33869	988415	755	979	1734	2·23	2·89	5·12	0·76	0·99	1·75
Illinois	55405	851470	296	1662	1958	0·53	3·00	3·53	0·35	1·95	2·30
Missouri	67380	682033	..	515	515	..	0·77	0·77	..	0·76	0·76
Wisconsin	53924	305091	56	417	473	0·10	0·77	0·87	0·18	1·37	1·55
Total	1,139891	22,587493	13315	12039	25354	77·75	44·02	121·77	16·57	13·38	29·95

It must be admitted that the results here exhibited present a somewhat astonishing spectacle. It appears from this statement that in 1853 there were in actual operation in the United States 13315 miles of railway, and 12029 projected and in process of execution. So that when a few years more shall have rolled away, this extraordinary people will actually have above 25000 miles of iron road in operation.

16. It results from the above, compared with the previous report, that the average cost of construction has been diminished as the operations progressed. The average cost of construction of the 6500 miles of railway in operation in 1849 was 8129*l.* per mile, whereas it appears from the preceding table that the actual cost of 10289 miles, in operation in 1851, has been at the average rate of 6478*l.* per mile. On examining the analysis of the distribution of these railways among the States, it appears that this discordance of the two statements is apparent rather than real, and proceeds from the fact that the railways opened since 1849, being chiefly in the southern and western States, are cheaply constructed lines, in which the landed proprietors have given to a great extent their gratuitous co-operation, and in which the plant and working stock is of very small amount, so that their average cost per mile is a little under 4000*l.* It is also worthy of observation that the distribution of this network of railways is extremely unequal, not only in quantity, but in its capability, as indicated by its expense of construction. Thus, in the populous and wealthy States of Massachusetts, New Jersey, and New York, the proportion of railways to surface is considerable, while in the southern and western States it is trifling.

17. The States of Ohio, Indiana, and Illinois, which form the great highway along which the vast tide of western emigration flows, have, within the last few years, been making extraordinary exertions to complete a system of internal railway communication; and, before ten years shall have elapsed, their extensive territory will be literally overspread with a network of railways and canals.

18. A glance at any recent map of the internal communications of the United States will fill any reflecting observer with astonishment at the enterprise of this extraordinary people. A line of railway, already 1200 miles in length, and which is incessantly increasing, stretches along the Atlantic coast. There are besides not less than eight great trunk-lines extending from the seaboard to the interior:—

	Miles.
1. Portland (Maine) to Montreal, communicating with the St. Lawrence and Ottowa rivers	300
2. Boston to Ogdensburg, where the St. Lawrence issues from Lake Ontario	400
3. Boston to Buffalo on Lake Erie	600

		Miles.
4.	New York to Lake Erie	400
5.	Philadelphia to Pittsburgh on the Ohio	400
6.	Baltimore to the Ohio	350
7.	Charleston, South Carolina, to Chatianoogy, in Tennessee	350
8.	Savannah, Georgia, to Decatur, Georgia, and Montgomery, on the Alabama	500

There are also in progress of construction several detached lines of railway along the southern shores of the great lakes, intended to connect together the numerous cross-lines which traverse that country, and so to form an unbroken system of railway communication with the interior. An extensive line commencing at Galena, on the Upper Mississippi, in the heart of the mining region, crosses the state of Illinois, and passing Chicago, skirts the southern shore of Lake Michigan. This line is complete and under traffic. From Michigan city it crosses the State of that name, arriving at Sandusky, on the southern shore of Lake Erie. From Sandusky this vast artery, following the shore of the lake, arrives at Dunkirk, where it unites with several great trunk-lines, which, traversing the States of New York and Pennsylvania, communicate with the seaboard at Baltimore, Philadelphia, and New York. The extent of this line, running west and east from the Mississippi to the Atlantic, is not less than 1800 miles.

19. When it is considered that the railways in this country have cost upon an average about 40000*l*. per mile, the comparatively low cost of the American railways will doubtless appear extraordinary.

This circumstance, however, is explained partly by the general character of the country, partly by the mode of constructing the railways, and partly by the manner of working them. With certain exceptions, few in number, the tract of country over which these lines are carried is nearly a dead level. Of earthwork there is but little; of works of art, such as viaducts and tunnels, commonly none. Where the railways are carried over streams or rivers, bridges are constructed in a rude but substantial manner of timber supplied from the roadside forest, at no greater cost than that of hewing it. The station-houses, booking-offices, and other buildings, are likewise slight and cheaply constructed of timber. On some of the best lines in the more populous states the timber bridges are constructed with stone pillars and abutments, supporting arches of trusswork, the cost of such bridges varying from 46*s*. per foot, for 60 feet span, to 6*l*. 10*s*. per foot for 200 feet span, for a single line, the cost on a double line being 50 per cent. more.

20. When the railways strike the course of rivers, such as the Hudson, Delaware, or Susquehanna—too wide to be crossed by bridges—the traffic is carried by steam-ferries. The management of these ferries is deserving of notice. It is generally so

arranged that the time of crossing them corresponds with a meal of the passengers. A platform is constructed level with the line of railway, and carried to the water's edge. Upon this platform rails are laid, by which the waggons which bear the passengers' luggage and other matters of light and rapid transport are rolled directly upon the upper deck of the ferry-boat, the passengers meanwhile going under a covered way to the lower deck. The whole operation is accomplished in five minutes. While the boat is crossing the spacious river, the passengers are supplied with their breakfast, dinner, or supper, as the case may be. On arriving at the opposite bank the upper deck comes in contact with a like platform, bearing a railway, upon which the luggage waggons are rolled; the passengers ascend, as they descended, under a covered way, and, resuming their places in the railway carriages, the train proceeds.

21. The prudent Americans have availed themselves of other sources of economy, by adopting a mode of construction adapted to the expected traffic. Formed to carry a limited commerce, the railways are frequently single lines, sidings being provided at convenient situations. Collision is impossible, for the first train which arrives at a siding must enter it, and remain there until the following train arrives. This arrangement would be attended with inconvenience with a crowded traffic like that of many lines on the English railways, but even on the principal American lines the trains seldom pass in each direction more than twice a day, and their time and place of meeting is perfectly regulated. In the structure of the roads, also, principles have been adopted which have been attended with great economy compared with the English lines. The engineers, for example, do not impose on themselves the difficult and expensive condition of excluding all curves but those of large radius, and all gradients exceeding a certain small limit of steepness. Curves of 500 feet radius, and even less, are frequent, and acclivities rising at the rate of 1 foot in 100 are considered a moderate ascent, while there are not less than fifty lines laid down with gradients varying from 1 in 100 to 1 in 75; nevertheless, these lines are worked with facility by locomotives, without the expedient of assistant or stationary engines. The consequences of this have been to reduce in an immense proportion the cost of earthwork, bridges, and viaducts, even in parts of the country where the character of the surface is least favourable. But the chief source of economy has arisen from the structure of the line itself. In many cases where the traffic is lightest, the rails consist of flat bars of iron, two-and-a-half inches broad and six-tenths of an inch thick, nailed and spiked to planks of timber laid longitudinally on the road in parallel lines, so as to form what are called continuous bearings. Some of the most profitable American

railways, and those of which the maintenance has proved least expensive, have been constructed in this manner. The road structure, however, varies according to the traffic. Rails are sometimes laid weighing only from 25 lb. to 30 lb. per yard. In some cases of great traffic they are supported on transverse sleepers of wood, like the European railways; but in consequence of the comparative cheapness of wood and the high price of iron, the strength necessary for the road is mostly obtained by reducing the distance between the sleepers, so as to supersede the necessity of giving greater weight to the rails.

22. The same observance of the principles of economy is maintained with regard to their locomotive stock. The engines are strongly built, safe, and powerful, but are destitute of much of that elegance of exterior and beauty of workmanship which have excited so much admiration in the machines exhibited in the Crystal Palace. The fuel is generally wood, but on certain lines near the coal districts coal is used. The use of coke is nowhere resorted to. Its expense would make it inadmissible, and in a country so thinly inhabited, the smoke proceeding from coal is not objected to. The ordinary speed, stoppages included, is from fourteen to sixteen miles an hour. Independently of other considerations, the light structure of many of the roads would not allow a greater velocity without danger; nevertheless, we have frequently travelled on some of the better constructed lines at the ordinary speed of the English railways, say thirty miles an hour and upwards.

Of late years, however, many exceptions to this system of economical construction are presented. The competition for goods traffic which has been recently produced by the great and rapid extension of railway communication has induced the companies to impose a more strict limit on the gradients and curves, and the engineer is often restricted in laying out the lines to gradients not exceeding forty feet per mile, and curves not less than 2000 feet radius.

23. The lines are also more generally now built with greater solidity. The flat bar rail is fast giving way to rails of the more durable form, weighing from 40 lb. to 60 lb. per yard. On the Camden and Amboy roads, rails have lately been laid down, having a depth of not less than seven inches, and weighing 90 lb. per yard.

Within the last few years, also, more attention has been given to the style of the engines. They still continue generally light compared with the English locomotives, but the working machinery vies with that of the river boats in beauty of workmanship, and the engine is often even covered with a profusion of superfluous ornament.

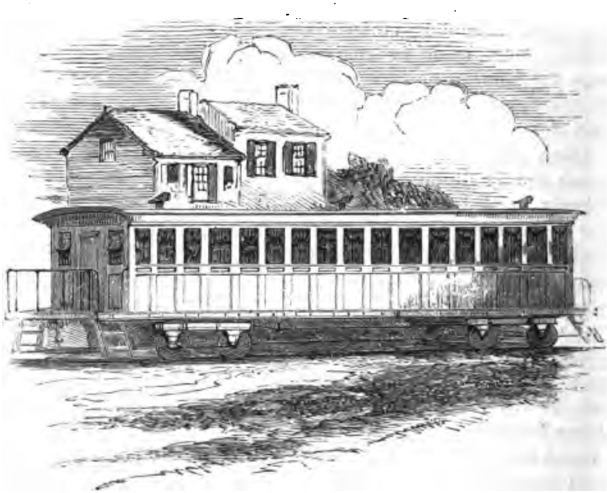
On the railways of the Northern and Eastern States, the platform on which the engine-driver stands is now invariably surrounded and covered so as to shelter the engine-driver from the inclemency of the weather, from the cold, wind, and snow in winter, and the scorching rays of the sun in summer. This covering is glazed at the front and the sides, so as to enable the driver to see the line before him, and at either side, and to prevent, at the same time, the blinding effect of rain, snow, or sleet. He is thus always enabled to act with promptitude and energy in case of any accident or emergency.

24. All passenger-carriages on these lines, which make long trips of above twelve hours, are furnished at one extremity with a saloon for ladies only, supplied with sofas, chairs, and all the necessary comforts and conveniences.

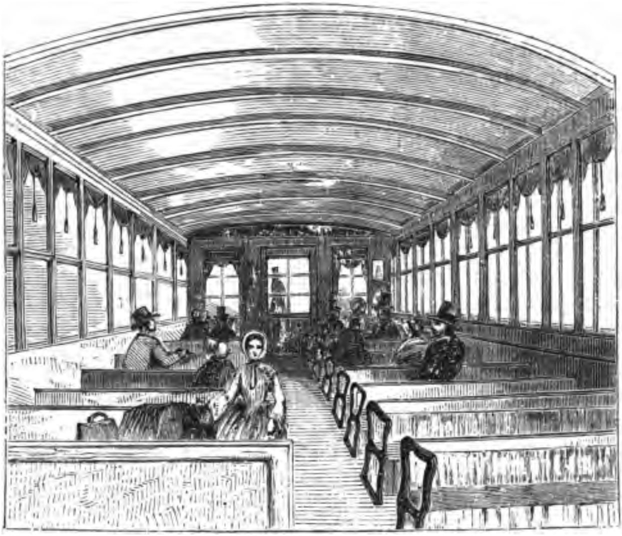
The form and structure of the carriages is a source of considerable economy in the working of the lines. The passenger carriages are not distinguished, as in Europe, by different modes of providing for the ease and comfort of the traveller. There are no first, second, and third classes. All are first class, or rather all are of the same class. The carriage consists of a long body like that of a London omnibus, but much wider, and twice or thrice the length. The doors of exit and entrance are at each end; a line of windows being placed at each side, similar exactly to those of an omnibus. Along the centre of this species of caravan is an alley or passage, just wide enough to allow one person to walk from end to end. On either side of this alley are seats for the passengers, extending crossways. Each seat accommodates two persons; four sitting in each row, two at each side of the alley. There are from fifteen to twenty of these seats, so that the carriage accommodates from sixty to eighty passengers. In cold weather, a small stove is placed near the centre of the carriage, the smoke-pipe of which passes out through the roof; and a good lamp is placed at each end for illumination during the night. The vehicle is thus perfectly lighted and warmed. The seats are cushioned; and their backs, consisting of a simple padded board, about six inches broad, are so supported that the passenger may at his pleasure turn them either way, so as to turn his face or his back to the engine. For the convenience of ladies who travel unaccompanied by gentlemen, or who otherwise desire to be apart, a small room, appropriately furnished, is sometimes attached at the end of the carriage, admission to which is forbidden to gentlemen.

25. It will occur at once to the engineer, that vehicles of such extraordinary length would require a railway absolutely straight; it would be impossible to move them through any portion of a line which has sensible curvature. Curves which would be altogether inadmissible on any European line are nevertheless admitted in the construction of American railways without difficulty or hesi-

tation, and through these the vehicles just described move with the utmost facility. This is accomplished by a simple and effectual arrangement. Each end of this oblong caravan is supported on a small four-wheeled railway truck, on which it rests on a pivot; exactly similar to the expedient by which the forewheels of a carriage sustain the perch. These railway carriages have in fact two perches, one at each end; but instead of resting on two wheels, each of them rests on four. The vehicle has therefore the facility of changing the direction of its motion at each end; and in moving through a curve, one of the trucks will be in one part of the curve while the other is at another,—the length of the body of the carriage forming the *chord* of the intermediate arc! For the purposes they are designed to answer, these carriages present many advantages. The simplicity of the structure renders the expense of their construction incomparably less than that of any class of carriage on an European railway. But a still greater source of saving is apparent in their operation. The proportion of the dead weight to the profitable load is far less than in the first or second-class carriages, or even than in the third-class on the English railways. It is quite true that these carriages do not offer to the wealthy passenger all the luxurious accommodation which he finds in our best first-class carriages; but they afford every necessary convenience and comfort.



AMERICAN RAILWAY CARRIAGE.—EXTERIOR.



AMERICAN RAILWAY CARRIAGE.—INTERIOR.

LOCOMOTION BY RIVER AND RAILWAY

IN THE UNITED STATES.

CHAPTER III.

1. Railways carried to centre of cities—Mode of turning corners of streets. —2. Accidents rare.—3. Philadelphia and Pittsburgh line.—4. Extent and returns of railways.—5. Traffic returns.—6. Western lines —Transport of agricultural produce.—7. Prodigious rapidity of progress.—8. Extent of common roads.—9. Railways chiefly single lines.—10. Organisation of companies and acts of incorporation.— 11. Extent of railways in proportion to population.—12. Great advantages of facility of inland transport in the United States.—13. Passengers not classed.—14. Recent report on the financial condition of the United States railways.—15. Table of traffic returns on New England lines.—16. Cuban railways.—17. Recapitulation.

1. In several of the principal American cities, the railways are continued to the very centre of the town, following the windings of the streets, and turning without difficulty the sharpest corners. The locomotive station is, however, always in the suburbs. Having arrived there, the engine is detached from the train, and

horses are yoked to the carriages, by which they are drawn to the passenger depôt, usually established at some central situation. Four horses are attached to each of these oblong carriages. The sharp curves at the corners of the streets are turned, by causing the outer wheels of the trucks to run upon their flanges, so that they become (while passing round the curve) virtually larger wheels than the inner ones. I have seen, by this means, the longest railway carriages enter the depôts in Philadelphia, Baltimore, and New York, with as much precision and facility as was exhibited by the coaches that used to enter the gateway of the Golden Cross or the Saracen's Head.

2. Notwithstanding the apparently feeble and unsubstantial structure of many of the lines, accidents to passenger trains are scarcely ever heard of. It appears by returns now before us that of 9,355474 passengers booked in 1850 on the crowded railways of Massachusetts, each passenger making an average trip of eighteen miles, there were only fifteen who sustained accidents fatal to life or limb. It follows from this, that when a passenger travels one mile on these railways, the chances against an accident producing personal injury, even of the slightest kind, are 11,226568 to 1; and, of course, in a journey of 100 miles, the chances against such accident are 112266 to 1. It has been shown that the chances against accident on an English railway, under like circumstances, are 40000 to 1.* The American railways are, therefore, safer than the English in the ratio of 112 to 40.

3. A great line of communication was established, 400 miles in length, between Philadelphia and Pittsburg, on the left bank of the Ohio, composed partly of railway and partly of canal. The section from Philadelphia to Colombia (eighty-two miles) is railway; the line is then continued by canal for 172 miles to Holidaysburg; it is then carried by railway thirty-seven miles to Johnstown, whence it is continued 104 miles further to Pittsburg by canal. The traffic on this mixed line of transport was conducted so as to avoid the expense and inconvenience of transhipment of goods and passengers at the successive points where the railway and canals unite. The merchandise was loaded and the passengers accommodated in the boats adapted to the canals at the depôt in Market Street, Philadelphia. These boats, which were of considerable magnitude and length, were divided into segments by partitions made transversely, and at right angles to their length, so that each boat can be, as it were, broken into three or more pieces. These several pieces were placed each on two railway trucks, which support it at its ends, a proper body being

* Museum, Vol. i., p. 168.

provided for the trucks, adapted to the form of the bottom and keel of the boat. In this manner the boat was carried in pieces, with its load, along the railway. On arriving at the canal, the pieces were united so as to form a continuous boat, which being launched, the transport is continued on the water. On arriving again at the railway, the boat was once more resolved into its segments, which, as before, were transferred to the railway trucks, and transported to the next canal station by locomotive engines. Between the depôt in Market Street and the locomotive station, situated in the suburbs of Philadelphia, the segments of the boat were drawn by horses on railways conducted through the streets. At the locomotive station the trucks were formed into a continuous train, and delivered over to the locomotive engine. As the body of the truck rests upon a pivot, under which it is supported by wheels, it is capable of revolving, and no difficulty is found in turning the shortest curves; and these enormous vehicles, with their contents of merchandise and passengers, were seen daily issuing from the gates of the depôt in Market Street, and turning with facility the corners at the entrance of each successive street.

More recently, a continuous line of railway has been completed, and is now in operation, between Philadelphia and Pittsburgh. Indeed, so rapid is the progress of improvement in the United States, that a report of the state of inland communication, as it existed a year or two ago, will be found to be full of inaccuracies as applied to the present moment.

4. By a comparison of the returns published in my work already quoted, with the more recent results already given, it will appear that within the last four years not less than 6750 miles of railway have been opened for traffic in the United States. Among these are included several of the most important lines, of which the most especially to be noticed is the great artery of railway communication extending across the State of New York to the shores of Lake Erie, the longest line which any single company has yet constructed in the United States, its length being 467 miles. The total cost of this line, including the working stock, has been 4,500000*l.* sterling, being at the average rate of 9636*l.* per mile—a rate of expense about 50 per cent. above the average cost of the American railways taken collectively. This is explained by the fact that the line itself is one constructed for a large traffic between New York and the Interior, and therefore built to meet a heavy traffic. Immediately after being opened, its average receipts have amounted to 11000*l.* per week, which gave a net profit of 6½ per cent. on the capital, the working expenses being taken at 50 per cent. of the gross receipts. One of the great lines connects New York with Albany, following the valley of the

Hudson. It will no doubt create surprise, considering the immense facility of water transport afforded by this river, that a railway should be constructed on its bank, but it must be remembered that for a considerable interval during the winter the navigation of the Hudson is suspended from the frost.

5. It is difficult to obtain authentic reports from which the movement of the traffic on the American railways can be ascertained with precision. I obtained, however, the necessary statistical data relating to nearly 1200 miles of railway in the states of New England and New York, from which I was enabled to collect all the circumstances attending the working of these lines.

It appears from calculations, the details of which will be found in my work,* that upon those railways the total average receipts per mile per annum was 4694*l.*, and that the profit per cent. of capital amounted to 8·6 per cent.

6. It appears by recent and well-authenticated returns, that the Western lines, most of which are of recent construction, and derive their revenue almost exclusively from the transport of agricultural produce, have proved even more profitable than the Eastern Railways, whose traffic is chiefly passengers. A large proportion of these Western lines paid from 7 to 10 per cent., even before they were quite completed, according to a report obtained by the "Times."† This prosperous result was obtained even from the lines which traversed uncleared districts and dense forests. The source of this advantage is the profit sure to be obtained from the transport of agricultural produce. In these districts there are no inland markets. The farmer is obliged to send his produce either to the sea-coast or to the bank of one of the great rivers, where alone markets are found. There alone are the manufacturers, and there alone the exporting merchants established. It has been proved that agricultural produce can, at least in the United States, be transported on railways at one-tenth of the expense of its carriage on common roads. In the following table (page 53) is given the comparative value of a ton of wheat and of maize at various distances from the farm-yard, the cost of its transport by each mode of conveyance being deducted from its cost at the place of production.

It appears, therefore, that the whole value of wheat is absorbed by the cost of its transport 330 miles on a common road, while 10 per cent. of its value is absorbed by its transport the same distance by railway. In like manner, while the entire value of maize is absorbed by its transport over 160 miles of common road, no more than 9¾ per cent. of its value is absorbed by transport to the same distance by railway.

* Railway Economy, chap. xvi. † September 3, 1853.

	Transportation by Railroad.		Transportation by Ordinary Highway.	
	Wheat. dols. c.	Maize. dols. c.	Wheat. dols. c.	Maize. dols. c.
Value at . .	49 50	24 75	49 50	24 75
10 miles . .	49 35	24 60	48 0	23 25
20 ,, . .	49 20	24 45	46 50	21 75
30 ,, . . .	49 5	24 30	45 0	20 25
40 ,, . .	48 90	24 15	43 50	18 75
50 ,, . . .	48 75	24 0	42 0	17 25
60 ,, . .	48 60	23 85	40 50	15 75
70 ,, . . .	48 45	23 70	39 0	14 25
80 ,, . .	48 30	23 55	37 50	12 75
90 ,, . . .	48 15	23 40	36 0	11 25
100 ,, . .	48 0	23 25	34 50	9 75
110 ,, . . .	47 85	23 10	33 0	8 25
120 ,, . .	47 70	22 95	31 50	6 75
130 ,, . . .	47 55	22 80	30 0	5 25
140 ,, . .	47 40	22 65	28 50	3 75
150 ,, . . .	47 25	22 50	27 0	2 25
160 ,, . .	47 10	22 35	25 50	0 75
170 ,, . . .	46 95	22 20	24 0	
180 ,, . .	46 80	22 5	22 50	
190 ,, . . .	46 65	21 90	21 0	
200 ,, . .	46 50	21 75	19 50	
210 ,, . . .	46 35	21 60	18 0	
220 ,, . .	46 20	21 45	16 50	
230 ,, . . .	46 5	21 30	15 0	
240 ,, . .	45 90	21 15	13 50	
250 ,, . . .	45 75	21 0	12 0	
260 ,, . .	45 60	20 85	10 50	
270 ,, . . .	45 45	20 70	9 0	
280 ,, . .	45 30	20 55	7 50	
290 ,, . . .	45 15	20 40	6 0	
300 ,, . .	45 0	20 25	4 50	
310 ,, . . .	44 85	20 10	3 0	
320 ,, . .	44 70	19 95	1 50	
330 ,, . . .	44 55	19 80	0 0	

These results are important to the holder of stock in these western lines, in so far as they demonstrate how permanent and secure must be the revenue of the western railroads. The vast bulk of the western population is agricultural, and will long continue to be so, and by far the largest proportion of the receipts of their railways will be from the transportation of freight. There is, besides, hardly a country in the world where the same amount of labour produces an equal amount of freight. These, and other reasons which will suggest themselves from the facts given, go to show how solid the basis would seem to be for the prosperity of the western roads generally, while the premium for which their stocks are selling, and the dividends they divide, illustrate the matter by incontestable facts.

The year 1852 was the most prosperous year for the American western railroads in operation and in progress. Their increased earnings are said, upon good authority, to average an increase of 15 per cent. upon their *mileage*, and 10 per cent. upon their *cost*. This vast increase is attributed partly to abundant crops and partly to a general increase of activity in every department of business; but in that country more than in any other, the extension of the railroad system seems likely to exert a beneficial effect upon each individual railroad for itself. There is scarcely such a thing now heard of as travelling or freight transportation, except on railroads or by water. The public sees that undue importance has been hitherto attached to canals, and it is now found to be difficult, if indeed it will not ultimately prove impossible, to get the people of the State of New York to appropriate 10,000,000 dollars more for the final enlargement or completion of the canals already built in that State alone. Transportation or travel by canals is too slow—it does not suit the electric speed of the age. We may, therefore, expect in the future that little more will be done for canals, while a network of railroads seems destined inevitably to cover that continent.

7. Americans themselves can hardly imagine the railroad progress of the United States till they come to the figures of what has actually been done; much less can they comprehend their probable progress in the future. Those who have bestowed the most reflection on the subject entertain no doubt that the construction of railways in the south-west and west—that boundless granary of the world—will continue and increase with augmented ratio for a long time to come. If that vast district should be supplied with railways as Massachusetts now is, it would demand at least 100000 miles of railway! What political economist in England or in America can fail to draw an inference here in favour of Free Trade? With the superior facilities of Great Britain for manufacturing iron, and the still greater facilities of the United States for the prosecution of agriculture, who is so blind as not to see that they ought to take our iron and to pay for it in bread, unless bad and unhealthy legislation interrupt this natural order of the law of Providence? *

8. The extraordinary extent of railway constructed at so early a period in the United States has been by some ascribed to the absence of a sufficient extent of communication by common roads. Although this cause has operated to some extent in certain districts, it is by no means so general as has been supposed. In the year

* "Times," September 3, 1853.

1838, the United States mails circulated over a length of way amounting on the whole to 136218 miles, of which two-thirds were land transport, including railways as well as common roads. Of the latter there must have been about 80000 miles in operation, of which, however, a considerable portion was bridle-roads. The price of transport in the stage coaches was, upon an average, 3·25*d.* per passenger per mile, the average price by railway being about 1·47*d.* per mile.

From what has been stated above, it will be apparent that the true cause of the vast extension of railways in the United States is the immense economy and speed of transport upon them compared with transport on common roads.

9. Of the entire extent of railway constructed in the United States, by far the greater portion, as has been already explained, consists of single lines, constructed in a light and cheap manner, which in England would be regarded as merely serving temporary purposes: while, on the contrary, the entire extent of the English system consists, not only of double lines, but of railways constructed in the most solid, permanent and expensive manner, adapted to the purposes of an immense traffic. If a comparison were to be instituted at all between the two systems, its basis ought to be the capital expended, and the traffic served by them, in which case the result would be somewhat different from that obtained by the mere consideration of the length of the lines. It is not, however, the same in reference to the canals, in which it must be admitted that America far exceeds all other countries in proportion to her population.

10. The American railways have been generally constructed by joint-stock companies, which, however, the State controls much more stringently than in England. In some cases a major limit to the dividends is imposed by the statute of incorporation, in some the dividends are allowed to augment, but when they exceed a certain limit the surplus is divided with the State; in some the privilege granted to the companies is only for a limited period, in some a sort of periodical revision and restriction of the tariff is reserved to the State. Nothing can be more simple, expeditious, and cheap than the means of obtaining an act for the establishment of a railway company in America. A public meeting is held at which the project is discussed and adopted, a deputation is appointed to apply to the Legislature, which grants the Act without expense, delay, or official difficulty. The principle of competition is not brought into play as in France, nor is there any investigation as to the expediency of the project with reference to future profit or loss, as in England. No other guarantee or security is required from the company than the

payment by the shareholders of a certain amount, constituting the first call. In some States the non-payment of a call is followed by the confiscation of the previous payments, in others a fine is imposed on the shareholders, in others the share is sold, and if the produce be less than the price at which it was delivered, the surplus can be recovered from the shareholder by process of law. In all cases the Acts creating the companies fix a time within which the works must be completed, under pain of forfeiture. The traffic in shares before the definite constitution of the company is prohibited.

Although the State itself has rarely undertaken the execution of railways, it holds out, in most cases, inducements in different forms to the enterprise of companies. In some cases the State takes a great number of shares, which is generally accompanied by a loan made to the company, consisting in State stock delivered at par, which the company negotiate at its own risk. This loan is often converted into a subvention.

11. The great extent of internal communication, by railways and canals, in America, in proportion to its population, has been a general subject of admiration. The population of the United States in 1840 amounted to 17 millions, and if its rate of increase during the ten years commencing at that epoch be equal to the rate during the preceding ten years, its present population must be about 23 millions. There are, as I have stated, about 6500 miles of railway in actual operation within the territory of the Union. This, in round numbers, is at the rate of one mile of railroad for every 3200 inhabitants.

In the United Kingdom, there are in operation 5000 miles of railway, with a population of 30 millions, which is at the rate of one mile for every 6000 inhabitants.

It would therefore appear that, in proportion to the population, the length of railway communication in the United States is greater than in the United Kingdom in the proportion of 6 to 3½. The result of this calculation, however, requires considerable modification.

12 There is no country where easy and rapid means of communication are likely to produce more beneficial results than in the United States. Composed of twenty-six independent republics, having various, and in some instances opposite interests, the American confederacy would speedily be in danger of dissolution, if its population, scattered over a territory so vast, were not united by communications sufficiently rapid to produce a practical diminution of distance. In this means of intercommunication, Nature has greatly aided the efforts of art, for certainly no country in the world presents such magnificent lines of natural water communication.

To say nothing of the streams which intersect the Atlantic States, and carry an amount of inland steam navigation wholly unexampled in Europe, we have the gigantic stream of the Mississippi, intersecting the immense valley to which it gives its name, with innumerable tributaries, navigable by steam-boats having a tonnage of first-rate ships for many thousands of miles, and traversing territories which present immense tracts of soil, of the highest degree of fertility, as well as sources of mineral wealth which are as yet unexplored.

13. On the American railways, passengers are not differently classed, or admitted at different rates of fare, as on those in Europe. There is but one class of passengers and one fare. In one or two instances, second and third-class carriages were attempted to be established, but it was found that the number of passengers availing themselves of the lower fares and inferior accommodation was so small that they were discontinued. The only distinction observable among passengers on railways is that which arises from colour. The coloured population, whether emancipated or not, are generally excluded from the vehicles provided for the whites. Such travellers are but few; and they are usually accommodated either in the luggage van or in the carriage in which the guard or conductor travels.

14. We take the following observations on the financial condition of the railways of the United States from the report already quoted from the "Times." Although it emanates evidently from a partisan, it is from an intelligent, well-informed, and honest partisan, and is well deserving of attention.

"1. In all instances the railroads of the United States have received their charters from the governments of the several States through which their routes extend. I am not aware, with a few exceptions, of an instance in which the application of a company for a charter for a railway has been refused, provided the responsibility of the applicants, or the amount of capital stock subscribed, has afforded a satisfactory guarantee for the execution of their designs. The powers and privileges conferred by these State charters are very similar to those conferred by the British Parliament. Railroad property in the United States occupies the same relations to State Governments as the property of individuals. The companies are independent in their action, and responsible to the State authorities as private citizens.

"2. I shall dwell more particularly upon the western railroads, because their history, condition, and prospects more materially concern European readers, their bonds being those now most frequently in the market. A very large number of the western railroads have obtained their charters under what are termed general railroad laws, in distinction from special statutes enacted for the incorporation of companies named within the Acts.

Within the last few years the tendency in this country has been to general rather than to special legislation. The great States (New York leading the way) have many of them enacted general laws authorising the construction and providing for the management of railways, as well as other corporations and great institutions. General railroad laws now exist in New York, Illinois, Ohio, Indiana, and Wisconsin, in all which States special charters conferring special powers are prohibited. The same principle of legislation will doubtless be adopted in other States. There are many advantages to the public in general laws, particularly as they concern railways; for monopolies are thereby rendered impossible, and the principle of *laisser faire* is adopted and carried out with the least possible interference with private rights. Under their operation, associations of men have the same right to construct railroads as to build factories or ships, and it is found by experience that each community is fully competent to regulate its own affairs.

"3. The stock and bonds of railroads are regarded as personal property, and, as such, within specific limitations, subject to taxation. No tax ever can be laid upon the bed of a road, its iron, cars, &c.; but where valuable real estate is owned for depôts, taxes may be levied. But shares and bonds can only be taxed to the holder thereof; and, of course, cannot be taxed when held abroad. In this respect, European holders of American shares and stocks have an advantage over ourselves.

"4. Companies organised under general laws cannot be dissolved without special authority from the legislature of a State; and, if the time comes that any American railway company asks for a dissolution, then, and then only, will the property of the company be distributed *pro rata* among the stockholders. I do not know of a single onerous condition or obligation laid upon an American railroad company by any State, while I am not aware that any railroad corporation has been formed in England of which the same can be said.

"5. No railroad can exist in the United States that has any right to declare dividends until it has discharged all its obligations due at the time; and all its bonds and debts of every description take precedence, and can be prosecuted and collected before the original stockholders can either receive a dividend or profit from it in any shape whatever. If there be a failure to pay its bonds or mortgages, the bondholders or mortgagees can, by a short and simple legal process, become vested with entire control over the property, and manage it on their own account. In other words, the right to apply the well-known principles of law to the relation of mortgagees and mortgagors obtain in all our railroads, and they can be enforced by any court of equity within the judicial district. The payment of railroad bonds is generally secured by deed of trust to some known and responsible citizen of New York as trustee, with full power given in the deed to the trustee to take possession of the road, its income, franchises, personal effects, &c., in case of default, and to sell the same for cash to the highest bidder, at sixty days' notice, without the intervention of a Court of Chancery.

"6. Nearly all the bonds issued by American railways have the same general features. They are either secured by mortgage upon the property of the roads themselves, or they are common bonds for the payment of money. But they are subdivided into two classes—those which are convertible into stock at the option of the owner, to the amount on their face, whenever the holder sees fit; or they have no such condition attached. Convertible bonds have an advantage over the latter, inasmuch as they can be converted into stock so soon as that stock rises above par. This condition has been found peculiarly advantageous to many of the holders of the bonds on the western roads, since the stocks of most of these roads have gone above par as soon as they were completed.

"7. Nearly all the western railroads were projected and built for the special benefit of the people themselves in those districts through which they pass. Their sole object was to be brought nearer to a market for their produce, and many municipal bodies subscribed for stocks with no expectation that they would ever become valuable in any other way. Capital was scarce in the west, as it is in most new countries. There was a serious want of outlets to New York and navigable streams. Hence these railroads were undertaken with the expectation of general advantages to the community. But cities and counties could not create debts, or expend the money in their treasuries for such purposes, without special authorisation from the State legislatures. The object of this was to give character and legality to their acts, that they might have binding force, and also to equalise the burden of those debts over the owners of property in those sections. The charters, therefore, of almost all the western railroads authorised those cities and counties through which they passed to subscribe by a uniform mode to the stock of those roads. But invariably one safe condition was attached to this permission—that such action should also be authorised by a vote of the majority of the citizens themselves. This voluntary principle has worked admirably; because no city or county has had the right to subscribe for stock in roads until a majority of the voters thereof so decided; and thus the highest sanction of the will of the taxpayers and of law was imparted to their action. In no one instance can I ascertain that any city or county has thus incurred a debt of more than from 2 to 5 per cent. on the taxable property of its citizens. The amount subscribed by cities and counties has ranged from 50,000 to 400,000 dollars, where the taxables would rise as high as from 4,000,000 to 16,000,000 dollars.

"8. These municipal debts thus created have been secured by all the guarantees that the State legislatures could throw around them. The cities and counties have been required to levy and collect, in case of necessity, taxes (as any and all other municipal taxes are) from their own citizens, sufficient to pay the interest, and provide a balance as a sinking fund to pay off the debt, when it should finally become due. In no instance has any western city or county hitherto neglected to do this, nor is it likely that any ever will.

"9. The bonds thus issued to railroad companies by cities and counties are guaranteed by the roads, and then sold in the market. They have all the legal force of a lien on all the property of those cities or counties, real and personal, and, if the proper authorities do not provide for the payment of the interest and principal, a *mandamus*, or an ordinary suit at law, can be issued, by which all the real and personal property of the citizens of those cities and counties can be attached and sold. Many years since the city of Bridgeport, in Connecticut, gave her bonds to a railway company for 100,000 dollars. For some reason the payment of these bonds was delayed. A holder brought a suit against the city in the State Court, and the Supreme Court decided on appeal that the individual property, real and personal, of each citizen, was liable for the debt of the city, and could be sold on execution of the decree.

"10. The operation of these laws and of this system of subscription to roads has been uniformly, I believe, beneficent. I cannot learn that there is a completed road in Ohio, for instance, that has paid less than from 10 to 14 per cent.; and, as in a great majority of instances, the cities and counties that gave their bonds have been enabled, either by converting them at their will into stock or otherwise, to sell them, and often at a large premium, thus realising large profits for thus lending their credit. The city of Cleveland, in Ohio, subscribed 400,000 dollars to two or three roads, and she is now selling that stock at a premium of from 24 to 27 dollars advance. Her taxable property since 1849 has risen from 3,000,000 to 7,000,000 dollars, while the population as well as taxable property has increased in almost the same ratio in those cities and those counties throughout the west where railroads have been built."

15. It would be extremely interesting, were it practicable, to obtain even an approximate estimate of the actual commerce in

passengers and goods on the American railways. No such general return, however, is attainable. In my work on Railway Economy, in the absence of more complete information, I have given the necessary statistical data to determine the commerce on nearly twelve hundred miles of railway in the States of New England and in that of New York, from which I was enabled to calculate all the circumstances attending the working of these lines. I have, accordingly, given these in the following table :—

TABULAR ANALYSIS of the average daily Movement of the Traffic on Twenty-eight principal Railways in the States of New England and in the State of New York during the year 1847.

