X

THE PHYSICAL SYSTEM OF THE UNIVERSE

AN OUTLINE OF PHYSIOGRAPHY

"All are but parts of one stupendous whole."

By SYDNEY B. J. SKERTCHLY, F.G.S.
H.M. GEOLOGICAL SURVEY

LONDON
DALDY, ISBISTER & CO.
56, LUDGATE HILL
1878

LONDON:
PRINTED BY VIRTUE AND CO., LIMITED,
CITY ROAD.

TO

ALFRED TYLOR, F.L.S., F.G.S.

WHO LED ME INTO THE RANKS OF SCIENCE

This Work

IS AFFECTIONATELY INSCRIBED

PREFACE.

Some years ago, while engaged in the preparation of a little Manual of Physical Geography, which, like other works of the kind, dealt with the chief phenomena of the earth in a direct and simple manner, the impression deepened on me that this was hardly the best method of treating the subject. It seemed to me that one was apt thus to lose sight of the simplicity of the great scheme of nature in mere multiplicity of detail, and to ignore the prime principle enunciated long years ago, that "no man liveth unto himself"—a principle as applicable to inanimate as to animate nature.

I subsequently delivered before the Charterhouse College for Science Teachers a lecture, in which I endeavoured to embody the principle that the earth is an integral part of the universe, and that its past and present conditions result from the action of heat upon matter in its different states. This view was further elaborated in a series of short papers published in the "Fenland Meteorological Circular" for

1874, under the title of "The Mechanism of the Globe."

The Department of Science and Art having also recently become impressed with the inexpediency of teaching Earth-lore as a chaotic assemblage of isolated facts, inaugurated a new subject for examination under the title of *Physiography*—a term which has long been a household word among geologists.

Meanwhile this little book was gathering shape. It embodies the thought and studies of several years, and, so far as I know, is the first attempt of its kind.

Of course, it must be imperfect, for no man can be an expert in all those sciences which are but one science. I trust, however, that no glaring error disfigures its pages.

One point causes me some uneasiness. It has been impossible, within the limits of a small work, to render credit in all cases where credit is due; and this I feel especially in regard to the noble work of our American brethren. These omissions, though necessary, are not wilful, and I feel certain that the magnanimity of science on both sides of the Atlantic will acquit me of any desire to hide the lustre of original research.

S. B. J. S.

H.M. Geological Survey.
May 8th, 1878.

CONTENTS.

CHAPTER I.

INTRODUCTION.

CHAPTER II.

MATTER AND MOTION.

CHAPTER III.

LIGHT AND ITS REVELATIONS.

CHAPTER IV.

THE SIDEREAL SYSTEM.

CHAPTER V.

THE SOLAR SYSTEM.

GRAVITATION, ETC.

CHAPTER VI.

THE SOLAR SYSTEM (*continued*).

METEORS.

CHAPTER IX.

THE EARTH'S INTERNAL HEAT.

CHAPTER X.

EFFECTS OF INTERNAL HEAT.

CHAPTER XI.

THE EARTH'S EXTERNAL HEAT.

CHAPTER XII.

EFFECTS OF THE EARTH'S EXTERNAL HEAT—EARTH SCULPTURE.

CHAPTER XIII.

CLIMATE.

CHAPTER XIV.

LIFE.

CHAPTER XV.

THE PAST AND THE FUTURE—THE NEBULAR HYPOTHESIS, ETC.

CHAPTER I.

INTRODUCTION.

What the World is.—The man who carried a brick about as a specimen of the house he had to sell did not deserve to be treated with the scorn he is represented to have suffered. Indeed, the proceeding showed a certain amount of wisdom, inasmuch as he recognised the fact that from a brick some notion of a house could be formed. It was the old adage of *ex pede Herculem* in another form. Bricks may be types of cities—pebbles of worlds.

Ever since the astounding discoveries of astronomy have been brought home to the minds of man, the infinite insignificance of the world has been the theme alike of scientific men and popular writers. A drop of water in the ocean, a grain of sand upon the shore, a moment in the lapse of eternity: such have been the similes employed to impress upon us with overwhelming force a due sense of the littleness of the orb which constitutes our home; and it is true. Terrestrial measurements are but as a point compared with celestial distances; and, in fact, they are so treated by astronomers when the fixed stars are under observation. It was necessary to impress this fact upon the mind, because, in ages not long past, the world was deemed the central, most important, and largest body in the visible universe; and, with the rise of more exact knowledge, such misleading ideas called for a sturdy rooting out.

It is, however, often forgotten that this comparative insignificance is merely a mathematical one. From a physical point of view it is absolutely false; and, as we shall presently see, the world is a type of the solar system; that system is a type of the stellar universe. The world is a brick in the solar house; that house an unit in the stellar city.

This volume is in one sense a manual of Physical Geography, but it differs from other works in attempting to knit the phenomena of the globe into a coherent train of reasoning. Physical geography is too often degraded into a sort of scientific curiosity shop, in which there is a vast collection of isolated facts respecting astronomy, geology, physics, biology, and what not, without the slightest attempt at grouping them to show how interdependent they are one upon the other. In this way it is as impossible to learn what the world is and how it works, as it would be to draw and illustrate the working of a steam-engine from an examination of a quantity of loose bolts, pipes, and cog-wheels.

Yet this knowledge can be expressed in a single sentence: *the past and present conditions of the globe* *depend upon the action of heat upon solid, liquid, and gaseous matter.* And this without reservation of any kind. The first mapping out of our orb, with all its subsequent series of geological changes; the present configuration of the surface; the rude sculpturing of continents and mountains, and the delicate modelling of the scarred surfaces; the winds and tides and ocean currents; climate and weather; the beauty of cloud-form; the life of plants and animals, and their distribution also, depend upon this simple law, which it is the object of this volume to expound. Nor is this true of the earth only, for it seems that the planets, the comets, the sun, the stars, and the nebulæ are equally under its influence; and thus the earth is a type of the universe.

Let us throw our knowledge into a few terse sentences to show that the earth is a typical portion of, and not an isolated fragment in, the universe.

1. The earth consists of matter.
2. This matter is obedient to the force of gravity.
3. The sun and other orbs are shown by the spectroscope to consist of the same kinds of matter as the earth.
4. The motions of the planets, of nebulæ, and of double stars show that they too are obedient to the force of gravity.

Hence we are justified in looking upon our earth as something more than an atom in immensity, for we see that by a study of its properties we can acquire a knowledge of the properties of the heavenly bodies. But we can go further, and show that the earth is intimately connected with those bodies.

5. The inter-planetary and inter-stellar regions are not void, but are filled with a highly elastic medium whose vibrations influence us as light, heat, chemical action, and perhaps as electricity and magnetism also.

Hence *there is no emptiness in the universe.* This highly important fact shows us how the earth is linked, as it were, to the most distant orb by bands as visible to the mental eye as is the grossest chain to physical vision.

6. It is highly probable that all the members of the universe are moving: satellites around planets, planets around suns, suns in systems, systems in galaxies, sweeping onwards in as yet unknown paths in ever-growing richness, to end—where?
7. It is equally probable that each molecule of matter is in a state of vibration, in the earth and elsewhere.

Hence we arrive at the conclusion that *there is nothing at rest in the universe.* Again, we see in the earth a trustworthy fragment of that restless fulness we call the stellar universe; which, for aught we can tell, may itself be but a satellite of systems, foiling comprehension in their magnitude, which make up the immensity of space.

We now know what the earth is in relation to other heavenly bodies, and that we must not look upon it altogether as the insignificant orb that it is often represented to be; for, although in size it falls short of most of the heavenly bodies, it is nevertheless part and parcel of the great scheme which is limited to us only by those unfathomed star-depths which our most powerful telescopes fail to sound.

Proceeding with our terse statements, we can readily say what the earth is of itself.

8. The world is an orb whose surface at least is solid. It is partly covered with water, and entirely immersed in a gaseous atmosphere. It revolves upon itself, and travels in an almost circular path about the sun.
9. The surface of the earth receives heat from internal and external sources. The internal sources vividly manifest themselves in volcanoes, hot springs, &c.; but the almost unnoticed stores of heat which influence the earth as a whole are, perhaps, more important. The external sources are the sun, and in a much smaller degree the other heavenly bodies.
10. The latter of these sources is comparatively steady in its supply.

11. The heat from the former source is being continually dissipated into space.

From this last fact we know that *the world is a cooling body.* We have now a very vivid idea of what the world is from two standpoints, yet at the risk of being deemed prolix we will condense these eleven statements into two.

First. The same forces act upon the same kinds of matter throughout the visible universe.

Second. The world is a cooling planet, whose solid surface is covered partly by a liquid ocean, and entirely by a gaseous atmosphere. This surface receives heat from internal and external sources.

How the World works.—We are now in a position to try and find out *how the world works.* Imagine, in the first place, the world stripped of its oceanic and atmospheric envelopes, and without any irregularities of surface. What would happen? Clearly such a globe would be under the influence of the same forces as at present, but their action would not be modified by water or air. The earth would revolve upon its axis, circle round the sun, and otherwise behave much as we are accustomed to witness.

The sun's rays would, however, fall with unalleviated fierceness upon the rocks by day, rendering them exceedingly hot. The heat thus acquired would radiate into space very rapidly, and soon after sunset intense cold would set in. There would be no medium between baking heat and freezing cold. The rocks would expand a little under the influence of heat by day, and shrink during the bitter nights; but this action would be almost inappreciable as affecting the shape of the globe. The sun would shine with intolerable radiance in a jet black, star-studded sky.

But how about the internal heat of the earth itself? We know that this is diminishing: in other words, that the earth is cooling, and this action would go on with enhanced speed owing to the absence of any radiation-checking envelopes. With this phase of the question, however, we have nothing to do, as our orb is in a purely imaginary state of nudity, being stripped to enable us the more readily to grasp the following important, because real, effect of the secular cooling. *A cooling body is of necessity a* CONTRACTING *body.* If the earth were made of perfectly homogeneous materials, and there were no disturbing forces, the contraction would take place with perfect regularity, and the shape of the globe would remain unchanged. But these conditions do not, and probably never did, obtain; hence the earth contracts irregularly, and the result is that the shape is not that of a perfect sphere, but has a very uneven surface. The irregularities measured from the highest to the lowest points do not exceed 11 miles; and, as the circumference of the globe is about 25,000 miles, they are very slight in comparison with the size of the earth, being only about as 1 is to 2,272. On a globe 3 feet in diameter they would only represent elevations of about $\frac{1}{20}$th of an inch. Nevertheless, to us these tiny crumplings are of the utmost importance, for they represent the heights of mountains and the depths of oceans. In fact, it is primarily due to the contraction of the cooling globe that its surface is diversified with upraised and depressed areas.

Nor must it be supposed that the irregularities once formed were fixed for ever: the contraction has been going on through all the vast periods of geological time, and is still in action, and the steps in the process are ever marked with variation. Hence once-elevated portions are depressed, and low-lying districts thrust up; and so the motion goes on. The solid framework is as unstable, viewed on a grand scale, as it was of old imagined to be firm. This gives us a new idea of the world, and we must look upon it as a slowly heaving, seething mass; and thus we have learned the first process of the mode in which the world works.

We purposely stripped the earth of its water and air, because, living as we do upon the land, there is a tendency to imagine the subterranean forces of nature to act upon the land area only, and this is likely to lead to grave misapprehensions. It is essential that throughout this inquiry we keep the whole world in view, and do not form our opinions upon that small portion of its surface which is uncovered with water, and of which, again, most of us know but a trivial part. Look, then, earnestly upon the world, and, though our lifetime be too short to witness an appreciable movement in the earth's crust, forget that, and turn to the world's lifetime, and see there how rapidly the face of nature changes, how that crust is writhing under the influence of its pent-up force; fix vividly in the mind the throes of this straining planet, and the first great step towards understanding its working is taken.

Now imagine an ocean of the same bulk as the present one to overspread the smooth rocky earth-ball we conjured up. It would as entirely surround it as does the atmosphere (also supposed to be replaced), though its depth would be under a mile. As soon as the upheaving and depressing movements commenced the water would gather itself, or rather be thrust, into the hollows, and thus continent and ocean would be planned out. With every variation in the great features the relative extent of land and water must alter, and we have not the slightest grounds for supposing that the present ratio has obtained in any of the former ages of our earth. This too is important, for there is a tendency to look upon the ratio of land to water as invariable, and upon the sea-level as a datum-line for all time. I do not believe this, for until it can be shown that upheaval and depression are regulated by a law which determines the one to be equal to the other, it is pinning our faith upon the one chance of its always having happened so, and ignoring the infinite chances against such a fortuitous coincidence.

If the earth were destitute of water (liquid or gaseous), but possessed an atmosphere of dry air, the same state of things, so far as heat is concerned, would occur as if air also were wanting; for air is diathermous, that is, it offers no obstacle to the passage of radiant heat and cannot be warmed by it. The lower portions of the atmosphere would, it is true, be warmed by conduction, and in this way: the solar radiant heat streaming through the air would impinge upon the solid rocks and be there converted into sensible heat: in other words, the rocks would be warmed. The heat so acquired would be communicated to the air in contact with the rocks by conduction; these particles would warm those above them, these in their turn would communicate heat to those in superior contact with them, and so on. In this way a greater or less thickness of air would be heated. But radiation would go on unchecked, alike from the warmed rocks and warmed air, and this would limit the temperature and thickness warmed of both rock and air. Soon after sunset both air and rock would rapidly cool, for radiation would speedily rid them of the heat obtained by day, and the intensity of the cold would far exceed anything known to us.

Let us consider the nature of the landscape in this waterless world. It would be one of considerable ruggedness; the upthrown and downcast portions standing out in all their grandeur. Where the rocks had broken with the strain, or, as geologists would say, were faulted, the cliff-like fracture-surfaces would be exhibited in their original ruggedness. The landscape would in all probability possess a singular angularity in its features, and would be totally unlike anything the eye of man has ever rested upon on earth. Notably the plains and swelling hills would be missing; and, save where ashes fell around the volcanic vents whence they were ejected, hardly a curve or softened outline would be seen. Neither would the mountain regions present the cragged aspect which gives to many of them their characteristic grandeur. In place of the beautiful diversity of scenery which we behold on every hand, there would be more or less prismatic areas of elevation and depression, often rising in steps, plateau after plateau.

So soon as water appeared upon the surface all this would begin to change. Let us suppose an ocean suddenly to fill the deepest hollows of this cheerless globe. The sun's rays impinging upon the water would warm it, and an increasing uprising of invisible vapour would take place; in fact, evaporation would immediately commence. The atmosphere would now consist of air and watery vapour, and the latter, being warmable by the sun's heat, would cause an amelioration of the intensity alike of the burning days and frigid nights. The firmamental blackness would give place to a cerulean-tinted sky, in which the stars would be lost to sight by day. The atmosphere, moreover, would be warmed to a considerable height above the surface of the earth. Some of the vapour meeting with the cold air above would condense into clouds. This condensation, especially at night, would in places result in the precipitation of rain and snow, and thus the surface of the land would begin to receive water.

Most of the water thus received by the land would again evaporate: some would soak into the ground, and some would flow down the slopes on the surface, and thus streams and lakes would begin to form.

From the moment water was received upon the land the unpicturesque formality of the rocks would begin to be modelled into diversified and beautiful forms. The flowing water would wear away the rocks, the frost would shatter them, ice would grind them; and in this way, in the course of ages, have been formed all the features of the landscape with which we are familiar. Even the craggy mountains owe their aspect to these agencies of rain and frost and rivers. The worn material transported by the streams, and carried down in solution, would be deposited in the beds of lakes and seas, and thus would arise the great subdivision of rocks known as sedimentary. These, being elevated now and again by the internal forces, would form more or less perfect plains to be fretted into rounded hill and valley by the silent agency of water.

The coast lines would be worn by the waves and currents which impinged upon them, and beaches be formed, and indeed the whole aspect of the globe would become such as we now see it.

In all probability there never was such a waterless globe as we have pictured; but we can best understand how much we owe to the presence of that material by thus imagining the state of an earth devoid of it, and the results which would follow from its introduction. There is nothing illusory in this description, and we can see in our satellite, the moon, much such a state of things; for if there be any water there, as recent researches seem to show, it is very small in quantity. We thus see how much the habitability of our globe is dependent upon the action of heat upon water in its different aspects of liquid water, solid ice and snow, and gaseous cloud and vapour.

Again, let us imagine a waterless, perfectly smooth globe surrounded by air. We should have the frigid, temperate, and torrid zones as usual. The air heated to excess in the torrid zone would rise to the upper regions of the atmosphere, and flow away towards the colder regions of the north and south as upper currents, and at the same time the cooler air of the temperate zones would flow in towards the equator. Owing to the rotation of the earth from west to east, these winds would not blow directly north and south; but the warm upper currents would be deflected towards the west, and the cooler currents towards the east: these latter would, in fact, form the N.E. and S.E. trade-winds. There is, however, one peculiarity about the course of the winds that has not yet been satisfactorily explained. This is that heated air rising from the equatorial region and flowing towards the north pole in a north-easterly direction, instead of continuing as part of an upper current all the way, sinks down near the tropics and thence travels northwards as part of a surface wind with a still more westerly trend than at first. Indeed, from the poles to the tropics we have a north and south region of prevailing westerly winds, about the tropics there are belts of calms, within the tropical zones the N.E. and S.E. trade-winds blow, and about the equator we have another belt of calms. Nevertheless the point we are now aiming at is clear—namely, that the chief course of the winds is determined by the heat of the sun.

Let us now suppose an universal ocean to cover the earth. The winds impinging upon the waters will give rise to a series of currents, corresponding in direction with the winds, with a great equatorial current flowing round the world caused by the meeting of the trade-winds.

Now this distribution of the winds and ocean currents is just what takes place at present, only the uniformity is broken by the continents, which prevent the free flow alike of air and water. Moreover, the general distribution of the rainfall follows the same system: in the regions of the variable westerly winds we have variable and light rains, in the districts of the trade-winds we have regular and heavier rains, and in the calm belt of the equator rain falls nearly every day. Once more we see how great is the influence of solar heat.

Nor is the influence of the sun confined to such palpable effects as those just described. We know that the face of that luminary presents at times a spotted appearance, and that there is a more or less regular periodicity about these spots, or, in other words, at certain times they are more frequent than others. Now it is found that in those years in which sun spots are most frequent, auroras, those brilliant meteoric displays with which all readers of arctic travels are familiar, are most plentiful; and at the same time certain movements of the magnetic needle are also most pronounced.

Every one knows that the earth revolves upon its axis and at the same time circles about the sun. The axis of revolution, however, is not perpendicular to the plain of the path of the earth about the sun, and in consequence of the inclination, the phenomena of the seasons are brought about. The orbit or path in which the earth travels round the sun is not quite circular, but elliptical, and the sun occupies one of the foci of the ellipse and not the centre. Hence the earth is nearer the sun in some parts of its course than at others. At present the earth is nearest the sun when it is winter in the northern hemisphere, and the winter half is shorter by about seven days than the summer half of the [year. It is chiefly owing to this arrangement that the climate is what it is. Geology teaches us that the present climatal aspect of the globe has not always prevailed: it assures us, for instance, that the northern hemisphere has been very much colder than now, and it points out with equal force that the severity of the arctic regions has been so ameliorated that the far north has supported such warmth-loving beings as corals and palms. Without entering into details we may observe that recent researches in astronomy and physics have given us the clue to this alternation of warm and cold periods. Briefly stated this result is brought about by the influence of the larger planets, which are constantly pulling at the earth, altering the shape of its orbit, and otherwise influencing it. When the planets are in such positions as to pull the orbit into a much more flattened ellipse than at present, and when at the same time the northern hemisphere, for instance, is turned away from the sun when the earth is farthest from that luminary, a cold period is experienced in the northern, and a warm period in the southern hemisphere. Once more we see how dependent our earth is upon the other heavenly bodies, and it in its turn acts upon them, and so this marvellous mechanism works on ever varying yet ever in harmony.

We have now traced roughly what the world is, and how it works. We have seen that the grand features of the land and ocean basins are the result of the silent action of the pent-up internal heat-force of the earth, and that these areas are constantly though slowly changing. We have learned how all-important water is, acting mechanically in sculpturing the surface into hill and vale, crag and basin, cliff and shore; how vastly it influences the earth through evaporation by tempering the extremes of heat and cold, and through precipitation in the formation of cloud, rain, snow, and ice, forming rivers and what not. We have noticed how the winds and ocean-currents are due directly and indirectly to the action of the sun. We have observed how the sun re-acts upon the earth in governing the occurrence of auroras, and the deflections of the magnetic needle; and finally, we have learned how the variations of climate are due to the influences of the planets and of the sun. By all these phenomena the conviction is forced upon us, that our earth is closely allied in its constitution and working to other heavenly bodies—that it is influenced by and influences them. In fine, that from all but a mathematical point of view, so far from being an insignificant morsel of the universe, it is an essential part thereof, and from its study we can learn much respecting the celestial bodies which would otherwise be hidden from us. The succeeding pages will much more fully illustrate this great fact, and it now only remains for us to show succinctly how much the life of plants and animals is also dependent upon the same great law.

Into the origin of life it is not our province to enter, nor can we deal, save in the barest outline, with the stores of knowledge which geology unfolds on this point. Suffice it to say that in the rocks are entombed the remains of beings whose organisation proves that they were unfitted to live in the areas in which their relics lie, under the conditions of climate which now prevail. For instance, in English rocks we have the remains of animals and plants whose living representatives inhabit the dreary regions of the north, and of others whose homes are in the fervid zones of the tropics. We have learned that climates change from hot to cold, and we can readily understand, for example, how when a cold period was coming on in the northern hemisphere, burying the land in an impenetrable sheet of ice, the animals and plants would be driven gradually southwards. Take plants as an illustration: as the cold increased, their old homes would become unsuited to them, and in more southern regions they would find a congenial habitat. Hence we might expect to find arctic forms invading England at such a time. Now imagine an amelioration of climate: the southern homes would grow too warm for the plants, and they would retreat northwards, and gradually abandon the plains for the cool mountains. This is just what we find, and in no other way can we explain the remarkable fact that the mountain flora of the temperate, and even of the torrid zone, is like that of the arctic lowlands. The plants have, in truth, been flooded out with sunshine and driven to the mountain tops for shelter. Hence we obtain a glimpse of the manner in which life itself is dependent upon the same causes which govern the physical peculiarities of the globe.

We have now briefly sketched the plan of this work, and have proved the truth of our original proposition, that the past and present state of the globe is the result of the action of heat upon solid, liquid, and gaseous matter. It is now our task to take up these questions in detail, and add proof to proof of this great law.

CHAPTER II.

MATTER AND MOTION.

THE term matter, in its scientific meaning, expresses much the same idea as the words things and substances; but it possesses a wider signification, for it includes solids, liquids, and gases both simple and compound, and also that subtle, invisible, almost inappreciable something called ether, whose vibrations affect our senses as heat and light.

Chemists have shown us that the elementary forms of matter are few in number—sixty-six only have hitherto been recognised, three of which have been discovered within the past few months. From these elements are formed all the various forms of matter (ether excepted) known to us in the organic and inorganic worlds. Most of them are composed of more than one element; and, moreover, the majority are true chemical compounds possessing qualities quite distinct from their component elements, comparatively few being mechanical mixtures. Of the former class we may cite water: a colourless, inodorous, tasteless fluid, which is a chemical compound of two invisible gases possessing qualities differing entirely from each other and from their compound. Of the latter class we may take air as an example, it being a mechanical admixture of two gases whose properties it combines in itself.

Chemical elements combine together with very different degrees of readiness: some, as it were, rushing together with explosive violence on being brought in contact with each other; others requiring adventitious aids, such as heat or electricity, to cause them to unite; while yet others seem almost to possess an aversion to each other. Nevertheless, it is found that elements, when they combine, always do so in certain definite proportions, which are constant for each element, and this fact lies at the base of our knowledge of the physical constitution of matter. Our countryman, Dalton, at the beginning of this century, established the law of multiple proportions, above enunciated, and with it advanced a theory which all subsequent research has tended to confirm. He supposed that matter was composed of minute particles, to which he gave the name of *atoms*, and that the weight of these atoms was in the proportion of their combining numbers. Taking hydrogen as the standard, and calling its combining proportion 1, it is found, for instance, that the "atomic weights" of oxygen and iron are respectively 16 and 56. To form the simplest oxide of iron 56 parts by weight of iron must be combined with 16 of oxygen; but the combination of these elements takes place in other proportions also, as, for instance, in the case of magnetic iron ore, in which 112 parts of iron are combined with 48 of oxygen. Now, 112 is twice 56 (the atomic weight of iron), and 48 is thrice 16 (the atomic weight of oxygen); hence we conclude that this substance is formed by the union of two atoms of iron with three of oxygen. The law thus illustrated holds good in every instance, and we legitimately conclude that, so far as chemical union is concerned, matter is not divisible beyond a certain point, and we may define an atom as the smallest possible quantity of an element that can enter into chemical combination. This atomic theory, however, does not teach us directly what are the size and shape of atoms, but future research may enable us to form some idea of even this abstruse question; Dr. Thomson, for instance, has proved that a particle of lead not exceeding the 888,492,000,000,000th of a cubic inch is still visible.

A chemical compound is an union of atoms of different elements. Let us suppose one atom of an element A to be combined with one atom of an element B to form the compound A B, and, for the sake of simplicity, let this compound be a solid. We may break a mass of A B into smaller and smaller fragments until it is reduced to an impalpable powder, yet every particle possesses the property of A B, and not of the elements A and B. In other words, we cannot mechanically break asunder the elements, yet we can be certain that if this division were carried so far that a particle consisted of but one atom of each of the elements A and B no further reduction of size could be effected without severing the chemical bond which united the elements into A B. Such ultimate particles of compounds have received the name of *molecules*,* which may be defined as the smallest quantity of a compound that can exist in a free state. Mr. Tomlinson has made an interesting calculation respecting the size of the molecules of the common substance soap. From the nature of soap, we know that its molecules must contain many atoms of several elements, and unless all these are united the compound ceases to be soap. Every schoolboy knows that it is impossible to blow bubbles with pure water, but that the addition of soap renders the process easy. Now, if we add to water less than 100th of its bulk of soap, bubbles can be blown, and by physical reasoning, which we need not enter into, it can be shown that the thickness of the film of some such bubbles is not greater than a 2,600,000th of an inch. It is evident, therefore, that in such a bubble there must be at least one molecule of soap in each cubic 2,600,000th of an inch; and, as in that quantity 99 parts are water, it follows that a molecule of soap must be less than a 1,757 trillionth (1,757,000,000,000,000,000th) of a cubic inch. When we remember how complex this molecule is,

* They are indeed *compound* molecules, for most elements in a free state consist of two or more atoms, which combination is known as an *elementary* molecule.

we are vividly impressed with the almost infinite littleness of the atoms which constitute the molecule. It is impossible to conceive such minuteness, but the following calculation may assist us. If the population of the globe be taken at 1,000 millions, and every individual had started counting at the rate of ten per second at the moment when the first stone of the Great Pyramid was laid 4,000 years ago, and had continued at the same rate day and night without cessation, so far from having finished counting by this time, they would have to go on for another thousand years before reaching 1,700 trillions!