	PASSENGER TRAFFIC.				GOODS TRAFFIC.			
	Number booked.	Mileage.	Receipts.	Mileage of Trains.	Tons booked.	Mileage.	Receipts.	Mileage of Trains.
Albany and Schenectady	630	9,787	£ 65	136			32	62
Utica-Schenectady	733	37,600	300	406			111	360
Syracuse-Utica....	544	21,550	169	288			38	151
Auburn-Rochester	518	24,200	197	400			37	212
Tonawanda	367	13,000	92	212			23	40
Attica-Buffalo	358	9,850	61	162			19	48
Saratoga-Schenectady.	146	2,068	22	54	1730*	65,550*	4	4
Troy-Schenectady.	189	3,340	20	140			8	9
Ransaeller-Saratoga..............	181	2,625	24	680			12	26
Troy and Greenbush	545	3,090	21	131			25	19
New York and Haarlem........	4,336	17,000	133	450			80	170
New York-Erie ..	326	12,400	60	246			102	191
Boston-Worcester .	1,640	39,672	180	580	775	29,450	221	459
Western	1,062	48,952	296	648	752	76,580	471	1,408
Norwich-Wor'ster.	434	8,158	67	326	249	7,858	64	204
Connecticut River.	650	6,454	42	203	122	2,210	28	64
Pittsfield-N. Adam	98	11,048	9	45	29	469	6	31
Boston-Providence	1,338	19,680	133	464	240	5,310	69	148
Tarenton	297	3,234	20	60	83	910	10	19
New Bedford......	268	4,460	40	173	53	930	13	53
Stoughton Branch.	46	482	3	11	22	238	3	4
Lowell	1,328	26,050	120	452	770	19,450	139	194
Nashua	618	8,540	41	81	414	6,130	49	55
Boston-Maine	1,995	34,500	189	625	330	9,880	106	200
Fitchburg	1,342	21,920	98	434	670	14,230	119	192
Eastern	2,240	34,910	203	557	112	3,190	30	93
Old Colony	1,068	13,420	73	288	117	2,048	24	77
Fall River	474	8,860	46	219	79	1,718	18	72
	23,771	447,350	2,724	8,471	6,547	246,151	1,861	4,560

* The reports do not supply the tonnage and mileage of these railways separately, and the above numbers are estimated by analogy with the other American railways.

	Miles.
Total length of the above railways in the State of New York	490
" " " States of New England	670
Total	1160

	£
Average cost of construction and stock per mile in the State of New York	7,010
" " " States of New England	10,800
General average	9,200

	Receipts.	Expenses.	Profits.
Total average receipts, expenses, and profits per day in the State of New York .	1654	684	970
" " States of New England	3040	1505	1535
Totals	4694	2189	2505

	Per Mile of Railway per day.	Per Mile run by Trains.	Per Cent. per Annum on Capital.
Receipts	4·05	7 5	16·1
Expenses	1·89	3 5½	7·5
Profits . . .	2·16	2 11½	8·6
Expense per cent. of receipts . . .			46·8

Average receipts per passenger booked . . .	27·0*d.*
Average distance travelled per passenger	18·2 miles.
Average receipts per passenger per mile . . .	1·47*d.*
Average number of passengers per train	54·0
Total average receipts per passenger train per mile	7*s.*
Average receipts per ton of goods booked . . .	5*s.* 8½*d.*
Average distance carried per ton	38·0 miles.
Average receipts per ton per mile	1·8*d.*
Average number of tons per train	54·5
Total average receipts per goods train per mile .	8·2*s.*

The railways, of the traffic of which I have here given a synopsis, include the most active and profitable enterprises of this kind in the United States. We cannot, therefore, infer from the results obtained the corresponding movement on the remaining lines. It appears that of the entire system of American railways. the dividends, exclusive of those contained in the preceding analysis, are in general small, and in many instances nothing. It is therefore probable that, in the aggregate, the average profits on the total amount of capital invested in the railways do not exceed, if they equal, the average profits obtained on the capital invested in English railways.

16. Although Cuba is not yet *annexed* to the United States, its local proximity here suggests some notice of a line of railway which traverses that island, forming a communication between the

city of Havannah and the centre of the island. This is an excellently constructed road, and capitally worked by British engines, British engineers, and British coals. The impressions produced in passing along this line of railway, though different from those already noticed in the forests of the far west, is not less remarkable. We are here transported at thirty miles an hour by an engine from Newcastle, driven by an engineer from Manchester, and propelled by fuel from Liverpool, through fields yellow with pine-apples, through groves of plantain and cocoa-nut, and along roads inclosed by hedge-rows of ripe oranges.

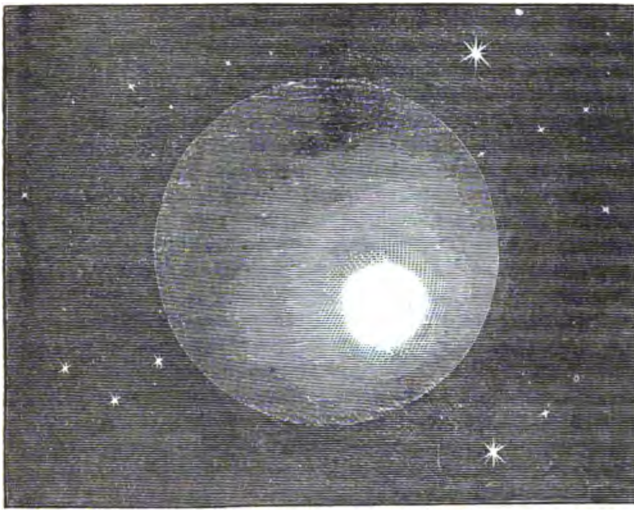
17. To what extent this extraordinary rapidity of advancement made by the United States in its inland communications is observable in other departments will be seen by the following table, exhibiting a comparative statement of those data, derived from official sources, which indicate the social and commercial condition of a people through a period which forms but a small stage in the life of a nation:—

	1793.	1851.
Population	3,939,325	24,267,488
Imports	£6,739,130	£38,723,545
Exports	£5,675,869	£32,367,000
Tonnage	520,704	3,535,451
Lighthouses, beacons, and lightships	7	373
Cost of their maintenance . .	£2,600	£115,000
Revenue	£1,230,000	£9,516,000
National expenditure . . .	£1,637,000	£8,555,000
Post-offices	209	21,551
Post roads (miles) . . .	5,642	178,670
Revenues of Post-office . . .	£22,800	£1,207,000
Expenses of Post-office . . .	£15,650	£1,130,000
Mileage of mails	—	46,541,423
Canals (miles)	—	5,000
Railways (miles)	—	10,287
Electric telegraph (miles) . . .	—	15,000
Public libraries (volumes) . .	75,000	2,201,623
School libraries (volumes) . . .	—	2,000,000

If they were not founded on the most incontestable statistical data, the results assigned to the above table would appear to belong to fable rather than history. In an interval of little more than half a century it appears that this extraordinary people have increased above 500 per cent. in numbers; their national revenue has augmented nearly 700 per cent., while their public expenditure has increased little more than 400 per cent. The prodigious extension of their commerce is indicated by an increase of nearly 500 per cent. in their imports and exports, and 600 per cent. in their shipping. The increased activity of their internal communications is expounded by the number of their post-offices, which has been increased more than a hundred fold; the extent of their post-roads, which has been increased thirty-two fold; and the cost of their post-office, which has been augmented in a seventy-two fold ratio. The augmentation of the machinery of public instruction is indicated by the extent of their public libraries, which have increased in a thirty-one fold ratio, and by the creation of school libraries, amounting to 2,000,000 volumes. They have completed a system of canal navigation, which, placed in a continuous line, would extend from London to Calcutta; and a system of railways which, continuously extended, would stretch from London to Van Diemen's Land, and have provided locomotive machinery by which that distance would be travelled over in three weeks, at the cost of 1½*d.* per mile. They have created a system of inland navigation, the aggregate tonnage of which is probably not inferior in amount to the collective inland tonnage of all the other countries in the world; and they possess many hundreds of river steamers, which impart to the roads of water the marvellous celerity of roads of iron. They have, in fine, constructed lines of electric telegraph which, laid continuously, would extend over a space longer by 3000 miles than the distance from the north to the south pole, and have provided apparatus of transmission by which a message of three hundred words despatched under such circumstances from the north pole might be delivered *in writing* at the south pole in one minute, and by which, consequently, an answer of equal length might be sent back to the north pole in an equal interval.

These are social and commercial phenomena for which it would be vain to seek a parallel in the past history of the human race.*

* Lardner on the Great Exhibition, p. 251.



TELESCOPIC VIEW OF ENCKE'S COMET, BY STRUVE, AS IT APPEARED ON NOV. 7, 1828.

COMETARY INFLUENCES.

CHAPTER I.

1. Popular tendency to connect terrestrial events with celestial phenomena. —2. Popular opinions as to influences of Comets.—3. Explanation of Comets, their nature — attractions — their shape, volume, and mass — tails — density—non-luminous.—4. Question discussed as to a Comet encountering the Earth, and the result — Comet of 1832, of 1805—Probabilities of such an occurrence.—5. Question discussed as to the temperature of the seasons being affected by Comets.—6. Question discussed as to the Earth passing through the tail of a Comet, and the probable consequences.—7. Suppositions adopted by some authors as to Comets producing epidemic diseases—Comet of 1680—Great Plague of London—Comet of 1668 alleged to have produced a remarkable epidemic among cats in Westphalia.—8. Comet of 1746—Earthquakes of Lima and Callao ascribed to it.—9. Various influences ascribed to particular Comets—Earthquakes—Plagues—the success of the Turks under Mahommed II.

1. In all ages, and among all people, a tendency has prevailed to connect terrestrial events with celestial phenomena. Popular opinion in such cases seeks no reason for its foundation. No attempt to establish any such relation as that of cause and effect

is thought of. The appearance presented in the heavens, whatever it be, is simply regarded as the harbinger, precursor, or presage of the terrestrial events which are supposed to accompany or to succeed it. When the celestial phenomena thus regarded are from their nature periodical and recurring, as in the case of the succession of lunar phases, some attempt is made to generalise the imputed effects, and to reduce them to rules. In the case, however, of celestial appearances, which are occasional and extraordinary, and which have no discovered periodicity, no such general rule can be established. In such cases mankind is, however, not less prompt and confident in ascribing to their appearance any extraordinary events whatever which may have taken place simultaneously with or immediately after them.

2. Among this latter class of occasional phenomena comets hold a conspicuous place, and have at all times and in all countries operated powerfully on the superstitious feelings of mankind. These bodies, scarcely less in modern and enlightened times than in the more remote and darker ages, and scarcely less among the most civilised than among the most barbarous nations, have been regarded with feelings of inexpressible awe and terror, and looked upon as the harbingers and precursors of the most extraordinary diversity of effects, physical, physiological, social, and political. To them are unhesitatingly ascribed extraordinary extremes of heat and cold of the seasons, whether general or local; storms of snow, hail, wind and rain, hurricanes, earthquakes, volcanic eruptions, floods, droughts, and fogs; every form and character of epidemic malady, whether affecting the human race or the lower animals, the state of the harvest and the vintage, whether it be that of scarcity or abundance, of good or bad quality; the fruitfulness of women, the births and deaths of extraordinary men, the march of armies, and the fall of empires.

3. Without insisting, as we very well might, upon the manifest absurdity and glaring contradiction and inconsistency of most of these supposed influences or effects, let us first explain briefly, so far as observation has informed us, what the bodies are, to which effects so diverse and extraordinary are imputed. Such an explanation will of itself go far to dispel most of these errors. We shall also compare the effects ascribed to the presence and influence of comets with the dates of the appearances of these bodies, their number, magnitude, and proximity, so as to ascertain whether any such correspondence has really existed as has been assumed.

Comets are not, as was anciently supposed, atmospheric phenomena. They move through the regions of space occupied by the planets. Most of them come into the solar system from parts of the universe which extend to enormous distances beyond its limits, and after passing among the planets and approaching more or less near to the sun, they again disappear, issuing to distances not less remote.

The number of those which have been actually seen, and whose appearances have been recorded, amounts to many hundreds. But when the chances against these bodies being visible during the intervals, often very brief, of their passage through the solar system, the vast numbers of them which can only be seen by the aid of telescopes, the frequency of their position being such that they are only above the horizon of observers during the day, or that they can only be within the range of vision in latitudes where no observers are found, are severally considered, it will be evident that the number of comets actually seen must form a very small fraction of the total number which have visited our system.

Reasoning upon the common principles of the doctrine of probabilities, Arago has shown that the number of comets which have passed through the system cannot be less than three and a half millions, but that it is possible that they may amount to twice that number. Even with the limited information respecting these bodies, which was attainable by Kepler, that astronomer declared that "there are more comets in space than fishes in the ocean."

Of the many hundreds whose appearances have been recorded, dating from the earliest historical notices of these bodies, about two hundred have been observed during the short intervals of their appearance, with sufficient precision to enable astronomers to calculate the paths or orbits in which they moved. These calculations have led to a result of the highest importance, inasmuch as they have established demonstratively the fact that these comets are masses of ponderable matter. The forms of their orbits prove this. It has been shown by Newton that if a body move in a certain form of curve, called by geometers a conic section, having a point called its focus at the centre of the sun, it must be subject to the attraction of the sun's gravitation, and it must reciprocally attract the sun. Now these comets have been ascertained by observation to move in these very curves, the sun being in their common focus. Hence they and the sun mutually attract each other, according to the universal law of gravitation. They are, therefore, masses of ponderable matter.

But these masses are not only attracted by the sun but by the planets, primary and secondary, near to which they pass, and they are ascertained to deviate considerably, by reason of such attractions, from the paths they would follow if subject only to the sun's attractive force. Now, by the general law of gravitation, that attraction is always reciprocal, and it is certain that the comets attract the planets as strongly as the planets attract them, and if the masses of the comets were as great as those of the planets, they would cause the planets to deviate from their accustomed path as widely as the planets cause them to deviate. If, however, we find, that while the deviation of the comets, in virtue of this mutual attraction, is very great, that of the planets is extremely small, the inference must be that the masses of the comets are smaller than those of the planets, in exactly the proportion in which the effect of the attraction on the planet is less than its effect upon the comet.

Now, in fact, it has been found that while the deviation of the comets, due to the attractions of the planets, is very considerable, that of the planets, of the satellites, and even of the planetoids (the smallest bodies of the solar system), is so minute as to be absolutely inappreciable by the most exact means of observation. A case is even recorded in which a comet passed almost in contact with the satellites of Jupiter, if, indeed, it did not pass among these small bodies, yet its attraction upon them was so feeble as to produce not the slightest observable effect upon their motions, although the comet itself, by the attraction of the planet, was so strongly affected that its orbit was completely changed.

By such observations and calculations it has then been established that, although the comets are masses of ponderable matter, the quantity of matter composing each of them is incalculably less than that of the smallest planet, primary or secondary, of the solar system.

These bodies are as remarkable for the vastness of their magnitude, and the strangeness, variety, and mutability of their forms as for the smallness of their masses.

Comets in general, and more especially those which are visible without a telescope, present the appearance of a roundish mass of illuminated vapour or nebulous matter, to which is often, though not always, attached a train more or less extensive, composed of matter having a like appearance. The former is called the HEAD, and the latter the TAIL of the comet.

The tail is more significantly called the *brush* by Chinese astronomers.

The illumination of the head is not generally uniform. Sometimes a bright central spot is seen in the nebulous matter which forms it. This is called the NUCLEUS.

The nucleus sometimes appears as a bright stellar point, and sometimes presents the appearance of a planetary disk seen through a nebulous haze. In general, however, on examining the object with high optical power, these appearances are changed, and the object seems to be a mere mass of illuminated vapour from its borders to its centre.

The nebulous haze which always surrounds the nucleus is called the COMA.

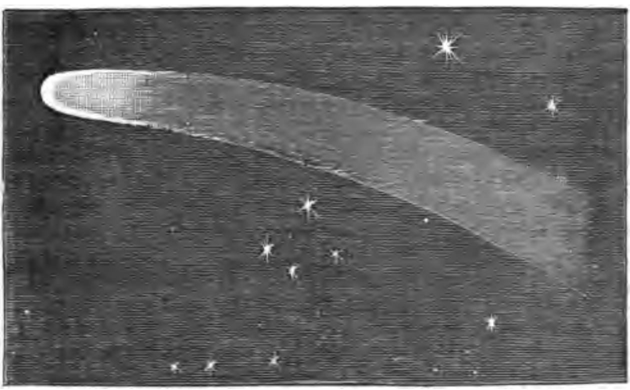
These terms COMA and COMET are taken from the Greek word κομή (komé) hair, the nebulous matter composing the coma and tail being supposed to resemble hair, and the object being therefore called κομήτης (kometes), a hairy star.

A telescopic view of one of the globular comets without a tail is given at the head of this chapter. This is the comet known as Encke's comet, so called from the astronomer who calculated its orbit.

This may be taken as a general representation of the apparent form of the comets without tails. The real form is evidently globular or spheroidal.

The comets with tails are infinitely various in form. In fig. 2 is represented the comet known as Halley's Comet, as it appeared on the 3rd October, 1835; and this may also be taken as a very general representation of comets with tails.

Fig. 2.



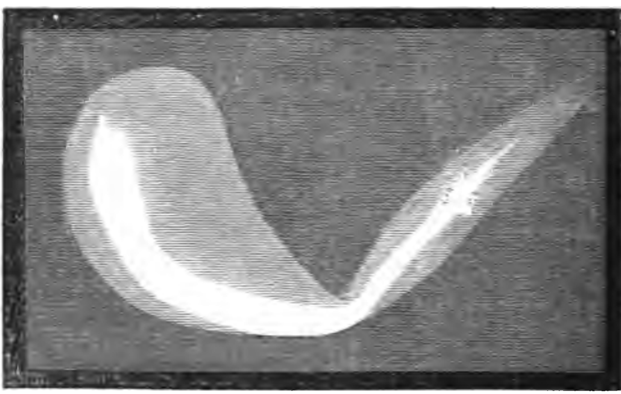
The rapidly changing and capricious forms of these singular bodies may be conceived from fig. 3, p. 70, which represents the same comet as it appeared on the 9th October; and the figure at the head of Chapter II. as it appeared on the 5th November.

Nothing which attends these extraordinary objects is more astonishing than their prodigious dimensions. The head of the great comet which appeared in 1811 was a globular mass, whose diameter measured 1,250000 miles. Its bulk must, therefore, have been thrice that of the sun, and ***nearly four million times that of the earth!*** But astounding as this is, the dimensions of the tail were still more so. The length of that vast appendage was an hundred and thirty millions of miles, so that if the head were at the sun, the tail would extend to thirty millions of miles beyond the earth!

Supposing this tail to consist of continuous matter, let us see what its quantity must be by measure. Its diameter at the point where it emanated from the head was equal to that of the head, but as its sides were slightly divergent, its diameter increased as the distance from the head increased; but let us take it as equal only to the diameter of the head.

The length of the tail having been an hundred and thirty millions of miles, while the diameter of the head was a million and a quarter of miles, it will follow that the length of the tail was 104

Fig. 3.



times the diameter of the head. If the sides of the tail, instead of being divergent, were parallel, it would thence follow, by the principles of geometry, that the volume or cubical bulk of the tail must have been an hundred and fifty times greater than that of the head, and since the bulk of the head was four million times that of the earth, that of the tail and head together (without taking into account the effect of the divergence of the tail), must have been ***nearly six hundred million times the bulk of the earth!!***

It must be observed, however, that some appearances observed in the tails of comets have suggested to astronomers the probability that they may be hollow, that is to say, that instead of being cylindrical or conical columns of vaporous matter, they are thin cylindrical or conical *tubes* of vapour, like the funnel or pipe of a stove. In that case, of course, the bulk or volume of vaporous matter entering into their composition would be much less than we have here computed, but the actual volume included within their limits would still be the same.

In form the tails are sometimes straight, and sometimes curved like a scymeter, as represented in fig. 2. When the great comet of 1456 appeared it had that form; and in the superstitious spirit of that age, it was regarded as a celestial sign of the success of the Turkish invasion of Europe, from its resemblance to a Turkish sabre.

The tail is not always single. Comets have appeared with two or more tails. In 1744 a comet appeared with six tails, each of which was curved nearly to the form of a quadrant.

The magnitude of these enormous appendages is even less amazing than the brief period in which they are sometimes thrown out from the head. The great comet of 1843 had a tail which measured two hundred millions of miles, so that if the head were at the sun, the tail would extend to an hundred millions of miles beyond the earth. Yet this tail was thrown out in less than twenty days. If, as we must suppose, it was wholly composed of matter issuing from the head, with what inconceivable force must not the matter have been ejected which formed the extremity of the tail! The matter having been driven through two hundred millions of miles in twenty days, must have had a velocity of ten millions of miles per day. This would be at the rate of above four hundred thousand miles per hour, seven thousand miles per minute, or an hundred and fifteen miles per second.

This velocity is nearly six times that of the earth in its orbit, and is two hundred and fifty times greater than that of a cannon ball.

It may be easily imagined that the matter to which such a velocity could be imparted by the reaction of such a body as the comet (itself, according to all probability, consisting of mere vapour), must be infinitely attenuated.

But there are other proofs how light and rarified must be the matter composing these bodies.

Since the masses of comets are so infinitely minute, while their volumes are so prodigious, it must follow that the density of the matter composing them is exceedingly small, so small indeed, that they must be, bulk for bulk, immeasurably lighter than air or the most expansive vapour. Other appearances attending them are also consistent with this. Thus it has been found that the smallest stars—stars so minute as to be barely visible by the aid of powerful telescopes, have been distinctly seen, and seen without any perceptible diminution of their lustre, through the very centre of the head of these bodies. It would follow, therefore, that the matter composing them is so attenuated that a thickness of so many thousand miles of it has no sensible imperfection of transparency.

There is, therefore, the strongest reason to conclude that the material of which comets are composed is vaporous or aëriform, and that it is in the most attenuated state that can well be imagined, being probably some thousand times less dense than our atmosphere.

It has also been ascertained on satisfactory grounds that this matter is not luminous, but, like the clouds which float in our atmosphere, is illuminated by the sun, and thus rendered visible. Some circumstances attending the variation of the magnitude of the visible material of these bodies also render it probable that they are composed of vapour, which when raised to a certain temperature by their proximity to the sun, becomes absolutely transparent and invisible, and which as the comet recedes from the centre of light and heat is gradually condensed and becomes visible, just as steam issuing from the safety-valve of a boiler is, at the moment of its escape and before its condensation, transparent and invisible, and assumes a greater and greater volume of whitish cloudy matter, as its distance from the valve and its exposure to the condensing effect of the cold air increases. In this way is explained the fact, that comets in general are augmented in their visible volume as they recede from the sun.

Such then being generally the nature and character of these bodies, so far as observation has enabled astronomers to determine them, it remains to inquire how far there are any grounds for the various effects and influences which have been ascribed to them.

4. Of all the effects which have been ascribed to comets, that of a collision with the earth is perhaps the least unreasonable.

That such an event is *possible*, cannot be denied. It remains, therefore, only to estimate its probability, and the effects it might produce if it occurred.

That a comet should encounter a planet, two conditions must evidently be fulfilled:—1st, the path of the comet must intersect that of the planet; and, 2nd, the two bodies must arrive at the same time at this point of intersection.

Now, of all the known comets there is not one of which the orbit intersects the orbit of any planet. There is, however, one whose orbit passes so near the earth's orbit, that the distance between the two points where they are nearest is less than the semi-diameter of the comet, and it follows, consequently, that if the earth and comet were to arrive together at these points, the earth must pass through the comet. If the comet were solid, which it is not, a collision must take place. But being composed of the lightest and most attenuated vaporous matter, the effect would be the same as if the earth were to pass through a very thin cloud.

This particular comet happens to be one of the few which have been ascertained to revolve round the sun in a definite period like the planets, with this difference, however, that the orbit is a somewhat elongated oval instead of one which is nearly circular. The period of this comet being about six years and three quarters, it follows that it must pass through the place of danger to the earth once in that interval.

It passed through that place in 1832, under circumstances which excited among the world in general, who were taught to expect its approach, and to know its proximity to the earth's path, a certain panic of apprehension as to the possible consequences. These fears were however groundless, for the comet passed through the point of danger on the 29th October, and the earth did not arrive at that point until the 30th November. Now, since the earth moves at the rate of above a million and a half of miles per day, it follows that on the 29th October, the day on which the comet passed through the point of danger, the earth must have been nearly fifty millions of miles from that point.

In 1805, the same comet passed through the same point, under circumstances which, had they been as generally known as in 1832, might have more reasonably excited apprehension, for in that case the distance of the earth from the comet was only five millions of miles.

It may, nevertheless, be observed with truth, that although the danger of an encounter with the comets whose orbits are known, be insignificant, the risk with relation to the far more numerous class of these bodies, whose motions are unascertained and which pass continually among the planets may be much greater.

Nothing, however, is more easy than to apply to this question the well understood principles of the theory of probabilities, assuming such conditions respecting the number and magnitude of the comets, as all must admit to be the most favourable imaginable to the catastrophe of collision. This has been accordingly done. It has been shown that, assuming the number of comets which pass within the earth's orbit to be the greatest that it can be imagined to be, and that the magnitudes of these comets be also the greatest that they can be conceived to be, the chances against a collision of the earth with any individual comet would be 281 millions to one.

Let us illustrate the meaning of this arithmetical conclusion. If a comet appear next month, and if such a comet, encountering the earth, would destroy the whole human race by the shock, how is the danger of such a catastrophe, as it affects each individual, to be estimated? We answer that this danger would be exactly the same as if 281 millions of white balls and one black ball were put into an urn, and that the death of the individual was to be the consequence of the single black ball being drawn from the urn by the hand of a blind man.

This conclusion, which is based upon strict mathematical reasoning, will, we presume, be sufficient to reassure the most timid and sensitive as to the danger of the collision of the earth with a comet.

5. Popular opinion is universal and emphatical in all countries that comets influence the temperature of the seasons, and although popular opinion is not always infallible, it is not to be lightly rejected.

All the world knows that the excellence of the celebrated vintage of 1811 was by common consent ascribed to the influence of the splendid comet which appeared in that year. The "wine of the comet" was long known, and bore a high price in the market. The abundant harvest of the same year was ascribed unanimously to the same cause.

An article appeared in the "Gentleman's Magazine," in 1818, upon the supposed influences of the comet of 1811, in which it was affirmed that, although the winter was mild, the spring humid, and the summer cold, the sun scarcely appearing with force sufficient to ripen the fruits of the earth, yet such was the effect of the comet that the grain harvest was exceptionally abundant, and certain sorts of fruits, such as melons and figs, were not only produced in unusual quantity, but had a delicious flavour. It was further observed wasps were few; that flies became blind, and disappeared early, and that the frequency with which women produced twins was especially remarkable! It even happened that the wife of a shoemaker at Whitechapel had four children at a birth!! and all these marvellous effects were ascribed to the comet.

As to the question of the influence of comets on the temperature of the seasons, it is one of the most simple and most easy of solution. In all observatories, the appearances and motions of the comets are recorded. The average daily and monthly and yearly temperatures of the weather are also exactly observed and recorded. To ascertain, then, whether the comets really exercise any influence on the temperature of the seasons, it is only necessary to place in juxta-position the comets and the temperatures, and to examine whether there be any correspondence between them.

This was accordingly done by M. Arago. The records of the public observatories supplied the data necessary to make the comparison during the century which ended with 1832, and the result was that no correspondence whatever was discoverable. Sometimes it happened that the years of greatest mean temperature were those in which several comets appeared; in some they were those in which none appeared. In some cases the years signalised by the most remarkable comets were characterised by a high, in some by a low mean temperature. Thus in 1737, when two comets appeared, the temperature was lower than in the two preceding years when none appeared. Of the twenty years which commenced in 1763, the coldest, 1766, was that in which two comets, one of which was remarkable for its splendour, appeared. In an interval of 16 years, the warmest was 1794, in which no comet appeared, and the coldest was 1799, in which two were seen.

But omitting further notice of the thermal character of particular seasons, let us see what was the general result of this investigation. Of 74 years, 49 were signalised by the appearance of one or several comets, and 25 by their non-appearance. The mean temperature of the former years was found to be 51.°6, and that of the latter 50.°7, the difference being less than one degree.

Again, of the 49 years in which comets appeared, a single comet was seen in 25, and two or more comets in 24. If these bodies produced any influence on the temperature, a difference ought to be expected between the mean temperature of the latter and the former years. It was found, however, that the mean temperature of 25 years of a single comet was 51.°6, while that of the 24 years of several comets was 51.°4, the difference being only the fifth of a degree, and even that being *against* the influence of the comets in augmenting the temperature.

In fine, the complete discussion of the cometary and thermal observations, continued through an entire century, fully establishes the conclusion that there exists no foundation whatever for the popular opinion that the comets influence the seasons.

6. Of all the eventualities which may arise out of the motion of comets through the system, the least improbable and moreover that of which the consequences are most difficult to foresee, is the passage of the earth through the tail of one of these bodies.

The comets are exceedingly numerous; but few of them have tails. These appendages where they exist are generally of very limited length, but in some rare instances, as has been already stated, their length is prodigious, extending over a space not less than the thirtieth part of the extreme diameter of the solar system. If such a comet had its head at the surface of the sun and its tail in the plane of the ecliptic, the tail would sweep over the space through which the planets, Mercury, Venus, the Earth and Mars move, and it might in that case encounter any or all of these planets.

It cannot, therefore, be denied that the immersion of the earth in the tail of a comet is a possible event. That it is extremely improbable, however, may be shown by the same reasoning as has been already stated in reference to the question of the probability of the collision of a comet and the earth, combined with the consideration that very few comets have tails of considerable length.

But, supposing such an event to take place, what would be the probable consequences?

It is certain that the matter composing the tails of comets is of such a nature that although these appendages have often a thickness measuring many thousand miles, the smallest telescopic stars are visible through it, without the least perceptible diminution of their lustre.

The matter of the tail being, therefore, so completely transparent, and producing moreover no perceptible refraction, its density, if it be vaporous or aëriform, must be extremely inconsiderable, and according to all probability, many thousands of times less than the density of our atmosphere.

If such be its nature, when the earth would pass through it, it would mingle with the terrestrial atmosphere, and if its density were, for example, a thousand times less dense than the air, the atmosphere would contain one particle of cometic matter to every thousand particles of pure air.

Let us suppose that the room we inhabit contains 10,000 cubic feet of air, and let 10 cubit feet of any noxious gas be introduced into it and mixed with the air. We should then take into the lungs in respiration one particle of the noxious gas with every thousand particles of pure air. So far as the possible injurious effects depend on the numerical proportion of impurity, there would appear in such case to be but little ground of reasonable fear.

We have, however, numberless examples of the strong effect produced upon our organs by effluvia with which the air is occasionally impregnated, which, nevertheless, prevail in a proportion so minute as utterly to escape the nicest and most exact analysis.

A grain of musk, or a single drop of the otto of roses, will be sensible to the organ of smelling in a large room, and will continue to be sensible for a long period of time. The actual proportion, nevertheless, which the material effluvia producing this powerful effect upon the organs bears to the total quantity of air impregnated with it is quite inappreciable.

It is pretended by some medical practitioners that the effluvia inspired in smelling certain medicaments is capable of producing on patients the effects of an aperient, and it is well known that the effects of an emetic are often produced by certain odours.

Such analogies, therefore, show that the extreme state of attenuation, which probably characterises the tails of comets, does not necessarily exclude the possibility of their producing formidable effects upon the organised world, if they should be mingled with the atmosphere.

7. This supposition has accordingly been adopted by some authors, and among them not a few holding a position of authority in the world of science, as the means of explaining the prevalence, at various epochs, of epidemic diseases.

Gregory, in a work on Astronomy, published at Oxford in 1702, affirmed that, among all people and in all ages, the appearance of comets has been attended with such general effects; and he adds that it does not become philosophers to treat such traditions with levity, or to reject them, without consideration, as mere fictions.

So recently as 1829, Mr. T. Forster, an English medical practitioner, published a work, entitled "Illustrations of the Atmospherical Origin of Epidemic Diseases," in which he professed to prove that, since the Christian era, the periods which have been the most insalubrious have been invariably those at which some great comet was visible. He maintains that the malignant influence of these bodies is not limited to the human race, nor even to the organised world. He ascribes to them innumerable effects upon the inferior animals, and all the violent changes incidental to the atmosphere besides earthquakes, volcanic eruptions, floods, droughts, and famines.

Comets appear on the average at the rate of very nearly two per annum. Now, it is generally assumed by the partisans of their influence that they exercise these effects for some time before their appearance, and for some time after their disappearance. It cannot, therefore, be surprising that those who favour this theory should find a comet for every epidemic or other visitation, whether physical, or physiological, which they desire to ascribe to such a cause.

Nevertheless, frequent as are the appearances of these objects, and various as are the effects which the partisans of this theory are disposed to ascribe to them, cases have been presented in which the most ardent supporters of such a hypothesis are hard driven to find a misfortune or a malady to visit even upon the most formidable of the comets, and on the other hand, it is sometimes difficult to find a comet on which to saddle some of the greatest scourges which have visited our race.

One of the largest and most remarkable comets of modern times was that of 1680. It was also that which passed nearest to the sun, and not very far from the earth. Nevertheless the partisans of cometary influences have found it difficult to discover any calamity to visit upon that body. There were no epidemic diseases, local or general, to ascribe to it; but Mr. Forster assigns it as the cause of a cold winter, followed by a dry and warm summer, and some remarkable meteors seen in Germany!

The year of the great plague of London (1665) was signalised by a comet which appeared in the month of April, and to the influence of which that visitation was, of course, ascribed. No reasons, however, are given why London alone was obnoxious to this malign influence, and why no similar effect was produced in other European capitals, or even in other great towns of England, nor even in many of the villages with which London is begirt.

To this and all similar speculations it may be answered that, admitting the possible influence of comets, their effect ought to be general and not local. There can be no imaginable reason why such a body should affect, in a special manner, one particular spot upon the earth's surface, while the surrounding countries are exempt from the like consequences of its influence.

This is the conclusive answer to all the absurd speculations on cometary influences which fill the elaborate treatises of Gregory, Sydenham, Lubienetski, Forster, and others. Some of these effects appear so ludicrous that it is difficult to quote them in any serious discussion on a question of physical science.

A great comet appeared in the heavens in 1668, which there is some reason to suppose to be identical with the splendid object which passed through the system in 1843. One of the advocates of cometic influences discovered that the presence of this body in 1668 produced a remarkable epidemic among *cats in Westphalia!* We have not heard of any similar calamity in 1843.

8. A comet, not very conspicuous either for magnitude or brightness, passed near the earth in 1746. The destruction of the cities of Lima and Callao by an earthquake is imputed to this body, but no reason is assigned for the exemption of other cities of the South American continent.

9. To another comet is ascribed the destruction of a steeple-

clock in Scotland, by the fall of a meteoric stone; to another, the prevalence of flocks of wild pigeons in America; to another, remarkable eruptions of Etna and Vesuvius. The authors who, at great labour of research, rake together such incidents, make a vain display of erudition, and, as M. Arago wittily observed, are under a delusion similar to that of a lady mentioned by Bayle, who never looked out of the window of her apartment, situated in the greatest thoroughfare of Paris, and saw the street filled with carriages, without imagining that her appearance at the window was the cause of the crowd.

The celebrated traveller, Rüppel, writing from Cairo, on the 8th of October, 1825 (in which year three comets appeared), observed that "the Egyptians thought the comet then visible was the cause of the shocks of an earthquake which were felt in that country on the 21st of August, and that the same object exercised so malignant an influence on some of the lower animals, that horses and asses perished in great numbers. The truth was, that the poor animals died of starvation, the deficiency of the overflowings of the Nile having produced a scarcity of their forage."

"If I were not restrained by considerations of politeness," observed M. Arago, "I should find no difficulty in proving that, as far as respects astronomical information, there are other Egyptians beside those which are found on the banks of the Nile."

Physical effects are not the only influences imputed to comets. The comet now so familiarly known to the public as that of Halley, and whose last periodical re-appearance took place in 1835, appeared with extraordinary splendour in 1305, being described as "Cometa horrendœ magnitudinis visus est circà ferias paschatis, quem secuta est pestilentia maxima." Thus, as usual, the great plague was laid to the account of this body.

The next visit but one which the same comet paid to the solar system was in 1456, when it is represented as having an "unheard-of magnitude," and as having a tail which extended over sixty degrees of the heavens, being two-thirds of the distance from the zenith to the horizon. It was visible thus during the month of June, and spread terror throughout Europe. It was regarded as presaging the rapid success of the Turks under Mohammed II., who had taken Constantinople, advanced to the walls of Vienna, and struck terror into the whole Christian world. Pope Calixtus II., terrified for the fate of Christianity, directed the thunders of the Church against the enemies of the faith terrestrial and celestial, and in the same bull exorcised the Turks and the comet; and in order to perpetuate this manifestation of the power of the Church, he ordained that the bells should be rung at noon, a custom still observed in Catholic countries. Neither the progress of the comet, nor the victorious arms of the Mohammedans, were, however, arrested. The comet tranquilly proceeded in its orbit, passing through its appointed changes, regardless of the thunders of the Vatican, and the Turks established their principal mosque in the Church of St. Sophia.

A comet appeared in the year 590, to the presence and influence of which was ascribed a fearful epidemic, which prevailed in that year, in the crisis of which the patients were seized with violent paroxysms of sneezing, often followed by death. It became the custom, therefore, when these paroxysms manifested themselves, for the bystanders to address their benediction to the sufferer, exclaiming, "God bless you." This custom became permanent and universal, and to this day the sneezer is addressed in the same words

TELESCOPIC VIEW OF HALLEY'S COMET ON 5TH NOVEMBER, 1835, BY STRUVE.

COMETARY INFLUENCES.

CHAPTER II.

10. The birth and death of heroes, &c.—11. Questions discussed as to whether the dry fog of 1783 or that of 1831 was produced by the immersion of the Earth in the tail of a Comet.—12. Influences of atmospheric disturbances and currents in producing extraordinary effects on epidemic diseases—The periodical wind called Harmattan from the interior of Africa.—13. Question discussed as to whether the Earth at any former epoch has been struck by the solid nucleus of a Comet—Its consequences.—14. Questions discussed as to whether the geographical condition of the Earth has ever been disturbed by the near approach of a Comet, and whether the Biblical Deluge can have been produced by such a cause.—15. Probability of the terrestrial equilibrium being injuriously deranged by near approach of a Comet reduced to nothing.—16. Opinions of Laplace.—17. Curious phenomena of Biela's comet.

10. As we go further back in history, the moral and political influences imputed to comets are multiplied in proportion to the darkness of these times. These objects have been supposed more especially to have portended the birth and the death of heroes. Thus a comet which appeared in 43 B.C., and which was stated to be so brilliant as to be visible to the naked eye in the day time,

was regarded by the Romans as the soul of Julius Cæsar (who was then recently murdered), transferred to the heavens.

A comet which appeared at the epoch of the birth of Mithridates, and another which was seen immediately before the birth of Mohammed, were each regarded as the portents of these historical celebrities.

A comet, supposed to have signalised the birth of Christ, was said to have appeared during an interval of twenty-four days, producing a light *surpassing that of the sun* (!), and with a magnitude which extended over a fourth part of the firmament, so as to occupy four hours in rising and setting.