Here, by a process of reasoning as incontrovertible as it is simple, we have risen to the conception of atoms which have a definite existence, but whose exceeding smallness precludes the possibility of our ever seeing them, for the greatest future extension of our microscopic powers must (from the attendant loss of light) fall very far short of that necessary to render them visible.

There is a fundamental difference between the manner in which the atoms forming a molecule are held together, and that which the molecules forming a mass are united. We cannot separate the atoms of a molecule without destroying or decomposing it; indeed, the very terms themselves indicate this. It is otherwise with molecules, for they can be widely separated without the mass losing its properties. Thus, in the case of ice, we have the aqueous molecules so closely compacted as to be almost incapable of moving one among the other,* but, by the application of moderate heat, we can force them so far asunder as to allow of a free play amongst themselves, and in this state the compound is no longer the solid ice but the liquid water. On still further heating this water we can separate the molecules, so that they move with almost absolute freedom, and we have the gas known as aqueous vapour. So long as the substance retains its solid or liquid form the molecules mutually attract each other, and the force so exerted is termed cohesion; but so soon as the gaseous condition is attained this cohesion is overcome, and the molecules have a tendency to fly apart. This expansive tendency of gases can be illustrated by a simple experiment. Take a tube fitted with an air-tight piston, and let the piston rest three-quarters of the way down the tube. Admit a certain quantity of air beneath the piston and note its density. Now raise the piston to one-half the length of the tube; the air will expand and still fill the space, but, as the same quantity occupies double space, its density will be halved; raise the piston another quarter, and the air will still fill the space beneath, but its density will only be one-third of that at starting; bring the piston to the top of the tube, and the air will fill the tube completely, but it will only have one-fourth its original density. This is true irrespective of the size

* Ice, it is true, is almost unique in occupying a larger space than the water formed by its melting. This is due to the peculiar polar arrangement of the molecules.

of the vessel. The atmosphere may be looked upon as a quantity of gas in a vessel of unlimited dimensions upwards. This gas is prevented from passing right away by the pull which gravity exerts upon it. This pull from below has precisely the same effect as a pressure from above. It is clear that each particle of air is pressed downwards by the air above it. Hence the lower layers of the atmosphere are denser than those above. If another atmosphere, of the same weight, were superposed upon the present one, the density of the air at the surface would be doubled. Thus it is seen that the atmosphere obeys the law above enunciated, which law is named from its discoverer, Boyle's Law.

From the fact that all kinds of matter are more or less compressible, we may infer that the molecules are not in mathematical contact, and this view will be strengthened when we come to consider the nature of heat and its effects upon matter. The force of cohesion acts only at inappreciable distances. It is strongest in solids, very feeble in liquids, and altogether absent from gases; and this is in accordance with our statement that the molecules are closest together in solids and farthest apart in gases.

If we place a measured quantity of ice-cold water in a graduated vessel over a spirit-lamp the water immediately begins to rise in the vessel, so that as the liquid warms it increases in bulk, although from the evaporation that is taking place the mass is really decreasing. Nothing has been added to the water but heat, and it might hence be inferred that heat is a material substance whose addition was the cause of the increase of bulk of the water. An equally simple experiment would soon cause us to hesitate before accepting this conclusion as certain; for if we took a quantity of ice of the same temperature as the water in the above experiment and treated it similarly, we should find that the bulk actually decreased, and the temperature could not rise until all the ice was melted, notwithstanding the continued addition of heat. What, then, has become of the heat imparted to the ice? It has been employed in tearing asunder the molecules of the solid ice to form the liquid water. If we continued this experiment it would pass through the phase above described; but when the temperature arrived at boiling point the water would cease to expand or to grow hotter, no matter how much heat was applied, and the steam produced would have the same temperature as the boiling water. Here we see that it is impossible to heat water beyond a certain temperature, the extra heat being used in tearing asunder the molecules of the liquid water to form the gas steam. It is not our province to trace the history of the demolition of the idea of the materiality of heat; suffice it to say, that the consideration of phenomena similar to those raised in the simple experiments described induced men of science to examine the question more accurately, and it became abundantly evident that matter could not act as heat is known to do, and that what we call heat is the effect of some kind of motion. In the case of the heated ice and water we have said that the heat was employed in doing the mechanical work of rending molecules asunder: no material body could do this, and it has been proved by rigid experiments that when heat so disappears and work is done, the amount of heat destroyed and work done are definitely proportionate to each other. For instance, if we, by mechanical means, stir water about, we can raise its temperature. Suppose a perfect engine* to be employed thus to stir water until its temperature is raised one degree; a certain amount of work has been done by the engine, and this work can be measured. If now we make the same engine do the same amount of work in raising a one-pound weight, it will lift it 772 feet high.† We can, in point of fact, not merely change work into heat, but we can change that heat back again into work. Thus we could make an engine raise the temperature of gas, and then cool the gas down again to its former temperature by making it work the engine; and the quantities of work done in each case would be the same. Now what happens in these cases is the conversion of the sensible motion of the engine into molecular motion, and this molecular motion

* That is, one that was free from friction, and did not itself become heated.

† The force necessary to raise 1 lb. 1 foot high is called a *foot pound.*

manifests itself as heat. A body, then, at a certain temperature is a body whose molecules are vibrating at a certain rate. Increase of temperature means increase of vibration; but if the molecules swing to and fro* through greater distances, they must be pushed farther apart, and hence it is that heated bodies expand. A heated body is one in which all the molecules are in a state of vibration, and the to-and-fro movements compensate each other so as not to impart sensible motion to the mass any more than the undulatory motion of the chest in breathing causes us to move from place to place. Suppose a bullet to be projected with great velocity from a rifle: its motion as a whole does not influence the vibration of its particles; but when the bullet strikes the target the sensible motion is suddenly destroyed, the molecules are thrown into a violent state of vibration, and the bullet is made hot. Just in the same way if we hammer a piece of iron. The sensible motion of the hammer is checked at each blow and converted into molecular motion, and both hammer and iron become hot. We can no more see this molecular motion than we can perceive the molecules themselves; but so many phenomena are solely explicable on the theory that heat is molecular motion, that it must be accepted as an established fact.

The lowest temperature which can be produced artificially is 490° F. below freezing point; but matter

* It is highly probable that the molecules do not move as a whole, but that, being elastic, they expand and contract.

at even this fearful degree of cold possesses heat, and no natural cold on earth approaches to anything near such a temperature. Hence we are compelled to admit that every particle of matter in the globe is in a state of molecular vibration. By analogy we conclude that this is equally true of the other members of the solar system, and, carrying the analogy to its ultimatum, we assume that each stellar orb is in a similar state of activity; all which points will be made clear in the sequel. Hence we see that, even apart from the sensible motions which the earth and the celestial bodies possess, it is still true that there is no quiescence in nature—the great masses not only sweep on in interdependent paths, but each molecule is pregnant with motion.

On the theory that heat is an effect of motion, it is easily seen how a warm body can communicate heat to a cooler one in contact with it. The molecules jostle each other, and the more vigorous vibrations are taken up by the molecules which are in less violent commotion. We can also understand how warm currents of air or water can carry heat into cooler regions, for this is but a phase of the above method. In both cases there is a material medium, and the heat is communicated from molecule to molecule. But at first sight it is difficult to understand how heat can wing its way through such wide regions of space as that which intervenes between us and the sun. In that vast tract there is no appreciable matter; yet upon the heat and light that come to us through it, our very existence depends. If heat be motion, what is there in interstellar space which vibrates? The answer is that space is filled with a highly elastic medium, to which the name of *ether* has been given, and it is this which vibrates and transmits its pulse-like waves to earth, where they break up into heat, light, and chemical action. No balance has weighed this subtle something, no eye has seen it, the sense of touch has not revealed it, nor hearing disclosed it, neither can taste divulge its presence. Yet it must pervade alike the particles of the densest and of the lightest matter; it must stretch to the confines of the universe, and fill the immeasurable regions which separate the stars, permeating every orb and every particle of an orb. This idea must be firmly grasped, and with it the inevitable consequence that in Nature there is no emptiness. We are linked to the most distant star by bands as palpable to the intellectual eye as are the different portions of our frame to physical vision.

The universe may be compared to a block of pure glass within which, here and there, are tiny aggregations of minute particles. The glass is quite invisible, and if it were beyond our reach we should be unconscious of its presence. The dots represent orbs, the glass ether. This simile is not so far-fetched as might be imagined, for the ether possesses many of the properties of a solid. It is the vibration of the ether which brings to us the light and heat of the sun and other celestial bodies. We have seen that those bodies are in a state of molecular agitation; we now see that space itself is at one with the grosser matter in this respect: hence all interstellar space is quivering, and there is no such thing as stillness in the universe. When bodies vibrate rhythmically, at rates of from 16 to 38,000 times per second, they produce musical sounds, each particular tone having a separate fibre within the ear which vibrates in unison with it, and renders it audible. The waves or vibrations which produce light vibrate at the rate of from 400 to 700 billions of times per second. If we conceive our ears so perfectly attuned as to be sensible to such motion, the universe would resound with music. It is full of music: only our senses are too dull to perceive it, and Pope's magnificent lines, which have been so much condemned for artificiality, are far nearer the truth than his detractors were aware of:

> "If nature thundered in his opening ears,
> And stunned him with the music of the spheres,
> How would he wish that Heaven had left him still
> The whispering zephyr, and the purling rill."

We have spoken of heat as vibrations of the atoms of matter, and also of that ethereal medium which forms so subtle a bond between us and the limits of the known universe. That these two operations may not confuse us, we will examine them a little closer, for they very intimately concern our investigation.

The sun is an intensely hot body, and we receive a very sensible amount of heat from it, by means of which the earth becomes warmed. Between the sun and the earth is an immense space filled with ether, through which the heat travels. But the ether is not itself warmed; it merely transmits the heat-waves. When these waves enter our atmosphere they do not communicate warmth to it, provided it be free from vapour, and the heat-waves finally reach the earth without having warmed anything through which they have travelled. Ether and dry air transmit heat-waves as readily as clear glass transmits light; and this property is termed *diathermity*. Ether and dry air are diathermous; that is, do not oppose the free passage of heat-waves. Diathermity is to heat what transparency is to light.

The earth, however, is not diathermous, and as the waves cannot pass through it, they impinge upon its atoms and set them vibrating. A rude idea of this action may be formed by imagining the waves of the sea to fall upon an immense drum-head. The billows strike the membrane and are shivered into vibrations, and the drum yields its music. In like manner, the ethereal heat-waves strike the solid earth and communicate motion to its atoms; and the result is the silent music we call heat. The earth is warmed. The atoms of the sun are vibrating in the same manner as those of the warm earth, but much more vigorously. They originate billows in the ethereal ocean which roll onwards and outwards until their progress is opposed. Then, yielding their impulses, they convert the recipient body into a miniature copy of the orb which gave them birth. The idea must be firmly grasped that in hot bodies the atoms are in a state of vibration; and these vibrations produce undulations in the ether, and so long as these waves alone are in existence the heat is insensible, for heat is one of the *effects* of these undulations. Hence we may conclude that the regions of space are intensely cold, although the heat-waves from all the burning orbs of heaven are poured through it. That the sun's rays do not heat the air directly is a matter of common experience on bright winter days such as the 27th of February last, when the thermometer exposed to the direct rays of the sun stood at 89·0° F., while at the same time the temperature in the shade was only 36·0° F., or but little above freezing. The exposed thermometer intercepted the heat-waves and converted them into sensible heat, while the instrument which was screened from the sun's rays showed the temperature of the air.

We shall fully consider the question of the sun's action in a future chapter. We now desire merely to show the difference between that kind of heat which is possessed by hot bodies and that which they emit. The former is called *sensible* heat; the latter *radiant* heat.* The exposed thermometer converted

* The term radiant *heat* is, perhaps, somewhat misleading. It is not heat, but merely wave-motion, until it impinges upon some material substance. Neither is there any light nor chemical action until the ethereal waves are checked by matter. Heat, light, and chemical action are thus *effects* of motion.

radiant into sensible heat, and the shaded one showed how incompetent air was to effect a similar change.

Radiant heat and light are one and the same thing: namely, ethereal waves, and the waves themselves are similar and sometimes identical. The same waves which falling upon the eye produce the sensation of light, incite the sensation of heat and produce chemical action upon the skin. But while nearly all the light-producing rays possess some heating power, a great many heat-producing rays are incapable of yielding light. The ether waves must attain a certain rapidity before luminous effects are produced. Every one, for example, is aware that iron is very hot long before it begins to glow.

This question of the identity of radiant heat and light is a most important one. We have seen that heat is insensible till the waves are opposed, and that space is consequently a region of immeasurable cold, compared with which the rigours of a Siberian winter are as a furnace, and the same reasoning is applicable to the case of light. Until the light waves meet with something that bars their progress they are invisible; and space, though filled with the outpourings of every star, is in perfect darkness. A beam of sunlight entering a dark room through a pinhole in a shutter marks its course as a brilliant bar among the dancing dust particles with which the air is filled; but if these be strained out, and the air be thus purified, the presence of light is unperceived till it falls upon the floor.

Remove the atmosphere and our globe would be face to face with the everlasting blackness and coldness of space. By day the sun would glow with unutterable splendour, and pour his beams with scorching fervour on the landscape; but every shady spot would be dark as midnight, and colder than frozen mercury. The stars would be seen by day as well as by night shining in an inky firmament. Such a state of things exists, perhaps, in the moon, where, therefore, there is no blue vault above, no diffusion of light and heat, no medium between excessive light and intense darkness, no gradation from withering heat to desolating cold.