The exaggeration of such statements must become glaringly apparent when it is considered that comets like planets and the moon derive all their light from the sun.

A comet appeared in March, 1402, the splendour of which is stated to have been so great, that it was visible at noon. A second appeared in the same year in June, which was so brilliant as to be visible for some hours before sunset. This comet was said to presage the death of John Galéas Visconti. That prince, being a believer in astrology, had consulted the charlatans of the day, and the fright produced by the appearance of the comet no doubt contributed to the fulfilment of the prediction.

Another conspicuous comet appeared in 1532, which was also stated to be visible before sunset. It produced much excitement in Northern Italy, where it was considered to presage the death of Sforza II.

11. It has been conjectured, not without some show of probability, that the great dry fogs which spread over a large portion of the surface of the earth in 1783 and 1831, were produced by the passage of the tail of a comet over the earth or over a part of it.

The great fog of 1783 had several characters which would entitle it to serious consideration in relation to this question. It commenced nearly on the same day (the 18th of June), at places very distant from each other, such as Paris, Avignon, Turin, and Padua. It covered a part of the earth's surface, extending north and south from Africa to Sweden. It prevailed on the North American as well as upon the European continent. It can scarcely, therefore, be denominated a local phenomenon in the ordinary use of that term.

It lasted for a month. That the atmosphere did not convey it over the regions in which it prevailed was proved by the fact that its position was not affected by the winds. Whatever direction the wind took, the position of the fog remained the same. It prevailed equally at all accessible heights above the surface. It was as dense upon the summits of the Alps as upon the plains of France.

The heavy and constant rains which fell in June and July, and the storms of wind which accompanied them, did not dissipate it.

Its density and partial opacity varied in different places. In Languedoc it was so dense, that the sun was not visible at altitudes below 12°; and at greater altitudes its light was red, and so subdued, that it could be looked at without inconvenience.

The quality by which it was distinguished from common fogs was its absolute dryness. Hygrometric instruments exposed in it indicated the complete absence of humidity.

One of the most remarkable circumstances, however, attending it was, that it appeared to be endowed with some faintly luminous quality, such as might be supposed to proceed from a slight degree of phosphorescence. Thus it appeared from the declarations of many observers that, while it prevailed at the epoch of new moon, and therefore in the total absence of moonlight, the light proceeding apparently from the fog was sufficient to render objects visible at distances of two or three hundred yards.

Such being the actual phenomena, it remains to be considered whether the hypothesis that the earth passed at that time through the tail of a comet can be admitted to explain them.

In the first place, it must be observed that the *head* of the comet, if such a body were present, was not visible. This cannot be explained by the supposition that the tail rendered the head invisible, inasmuch as the fog did not prevent the stars being seen as usual at night in all places where it prevailed.

It has been suggested that the position of the head might have been such, that it rose and set with the sun, or nearly so, and could not therefore be seen in the absence of that luminary either before sunrise or after sunset. But although this might be admitted for a very short interval, its continuance for a month would not be compatible with what is known of the motion of comets. If it were a comet, the tail being generally turned from the sun, the head must have been within the earth's orbit, and between the earth and sun, or nearly so. The angular motion of the comet must have been such as to remove it from the position of inferior conjunction in the course of a few days, after and before which the head would have either risen before the sun, or set after it, and so would have been visible. No such object, however, was seen at or near the time of the great fog of 1783.

No combination of any possible orbital motion of the comet with the orbital and diurnal motion of the earth has been or can be suggested which would be compatible with the position and continuance of the great dry fog of 1783. It may therefore be concluded that that phenomenon did not arise from the immersion of the earth in the tail of an unseen comet.

The great fog of 1831 is subject to nearly the same observations, and the cometary hypothesis is removed by nearly the same reasoning. This fog was manifested during the month of August. It spread over the three continents of the northern hemisphere, commencing on the north coast of Africa on the 3rd, at Odessa on the 9th, throughout France on the 10th, in the United States on the 15th, and in China during the latter part of the month.

The sun's light was so enfeebled, that it could be looked at without coloured or smoked glass. On the coast of Africa, the sun was not visible at all at altitudes below 15° or 20°; yet the nights were so clear, that the stars were visible. Observers in the north of Africa, in the south of France, in the United States, and in China, reported that the disk of the sun seen through the fog had the tint of azure, and in some places of emerald green.

This appearance was explained by the supposition of the well-known optical illusion called "accidental colours." The fog or the clouds around the solar disk, and through which the latter was seen, being, like fogs and clouds in general, when seen by the transmitted light of the sun, reddish, the white disk of the sun seen in juxta-position with them would, by the mere effect of contrast, appear to be bluish or greenish, according to the tint of red transmitted by the surrounding clouds.*

Like the great fog of 1783, this fog seemed to have a proper light. During its prevalence there was, strictly speaking, no nocturnal darkness. During the month of its prevalence there was light enough at midnight to read the smallest written or printed characters. This fact was reported equally by observers in places the most distant, as in Italy, Prussia, Siberia, &c.

Since twilight ceases when the depression of the sun below the horizon exceeds 18°, and since at these places, in August, the depression considerably exceeds that limit, it is evident that the light thus observed could not have been common twilight.

Whatever may be the explanation of this phenomenon, that of the immersion of the earth in the tail of a comet is overthrown completely by the fact that the fog, though extensively spread, was not continuous, much less uniform. Some parts of the European continent were altogether or nearly free from it, and in other parts it was developed in very different degrees. The times of its continuance in different places also varied much and

* See Lardner's "Hand-Book of Natural Philosophy" (1159).

irregularly, and in such a manner as to be quite incompatible with the cometary hypothesis.

The cometary hypothesis, then, being rejected, it has been suggested that these fogs may have had much nearer and less extraordinary causes. It was recorded that great physical commotions were manifested at opposite extremities of Europe in the year 1783. In the month of February terrible and long-continued shocks of an earthquake took place in Calabria, which produced great devastation, and by which more than 40,000 inhabitants of that country were buried under the ruins of overturned houses and buildings, and in the profound crevices of the cracked crust of the earth. At a later part of the year, Mount Hecla underwent the most violent eruptions ever witnessed, and new craters were opened at various points at the bottom of the surrounding sea, and even at considerable distances from the shore.

Considering these and like commotions, it has been suggested that the vapour, smoke, and gaseous matter ejected in enormous quantities during such eruptions, dissipated by the winds, might have been diffused through the atmosphere over the countries where the fog prevailed.

Another supposition assigns these fogs to the same cause as that which produces showers of meteoric stones, noticed in another number of this series. Among the various forms assumed by this class of bodies, that of showers of fine dust is not unusual. Now, we have only to admit the possibility of a still greater degree of attenuation, to reduce such dust to the condition of the matter composing a dry fog. This explanation would be quite compatible with the local and unequal distribution of the phenomenon.

Several medical authorities conjectured that the fog of 1831 might have been the cause of the epidemic cholera which prevailed about that time. This supposition, however, is overturned by the fact of the frequent prevalence of the same epidemic since then, at epochs at which no such fogs were seen.

12. Nevertheless, facts are recorded which render it certain the atmospheric disturbances and currents do produce extraordinary and hitherto unexplained effects upon epidemic diseases. A very curious and remarkable instance of this influence is quoted by M. Arago from the narrative of Matthew Dobson, an English traveller.

"A periodical wind, called Harmattan, blows three or four times a-year from the interior of the African continent towards the Atlantic coast, between latitudes 15° north, and 1° south. The periods of its prevalence are stated to be chiefly from the end of November to the beginning of April, its direction varying from east-south-east to north-north-east. Its duration at any one time varies from one to six days, and its force is always very moderate. A fog, thick enough to render the disk of the sun red, always accompanies this wind. The particles deposited by this fog upon the leaves of vegetables and on the black skin of the natives appears always white, but the nature of this whitish matter was not ascertained. It was remarked that this fog was speedily dissipated by the sea; for although the wind was sensible on sea at many leagues from the coast, the fog became rapidly less dense, and, at the distance of little more than a league, it disappeared.

"One of the characteristics of this wind and fog is extreme dryness. When it continued for any time, the foliage of the orange and lemon trees exposed to it became shrivelled and withered. So extreme is this dryness, that the covers of books, even when closed, locked in chests, and enveloped in linen cloth, were curved by it just as if they had been exposed to the heat of a strong fire. The panels of doors and frames of windows, and the furniture, were often cracked and broken by it. Its effects upon the human body were not less marked. The eyes, lips, and palate were parched and painful. If the wind continued unabated so long as four or five days, the face and hands grew pallid. The natives endeavoured to counteract these effects by smearing their skin with grease."

Considering all these effects, it might be naturally inferred that the Harmattan must be highly insalubrious; yet observation proved it to have the extreme opposite quality. It was found that its first breath completely banished intermittent fevers. Those who had been enfeebled by the practice of excessive bleeding, then prevalent there, soon recovered their strength. Epidemic and remittent fevers, which had a local prevalence, disappeared as if by enchantment. But the most wonderful effect of this atmospheric phenomenon was, that it rendered infection incommunicable, even when applied by artificial means, such as inoculation.

There was at Wydah, in 1770, a British slave ship called the *Unity*, having on board a cargo of above 300 negroes. The smallpox having broken out among them, the owner resolved on inoculating those who had not taken the natural disease. All those who were inoculated before the commencement of the Harmattan took the disease, but of seventy that were inoculated on the second day after its commencement, not one took the infection; yet after the lapse of some weeks, when the Harmattan ceased these seventy negroes took the natural disease. Soon after they were attacked by it, the Harmattan recommenced, and the disease almost immediately disappeared.

The country over which the Harmattan blows, for more than a hundred leagues, is a series of extensive plains covered with verdure, with a few patches of wood here and there, and intersected by a few rivers, with some small lakes.

13. Various phenomena have raised the question whether at any remote epoch of its physical history the earth was ever struck by the solid nucleus of a comet.

We have already stated the circumstances which render it highly probable that the comets generally are mere masses of aëriform or vaporous matter. Nevertheless, although this be certain as respects the large majority of these bodies, some among them, more especially those which appeared at remote dates, have had a splendour which it would be difficult to imagine to be produced by the reflection of the sun's light by mere vaporous matter; and even in modern times, since the instruments of observation have been improved, and observers have increased in zeal, activity, and vigilance, and have been greatly multiplied in number, appearances of a nucleus have been observed which some astronomers have considered to afford pretty conclusive evidence of the existence of a solid nucleus within the nebulous envelope; and although many entertain doubts of this, it cannot be said that the existence of a solid nucleus in some of the many comets which have passed through the system is absolutely disproved.

Assuming, then, the possible existence of a solid comet, and considering the possible (however improbable) eventuality of such a body and the earth passing at the same moment through the same point of space, it may be reasonably asked,

What would be the consequences of such a catastrophe?

It must be observed, in the first place, that admitting the bare possibility of certain comets having a solid nucleus, such a mass must be less, incomparably, than the smallest body of the solar system. The grounds upon which this inference rests, have been already stated.

Now, assuming the earth to move round the sun, and at the same time to have a diurnal rotation upon a certain diameter as its axis, let us see what would happen if it were to receive suddenly a blow, from a much smaller solid mass encountering it.

If, in case of such an event, the earth had no previous motion of rotation, and if, as would probably happen, the direction of the blow given to it did not pass through its centre, it would receive a motion of rotation round an axis at right angles to the plane drawn through the direction of the blow and the centre of the earth, and the time of rotation would depend on the distance of the centre of the earth from the direction of the blow.

If, however, the earth, before receiving the blow, had already a motion of rotation, the effect of the blow would be to change either its axis of rotation or the time of rotation, or both one and the other. Its new axis of rotation would have a certain position between its previous axis and that upon which the blow would have made it revolve if it had no previous rotation. The determination of this new axis would be a problem of no difficulty.

Such being the immediate consequences of such a collision, it remains to consider what would be its secondary results.

If a carriage moving uniformly on the smooth surface of a railway, or a boat propelled or drawn uniformly on the surface of water, receive an impulse by which its speed is suddenly changed, all loose bodies upon it will be thrown backward or forward, according as its speed is increased or diminished, inasmuch as they do not at first participate in the increase or diminution of velocity imparted to the vehicle on which they are placed. Hence it happens, that if a horse going at speed suddenly retards his motion, or stops, the rider is thrown forward, and if he suddenly starts forward with increased speed, the rider is thrown backwards.

A similar disturbance of position would be produced by a change of direction of the motion of the vehicle. If it suddenly turn to the right, loose bodies will fall to the left, and *vice versâ.*

The earth, moving in its annual course round the sun, and at the same time revolving uniformly upon its axis, producing the vicissitudes of day and night and the succession of seasons, must be regarded as a vehicle upon which all loose bodies, such as air, water, and other fluids, animals, and all natural and artificial objects, not planted and firmly fixed in the solid ground, are transported, first round the axis of rotation by the diurnal motion, and secondly, round the sun by the annual motion of the earth in its orbit. Now if, under such circumstances, either of these motions were to receive a sudden change either in velocity or direction, the fluids composing the atmosphere, and the oceans, seas, lakes, and rivers, not partaking of that change, would, for the reasons explained above, be thrown from their position of relative equilibrium. Violent atmospheric commotions would ensue. The waters of the oceans and seas, thrown from their beds, would inundate the continents; rivers would change their directions, and either run in new channels or inundate the surrounding plains; lakes would desert their positions, and would flow in any channels open to them, or would flood the surrounding countries. Animals would be precipitated against all solid objects near them, with a force greater probably than that of a cannon-ball. Trees would be torn from their roots; buildings, especially such as have much elevation, would be overthrown; and if the change of motion were of a certain intensity, lofty mountain peaks would be cast into the adjacent plains or valleys. It is evident that a general destruction of the organised world would be inevitable.

But even though the change of axis and the change of velocity of rotation of the earth might be so very inconsiderable, owing to the smallness of the mass of the striking comet and other causes, that such devastation might not take place, other effects would ensue which would speedily show the disturbance consequent on such a catastrophe. The least change in the axis would cause a corresponding change in the position of the terrestrial poles and the equator. The latitudes and longitudes of all places on the earth would suffer a change, the extent of which would be commensurate to the change of position of the axis of rotation.

But it is demonstrated in mechanics that a spheroid, such as the earth is known to be, cannot permanently revolve round any axis except its shortest diameter, that is the diameter which passes through the two points which form the centres of its flatness; and such we know by exact and numerous observations to be the axis upon which the earth actually revolves. Now, if by the collision of a solid comet the earth were made to revolve on any other diameter, it could not continue so to revolve. It would change its axis from hour to hour until at length it would again revolve round its shortest diameter.

But during this continual change of axis, what inconceivable physical and geographical confusion would arise! Not only would the latitudes and longitudes of places be constantly changed, but their climates and seasons, the conditions and qualities of their vegetable productions would undergo corresponding variations. Animals would migrate from country to country, seeking a congenial climate, and flying from vicissitudes and extremes of temperature which their instincts would not fail to tell them are incompatible with their well-being. The distribution of land and water, though perhaps exempt from the devastating effects attending extreme changes of velocity and direction, would nevertheless gradually undergo a total and general change, and the geographical features of the earth, the land-marks of nations and races, would be utterly deranged and effaced.

To answer the question, then, whether the earth has ever at any epoch been struck by the solid nucleus of a comet, we have only to examine whether there be any traditions in history, or any physical traces on the surface of the globe, of phenomena such as we have described above.

It is scarely necessary to observe that, in the records of history and the traditions of nations, there are no traces of any such catastrophe as that which we have here described. The deluge, which we shall presently notice, did not correspond to the conditions stated. That there are indications on the crust of the earth which prove that many parts of the continents, now elevated to considerable heights above the level of the sea, were at some former epoch submerged, is incontestable. The researches of geologists have established this fact. But the manner in which these marine deposits are found to be disposed is not such as a change in the earth's axis or in its time of rotation would explain. These deposits are frequently horizontal, of great breadth, very thick, and very regular. The varied and often very small shells found in them have preserved their most delicate points, their most brittle parts, unbroken. Every circumstance, then, dissipates the idea of a violent transposition; everything shows the deposits to have been formed on the spot. What now remains to complete the explanation without having recourse to an eruption of the sea? It must be admitted that the mountains and undulating grounds upon which they are based have risen up from below, like mushrooms; that they have grown up through the bosom of the waters. In 1694, Halley already cited this hypothesis as a *possible* explanation of the presence of marine productions upon the sides and on the summits of the highest mountains. This explanation is at present generally admitted. A comet which should perceptibly alter either the movement of rotation or the progress of translation of the earth would, without any doubt, occasion terrific convulsions in the shell of the globe; but, it must be repeated, these physical revolutions would differ in a thousand circumstances from those which are at present the objects of geological research.

14. *Has the geographical condition of the earth been ever disturbed by the near approach of a comet? Can the biblical deluge have been produced by such a cause?*

A remarkable comet appeared in the year 1680, which has been rendered memorable by the attempt of Whiston to prove that it was periodic, and that on one of its former visits it was the proximate cause of the Mosaic deluge. Arago, in his essays on comets, has discussed fully the question raised by Whiston.

Whiston proposed to show not only in what manner a comet might have occasioned the deluge of Noah, but was desirous, moreover, that his explanation should agree minutely with all the circumstances of that great catastrophe as related in Genesis. Let us see how he has succeeded in his object.

The biblical deluge happened in the year 2349 before the Christian era according to the modern Hebrew text; or the year 2926, after the Samaritan text, the Septuagint, and Josephus. Is there, then, reason to suppose that at either of those periods a great comet had appeared?

Among the comets observed by modern astronomers, that of 1680 may, from its brilliancy, without hesitation, be placed in the first rank.

A great many historians, both native and foreign, mention *a very large comet, in similitude to the blaze of the sun, having an immense train,* which appeared in the year 1106. In ascending still higher, we find a very large and terrific comet designated by the Byzantine writers by the name of Lampadias, because it resembled a burning lamp, the appearance of which may be fixed in the year 531. A comet appeared in the month of September, in the year of the death of Cæsar, during the games given by the Emperor Augustus to the Roman people. That comet was very brilliant, as it became visible from the eleventh hour of the day, that is, about five o'clock in the evening, or *before sunset.* Its date is in the year 43 before our era.

Let us, then, compare the dates of these appearances:—

From 1106 to 1680 we find	574 years.
,, 531 ,, 1106 ,, ...	575 ,,
,, 43 B.C. to 531 we find . . .	575 ,,

These periods may be regarded as equal to each other, and thence it appeared probable enough that the comets of the death of Cæsar, of 531, of 1106, and of 1680, have been only the reappearances of one and the same comet, which, after having run through its orbit—after having made its complete revolution in about five hundred and seventy-five years—became again visible from the earth. Then if the period of five hundred and seventy-five years is multiplied by four, we have twenty-three hundred, which, added to 43, the date of Cæsar's comet, gives, with the difference of only six years, the epoch of the deluge, resulting from the modern Hebrew text. In multiplying by five, the date of the Septuagint is found within eight years.

If we recollect the marked differences of the comet of 1759 in the period of its revolution round the sun, we shall acknowledge that Whiston might legitimately have felt authorised to suppose that the great comet of 1680, or of the death of Cæsar, was near the earth at the period of Noah's deluge, and that it had some part in that great phenomenon.

We shall not stop to explain minutely the series of transformations by which the earth, which, according to Whiston, was originally a comet, became the globe we now inhabit. It is enough to observe that he considered the nucleus of the earth as a hard and compact substance, which was the ancient nucleus of the comet; that the matters of various natures confusedly mixed which composed the nebulosity, subsided more or less quickly, according to their specific gravities; that then the solid nucleus was at first surrounded by a dense and thick fluid; that the earthy matters precipitated themselves afterwards, and formed a covering over the dense fluid—a kind of crust, which may be compared to the shell of an egg; that the water, in its turn, came to cover this solid crust; that in a considerable degree it became filtered through the fissures, and spread itself over the thick fluid; that, in fine, the gaseous matters remaining suspended, purified themselves gradually, and constituted our atmosphere.

Thus, according to his theory, the great biblical abyss is supposed to consist of a solid nucleus and of two concentric orbs. Of these orbs, that nearest to the centre is formed of a heavy fluid which first precipitated itself; the second is of water; it is then, properly speaking, upon the last of these fluids that the exterior and solid crust of the earth reposes.

It is proper now to examine how, after the constitution of the globe to which at least many geologists could oppose more than one difficulty, Whiston explains the two principal events of the deluge described by Moses.

"In the six hundredth year of Noah's life," says the book of Genesis, "on the seventeenth day of the second month, the same day were *all the fountains of the great deep broken up; and the windows of heaven were opened.*"

At the period of the deluge, the comet of 1680, says Whiston, was only nine or ten thousand miles from the earth: it attracted, therefore, the water from the great deep, as the moon at present attracts the waters of the ocean. Its action, on account of that great proximity, must have tended to produce an immense tide. The terrestrial shell could not resist the impetuosity of the inundation; it broke in at a great number of points, and the waters, then free, spread themselves over the continents. The reader will here recognise *the rupture of the fountains of the great deep.*

The ordinary rains of our days, even continued for forty days, would have produced but a small accumulation. In taking for daily rain that which falls at Paris annually, the produce of six weeks, far from covering the highest mountains, would scarcely have formed a depth of eighty feet. It was therefore necessary to refer to other sources *than the cataracts of heaven.* Whiston has found them in the nebulosity and tail of the comet.

According to him, the nebulosity reached the earth near the Gordian (Ararat) mountains. Those mountains intercepted the entire tail. The terrestrial atmosphere, thus charged with an immense quantity of aqueous particles, was sufficient to produce forty days' rain of such violence as the ordinary state of the globe can give us no idea.

Notwithstanding all its strangeness, we have stated the theory of Whiston in detail, both on account of the celebrity which it has so long enjoyed, as well as because of the consideration due to the man whom Newton himself designed as his successor in the University of Cambridge; yet the following are objections which it seems his theory cannot resist.

Whiston having required an immense tide to explain the mystery of the biblical phenomena of the great deep, was not content to pass his comet extremely near the earth at the moment of the deluge: he has, moreover, given it a very great magnitude, in supposing it six times greater than the moon.

Such a supposition is completely gratuitous, but this is its least fault; for it is not sufficient to account for the phenomena. If the moon produces a tide on the waters of the ocean, it is because its angular diurnal motion is not very considerable; that in the space of some hours its distance from the earth scarcely varies; during a considerable time it remains vertically over almost the same points of the globe; the fluid which it attracts has therefore always time to yield to its action before it moves to a region where the force which emanates from it will be otherwise directed. But it was not the same with the comet of 1680. Near to the earth, its apparent angular motion must have been extremely rapid; in a few minutes it corresponded with a numerous series of points situated on terrestrial meridians very distant from each other. As to its rectilinear distance from the earth, it might, without doubt, have been very small, but only during a few instants. The union of these circumstances, it must be observed, was but little favourable to the production of a great tide.

It is true that, to diminish these difficulties, it is sufficient to increase the comet—to make its mass not only six times the size of the moon, but thirty or forty times larger: but the comet of 1680 does not afford that latitude. On the 1st of November in that year it passed very near to the earth. It is shown that at the period of the deluge its distance was not less; then, as in 1680 it produced neither celestial cataracts, nor terrestrial tides, nor ruptures of the great deep; as, moreover, its train nor its nebulosity did not inundate us, we may in all confidence say that Whiston's theory is a mere romance, unless, in abandoning the comet of 1680, we venture to attribute the same effect to another much more considerable object of the same description.

In fine, we must observe that, even the argument of Whiston, based upon the apparent equality of the supposed successive appearances, from which he deduces a period of 574 or 575 years for the comet in 1680, is shaken by more recent calculations, which give to that body* an elliptic orbit in which the period is 8813 years.

15. The probability of the terrestrial equilibrium being injuriously deranged by the near approach of a comet, which, nevertheless, does not actually come in contact with the earth, is reduced to nothing by the established fact that the masses of these bodies generally are so utterly insignificant that none of them has ever yet produced by its proximity the slightest sensible deviation from its customary path in the smallest body of the solar system.

16. Notwithstanding the many arguments which we have here developed against the probability of any fatal influence exerted by comets upon our planet, it must not be concealed that high authorities have regarded such influences and effects as not impossible. Thus Laplace, referring to the possible collision of a solid comet with the earth, says: "It is easy to foresee the effects of such an eventuality: the earth's axis and rotation changed: the waters of the seas and oceans deserting their beds, and rushing towards the new equator: the chief part of the human race and inferior animals drowned in an universal deluge, or destroyed by the violence of the collision: whole species annihilated:—all monuments of human industry overturned!" Notwithstanding the many and obvious evidences against the geological phenomena having been produced by such a cause, Laplace did not reject it, probably because the phenomena were not so fully known at the time he wrote as they are at present. "We see then," he observed, "why the ocean deserted the most lofty mountains, on which it left, however, incontestable evidence of its presence. We see why the animals and plants of the tropics may have existed in the higher latitudes, where their relics and footsteps are still seen. In fine, it explains the recent date of the present races, whose earliest monuments do not go further back than about 3000 years. The human race, reduced to a small group of individuals, in a deplorable condition, occupied exclusively in providing for their physical wants, must necessarily have lost the remembrances and records of all the sciences and arts; and when later, new wants were created by the progress of civilisation, all was to be recommenced as if no previous progress had been made, and as if man had been then for the first time placed upon the earth."

17. Having disposed of the question of the physical influences imputed to comets, we shall conclude this notice by a brief statement of one of the most extraordinary and unexplained phenomena

* Lardner's "Handbook of Natural Philosophy and Astronomy." (3072).

ever witnessed in the heavens, which has been not only seen, but observed with the most scrupulous accuracy in our own times.

A periodical comet, called Biela's from its discoverer, revolves round the sun in an oval orbit of 6¾ years. On the occasion of its appearance in 1846, it was seen to resolve itself into two distinct comets, which, from the latter end of December, 1845, to the epoch of its disappearance in April, 1846, moved in distinct and independent orbits. The paths of these two bodies were in such optical juxtaposition, that both were always seen together in the field of view of the telescope, and the greatest visual angle between their centres did not amount to more than a third of the apparent breadth of the moon.

M. Plantamour, director of the Observatory of Geneva, calculated the orbits of these two comets, considered as independent bodies; and found that the real distance between their centres was, subject to but little variation while visible, about thirty-nine semi-diameters of the earth, or two-thirds of the moon's distance. The comets moved on thus side by side, without manifesting any reciprocal disturbing action; a circumstance no way surprising, considering the infinitely minute masses of such bodies.

The original comet was apparently a globular mass of nebulous matter, semi-transparent at its very centre, no appearance of a tail being discoverable. After the separation, both comets had short tails, parallel in their direction, and at right angles to the line joining their centres; both had nuclei. From the day of their separation the original comet decreased, and the companion increased in brightness until (on the 10th February) they were sensibly equal. After this the companion still increased in brightness, and from the 14th to the 16th was not only greatly superior in brightness to the original, but had a sharp and starlike nucleus compared to a diamond spark. The change of brightness was now reversed, the original comet recovering its superiority, and acquiring on the 18th the same appearance as the companion had from the 14th to the 16th. After this the companion gradually faded away, and disappeared previously to the final disappearance of the original comet on 22nd April.

It was observed also that a thin luminous line or arc was thrown across the space which separated the centres of the two nuclei, especially when one or the other had attained its greatest brightness, the arc appearing to emanate from that which for the moment was the brighter.

After the disappearance of the companion, the original comet threw out three faint tails, forming angles of 120° with each other, one of which was directed to the place which had been occupied by the companion.

It is suspected that the faint comet which was observed at Rome by Prof. Secchi to precede Biela's comet in 1852, may have been the companion thus separated from it; and if so, the separation must be permanent, the distance between the parts being greater than that which separates the earth from the sun.

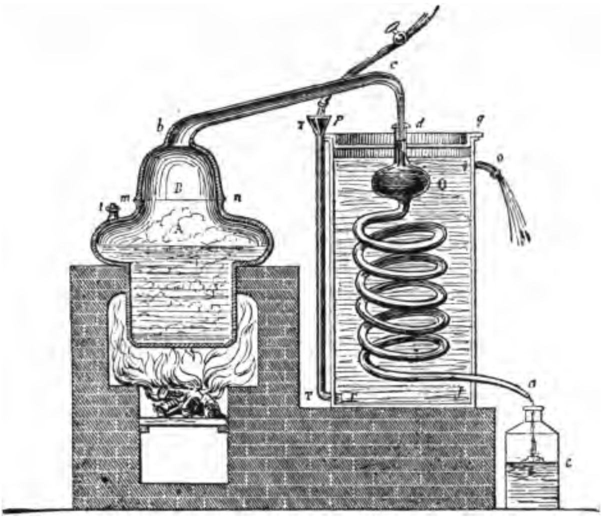


Fig. 1—DISTILLING APPARATUS.

COMMON THINGS.

WATER.

1. Water may be solid, liquid, or vapour.—2. Colourless and tasteless.—3. Its weight.—4. Expands by heat.—5. Point of greatest density.—6. Freezing-point.—7. Boiling.—8. Evaporation.—9. Heat absorbed in evaporation.—10. Superficial evaporation.—11. Saturation of air by vapour.—12. Process of drying.—13. Case of roads and paths.—14. Drying linen.—15. Wind promotes drying.—16. Water never naturally pure.—17. Contains fixed air.—18. And other substances in solution—Hard water.—19. Soft water.—20. Mineral springs.—21. Filtration.—22. Filtering-paper.—23. Artificial filters.—24. Water not absolutely colourless.—25. How to obtain water absolutely pure.—26. Rain water nearly so.—27. River water.—Thames water.—28. Water not an element—Its composition.—29. Methods of purifying it.—30. Distillation of water.—31. Conversion of vapour into water.—32. Weight of vapour.—33. Condensation.—34. Distilling apparatus.—35. Composition and decomposition.—36. Oxygen and hydrogen.—37. Hydrogen.—38. Fitted for balloons.—39. Inflammable.—40. Water produced by combining oxygen and hydrogen.—41. Apparatus for this experiment.—42. Composition of water.—43. Analysis of water.—44. By voltaic current.—45. By other methods.—46. By potassium and sodium.—47. By iron.

1. Next to air water is the most common of natural substances. It is less universally present, and although the uses to which it subserves are not less numerous and important, the want of it on the part of the animal and vegetable creation cannot be regarded as so incessant.

Water, according to certain varying physical conditions, may exist either in the solid, liquid, or vaporous state. It is perhaps in the last state that it is most universally diffused over the surface of the globe; but not being so obvious to the senses as it is when in the former two states, it is not recognised except by those who are familiar with the scientific tests of its presence.

It is therefore in the liquid form that we are most familiar with it.

2. At ordinary temperatures, and exposed to common atmospheric conditions, pure water is a colourless and tasteless liquid, having great transparency.

3. Its weight in relation to its bulk is very easily remembered, for it has been found that a cubic foot weighs almost exactly a thousand ounces, the temperature being 60°, the ordinary temperature of the atmosphere in these climates.

It may also be easily remembered that an imperial gallon of pure water, at this temperature, weighs 10 lb., and consequently that an imperial pint or the eighth part of a gallon weighs $1\frac{1}{4}$ lb.

4. All liquids expand or swell when heated, and contract when cooled. This is a general fact with which every one is familiar. Water is not an exception to this. A gallon of boiling water will be less than a gallon when it becomes cold, and a gallon of cold water will be more than a gallon when it is heated.

Water is therefore rendered more dense, that is to say, heavier in a given bulk, by cooling it, and less dense, that is lighter in a given bulk, by heating it.

5. There is, however, at a certain point in the thermal scale, a very striking exception to this general law in the case of water. If it be gradually cooled, its dimensions will continually contract, and it will become denser and denser until its temperature is reduced to $38^\circ\frac{8}{10}$ of Fahrenheit's thermometer. But when it is cooled below that point, instead of contracting, it is found to expand; instead of becoming denser and heavier, it becomes less dense and lighter.

Water, therefore, bulk for bulk, is heavier and denser at the temperature of $38^\circ\frac{8}{10}$ than at any other temperature, whether higher or lower.

This is therefore called the "temperature of greatest density."

6. When the temperature is reduced to 32° water becomes solid. This change from the liquid to the solid is called congelation

or freezing, and the temperature 32° at which it takes place, is called the freezing point of water.

7. If water be exposed to any source of heat, such as a fire or a lamp, it will, as may be naturally imagined, become continually hotter and hotter, but this increase of heat will not be unlimited. It will, on the contrary, after a certain continuance of the action of the fire or lamp upon it, attain a degree of heat or temperature which it will never exceed, however intense or long continued the action of the fire may be. In the ordinary state of the atmosphere, this temperature is that marked 212° on the thermometer. If a thermometer be immersed in the water, it will stand constantly at this temperature, although the action of the fire upon the water still continues.

When the water attains this stationary point of temperature it will be observed to be affected by a violent agitation throughout every part of it. Bubbles of vapour are formed at the parts of the vessel which are next the fire, and these rising with a certain violence, escape continually from the surface and produce the peculiar agitation of the liquid which has been just mentioned.

This state of water is called EBULLITION or BOILING, and the stationary temperature of 212°, at which it takes place, is called the BOILING POINT of the thermal scale.

8. Until the water exposed to the action of fire has attained the boiling-point, the heat imparted to it is employed in raising its temperature, or, in familiar language, in rendering it hotter. But after it has attained the limit of its temperature, and ceases to be rendered hotter, the fire still continues to impart the same heat to it, and it may be asked, What becomes of this heat? How is it absorbed, employed or disposed of? since it is certain that the water does not receive it.

This is easily explained. The water which the vessel contains does not become hotter, and therefore can receive none of the heat imparted by the fire, but it is rapidly converted into vapour, and this vapour, escaping continually from the surface of the water, rises into the air. The quantity of water in the vessel is continually diminished by the quantity thus escaping in the form of vapour, and if the process be continued, the water will altogether disappear from the vessel, being all converted into vapour.

The heat, then, imparted by the fire, in this case, and which fails to augment the temperature of the water in the vessel, is altogether absorbed by the vapour into which the water is converted. This vapour, it is true, is not hotter than the water in which it is formed, its temperature, like that of the water, being 212°; but it is proved by experiments, made in the laboratories of chemists and philosophers, that much more heat is required to impart to vapour the temperature of 212° than to impart the same temperature to water, and it is in raising the vapour formed from the water to the temperature of the water itself that the entire quantity of heat received from the fire is absorbed.

9. Thus it is found that a given weight of water at 212° when it passes into vapour, absorbs as much heat as would be sufficient to raise five and a half times the same quantity of water from the freezing to the boiling-point.

10. It is not alone when raised to the boiling-point that water is converted into vapour. It is vapourisable more or less at all temperatures, and it has been ascertained that a vapour is produced even from ice. But the evaporation which takes place from water below the boiling-point, is produced in a different manner, and under different conditions. At the boiling-point, water is converted into vapour at all points and at every depth, and most abundantly at those parts where it is in contact with the surface of the vessel upon which the fire acts. But at other temperatures the evaporation is altogether superficial. The vapour is evolved from the surface of the water above, and rises into and mingles with the stratum of air which rests on the surface of the water. This evaporation is also infinitely less rapid and copious than that which is produced by raising the whole mass of water to the boiling-point, and maintaining it at that point.

11. The stratum of air which rests upon the surface of water may be regarded as a medium which has a certain limited power of absorbing the vapour of the water, exactly as a sponge receives liquid water into its numerous pores. The air, like the sponge, has a limited capacity for vapour, and it may become so charged with vapour as to be incapable of absorbing more. The air in this case is said to be *saturated* with vapour.

Evaporation from the surface of water, therefore, takes place more or less freely and copiously as the air is more or less below the point of saturation; and when the air has already attained the point of saturation all evaporation ceases.

12. The process of drying moist or wet objects is an example of the effects of evaporation. The moisture upon the surface, or in the texture or pores of the object is evaporated by exposure to the air, and the object becomes free from moisture, or dry. This evaporation takes place so much the more rapidly as the air is below the point of saturation, and so much the more slowly as it is nearer to that point.

13. Every one is familiar with the fact, that wet roads and footpaths will on some days be dried in a few hours, while on others they will continue wet without any marks of drying. These are mere consequences of the state of the air in relation to

the vapour with which it is charged. In the former case it is under-charged, and therefore readily receives the evaporation from the roads and footways, which accordingly become dry; in the latter it is surcharged, and is at or near its state of saturation; it can receive no more vapour; no evaporation is possible, and the roads remain wet although no rain fall.

14. Washerwomen who spread linen in the air to be dried, well know that the facility of drying it varies on different days. Some days have no drying power, the air being saturated with vapour. Others dry the linen easily and quickly. Then the air is little charged with vapour, and is far below the point of saturation. Between these there are many degrees in which the facility of drying varies.

15. Wind stimulates evaporation, and therefore expedites drying. This is easily explained. So fast as the stratum of air over water becomes charged with vapour and raised towards its point of saturation, it is swept away, and a fresh portion of dry air is brought into contact with the wet surface. This in its turn is swept away, giving place to another dry portion of air, and so on. In this way, all moist objects exposed to wind or currents of air are speedily dried.

Wet objects are quickly dried when exposed to artificial heat, the moisture they contain being rapidly evaporated.

16. Water when absolutely pure is without taste, and insipid. But in its natural state water never is pure. Spring water raised from inferior strata of the ground has always various earthy and saline matters dissolved in it. In fact, every constituent of the strata from which it has been raised, or through which it may have passed, which is soluble in water, is necessarily dissolved in it in greater or less quantity. River water contains more or less of all the soluble constituents which it encounters either at its sources or on the beds and banks of the channels through which it has passed, besides the soluble parts of various dead animal and vegetable matter which it inevitably receives in its course.

17. All water in its natural state contains more or less fixed air mixed with it. This is most commonly carbonic acid. This gas, which is the same as that which effervesces in soda water, lemonade, champagne, and bottled malt liquors, gives to the flavour of water a certain agreeable pungency.

18. Water acquires very various flavours and other qualities, according to the nature of the substances which it holds in solution. Spring water, in general, even when it is most pure, holds lime and silicious earths in solution. It is from these that it acquires the quality popularly called hardness. It will not easily mix with soap, and it is not suited to culinary purposes.

19. Water which is free from this quality, and which holds but

little earthy matter in solution, is called, on the contrary, soft water. Rain water and river water is in general soft, although the latter is never free from some portion of earthy combination.

20. Mineral springs are examples of water holding peculiar mineral salts in solution, in quantities so considerable and of qualities so peculiar as to render it altogether unfit for common use. It acquires, however, from these, peculiar medicinal virtues.

21. Water generally holds suspended in it various impurities which are not dissolved in it. Muddy water is an extreme example of this. But without being actually muddy, water often has many impurities, suspended without being dissolved in it. All such impurities are removed by FILTRATION.

22. In chemical researches, where the quantities of liquid operated on are usually small, a species of paper, called filtering paper, is used. This is white unsized paper, which is formed into a conical bag, and placed in a glass funnel of corresponding shape. The liquid to be filtered is made to pass slowly through the pores of the paper, by which it is strained of the foreign matter suspended in it.

23. The filters used in the arts and in domestic economy for the purification of water have been very various. An open grained stone from Teneriffe was formerly much used for this purpose, as also porous unglazed earthenware. These have been more recently, however, completely superseded by a variety of artificial filtering apparatus, which for the most part consist of strata of gravel, sand, and charcoal powder, through which the foul water is pressed by its own weight, and by which it is very effectually strained of its solid impurities.

24. It has been stated that water is transparent and colourless; and, so far as respects any moderate quantity of the liquid which is submitted to observation, this is true. But, strictly speaking, water is neither absolutely transparent nor absolutely destitute of colour. If we look into the sea, where the water has any considerable depth, we find that its colour is a peculiar tint of blue; but if, however, we take up a glass of the water, which thus appears blue, we shall find it limpid and colourless. The reason of this is, that the quantity of water contained in the glass reflects to the eye too small a quantity of the colour to be perceivable; while the great mass of water viewed when we look into the deep sea, throws up the colour in such abundance as to produce a strong and decided perception of it.

The same is true of all transparent coloured liquids. Sherry in a decanter has a deep golden colour. Seen through the thin stem of a tapering champagne glass it appears paler and paler, until towards the point of the cone it loses all colour.

It is probable that the colour of water arises partly from the substances which it holds in solution. The fresh water of a lake has a colour different from that of the salt water of the sea. How far the colour of water may arise from the various substances which it holds in solution is difficult to decide, inasmuch as we cannot obtain a sufficient quantity of water absolutely pure to be enabled to ascertain its proper colour.

25. It appears from what has been explained that filtration only disengages from water the solid impurities which may be mechanically mixed with or suspended in it; and if all water in the natural state holds in solution more or less foreign matter, it may be asked how water absolutely pure can be obtained?

It must be observed that, for all ordinary purposes, water chemically pure would be less suitable than such water as is commonly obtained. For alimentary purposes, absolutely pure water would be neither agreeable nor sanitary. For culinary and domestic purposes such purity is not needed.

26. Of all water found in the natural state, rain water is the purest. But this, as commonly obtained, having first fallen on the roofs of buildings, and then passed through pipes and conduits to the reservoirs in which it is collected, takes up and dissolves more or less of the impurities formed upon the surfaces over which it passes. To obtain rain water in perfect purity, it must therefore be received directly as it falls in clean vessels. But even then it is found to be impregnated more or less with air, and especially with carbonic acid, which it absorbs from the atmosphere. Minute portions of ammoniacal salts are also found in it, and if it fall near the sea, it has generally a small portion of common salt in solution. Rain which falls during thunder storms has often traces of nitric acid, formed probably by the effect of the atmospheric electricity.

27. Next to rain water, river water is the purest. The Thames water, where it is not polluted by the drainage of the metropolis, is found to contain no more than two grains of foreign matter in solution in a pint. The matter which it thus holds in solution is principally carbonate and sulphate of lime, common salt, chloride of magnesium, and animal matter. A gallon of Thames water in its most impure state, when properly filtered, does not contain more than twenty-four grains of earthy or saline matter, and in its purest state not less than sixteen grains.

When water is contaminated by animal and vegetable matter, if kept for some time, it undergoes a spontaneous purification, losing its offensive odour and colour, and depositing more or less sediment. Water for the supply of ships is well known to undergo this process of purification by fermentation, and the larger the quantity of destructible matter suspended in it, the more complete and rapid is its purification. A preference is given to Thames water for marine stores on this account, the more pure river water fermenting less rapidly, and remaining more or less foul and putrid for a much longer time.

For the supply of London, however, where this spontaneous purification is not to be waited for, it is obvious that the water should be taken from that part of the river above Richmond which is beyond the influence of the tides, and where it is not liable to be polluted by the contents of the sewers, the offal of manufactories, and the mud stirred up by steamers.

28. Water was supposed by the ancients to be one of the elements or simple substances of which all others are composed. It was ascertained, however, towards the close of the last century, that it is a compound of two substances as different in their form and properties from water itself as can well be imagined. Water is a heavy liquid. Its constituents are light gases, one of them being the lightest material substance ever yet discovered. Water is an antagonist of fire. One of its constituents is the most highly combustible substance in nature, and the other is a gas whose presence is necessary to fire, and hence called a supporter of combustion. In order to demonstrate the composition of water, it is necessary, in the first instance, to obtain that liquid absolutely pure, and it has been already stated that it is never so found naturally.

29. All fixed air with which water is charged may be dismissed from it by boiling; but to separate it from such matters as it may hold in solution, it must be submitted to the process of DISTILLATION.

30. The principle of distillation is easily explained.

If water which holds in solution any earthy or saline substance be raised to its boiling point, it will be converted into vapour, but the substance it holds in solution will not be so converted. As the water is gradually evaporated, the substance held in solution remaining undiminished, the solution first is rendered stronger and more concentrated, inasmuch as the same quantity of saline matter is dissolved in a less quantity of water. As the process goes on, the entire quantity of water will at length be evaporated, and the earthy or saline matters which it held in solution will remain in the vessel in which the evaporation takes place. This is an experiment which may be tried by any person. Let a tablespoonful of water, in which salt has been dissolved, be held for some minutes over the flame of a spirit lamp. The liquid will boil, and will soon be entirely converted into vapour, the salt alone remaining in the spoon.

31. But when it is the object, as in distillation, to obtain, not the matters held in solution by the water, but the pure water itself separated from these matters, it is necessary to prevent the vapour

from escaping, and to reconvert it into water. Now, as water is converted into vapour by heat, so, on the other hand, vapour is reconverted into water by cold. If, therefore, an apparatus be so constructed that as the vapour rises from the boiling water it shall be received into a close vessel where it is exposed to the contact of a cold surface, it will be restored to the liquid form, and being collected in that state, it will be so much pure water; pure, at least, so far as it has been separated from the substances which it held in solution before it underwent the process of evaporation.

32. The vapour of water is many hundred times lighter, bulk for bulk, than water itself. It has resulted from accurately conducted experiments, that a gallon of water evaporated at the temperature of 212° will produce nearly 1800 gallons of vapour. It follows, therefore, that when vapour is reconverted into water by exposure to cold, a very great volume of it will produce a very small volume of water. Thus, to produce a gallon of pure water, we must have nearly 1800 gallons of vapour.

33. It is for this reason that the conversion of vapour into water has been called CONDENSATION, and the apparatus in which such change is produced has been called a CONDENSER. The vapour is condensed, because it is reduced to a bulk 1800 times less, and is, therefore, rendered 1800 times denser and heavier.

The process by which water is first converted into vapour and then restored to the state of water is called distillation, from a Latin word DISTILLATIO, which signifies "falling in drops." The conversion of the vapour into liquid in the condenser usually proceeds so slowly that the liquid falls from the spout of the condenser, not in a continuous stream, but in a succession of drops.

34. In the industrial arts, and in chemical laboratories, where water absolutely pure is needed in considerable quantities, its distillation is conducted in an apparatus which is represented in fig. 1.

This distilling apparatus, or alembic, consists of a copper boiler, A, fixed in a brick furnace, having a dome-formed cover, B, adapted to it, from which a bent tube, *b c d*, proceeds, and is connected with a spiral tube called a *worm*. This worm is inclosed in a large cylindrical cistern, *p q j r*, constructed in metal, and which is kept constantly filled with cold water. The lowest part of the worm passes out of this cistern near its bottom, and terminates at *a*, over the mouth of a jar, *c*, intended to receive the distilled water. An opening, *t*, having a steam-tight stopper, is provided in the boiler, through which the water to be distilled is introduced into it.

The vapour issuing from the boiler through the tube, *b c d*, passes into the worm, being first received by the vessel, O, where the condensation begins.

Passing next through the coils of the worm, it is exposed to the contact of its cold surface, and is entirely condensed and reduced to the liquid state before it arrives at the lower extremity, *a*, from which it trickles in drops into the jar, *c*.

The heat disengaged from the vapour in the process of condensation being constantly imparted to the water in the cistern, *p q j r*, that water would be gradually warmed, and if it were not discharged and replaced by cold water, it would no longer keep the worm cold enough to condense the vapour. A supply of cold water is therefore introduced through a pipe, T T, while the heated water flows away through the pipe of discharge, *o*.

Heated water being lighter, bulk for bulk, than cold water, will float upon the latter without mixing with it, unless the liquid be agitated. The cold water, therefore, being introduced at the lowest part, T, of the cistern, will form the inferior strata, while the heated water will collect at the superior strata, and being pressed upwards by the cold water will flow out at *o*. The supply pipe, *p*, which feeds the pipe, T T, and the discharge pipe, *o*, may be, and generally are, so regulated that the water discharged from *o* is very little below the temperature of the vapour coming from the boiler, while the water of the lowest strata is as cold as the external atmosphere. The vapour, therefore, which enters at *d*, is at first only partially condensed, the condensation being rapidly increased, as winding through the worm it passes in contact with a surface colder and colder, until, at length, arriving at the lowest coil, it is wholly condensed.

The heated water which flows from the discharge pipe, *o*, may be used to feed the boiler, B; and being already at a high temperature, an economy of fuel is thus effected.

When extreme purity is required in the distilled water, it is evaporated at a temperature lower than 212°, because at that temperature a certain small portion of the foreign matters which it holds in solution sometimes go over in the vaporous state through the worm, and are ultimately deposited in the jar, *c*. The lower the temperature at which the water in the boiler is evaporated, the less of this impurity will pass through the worm.

By these expedients, with proper precautions, water absolutely pure, and entirely free from all foreign matter, may be obtained.

35. It remains now to show how the compound nature of this liquid can be demonstrated, and the characters and proportions of its constituents ascertained.

This may be accomplished by either of two methods; by COMPOSITION or DECOMPOSITION, or, if the Greek derivatives be preferred, by SYNTHESIS or ANALYSIS.

The method by synthesis presumes the previous knowledge of the constituents, and consists in showing, that by combining these constituents water may be produced.

The method by analysis presumes the previous discovery of some physical agent capable of overpowering the mutual attraction by which the constituents of water are held together, and tearing them asunder, and exhibiting them separated one from the other, so that their characters and properties may be ascertained.

Since the question itself is of the very highest interest and importance, and since both the methods of synthesis and analysis are in themselves most instructive and easily intelligible, we shall here explain them.

36. There are two airs or gases known to chemists, and denominated oxygen and hydrogen.

A general idea of oxygen and its leading properties has been already given in our Tract on Air.

Hydrogen, like gases in general, is an invisible colourless air, which when perfectly pure is without taste or odour. But as commonly produced it is mixed with very minute proportions of impurities, which impart to it a peculiarly disagreeable odour, with which every one is rendered familiar by the occasional leakage of the pipes used for gas-lighting.

37. This gas is the lightest of all material substances, being bulk for bulk more than fourteen times as light as common air.

38. For this reason it is eminently fitted for the inflation of air-balloons. Two thousand cubic feet of this gas will weigh only about 11 lbs., while the same volume of common air will weigh about 160 lbs. A balloon, therefore, which would contain 2000 cubic feet of hydrogen would have a buoyancy or tendency to ascend, amounting to 149 lbs., and if the silk bag, cordage, and car, with its load, have less than this weight, it will have an ascensional force equal to the excess.

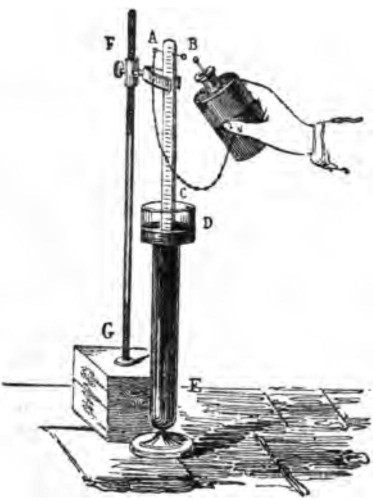
39. Hydrogen is one of the most inflammable bodies in nature. It burns with a very pale bluish flame, giving very little light, but intense heat.

40. If a mixture of oxygen and hydrogen gases be introduced into a strong glass vessel, and be shut into it by closing the stop-cock in the pipe by which the gases are introduced, an electric spark transmitted through the mixture will inflame the hydrogen gas, and an explosion will take place, after which the glass vessel will appear to be filled with vapour, and will acquire an increased temperature. When, after a short interval, it cools, the inside surface of the glass will appear to be bedewed. Water will trickle down the sides. A certain quantity of gas will remain in the vessel. If this gas be examined by the usual tests it will be found that it is no longer a mixture of oxygen and hydrogen, but is one

or the other gas in its separate and pure state. Whether it be pure and unmixed oxygen, or pure and unmixed hydrogen, will depend on the proportions in which the gases were originally mixed in the vessel before the explosion.

41. There are many forms of apparatus by means of which this important experiment may be performed. One of them is represented in fig. 2.

Fig. 2.



A cylindrical vessel, D E, wider at the top than below, is filled with mercury. A graduated tube, B C, of thick and strong glass, about an inch in diameter, closed at one end, B, and open at the other, C, being filled with mercury and stopped by the hand at the open end, is inserted and plunged in the mercury in the cistern, D E. The mercury will not fall out of B C, because the atmospheric pressure acting on the external surface of the mercury in D E will support it. The gases, oxygen and hydrogen, may now be introduced into B C, by discharging them in the mercury under the open mouth of the tube, B C. They will rise in bubbles through the mercury, and will displace a portion of that liquid in the top of the tube, B C. In this manner any desired proportions of the gases may be introduced into the tube, B C, limited only by the capacity of the tube.

Near the top of the tube, B C, two small holes on opposite sides are bored, through which two pieces of platinum wire are inserted, terminating inside and outside in knobs. The inside knobs are close to each other, without being actually in contact. When the knob of a charged electric jar is presented to B, while A is connected by a metallic chain with the outside coating of the jar, the electric discharge will pass between the two inner knobs, and will inflame the hydrogen contained in the tube, B C.

It is in experimental researches of this kind more convenient to express the quantities of the gases by their measures as indicated by the graduation of the tube, B C. It will render this explanation, however, more easily intelligible to express them by their weights.

Let us then suppose, in the first instance, that 1 grain of hydrogen and 12 grains of oxygen are contained in B C. When the electric discharge is transmitted, the hydrogen inflamed, and the tube, B C, cooled, water and gas, as already stated, will be found in it. If the water be exactly weighed, it will be found to amount to 9 grains, and the gas will amount to 4 grains. If these 4 grains of gas be examined they will be found to be pure oxygen. Thus this residual gas will not be inflammable, but if a lighted taper be plunged in it, the flame will become larger and brighter. In a word, it will have all the properties of pure oxygen, explained in our Tract on Air.

It appears, then, that of the mixture of 1 grain of hydrogen and 12 grains of oxygen, which were in B C before the explosion, the entire grain of hydrogen has entered into combination with 8 of the 12 grains of oxygen, and has produced 9 grains of water, the other 4 grains of oxygen remaining unchanged in B C.

It follows, therefore, that the gases hydrogen and oxygen, being combined in the proportion of 1 grain of the former to 8 of the latter, produce water.

If 2 grains of hydrogen and 8 of oxygen had been introduced into B C, the explosion would still produce 9 grains of water, but in this case the residual gas would be 1 grain of hydrogen. Thus 1 of the two grains of hydrogen, combining with the 8 grains of oxygen, would produce 9 grains of water, while the other grain of hydrogen would remain in its pure and separate state.

If 1 grain of hydrogen and 8 of oxygen had been introduced into B C, the explosion would have converted the whole of the gases into 9 grains of water, and no residual gas whatever would be found in B C.

From all this we must infer that water is a compound liquid, whose constituents are the two gases, oxygen and hydrogen, combined in the proportion of 8 parts by weight of the former to 1 of the latter.

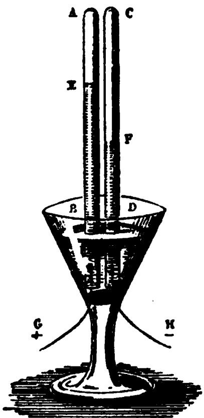
42. It follows, therefore, that one-ninth part of water, the natural antagonist of fire, is the most inflammable of bodies, and the other eight-ninths is a body without whose presence fire cannot exist.

Having thus explained the manner in which water is produced by the combination of its two constituents in due proportion, it now remains to show how the liquid itself may be resolved into its constituent gases.

43. There are several methods of accomplishing this, but the most direct and simple is by submitting water to the action of a voltaic current of sufficient force. It has been proved that the poles of a voltaic battery have specific attractions for different

bodies; the positive pole for some, and the negative for others. Now it happens that of all natural bodies that for which the positive pole has the strongest attraction is oxygen, and one of those for which the negative pole has a strong relative attraction is hydrogen. If, therefore, under certain conditions the two poles be brought to act on water, it may be expected that its decomposition will ensue, the oxygen being disengaged at the positive, and the hydrogen at the negative pole, and this in fact does take place.

Fig. 3.



44. Various forms of apparatus have been contrived for the exhibition of this experiment. The most simple and instructive is represented in fig. 3.

Two small holes are pierced near the bottom of a wine-glass, through which the ends of two wires, G and H, being inserted, so as to rise to the height of an inch or two near each other in the glass, they are cemented in the holes by mastic. These wires are put in connection, one with the positive or + pole, and the other with the negative or — pole of a voltaic battery. Water, slightly acidulated to give it more conducting power for electricity, is then poured into the glass, and two graduated glass tubes, A B and C D, each about half an inch in their interior diameter, being first filled with acidulated water, and being stopped at the open ends by the hand, are inverted and immersed in the glass, one over each of the wires. The water will then be supported in the tubes by the atmospheric pressure.

The electric current will now immediately begin to flow from the extremity of one wire through the water to the extremity of the other, and by its attraction the water will be decomposed, the oxygen constituent being attracted to the extremity of the positive, and the hydrogen to that of the negative wire. These gases will be therefore disengaged at the points of the wires as if they issued from them, as they would from small apertures in vessels containing them. They will be seen rising rapidly in small bubbles in each of the tubes, in the upper parts of which they will collect, displacing the water and pressing it downwards. After a short time, the tube containing the negative wire will be filled with gas, the water being totally expelled from it from the top to the level of the water in the glass, and at the same time the tube over the positive wire will be half filled.

Thus it appears, the tubes being of equal capacity, that the volumes of the two gases produced are in the proportion of 2 to 1, the volume of hydrogen being twice that of oxygen.

It will be further observed, that continually throughout the process of the experiment, the same proportion is maintained between the volumes of the gases evolved. At every stage of the process, the volume of hydrogen, C F, evolved, is found to be exactly double that of the oxygen, A E.

But a comparison of the weights of these two gases, bulk for bulk, proves that oxygen is sixteen times heavier than hydrogen. It follows from this that the weight of the double volume of hydrogen evolved in the experiment here described, will be exactly one-eighth of the single volume of oxygen simultaneously evolved.

Thus it appears that the water is decomposed by the voltaic current, and that its constituents are the gases oxygen and hydrogen, in the proportion of 8 parts by weight of oxygen to 1 of hydrogen.

46. Certain metals which are obtained in the laboratories of chemists, though unknown in the arts, such as potassium and sodium, have so strong an attraction for oxygen that they cannot be exposed in the atmosphere without spontaneously combining with that constituent of it. If a piece of one of these metals be plunged in water, it will exert an attraction on the oxygen of the water so powerful as to separate it from the hydrogen. The oxygen will, in virtue of this attraction, desert the hydrogen, and, combining with the potassium or the sodium, will form potash or soda, while the hydrogen, disengaged in the form of gas, may be collected in a glass receiver in the usual way. If the potash or soda thus produced be weighed, it will be found to be heavier than the potassium or sodium, by the weight of the oxygen which has entered into combination with it, and this excess of weight will be exactly eight times the weight of the hydrogen which is disengaged; from which it follows as before that water consists of 8 parts by weight of oxygen and 1 of hydrogen.

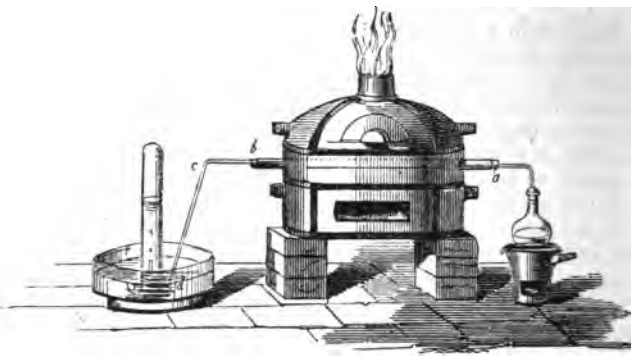
47. None of the metals commonly used in the arts have an attraction for oxygen sufficiently energetic to effect thus spontaneously the decomposition of water. The attraction, however, of some of them—iron, for example—may be so exalted by elevation of temperature that it may, by means of certain arrangements, produce a like effect.

An apparatus for the decomposition of water, by means of heated iron, is represented in fig. 4.

A porcelain tube, *a b*, the middle part of the length of which is filled with fragments of fine iron wire, is inserted across a furnace, by means of which the tube may be heated, so that the iron it contains shall be red-hot. One end, *a*, communicates by a rectangular tube with a glass vessel containing water, placed upon a charcoal fire, or supported over a spirit lamp. The other end, *b*, communicates by a bent tube, *b c d*, with a glass tube filled with water, inverted and immersed in a capsule or dish containing water. The water is supported in the tube, as in the former experiments, by the atmospheric pressure. If gas issue from the mouth of the tube, *d*, which is bent under that of the wide tube containing the water, this gas will rise in bubbles, displacing the water in the top of the tube.

These arrangements being made, and the iron contained in the tube, *a b*, being rendered red-hot, the water in the glass vessel is made to boil. The vapour proceeding from it entering the tube *a b* at *a*, forces its way through the interstices of the red-hot iron wire; there it is decomposed, the iron attracting the oxygen,

Fig. 4.



with which it combines, forming a substance called the *oxide of iron*, which is familiarly known as *rust*. The hydrogen alone issues from the tube at *b*, and passing through *b c d* rises into the large tube, displacing the water, as represented in the figure.

When a sufficient quantity of gas is collected, its weight is ascertained, and also the increase of weight imparted to the iron wire in the tube, *a b*, by the oxygen which has been combined with it, and it is always found that the latter is exactly eight times the former.

Thus we still find the same remarkable fact reproduced in various forms. The rusted wire is heavier than the original clean wire by the weight of the oxygen which it has attracted from the aqueous vapour, and which, combining with it, forms the rust; and this weight is eight times that of the hydrogen from which it has been separated, showing as before that water consists of 8 parts by weight of oxygen and 1 of hydrogen.

Fig. 11.—THE CELEBRATED CUP OF ARCESILAUS, IN PLAN, WORK OF THE CYRENIAN POTTERS CONTEMPORARY WITH PINDAR, 500 B.C.

THE POTTER'S ART.

CHAPTER I.

1. Antiquity and general estimation of the art.—2. Its materials and their treatment.—3. Potter's wheel.—4. Allusions to the art found in ancient writers.—5. Ancient drawings in Theban catacombs.—6. Processes of potters 1900 B.C.—7. Homer and the potters of Samos.—8. Ancient tombs containing pottery excavated near Naples.—9. Proofs of their antiquity.—10. Campanian sepulchral chamber with pottery.—11. German sepulchres.—12. Cup of Arcesilaus.—13. Ancient Greek potters.—14. Chinese traditions of pottery.—15. Chinese pottery found at Thebes.—16. Porcelain works of King Te Tching.—17. Processes practised there.

1. AFTER the fabrication of weapons for personal defence and the procuring of food, and that of some rude species of clothing, the formation of vessels from baked clay is the most ancient

of industries; and it is worthy of note, that, simple as were its original processes and rude its primitive productions, no art has more ministered to luxury; none has produced more gorgeous specimens of ornamentation; in none does the value of the finished article bear so enormous a ratio to that of the raw materials; none has so steadily and continuously advanced and improved with the progress of knowledge; none is more largely indebted to the resources and discoveries of science; nor has any more constantly received the homage of the great and the admiration of mankind in all countries, and especially in those which have attained the highest condition of civilisation and refinement.

2. The materials of the potter are certain sorts of clay which possess the property, when moistened with water, of acquiring the consistency of dough. This dough being shaped into the desired form, the water which gave it softness and plasticity is expelled from it by evaporation, produced by exposure in ovens to intense heat. The article is thus rendered hard and strong, so as to retain its shape, and to resist fracture from slight causes.

In this state however, the surface is rough and the material is porous, so that it would imbibe any liquid in which it might be immersed, or which might be poured into it. To give it a more brilliant surface, and to render it impervious to liquids, it is therefore covered with a thin coating of some vitrifiable matter, which being exposed to the action of fire, is converted into a skin of glass. This gives increased beauty to the article, and at the same time renders it impermeable by liquids, and enables it also to resist their chemical action.

The ornamentation of the article is produced either by the beauty of form imparted to it, or by figures in relief produced by moulds pressed upon it while yet soft, and before the process of baking; or, in fine, by designs painted in colours either upon the surface before glazing, or upon the glaze. In either case the colouring-matter is submitted to the action of fire, and the process has more or less of the character of enamelling.

The plastic clay of the potter does not usually exist in its pure state in the earth. It is found, on the contrary, like the metals, mixed, or chemically combined, with many heterogeneous substances, from which it is separated by a variety of complicated processes.

When it is reduced to a sufficient degree of purity, it is necessary to mix with it such a proportion of water as will convert it into a dough of a certain consistency. This is a process of some difficulty and labour, for the water will at first be unequally diffused through the mass, one part being too plastic and another part not sufficiently so. The whole is reduced to an uniform consistency by the process of kneading, in a manner exactly similar to that by which the dough of flour is treated in bread making; and, as in this latter case, the method most commonly adopted for effecting this is by treading the dough with the feet. This, indeed, is one of the most characteristic operations of the potter, being quite inseparable from his art, to whatever objects it be applied, from the making of common bricks to the fabrication of the most splendid porcelain.

The mass of dough being spread out upon a flat surface of stone or wood, the potter walks upon it with his naked feet, beginning from the centre of the cake, and following a spiral course until he reaches the circumference, after which he returns by the same spiral to the centre.

When the proper consistency and homogeneity are thus imparted to the dough, the next process is to give it the form of the articles intended to be fabricated. This is effected by different methods, according to the shape desired; but as by far the greater number of articles of pottery are round in their horizontal dimensions, the method most common is as follows:—

A ball of the dough, sufficiently large for the article to be formed, is laid upon the centre of a small horizontal circular disc of plaster of Paris, supported on a circular stage or table which rests on a central pillar fixed in pivots, so as to be capable of receiving a motion of rapid rotation. This motion being imparted to the ball of dough placed upon the table, the potter applies his hands to it, and gives it the desired form by the gentle pressure of his palms and fingers. The process resembles in all respects that of turning with the lathe, only that the revolving shaft is vertical instead of being horizontal. The rude and soft mass of dough assumes, under the dexterous fingers of the potter, the most symmetrical and beautiful forms with marvellous facility and celerity.

3. This apparatus, called the "Potter's-wheel," is of high antiquity, being indeed co-eval with the art, and has had very nearly the same form and arrangement in times the most ancient and the most modern, and in parts of the earth most remote from each other, and often among people between whom there are no traditions of intercommunication.

The custom which prevailed in the earliest ages and in all countries of consecrating certain articles of pottery to religious uses, and depositing them in sarcophagi and in tombs, sometimes with drawings representing the processes of their fabrication, proves the veneration in which the art was held, and has happily also been the means of bringing to the knowledge of modern times its early history.

The antiquity of the art is also attested by the frequent allusions to it in poetic writings of remote date. These allusions, in many cases, incidentally disclose the processes of the art, and prove their almost exact identity with those of the present age.

4. Every one is familiar with the frequent metaphors and comparisons taken from the processes and productions of the potter in the Hebrew Scriptures.

"The Lord said to Jeremiah—arise and go down to the potter's house. Then I went down and behold he wrought a work on the wheels. And the vessel that he made of clay was marred in the hand of the potter; so he made it again another vessel, and the Lord said, O house of Israel, cannot I do with you as this potter? Behold, as the clay is in the potter's hand so are ye in mine."—*Jer.* xviii. 1—6.

"I will break this people and this city as one breaketh a potter's vessel." —*Jer.* xix. 11.

The antiquity of the process of kneading the dough with the feet is proved by many allusions to it in the ancient writers.

"I have raised up one from the north, and he shall come: from the rising of the sun shall he call upon my name, and he shall come upon princes as upon mortar, and *as the potter treadeth clay*."—*Isaiah*, xli. 25.

In ancient Greek and Latin authors allusions are frequent.

Homer, describing the shield of Achilles, compares a dance by figures forming a ring upon it, as having as much precision and rapidity as the wheel of a potter put in motion by his hands.—Iliad, xviii., 599—600.

For the more common sorts of ware, the potter still imparts, in many cases, the motion to the wheel with his hands.

The wheel, however, is more generally moved by the feet, and often by an assistant, or even by steam or other moving power, when many of them are required to be kept in motion.

In Plautus we have—

"Vorsutior es quam rota figularis."—3 Epid. ii. 35.

"Thou turnest more rapidly than a potter's wheel."

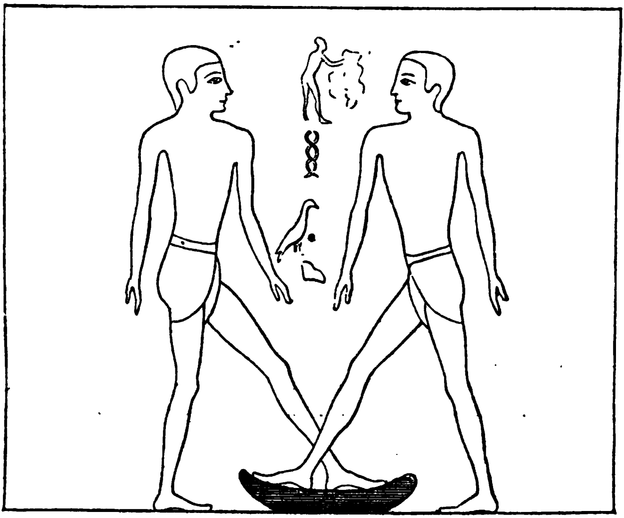
"——Amphora cæpit
Institui: *currente rotâ* cur urceus exit?"—Hor. Art. Poet. 21.

"A large vase was designed: why, as the wheel revolves, turns out a little pitcher?"

"——Testa alta paretur
Quæ tenui muro spatiosum colligat orbem:
Debetur magnus patinæ, subitusque Prometheus.
Argillam, atque rotam citius properate: sed ex hoc
Tempore jam, Cæsar, figuli tua castra sequantur."
Juvenal, Sat. iv. 131.

"No, let a pot be formed, of amplest size,
Within whose slender sides the fish, dread sire,
May spread his vast circumference entire!
Bring, bring the tempered clay, and let it feel
The quick gyrations of the plastic wheel:
But, Cæsar, thus forewarned, make no campaign,
Unless your potters follow in your train."—GIFFORD.

Fig. 1.



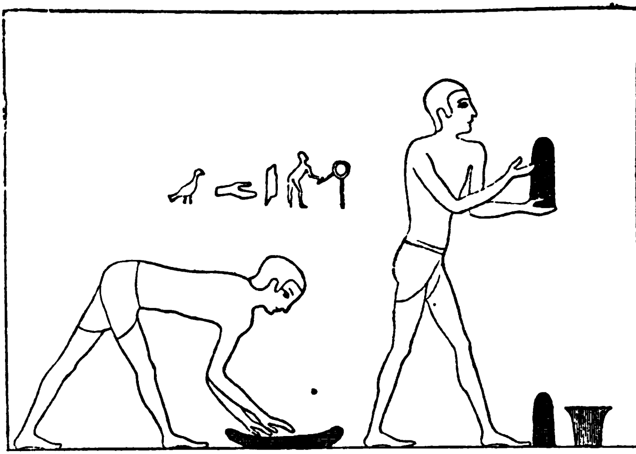
5. In the catacombs of Thebes and Beni-Hassan, which have been proved to have existed nineteen centuries before Christ, and therefore 3700 to 3800 years from the present time, drawings have been discovered, exhibiting, in a great variety of forms, the processes of the potter's art as then practised. The annexed engravings (fig. 1 to 5) have been copied from paintings discovered in the catacombs of Thebes, and described by Champollion. They exhibit the processes of the potter, from the kneading of the dough by the feet to the removal of the baked article from the oven.

6. Fig. 1 represents two potters kneading the paste by the process of treading. The hieroglyphics signify "he treads."

Fig. 2.—A man taking up the dough to form it into a mass for the wheel. The hieroglyphics express this action.

Fig. 3.—The same man taking the ball, or prepared mass, to the potter who works at the wheel.

Fig. 2. Fig. 3.



Figs. 4 and 5.—Two potters shaping an article on the wheel. The vessel which stands between the wheels, and which also appears in fig. 3 in a water-pot, in which the potters occasionally dip their fingers to regulate the moisture of the dough.

Fig. 4. Fig. 5.

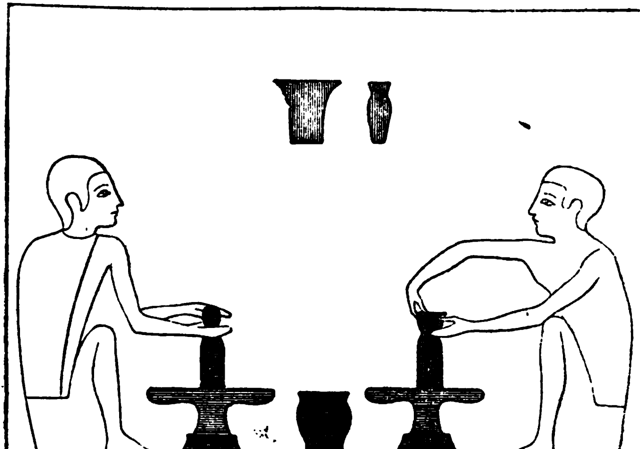
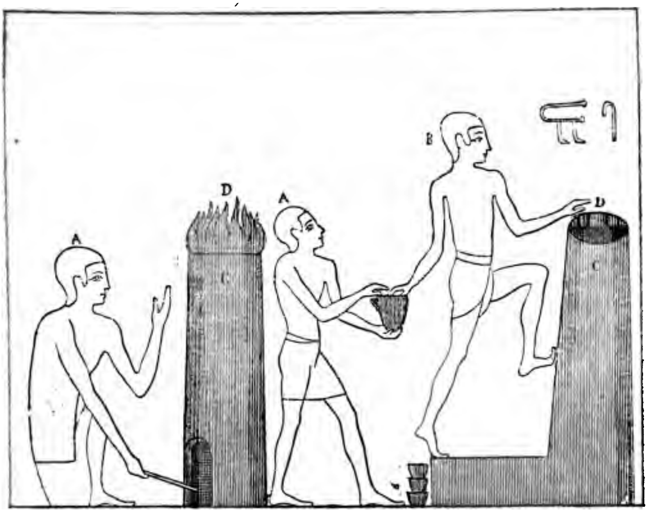


Fig. 6. Fig. 7.



This painting does not show how the wheel is turned, but in another the potter is represented giving with his left hand the motion of rotation to the wheel. When this motion, by the repeated action of the hand, acquires a sufficient rapidity to be continued without further impulse, both hands are applied to the dough, as represented in the figures.

The potter (fig. 4) forms a ball of the magnitude necessary to make a cup. The potter (fig. 5) forms the outside of the cup by the pressure of his first finger, and the inside by his thumb. Every one who is familiar with the action and attitude of a potter working at the wheel, will recognise the peculiar position and rounding of the arm in fig. 5. If the modern potter had served his apprenticeship to him of 2000 B.C., the resemblance could not be more exact.

A cylindrical oven, C, is represented in fig. 6. The attendant, A, is feeding the furnace beneath it with a stick of wood; the flames, D, which play around the cases containing the articles to be baked are seen issuing from the top of the oven.

Fig. 7, represents the oven after the baking has been completed and the fire extinguished, the fire-door of the furnace being on the other side. The potter, B, is in the act of taking out the articles baked, and handing them to another, A, who piles them in heaps, one of which appears at his feet. The hieroglyphics signify "He takes them out."

In the original paintings from which these drawings were taken the masses of dough in fig. 1 to 5, have a dark grey colour. The articles of baked pottery in fig. 7, have the reddish colour which characterises the ancient Egyptian pottery.

It appears, therefore, from these remarkable paintings, that in all its essential processes, the art of pottery, 4000 years ago, was nearly what it is at present.

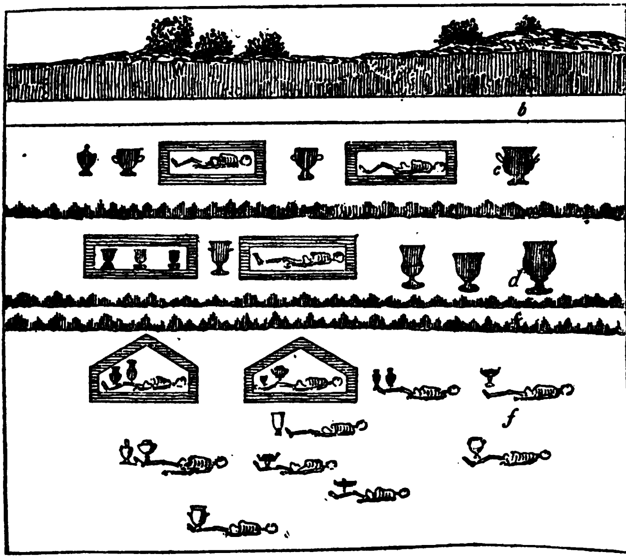
7. It is related in a life of Homer, attributed to Herodotus, that the poet when blind happened one day to pass near the celebrated potteries of Samos. The potters addressed him, and requested him to compose a poem on their art, offering him, as a reward, a selection of their vases. Homer accepted their offer, and composed for them the hymn called the Furnace, still extant, in which are described with singular felicity and exactitude the qualities and excellences of the vases fabricated by these artisans, and the accidents to which they are exposed in the process of baking. These incidents of the oven and their effects have counterparts so exact in the processes of the present day, that the reader of Homer's lines might well imagine that the poet had visited a Staffordshire pottery.

Thus it appears that in Homer's time, that is about nine or ten centuries before Christ, the potters of Samos had already risen to some celebrity. According, however, to the researches of some antiquarians, and their arguments founded on the results of excavations made near Naples, known to have been the place where ancient Greek colonists had established themselves, this art must have been cultivated in Greece in times much more ancient than the Homeric age.