We must, however, return to the question of the transference of heat. We understand how this takes place by radiation, and we have now to consider how sensible heat may be imparted by one body to another without radiation. Let us imagine that a wave of heat from the sun has impinged upon a single molecule of the earth's surface, and been by it converted into sensible heat: in other words that the wave has yielded its motion to the molecule. This original molecule, as we may term it, is surrounded by other molecules: molecules of solid earth around and beneath, molecules of gaseous air above. We will for the present confine ourselves to those of earth.

The original molecule is set vibrating and communicates motion to those closest to it. These in their turn impart motion to the contiguous particles, and so the heat travels from one molecule to another.

It is apparent, however, that the vibration which the original molecule imparts cannot be so intense as that which it possesses itself. These feebler vibrating molecules impress still gentler motions upon their neighbours, and soon the effect becomes inappreciable. In fact, although the original molecule warms those surrounding it, the heat grows less intense as the distance from the original molecule increases. It may be as well to observe that the intensity of the heat depends upon the distance through which the dancing molecules swing. In our supposed case the times in which they swing are the same, the distance through which they move varies. To use a rough illustration a series of marbles may vibrate to and fro once in a minute, but if we double the distance of each excursion they must move twice as fast to accomplish it in the same time. Radiant heat travels with the velocity of light, or 190,000 miles in a second: sensible heat would not travel from one end of a poker to the other in the same time.

The above mode of communicating heat is called *conduction*, and it must be clearly understood since it is essential to our investigation. A very important result follows from the manner in which conduction is performed. Suppose our original molecule to occupy the centre of a sphere, say of a round shot. It will warm, or set vibrating, every other molecule, and in time heat will be perceived at the surface. The surface heat, however, will be much feebler than the central, and if we passed a thermometer from the surface to the centre the column of mercury would be found to increase steadily.

Unless some means exist by which the heat of the original molecule can be maintained, its vibrations will decrease in intensity as it imparts motion to the others. When, therefore, we find a body whose temperature increases from the surface downwards we may infer that the body is cooling. This we shall presently see is the case with the earth. The temperature increases as we descend, and the earth is consequently a body which is continually growing cooler.

A peculiar variety of conduction now demands attention, which we can conveniently study by reference to the action of our original molecule upon the air in contact with it. The air molecules are set vibrating by conduction in the ordinary manner. The air thus warmed becomes lighter than the colder air above, and in consequence rises, or what is more correct the heavier air falls through it. In its passage through the cooler air it parts with some of its heat by conduction to the air around. In fact the warm air conveys its heat to molecules which could not receive so large a share by the ordinary mode of conduction. This variety of conduction is termed *convection*.

The radiation, conduction, and convection of heat and light exercise a most powerful influence upon the globe. This influence it is our object to expound; and we shall, in the sequel, learn that upon the action of heat, external and internal, upon the solid earth, the liquid water, and the gaseous atmosphere, the configuration and habitability of the globe depend.

It is essential that we recognise the power of molecular forces, for they are among the most potent in the universe. The force with which the atoms of a compound rush together and are maintained in their molecular condition, and the force of cohesion which holds molecules together, have both been measured; and, as might be inferred, the former is the mightier of the two. It has been found that a pound of hydrogen, in combining with eight pounds of oxygen to form water, produces heat sufficient to raise 34,000 lbs. of water 1° C. We cannot do better than quote the admirable and eloquent words of Tyndall on this subject:—"Let us then," says the author, "fix our attention upon this wonderful substance water, and trace it through the various stages of its existence. First, we have its constituents as free atoms of oxygen and hydrogen which attract each other and clash together. The mechanical value of this atomic act is easily determined. The heating of one pound of water 1° C. is equivalent to 1,390 foot-pounds; hence the heating of 34,000 lbs. of water 1° C. is equivalent to 34,000 × 1,390 foot-pounds. We thus find that the concussion of our one pound of hydrogen with eight pounds of oxygen is equal, in mechanical value, to the raising of forty-seven million pounds one foot high. It was no over-statement which affirmed that the force of gravity, as exerted near the earth, is almost a vanishing quantity in comparison with these molecular forces. The distances which separate the atoms before combination are so small as to be utterly immeasureable; still, it is in passing over these distances that the atoms acquire a velocity sufficient to cause them to clash with the tremendous energy indicated above.

"After combination, the substance is in a state of vapour, which sinks to 100° C. (212° F.), and afterwards condenses to water. In the first instance, the atoms fall together to form the compound; in the next instance, the molecules of the compound fall together to form a liquid. The mechanical value of this act is also easily calculated: 9 lbs. of steam, in falling to water, generate an amount of heat sufficient to raise $537{\cdot}2 \times 9 = 4{,}835$ lbs. of water 1° C., or $967 \times 9 = 8{,}703$ lbs. 1° F. Multiplying the former number by 1,390, or the latter by 772, we have in round numbers a product of 6,720,000 foot-pounds as the mechanical value of the mere act of condensation. The next great fall is from the state of liquid to that of ice, and the mechanical value of this act is equal to 993,564 foot-pounds. Thus, our nine pounds of water, at its origin and during its progress, falls down three great precipices. The first fall is equivalent, in energy, to the descent of a ton weight down a precipice 22,320 feet high; the second fall is equal to that of a ton down a precipice 2,900 feet high; and the third is equal to the fall of a ton down a precipice 433 feet high. I have seen the wild stone-avalanches of the Alps, which smoke and thunder down the declivities with a vehemence almost sufficient to stun the observer. I have also seen snow-flakes descending so softly as not to hurt the fragile spangles of which they were composed; yet to produce, from aqueous vapour a quantity which a child could carry of that tender material, demands an exertion of energy competent to gather up the shattered blocks of the largest stone-avalanche I have ever seen, and pitch them to twice the height from which they fell."*

A few other points in connection with heat must now be noticed. The atoms of the various elements, we have learned, are of different weights, and these are known as the atomic weights of the elements. The atoms of hydrogen being the lightest known, this substance is taken as the unit, and the atomic weights of the other elements are expressed in terms of it. For example, when we say that the specific weights of oxygen and iron are respectively 16 and 56, we mean that their atoms are 16 and 56 times as heavy as those of hydrogen. We have already learned that these numbers express the combining proportions of the elements. Now equal weights of the different elements require different amounts of heat to raise their temperature to a given amount, and this peculiarity is expressed by saying that the *capacity for heat* of the different elements

* "Heat, a Mode of Motion," p. 146; 4th edition, 1870.

varies. This being put into physical language, means that more heat is required to set a given weight of an element such as iron in a certain state of atomic vibration than is the case with an equal weight of another element such as copper. The *specific heat* of an element is the quantity of heat required to raise the temperature 1°, the quantity necessary to effect a similar change in an equal quantity of ice-cold water being taken as unity. Thus when we say the specific heats of iron and copper are respectively 0·1138 and 0·0951, we mean that the quantities of heat which would raise the temperatures of iron and copper 1° would only raise that of an equal weight of water 0·1138 and 0·0951 of a degree.

It is clear, however, that a given weight of a light element contains more atoms than a like weight of an element having a higher specific gravity. Hence in raising the temperature of a light element more atoms have to be set vibrating than is the case with a heavier element. Now if we operate upon quantities containing equal numbers of atoms (that is, if we take weights proportional to the specific gravities of the substances), we find that the quantities of heat necessary to raise the temperature of the masses 1° are practically equal. The obvious interpretation of this fact is that the same amount of heat is necessary to set an atom in a given state of vibration, no matter to what element it belongs. It follows from this that for equal weights the specific heat diminishes as the specific gravity increases. If, therefore, we multiply the specific heat by the specific gravity the product is the same for each element, and this product is called the *atomic heat.* The lighter atoms must, therefore, make up in velocity what they lack in weight. A bullet weighing half an ounce, moving with twice the velocity of one weighing an ounce, will strike a target with the same force as the heavier missile.

The molecules of compound bodies follow the same law. The molecular heat is the sum of the atomic heats of the elements existing in the compound. For instance, common salt is composed of one atom of sodium and one of chlorine. Its specific heat is 0·219; its molecular heat (specific heat multiplied by molecular weight) is 12·8; and its atomic heat is 6·4. There are two atoms in the molecule, and $6{\cdot}4 \times 2 = 12{\cdot}8$, which is the same as the molecular heat.*

The above remarks apply to solids, and may be taken as expressing the broad facts of the phenomena. Certain slight variations are observed, however, depending upon the temperature and density of the substance under examination. As the density increases the specific heat diminishes, and as the temperature is raised the specific heat falls. Inasmuch as an increase of temperature causes an expansion of the material, and consequently a diminution

* The atomic heat here mentioned is of course the same as that for other substances. Salt is merely given as an illustration. It must not be imagined that other materials, such as iron, have different atomic heats.

of the density, it appears that the specific heat depends on the comparative freedom of the molecules or atoms.

The specific heats of liquids are generally higher than those of the same substances in the solid state. Solids and liquids expand under the influence of heat, and it is impossible to prevent this by any mechanical appliance. It is quite otherwise in the case of gases whose atoms or molecules have no cohesion. Hence, in determining the specific heats of gases, we must define the conditions under which the experiments are made. We can, for example, maintain the gas at a constant volume by placing it in a closed vessel, in which case the pressure increases with the temperature; or we can keep the gas at constant pressure by allowing it to expand under the influence of heat, in which case the volume increases with the temperature. Under a constant volume the pressure is greater than under a constant pressure, so that after heat has been communicated the density remains the same. In the gaseous state the specific heat of a substance is somewhat lower than when in the solid state, and under constant pressure it is greater than at constant volume.

The specific heat of water is about double that of ice, and rather more than double that of steam or aqueous vapour. It happens that the specific heat of water is greater than that of any other known substance; and this fact is of the gravest importance in the economy of nature. When we come to the consideration of the causes which produce and modify climates, the immense interest of these questions of specific and atomic heats will be manifest. It is not too much to say that the habitability of the globe, and most of the phenomena of climates, depend upon the comportment of water with respect to heat.

In speaking of the action of heat upon water in its solid and liquid forms, we stated that, no matter how much heat is applied to ice, its temperature never rises above the freezing point until every particle of ice is melted; a fiercer heat causes the ice to melt quicker, but does not warm the water, the heat-force being used up in the mechanical work of effecting a change of molecular state in the ice. In like manner, if water be heated up to the boiling point, no amount of heat will raise the temperature of either the water or steam above the boiling point; and here again the force is expended in effecting a change of condition. The heat which thus disappears is known as *latent* heat, a term coined when heat was considered to be a substance, but its modern application can lead to no confusion now that we are satisfied that heat is a form of motion. We speak of the latent heat of liquefaction or of fusion, and the latent heat of vaporisation, to express the two phenomena above indicated. Latent heat can be accurately measured. If, for example, we mix a pound of boiling water at 212° F. with a pound of ice-cold water at 32° F., the resultant mixture will have a temperature of 122° F., which is the mean of the two temperatures; but if we melt a pound of ice at 32° F. in a pound of boiling water we obtain two pounds of water at 51° F. Now, $122 - 51 = 71$, and this shows us that there has been an apparent loss of heat sufficient to raise a pound of water 71°; this quantity having been consumed in melting the ice. Water possesses the highest degree of latent heat known, and the unit for other substances is taken as the quantity of heat necessary to raise the same weight of water from 32° to 33°.

In a similar manner we can measure the latent heat of vaporisation, and it is found that to convert a pound of boiling water into steam at the same temperature an amount of heat is necessary sufficient to raise 967 pounds of water 1°.

In connection with this subject of heat we must examine the powers of absorption of different bodies. As is well known, certain bodies allow heat to pass through them much more readily than others. We can form a very fair idea of the nature of absorption by an illustration from the well-known effects of sound. A certain harp-string, for example, is struck, and thus thrown into a state of vibration. It communicates this motion to the air, and a musical note is the result of the impact of these air-waves upon the ear. If another harp be in the neighbourhood, the air-waves impinging upon it will cause the corresponding string to vibrate and emit its note; and in like manner other strings, whose vibrations have a certain numerical relation to the first, will also be thrown into vibration, while others will be uninfluenced. Similarly, when an ethereal heat-wave impinges upon a substance it will cause it to vibrate (that is, to become warmed), or not, according as the molecules of the substance are capable of vibrating in accord with it or otherwise. If the substance take up the vibrations it becomes warmed, and the heat does not pass readily through it; whereas, if it cannot accept the vibrations, the heat passes on comparatively unchecked. The terms diathermous and adiathermous are used to signify these conditions, diathermity corresponding with "transparency" to heat, athermity to opacity. Just as sound-waves vary in pitch (that is, in vibration-frequency), so do heat-waves; hence, in comparing the absorptive power of a body, heat of the same kind must be employed, for it is clear that bodies may be adiathermous to heat-waves of a certain frequency, and diathermous to others whose frequency is greater or less. Clear rock-salt is the most diathermous substance known, and it offers scarcely any obstacle to the passage of heat-waves of any kind: water is almost impervious. There is also a very great difference in the absorptive power of gases; for dry air admits the passage of radiant heat almost unchecked, whereas the equally transparent and lighter vapour of water is almost adiathermous. Professor Tyndall has made a series of splendid experiments upon the absorption of radiant heat by gases and vapours, and some of his conclusions are perfectly marvellous; as, for instance, when he shows that if the globe were encircled by an envelope of olefiant gas, only two inches in thickness, it would cut off 33 per cent. of the radiation from the surface, although it would offer scarcely any obstacle to the passage of the solar rays earthward. The most important result, from a physiographic point of view, was his determination of the adiathermity of aqueous vapour. Comparing the two, Tyndall finds that the absorptive power of a molecule of aqueous vapour is 16,000 times that of an atom of oxygen or nitrogen, the components of air.* The importance of this discovery can scarcely be over-estimated. The sun's rays pass without opposition through dry air to the earth, and would return with equal facility into space by radiation, were it not for the aqueous vapour which always exists in the atmosphere. This intercepts some of the heat-rays from the sun, especially the long obscure rays, to be presently described; and the vapour is thus warmed, and in turn imparts warmth to the earth. Other luminous heat-rays of shorter period pass comparatively unchecked, impinge upon the earth, warm it; and the radiation back into space of this heat, which is obscure, is greatly hindered by the presence of the aqueous vapour. The short, luminous heat-rays

* See Tyndall's collected papers entitled "Contributions to Molecular Physics in the Domain of Radiant Heat." London, 1872. Longmans.

are, in fact, converted into long obscure rays, and we have the lower strata of the atmosphere tempered by the influence of the aqueous vapour. This vapour protects us, on the one hand, from the fierceness of the direct sun-heat, and, on the other, prevents the chilling effect of radiation to a large extent; for Tyndall has shown that at least 10 per cent. of the earth's heat is intercepted within ten feet of the surface. It is not too much to say that, without this singular property of aqueous vapour, the globe would be uninhabitable by the present orders of living beings.