8. The Abbé Mazzola has described and delineated, with elaborate minuteness, the position of tombs and skeletons found in excavations made in Campania. Beneath a stratum of vegetable mould, having a depth of about forty inches, and forming the richly fertile soil for which that tract of country is so celebrated, is found a stratum of white sandy earth, mixed with pummice stone, hard and impenetrable by water. This stratum, which is called *terra maschia*, has a thickness of about twenty inches, and beneath it is a third stratum about thirty inches thick, composed of good black mould. It is beneath this last stratum that the skeletons, sarcophagi, and accompanying vases were found.

A vertical section of the strata, showing the position and arrangement of the skeletons and vases, in a part of the Campania, near Nola, copied from the Treatise of Dubois Maisonneuve, on Antique Vases, fol. 1817, is given in fig. 8.

Fig. 8.



The vases and skeletons were found at different depths and differently disposed. In some cases the vases alone were found, as at *d*; in others, the skeletons without, in others, included in sarcophagi; but in all cases the skeletons were accompanied by vases.

9. The Abbé Mazzola maintains, that notwithstanding the presence of pumice stone in the second stratum, it cannot be regarded as the direct result of volcanic action. He concludes that the superficial stratum of fertile earth is of comparatively recent formation, and that at a remote epoch the second stratum of *terra maschia* must have been superficial. Now, as the deposition of the bodies and vases under the *terra maschia* must have preceded the commencement of the formation of the present superficial stratum of vegetable soil, and as the formation of this stratum must have occupied a long succession of ages, he argues that the vases found below the *terra maschia* must have a date long anterior to that of Homer. He adds, in support of this inference, that these vases represent scenes which have never been alluded to, or described by Homer or succeeding poets, such as the combat of Neptune and Ephialtes; that these skeletons found at Nola are always

Fig. 9.

buried immediately in the ground, while elsewhere, as for example, at Avila, they are included in sepulchres; that the inscriptions on the vases are written in the primitive Greek, to be read from right to left, like Hebrew and other oriental languages; and, in fine, that the lateness of their discovery is to be explained by the fact that the strata beneath which they were deposited consisted of stone not used for building by the Romans, but used for that purpose in modern times.

A more distinct notion of the disposition of vases in the ancient tombs may be obtained from the drawings, on a larger scale and with more detail, given by d'Hancarvillc and other antiquarian writers.

10. As an example of a Campanian sepulchral chamber, we give fig. 9, representing a tomb discovered in the neighbourhood of Naples, showing the relative position of the body and the vases.

11. In fig. 10 is represented the tomb of a German family, including two skeletons with urns, found in the excavation of a tumulus at Unterwelden, near Oberfarrenstadt.

12. Most of the numerous Greek vases which have been recovered in modern excavations, belong to the sixth or seventh century before

Fig. 10.

Christ, and to later dates. Specimens of these were already rare and much prized in the time of Julius Cæsar.

Among the most admired and interesting of these may be mentioned the celebrated cup of Arcesilaus. This vase is represented in plan in fig. 11, (p. 113), and in elevation in fig. 12. It is preserved in the Bibliothèque Royale, now (December, 1853) Impériale. Its height is 10 inches, and its diameter 11 inches.

This cup which was found at Vulci (Camino), in Etruria, represents Arcesilaus, King of Cyrene, seated on the deck of a vessel, the crew of which are engaged, under his superintendence, in weighing baskets of asafœtida, and depositing them in the hold.

This vase is considered to be the work of Cyrenian potters contemporary with Pindar.

13. The names of about forty of the most celebrated potters of Greece have been recorded in the works of philosophers, historians, and poets. Among these the following may be mentioned:—

DIBUTADES, of SICYON, whose works were brought to Corinth, where they were preserved. The epoch at which this potter flourished is unknown.

CORŒBUS, of ATHENS, flourished in the time of Cecrops, fifteen centuries before Christ. He was reputed to have been the inventor of pottery. It will, however, be shown hereafter that this art was practised in the East at least a thousand years earlier.

TALOS, the son of PERDIX, sister to DÆDALUS. This personage

Fig. 12.

was reputed to be the inventor of the potter's wheel. Other mechanical inventions were also ascribed to him, among which were the saw, the chisel, and the compasses. He was said to have taken the idea of the saw from the back-bone of a fish. His skill was said to have excited so violent a jealousy on the part of his uncle Dædalus, that the latter having enticed him to the Temple of Athena, on the Acropolis, flung him headlong from its summit. The goddess of the shrine, however, caught him in his fall, and metamorphosed him into a bird, to which she gave the name PERDIX, *the Partridge.*

THERICLES, of CORINTH. According to Theophrastus, this celebrated potter invented a composition consisting of a black paste susceptible of an high polish, which was much prized. He gave his name to a certain sort of vases called THERICLEAN.

Some scholars have, however, questioned his existence altogether, contending that the name of the vases was derived from their style of ornamentation, which included the representation of animals, *θηρία*, Theria.

As in modern times, the most eminent sculptors supplied models and designs to the Greek potters. Among these may be named PHIDIAS, POLYCLETES, and MYRON.

14. The Chinese traditions carry back the practice of the potter's art to a very remote epoch. Father Entrecolles, a French missionary, resided in China at the beginning of the last century, and his letters published in Paris, in 1741, supply some curious and interesting information on this subject. Writing in 1712, he says, that at that time ancient porcelain was very highly prized, and bore large prices. Articles were extant which were reputed to have

Fig. 13.

Fig. 14.

Fig. 15.

belonged to the Emperors YAO and CHUN, two of the most ancient mentioned in the Chinese annals. YAO reigned in 2357 and CHUN in 2255 before Christ. Other authorities place the reign of CHUN in 2600 before Christ. It appears from the researches of M. Stanislaus Julian that, from the time of the Emperor HOANG-TI, who reigned 2698 to 2599 before Christ, there had always existed a public officer bearing the title of the Intendant of Pottery, and that it was under the reign of Hoang-ti that the potter's art was invented by KOUEN-OU. It is also certain that porcelain, or fine pottery, was common in China in the time of the Emperors HAN, 163 B.C.

In digging the foundations of the palaces, erected by the dynasties of Han and Thang, from 163 B.C. to 903 A.D. great quantities of ancient vases were found which were of a pure whiteness, but exhibited little beauty of form or fabrication. It was only under the dynasty of SONG, that is to say, from 960 to 1278 A.D., the Chinese porcelain began to attain a high degree of perfection.

15. Further evidence of the antiquity of the potter's art in China as well as of the existence of intercommunication between that country and Egypt, is supplied by the discoveries of Rossellini, Wilkinson, and others, who found numerous vases of Chinese fabrication, and bearing Chinese inscriptions, in the Tombs at Thebes. Professor Rosellini found a small vase of Chinese porcelain with a painting of a flower on one side, and on the other Chinese characters not differing much from those used at the

Fig. 16.

present day. The tomb was of the time of the Pharaohs, a little later than the eighteenth dynasty.

This vase, with its Chinese inscription, is represented in fig. 13, from an exact cast made by Mr. Francis Davis.

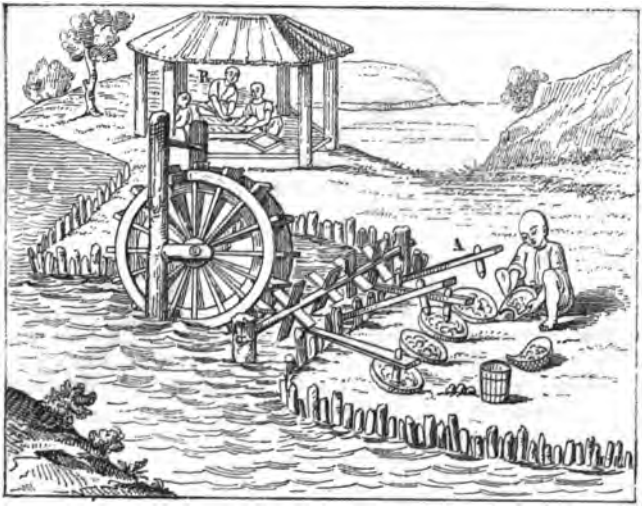
Another of the Chinese vases, found in the Theban tombs, is represented in fig. 14. This is preserved in the Museum of the Louvre. The shape of the vase is that of a flat-sided flask. A side view is given in fig. 15.

These flasks are very small. The engravings represent them of their proper dimensions. Mr. Wilkinson thinks it probable that they were brought to Egypt from India, the Egyptians having had commercial relations with that country at a very remote epoch, and that they came not as pieces of porcelain, but as vessels containing some article of importation.

16. Among the articles seen at the Great Exhibition, in the Chinese department of the Crystal Palace, was a complete collection of the various materials employed at the great Porcelain Works of King Te Tching. This collection consisted of the plastic clay of which the Chinese porcelain is formed, and of the various colouring matters with which it is decorated.

The place from which these specimens were sent is one of the most ancient and celebrated of the porcelain manufactories still

Fig. 17



existing in China. Father Entrecolles, already quoted, who resided there in 1712, stated that, at that time, there were in operation there not less than 3000 ovens, which gave to the town at night the appearance of one vast furnace with numerous chimneys. He describes the earths of which the china was made as of two kinds, called Kaolin and Petung-tse. These were brought to King-Te-Tschin in the form of bricks from the quarries where the raw material is found.

The process by which these raw materials of the Chinese potter were at that early period prepared in the quarries differed very little from those by which the like materials are prepared for our potters at the present day, and some of the contrivances which have been claimed as modern inventions are merely reproductions of what have been for ages in use in the East.

17. Some details of these processes, as they were practised in China nearly two centuries ago, will be not less instructive than amusing.

The process of quarrying the petung-tse is represented in fig. 16. The mineral is detached in lumps with the mallet and pick-axe. Two of the miners are employed at the sides of the quarry, while a third is getting the mineral from its roof, which is supported by a number of upright posts. A fourth workman is carrying the produce of the labour of the others to the pounding or crushing-mill represented in fig. 17. The water-wheel acting upon the rectangular arms projecting from the shaft keeps the latter in constant revolution. These arms act upon a series of levers, to the opposite ends of which are attached stone sledges faced with iron. By the action of the wheel upon the short arms of the levers, the long arms carrying the iron-shod stone hammers are alternately raised and let fall. Beneath each of them is placed a trough filled with the rough lumps of petung-tse, which are thus pounded until they are reduced to powder. A man sits near them collecting their contents when pulverised, which he carries in buckets to a large reservoir of water represented in fig. 18, (p. 129), where being thrown, it is strongly agitated until it comes to be well mixed with the water. The mixture thus produced being allowed to remain quiescent for some moments, the grosser and heavier parts of the mineral dust sink to the bottom, and a cream-like liquid remains. This last is then removed in buckets and brought to another reservoir, shown in the drawing, into which it is thrown and agitated as before.

Fig. 18.—ANCIENT CHINESE DRAWING OF THE METHOD OF PREPARING THE PORCELAIN CLAY FOR FABRICATION.

THE POTTER'S ART.

CHAPTER II

1. Processes of Chinese.—2. Their materials.—3. Petungse and kaolin. 4. Kneading and throwing.—5. Ovens.—6. Majolica in Spain.—7. Italian Lucca della Robbia.—8. Altar-screen by him.—9. Process of fabrication.—10. Productions of Italian potters.—11. Royal presents.—12. Decline of the art in Italy.—13. Pottery in France—Bernard de Palissy.—14. His character, persecution, and death.—15. Palissy and Henry III. in the Bastille.—16. Style of his productions.—17. La belle Jardinière.—18. Origin of the Staffordshire potteries.—19. Discovery of salt glaze.—20. Messrs. Elers.—21. Astbury discovers the use of flints.—22. Origin and character of Josiah Wedgwood.

1. THE grosser parts of the mineral which sink to the bottom of the first reservoir, are then brought back to the crushing-mill, fig. 17, and are again submitted to the action of the hammers, and the same process is repeated at the trough, fig. 18.

The cream-like liquid thrown into the second reservoir being allowed to stand for a sufficient time, all the fine matter suspended in it at length subsides to the bottom, the water becoming clear above. This water is then allowed to flow off, when a stratum of fine and pure petung-tse is found on the bottom of the trough. This is then consolidated and formed by moulds, as represented in the background of fig. 17, into bricks, in which state it is sent to the potteries.

2. This mineral substance, which plays a part so important not only in the Chinese potteries, but in those of other nations, is a variety of that which mineralogists have called felspar, having a slight admixture of quartz.

3. The PETUNG-TSE thus prepared is a white substance of the finest imaginable grain, about two and a half times heavier than water.

The other material used in the formation of the dough or paste, of which the Chinese make their porcelain, called KAOLIN, is found in very deep strata of some of their mountains, and took its name from a mountain near King-Te-Tschin, where the first vein of it had been discovered, which was the origin of the great pottery works established at that place.

The manner of working and purifying the kaolin and forming it into bricks for the potter, does not differ in any important particular from the treatment of petung-tse already described.

Kaolin, when submitted to chemical analysis, proves to be a compound body whose constituents are silica, and alumina, or the pure earth of clay combined with small proportions of magnesia, potash, soda, and iron.

The earths called kaolin or china clay include these constituents in very different proportions as found and used in different countries. That used in the fabrication of the old Chinese porcelain contains 76 per cent. of silica, from 10 to 17 per cent. of alumina, and small proportions of magnesia, potash, and soda.

The Chinese consider that it is to the kaolin that the ware owes all its strength. They call it the *nerve* of the porcelain, meaning probably the plasticity of the paste and its power to resist the intense heat of the furnace. Hearing of the attempts of the European potters (before their discovery of china clay) to make porcelain of petung-tse or felspar alone, they ridiculed the attempt, observing that "they might as well attempt to make a body of flesh without bones."

This alludes plainly enough to the comparatively easy fusibility of petung-tse, and the infusibility of kaolin by the porcelain furnaces, and it would even indicate the probability that the Chinese themselves had tried and abandoned the manufacture of porcelain without kaolin.

Fig. 19.

The ingredients of which the paste is formed being thus supplied to the potter, the process of the formation of the paste from the bricks is also described by Entrecolles as practised in his time.

The bricks of kaolin and petung-tse being again pulverised are further purified by washing, and any sandy matter they may contain removed. The two materials are then mixed in different proportions according to the sort of porcelain intended to be fabricated.

4. The laborious process of kneading the dough is represented as being executed by buffaloes in fig. 19, copied like the others from contemporary drawings.

This method of kneading is still used in China. M. Chavagnon, who penetrated into the interior of that country, assured M. Brongniart, the director of the Sèvres manufactory, that he witnessed the process.

The paste being prepared thus for the fabrication of the porcelain, the process of forming the articles at the potter's wheel as practised at the same epoch in China, is represented in fig. 20.

The wheel is kept in rotation by a man, who holds the ends of a flat strap, which he presses lightly against the edge of the wheel when he impels it by drawing one end of the strap, and

Fig. 20.

yielding to its motion at the other end. After each impulse the strap is loosened and restored to its first position on the edge in order to repeat the impulse. The strap is prevented from slipping over the surface of the edge of the wheel by pins or points projecting from its surface.

The potter places the paste to be formed into the desired article on the head of the wheel, and shapes it with his hands and fingers.

Another man is represented carrying away the finished articles to the oven.

5. The ovens and the process of baking are represented in fig. 21. A man in a shed on the left is employed in placing the articles to be baked in cylindrical cases of baked earth, which correspond to those which our potters call SAGGERS.

An empty oven is represented at A, where a man receives the saggers filled with the articles to be baked, and arranges them in the oven. When the oven is thus filled it is closed by brickwork. A second oven thus filled, and bricked up, is represented at C.

The fire doors or feeding mouths of the furnaces, by which the ovens are heated, appear at D, and the openings for the escape of smoke and the products of the combustion are represented at *a*, *b*, and *c*.

Fig. 21.

The Chinese ovens used at the present time do not differ much in form or arrangement from those designed and described by Entrecolles in the beginning of the last century. M. Chavagnon, who witnessed their performance at a recent period, says that the construction of the flues is so well managed, that the distribution of the heat is sensibly uniform, the ovens such as A, which are most remote from the furnace, being as effectually heated, and the articles in them as well baked, as those, such as C, which are nearest to it.

6. The first attempts made in Europe to fabricate a hard earthenware covered with a glaze, are ascribed to the Moors of the Spanish Peninsula. After this, a manufacture upon a large scale, was established in the Balearic Isles; and the wares originally produced there, and subsequently reproduced in Italy, acquired the name *Majolica,* being a corruption of Majorica or Majorca, the principal island of the Balearic group.

7. The first of the improvers of this art after its importation into the Italian peninsula, was Lucca della Robbia, a Florentine sculptor, whose name has thus become inseparably associated with the history of this ornamental industry. This celebrated artist, born in 1388, died prematurely in his forty-second year. He left, nevertheless, an immense number of works, which have come down to the present times, and are highly prized.

He was succeeded by his brothers and their descendants, all of whom continued, for nearly a century and a half, to practise the art on a large scale, so that it must be always difficult, if indeed it be possible, to ascertain what are the genuine works of the great artist, and to distinguish them from those of his family, some of whom worked under and with him during his lifetime.

The productions of this family of artistic potters are formed of a paste, consisting of about 50 per cent. of silica, combined with 15½ per cent. of alumina and 22½ per cent. of lime, with small proportions of carbonic acid, magnesia, and iron. The decorations were figures in relief, variously coloured with yellow, produced by lead and antimony, a dark opaque blue, the green produced by copper, and a bad violet produced by manganese. The art of producing colours by means of gold was not then known in Europe.

8. In fig. 22 is represented an altar-screen by Lucca della Robbia. This consists of four pieces and two pilasters. The ground is a fine azure blue; the figures are white; the fruits, cup, &c., in gold-yellow, and the garlands green. The thickness of the earthen ware or *faiençe*, of which it is composed, is little more than an inch and an half. This piece is preserved in the Cabinet Sauvageot.

9. The paste used at this epoch not having the whiteness of the finer porcelain, the articles fabricated were covered with an opaque glaze of some particular colours, by which the coarse and ill-coloured ground of the porcelain was concealed. The process by which these opaque glazes were produced was nearly the same as that by which the transparent and colourless glazes of the present day are produced. The baked article, which before it is glazed is called biscuit, is submerged in a vessel containing the vitrifiable matter, mixed with such a proportion of water as to give it a creamy consistency. After immersion, a coating of this liquid adheres to the surface. The water which holds the vitrifiable substance in suspension is partly imbibed by the material of the vessel. The vessel, thus coated, is placed in an oven, and again exposed to the action of heat of sufficient intensity to vitrify the coating with which it is invested, so that, when withdrawn from the oven, the coating is converted into a coloured and opaque glass, and the vessel is glazed. Sometimes the article, before being baked, was covered with a coat of earthy matter, not vitrifiable but opaque, by which the coarse surface of the paste was concealed, and this coat being hardened in the oven, a transparent glaze was put over it.

10. The majolica ware of Italy was in its most flourishing state from 1540 to 1560. It was during this interval that the finest table-services were produced. The chief places of its fabrication were Castel Durante and Florence; but its celebrity and the

Fig. 22.

ALTAR SCREEN BY LUCCA DELLA ROBBIA.—1400 A.D.

general taste for it increasing, all the principal Italian cities produced it, and all the most renowned artists, including Raphael himself, supplied designs for it, which potters scarcely less renowned, executed.

It has been often stated that Raphael himself worked at this art. Such, however, was not the fact. The Duke of Tuscany, Guidobaldo II., who extended to this art the most magnificent patronage and encouragement, procured designs from Raphael and his pupils, which he gave to the potters whom he had established at Pesaro to execute; and it happened that among the most skilful of the decorators of these potteries there were two who bore the name of Raphael. Hence the productions were said to be those of Raphael; and, at a later period, those who were unacquainted with these circumstances concluded that they were the immediate work of the celebrated painter.

11. It was at this time that the celebrity of such productions, and the universal admiration which they excited, produced the custom, continued to the present time, of offering them as royal presents by sovereign to sovereign. The Duke Guidobaldo caused to be executed at Pesaro magnificent services, which he presented to sovereigns and other eminent personages. The splendid service is especially mentioned which he presented to the Emperor Charles V., made by Taddeo Zucarro and Battista Franca, under the direction of the brothers Flaminio and Orazzio Fontana.

Nothing was omitted which could enhance the interest and increase the excellence of those productions of artistic industry. To genius, talent, skill, and care, were united the researches of erudition, and the counsels of taste, to impart to them the greatest attainable perfection.

12. This high excellence was sustained so long as the art was protected and fostered by royal patronage. The time was not yet arrived when the patronage of the public was more advantageous than that of the sovereign; and after the decease of Guidobaldo and Orazzio Fontana, the art being left to the unaided influence of the public demand, it became necessary to meet that demand by low-priced and, therefore, inferior articles. The taste accordingly declined with the excellence which excited it, and the Italian majolica gradually but speedily lost its reputation.

About 1772, Cardinal Stoppani attempted to revive it at Urbino, and some temporary effect was produced about 1775, but it was only temporary. It is probable that the importation of Chinese porcelain into Europe, which was simultaneous with the decadence of majolica, may have had some influence in producing that result.

13. The epoch of della Robbia in Italy was followed by that of Bernard Palissy in France. This eminent potter was born at La Chapelle-Biron, a small village of the Perigord, about 1510, and died in 1589.

Although he was the author of many published works, and one upon the art which he practised with so much success, he has left no available information respecting his processes. His desire seems to have been exclusively to leave to the world a record of the unparalleled difficulties he encountered, the sacrifices he made, the sufferings he endured, and the obstinate perseverance, amounting, it must be admitted, to a sort of heroism, which he displayed in the attainment of his objects. In his experiments, which were continued for a long period of time, and pursued with an admirable patience, he expended all that he was worth, even to the sale of his furniture and wardrobe.

Palissy had the weakness and ignorance so common with practical men, of inveighing against theory, yet in the only work which he has left on the subject of his art, he has not only been sparing, obscure, and mysterious in his practical details, but has mixed them up with theories of his own which only prove how much painful toil, how many abortive experiments, and how great an expenditure he would have been spared, had he condescended to consult those who were qualified to inform him of the true principles of physical and chemical sciences applicable to his researches.

14. The character of this great improver of his art was strongly marked, not only by patience, perseverance and sagacity, in the pursuit of his purposes, but by eminently high moral firmness, and unshaken rectitude. No example can be found of one to whom the well-known lines of the Roman poet are more truly applicable :

> "Justum ac tenacem propositi virum,
> Non civium ardor prava jubentium,
> Non vultus instantis tyranni
> Mente quatit solida."—HORACE.

> "The man, in conscious virtue bold,
> Who dares his secret purpose hold,
> Unshaken hears the crowd's tumultuous cries,
> And th' impetuous tyrant's angry brow defies."
>
> FRANCIS.

15. Palissy was a conscientious Protestant, and did not hesitate publicly to avow and express his opinions even in his discourses on subjects of his art. By this boldness and indiscretion, he was in his ninetieth year dragged before the ecclesiastical authorities, and refusing peremptorily to renounce his opinions, or to retract his expressions, he was thrown into the Bastille. He was visited there by the King, Henry III., who wished to liberate him, when the following memorable colloquy took place between the monarch and the manufacturer :

"My good man," said the king, "if you cannot conform yourself on the matter of religion, I shall be compelled to leave you in the hands of my enemies."—"Sire," replied the old man, "I was already willing to surrender my life, and could any regret have accompanied the action, it must assuredly have vanished upon hearing the great King of France say 'I am compelled.' This, sire, is a condition to which those who force *you* to act contrary to your own good disposition can never reduce *me;*

because I am prepared for death, and because your whole people have not the power to compel a simple potter to bend his knee before images which he has made."

Palissy, to the eternal disgrace of the monarch and the priests, was detained in the Bastille, where he died at little short of a hundred.

16. The works of Palissy are characterised by a peculiar style and qualities. While the forms are in general correct and pure, there is no painting properly so called. The figures are given in coloured relief, whether they be mere ornaments, representations of natural objects, or historical, mythological, or allegorical subjects. The enamel is hard and brilliant, but often disfigured by a multitude of small inequalities; a defect which is also observable in the productions of the German potters of that day. The colours are generally brilliant, but little varied. The white is yellowish, and very inferior to that of della Robbia. The other tints are confined to a pure yellow, an ochre yellow, a fine indigo blue, a greyish blue, an emerald green, a yellowish green, the violet produced by manganese, and a brownish violet. They included no fine white, nor any tint of red.

The bottoms of the articles are generally marbled with tints of blue, yellow, and brownish violet.

In fig. 23 is represented a porcelain flask (Bouteille de Chasse), attributed to this potter, preserved in the *Cabinet Sauvageot*. It is oval in form, the largest diameter being 10¼ inches, and bears the Montmorenci arms. Palissy was employed by the Duc de Montmorenci to decorate the Château d' Ecouen.

The natural objects represented on the pieces of Palissy, are remarkable for truth of form and colour, having been, with the exception of certain leaves, moulded from nature. It would appear from the selection of this class of decoration that Palissy was more or less a naturalist. The shells with which he has ornamented many of his pieces are all tertiary fossil shells from the Paris basin, and probably also that of Grignon and its environs. The fishes are those of the Seine, and the reptiles, a prevailing subject, those of the banks of the same river.

Most of the pieces, and especially the dishes and plateaux, are surcharged with objects in coloured relief, and evidently were never designed for the table, but were used to furnish the great buffets and sideboards called Dressers, which were placed in the dining halls of that day.

The productions of this potter must have been extremely numerous, for they are still found in great quantities in the cabinets and collections, public and private, and with the vendors of antiquities and curiosities of all countries. The varieties of

Fig. 23.

form and design, however, bore no proportion to the number of articles produced, and we accordingly find a limited number of forms and patterns, indefinitely repeated in the extant collections.

17. An oval plateau highly decorated in relief by this potter is represented in fig. 24. This piece is well known to amateurs under the name of the dish of the fair garden-girl, *plat de la Belle Jardinière.* The decorations, coloured yellow and green, are in low relief. The bottom is scaled green and reddish yellow. This piece is in the collection Sauvageot.

18. Between the middle of the seventeenth century and its close commenced the manufacture of the fine earthenware, which, without attaining the excellence of porcelain, constituted a great improvement on the previous products of this industry. This was owing partly to the discovery of a white plastic clay as a substitute for the reddish clay previously used in France, Germany, and Italy, which rendered it possible to use a colourless transparent glaze instead of the opaque coloured glaze, which had been previously used. Besides this, there were numerous improvements made in the details of the manufacture by the potters who established themselves in Staffordshire, and gave celebrity to the extensive district since known as the Potteries.

The establishment of this industry in Staffordshire originated from the circumstance of strata of good plastic clay being found

Fig. 24.

there in immediate juxta-position with the coal necessary for its conversion into the fabricated article.

The chief town of the district, Burslem, is supposed to derive its name from two Saxon words, Burn or Byrn, a *stream* or a *farm*, and Lœm, *clay*. If this be the origin of the name, it would follow that the fabrication of earthenware in that district must have prevailed since a very remote epoch.

19. About 1680, Messrs. Palmer and Bagnall, potters at Burslem, discovered accidentally the property of marine salt, by which it supplied a glaze. In some culinary process, salt being thrown into the fire its vapour came in contact with the biscuit of an unglazed article, and was observed to have the effect of giving it a glaze. The expedient was tried in the manufacture, and succeeded. The salt, when vaporised, coming in contact with the unglazed ware, was decomposed by the silica which formed so large an ingredient of the paste, and the soda deposited combining with the silica produced the glaze.

It was about this time that the brothers Elers of Nuremberg immigrated to England, and erected a small factory in Staffordshire. There were then no more than twenty-two ovens at Burslem.

20. The Messrs. Elers had not long been there before they discovered in the neighbourhood a bed of clay of very superior quality, and, erecting upon the spot itself a factory, resorted to

extraordinary and curious measures to keep in profound secrecy their materials and their processes. With this view they not only excluded most rigorously from their works all visitors whatever, but selected for their operatives the most stupid and ignorant persons they could find, and so divided the labour that no one individual possessed more knowledge than that of the very process at which he was employed. These precautions were, however, of little avail. The stimulus of profit and the spirit of enterprise are not to be repressed by such shallow expedients. A workman named Twyford imposed upon them by affecting indifference to the art, and managed to get admitted to their employment. He soon ascertained some of their secrets, but it remained for another more astute and persevering person to discover all the details of their processes. An individual named Astbury, appreciating the importance of the manufacture, and foreseeing the profits likely to arise from it, decided on adopting a course and persevering in it, which, as he imagined, and as proved by the event, would lead to a complete discovery. He affected the manners of an idiot, deceived them, and got into their employment, and was adroit enough to sustain the deception for several years, until he became complete master of their secrets. After this, the Messrs. Elers left Staffordshire in apparent disgust, and settled in London, where, at a later period, they were probably instrumental in establishing the well-known porcelain works at Chelsea.

21. One of the ingredients of fine pottery is silica, or the earth of flints. The circumstance which led to the application of this substance to the art is thus related:—Mr. Astbury, the son and successor of him who gained the knowledge of the Elers's secret by feigning idiocy, being on his road to London, and making the journey on horseback, was stopped at Dunstable in consequence of his horse being attacked with a malady of the eyes. The innkeeper at whose house he put up advised him to apply a poultice of calcined flints. Astbury observed that the flints, which before calcination were black, and semi-transparent, were by this process of calcination converted into a white opaque substance. It occurred to him that he might by like means bleach the clay of which the pottery was made, and which was reddish in its colour, by mixing with it more or less of the matter thus whitened in the fire. He accordingly realised this idea with complete success, and silica or the earth of flints became thenceforward a necessary ingredient of the paste.

22. Among the improvers and inventors of this epoch the most memorable was Josiah Wedgwood, whose name has since become so inseparably connected with this branch of the national industry.

This celebrated potter, born at Burslem in 1730, was the son of Thomas Wedgwood, who followed the same business. The education of Josiah must necessarily have been limited to reading and writing, for at the early age of eleven years he worked at the wheel in his father's pottery.

After being united in partnership for short intervals with Messrs. Harrison and Whieldon, he commenced working on his own account in a little thatched building, in 1760. He soon extended his works, erecting another small manufactory called the "Bell Works," from the fact, then unusual, that the workmen were assembled and dismissed by a bell. It was here that he commenced the fabrication of the cream-coloured ware, with a plombiferous glaze, which afterwards became so celebrated, and which being approved and patronised by Queen Charlotte, consort of George III., was called *Queen's ware*, and procured for Wedgwood the appointment of potter to the Queen.

Wedgwood was esteemed as much for his public spirit and private virtues as for his industrial enterprise and skill. It was to him was chiefly due the construction of the canal connecting the Trent with the Mersey, commenced in 1760, and completed in 1777.

His fortune being increased by inheritance as well as by his commercial success, he purchased the estate called Ridge House, where he established, in 1770, his manufactory of black ware.

It was here also that he erected the noble mansion which became his family residence, and the surrounding village called Etruria, where he established his principal works, having removed from Burslem in 1771, and where he accumulated that princely fortune, which he devoted to so many noble and charitable uses. The name conferred on this establishment, and the industrial village created around it, was taken from that of one of the ancient Italian states, which had attained a high celebrity for the tasteful forms of its potteries.

He died at Etruria, in 1795, at the age of 64.

The effects of the genius and perseverance of this prince of manufacturers were not limited to the improvement of the mere processes of fabrication. His efforts were directed with not less success and effect to the improvement of forms and decoration. He resolutely rejected the uncouth and distorted shapes which had till then prevailed, and replaced them by forms at once pure, simple and elegant. He availed himself of the collection of ancient vases, which Hamilton had brought from Italy, and took his models from them. He substituted for the vulgar style of ornament which had been till then exclusively adopted, decorations characterised by a severe taste, and, like the earlier potters of Tuscany, he called to his aid the greatest living artists, procuring designs from the celebrated Flaxman, according to which he fabricated his improved wares. This system has been continued by his son and successor.

Wedgwood was as remarkable for enlightened liberality in his private character as for well-directed enterprise as a manufacturer. An example of his munificence was lately mentioned in one of the leading journals, which we cannot pass without mention here. The family attracted around them men of genius in literature and art, among whom were Sir James Mackintosh, his brother-in-law, Mr. Stuart, then editor of the *Morning Post*, Coleridge, Southey, and others. In the beginning of 1798, Coleridge received an invitation to accept the functions of minister to the Unitarian congregation at Shrewsbury. Thomas Wedgwood hearing of this wrote to him to dissuade him from taking such a step, considering it to be adverse to the prosecution of literary works, in which he was likely to found a great reputation, and to confer a great benefit on society; and that no immediate pecuniary exigency should force him to accept the proposition he enclosed a cheque for an hundred pounds. Coleridge, however, considering that the Shrewsbury appointment opened to him for the first time in his life the prospect of a certain income and permanent establishment, decided to accept it, and returned the cheque. He accordingly went to Shrewsbury, preached his probation sermon with general satisfaction to his flock, the afterwards celebrated William Hazlitt being one of his auditors. The Wedgwoods, however, sensible that the poet was misplaced, and would be lost to the world, again wrote to him, expressing that opinion, and proposed that he should at once relinquish his clerical charge, to which he was unsuited, and with princely munificence offered to place him at ease for the future by settling on him a life annuity of an hundred and fifty pounds. The offer was promptly and gratefully accepted.*

Before the commencement of Wedgwood's labours the English potteries produced wares flimsy in their materials, grotesque in their forms, and utterly destitute of all correct taste in their ornamentation, being miserable copies of the Chinese procelain. Owing to the influence of the enterprise and genius of this eminent man, the style and character of the ceramic manufacture of the country was thoroughly reformed, so that not only have the productions of Staffordshire, Derbyshire, Worcestershire, London, and other places where this industry has been established, superseded foreign goods in the home market, but they have spread over

* Edinburgh Review, April 1848, p. 379.

the whole civilised world. M. Faujas de St. Fond, a foreign writer on this subject, says:—

"The excellent workmanship of English porcelain, its solidity, the advantage which it possesses of sustaining the action of fire, its fine glaze, impenetrable to acids, the beauty and convenience of its form, and the cheapness of its price, have given rise to a commerce so active and universal, that in travelling from Paris to St. Petersburgh, from Amsterdam to the furthest part of Sweden, or from Dunkirk to the extremity of the south of France, one is served at every inn upon English ware. Spain, Portugal, and Italy are supplied with it, and vessels are loaded with it for both the Indies and the continent of America."

Fig. 28.—TURNER OR THROWER'S SHOP IN PORCELAIN WORKS.

THE POTTER'S ART.

CHAPTER III.

1. Improvements effected by Wedgwood.—2. General commercial advantages attending the manufacture.—3. History of Chinese porcelain. —4. Its first importation into Europe.—5. Great plasticity of the material.— 6. Perfection of its forms.— 7. Pagoda of Nankin.— 8. Forms of vases.—9. Figure called "pou-sa."—10. Discovery of the material of porcelain in Europe.—11. Origin and history of Böttger.—12. His labours in Saxony.—13. Anecdotes of his imprisonment.— 14. Is established at Dresden.— 15. First results of his labours.—16. White earth of Schnorr.—17. Discovery of Saxon kaolin.—18. Establishment of the royal manufactory at Meissen.— 19. Curious precautions to ensure secresy. — 20. Anecdote of Brongniart.—21. Death of Böttger.—22. Analysis of the Dresden paste.—23. Style of the Dresden porcelain.—24. Grotesque figures. 25. Secrets transpire.—26. Ringler at Hochst.—27. Paul Becker.— 28. Establishment of the Royal Bavarian manufactory.—29. In other German states.—30. Invention of the Sèvres *pâte tendre.*—31. Its defects.

1. AMONG the principal improvements for which the art is indebted to the genius of Wedgwood, may be mentioned—besides

the queen's ware—a terra cotta resembling porphyry, granite, Egyptian pebble, and other ornamental stones; a black unglazed ware called basaltes, hard enough to emit sparks when struck with steel, and capable of receiving a high polish, of resisting acids, and of sustaining a high temperature; a white unglazed ware having like properties; a bamboo or cane-coloured ware of the same kind; a biscuit adapted to chemical purposes by reason of its hardness, its resistance to acids, its impenetrability by liquids; its incorrosiveness, and its refractory quality when exposed to high temperatures; and, in fine, for a production denominated JASPER, consisting of a white porcelainous biscuit of extreme beauty, having besides the properties of the basaltes above-mentioned, the quality of receiving from the application of metallic oxides colours which penetrate its entire thickness like those imparted to glass or enamel in fusion. This peculiar property, possessed by no other porcelain or earthenware body ancient or modern, renders it applicable to the production of cameos and all subjects which require to be shown in relief upon a ground of another and darker colour, the figures in relief formed with this biscuit being of the purest white.

2. We cannot give a more clear idea of the benefits conferred by this manufacture on our national industry than may be obtained from the following evidence, given by Wedgwood before a Parliamentary committee:—

"Though the manufacturing part alone in the Potteries, and their immediate vicinity, gives bread to 15 or 20,000 people, yet this is but a small object when compared with the many others which depend on it; namely, 1st, The immense quantity of inland carriage it creates throughout the kingdom, both for its raw materials and finished goods. 2nd, The great number of people employed in the extensive collieries for its use. 3rd, The still greater number employed in raising and preparing its raw materials in several distant parts of England, from near the Land's End, in Cornwall—one way along different parts of the coast, to Falmouth, Teignmouth, Exeter, Pool, Gravesend, and the Norfolk coast; the other way to Biddeford, Wales, and the Irish coast. 4th, The coasting vessels, which, after having been employed at the proper season in the Newfoundland fishery, carry these materials coastwise to Liverpool and Hull, to the amount of more than 20,000 tons yearly; and at times when, without this employment, they would be laid up idle in harbour. 5th, The further conveyance of these materials from those ports, by river and canal navigation, to the Potteries, situated in one of the most inland parts of this kingdom; and, 6th, The re-conveyance of the finished goods to the different parts of this island, where they are shipped for every foreign market that is open to the earthenwares of England."

Mr. Wedgwood very justly observed further, that this manufacture is attended with some circumstances of advantage which are almost peculiar to itself; viz. that the value of the finished goods consists almost wholly in the labour bestowed upon them; that every ton of raw materials produces several tons of merchandise for shipping, the freight being paid, not upon the weight, but according to the bulk; that scarcely a vessel leaves any of our ports whose lading is not in part made up of these cheap, bulky, and, for these reasons, valuable articles, to this maritime country; and that fully five parts in six of the aggregate manufactures of the Potteries are exported to foreign markets.

3. While the potters of Europe were engaged with more or less success in the fabrication of an earthenware, which, whatever may have been its merits, was formed of a paste coarse and opaque; the fine porcelain, which attracted so much and so well merited admiration, was for a long period of time obtained exclusively from the East.

Without insisting on the claims of the Chinese to the production of this beautiful article at the epochs of remote antiquity, which have been already referred to, there is sufficiently conclusive evidence that they possessed and practised the art hundreds of years before it was discovered in Europe or elsewhere. Thus it is certain that fine porcelain was made in China 163 B.C., and that its fabrication existed still in 442, A.D.

The first porcelain oven, however, of which there are distinct and detailed historic records in China was called TAOU-YAOU, and was situate at Chang-Nan in the province of KEANG-SI. Tributes of porcelain were sent from this factory to the court of Woo-tih in the year 630 A.D.*

The celebrated works of King-Te-Tching, already mentioned, were not established until 1000 A.D.

In the Ceramic Museum of Dresden are pieces of porcelain which bear dates from 1403 to 1425, from 1465 to 1488, and 1573 to 1620, which are, therefore, spread over two centuries. The stationary character of the Chinese is remarkably indicated by the fact that the earliest of these specimens does not differ in the slightest degree from the latest, either in its mode of fabrication, the nature of its material, nor even in its colours or style of decoration.

4. It was not until 1518 that the Chinese porcelain was brought to Europe by the Portuguese, and two centuries elapsed before any successful attempt was made to fabricate it. In England this fine

* Morrison's Chinese Dictionary, part iii., p. 326, word "porcelain."

pottery was called CHINA, from the place of its production, but on the Continent it was distinguished from the coarser sorts of pottery by the name porcelain; the origin of which is not certain, but which is supposed to be derived from the Portuguese word PORCELLANA (a drinking cup).

Although the art of fabricating porcelain was thus late in reaching Europe, it extended from China to other adjacent parts of Asia, and especially to Japan, and even to Persia, at a much earlier period.

5. The paste of which the oriental porcelain is composed is generally deficient in pure whiteness, having rather a grayish hue, while the glaze which covers it is greenish. It is hard, brittle, and stands the fire only with many precautions. It is not as translucent as the fine porcelain manufactured in France and Germany.

That in its unbaked state it possesses the quality of plasticity in an extraordinary degree is rendered manifest by various circumstances. The process of the fabrication is one to which no material but the most plastic could lend itself. It is also proved by the enormous magnitude of the vases which are fabricated in a single piece, free from those defects which would be inevitable with a material not possessing that quality in the highest degree.

Without being as fusible as the paste of which the tender porcelain is formed, it is less infusible than that of the hard European porcelain. A cup of Chinese porcelain was softened and distorted in one of the Sèvres ovens.

6. The forms given to the Chinese porcelain are remarkable for their perfection, even in the case of articles presenting the greatest difficulties and delicacies. The pieces, although large, are frequently not thicker than an egg shell. Open cylindrical vases eight or nine inches in height are proportionally delicate; plates decorated with ornaments in relief, are remarkable for their lightness and evenness of surface; and as to magnitude, the vases made in a single piece are sometimes fifty-four inches high and twenty-two inches diameter. A vase of these dimensions is in the possession of M. Cambacères, remarkable for the magnificence of its ornamentation in relief, and its dragon-formed handles.

7. Among the pieces of Chinese porcelain most memorable for magnitude, is the celebrated pagoda of Nankin in the province of Kiang-Ming, the height of which is 213 feet. This structure consists of nine stages, the walls of each of which are covered with plates of coarse porcelain. Two models of this, on a small scale, may be seen in the Imperial (Royal) Library at Paris.

8. One of the most characteristic forms of the Chinese vases is

that of the two round vases or bottles connected by a contracted neck, of which figs. 25 and 26 are examples. The most usual ornaments on these vases are lizards or other reptiles with a

Fig. 25.

Fig. 26.

curved and bifurcated tail, which are represented crawling from one of the vases to the other in the contracted neck, by which they are connected.

This form of vase has been seen no where on the old continent

Fig. 27.

except in China and in Egypt. M. Brongniart, however, notices a fact which has some interest for geographers and antiquaries. It is that vases of the same form and similar decoration have been found among the remains of ancient pottery in Peru and Chili in South America, which must have existed ages before the time of Columbus. One of these jars, found in Peru, is represented in fig. 27. It will be observed as a coincidence deserving of notice, that while in the Chinese vases lizards are represented creeping from one part of the vase to the other, a species of small ape is represented in a like position and action on the Peruvian vase, and that in both cases the tails are bifurcated.

9. The figures so often seen on Chinese porcelain, with a large paunch, which amateurs call POU-SA, and which are often in coloured glaze, represent the Chinese god of porcelain, whom a legend records as being a martyr to the art. Being engaged in the process of baking, he found that the action of the furnace was irregular, and such as must destroy the articles in the oven. To prevent this, according to the Chinese traditions, he sacrificed himself by throwing himself bodily into the furnace, and attained his object.

10. It was not until the beginning of the last century that the art of fabricating the true porcelain made its way to Europe. The circumstances attending its discovery are highly interesting and curious.

During the seventeenth century, the oriental porcelain which had been brought to Europe by the Portuguese, and which was distinguished from the wares fabricated there by the name of porcelain, excited the unbounded admiration of all classes. No efforts were left untried to discover its materials and the means of producing it. European agents in the East, and more particularly Father Entrecolles already mentioned, contrived, in spite of the jealous vigilance of the Chinese, to obtain specimens of the materials of which the precious ware was fabricated. But these materials were in the state in which they were prepared for the potter, and not in the raw form in which they were first taken from the quarries. Nevertheless, they were assiduously examined and analysed by the most eminent chemists and physicists of the day.

These researches, however, led to no practical result; and, as so often happens in the progress of discovery, as well in the arts as in the sciences, chance accomplished what sagacity and industry failed to attain. Even chance, however, can accomplish nothing, unless it presents its results where talent and genius are present to recognise them and turn them to account. Happily, in the present case, the talent and genius were not wanting. Saxony was destined to have the honour of the first accomplishment of this great advance in the ornamental arts.

11. John Frederick Böttger (or Böttcher) was born at Schlaiz, in Voigtland, on the 4th of February, 1682. He was brought up at Magdeburg, where his father had a place in the Mint. The father was given to alchemy, and pretended to the discovery of the philosopher's stone, the secret of which he was reputed to have imparted to his son. In the superstitious spirit of the age, Böttger believed himself gifted with the power of divining the future, in consequence of being a "Sabbath child," having chanced to come into the world on a Sunday.

He was apprenticed to an apothecary named Zorn, at Berlin, but the fascinations of alchemy did not long permit him to give his attention to the preparation of medicines; and he deserted his master and his business. He was soon, however, obliged to return, and was received and forgiven, on the condition of abandoning his favourite study of alchemy.

Soon after this, being informed that the fame of his researches and the rumours of his prospects of successful results, which gave him among his fellow citizens the name of the "Goldmaker," had reached the ears of Frederick I. of Prussia, and fearing, or affecting to fear, that he would be seized by royal order for the purpose of extorting his secret from him, he again fled, and took refuge in Saxony, where his arrest was procured by the Prussian authorities. The Elector of Saxony, however, having resolved not to surrender so precious a personage, had him carried away from Wittemberg, and secretly confined, but well cared for and treated.

He was supplied with all the means necessary to carry on his chemical researches, but was kept under constant surveillance, and was in reality a prisoner.

12. After some time the Elector, finding that the labours and researches of Böttger were without any practical results, and suspecting all the prospects of success so much vaunted to be mere illusions, but finding nevertheless that his protegé and prisoner was endowed with considerable natural genius, combined with much acquaintance with chemical science, such as it was at that time, resolved on endeavouring to turn Böttger to better account; and, with this view, put him in communication with Ehrenfried Walther de Tschirnhausen, who was then occupied in experimental researches directed to the improvement of the fabrication of earthenware, and more especially to the discovery of means for the production of the oriental porcelain.

Böttger himself, having probably some misgivings as to his eventual success in the fabrication of gold, was the more ready to give ear to the counsels and suggestions of Tschirnhausen, and was soon brought to cooperate with that person, and to deliver himself with all his characteristic ardour to a series of experiments on the fabrication of an improved pottery.

13. In order to remove them more effectually from popular interference and observation, the Elector had established Böttger and Tschirnhausen in the château of Albrechtsburg at Meissen. They were there abundantly supplied with artisans to work under them, and with all that was necessary for a porcelain laboratory and workshop. Böttger was liberally afforded all that could render life agreeable, except liberty. A carriage was provided for him, and he was allowed to visit Dresden and the neighbourhood at his pleasure, but an officer always accompanied him, never for a moment losing sight of him, lest he should escape, carrying with him his inestimable secrets.

The first result of their labours, which were still prosecuted under the strict surveillance of government, was merely the production of articles of earthenware, composed of a red and compact paste, differing, however, in nothing which was essential from the pottery of Spain, Italy, and France.

In 1706, the King of Sweden, Charles XII., entering Saxony, the King of Poland, Elector of Saxony, fearing that Böttger should be seized and carried away with his secrets, had him conducted with Tschirnhausen and three principal artisans, Ritter, Romanns, and Beichling, to the fortress of Konigstein, where they were strictly imprisoned, but supplied with a laboratory, where they were allowed to prosecute ther labours under rigid surveillance. Böttger is related to have lost none of his gaiety and animal spirits here. He amused his leisure hours and those of his companions in captivity in various ways, and among others, by the composition and recitation of verses.

Notwithstanding all the precautions which were observed for their safe keeping, Ritter and the others managed to form a plan of escape.

14. In 1707, after remaining a year at Konigstein, Böttger and Tschirnhausen were reconducted to Dresden, and established in a new laboratory which had been prepared for them on the Jungferbastei. Here they continued to prosecute their labours, all their researches being directed still to the discovery of the means of producing a pottery such as that which came from China. Their labours were incessant, and their spirit indefatigable; and it is related as an example of the untiring spirit of Böttger, that when it was considered necessary to watch the oven day and night for three or four successive days, he never left them himself, and kept his assistants awake by his inexhaustible fund of anecdote, and the gay and frequent sallies of his conversation.

It was said, that at this time some of the firing processes which required a more intense heat than could be obtained by the furnaces then in use, were effected by means of the solar rays collected in the focus of a large burning mirror, constructed by Tschirnhausen.

Tschirnhausen died the next year, 1708. This event, however, did not interrupt the course of experiments. Large ovens were erected, and batches of earthenware were exposed in them to the effect of the furnaces, often for five consecutive days and nights, producing successful results so far as the nature of the clays used permitted. The king, wishing to witness one of these experiments, they drew from the oven, in his presence, a tea-pot, still red-hot, which, being plunged in water, sustained the sudden change of temperature without injury.

15. The pottery thus produced was still, however, only a good stone-ware, with a red body, to which the brilliancy of porcelain was attempted to be imparted, either by polishing it on the wheel of a lapidary, or by covering it with an opaque-coloured glaze, which was vitrified at a comparatively low temperature.

At length, however, chance brought to Böttger a knowledge of the constituents of the true oriental porcelain, so long and so vainly sought for.

16. About this time, John Schnorr, one of the most wealthy and extensive iron-masters of Erzgebirge, happened to pass on horseback near Aue, where he observed the action of his horse to be impeded by reason of his feet sticking in a sort of white, soft, and tenacious earth, which lay upon the road, and which evidently formed the superficial stratum of the ground at that place. At that time, the use of hair-powder was universal, and that article formed consequently an object of commerce of capital importance. Engaged largely himself in commercial speculations, and endowed with an enterprising genius and quick sagacity, Schnorr conceived the idea of submitting this white clay to experiment, for the purpose of purifying it, and reducing it to a fine powder, which might find a profitable market as hair-powder, thus displacing the powder produced from wheaten flour.

Schnorr realised this project with complete success, and after a series of experiments made at Carlsfeld, established a manufactory of it, and soon found an extensive market and large demand for the article at Dresden, Leipsic, Zittau, and, in short, in all the German towns, where the new powder was known under the name of Schnorr's White Earth.

17. Böttger, like all others of that day, wearing powder, he happened, while Klunker, his valet, was occupied in dressing his hair, to take in his hand a packet of the powder which he was using, and being struck with its extraordinary weight, greatly

exceeding that of powder made from flour, he asked Klunker where he bought it, and what it was called. Being informed that it was "Schnorr's White Earth," the idea instantly occurred to him that a clay so beautifully white, and admitting of pulverisation so infinitely fine, would serve as a material for fabricating an improved pottery; he instantly ordered a quantity of it to be procured sufficient for an experiment, which was no sooner tried than its precious qualities became conspicuously apparent. It was, in fact, the true kaolin, the very material of which the so highly-prized oriental porcelain was formed, and for which so many and such fruitless searches had been made in all parts of Europe.

18. The king now proceeded to establish the Royal Manufactory of Porcelain, which has since attained such universal celebrity. The Château of Albrechtsburg, at Meissen, was assigned to it, and Böttger was appointed its director.

The most rigid precautions were adopted to prevent the discovery, or its consequences, passing out of the country. The exportation of the "white earth" was interdicted under the most severe penalties, and it was transported from Aue to the manufactory at Meissen in sealed barrels, under military escort, and in the care of sworn keepers.

The precautions to ensure the secresy of the processes exceeded all belief. The precept solemnly inculcated into all who were employed in the manufactory, from the director to the lowest labourer, was "SECRESY TILL DEATH!" An oath to this effect was solemnly administered monthly to all the foremen and principal artisans, and was painted in conspicuous characters on the doors of all the workshops.

Whoever should be detected in disclosing any of the secrets of the processes was menaced by the royal ordinances with imprisonment for life in the fortress of Königstein.

19. In a word, the royal manufactory of Meissen was placed under the rigorous conditions of a fortress, the drawbridge never being lowered except at night. No one was admitted within its walls except those employed in the works; and even when the king brought foreigners of distinction to view the works, the processes were carefully concealed from them.

20. So late as the year 1812, M. Brongniart, then director of the Royal Manufactory of Sèvres, was sent by the Emperor Napoleon to inspect the porcelain works of Germany, and among others he visited those of Meissen. Even then the same rigorous system of secresy and exclusion was maintained. The King of Saxony, at the personal request of Napoleon, permitted M. Brongniart to see the works; but in order to do so, he was obliged to absolve M. Kuhn, the director, from his oath of exclusion. He did so,

as far as related to M. Brongniart individually, but he refused to include in the admission the associate who accompanied him.

The fine hard porcelain was now manufactured at Meissen, the colours, forms, painting and gilding of the oriental porcelain being so perfectly re-produced, that on examining the specimens of this early date preserved in the Dresden collection, M. Brongniart affirmed that he was only able to ascertain that they were not genuine Chinese porcelain by the mark of the Meissen manufactory impressed on them.

21. Böttger was unable to bear his elevation. Intoxicated with success, and supplied with pecuniary resources beyond his habits, he fell into a course of dissipation, and died in 1719, at the early age of thirty-five.

Such was the origin of the manufactory of porcelain at Dresden, which has since obtained a world-wide celebrity, and the source from which Europe for more than a hundred years obtained the most admired productions of the ceramic art.

22. The kaolin of Aue, discovered by the accidental circumstances above stated, continued, and still continues, to be used as one of the materials of the Saxon porcelain. Two sorts of paste are at present used in this manufacture. What is called the service paste, or that used for porcelain in general, is thus composed:

Kaolin of Aue	18
Kaolin of Sosa	18
Kaolin of Seidlitz	36
Feldspar, &c.	8
	100

For the statuary porcelain the feldspar of Carlsbad and quartz are mixed with the kaolin of Aue.

The manufacture of fine porcelain being thus established in Saxony, it soon spread to other parts of Europe, partly by the treachery and desertion of the parties engaged in the Meissen manufactory, and partly by the invention of other materials for the paste; and, in fine, by the discovery of strata of kaolin in other localities.

23. The style of the Dresden porcelain is familiar to all amateurs, and, whatever difference of opinion may prevail as to its taste, there can be none as to the admirable excellence of its execution. All who have visited the collection at Dresden, will be familiar with the series of animals, represented on a scale approaching to the natural size, including bears, rhinoceroses, vultures, peacocks, &c., made for the grand staircase which conducts to the electoral library. These were fabricated as early as 1730. At a later

period, when the manufacture had undergone improvements, large ornamental pieces of porcelain were made, such as the slabs of consoles and tables, some of which measure from 45 to 50 inches by 25, and are richly decorated with flowers.

24. Among the varieties of Dresden porcelain the grotesque figures and groups have always been much admired for their execution, if not for their style. The costumes are especially admirable, and the representation of fine work, such as lace, truly wonderful. One of the grotesque pieces which has attained most celebrity, and is familiar to all amateurs, is the famous tailor of the Count de Bruhl, a figure which is remarkable for the difficulty of its execution owing to the numerous accessories which it includes. The figure of the tailor is represented riding on a goat surrounded with all the implements and appendages of his trade, and is about 20 inches in height. This celebrated group was composed by Kundler in 1760, and is usually sold for about 12*l*.

The Dresden manufacture has always been remarkable for its representation of flowers; and a beautiful specimen of this work was seen in the Great Exhibition in 1851, consisting of a *camellia japonica* with leaves and white flowers in porcelain, in a gilt pot, on a stand of white and gold porcelain. This article is priced at 90*l*.

25. The efforts made to conceal the important discovery thus made, and to monopolise the manufacture of fine porcelain at Dresden, were ineffectual. The force of interest proved more powerful than the respect for oaths, and the art, as improved in Saxony, soon spread to other parts of Germany.

One of the foremen of Meissen, named Stobzel, had deserted from that establishment about the year 1718, and escaped to Vienna, where, aided by a Belgian named Pasquier, and favoured by a privilege, or a sort of monopoly, for twenty-five years, granted to him by the Emperor Charles VI., he established, in 1720, a small porcelain manufactory. Not having, however, sufficient capital to carry it on, it declined, and was finally purchased by the Empress Maria Theresa in 1744, and erected into a royal manufactory. During nearly twenty years it required considerable subsidies for its support, but at length, by good management, it became profitable in 1760, and in 1780 yielded an annual profit of about 4000*l*. The number of operatives who were lately employed in this factory was about 400. The kaolin or porcelain clay used in this factory, until 1812, was obtained from the neighbourhood of Passau, on the confines of Bavaria, and from Prinzdorf, in Hungary. Lately, however, it has been supplied by clay obtained from the neighbourhood of Brün, in Moravia, and Unghbar, in Hungary.

As deserters from Meissen were instrumental in establishing the manufactory of porcelain at Vienna, deserters from Vienna soon spread the knowledge of the art to a greater or less extent in other parts of Germany.

26. Ringler, one of those who had originally deserted from Meissen, again breaking his engagements, and disregarding his oaths, left Vienna, taking with him plans of the ovens, and associating himself with M. Gelz, a manufacturer of earthenware at Höchst, near Francfort-on-the-Maine, he enabled that potter, with the aid of Lowenfink and Bengraf, two others, to establish the manufacture of the fine porcelain.

The German princes, captivated by the productions of this art, and ambitious, each in his own state, to establish a royal manufactory, in imitation of those of Dresden and Vienna, left no means of corruption and seduction untried to attract the potters, or even the subordinate workmen, who were engaged in the manufactories already established. Thus, the Duke of Brunswick endeavoured, by highly advantageous offers, to tempt the potter Bengraf to desert his employer, and succeeded, though not without much delay and many difficulties, for Bengraf was arrested by order of the Elector of Mentz, and was kept without food, until he was compelled to leave with his employer the full details of his processes, and to verify their exactitude. At length he was permitted to depart, and, in fine, he founded, in 1750, the well-known manufactory of Furstenberg, on the Weser. But as he died before his processes were carried into practical effect, the Duke of Brunswick failed in his object, and lost the expense he had incurred. He resorted in vain to the aid of an eminent chemist of that day, the Baron de Lang, to find means of realising the plans of Bengraf.

Ringler having remained at Höchst, continued to direct the processes of that manufactory, taking care, however, to conceal his processes, so that without his personal superintendence the works could not proceed. Being addicted to drinking, his companions, availing themselves of his infirmity, and knowing that he usually carried on his person receipts for his processes, tempted him into an excessive indulgence in wine, which ended in his falling into a state of insensibility. Availing themselves of this, they rifled him of his papers, and his receipts being copied and re-copied, were carried about the German States, and sold for considerable sums to wealthy persons, who considered themselves fortunate in becoming the possessors of the processes of an art so much and so universally admired.

27. Among these hawkers of Ringler's receipts or notes, one of the most noted and active was a certain Paul Becker, who, after

travelling through France and the Netherlands, at length settled in Brunswick, where he received a pension from the Duke, on the condition of ceasing from his peregrinations. Most of the notes and receipts which were thus put in circulation, were either garbled and fragmentary, or altogether spurious, so that little or no practical advantage was derived by those who became their possessors.

Ringler quitting Höchst, went to Frankenthal, where, associating himself with a merchant, named Hammung, he established a porcelain factory, which afterwards became one of the best known in Germany.

28. He went to Munich, where he established, under the protection of the King of Bavaria, the royal porcelain works at Nymphenburg, within a few miles of the city, in 1758.

This establishment still continues, and is now the Royal porcelain manufactory of Bavaria. The white biscuit is manufactured at Nymphenburg, and its ornamentation effected in workshops at Munich. The porcelain clay used in this manufactory is obtained near Passau, already mentioned, the felspar from Raberstein, in Bavaria, and the quartz from Abensburg, near Ratisbon. It was, in like manner, by means of information brought by deserters and runaways from factory to factory, that the fabrication of porcelain came to be established successively in the royal manufactories of Louisberg near Stuttgard, at Berlin, Copenhagen, Brunswick, and St. Petersburgh.

After the peace of Hubertsburgh, Frederick II. of Prussia, erected the royal manufactory of Berlin. While he was master of Dresden, he sent a considerable quantity of the porcelain clay of Meissen, and several of the operatives of this factory, to Berlin, to aid in the establishment of the manufactory in that city.

29. Chance, which played so remarkable a part in the progress of the ceramic art elsewhere, was also the origin of its establishment in the Thuringen.

In 1758, an old woman brought to the laboratory of the cnemist Macheleid, a powder, which she proposed to be used as sand for drying writing. The grain and colour of this powder struck Henry Macheleid, the son of the chemist, who had studied at Jena, as bearing a resemblance to china clay. He submitted it to analysis, and found that it was kaolin. In fine, he succeeded in making porcelain with it, and founded in 1762 a manufactory of that article at Sitzerode, which in 1767 was transferred to Volkstadt, and became the origin of all the other manufactories of that district of the German states.

30. While the art made this progress in Germany, the French potters failing to discover either a true kaolin or any other clay

having the qualities necessary to render it a tolerable substitute for the fine china clay, directed all their efforts to invent some artificial composition which might serve the purpose and enable them to compete with foreign potters.

The result was the invention of an artificial imitation of the porcelain paste, which soon became the basis of a great manufactory in France, and which continued for half a century to be known as the *pâte tendre* of the Royal manufactory of Sèvres.

This material did not contain a particle of kaolin or felspar, the essential constituents of all genuine porcelain. Its composition was subject from time to time to slight variations; for, for the best porcelain, it consisted of the following constituents in an hundred parts by weight:—

Fused nitre (mineral crystals)	22·0
Grey sea-salt	7·2
Alum	3·6
Soda of Alicant	3·6
Gypsum of Montmartre (plaster of Paris)	3·6
Sand of Fontainbleau	60·0
	100·0

These materials being well mixed, were fritted either in the porcelain oven, or in an oven expressly appropriated to this process. It was usual, however, to calcine the alum and the gypsum previously to disengaging their water of crystallisation.

The dough called the *pâte tendre,* was formed by the mixture of this frit with white chalk and calcareous marls from the gypseous earth of Argenteuil, in the following proportions by weight:—

Frit	75
Chalk	17
Gypseous earth	8
	100

The whiteness and consistency or hardness of this dough was modified by varying the proportion of chalk.

All these materials were intimately kneaded together, bruised with water in a mill, and in fine passed through silken sieves.

The glaze used for this factitious biscuit was composed as follows:—

Litharge	38
Calcined sand of Fontainbleau	27
Calcined silex	11
Sub-carbonate of potash	15
Sub-carbonate of soda	9
	100

31. This paste after all was so utterly wanting in plasticity and

consistency that it could not be worked on the potter's wheel, and was even moulded not without much difficulty.

To give it sufficient tenacity and consistency to prevent it from cracking or crumbling to pieces in the process of moulding, it was mixed with about twelve per cent. of its own weight of a mixture of black soap and parchment size, the soap at a later period being replaced by a solution of tragacanth gum, to which are attributed the saline efflorescences which were occasionally manifested on the articles fabricated. In the process of turning the moulded pieces a saline and silicious dust was produced, which was extremely injurious to the potters, and caused asthmatic and pulmonary complaints. This was one of the reasons why the fabrication of tender porcelain was the more readily discontinued after the discovery of kaolin.

Owing to the want of plasticity and coherence in this artificial paste, great difficulties were encountered in the several stages of its manufacture. The want of tenacity rendered it necessary, when the articles were placed in the oven, to support all the projecting parts during the process of baking ; and, in order that the forms of these parts might not be distorted, it was necessary that their supports should be formed of the same paste as the articles themselves, so that the whole mass, including the supports, might contract together. The linear dimensions contracted in the baking by one-seventh, and, consequently, the bulk or volume of the article was diminished in the proportion of three to two.

Fig. 35.—MOULDER'S SHOP IN PORCELAIN WORKS.

THE POTTER'S ART.

CHAPTER IV.

1. Meaning of the epithet "tender" as applied to porcelain.—2. Qualities and value of this porcelain.—3. Art of making it not lost.—4. Origin of the Sèvres manufactory.—5. Efforts to discover kaolin—Paul Hannong.—6. Kaolin of Limoges discovered.—7. Anecdote of Madame Darnet.—8. English porcelain at Bow, Derby, and Worcester.—9. Cornish china clay.—10. Properties of true porcelain.—11. Stoneware.—12. Cause of translucency.—13. Hard and tender porcelain distinguished.—14. English tender porcelain.—15. Mode of preparing the clay.—16. Statuary porcelain.—17. Process of its fabrication.—18. Process of producing colours on porcelain.—19. Coloured figures on common ware; press and bat printing.—20. Distinctive marks of the manufactories—21. Various recent applications of the art.

1. THE epithet *tender*, applied to this porcelain, must not be understood as implying the quality of softness. It is intended, on the other hand, to express two qualities by which it is distinguished

from the hard porcelain: first, that the paste is fusible at a certain temperature lower than that at which the hard porcelain is baked; and, secondly, that the glaze is so soft that it may be scratched with a steel fork or knife.

This artificial imitation of porcelain enjoyed for a long time great celebrity; and after its manufacture was discontinued, it was still more eagerly sought by amateurs, and its price was enhanced by its comparative scarcity.

2. The very defects of this artificial porcelain conferred upon it some advantages, in its decoration, over the real porcelain made from the paste of kaolin and felspar. The softness of the glaze caused painting laid over it to penetrate more or less into it, and thus to assume the appearance of being incorporated with it. It had the same effect as if it were placed under the glaze, retaining nevertheless the most perfect brilliancy. This is an effect difficult to be attained, owing to the facility with which the colouring matter is affected by the saline constituents of the glaze. It has not reappeared in the productions of the Sèvres factory since the fabrication of the *pâte tendre* was discontinued there. Since the great Exhibition, however, some of the British manufacturers have produced similar effects.

There are certain coloured grounds which are eminently characteristic of the old Sèvres porcelain, the proper porcelain paste not being in the same degree susceptible of receiving them. These are the beautiful light blue called TURQUOISE, from its resemblance to the colour of the stone of that name, the GROS BLEU, the GREEN obtained from copper, and the red distinguished as the ROSE DUBARRY, from the preference shewn to it by the notorious mistress of Louis XV.

Although this factitious ware contained no portion of either of the essential constituents of true porcelain, and ought not, therefore, ever to have received the name, or to be regarded as anything else than a spurious imitation of that admired production of Art; it must at the same time be admitted to be, in its superficial and external qualities, a beautiful copy of a beautiful original, and to require in its preparation and fabrication much more profound resources of science and art than what is composed chiefly of matters which nature presents nearly in the state in which they enter into the composition of the article fabricated. To discover and fitly combine the complicated elements of this artificial porcelain required patient research, great chemical skill, much sagacity, perseverance, and genius; while the casual discovery of a vein of kaolin and felspar would have at once enabled any potter, already master of his art, to fabricate the genuine porcelain.

The fabrication of this celebrated pottery commenced in France about the year 1695, and was continued for more than a century. The existence of true kaolin in France was not discovered until 1768, when the manufacture of real porcelain was commenced, and was prosecuted concurrently with the fictitious porcelain until 1804, when the fabrication of the latter was discontinued; and since that time the real porcelain only has been produced in the French Royal Manufactory.

3. Among amateurs in porcelain, including even those who are otherwise well-informed, there prevails a notion that the art of fabricating the tender porcelain of Sèvres has been lost, and that, since it is impossible to reproduce the articles, they must necessarily have a high value in the market. This, however, is erroneous. All the materials and processes for the fabrication of this description of artificial porcelain are preserved at Sévres, and the manufacture can be re-established whenever it is desired to do so. Indeed, we are informed that the Administration entertains an intention of recommencing the fabrication of this description of porcelain for articles of ornament, such as vases, pictures, &c., the imperfections incidental to it not affecting such objects.

In 1695, when the first attempt at the fabrication of the *pâte tendre* was made, the porcelain works at St. Cloud were the property of a private individual named Morin. The invention of this artificial paste was the result of twenty-five years of labour and research. It appears, therefore, that this manufacture commenced about fifteen years before the discovery of kaolin, and the commencement of the fabrication of hard or real porcelain at Dresden.

4. The establishment which has since attained such celebrity as the Royal Sèvres Porcelain Works, was previously established at Vincennes, where it was first conducted as a private enterprise. In 1753, Louis XV. became joint-proprietor of it, taking a third share, and gave it the sanction of royal protection, and the title of the Royal Manufacture of Porcelain. Having attained, about 1754, great celebrity from the extraordinary perfection and beauty of its productions, and especially for a magnificent service presented by the king to the Empress Catherine of Russia, the manufacture enlarging its works, the buildings at Vincennes were found to be too confined for its more extended operations: and a site having been obtained at the village of Sèvres, on the highroad from Paris to Versailles, a building on a vast scale was erected there for the manufacture, which was removed there in 1756.

A few years later, in 1760, the king purchased the interests of the other proprietors, and the works became, and have ever since continued to be, the exclusive property of the Government.

5. It may be easily imagined that the celebrity of the German porcelain, and more especially that of Dresden, excited the most lively desire, and the most unceasing endeavours, to discover in France the precious mineral which alone formed the base of the genuine article. It was necessary, however, first to ascertain what the actual material was, which still remained to a great extent a secret; and next to discover where, if at all, it could be obtained in France.

In 1753, just before the removal of the Royal Manufactory from Vincennes to Sèvres, Paul Hannong, a citizen of Strasburg, who was proprietor of earthenware and porcelain works at Hagenau, being in possession of the full knowledge of the materials and processes of the German porcelain manufacture, proposed to M. Boileau, director of the manufactory at Vincennes, to sell to that establishment the secret of the manufacture, for which he demanded 4000*l.* in cash, and a life annuity of 480*l.* This proposal being declined, a royal decree in 1754 prohibited him from carrying on his works in France, and he accordingly established them at Frankenthal.

Paul Hannong died and was succeeded by his brother Pierre Antoine, with whom the French Government re-opened the negotiations which had been broken off by reason of the exorbitant demands of Paul. A greater facility now appearing to be manifested, the ministers of Louis XV. spared no exertion to secure to France the possession of an art so highly esteemed, and to rescue the country from the necessity of obtaining only by importation articles so highly prized. M. Boileau, the director of the royal works at Sèvres, was sent to Frankenthal with full powers, and the result of his negotiation was a contract signed on the 29th July, 1761, by which Pierre Antoine Hannong engaged to make known all the processes and the materials for manufacturing the true porcelain. Eventually, however, the execution of this contract to the advantage of the French government was rendered impossible by the fact, not foreseen, that the raw materials, kaolin and felspar, indispensable for the fabrication of the porcelain, not having been discovered in France, could only be obtained from countries where their exportation was prohibited. Under these circumstances the contract with Hannong was dissolved, the Government, however, granting him as compensation a sum of 160*l.* and a life annuity of 48*l.*

6. The time, however, had now arrived when chance was destined to do for the porcelain manufacture in France what it had done elsewhere, by leading to the discovery of kaolin.

Madame Darnet, the wife of a village surgeon, residing at St. Yrieix, near Limoges, accidentally found in a valley in the neighbourhood of that town a white unctuous earth, which she regarded as being capable of being rendered useful in the washing of linen. With this purpose she showed it to her husband, who, better informed, suspected other and more valuable properties in it, and undertook a journey to Bordeaux to submit it to a chemist of that place, named Villaris. This person, who had been already informed of the qualities necessary for porcelain clay, and of the eagerness with which it was sought for, suspected that the specimen brought to him by M. Darnet possessed these qualities. It was accordingly sent to Macquer, the chemist at Paris, who was then occupied in experiments on the improvement of porcelain. He immediately recognised in this specimen of clay the true kaolin, and went to St. Yrieix in August 1768, where he found a large vein of this precious material. Experiments were made upon it upon a considerable scale at Sèvres, where all doubts upon the subject were soon removed; and the kaolin of St. Yrieix near Limoges was immediately adopted as the material, and the fabrication of the hard porcelain was commenced.

7. M. Brongniart relates a curious and interesting anecdote connected with this subject. He says that, in 1825, being at Sèvres, where he was still director, an aged woman addressed herself to him one day supplicating temporary relief, and apparently suffering from extreme want. She asked for aid to enable her to return on foot to St. Yrieix, whence she had come. This woman was Madame Darnet, the discoverer of the kaolin of Limoges. The relief she sought was immediately given to her; and, on the application of M. Brongniart, Louis XVIII. granted her a small pension on the civil list, which she enjoyed till her death.

8. The first English porcelain was manufactured at Bow and Chelsea, near London, the paste being composed of a mixture of the sand from Alum Bay, in the Isle of Wight, with a plastic clay and powdered flint glass; this was covered with a leaden glaze. This manufactory had considerable success.

In 1748, the manufacture was transferred to Derby; and in 1751, Dr. Wale established at Worcester a manufactory of tender porcelain, called the "Worcester Porcelain Company," which still exists, though in other hands. To Dr. Wale is attributed the invention of printing on porcelain, by the transferring of printed patterns from paper to the biscuit. The proposed design is first engraved on copper, and the colouring matter being applied to the engraving in the same manner as in common copper-plate printing, the design is transferred to paper. This paper is afterwards applied to the biscuit, to which the colouring matter forming the design adheres. The paper is then dissolved and washed off, the colouring matter forming the design remaining upon the biscuit. The biscuit is then glazed over the design with a glass glaze, so that after vitrification the design appears under the glass.

The original Worcester Porcelain Company principally limited their business to the manufacture of blue and white porcelain, in imitation of that of Nankin, and making the Japanese pottery. Cookworthy, of Plymouth, continued to carry on the porcelain business at Worcester until 1783, when the manufactory fell into the hands of Mr. Thomas Flight.

9. About 1751, Messrs. Littler, Yates, and Baddeley attempted the same manufacture in Staffordshire, but without success, and it was not until 1765 that Messrs. Baddeley and Fletcher succeeded in the manufacture of porcelain at Shelton.

The kaolin or china clay, as it is usually called, which is used in the manufacture of British porcelain, is found in the counties of Cornwall, Devon, and Dorset. That of Cornwall was discovered about the same time as that of the discovery of the kaolin of St. Yrieix, in 1768, by Cookworthy. This is the most esteemed, and its introduction into the manufacture of porcelain gave a great impulse to the art.

10. The qualities by which porcelain is distinguished from the inferior productions of the potter are, density, whiteness, transparency, and fine texture of the glaze. These properties are estimated in the order wherein they are here enumerated, compactness of body being the point which it is considered most desirable to attain. The glaze, as seen in the finished porcelain, should not put on a lustrous appearance; but while beautifully smooth to the touch, should present to the eye rather the softness of velvet than the gloss of satin. This peculiar semblance will only be produced with glaze that melts with difficulty, and when the heat has been raised precisely to, and not beyond, the point that is necessary for its fusion.

11. Stoneware is a very perfect kind of pottery, and approaches nearer than any other description to the character of porcelain. Its body is exceedingly dense and compact, so much so, indeed, that although vessels formed of it are usually glazed, this covering is given to them more with the view of imparting an attractive appearance than of preserving them from the action of liquids. When properly made and baked, stoneware is sufficiently hard to strike fire from a flint, and is as durable as porcelain.

12. The translucency of porcelain arises from the vitrification of one of the constituents of the paste in the process of baking. The other constituents being much more refractory, the article still

retains its form, just as a porous vessel such as a flower-pot would, if it were thoroughly saturated with water. The semi-transparency of porcelain thus produced is an effect of the same class as that imparted to paper or linen cloth by saturating it with melted wax. The vitrifiable constituent which thus renders porcelain translucent is generally the felspar; in some cases, however, it is lime which, entering into combination with the alumina and silica of the clay, forms a double silicate of alumina and lime, more fusible still than the simple silicate of alumina. The oxide of iron produces a like effect, but as it gives a colour to the paste, it can only be used in the commoner sorts of ware. By increasing the proportion of the vitrifiable constituent, greater translucency is imparted to the ware, but the body becomes less plastic, more liable to distortion, and more difficult to work.

13. It is most necessary to comprehend the distinction between the hard porcelain, the manufacture of which, as we have stated, was carried on at a very early date in the East, and the varieties of tender porcelain. The body of the latter sorts is more fusible than that of the former. This property is given to it by introducing into it a larger proportion of alkaline constituents, either in the form of felspar, or of alkaline silicate, prepared expressly for the purpose, and called *frits*. The glaze used for these porcelains is also more fusible than that of hard porcelain, a quality which it receives from a certain proportion of the oxide of lead which enters into its composition.

In certain sorts of tender porcelain no clay whatever is used, and the entire body consists of an artificial *frit*. Such ware, however beautiful it may be rendered in external form and appearance by fine workmanship and rich ornamentation, cannot properly be called porcelain at all. It is at best only an ingenious imitation of that article, bearing to it the same relation as a gilded article bears to a gold one. Nevertheless, such is the article so much admired and so highly prized under the denomination of the "Old Sèvres Porcelain."