This conclusion has been independently verified by Mr. Crookes, in his researches upon repulsion resulting from radiation. He describes an experiment which "shows that the presence of even a small quantity of aqueous vapour in the exhausted apparatus almost, if not quite, neutralises the more energetic action which luminous rays appear to exert on a blackened surface."* The quantity of vapour was so infinitesimal that the gauge attached to the apparatus was level with the barometer.

A substance which is a good absorber of heat is also a good radiator. This is only another way of saying that a substance which can accept vibrations from ether can impart motion to the ether by its own vibrations, and in this form the statement is self-evident. This has an important bearing upon the formation of rain and clouds, as will be shown farther on.

* "Repulsion from Radiation," Part III. par. 130. 1876.

On the 11th of December, 1873, one of the grandest discoveries of modern times was presented to the Royal Society by Mr. W. Crookes, F.R.S., his communication being entitled "On Attraction and Repulsion resulting from Radiation." In this paper the author showed how by means of an instrument of marvellous delicacy he had been led to the discovery that when light, or dark radiant heat, or even the ultra-violet so-called actinic rays of the spectrum are allowed to impinge upon a delicate balance in a nearly complete vacuum, the beam is moved. Since that time Mr. Crookes has continued his researches, and by the invention of various instruments of almost miraculous sensibility, and by experiments demanding in the highest sense all the caution and daring of a great philosopher, has revealed to us some of the most astounding phenomena in molecular physics.* The earlier experiments were made with various forms of exceedingly light torsion balances, consisting of a bar of straw or other light material carrying

* Mr. Crookes's papers are as follows. Except where stated, they are published in the Phil. Trans. and Pro. Roy. Soc. "On Attraction and Repulsion resulting from Radiation," read Dec. 11th, 1873; Do. Part II., read April 22nd, 1875; Do. Part III., read Feb. 10th, 1876; Do. Part IV., with postscript, dated Jan. 17th, 1877; Do. Preliminary Notice on the Otheoscope, read April 26th, 1877. "Experimental Contributions to the Theory of the Radiometer (Preliminary Notice)," read Nov. 16th, 1876. "On the Movement of the Glass Case of a Radiometer," read March 30th, 1876. "On Repulsion from Radiation: Influence of the Residual Gas," read June 15th, 1876. "Notes on the Radiometer," *Comptes Rendus*, Sept. 11th, 1876. "On the Influence of the Residual Gas on the Movement of the Radiometer," read at the Glasgow Meeting of the British Association, Sept. 12th, 1876.

discs of pith, aluminium, or what not, at the extremities, and supported by a thread of unspun silk or glass; the whole being enclosed in a vessel which could be exhausted by means of a modification of the Sprengel pump designed by the author. Many balances on different principles were constructed, some of which were too sensitive to be available for research, inasmuch as the slightest movement of the experimenter—even the shifting of the weight of the body from one leg to the other—was sufficient to derange the balance by shaking the solidly built laboratory in which the experiments were carried out! Without attempting to follow the author through his interesting studies, we may state that the instruments used were of various shapes and degrees of sensitiveness according to the nature of the work demanded of them; but they all contained one simple principle—a light body was so arranged in a glass vessel that the slightest force (say a millionth of a grain) was sufficient to move it. The glass vessel could be exhausted to any degree, even to some millimetres *above* the vacuum in a good barometer. Suppose a bar of pith, one half coated with lamp-black, and the other left white, to be suspended by a very fine cocoon fibre, and a suitable arrangement made to measure the angle of deflection. Let the glass vessel in which this balance is suspended be full of air at the beginning of the experiment. The instrument being packed so that no external radiation may derange it, the light from a standard candle is allowed to shine upon the blackened pith. It immediately moves towards the light as if attracted by it. As the vessel is gradually exhausted the attraction grows feebler, and when a certain degree of exhaustion is reached the bar remains stationary. This *critical point* passed, repulsion sets in—the black pith moves away from the light—and this action augments as the vacuum becomes more perfect, and as perfect vacuity is approached it gradually decreases, and if such a thing as a perfect vacuum could be obtained there can be little doubt that motion would altogether cease.

If, with as perfect a vacuum as can be produced, a standard candle be allowed to shine upon the pith a certain deflection will take place. If the distance of the candle be doubled, the deflection is reduced to one-fourth, at three times the distance the deflection is one-ninth, and so on. It is thus proved that the repulsion varies inversely as the square of the distance. The mechanical force of the light of the candle was also measured. At a distance of 12 inches it was found to be 0·000444 grain, and at 6 inches 0·001772 grain. Now as the pressure (theoretically) at the latter distance should be 0·001776 grain, and the experimental value only differed by 4 millionths of a grain, the marvellous delicacy of the balance and the law of inverse squares were alike well established. Nor was it necessary to use so powerful a source of heat as a candle, for the warmth of the finger brought near the instrument, or of the body when standing near it, proved amply sufficient to effect a measurable deflection. Two candles at the same distance produced, as might be anticipated, double the effect of one, showing that the repulsive force varies directly with the intensity and inversely as the square of the distance. It was also proved that, the mass being the same, the repulsion increased with the area of the surface exposed. So delicate are these wonderful balances that the light of the moon is sufficient sensibly to deflect them.

Mr. Crookes afterwards designed an instrument to which the name of Radiometer was given. It consists essentially of two, four, or more light vanes of pith, metal, or other material mounted on a pivot and enclosed in an exhausted glass vessel. In the ordinary form the sides of the vanes are alternately black and white. When heat or light is allowed to fall upon the instrument the vanes revolve, the black sides moving backwards. A cold body, such as a piece of ice, causes rotation in the opposite direction. These instruments, though not quite so sensitive as the balances, are much more convenient for ordinary purposes.

So astounding were the results of these experiments that much discussion arose as to the cause of movement. Electricity was suggested; but Mr. Crookes has conclusively shown that this cannot be the true source of motion. After describing an apparatus especially fitted up to test the electricity theory, he tells us: "With this I have tried numerous experiments bearing on the action of electricity. I have connected the projecting end of the platinum wire with 'earth,' with either pole of an induction coil (the other pole being more or less isolated), with either pole of a voltaic battery, and with a delicate electroscope. I have charged it with an electrophorus, and have submitted it to the most varied electric conditions; and still, on allowing radiation to fall on the suspended mass, I invariably attain attraction in air and repulsion in a vacuum. The heat has been applied from the outside, so as to pass through the glass, and also inside by means of the ignited spiral; and the results show no difference in kind, but only in degree, under electrical excitement. I often obtain troublesome electrical interference with the usual phenomena, but never of such a character as would lead me to imagine that the normal results were due to electricity. I also obtain the normal actions, whether the apparatus has been standing isolated in the air, or whether it has been completely immersed in water connected electrically with 'earth,' or surrounded with wet blotting-paper."*

A more plausible theory was that by the action of heat air currents were set up in the residual air in the vessel, which by their strength literally blew the vanes round. Some colour of truth is given to this theory by the fact that motion ceases in a perfect vacuum. But it will not account for many well-

* "Repulsion resulting from Radiation," Part II. par. 120; Phil. Trans. vol. clxv.

established phenomena. For instance, on this supposition there is no reason why the motion should not be the same in air of ordinary density as in a so-called vacuum, but we know that in the former case attraction, and in the latter repulsion, ensues; nor is there any reason why the action should be more rapid in a small than in a large bulb.

Mr. Crookes, after testing the matter in a great variety of ways, adopts the suggestion of Mr. Johnstone Stoney, F.R.S., and the explanation is best given in Mr. Crookes's own words. "The presence of the residual gas is the cause of the movement of the radiometer, and generally of the repulsion resulting from radiation, the maximum effect being at a pressure of about 50 millionths of an atmosphere. According to the dynamical theory of gases, the repulsion is due to the internal movements of the molecules of the residual gas. When the mean length of path between successive collisions of the molecules is small, compared with the dimensions of the vessel, the molecules rebounding from the heated surface, and therefore moving with an extra velocity, help to keep back the more slowly moving molecules which are advancing towards the heated surface; it thus happens that though the individual kicks against the heated surface are increased in strength, in consequence of the heating, yet the number of molecules struck is diminished in the same proportion, so that there is equilibrium on the two sides of the disc, even though the temperatures of the faces are unequal. But when the exhaustion is carried to so high a point that the molecules are sufficiently few, and the mean length of path between their successive collisions is comparable with the dimensions of the vessel, the swiftly moving, rebounding molecules spend their force, in part or in whole, on the sides of the vessel and the onward crowding, more slowly moving molecules are not kept back as before, so that the number which strike the warmer face approaches to, and in the limit equals, the number which strike the back cooler face; and as the individual impacts are stronger on the warmer than on the cooler face, pressure is produced, causing the warmer face to retreat."*

Mr. Crookes's inventive genius seems as inexhaustible as the delicacy of his inventions; and, where others were looking on in admiration of perfection, he saw fault upon fault, and has vastly improved upon all preceding instruments in his recently constructed otheoscope. The radiometer, as a heat engine, he remarks, is very imperfect. The black surface, which may be looked upon as the heater or driving surface, being part of the moving body, is limited as to size and weight. It is further limited in material; for, unless it be a bad conductor of heat, it is useless. Moreover, the "cooler" of this engine is the glass, essentially a bad material for the purpose, and one which must be of a particular shape, and which cannot be brought very near to the driving surface.

* "Repulsion resulting from Radiation," Part III., postscript, Jan. 17th, 1877.

"A perfect instrument would be one in which the *heater* was stationary; it might then be of the most suitable material, of sufficient area of surface, and of the most efficient shape, irrespective of weight. The *cooler* should be the part which moves; it should be as close as possible to the heater, and of the best size, shape, and weight for utilising the force impinging on it. By having the driving surface of large size, and making it of a good conductor of heat—such as gold, silver, or copper—a very faint amount of incident radiation suffices to produce motion. The black surface acts as if a molecular wind were blowing from it, principally in a direction normal to the surface. This wind blows away whatever easily movable body happens to be in front of it, irrespective of colour, shape, or material, and in its capability of deflection from one surface to another, its arrest by solid bodies, and its tangential action, it behaves in most respects like an actual wind." *

An otheoscope (*otheo*, I propel) consists of vanes mounted as in a radiometer, but without being blackened on one side. The driving surface is fixed to the side of the vessel, and the radiation allowed to fall upon it. The advantage of such an instrument over the radiometer is at once apparent. If a radiometer were placed in space where the atmospheric pressure was, say one millimetre, and the bulb were removed, it would not rotate, however powerful the radiations upon it were; but it is clear that an

* "Preliminary Note on the Otheoscope," read April 26th, 1877.

otheoscope would act perfectly. Even this instrument does not close the list of Mr. Crookes's splendid productions, for he has recently constructed one which will act in air of ordinary density!

It may here be well asked, what is it that moves the vanes? Is it heat, or light, or what? The answer is obvious. It is neither. It is the ethereal undulations which are the cause of motion, and they produce mechanical pressure through the medium of the residual gas. Light, heat, and chemical action are *effects* of these undulations upon different bodies. The same undulation can produce the sensations of light and heat, and incite chemical action. We have had to coin such curious expressions as *dark-heat*, *ultra-violet* rays, *actinic* rays, *chemically active* rays, to express these different effects. But darkness has no relation to heat, neither has it to colour, and we might call the ultra-violet rays *cold-heat* just as appropriately. Must we, then, coin another such expression for the action Mr. Crookes has discovered? I think not: it is common to every ray whose existence has been determined, and will probably reveal the presence of hitherto unknown ones. Draper has shown that all the light rays are chemically active, under certain circumstances, and the most active of these rays is sometimes incapable of exciting chemical action. Is it not time we ceased calling these undulations of different period by separate names according to the work they do? Such a term as *unda* (plural *undæ*) would meet the case exactly. We could speak of the undæ without getting into such physical difficulties as beset us when we talk of the chemical action of light, the heating properties of red rays; and still more when we speak of *radiant* heat, in which case we have carefully to inform the reader that it is not heat until the rays fall upon certain kinds of matter. We speak of light streaming through the darkness of space without illuminating it, and so on through a multiplicity of similar phrases, all of which need careful explanation, and all of which would be avoided by the use of the term undæ. The words undulations, vibrations, waves, have too wide and colloquial an application to be pressed into this service. The simple Latin word undæ enjoys the merits of shortness and euphony, and obviates the necessity of prefixing the adjective ethereal, as would be necessary if the other terms were adopted. We could speak of the undæ excited by the sun, without hinting the passage of dark light, cold heat, or quiet chemical activity. The revision of our nomenclature in this respect seems very necessary. We talk of measuring "radiant" and "sensible" heat by the thermometer, whereas we measure the *expansion* of some substance caused by the impact of the undæ; we use the term thermopile for the same purpose, whereas we here note the intensity of an electrical current (reacting upon a magnetic needle) caused by the impact of the undæ; we may use the radiometer or otheoscope in the same manner, whereas we here measure mechanical force. Surely some such term as undæ is imperatively called for. When the blind man likened the colour red to the sound of a trumpet, he was not much further from the truth than when we speak of radiant or insensible heat—it is like speaking of still motion.