14. The English porcelain, and certain sorts still produced in some of the private manufactories of France, belong to the class of tender porcelain, though not all identical with, or even resembling, the Old Sèvres Porcelain. The English porcelain is composed chiefly of clays found in Cornwall, Devon, and Dorsetshire. The Cornish is the best quality, and is technically termed by potters "china clay;" it enters very extensively into the composition of the best kind of ware. It is the decomposed felspar of the granite, and is prepared by the clay merchants themselves in Cornwall, prior to its being sent to the potteries. Huge masses of white granite abound in Cornwall, which is in some parts found partially decomposed;

and when this is the case, the mineral is raised and prepared for the potter's use.

15. The following is the method of preparation:—The stone, having been broken by a pickaxe, is laid in a stream of running water: the light argillaceous parts are thus washed off and kept in suspension; the quartz and mica being separated are allowed to subside near the place where the stone was first raised. At the end of these rivulets are a kind of catchpools, where the water is at last arrested, and time allowed for the pure clay with which it is charged to form a deposit, which, being effected, the water is drawn off; the clay is then dug up in square blocks and placed upon a number of strong shelves, called "linnees," so fitted as to allow of the free circulation of air, that the clay may be properly dried. Thus prepared, it is an extremely white mass, capable by being crushed to be reduced to a fine impalpable powder. In this state it is sent to the potteries under the name of China clay.

16. One of the departments of this manufacture, in which England has of late years gone considerably in advance of the continent, is that devoted to the fabrication of statuary porcelain. This beautiful branch of reproductive art has been almost created within the last six or seven years by some of the most eminent and enterprising establishments in Staffordshire.

Like all novelties in the arts, this process has undergone a succession of improving changes. At first the statuary material was limited to a thin superficial coating laid upon a common body. At present, however, the object is composed of one homogeneous mass of statuary porcelain. The articles thus produced are superior in quality, but much more difficult of manufacture, owing to the much greater degree of contraction which takes place in the oven, and the consequently increased chances of distortion and fracture, especially in pieces of complex form and considerable magnitude. The contraction of the linear dimensions amounts to as much as a fourth of the original magnitude, so that a figure, which as moulded or cast is four feet high, comes out of the oven definitively only three feet in height, the other dimensions being decreased proportionally. The actual contraction in the cubical dimensions which corresponds to this is more than one half, so that the baked materials are included in less than half the space occupied by the unbaked.

17. The process by which statuary porcelain is produced is that called casting, and it resembles in many respects that by which casts of objects are produced in metal.

If the object to be produced is such as can be cast in a single piece, a mould of its form is made in plaster of Paris, consisting of two parts which can be united by perfectly plane and smooth surfaces, each part having a sunk impression of one side of the intended object. A clear enough notion of such a mould may be obtained from a common bullet-mould.

When the two parts of the mould are brought into contact, it will leave within it a hollow space corresponding exactly in form with the intended figure, but having a small opening through which the liquid may be introduced.

The statuary paste is brought, by mixture with about its own weight of water, to the consistency of a thick cream, and being well and carefully mixed, so as to be quite homogeneous, it is poured into the mould, which is kept full of it for a certain time, more or less according to the thickness which it is desired to give to the statuary material composing the object. While it thus stands, the bibulous quality of the plaster mould causes it to imbibe water from that portion of the creamy liquid or "slip," as it is called, which is in contact with it, so that a coating of paste, in a sufficiently dry state to have coherence, remains attached to the surface of the mould. Within this is contained that portion of the slip which still remains in the liquid state. This being discharged through a small hole in the mould, provided for that purpose, the mould remains lined with a solid coating of the porcelain paste of a certain thickness.

If it be desired to render the coating upon the mould thicker, so as to give greater strength and weight to the object moulded, the process is repeated; and, in order to equalise the thickness of the deposit, the mould, if it be not too large, is reversed in its position each time that it receives a new charge of slip.

When the mould, by this process, has received a coating of sufficient thickness it is opened, and the object thus cast taken out of it; which is easily accomplished, since no adhesion takes place between its surface and that of the mould.

The thickness of the article thus formed may be varied within practical limits, from that of the egg-shell to the thickness required by objects of the largest attainable dimensions. A beautiful application of this process is practised in the continental factories, by which a thin, delicate article is produced, called egg-shell porcelain.

When a large figure, or group of figures, is to be produced, the process is more complex. Let us suppose its height in the model to be twenty-four inches. Separate and independent moulds are previously made for various parts of the piece, and in the larger and more complex subjects the number of these sometimes amounts to forty or fifty.

Supposing the figure or group to measure twenty-four inches in height as moulded, the shrinking that occurs before these casts can be taken out of the mould, which is caused by the absorbent nature of the plaster of which the mould is composed, is equal to a reduction of one inch and a half in the height. These casts are then put together by the "figure-maker;" the seams consequent upon the marks caused by the subdivisions of the moulds being carefully removed, the whole is worked upon to restore the cast to the same degree of finish as the original model. The work is then thoroughly dried, to be in a fit state for firing, since, if it were put in the oven while damp, the sudden contraction consequent upon the great degree of heat to which it would be suddenly exposed, would be very liable to cause it to crack: in this process it again suffers a further loss of one inch and a half by evaporation, and it is now but twenty-one inches high. Again, in the "firing" of the bisque oven, its most severe ordeal, it is diminished three inches, and is then but eighteen inches high, being six inches or one-fourth less than the original. It loses, therefore, in the entire process, one-fourth of its linear, and therefore more than one-half of its cubical dimensions. Nevertheless, such is the consummate skill brought to bear on this beautiful manufacture, that in good specimens there is not the slightest discoverable distortion or defect of form or outline.

The perfection to which this branch of the potter's art has recently attained, is such as to render it probable that it will eventually be to sculpture what engraving has been to painting, but with a much closer affinity, identity of colour and texture being attained, as well as that of outline and design.

18. The enamel colours used in the ornamentation of porcelain are produced by certain oxydes of the metals combined with other substances, called *fluxes*, which have the effect of facilitating their fusion. Thus the oxyde of gold produces tints of red, such as crimson, rose-red, and purple. Reds are also produced by the oxydes of iron and chrome. The same oxydes, as well as those of cobalt and manganese, produce blacks and browns; those of uranium, chrome, antimony, and iron produce orange; those of chrome, and copper, green; and those of cobalt and zinc, blue. The fluxes for these various oxydes are borax, flint, oxyde of lead, &c.

These colouring materials are worked up with essential oils and turpentine, and a very great disadvantage under which the artist labours is, that the tints upon the palette are in most cases different to those they assume when they have undergone the necessary heat, which not only brings out the true colour, but also by partially softening the glaze and the flux, causes the colour to become fixed to the ware. This disadvantage will be immediately apparent in the case where a peculiar delicacy of tint is required, as in flesh tones, for instance. But the difficulty does not end here, for, as a definite heat can alone give to a colour a perfect hue, and, as the colour is continually varying with the different stages of graduated heat, another risk is incurred—that resulting from the liability of its receiving the heat in a greater or less degree, termed "over-fired" and "short-fired." As an instance of its importance we will cite rose-colour, or crimson, which, when used by the painter, is a dirty violet or drab; during the process of firing it gradually varies with the increase of heat, from a brown to a dull reddish hue, and from that progressively to its proper tint. But if by want of judgment or inattention in the fireman, the heat is allowed to exceed that point, the beauty and brilliancy of the colour are destroyed beyond remedy, and it becomes a dull purple. On the other hand, should the fire be too slack, the colour is presented in one of its intermediate stages, as already described; but in this case extra heat will restore it. Nor must we forget to allude to the casualties of cracking and breaking in the kilns by the heat being increased or withdrawn too suddenly, a risk to which the larger articles are peculiarly liable. These vicissitudes render enamel painting in its higher branches a most unsatisfactory and disheartening study, and enhance the value of those productions which are really successful and meritorious.

In enamelling, ground-laying is the first process in operating on all designs to which it is applied; it is extremely simple, requiring principally lightness and delicacy of hand. A coat of boiled oil adapted to the purpose being laid upon the ware with a pencil, and afterwards levelled, or as it is technically termed "bossed," until the surface is perfectly uniform; as the deposit of more oil in one part than another would cause a proportionate increase of colour to adhere, and consequently produce a variation of tint. This being done, the colour, which is in a state of fine powder, is dusted on the oiled ground with cotton wool; a sufficient quantity readily attaches itself, and the superfluity is cleared off by the same medium. If it be requisite to preserve a panel ornament, or any object white upon the ground, an additional process is necessary, called "stencilling." The stencil (generally a mixture of rose-pink, sugar, and water) is laid on in the form desired with a pencil, so as entirely to protect the surface of the ware from the oil, and the process of "grounding," as previously described, ensues. It is then dried in an oven, to harden the oil and colour, and immersed in water, which penetrates to the stencil; and, softening, the sugar is then easily washed off, carrying with it any portion of colour or oil that may be upon it, and leaving the ware perfectly clean. It is sometimes necessary, where great depth of colour is required, to repeat these colours several times. The "ground-layers" do generally, and should always, work with a bandage over the mouth, to avoid inhaling the colour-dust, much of which is highly deleterious. Bossing is the term given to the process by which the level surfaces of various colours, so extensively introduced upon decorated porcelain, are effected. The "boss" is made of soft leather.

The process of gilding is as follows:—The gold (which is prepared with quicksilver and flux), when ready for use, appears a black dust; it is used with turpentine and oils similar to the enamel colours, and, like them, worked with the ordinary camel's-hair pencil. It flows very freely, and is equally adapted for producing broad massive bands and grounds, or the finest details of the most elaborate design.

To obviate the difficulty and expense of drawing the pattern on every piece of a service, when it is at all intricate, a "pounce" is used, and the outline dusted through with charcoal—a method which also secures uniformity of size and shape. Women are precluded from working at this branch of the business, though, from its simplicity and lightness, it would appear so well adapted for them. Firing restores the gold to its proper tint, which first assumes the character of "dead gold," its after brilliancy being the result of another process termed "burnishing." *

19. The ornamentation of the less costly descriptions of ware, such as are in common use for the table, and in which a single colour only is used, is accomplished by a process similar to that of copper-plate printing. There are two methods of effecting this, one called "press," and the other "bat" printing. In "press" printing the design is formed on the article before it receives the glaze, and is afterwards covered and protected by the glaze, through which, being quite transparent, it is visible. In "bat" printing, on the other hand, the design is laid upon the glaze, and fixed there by enamelling it.

In both cases the design is first executed on a copper-plate. For press printing it must be cut very deep to enable it to hold a sufficiency of colour to give a firm and full transfer on the ware. The printer's shop is furnished with a brisk stove, having an iron plate upon the top, immediately over the fire, for the convenience of warming the colour while being worked, also a roller, press, and tubs. The printer has two female assistants, called "transferrers," and also a girl, called a "cutter." The copper plate is charged with colour, mixed with thick boiled oil, by means of a knife and "dabber," while held on the hot stove plate, for the purpose of

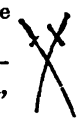
* Official Catalogue of the Great Exhibition, p. 713.

keeping the colour fluid; and the engraved portion being filled, the superfluous colour is scraped off the surface of the copper with the knife, which is further cleaned by being rubbed with a "boss," made of leather. A thick firm oil is required to keep the different parts of the design from flowing into a mass, or becoming confused, while under the pressure of the rubber in the process of transferring. A sheet of paper, of the necessary size and of a peculiarly thin texture, called "pottery tissue," after being saturated with a thin solution of soap and water, is placed upon the copper plate, and being put under the action of the press, the paper is carefully drawn off again, the engraving being placed on the stove, bringing with it the colours and design with which the plate was charged. The paper is then laid upon the ware, and rubbed upon it with flannel. During this friction the coloured design upon the paper is partly imbibed by the unglazed surface of the ware, and partly remains upon that surface. The article is then immersed in water, by which the paper being softened, and partially dissolved, it is easily washed off with a sponge, the coloured design alone remaining on the surface of the article. The oil included in the colouring matter is then expelled by exposure to heat in a kiln, called a hardening kiln, after which the design being left in perfectly dry colouring matter, the article is glazed. When covered with the raw glaze, the design is quite invisible, the glaze being opaque in that state; but when it is vitrified in the oven, it becomes quite transparent, and the design is apparent through it.

The bat printing is done upon the glaze, and the engravings are for this style exceedingly fine, and no greater depth is required than for ordinary book engravings. The impression is not submitted to the heat necessary for that in the bisque, and the medium of conveying it to the ware is also much purer. The copper plate is first charged with linseed oil, and cleaned off by hand, so that the engraved portion alone retains it. A preparation of glue being run upon flat dishes, about a quarter of an inch thick, is cut to the size required for the subject, and then pressed upon it, and being immediately removed, draws on its surface the oil with which the engraving was filled. The glue is then pressed upon the ware, with the oiled part next the glaze; and being again removed, the design remains, though, being in a pure oil, scarcely perceptible. Colour, finely ground, is then dusted upon it with cotton wool, and a sufficiency adhering to the oil leaves the impression perfect, and ready to be fired in the enamel kilns.

20. It has been the practice at all the great porcelain manufactories to stamp upon the bottom, or some other convenient

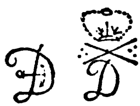
part not exposed to view, of each article fabricated, a peculiar distinctive mark, by which the place of its manufacture shall be always capable of being ascertained. It will not be without interest here to indicate some of the principal of these marks.



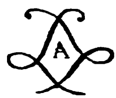
The Dresden porcelain, manufactured at the royal manufactory of Meissen, bears the mark of two swords crossed, as here represented.

The English porcelain, manufactured at the celebrated Chelsea works, is marked with an anchor, thus

The porcelain manufactured at Derby is marked with the cypher



The old Sèvrés porcelain, fabricated from 19th Aug., 1753, until the fall of Royalty in 1793, is marked with the cypher



During the Republic, from 1793 until the end of 1800, the mark over the Sèvres porcelain was simply the initials F. R.

From 1800 to 1804 the articles were marked with the characters,

M . N[le] (Manufacture Nationale).
Sèvres
— ıı =

During the Empire, 1804 to 1814, the words Manufacture Impériale, Sèvres, were stamped upon the porcelain.

From the Restoration to the Revolution of 1830, the articles bore the royal cipher, the double L or double C.

From 1830 to 1834, the symbol of equality, a double equilateral triangle was used: and from 1834 to the Revolution, 1848, the articles bore the cipher of Louis Philippe.

By these indications the amateur will be enabled to determine the epoch of the manufacture of such articles as may fall under his notice.

21. There is nothing more remarkable in this branch of industry than the great number and variety of unexpected uses to which the ingenuity of the manufacturer has rendered it subservient. At the Great Exhibition of 1851, this was especially conspicuous. Among the specimens there collected were found, for example, chimney-pieces of statuary porcelain. The advantages of this application are numerous and obvious. Among them are great durability and freedom from the susceptibility of discoloration and staining to which marble is liable. Plateaux and slabs for the covering of fire-places, tops of console toilet and chess-

tables, panels of doors and window-shutters, tiles for flooring and walls, terra-cotta for vases and garden pots, are among the many productions of this art.

Encaustic tiles for ornamental flooring merit especial notice. This branch of the earthenware manufacture has recently acquired considerable importance, and an export business of some extent has been already established in it. Large quantities of this article are now exported to the United States and the colonies, as well as to certain parts of Europe. The palace of the Sultan at Constantinople is paved with this tiling, as are also the House of Lords, Osborne House, and St. George's Hall, Liverpool. This flooring has got into very general use in churches, private mansions, conservatories, &c. It is as durable as marble, less liable to stains, and can be decorated with any design to suit the taste of the purchaser.

As a specimen of pottery on a large scale, the figure of Galatea, seven feet high, is deserving of attention. This claims to be the largest perfect object in pottery which has yet been produced in a single piece. Attempts are, we understand, being made, with some probability of success, to produce it in statuary porcelain.

Among the ornamental and merely artistic applications of this art, we must not omit to notice the copies of paintings, often upon a very large scale, made in enamel colours upon slabs of porcelain. These beautiful productions of the ceramic art proceed almost exclusively from the national manufactories of France and Saxony.

The portraits of the Queen and Prince Albert, which were exhibited in the great aisle of the Crystal Palace, are fine specimens of the largest porcelain paintings which have been produced at the Sèvres manufactory. These are half-length portraits of the size of life, each painted on a single slab of porcelain. They are copies of the well-known portraits by Winterhalter, and were executed by order of Louis Philippe, and presented to her Majesty. These works were commenced before the revolution of 1848, but not finished until after that event. Louis Philippe claimed them as his private property, and they were surrendered to him by the Republican Government; but the portrait of Prince Albert had met with an accident, by which it was broken. Louis Philippe desired to have another made, but the Queen would not hear of this expense being incurred; and the fracture being repaired at Sèvres, the portraits were sent to England and delivered to her Majesty. The portrait of her Majesty is by A. Ducluzeau, and that of Prince Albert by A. Bezanget.

Among the splendid collections of paintings and vases exhibited by the national manufactory of Sèvres, at the Great Exhibition, the most valuable and most worthy of attention and examination were the following:—

The painting of the Virgin, known as the *Vierge au Voile*, by Madame Ducluzeau, was copied from the celebrated picture by Raffaelle in the Louvre. The porcelain is of the same magnitude as the original, and measures 26 inches by 19. This work was executed in 1847-8, price 1000*l*. Another painting after Tintoretto, on a plate of porcelain 45 inches high, by Madame Ducluzeau, price 880*l*. A flower subject on a plate of porcelain, 40 inches high, by M. Jacober, 800*l*. A portrait of President Richardeau, by M. Beranger, 440*l*. A portrait of Vandyck, by Madame Ducluzeau, 280*l*. A painting on a plate of porcelain, eight inches high, reduced from Raffaelle's "Madonna," by M. Constantin, 100*l*.

Fig. 43.—BAKING ROOM IN PORCELAIN WORKS.

THE POTTER'S ART.

CHAPTER V.

1. Process of throwing.—2. Turning.—3. Moulding.—4. Turning and Moulding combined.—5. Glazing.—6. Bisque firing.—7. Ovens.—8. Sèvres ovens.—9. Statistics of pottery.

1. The brief explanation of some of the processes by which the beautiful productions of this branch of industry are obtained, which have been given in the preceding pages, will be easily understood by all persons who may have had the pleasure and advantage of visiting any of the great porcelain-works. For the benefit of those who have not been so fortunate, we shall here give some more developed explanations of the succession of processes by which the raw clay is converted into the finished article; in doing which we shall avail ourselves of some admirably executed sketches, showing the interior of some of the principal workshops of a porcelain factory, which were prepared under the direction of the late M. Brongniart, director of the Royal porcelain works of Sèvres, and executed by Mr. Charles Develey, an artist

employed in the establishment, who possessed, according to M. Brongniart, in a high degree, the talent of seizing with the greatest truth and exactitude the characteristic habits of each class of operatives, and their peculiar attitudes and movements in the execution of their work.

It will be remembered that the materials out of which the potter produces the articles of his fabrication are 1° kaolin, or china clay, and 2° flints. The former ingredient, as has been already explained, is prepared by the clay merchant in Cornwall, or whatever other place the clay is found, and is delivered to the potter ready to be mixed with the flint earth. But the latter is prepared from the natural flints in the potteries by the following process:—

The flint stones are first calcined, and this is effected in a kiln similar to that used for lime-burning. These stones are separated by alternate layers of coal, and the burning usually occupies about twenty-four hours. The flints are then very white and very brittle, and ready to be crushed by the "stamper," a machine composed of upright shafts of wood, six feet long, and about eight inches square, heavily loaded with iron at the lower end, which, by means of applied power, are made to rise and fall in succession on the flints, contained in a strong grated box. It is then removed to the grinding vats, which are from twelve to fourteen feet in diameter, and four feet deep, paved with chert stone, large blocks of which, being also worked round by arms connected with a central vertical shaft, propelled by an engine, become a powerful grinding medium. This peculiar stone is used because of its chemical affinity to the flint, which, therefore, suffers no deterioration from the mixture of the abraded particles, which necessarily results from the friction, a matter of serious moment. In these vats the flint is ground in water until it attains the consistency of thick cream, when it is drawn off and conveyed by troughs into the washing chamber. Here it undergoes a further purification; more water is added, and it is kept in a state of gentle agitation, by means of revolving arms of wood, thus keeping the finer particles in suspension while the liquid is again drawn away in pipes to a tank below. The sediment is afterwards re-ground. The cleansing process is not yet complete, for when the fluid has passed into these tanks, to about half their depth, they are filled up with water, which is repeatedly changed, until it is considered sufficiently fine, and free from all foreign matters: it is then fit for use.

The next process consists in mixing the clay with the flint. This is accomplished by mixing both with water, so as to give them a creamy consistency, and to convert them into what the potters technically call *slip*. For this purpose the two slips, that of clay and that of flint, are successively run off into the blending reservoir, against the inner side of which are "gauging rods," by which the necessary proportion of each material is regulated. The mixture is now passed into other reservoirs, through fine sieves on "lawns," woven of silk, and containing 300 threads to the square inch. A pint of slip of Dorsetshire or Devonshire clay weighs 24 ounces, of proper consistence; of Cornish clay 26 ounces; and of flint 32 ounces. Finally, the slip is conveyed to a series of large open kilns, heated underneath by means of flues, and about 9 inches deep. The excessive moisture is thus evaporated, and in about twenty-four hours the mixture becomes tolerably firm in substance. It is then cut into large blocks and conveyed to an adjoining building to undergo the process of "milling." The mill is in the form of a hollow cone, inverted, with a square aperture or tube at the lower part. In the centre is a vertical shaft, set with broad knives. When this shaft is in action (worked by steam power), the soft clay is thrown in, and forced downwards, being alternately cut and pressed until it exudes from the aperture at the bottom, in a perfectly plastic state, and ready for the hand of the potter.*

The paste thus prepared would serve for the purposes of manufacture, but it is found that it may be considerably improved by leaving it for an interval, more or less protracted, several years for example, stored in damp vaults or cellars. It suffers a sort of *rotting*, becomes black, and evolves an offensive odour of the gas called sulphuretted hydrogen. These effects are easily explained. The paste, as prepared, always contains a proportion, however minute, of organic matter, which the previous preparation has failed to extricate from it. This matter by the influence of the humid air, undergoes a spontaneous combustion, and acting upon some traces of sulphates, which also remain as unextricated impurities in the paste, transforms them into sulphurets, and accordingly sulphuretted hydrogen is evolved.

The utility of all these processes, by which the minutest particles of organic matter are disengaged from the dough, will be understood when it is considered that even the presence of a single hair in the dough would be sufficient to spoil completely an article of porcelain of great beauty and value; for the organic matter thus buried in the material being decomposed by the action of the ovens, a gas would be developed which would produce air-bubbles or even cracks in the article.

To work the paste, when ready for the manufacture, it is once

* Catalogue of the Great Exhibition, p. 718.

more tempered by the potter, who for that purpose divides it into balls of convenient size, which he *slaps* with great force upon his table. The last air-bubbles are expelled from the dough by this process.

The formation of the dough into the fabricated article is effected, either by the processes of *throwing* and *turning* on the wheel, or by moulding, the latter being effected either by *pressure* or by *casting.*

The process of forming the article on the potter's wheel has been briefly explained in a former chapter. It will be more clearly comprehended by the aid of M. Develey's sketch of the thrower and turner's shop, represented in fig. 28 at the head of Chapter III.

A ball of dough is given to the thrower, A, of sufficient magnitude for the piece intended to be made. He places it on the centre of the circular plaster disc, which is attached to the top of his wheel, and which revolves with the wheel. By the dexterous application of his hands and fingers, the ball of dough passing through a succession of forms assumes ultimately that which is desired.

Some idea may be formed of this most ancient and characteristic operation of the potter's art by the aid of the diagrams, fig. 29 to fig. 34.

Let it be supposed that the shape of the vase to be formed is that represented in fig. 29. It will then be produced in two

Fig. 29.

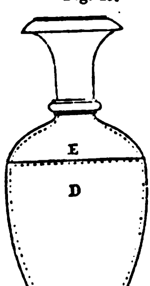


Fig. 30.

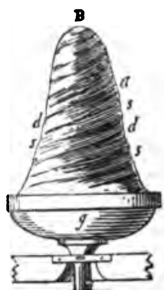


Fig. 31.

separate pieces, D and E, which after being formed on the wheel must be united and attached one to another by that general cement of the potter called SLIP.

A ball of dough, B, fig. 30, sufficient to produce the lower part D, fig. 29, being placed on the wheel and put in rotation, is shaped by the hands and fingers of the thrower, assuming successively the forms, C, fig. 31, and D, fig. 32, the shape of the hollow part or interior being indicated by the dotted line. The traces of the fingers appear in the spiral lines, *d s*. The circular disc forming the top of the wheel is represented at *g*.

The ball of dough, A, fig. 33, after similar manipulation, takes the form, E, fig. 34. The parts D and E being united, the superfluous part of the dough is turned off so as to give the desired form to the external surface.

Fig. 32.

D

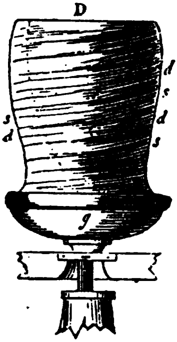


Fig. 33.

A

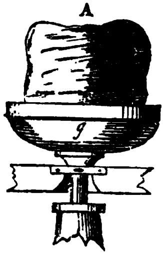
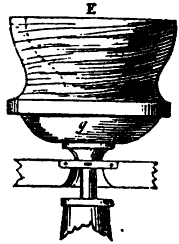


Fig. 34.

E



The peculiar attitude of the arms of the thrower, which is well represented in fig. 28, will be observed to bear a close resemblance to that represented in the ancient Egyptian drawing, fig. 5.

2. When the *thrown ware*, as it is called, which is thus produced, has been rendered sufficiently consistent by spontaneous air drying, it is transferred to the hands of the turner, who is represented at B, fig. 28, and who works at a wheel similar to the ordinary potter's wheel. This operative, by means of a cutting tool, renders the form of the article more exact and true, and shaves off all roughness and inequalities by a process precisely similar to that of turning with the ordinary lathe, only that in the present case the axis of the lathe is vertical, and the circular motion imparted to the article horizontal. The shavings which are detached in this process are mixed with fresh paste, to which they impart peculiar qualities.

Various tools and accessories appear in the figure, such as the gauge compasses, calipers, *c*, by which the diameter of the vase at different points is measured, the working drawing, *d*, which gives him both the profile and the dimensions, the latter being from time to time verified with the calipers.

3. The moulder's shop is represented in fig. 35, at the head of Chap. IV.

The work of the moulder consists of two processes; *first*, to impart the desired form to the piece; and *secondly*, to adapt and attach to the principal piece its various accessories, which are separately moulded or cast, such as handles, spouts, ears, &c.

The operative, A, places on a marble slab before which he stands a mass of dough which he flattens with a rolling-pin. Each end of the pin rests upon a lath by which it is prevented from pressing the dough below a certain thickness, and which also gives it a perfectly even motion, so that the cake of dough is not only of uniform thickness, but has also a perfectly even and uniform surface. This uniformity of surface on the under side it receives by pressure on the slab, and on the upper side by the regulated action of the roller.

Under the cake of dough, and between it and the slab, is previously spread a cloth, *b*, upon which it rests. By means of this cloth the operative is enabled to raise the dough from the slab without deranging its form.

The operative, B, having received it from A, thus supported by the cloth *b*, places it upon the mould, which, as here represented, will produce the inner or concave surface of a vase or cup, having a sort of fluted form. When the mould is completely covered with the dough, the operative, C, presses the dough strongly upon it with a sponge, so as to force it into exact contact with the most minute cavities of the mould. To accomplish this the more easily, the mould is placed upon the circular slab, *p*, supported on a vertical pillar, *f*, with which it turns freely, so that every side of the article to be moulded is brought successively under the hand of the operative.

Plates, dishes, and saucers, and in general the class of articles denominated "flat ware," are made from moulds, by which the inside or concave surface of the article is formed. The form is imparted to the convex surface by means of profiles usually made of fired clay and glazed. After the proper convex form is given by the turner C by means of the profile, the mould, with the article still upon it, is taken to the hot-air chamber, where it remains till it is tolerably dry. It is then brought back to the turner C, and the profile is again passed over it, by which the inaccuracies of form consequent upon shrinkage are corrected.

The operative, G, has just moulded or cast a handle from which he is removing the superfluous and excrescent parts with a tool, and cleaning out its cavities. He is about to attach it to the vase, as he has already done with the other handle. This he accomplishes by moistening, with the creamy liquid called *slip*, the surfaces to be united. This slip acts as a cement, becoming almost immediately hard enough to retain the handle in its place.

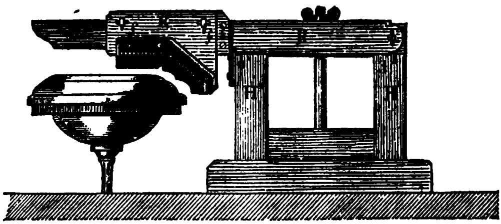
A number of handles ready moulded or cast are lying on the slab beside G, ready to be attached to similar articles. Various plaster moulds appear on the floor near the table.

The convex surface of the article to be moulded is produced in like manner, by pressing a concave mould upon it. Some of these concave moulds appear on the floor.

The process of moulding by casting has been explained in the case of statuary porcelain.

4. The operations of the thrower and moulder are sometimes abridged by combining them. The apparatus represented in fig. 36 supplies an example of this.

Fig. 36.



It consists of a porte-calibre, K, and a copper bar, RR′, which plays on a hinge or pivot, at one extremity, and is supported on a frame, HH′, of wood solidly attached to the table of the wheel. It is raised and lowered by turning it on the hinge, *t*, and when lowered is supported on the upright H′ at *t′*. The porte-calibre slides on this, its motion being regulated by a groove. To this is attached by screws the "calibre," or profile, *c*, which is formed to correspond with the shape and mouldings of the article to be produced.

The mould which gives the form to one side of the article, (suppose for example the concave or upper surface of a plate,) being attached to the disc of the potter's wheel, a cake of dough of the proper magnitude and thickness is laid over it, and pressed upon it by a wet sponge, so as to cause it to apply itself closely at every part to the surface of the mould. When this is accomplished the calibre or profile is lowered gradually upon it, and the wheel being put in revolution, the convex side or bottom of the plate receives its form in the same manner as an object placed in the chuck of a turner's lathe is shaped by a cutting tool guided by a slide-rest.

By this process the article receives a perfectly uniform thickness and diameter, the edges being subsequently rounded on the wheel in the usual way.

5. Ware which has received its proper forms by the processes above described and which has been to a certain degree hardened by air drying or exposure to a high artificial temperature, is in what is called by potters the *green* state. It is completely dry, all moisture being perfectly expelled from it, but is still very porous, so that it would readily imbibe water or other liquid which might be poured into it, or in which it might be immersed. It is in this state that the process of glazing, already described, must be executed.

The materials comprised in the various glazes commonly used for china and earthenware are—Cornish stone, flint, white lead, glass, whiting, &c. These, having been ground together in proper proportions to the consistence of milk, form the glaze. The process is effected in large buildings termed "dipping-houses" (china and earthenware being kept separate), fitted up with tubs for the glaze, and stages for the reception of the ware when dipped, upon which it is dried and heated, generally by means of a large iron stove or "cockle," from which iron pipes, extending in various directions, convey the heat throughout the whole extent of the "houses." Each dipper is provided with a tub of glaze, in which he immerses the bisque ware. We may note the results of practice and experience in imparting a facility and dexterity of handling, so necessary to perfection in this process. The ware is held so that as small a portion as possible shall be covered by the fingers; it is then plunged in the glaze, which, by a dexterous jerk, is made not only to cover the entire piece, but, at the same time, so disperses it, that an equal and level portion is disposed over the whole surface, which, being porous, imbibes and retains it. The ware is handed to the dipper by a boy, and another removes it when dipped to the drying or "hot-house." The glaze is opaque till fired, so that the design of pattern executed on the bisque is completely hid, after dipping, till they have been submitted to the glost fire. An able workman will dip about seven hundred dozen plates in a day.*

The dipping house is represented in fig. 37. The dippers, A, and B, immerse unglazed plates in the vessel containing the glaze, which, as already explained, is a creamy liquid in which the vitrifiable matter is mixed, and held in suspension, just as mud is in water. When the plate is withdrawn from the glaze it is held over it so as to allow all the liquid not absorbed by the plate to drip off, as represented in the case of the dipper B.

* Catalogue of the Great Exhibition, 725.

The females C and D are employed in detaching from articles which have been dipped the parts of the glaze which are redundant. Thus C scrapes off, with a bladed tool, a portion of the glaze where it is too thick, or where it remains attached to the surface in round drops called *tears*. The other, D, removes with a brush or a piece of felt the glaze from the circular ring at the bottom of a plate, that being the part on which it stands when placed in the oven. If this precaution were not taken, the plate would

Fig. 37.

adhere to the oven by means of the portion of glaze on this circular edge when vitrified.

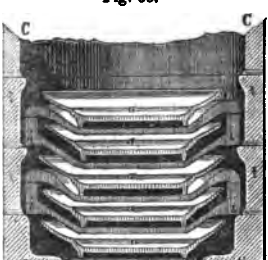
When the articles are thus prepared, they are put into an oven where they are exposed to a temperature which vitrifies the glaze upon their surface.

It is necessary that the glaze thus applied to the article should be such as will vitrify at a temperature lower than that which would soften the paste of which the article is made, and thus deform the article itself.

In the figure are seen several tools and utensils used in the process of glazing. Thus *g* is the wooden grating upon which the article is left to drip after being withdrawn from the glaze; *t* is a sieve which is used to strain off any solid impurities which may be seen floating in the glaze; *p* is the spatula used from time to time to agitate the glaze so as to prevent the pulverulent matter suspended in it from subsiding, and to maintain it of an uniform consistency. A bottle, *b*, contains vinegar, which is mixed in a certain proportion with the glaze; a small cup, *c*, containing liquid glaze is placed near the female D, who dipping a brush in it retouches all parts of the article on which the glaze is too thin or altogether wanting.

6. When the wares have been prepared for the final process of baking, which is called technically *bisque firing*, they are carried on boards as represented in fig. 43, to the "green-house," so called from its being the receptacle for ware in the "green" or unfired state. It is here gradually dried for the ovens: when ready, it is carried to the "sagger-house," in immediate connexion with the oven in which it is to be fired, and here it is placed in the "saggers:" these are boxes made of a peculiar kind of clay (a native marl), previously fired, and infusible at the heat required for the ware, and of form suited to the articles they are to contain. A little dry pounded flint is scattered between them, to prevent adhesion. The purpose of the sagger is to protect the ware from the flames and smoke, and also for its security from breakage, as in the clay state it is exceedingly brittle, and when dry, or what is called "white," requires great care in the handling. A plate sagger will hold twenty plates, placed one on the other, of earthen ware; but china plates are fired separately in "setters" made of their respective forms. The "setters" for china plates and dishes answer the same purpose as the "saggers," and are made of the same clay. They take in one dish or plate each, and are "reared" in the oven in "bungs" one on the other.

Fig. 38.



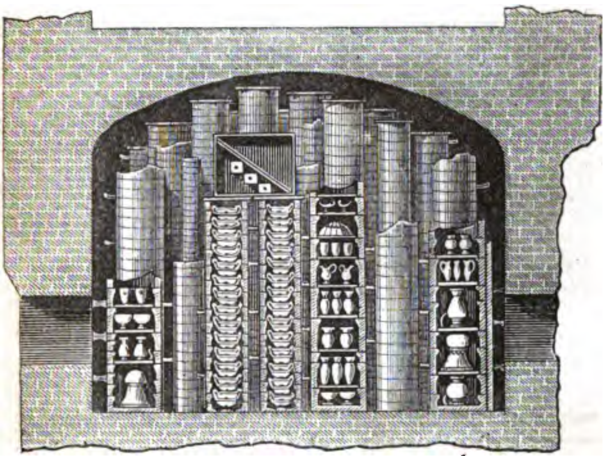
In fig. 38 is represented a pile of saggers containing plates. It will be perceived that in this case each sagger consists of two parts, one, *t t*, cylindrical, and the other, *i i*, having a form corresponding to that of the plate, the rim, at the bottom of which rests upon it. These saggers are placed one over the other, so as to form a vertical pile.

It will be evident, from what has been here explained, that the magnitude, form, and internal structure of the saggers must vary with those of the articles which they are intended to contain.

The disposition and arrangement of the piles of saggers in the oven are represented in fig. 39, some of the piles being represented in section, to show the arrangement of the articles within the saggers.

The process of baking highly decorated ornamental articles in porcelain is a process requiring much greater precaution, and a

Fig. 39.



different sort of apparatus. It is usually effected by means of special furnaces and saggers, of which an example is presented in fig. 40. The furnace is constructed in fire-clay or cast-iron, and the fire is regulated in it with the greatest care. Trial pieces are from time to time taken from the opening, *v*, by which the effect of the firing on the several colours is ascertained.

7. The hovels in which the ovens are built form a very peculiar and striking feature of the pottery towns, and forcibly arrest the attention and excite the surprise of the stranger, resembling as they closely do a succession of gigantic bee-hives. They are constructed of bricks, about 40 feet diameter, and 35 feet high, with an aperture at the top for the escape of the smoke. The "ovens" are of a similar form, about 22 feet diameter, and from 18 to 21 feet high, heated by fire-places, or "mouths," about nine in number, built externally around them. Flues in connection with these converge under the bottom of the oven to a central opening,

drawing the flames to this point, where they enter the oven: other flues, termed "bags," pass up the internal sides to the height of about four feet, thus conveying the flames to the upper part.

Fig. 40.

When "setting in" the oven, the firemen enter by an opening in the side, carrying the saggers with the ware placed as described: these are piled one upon another from bottom to top of the oven, care being taken to arrange them so that they may receive the heat (which varies in different parts) most suited to the articles they contain. This being continued till the oven is filled, the aperture is then bricked up: the firing of earthenware bisque continues sixty hours, and of china forty-eight.

The quantity of coals necessary for a "bisque" oven is from 16 to 20 tons; for a "glost" oven from 4½ to 6 tons.

The ware is allowed to cool for two days, when it is drawn in the state technically termed "biscuit," or bisque, and is then ready for "glazing," except when required for printing, or a common style of painting, both of which processes are done on the "bisque" prior to being "glazed."

8. A porcelain oven of three stages, used in the Sèvres manufactory, is represented in fig. 41 and fig. 42, the former being the exterior view, and the latter a vertical section by a plane through its centre. Each of the lower stages, L and L′, is heated by four furnaces, from which the flame and heated air is drawn into the oven through the flues *g*. Fire-doors of plate-iron are provided, by which the mouths of the furnaces and ashpits can be closed or opened at pleasure.

When the several stages of the ovens are charged with the wares to be baked, the firing is conducted so as to raise the temperature by slow and regulated gradation. The fires, at first moderate in their force, are constantly augmented for from sixteen to twenty hours. When the oven is thus well heated, the great firing is commenced by giving full charges of fuel to all the furnaces. The oven itself, which is cylindrical below, terminating in a conical roof with an opening at top, governed by a regulating plate or damper, *t*, discharges the functions of a chimney, so that the currents of flame and heated air drawn from the furnaces severally entering the oven, circulate around the ware with

Fig. 41.

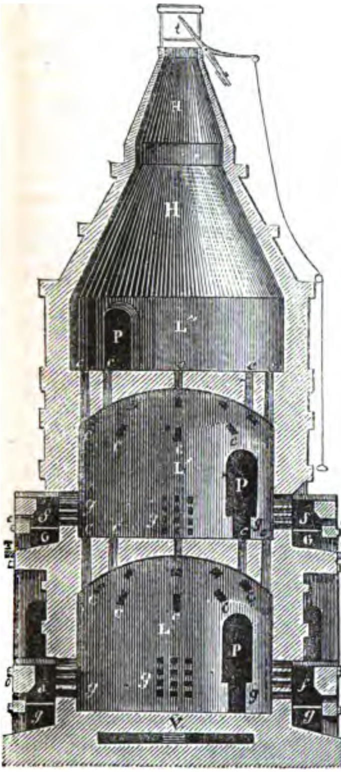
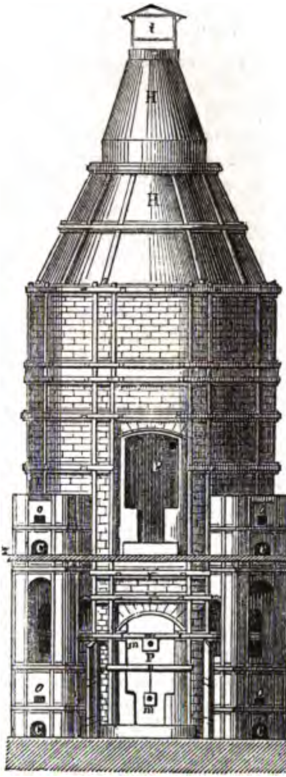


Fig. 42.



which it is charged, and rising to the conical roof, H H, escape at the opening *t*. The current passes from stage to stage through orifices, *c*, *c*, *c*, formed in the flooring for that purpose.

The great firing which completes the process of baking is maintained for ten or twelve hours.

The oven is built with fire-bricks, bound by bracings of iron, as represented in fig. 41. In each stage there is provided a door, P, through which the charge and discharge is made, and which during the process of baking is walled up with brickwork. In this brickwork small holes, *m m*, are left, through which the oven-man from time to time takes out trial-pieces, which are pieces of clay of known quality, and which indicate by the effect produced upon them the progress which the baking has made. When the appearance of these trial-pieces shows that the firing has been sufficiently continued, the furnace and ashpit doors and the damper *t* are closed, and the oven, with its charge, is left to cool gradually for twenty-four or thirty hours. It is not necessary to delay the withdrawing of the pieces from the oven until they have become quite cold; but the sudden alteration of temperature would occasion them to crack if they were taken out while their heat was greatly above that of the atmosphere.

Some potters are occasionally tempted, when the furnace contains articles of small value, to risk the damage here mentioned, and to withdraw the saggers with their contents without delay, their object being to profit by the heat of the furnace either for introducing a new charge, or for drying a fresh set of saggers. No one, however, would be so improvident as to expose the finer descriptions of porcelain to this hazard, in order to gain any such immaterial advantage.

From the similarity of its appearance to well-baked ship bread, the ware is now called *biscuit*. Its permeability to water when in this state fits it for being employed in cooling liquids. If previously soaked in water, the gradual evaporation from its surface by means of the air, causes an absorption of heat from the surrounding atmosphere, which is again supplied by neighbouring objects, until an equilibrium of temperature is restored.

9. As there are no excise or other regulations affecting the manufacture of earthenware, there are no official documents or records by which the actual extent of the manufacture can be ascertained with precision; but it is estimated that at the Potteries alone the value of the earthenware produced annually is about 1,700000*l*., and that the value of the manufactures of Worcester, Derby, and other parts of the country, may amount to about 750000*l*., making a total annual value of 2,450000*l*.

The value of the gold consumed annually at the Potteries in the ornamentation of porcelain is 36400*l*., and, since about half that amount is consumed in the other seats of the manufacture, it may be stated that the total value of the gold used annually in England in this manufacture is about 54600*l*.

The quantity of coals consumed annually at the Potteries is 468000 tons, and, about half that amount being consumed in other factories, it may be stated at about 700000 tons—an amount equal to what is consumed in working all the railways of the United Kingdom.*

* See Lardner's Railway Economy, p. 83.

It appears from the official reports that, in 1841—the latest year in which official returns have been made public—the declared value of the earthenware exported was 600759*l.*; in 1837 the declared value was 563238*l.* In the four years ending 1841, an increase, therefore, took place in this export trade of 37521*l.* upon 563238*l.* If this same rate of increase only has been maintained since 1841, the present annual export trade must have a declared value of a million sterling.

But, since the declared is known to be on an average one-fourth less than the true value, we may assume that the present total annual amount of the export trade in earthenware is about 1,300000*l.*

The proportion in which this enormous export is distributed among the different countries of the world is exhibited in the following table. In the second column is given the proportion of every 100*l.* value exported received by each of the countries named in the first column, and in the third column is given the number of pieces of ware out of 10000 received by each country respectively:—

Countries.	Per Cent. of the total Value.	Per 10000 of Number of Pieces.
United States	37·58	3560
North American British colonies	6·95	778
Brazil	6·36	1010
British East Indies	5·00	310
British West Indies	4·42	387
German States	4·28	401
Holland	4·11	397
Foreign West Indies	3·50	396
Australian colonies	2·69	216
Denmark	2·31	257
Italy and Italian islands	2·25	145
Sumatra, Java, and Indian islands	1·39	168
Spain and the Balearic islands	1·08	145
Western Africa	0·85	73
Cape of Good Hope	0·79	64
Channel Islands	0·69	65
Turkey	0·67	55
Russia	0·65	40
All other countries	14·43	1533
Total	100·00	10000

It appears from this table that the United States is our great foreign customer for this manufacture, taking in value 37½ per cent., and in quantity 35½ per cent., of our entire export. Of the remainder, our North American colonies, Brazil, and India, take 18 per cent.

In 1841, our export in this manufacture formed about 30 per cent. of its estimated total value. We have no returns later, but it is probable that at present the export forms a much larger proportion of the entire value fabricated.

COMMON THINGS.

FIRE.

1. Fire an ancient element.—2. Combustion.—3. Fuel.—4. Carbon.—5. Hydrogen.—6. Charcoal fire.—7. Its effect on the air.—8. Experimental illustration of combustion of charcoal.—9. Combustion of hydrogen.—10. How the combustion is continued.—11. Carbon burns without flame.—12. What is flame?—13. Combustion of hydrogen produces water—14. All combustibles produce carbonic acid and water.—15. Carburetted hydrogen.—16. Carbon renders flame white.—17. Olefiant gas.—18. Light carburetted hydrogen.—19. Fire-damp.—20. Will-'o-the-Wisp.—21. Experimental illustration.—22. Heavy carburetted hydrogen.—23. Pit-coal—24. Coal-fire explained.—25. Products of its combustion.—26. Its effect on the air.—27. Wood-fuel.—28. Combustibles used for illumination.—29. Their effect on the air.—30. Construction of grates and chimneys.—31. Analysis of a common coal-fire.—32. It warms and ventilates.—33. Necessity for ventilation.—34. Injurious effect of plants at night.—35. Effect of crowded and brilliantly lighted rooms.—36. Explanation of the burning of a candle.—37. And of lamps.

1. In the physical theory which prevailed among the ancients, and which maintained its ground for several thousand years, Fire was accounted as one of the elements; that is to say, as a material

essence, which with three others, air, water, and earth, constituted all natural bodies.

It was only towards the close of the last century, and within the lifetime of the elder part of the present generation, that the true character of fire was discovered.

2. It is now known that fire is neither a distinct substance nor essence, as supposed by the ancients. It is a phenomenon consisting of the sudden and abundant evolution of heat and light produced when a certain class of bodies called COMBUSTIBLES enter into chemical combination with the oxygen gas which, as has been explained in our Tract on Air, constitutes one of the constituents of the atmosphere. The term COMBUSTION in the modern nomenclature of physics has been adopted to express this phenomenon.

3. The class of combustible substances which are commonly used for the production of artificial heat is called FUEL. Such, for example, are pit coal, charcoal, and wood.

Another class of combustibles is used for the production of artificial light: such, for example, are oil, wax, and the gas extracted from certain sorts of pit coal, from oil, and from certain sorts of wood, such as the pitch pine.

4. The principal constituents of all these combustibles, whether used for the production of heat or light, are those denominated by chemists CARBON and HYDROGEN.

CARBON is the name given to charcoal when it is absolutely pure, which it never is as it is obtained by the ordinary industrial processes. It is in that state combined with various heterogeneous and incombustible substances. In the laboratories of chemists it is separated from these, and obtained in a state of perfect purity, being there distinguished from the charcoal of commerce by the name CARBON.

Carbon having never been resolved by any chemical agent into other constituents, is classed in physics as a simple and elementary body, which enters largely into the composition of a most numerous class of bodies which are found in nature, or produced in the processes of industry, the sciences, and the arts.

5. HYDROGEN has been already very fully described and explained in our Tract upon Water; we shall presently explain still more in detail its leading properties. Like carbon, it is classed as a simple and elementary substance; and also, like carbon, enters largely into the composition of a numerous class of bodies.

6. A quantity of charcoal being placed in a furnace through which a draught of air is maintained, if a part of it be heated to redness, the entire mass will soon become incandescent, and will emit a reddish light, which will be whiter as the air is passed through it more briskly, and will emit considerable heat. The charcoal will gradually decrease in quantity, and at length will

disappear altogether from the furnace, under which a small portion of ashes consisting of incombustible matter will remain. If the charcoal had been pure—that is, if it had been carbon—it would have altogether disappeared, no ash whatever remaining.

This phenomenon is an example of FIRE. The heat and light developed during the process here described are commonly called fire.

7. To comprehend what takes place in this process, we must consider that, as the air passes through the charcoal, the oxygen gas, which forms one-fifth part of it,* enters into combination with the pure carbon. A compound is thus formed consisting of carbon and oxygen. The formation of this compound is attended with so great a production of heat, that not only the compound itself, but the charcoal, from which it is evolved, is raised to a very elevated temperature.

The compound thus produced is a gas called carbonic acid, which has been already briefly noticed in our Tract on Air.

The air which enters the furnace being a mixture of azote and oxygen,* that which rises from it after the combustion has been produced is a mixture of azote and carbonic acid; the azote having passed through the furnace without suffering other change than an increase of temperature, while the oxygen has been converted into highly heated carbonic acid.

Several questions, however, arise out of this explanation. How is it known that such combination really takes place between the carbon and oxygen? If it do, in what proportion do they combine? How does it appear that the azote, which forms four-fifths of the air which passes through the furnace issues unaltered?

8. To supply satisfactory answers to these questions, it is only necessary to bring the two constituents of common air separately into the presence of carbon under the conditions necessary to favour combination, and to ascertain their weights before and after the development of the phenomena.

Fig. 1.

Let a glass flask containing sixteen grains of oxygen gas be inverted over mercury, as represented in fig. 1, and let a piece of carbon weighing more than six grains, supported in a platinum spoon, be introduced into it by means of a piece of bent platinum wire; let the sun's rays, concentrated by means of a burning-glass, be then directed upon the carbon through the glass flask. The carbon will be ignited by the solar heat, and will burn in the oxygen with great splendour.

* See Tract on Air.

When the combustion has ceased and the gas contained in the flask has cooled, it will be found that the mercury in the neck of the flask will stand at exactly the same elevation as it did before the combustion. The gas contained in the flask has therefore the same volume as before, nevertheless it is easy to show that it is by no means the same gas.

In the first place, if it be weighed, it will be found to weigh 22 instead of 16 grains; and if the unburned residue of the carbon be weighed, its weight will be found to be 6 grains less than it was before the experiment. The inference is, that 6 grains of the carbon have combined with the 16 grains of the oxygen previously contained in the flask, but that in thus combining, the carbon has not made any change in the volume of the gas.

If the gas contained in the flask be examined by the usual tests, it will immediately appear that it is no longer oxygen. No combustible will burn in it, and it will not support life by respiration. In fine, it will be found to be identical with the noxious gas called choke-damp, and to possess all the chemical characters of the gas called CARBONIC ACID.

If the same flask, similarly filled with nitrogen gas or azote,* be submitted to a like experiment, the result will not be the same. The solar rays concentrated on the charcoal will still render it red hot, but it will not burn nor undergo any other change. On removing the focus of solar rays from it, it will become gradually cool, and when removed from the flask will have the same weight as when introduced into it. The azote which fills the flask will also be found to be unaltered.

It follows, therefore, that the FIRE produced when carbon burns in common air is nothing more than the heat and light developed in the formation of carbonic acid, by the combination of the carbon with the oxygen of the surrounding air, and that these substances combine in the proportion of 6 parts by weight of carbon to 16 of oxygen.†

9. It has been already shown‡ that hydrogen combines with oxygen in the proportion of 1 part by weight of the former to 8 of the latter to form water, and that if the combination be formed in a pure or nearly pure atmosphere of the gases it is instantaneous and accompanied by an explosion. If, however, the combination take place, as it may, in common air, the phenomena will be very different.

If pure hydrogen, compressed in a bladder or other reservoir, be allowed to issue from a small aperture, a light applied to it

* See Tract on Air.

† More precisely 6·04 or 6·12 of carbon to 16 of oxygen.

‡ See Tract on Water.

will cause it to be inflamed. It burns tranquilly without explosion, producing a pale yellowish flame and very feeble light, but intense heat. This is the effect attending the gradual and continual combination of the hydrogen, as it escapes from the aperture, with the oxygen of the surrounding air. It may be asked why the hydrogen issuing from the aperture does not combine with the oxygen of the air without the application of a flame to it? And also, why being once inflamed by the application of such a body, its continued application becomes unnecessary?

These questions are easily resolved. The hydrogen gas has an affinity or attraction for oxygen, which is not strong enough to cause their combination at common temperatures, but when the temperature of the hydrogen is greatly elevated, its attraction for the oxygen becomes so exalted, that it enters into instant and spontaneous combination with it. Now by applying the flame of a lamp or candle, or any other burning body, to the jet of hydrogen, its temperature becomes so greatly raised, and its attraction for oxygen consequently so exalted, that it enters directly into combination with the oxygen of the air which is in immediate contact with it at the moment.

10. But it is also asked, How the continuance of the combination and the consequent maintenance of the flame takes place—the candle or lamp which produced its commencement being withdrawn? This is explained by the great quantity of heat produced by the combination of the hydrogen with the oxygen. The commencement of the combination being produced by the candle or lamp, the hydrogen and oxygen themselves in the act of combining develop an intense heat, and the succeeding portion of hydrogen gas being in contact with them becomes heated and combines like the former with a fresh portion of oxygen. In the same manner, the heat developed by these being shared by the succeeding portion of gas, a further combination and development of heat takes place, and so on. Thus the combustion being once commenced, the heat necessary for its maintenance and continuance is developed in the process itself, which accordingly goes on without the necessity of being again kindled by the application of any flame.

The continuance of the combustion of carbon, whether in pure oxygen gas or in common air, is explained in the same manner.

11. The combustion of carbon differs from that of hydrogen in this, that the former takes place without the production of *flame.* The charcoal being heated to redness, and still in the solid form, enters directly into combination with the oxygen of the surrounding air, and the carbonic acid which is formed being a gas which is not

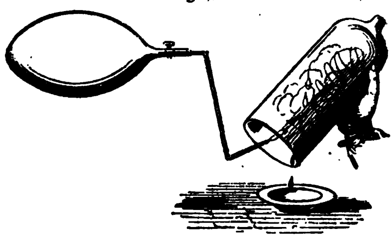
luminous nor visible, the carbon disappears. But in the case of hydrogen, the heat produced by the combustion is so intense as to render the gas itself luminous, just as intense heat will render a mass of iron red hot or white hot. When gas becomes thus luminous it is called *flame*.

12. Flame, therefore, must be understood to be nothing more than matter in the aëriform, gaseous, or vaporous state, rendered so intensely hot as to be incandescent, and to emit light, just as would a bar of iron taken from a furnace.

13. It is easy to show that, comformably with what has been already demonstrated in our Tract on Water, the product of the combustion of hydrogen is the vapour of water, which by exposure to cold can be reduced to the liquid state.

If a glass jar be held over a jet of inflamed hydrogen, as represented in fig. 2, the aqueous vapour formed by the combination of the hydrogen with the oxygen of the surrounding air, will be condensed upon the inside of the jar, and will appear first as a cloudy dew upon it, and, as the process is continued, it will increase in quantity, and, trickling down the side of the jar, may be received in drops by a dish placed beneath it.

Fig. 2.



14. As we have stated above, the principal constituents of every species of combustible, whether used for heating or lighting, are carbon and hydrogen, and the products of their combustion are therefore carbonic acid and water, the latter being evolved in the form of vapour.

15. It happens, however, rarely that the hydrogen is evolved in the pure state. It is more generally combined with a certain dose of carbon, forming a compound gas called CARBURETTED HYDROGEN. This gas burns with a much whiter and more luminous flame than that of pure hydrogen, and it is therefore much better fitted for the purpose of illumination.

16. That the flame owes its whiteness and illuminating power to the carbon with which the gas is charged, is proved by the fact,

that the more carbon the gas is charged with the whiter and brighter is the flame.

17. There are two sorts of carburetted hydrogen, one of which contains twice as much carbon as the other: the one called light carburetted or proto-carburetted hydrogen, and the other heavy carburetted or bi-carburetted hydrogen, or olefiant gas.

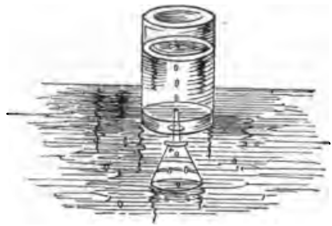
18. In light carburetted hydrogen 6 parts, or more exactly 6·12 parts by weight of carbon are combined with 2 of hydrogen, and heavy carburetted hydrogen contains twice that proportion of carbon.

Light carburetted hydrogen is a little more than half the weight of its own bulk of common air. When pure it has no odour; and it burns with a yellowish flame much more luminous than that of pure hydrogen. Like pure hydrogen it forms a highly explosive mixture when combined in a certain proportion with common air, or, more properly, with the oxygen of common air, since the azote has no influence on the phenomenon.

19. It is this gas which, under the name of FIRE-DAMP, produces occasionally such disastrous explosions in coal mines. Being contained in large quantities in the fissures and interstices of the seams of coal, it issues from them in the workings of the mines, and being one half lighter than common air, it first collects at the top of the working. After a certain time, by a common property of all gases, it mixes with the air, and attains occasionally that proportion which renders it explosive. If a light be brought into it in this state an explosion takes place, producing those destructive consequences to the operatives who happen at the moment to be present, with the details of which the public has been so often rendered familiar.

20. This gas is also that which over marshy ground and stagnant pools produces the appearance called WILL O' THE WISP, JACK O' LANTHORN, or ignis fatuus. The gas is produced by the decomposition of vegetable and animal matter, and rising from the ground or from the water is spontaneously ignited.

Fig. 3.



21. It is easy to verify this by actually collecting the gas from any stagnant pool. For this purpose, take a common funnel used for decanting liquors, and a bottle or beer glass; immerse the latter in the water, and, when it is filled, invert it under the water and raise it above the surface, keeping the mouth under the water. Then bring the inverted funnel under its mouth, the neck entering the bottle or glass; agitate the funnel, and the gas

will rise from the water in bubbles and will collect in the upper part of the bottle or glass.

The manner of performing this experiment is shown in fig. 3.

When the gas is thus collected its inflammable nature may be ascertained by applying a light to it as it issues from the bottle.

22. Heavy carburetted hydrogen burns with a much whiter and more luminous flame. Its weight is very nearly equal to that of common air, and, therefore, nearly double that of the light carburetted hydrogen; hence it has acquired the epithet "heavy."

The products of the combustion of both sorts of carburetted hydrogen are carbonic acid and water, the former proceeding from the combination of the carbon, and the latter from that of the hydrogen with the oxygen of the air.

These points being understood it will be easy to render intelligble the effects which are developed in all ordinary cases in which FIRE or COMBUSTION takes place.

23. The species of combustible used as fuel with which we are most familiar in this country is PIT COAL.

This mineral, exclusive of some extraneous and incombustible ingredients which it contains in very small proportions, consists of carbon and carburetted hydrogen of both kinds.

The proportion of carbon varies in different sorts of coal from 80 to 90 per cent., the hydrogen varying from 3 to 6 per cent., and the remainder consisting of oxygen and azote.

In the heavy coal of Wales, called anthracite, the proportion of carbon is above 90 per cent., while that of the hydrogenous gases is only 3 or 4 per cent. In the bituminous coal of Northumberland the proportion of carbon is about 87 per cent., and that of hydrogen from 5 to 6 per cent.

24. When a fire composed of such fuel is properly kindled and supplied with a draught of air necessary to sustain the combustion, the carbon will continue to combine with its proper proportion of oxygen, producing the corresponding quantity of heated carbonic acid, and rendering the solid part of the fuel red and luminous; and the hydrogenous gases will at the same time combine with their respective proportions of oxygen, producing carbonic acid and watery vapour, and rendering the gases as they issue from the fuel luminous, or, what is the same, converting them into flame.

The flame will be faintly luminous and bluish if any part of the gases be pure hydrogen, it will be yellowish and a little more luminous if they be light carburetted hydrogen, and it will be very white and very luminous if they be heavy carburetted hydrogen.

Thus all the phenomena exhibited by a common coal-fire,—the red unflaming fuel—the faint blue flames occasionally seen,

—and, in fine, the white brilliant flame which most commonly issues from the fissures of the coal, are severally explained and accounted for.

25. It has been shown that in combustion 6 parts, by weight, of carbon combine with 16 of oxygen, or, what is the same, 1 part with $2\frac{2}{3}$. It has also been demonstrated, that in the combustion of hydrogen, 1 part by weight of that gas combines with 8 of oxygen. Now by these simple numerical data may be easily explained the effects of a common coal-fire upon the air which feeds and sustains it.

26. It is thus found, that in burning 10 lb. of coal the oxygen contained in 1551 cubic feet of air is altogether absorbed.

To keep the atmosphere of a room in which a fire of such coal is burned fresh and pure, it would be, therefore, necessary to supply fresh air at the rate of 155 cubic feet for every pound of coal which is burned.*

27. Wood is a combustible generally used for the production of artificial heat in countries where coal is not so cheap and abundant as in England. This fuel, like coal, consists principally of carbon and hydrogen in various proportions, according to the sort of wood. All kinds of wood contain also a proportion of oxygen, as a constituent, much greater than is found in coal.

Wood, when green, contains a considerable proportion of water. In the combustion of such wood, a large proportion of the heat developed is absorbed in the evaporation of this water, and is, therefore, lost for heating purposes. Wood used as fuel should, therefore, be kept until this water, or the chief part of it, has been evaporated. For the same reason wood kept for fuel should be as little exposed to moisture or damp as possible.

28. All fatty, oily, and waxy substances are combustible, whether in the liquid or solid state. They consist of the same constituents as coal and wood, but combined somewhat differently, and in different proportions. Most of this class, burning with flame of more or less brilliancy, are used for the purposes of artificial illumination.

Whale, sperm, olive, and cocoa-nut oils, wax, spermaceti, and tallow are examples of this class of combustibles.

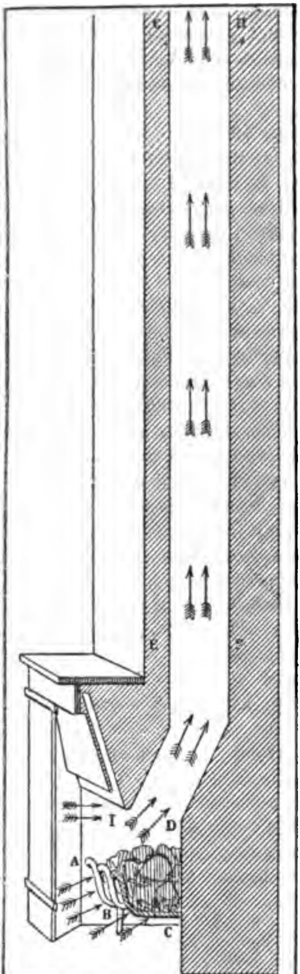
29. Whatever be the sort of combustible, or whatever be the purpose to which it is applied, whether for heating or lighting, it will be evident from the explanations which have been here given, that the combustion cannot be maintained with the necessary

* In the preceding explanation we have omitted to take into account the effect of a small proportion of oxygen which enters into the composition of coal. This, however, is so insignificant, that it would be needless to complicate the calculation by introducing it.

activity unless expedients be provided for the supply of the quantity of oxygen which must enter into combination with it.

30. The construction of grates, stoves, and chimneys is therefore designed to attain this end by causing such a volume of common air to pass through the fuel as is necessary and sufficient to combine with it. The more air which thus passes through the fuel, the more rapid and abundant will be the combination, and the more active and vivid the combustion.

Fig. 4.



31. The current of air which passes through a common grate is produced by the draught of the chimney. The column of air included in the chimney, being raised to a higher temperature than that of the external air, is rarefied and lighter, bulk for bulk, than the external air, and is proportionately more buoyant. It has therefore a tendency to ascend like that which oil would have in water. As it ascends the air from the room must rush in to fill its place. A part of this air will pass through the bottom and front of the grate, and a part will enter at the opening of the fire-place over the grate. This will be more easily understood by fig. 4. The front of the grate is A B, and the bottom B C, having the ash-pit below it. The opening over the grate is A I, and E F G H is the flue of the chimney. The ascensional force of the column of air in the flue is measured by the difference between its weight and that of an equal volume of the external air. The air which replaces that which ascends in the flue enters the bottom B C, the front B A of the grate and the

opening A I above it, as indicated by the arrows. The former portions, passing through the burning fuel, supply to it the oxygen gas necessary to combine with it, and thus maintain the combustion. These portions after passing through the interstices of the fuel, and after the oxygen or a part of it, has combined with the fuel, issue from the top of the fuel, being then a mixture of azote, such portion of oxygen as may not have combined with the fuel, carbonic acid and aqueous vapour, the latter being the products of the combination of the oxygen with the carbon and the hydrogen of the fuel.

All these gases issuing from the burning fuel at a high temperature, and mixing with the cold air which enters the chimney through the opening A I, render the column of air in the flue so warm as to give it the buoyancy necessary to sustain the draught.

When the fire is first kindled in the grate, if the air in the chimney have the same temperature as the external air, it will have no buoyancy, and there will be no draught. In this case the chimney will generally be found to smoke. This inconvenience may be sometimes removed by opening the windows, so as to fill the room with air as cold as the external air, and therefore colder than the air in the chimney. If, however, this be found insufficient, the air in the flue may be warmed and the necessary draught produced by holding under the chimney any blazing combustible.

The draught through the grate may be greatly increased in intensity by stopping up, either partially or completely, the opening A I. By this expedient, all the air necessary to replace that which ascends in the chimney must pass through the fuel in the grate. If the magnitude of the opening be for example three times the magnitude of the front and bottom of the grate, four times as much air will thus pass through the fuel as would pass through it when the opening AF is not closed, supposing the draught in the chimney to be the same in both cases.

But, in fact, the draught in the chimney will be greatly augmented by this process; for, so long as the opening A I is not closed, the air which fills the chimney will consist of a mixture of that which passes through the burning fuel, which is raised to a high temperature, and the much larger portion which passes into the chimney through the opening A I, and which, being cold, lowers the temperature, and therefore diminishes the buoyancy of the air in the chimney. But when all the air which passes through A I, by closing that opening, is made to pass through the burning fuel, it is raised to a high temperature, which not being lowered by admixture with any air not passing through the fuel, fills the chimney with air raised to a very elevated temperature, and which therefore produces in the chimney a much stronger upward current.

Thus the effect of closing the opening A I is to stimulate the fire not only by causing to pass through it all the air which previously entered the opening A I, but also by augmenting the draught in the chimney.

32. From what has been explained above, it will be perceived that an open fireplace such as is represented in fig. 4 serves the double purpose of warming and ventilating.

All the air which enters the chimney, whether it passes through the grate or through the opening above the grate, must be replaced by an equal volume of fresh air from without, which must find its way through the interstices of doors and windows, or through other openings provided expressly for its admission. That part of the air which passes through the grate subserves the double purpose of warming and ventilation. It warms by stimulating and maintaining the combustion of the fuel, and it ventilates by leaving in the room a void into which an equal volume of fresh air must enter. That portion of air which enters the chimney through the opening above the grate has no effect direct or indirect in warming, but its effect in ventilating is just so much greater than that of the air which passes through the grate, as the magnitude of the opening above the grate is greater than the magnitude of the spaces between the bars in the front and bottom of the grate.

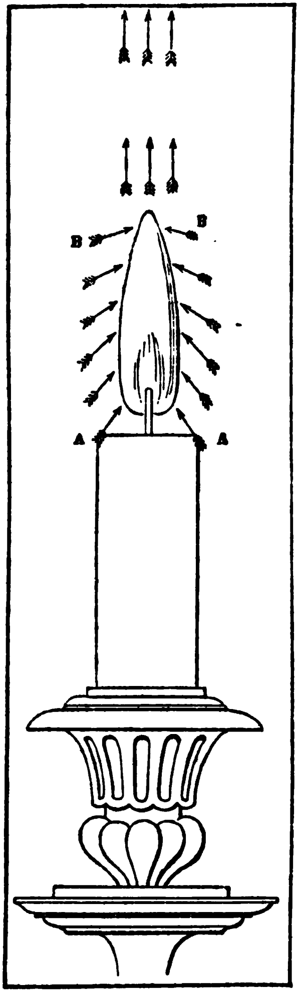
33. The necessity for ventilation is so much the greater as the room is smaller and lower, and as the causes of the pollution of its air are more numerous and active. The air of a room is deprived of its oxygen and rendered unfit for respiration by several causes. Each person who is present in the room absorbs oxygen by respiration. It is calculated that an adult of average size absorbs about a cubic foot of oxygen per hour by respiration, and consequently renders five cubic feet of air unfit for breathing. It is also computed that two wax or sperm candles absorb as much oxygen as an adult. It follows, therefore, that to keep the air of a room pure, five cubic feet for every person, and two and a half cubic feet for every candle in the room should pass per hour into the chimney, or through some other opening, and an equal volume of fresh air should be admitted.

34. Plants give out oxygen by day, but absorb it by night. Their presence in a room by day is therefore innocuous, but at night they have the effect of polluting the air, and should never be admitted except where there are ample means of ventilation.

35. A crowded room, illuminated with many candles and lamps, and, as generally happens, without a fire, soon becomes filled with air in which there is a deficient proportion of oxygen and a

corresponding volume of carbonic acid, unless means be provided, which is rarely the case, for other ventilation besides that of the chimney. Hence it arises that persons of delicate habits, especially those whose lungs are defective, in such a room, soon become sensible of general uneasiness, and are often affected with headache.

Fig. 5.



36. The manner in which the flame of lamps and candles is produced and maintained will require some explanation.

When a candle is lighted, the heat developed at the extremity of the wick melts the wax or tallow immediately below it, and thus liquefied, it is drawn up through the insterstices of the wick by the force called capillary attraction. When it comes in contact with the flame, it boils, and is converted into vapour, which rises over the wick. This vapour having a very high temperature, and exercising a strong attraction for the oxygen of the surrounding air, enters into combination with it, and becoming luminous, forms the flame around and above the wick. Within the flame arises a constant current of the vapour of the combustible, and outside it currents of air carry to the surface of the flame the oxygen which produces the combustion and the light. The combustible vapour and the oxygen meeting at the surface of the flame, there enter into combination, and the vapour burns. Within the flame no combustion takes place, and no light is produced.

In fig. 5 the wick and flame are represented. Within the flame currents of combustible vapour proceed from the wick to all parts of the surface of the flame. The arrows at the sides of the flame outside its surface represent the currents of the surrounding air produced by the heat of the flame; the oxygen, being attracted by the intensely heated combustible vapour, approaches it, and, by combining with it, sustains the combustion and produces the light. The arrows above the flame indicate the current of heated air, carbonic acid and aqueous vapour, the products of the combustion which form an ascending column above the flame.

It will be apparent from what has been here stated, that the luminous part of the flame is merely superficial. The vapour within the surface of the flame not having yet come into contact with the oxygen, and therefore not having entered into combustion, cannot be luminous. The flame, therefore, so far as relates to light, is hollow, or rather it is a column of combustible vapour, the surface being the only part which burns, and therefore the only part which is luminous. As this vapour ascends from the interior of the flame, it comes successively into contact with the oxygen of the air, is burnt, and becomes luminous, the column of light gradually contracting in diameter until it is reduced to a point. The flame thus tapers to a point until all the vapour produced by the boiling matter on the wick receives its due complement of oxygen, and passes off. It speedily loses that high temperature which renders it luminous, and the flame terminates.

37. In lamps of various construction, expedients are adopted to increase the magnitude of the luminous surface of the flame, and the intensity of the combustion. This is effected by modifying the form and magnitude of the wick, by feeding it with an abundant supply of oil, and by maintaining strong currents of air at all parts of its surface to sustain the combustion.

The most common form of wick used for lamps of strong illuminating power, is that of a hollow cylinder, varying from an inch to three inches in circumference. This wick being attached at its base to a small thin ring of metal is let down into the reservoir of oil, through a space included between two concentric tubes, one of which has a less diameter than the other, the space between them being a little wider than the thickness of the wick. The wick is from two and a half to three inches long, and descends through this space between the tubes to a certain depth. This space communicates with the reservoir of oil from which the oil is forced up either by the action of a pump worked by a main spring, through the intervention of wheelwork, as in the Carcel lamp, or by the more direct action of a strong spiral spring as in the Moderator lamp, or by the pressure of oil contained in a reservoir above the level of the wick, as in the old English ring-lamp called the Sinumbral lamp, and a variety of other forms constructed on the like principle.

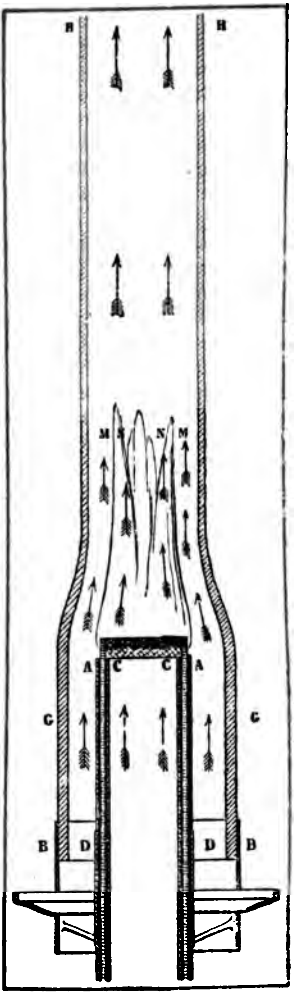
The flame issuing from such a wick is obviously a hollow cylinder, and requires to be fed with air, both at its exterior and interior surfaces. A current of air in contact with the interior surface of the flame is maintained by carrying the lesser of the two tubes between which the wick is included, down through the burner, and leaving it in communication with the external air. The exterior of the flame is exposed to the air and produces currents by its own heat, in the same manner as the currents already described, surrounding the flame of a candle.

But in the case of lamps with cylindrical burners these currents, both exterior and interior, are greatly augmented in intensity by the addition of a cylindrical glass-chimney of considerable height, the inner diameter of which a little exceeds the exterior diameter of the wick. This chimney being open at its base, and confining a column of air of its own height, acts upon the combustion of the lamp exactly as a common chimney acts on the combustion of fuel in a grate. The air which enters at the bottom, between this chimney and the burner, rises in a cylindrical current around the exterior of the wick, and passing in contact with the exterior surface of the combustible vapour proceeding from the oil, ignites it at that surface. The column of air which ascends at the same time through the inner tube passing in contact with the inner surface of the vapour ignites it in like manner. In this manner, a thin cylinder of oily vapour rising from the wick is kept in a state of vivid and constant combustion, both on its interior and exterior surfaces.

The force of these currents, exterior and interior, depends on the buoyancy of the column of air included in the chimney, and which also extends to a considerable height above it. The air after passing the flame of the lamp, being at a very high temperature, the glass-chimney itself becomes intensely hot. The column of air within the chimney being thus heated, it ascends to a considerable height above the chimney before it is cooled down to the temperature of the surrounding air. The force of the draught which maintains the currents around the flame is then determined by the difference between the weight of the column of air, extending from the base of the chimney to that height above it, at which the temperature of the ascending column becomes equal to that of the external air, and the weight of an equal volume of the external air.

This explanation of the combustion of the oil in a cylindrical burner will be more clearly comprehended by reference to fig. 6, where C C represents the interior, and A A the exterior tube, between which the wick is included. The oil is forced up to the wick in the space between these tubes; G H G H is the chimney, open at the base B B. The air ascends as indicated by the arrows between G H and D A, and passes in contact with the external surface of the flame, and it rises through the internal tube C C, passing in contact with the internal surface of the flame, as indicated by the arrows. The cylindrical flame, ascending from the wick, is represented at A M C N, and the course of the ascending column in the chimney is represented by arrows.

Fig. 6.



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LONDON, *August*, 1856.

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The Chinese Rebel Chief, Hung-Siu-Tsuen,

AND THE ORIGIN OF THE INSURRECTION IN CHINA.

By the Rev. THEODORE HAMBERG. Edited, with an Introduction, by GEORGE PEARSE, Foreign Secretary of the Chinese Evangelization Society. Foolscap 8vo., 1*s*. 6*d*. cloth.

The *Friend of China* contains a review of this narrative, which is attributed to the Bishop of Victoria, Hong Kong, and in which he says—"The author's well known caution, truthfulness, and candour, give to the little volume under review an interest and a reality which we miss while perusing the flighty groundless theories and statements hazarded in such works as those by MM. YVAN and CALLERY. . . . The author had with him in his own house a prominent agent in the events narrated, and kinsman of the Insurgent Chief.

Mr. Meadows, Chinese Interpreter in H.M. Civil Service, who accompanied the Hermes in her visit to the Rebel Chiefs at Nanking, thus speaks of this narrative in his new work, *The Chinese and their Rebellions*—

"This [the fact just mentioned in the preceding paragraph] is one of the many incidental proofs of the truthfulness of Mr. HAMBERG's informant."—p. 86.

And again, "This passage, I may remark in passing, is one of the strongest proofs of the truthfulness and general accuracy of the narrative in Mr. HAMBERG's book." —p. 103.