Leaving the consideration of light until the next chapter, we will recapitulate the conclusions to be drawn from our present subject.

1. Matter exists under three forms—solid, liquid, and gaseous. Many kinds of matter are known to us in all three states, as, for instance, water, which as ice, water, and vapour is the same substance in different states. Many substances which naturally occur in only one of these states can artificially be brought into others. Carbonic acid, for instance, is under ordinary circumstances a gas, but it can be liquefied and even solidified. No approach to liquefaction has ever yet been attained in the cases of some gases, such as oxygen and hydrogen.*

2. The simple substances or elements are few in number, sixty-six only being at present known. These in their simple state or combined with others form all known substances.

3. Elements always combine in certain definite proportions, to which the name of atomic weights has been given. The atomic weights differ for each element, and combination always takes place in the

* Since the above was written oxygen, hydrogen, nitrogen, and air have been liquefied.

proportion of the atomic weights of the elements, or multiples thereof.

4. It, therefore, appears that matter is composed of very minute fragments having different weights according to the nature of the elements. To these particles the name of atoms is given. An atom is the smallest quantity of an element that can enter into chemical combination. The smallest particle of a compound that can exist in a free state or enter into combination is called a molecule.

5. The force by which atoms and molecules are held together in solids and liquids is called cohesion, and is very great as compared with the ordinary forces, such as gravitation. Gases have no cohesion.

6. The force of cohesion can be measured by the amount of force necessary to overcome it.

7. Heat is the sensation produced upon us by certain kinds of motion. In a warm body the molecules are in a state of vibration. The heat which bodies possess in virtue of this molecular motion may be called sensible heat. The heat which streams to us from distant bodies is called radiant heat.

8. Heat being an effect of motion, there must be something between us and the heavenly bodies capable of transmitting motion. It is concluded that space is filled with an invisible, highly elastic medium to which the name of ether has been given. Ether is supposed to fill not only the interstellar spaces, but to permeate all matter occupying the inter-atomic and inter-molecular spaces.

9. Radiant heat is one of the effects of wave-motion in the ether. These heat-waves differ in length: some of them do and some do not also influence us as light. The luminous heat-waves are shorter than the obscure ones.

10. All bodies possess heat, or are in a state of vibration; there is, therefore, no stillness in the universe.

11. The ether unites us to all the members of the universe. Hence the earth is not an isolated fragment in space, but part of one great machine.

12. Heat is one of the most efficient agents in overcoming cohesion.

13. Heat can be converted into mechanical work, and *vice versâ*. The force necessary to raise one pound of matter one foot high is called a foot-pound. The quantity of heat necessary to raise the temperature or change the state of a body can be measured in foot-pounds.

14. Different substances require different quantities of heat to raise their temperature one degree. The ratio of this quantity to that necessary to raise water from freezing point to one degree above it is called the specific heat of a substance.

15. The specific heat of water is higher than that of any known substance. To raise the temperature of water one degree 772 foot-pounds of force are necessary.

16. Differences of specific heat show that the molecules of substances require different amounts of

force to overcome their cohesion, or to set their molecules in a certain state of vibration.

17. The specific heat of a body is greatest when it is in the liquid condition, and least when it is in the solid state. Thus the specific heat of water is twice that of ice, and rather more than twice that of vapour.

18. Heat can be communicated from one body to another by conduction, convection, and by radiation.

19. Conduction takes place by the transference of heat from one molecule to another in contact with it.

20. Convection is a form of conduction in which the heated molecules are conveyed to a distance amongst cooler ones, to which they impart heat.

21. Bodies are heated by radiation, in consequence of the molecules being thrown into a state of vibration by the heat-waves impinging upon them.

22. A substance under constant conditions of pressure cannot have its temperature raised above a certain amount without its state being changed. The water from melting ice, for instance, cannot be raised above 32° F. until all the ice is melted, and water and steam remain at 212° F. until all the water is evaporated. The heat which disappears in these processes is called latent heat.

23. The latent heat of water is higher than that of any other substance.

24. The high latent heat of water exercises an

important influence upon the climate of ice-clad regions, for it is clear that a vast amount of solar heat becomes latent in melting the ice.

25. The high specific heat of water makes it a most efficient agent in ameliorating the climate of polar regions by means of ocean currents. Were oceanic circulation stopped the globe would not be habitable.

26. A body which allows radiant heat to pass freely through it is said to be diathermous. One which opposes the passage is said to be adiathermous.*

27. Bodies which can vibrate in unison with a heat ray are adiathermous to that ray. Those which cannot so vibrate are diathermous.

28. Dry air is diathermous to nearly all heat rays.

29. Water is adiathermous to most heat rays, and aqueous vapour to those of long period.

30. Owing to this adiathermity of aqueous vapour, ten per cent. of the terrestrial radiations are cut off within ten feet of the ground. If aqueous vapour were diathermous, the earth would be uninhabitable.

31. In air of ordinary density a delicate balance is attracted by heat and repelled by cold.

32. When exhaustion is carried to a certain degree, a critical point is reached at which neither attraction nor repulsion take place.

* The opacity of bodies to radiant heat is usually spoken of as *athermity* or *athermancy*, but this term is more applicable to a body *without heat* (if such could be), *a*, without, *therme*, heat. *Adiathermity* correctly implies that the body has not the property of allowing heat to pass through it.

33. At a higher rarefaction the balance is repelled by heat and attracted by cold.

34. In a perfect vacuum no such motion is obtainable.

35. The motions are caused by the action of the ethereal vibrations upon the residual air surrounding the balance.

CHAPTER III.

LIGHT AND ITS REVELATIONS.

WE have before hinted that heat and light are only different effects of one and the same cause, namely, the waves of ether. These waves differ in length, some being comparatively long and slow, and others short and quick. These ethereal undulations possess different properties which we may thus express. The longest waves are essentially heat-producers; the shortest are powerful in effecting chemical change, and intermediate between these come the light-producers. The waves, however, which produce these phenomena are not separable by hard lines, but insensibly gradate into each other; so that many of the heat-waves are also luminous, and many of the light-waves are strong in chemical action. Indeed the luminous rays nearly all possess some heating and chemical powers.

In the previous chapter we spoke of heat *rays*, and the term is a convenient one; but in using the word ray, whether as applied to heat or light, it must be remembered that there is no such thing physically as a ray, but that it is merely a useful way of speaking of the direction in which the ethereal waves are travelling.

In order to study the properties of different waves it is necessary to separate them from each other. This can be done by sifting out those which are not required by causing them to pass through some substance which absorbs them; or by, as it were, fraying them out, so that waves of different lengths fall upon separate spots. This latter process can be accomplished owing to the fact that when a wave passes from one medium to another its direction is changed, and the amount of this change depends upon the wave-length. The longest waves are least changed in this manner; and hence we can so arrange a train of apparatus that the different waves of a "ray" can be spread out so that they shall not overlap. A "ray" of white sun-light, that is to say the combined waves which are emitted by the sun, can thus be broken up into its component waves. The amount of bending of the waves is called their *refrangibility*, and the longer, slower waves are the least refrangible. If we admit a beam of sun-light into a dark chamber through a narrow slit, and allow it to fall upon a prism of dense glass, the beam will be frayed out, and appear upon a white screen as a coloured band or spectrum. It will then be seen that the colours are those of the rainbow, namely, red, orange, yellow, green, blue, indigo, violet, the red being the least refrangible. It is not our province to inquire into the manner in which the wave-lengths have been measured. Suffice it to say that this has been accomplished with the utmost nicety; and that, too, before the nature of light was determined. By means of a series of prisms we can further expand the spectrum, or by means of what is technically called a grating (which is a piece of glass or metal ruled with exceedingly fine lines very close together) we can make the spectrum quite pure: that is, its various waves will not overlap. It is found, however, that in practice a train of prisms is the most convenient arrangement. Now a convenient arrangement of slit, dark chamber, and prism is called a spectroscope, and by means of this instrument some of the most marvellous discoveries have been made, as we shall presently describe.

If we measure the heat in different parts of the visible spectrum by means of a small thermometer (or, better still, a narrow thermopile *), commencing at the violet end, we shall find at first little or no effect; but as we approach the yellow the heating effects augment rapidly, and go on increasing right up to the limits of the visible red. Carrying the thermopile beyond the red, the heat will still continue to augment for a certain distance, after which

* A thermopile is an instrument composed of alternate bars of antimony and bismuth, the junctions of which, when warmed, give rise to an electric current. The intensity of the current depends upon the amount of heat. The current is made to deflect a magnetic needle, and the amount of deflection measures the relative intensity of the heat. The radiometer, described in Chapter II., will probably give even better results.

it will decrease, and, finally, at a distance roughly equal to the length of the visible spectrum its effects will cease to be appreciable. This shows us that, besides the light-giving waves, there are obscure waves which possess great heating power. These waves were frayed out exactly in the same manner as the light-waves, and this is one reason why we conclude that radiant heat and light are both effects of ethereal undulations.

The intensity of the chemically active rays can be measured by their power to blacken paper sensitised by chloride of silver, and in other ways; and it is found that chemical action increases steadily from the yellow to the violet, and continues beyond the visible spectrum, showing that there are invisible ethereal waves beyond the violet, just as there are beyond the red.* It must be clearly understood that the waves which produce heat, light and chemical action are essentially the same. They are all undulations of ether, and some, as the green rays, readily produce all three effects, and from such rays it would be impossible to separate the heat, light, or chemical activity, for these are merely different effects of the same ethereal undulation. Some of the ultra-violet rays can be rendered visible by allowing them to fall upon a screen washed with a solution of quinine, for instance, when a peculiar

* Mr. Draper, of the United States, has succeeded in photographing the red end of the spectrum; showing that all the light-waves are capable of exciting chemical action.

blue colour makes its appearance. This phenomenon is known as fluorescence. The blue colour is not due entirely to the ultra-violet rays, but is the result of a change of period in those rays caused by the quinine, by which they are rendered longer, and consequently more refrangible. This interesting subject is only mentioned here to show that the invisible rays beyond the violet are as amenable to experiment as the visible ones.

The wave-lengths of the light rays have been determined with great exactitude; and, being important to our present subject, they are here given. It is to be understood that the lengths in the following table represent only the mean length of the different colours, and that waves of all intermediate lengths occur in the spectrum. The measurements are in parts of an inch.

Extreme Red	0·0,000,266	Blue	0·000,196
Red	0·0,000,256	Indigo	0·000,185
Orange	0·0,000,240	Violet	0·000,174
Yellow	0·0,000,227	Extreme Violet	0·000,167
Green	0·0,000,211		

It may be useful here to institute a short comparison between the range of our perceptive powers of sound and light. It will be noticed that the range of the visible rays lies within very narrow limits, the difference being only 99 millionths of an inch between the wave-length of the extreme red and extreme violet. The velocity of light is known to be about 185,000 miles per second, and if we divide the wave-length by this velocity we obtain the number of vibrations per second. Sound we know is the effect of undulations of air upon the ear; when the undulations attain a frequency of 16 per second, a recognisable sound is produced, and when the frequency exceeds 38,000 per second, no sound is perceptible by ordinary persons. We have thus a range of 11 octaves; but if we examine light-waves in the same manner we find that the eye is only sensible to about one octave. The ear, therefore, is more perfectly attuned to sound than is the eye to light; and just as certain persons are deaf to notes of high pitch, so we can imagine persons capable of seeing light which, from its shortness of wave-length, is invisible to others. As a matter of fact people cannot see beyond the violet, but the limits of visibility vary with different observers. It is clear, then, from all that has been said that there is no physical difference between the obscure ethereal undulations and the visible ones.

By a consideration of the nature of light and heat we have learned that the earth and its kindred planets, and the sun and stars, are not mere aggregations of matter isolated in an empty void, but that

> "All are but parts of one stupendous whole."

We will carry our investigation a step further, and show that the ethereal vibrations reveal, to some extent, the composition of the shining orbs around us.

Let us consider a piece of iron wire, whose temperature, at first low, is gradually raised to such a pitch that the metal is dissipated in incandescent vapour. The vibrating atoms move at first too slowly to impress our sense of sight, but the existence of motion is indicated by the thermometer. As the temperature rises, that is as the atoms swing faster, the mercury ascends in the tube. Before the wire begins to glow the thermometer must be abandoned, for the temperature is already above that of boiling mercury (662° F.). The wire just becomes visible at a temperature of 978° F., and glows with a faint red heat. If we possessed means of rendering visible the actual vibrations of the atoms and of observing their velocity, we should see the solid atoms dancing to and fro at the rate of about 450 billions of times in a single second, and ethereal waves rolling away from them, whose lengths from crest to crest were only 0·0000266 of an inch. These waves travel so rapidly that 450 billions of them would pass a given point in a second, and by the time the last was counted the first would be 185,000 miles away. When, therefore, we see a luminous body emitting a red light, we know that its atoms are moving at a rate incomparably greater than that of an express train, and that 450 billions of waves enter our eye in a single second.

At the same time, the vibrations indicated by the temperature below red heat are still being performed, hence waves of greater length and longer periods are produced simultaneously with the shorter and quicker ones.

As the temperature of the wire rises still further, the brightness increases, and at length an intense white light is emitted, and the substance is said to be white-hot. Waves are now formed whose lengths are much smaller than those which produced red light. The vibrations corresponding to lower temperatures are still being performed, and the white-hot body emits as many, or even more, red light-waves than when the wire was red-hot.

We have seen that a vibration-frequency of about 450 billions per second corresponds to red light. We can attach values in like manner to other coloured lights, such as orange, yellow, green, blue, violet, &c. White light, on the other hand, cannot be said to depend upon vibration-frequency in the same sense that coloured light can, for it is the effect upon the eye of lights compounded of two or more colours. Thus red and greenish yellow, orange and Prussian blue, and yellow and indigo blue, are pairs of coloured lights which appear white in combination, and a light compounded of all the spectral colours is white.*

The white-hot iron is, consequently, emitting light of more than one colour. We can separate these colours by sending the light through a narrow opening, and then through a glass prism. The

* Mixtures of pigments act by the subtraction of light and not by addition, as in the above case. Hence the differences of result.

light which, before traversing the prism, formed a narrow white line upon a screen, now appears as a coloured band, showing all the above-mentioned colours, perfectly gradating into one another in the order given.

Now let the heat so increase that the iron vaporises, that is to say, passes into the gaseous condition. Hitherto the atoms have been constrained in their movements by jostling against one another, and this is the reason why rays of every period, within certain limits, were emitted simultaneously, but now the atoms are free to vibrate almost uninfluenced by their neighbours. The light, viewed as before, through a prism, no longer forms a continuous spectrum from red to violet, but a great number of fine bright lines appear instead. These lines possess the colours of the corresponding portions of the continuous spectrum, and their interpretation is that iron vapour emits rays of definite length only. It has been shown that the incandescent vapour of every element emits rays of a peculiar kind, and by their spectra we can determine the presence of the particular element, for no two have been found to emit the same set of rays.

So delicate is this test that one two-hundred-millionth of a grain of sodium can be detected by the spectroscope.

We have thus shown that there are two kinds of spectra; the one continuous, the other composed of bright lines. The former is produced by glowing solids and liquids, the latter by incandescent gases, which may, of course, be either ordinary gases at a very high temperature, or the glowing vapours of bodies which are generally known to us in their solid or liquid conditions.

There are, however, two very important orders of spectra yet to be described, namely, a continuous spectrum crossed by fine dark lines, and a continuous spectrum crossed by bright lines. In dealing with radiation and absorption we found that those bodies which were good absorbers were also good radiators. Applying this principle to light, it has been proved that bodies absorb rays of the same kind as they emit. Burning sodium, for instance, emits rays practically of one refrangibility, producing a spectrum of one strong yellow line (known as the D-line *). If a beam of white light (which produces a continuous spectrum) be sent through the sodium flame, the spectrum is no longer continuous, but is broken by a dark line occupying exactly the position of the bright sodium line. The explanation of this phenomenon is simple. The sodium vapour has absorbed from the white light just the rays which correspond to those which it emits itself; hence only the feebler rays from the sodium fall upon that particular portion of the yellow of the continuous spectrum, and the line appears dark by contrast. If, however, the temperature of the

* The D-line is separated into two or more with a large spectroscope.

sodium vapour were higher than that of the source of white light, a bright band would have appeared in the yellow of the continuous spectrum. Collecting these facts they may be thus summarised.

1. *A continuous spectrum* reveals the existence of an incandescent solid, liquid, or dense gas.

2. *A spectrum of bright lines* is produced by incandescent gases and vapours.

3. *A continuous spectrum traversed by dark lines* is caused by an incandescent solid or liquid shining through an incandescent gas or vapour at a lower temperature.

4. *A continuous spectrum traversed by bright lines* results when an incandescent solid or liquid shines through an incandescent gas or vapour at a higher temperature.

Mr. J. Norman Lockyer recognises a modification of the dark-line spectrum, consisting of dusky bands, to which he gives the name of channelled-space spectrum. This he shows is characteristic of the metalloids, and compounds containing them. As compounds are dissociated at a very high temperature, he justly infers that any body giving a channelled-space spectrum is known, not only to contain metalloids and compounds, but to possess only a moderate temperature. This gentleman is adding much to our knowledge of molecular physics by his spectroscopic researches. One of the most daring of his conclusions is that the simplicity of spectra increases with the temperature. The channelled-space spectrum, for instance, is produced by a comparatively low temperature; a complex line-spectrum (like that of the sun) shows a temperature sufficiently high to dissociate most compounds; a very simple spectrum (like that of Sirius) shows that the temperature is even more excessive. We shall have to examine this question at some length in a future chapter.

Each element possesses a spectrum peculiar to itself, and with very few exceptions, which may hereafter be shown to be fallacious, no two incandescent gases or vapours emit light of the same degree of refrangibility. By means of the spectroscope chemists are now enabled to analyze substances in quantities so minute as to be almost imperceptible by other means; and indeed they have discovered new elements whose existence might never have been suspected had not this wonderful method of research been brought to light.

Spectrum analysis, moreover, is not confined to terrestrial matter, for we have only to examine the light of the heavenly bodies to learn whether they are composed of like matter with the earth, all that is essential being that the bodies must be in a state of incandescence.

An analysis of the sun's light reveals the existence of numerous dark lines crossing the spectrum. What conclusion can be derived from this simple fact? This: that the solar spectrum is of the same nature as certain spectra formed by the incandescent vapour of known elements. The elementary bodies, therefore, which constitute the sun behave similarly to terrestrial elements. But this investigation has been pushed much further and has revealed the most astounding discovery since Newton showed how the members of the solar system were linked together by the subtle bonds of gravitation. *Precisely the same elements occur in the sun as are known to us on earth.*

Who would have predicted fifty years ago that we were on the verge of so transcendent a discovery—that we should be able to tell with absolute certainty the composition of the stars?

No shade of doubt dims the lustre of this grand idea, and it stands a proven fact upon a more palpable basis than the accepted theory of the revolution of the earth around the sun.

To return to the case of iron vapour. More than four hundred and fifty lines of the solar spectrum correspond with those of the spectrum of iron. The conclusion is inevitable. *Iron must exist in the sun.* Up to the present time the spectra of the following elements have been detected in the sun's light:

Hydrogen	Calcium	Chromium	Zinc
Oxygen	Magnesium	Cerium	Cobalt
Sodium	Aluminium	Uranium	Nickel
Barium	Iron	Lead	Copper
Strontium (?)	Manganese	Cadmium	Titanium

We have before said that the sun is a star, and this statement may now be reversed, and we may say the stars are distant suns. Their spectra are similar to that of the sun, but the greater difficulty of examining them renders the results comparatively meagre. The following may be cited, as examples of stars which have been examined spectroscopically:

ALDEBARAN contains Hydrogen, Sodium, Magnesium, Calcium, Iron, Bismuth, Tellurium, Antimony, Mercury.

BETELGEUX (α Orionis) contains Sodium, Magnesium, Calcium, Iron, Bismuth, Thallium (?).

SIRIUS contains Sodium, Magnesium, Iron, Hydrogen.

The nebulæ are found to consist of incandescent gases, chiefly hydrogen, and some of the comets of a compound of carbon.

Slowly and surely we approached these deeper mysteries of nature, and amidst their seeming complexity have ever found the greatest harmony and the most wonderful simplicity. Not alone are we united with the orbs of heaven by the impalpable quivering ether, and the majestic force of gravitation; but we share their very nature, and are part of the entity called the Universe, whose members differ not in kind, but only in condition. Who, hereafter, can contemplate the mild light of the stars without feeling awed at the story they have been telling us so patiently since our earth first saw light—a story which admits of no false renderings, and stands unequalled in majesty and unparalleled in simplicity?

Spectrum analysis, however, tells us more than this: for by variations in the thickness, and changes in the position, of the bright lines of known elements, it has been demonstrated that vast eruptions are constantly taking place in the sun, and the velocity and extent of many of these have been accurately measured. Moreover, this most subtle means of research has enabled us to measure the rates at which certain stars are approaching or receding from our system. As this is an important question, we will briefly show the principle upon which these measurements have been made. The colour of light, like the pitch of a musical note, depends upon the length of the wave which produces it. A wave of given breadth moving with a known velocity will pass a fixed point in a certain time; a shorter wave will pass quicker, a longer one slower than this space of time. Suppose a body emitting a certain sound to approach the observer, it is evident that the waves will be crowded together, and the effect upon an observer will be the same as if the pitch were heightened. This can be well noticed in a railway-engine which is whistling as it approaches and passes us. The pitch of the whistle increases as the engine comes towards us, and diminishes as it travels from us, although the note is actually the same throughout. In the case of a star travelling towards the earth, the waves of light are in like manner crowded together, and in consequence the bright lines are shifted towards the violet end of the spectrum; and, on the other hand, if the star be moving from us, the lines are shifted towards the red end of the spectrum. The amount of displacement affords data for calculating the rate of motion. It has been laid down as an exact law, however, that the spectral lines of the elements occupy definite positions, and it may be asked how the presence of any element can be ascertained if its lines are displaced? The reason is that in the majority of cases the spectrum consists of a number of lines forming a system, and if all these lines are shifted to the same amount, that is, if their relative positions remain unchanged, they are as recognisable as if they occupied their normal position. By this means it has been found that certain stars are moving towards and others away from the earth. Castor, for instance, is travelling away from the earth at the rate of twenty-five miles per second, and Pollux is approaching at the rate of forty-nine miles per second.

It is to be clearly understood that the spectroscope only reveals to us motion directly towards and away from the earth. It by no means follows that such is the actual path in which the star is travelling, as will be evident from the following consideration. Suppose the planet Mercury gave a spectrum of bright or dark lines, and that it was so far distant from us, that its orbit was reduced practically to a point. Leaving the sun out of consideration, it is clear that as the planet moved in its orbit from opposition to conjunction, that is, from its most distant to its nearest point to the earth, it would by the spectroscope appear to be moving directly towards us; but we should detect the fallacy of this on examining the spectrum when the planet was passing from conjunction to opposition, for then it would appear to be moving directly from us. All that can be said, then, of the motions of the stars as revealed by the spectroscope is that the motion is real, and is such that at present it is bringing the star nearer to, or removing it farther from us, as the case may be. It is, indeed, highly improbable that the stars should be moving in straight lines, and in the case of one of the nearest stars, Sirius, there are reasons for suspecting that it is travelling in an elliptic orbit.

The telescope reveals to us just that part of the motion which the spectroscope is incompetent to resolve, and thus the one instrument complements the other. The changes of position of the stars are so minute that only very accurate and long-continued observations will reveal their existence; but so carefully have the positions of the stars been determined for generations, that the proper motions (as they are called) of about 1,500 have been determined.

It has long been known that the sun has a motion of its own in space, with a velocity of about 150 millions of miles a year. The sun is a star, with a physical structure and proper motion like that of other stars; and, inasmuch as he carries with him a train of planets, we may assume that his peers are accompanied by a like glorious following. Whatever way we seem to look upon this world of ours, provided only that we take a comprehensive view, the fact comes home to us that it is a type of that great universe, of which it was once deemed so insignificant a portion.

Up to this point our work has been an introduction to the study of what the world is and how it works. Bearing in mind the fundamental truths, we have learned respecting the composition of matter, its chemical and physical properties, the nature of light and heat, and the consequences thereof, we will now pass on to a more definite examination of the globe and its surroundings. We will here recapitulate the points brought forward in this chapter.

1. The ethereal undulations which produce heat, light, and chemical action differ from each other only in wave-length. Some undulations produce all three effects.

2. These undulations are bent or refracted in passing from one medium to another.

3. By means of prisms, a ray can be so refracted as to allow of each kind of wave being studied. The light then forms a splendid rainbow-tinted band called a spectrum.

4. The longest waves are least, and the shortest most, refrangible.

5. The heat-rays extend, and reach their maximum intensity, beyond the limits of the extreme red.

6. The chemically-active rays extend, and attain their maximum, beyond the extreme violet.

7. Speaking very broadly, the heating effects are produced by the longest, slowest waves; the chemical effects by the shortest, quickest waves; and the light effects by waves of intermediate length and quickness.

8. Spectra are of four kinds, and are produced under the following conditions:

a. An incandescent solid or liquid produces a continuous spectrum.

b. An incandescent gas or vapour produces a spectrum of bright lines.

c. An incandescent solid or liquid, shining through an incandescent gas or vapour at a lower temperature, produces a continuous spectrum traversed by dark lines.

d. An incandescent solid or liquid, shining through an incandescent gas or vapour at a higher temperature, produces a continuous spectrum, traversed by bright lines.

9. Each element possesses a spectrum peculiar to itself.

10. The sun, stars, &c. contain the same elements known to us on earth.

11. The spectroscope reveals to us that portion of the motion of the stars which is towards or away from the earth.

CHAPTER IV.

THE SIDEREAL SYSTEM.

THE term Sidereal System is applied to the whole of the visible universe, with its hosts of stars, nebulæ, &c. With the exception of the sun, all these bodies lie at almost immeasurable distances from us; nevertheless, astronomers have attempted to solve this difficult problem, and not without some degree of success. In the cases of eleven stars an appreciable displacement or parallax has been noticed when the stars are observed from opposite points in the earth's orbit; but so slight is this parallactic displacement that even in the case of the nearest star, α Centauri, it falls short of one second of arc. Inasmuch as a parallax of one second implies a distance of nearly 19 billions (19,000,000,000,000) of miles, it follows that all the other stars exceed this enormous distance. Light, we have seen, travels with the inconceivable velocity of 186,000 miles per second, yet so distant are the stars that $3\frac{1}{2}$ years elapse before a ray of light can reach us after starting from α Centauri, and it takes

9½ years for the light to reach us from the next nearest star 61 Cygni.

Stars are mapped according to their apparent sizes, the brightest being called stars of the first magnitude. The number of stars visible to the naked eye (or of lucid stars, as they are called) in the northern hemisphere is about 2,000 and in the southern hemisphere 3,000; but this gives us no conception of the absolute number of stars, for over 300,000 have already been catalogued not exceeding the ninth magnitude, and it is probable that there are at least 77 millions of the first 13 magnitudes. The brightness of a star does not of necessity tell us anything respecting its relative size or distance. No telescope has ever revealed the actual disc of a star; all that we are able to see is the light which streams from it. It is clear that stars may differ in intrinsic brightness, and also vary in size. Nevertheless, it has been assumed that the brightest stars are the nearest, and that the sun forms part of a stellar system which includes all the lucid and most of the other separate stars, and that the Milky Way, or Galaxy, and the faint nebulæ are other star systems, separated from our own by vast distances of empty space. Mr. Proctor has proved how untenable this hypothesis is, as we shall presently show; and although as yet but little progress has been made in unravelling the mysteries of the sidereal system, we are able to catch a glimpse of its economy.

The distribution of stars at first sight appears to be capricious in the extreme, but Mr. Proctor has done much towards simplifying the apparent confusion. The distribution on the celestial sphere is evidently quite a distinct thing from the actual distribution in space, for two stars very distant from each other appear close together if they are nearly in line; and when it was considered that brightness necessarily depended upon the distance, the complication seemed inextricable. Mr. Proctor has shown that there is a distinct clustering of stars in the neighbourhood of the Milky Way, and that the innumerable stars which form that rich galaxy are, in fact, small stars, with which larger ones are associated. The same author has also shown that in the northern hemisphere "there is a marked tendency among the lucid stars to aggregate within a nearly circular region, covering the constellations of Cygnus, Cepheus, Cassiopeia, Lacerta, Ursa Minor, and part of Draco. Within this region, which covers about one-fourteenth part of the heavens, about an eighth part of the stars visible to the naked eye are collected. In the southern hemisphere a larger region of similar shape exists. It has the greater Magellanic Cloud for its centre, and extends about 45 degrees in every direction. It covers about a sixth part of the heavens, and contains nearly a third part of all the stars visible to the naked eye. Smaller regions rich in stars exist, and there is a sort of orderly sequence from regions rich in stars to closely crowded groups, clusters of gradually increasing density, &c., down to the irresolvable nebulæ."

The same author has also detected a peculiarity in the motions of the stars, which he denominates star-drift. Although the stars occupy such constant positions that they are appropriately termed fixed, it has long been known that they are not truly stationary, for the present positions of many of them are not quite the same as formerly. Part of this change of position is due to the sun's motion through space, but when this is eliminated there still remains a large residue caused by the proper motion of the star itself. If the sun be travelling through space it is unlikely that he is unattended by other suns, but there are special difficulties in the way of recognising these solar companions. Mr. Proctor has, however, detected a community of motion in certain groups of stars, which shows that they are companions in travel. A fine example of star-drift is seen in the constellation of the Great Bear, the principal members of which, commencing with Dubhe (the pointer nearest the Pole Star), are distinguished respectively by the Greek letters, α, β, γ, δ, ϵ, ζ, η. Mr. Proctor showed that β, γ, δ, ϵ, and ζ had proper motions in one direction, and that α and η did not partake of this star-drift. Dr. Huggins subsequently examining these stars spectroscopically finds that a great similarity exists between the members of the group β . . . ζ; and, moreover, that they are moving towards the earth, whereas *α* possesses different spectra, and has a motion in recess. This remarkable confirmation of Mr. Proctor's views may, as he suggests, help us to find the companions of our sun; for if the stars in the same drift possess similar spectra (that is, are in similar physical conditions) we may be able to pick out from the hosts of heaven the members of our solar drift.

Continuing his noble researches, Mr. Proctor has shown that in the proper motions of the stars we have means of successfully attacking the great problem of their distances. Assuming that the proper motions do not vary greatly in amount, as we may very well do (for even that portion which the spectroscope reveals to us only varies between 15 and 60 miles per second in different stars), it must follow that if the smaller stars are more distant than the larger ones, their proper motions by the simple laws of perspective must also be less. Dividing the stars into two sets, one containing the magnitudes 1 to 3 and the other those from 3 to 6, Mr. Proctor finds that the average proper motion of the larger stars is not greater than that of the smaller ones. "There seems no way of avoiding the conclusion," says he, "that by far the larger number of the fainter stars owe their faintness, not to vast distance, but to real relative minuteness."

It thus appears that in the vastness of the sidereal system there are streams and clusters of stars, that the small stars are not necessarily more distant than the larger ones, and that systems of stars are sweeping in unknown orbits around as yet unknown centres. We see these things but as through a glass darkly, yet so rapid have been the strides of modern science, that we may reasonably hope that the mechanism of the sidereal system will unfold itself step by step until all its fulness is recognised.

The stars differ much in colour. Antares, Betelgeux, and Aldebaran are ruddy; Arcturus and Pollux are yellow; Capella and Sirius white; Vega and Altair blue. Green, indigo, violet, grey, and other coloured stars are also found, but red and orange are the most frequent. Many of the double stars have their members differently coloured, such as the double star β Cygni, one of the components of which is blue, the other orange. When these coloured stars are examined spectroscopically, the reason of their colours is at once revealed. The blue star in Cygnus has a great quantity of fine lines in the red and orange; thus, to a large extent, cutting off that portion of the light, and leaving the blue end of the spectrum predominant. The orange star, on the other hand, has a number of lines in the blue and red, but none in the orange. Sir John Herschel has gracefully remarked that "It may be more easily suggested in words than conceived in imagination, what variety of illumination two suns—a red and a green, or a yellow and a blue one—must afford a planet circling around either; or what charming contrasts or 'grateful vicissitudes,' a red and a green day, alternating with a white one and with darkness, might arise from the presence or absence of one or other or both above the horizon." It may be too, as Mr. Proctor remarks, that the dependent planets are sufficiently distant from both suns to circle round their common centre of gravity. It is futile in one sense to speculate upon such possibilities, but it is useful to remember that worlds may exist under conditions very different from our own. When we remember how powerful are the chemically-active rays in promoting vegetable vigour, it is impossible to imagine what forms of life can exist in worlds from which such rays are largely cut off, or in others in which they are predominant.*

Father Secchi has examined the spectra of a great number of stars, and he finds that they fall into four groups, each possessing its own peculiar spectrum. His groups are:

1. *White Stars*, such as Sirius, characterized by four black lines which correspond to those of hydrogen.

2. *Yellow Stars*, such as Capella, having numerous fine lines, such as are seen in the solar spectrum. Our sun, therefore, belongs to this class.

* Some stars vary in colour. Thus *α* Ursæ Majoris, above mentioned, changes from fiery red to yellowish white with a period of about thirty-three days. The following show some of the recent changes. In 1876 it was red on Sept. 5, Oct. 10, Nov. 14, Dec. 21; in 1877, Jan. 16, Mar. 23. It was nearly white in 1876, on Oct. 28, Dec. 30; in 1877, on Feb. 8, Mar. 31. *Nature*, May, 1877.

3. *Red and Orange Stars,* such as α Herculis, whose spectra contain eight or ten parallel clusters of dark and bright lines, increasing in intensity towards the red.

4. *Small Red Stars,* having three bright zones, which increase in intensity towards the violet.

Of these, the two first comprises by far the greater number of stars hitherto examined, the third and fourth groups having comparatively few examples. These groups may be taken to illustrate the four principal kinds of suns; the blue, green, and other coloured stars being too rare to enter into comparison with them.

Mr. J. N. Lockyer, F.R.S., to whom we are deeply indebted for much of our knowledge respecting the physics of the heavenly bodies, has proposed a division of stars into three groups. In the first the continuous spectrum is crossed by a few lines, as may be seen in Sirius and Vega. These stars are considered to possess an excessively high temperature. A second series is characterized by the possession of a very complicated line-spectrum, like that of the Sun and Pollux. The temperature of these bodies is deemed to be less than that of the former, but still too high to permit chemical combination to take place. In the third class we have the singular channelled-space spectrum, which Mr. Lockyer has shown to be characteristic of compounds. Alpha Herculis and Beta Pegasi are types of the class which represent the coolest of the stars, the temperature not being sufficient to dissociate the compounds. We see in this classification (in all probability) three stages in the development of the stars, their spectra changing in character as they cool.

Another remarkable property which certain stars possess is that they do not always shine with the same lustre. Some of these variable stars, like Algol, diminish in brightness for a short time: in this case for 7 hours out of 69. Others go through a double change, the maxima being equal, and the minima unequal. Another variable star takes a shorter time to diminish than to recover its brightness, and yet another becomes altogether invisible for months. This last star, Mira Ceti, is still further remarkable in changing colour from white to red when near its minimum. Associated with the variable stars we may notice the temporary stars, one of the most singular of which was visible in the year 1866. A star in the Northern Crown, which was almost or quite unknown, suddenly blazed forth with a splendour equal to that of a star of the second magnitude. It as suddenly died away, and in eight days had diminished to the sixth magnitude. It then sank to the tenth magnitude, and has fluctuated in size ever since, though it has never become visible to the naked eye. The spectroscope revealed the reason for the sudden brilliancy, for upon the dark-line spectrum were superposed the bright lines of hydrogen. These lines died away as the star diminished, and the conclusion is inevitable that the outburst was due to an eruption of glowing hydrogen. We shall presently learn that Mr. Lockyer has, by his researches, given us grounds for believing that the sun is a variable star, and it is remarkable that just such eruptions of hydrogen (but of far less magnitude) have been observed in the Sun. Commenting upon this, Professor Roscoe observes: "The question at once suggests itself to the mind, 'Could a similar conflagration burst out in our system?' Of the effects there can be no doubt. The intensity of the Sun's rays being increased nearly eight hundred-fold, our solid globe would be dissipated in vapour, almost as soon as a drop of water in a furnace. The temperature in the sunlight would rise at once to that only attainable in the focus of the largest burning glass, and all life in our planet would instantly cease. In thus speculating on such a possible termination to our terrestrial history, it must be well understood that the probability of such an event occurring is undoubtedly infinitely small, and that the researches of geologists do not lead us to suppose that any approach to such an occurrence has ever taken place in former geologic ages, although it is not irrational to suggest that certain geological indications of secular variations of terrestrial temperature may have been produced by changes occurring in the heating power of the sun."* It is not indeed irrational to suggest such an origin for the vast changes of climate which geology proves have been

* "Spectrum Analysis," Ed. 3, p. 334; 1873.

experienced by the Earth, even within comparatively recent times; but the difficulties in the way of accepting such an explanation are so great that they appear to me insurmountable. The tendency of modern researches in this direction is to show that there is an alternation of cold, warm, and mild epochs in each hemisphere, and that these changes are the indirect result of certain changes in the Earth's motions as will be afterwards shown.

A remarkable new "star" was discovered in the constellation of Cygnus, by Professor Schmidt, of Athens, on the 24th of November, 1876, and is still under examination. When first seen it was of the third magnitude, and it rapidly decreased in size, becoming invisible to the naked eye by the 15th of December. Professor Schmidt announced his discovery early in December, and a number of observers at once began to examine it spectroscopically: the earliest notice I can find being on the 2nd of December. Herr Vogel, M. Cornu, Padre Secchi, Dr. Copeland, Mr. Backhouse, and others have paid particular attention to this subject. When first seen, the spectrum was bright, continuous, and crossed by many dark lines and bands, and several bright lines. "The intensity of this continuous spectrum, which at first was very brilliant, decreased rapidly, so that three months after the discovery of the star it was only partly visible, and even that part was very faint. The decrease of intensity did not spread evenly over the whole spectrum; the blue and violet rays grew fainter far more rapidly than the green and yellow rays. The red part of the spectrum, which already, during the first observations, was very dim, and crossed by broad absorption bands, soon disappeared altogether, so that a bright line in the red seemed to remain quite isolated. At first a dark band in the green, and, later on, a very broad band in the blue, were particularly conspicuous. With the exception of a bright line in the red, the other bright lines at first surpassed the continuous spectrum but very little in brilliancy; they would, therefore, be seen only with difficulty."*

I cannot find that the dark lines were determined; the chief interest attaching, in the opinion of the observers, to the bright lines. The bright lines undoubtedly showed two of the hydrogen lines, and the well-known nitrogen line so conspicuous in nebular spectra. Secchi feels sure that a sodium and a magnesium line were also visible; but Vogel thinks the determination is open to doubt. Dr. Copeland showed that the spectrum was similar to those of three faint stars in Cygnus, whose abnormal character had been noticed by Vogel. This became more apparent as the spectrum grew fainter, and the observation possesses considerable interest, as pointing to a physical connection between these bodies. The last notice of this interesting object that calls for remark is the observation of Lord Lindsay,

* *Nature*, vol. xvi. p. 400; 1877.

that by the beginning of September, 1877, the "star" presented the appearance of an ordinary planetary nebula.* By this time the spectrum had died away, leaving only the nebular line above mentioned—the "star," in fact, has become a nebula. Mr. Lockyer has just communicated an article to *Nature* † upon this subject of "Star or Nebula," which merits serious attention. He forcibly remarks that "It should have been perfectly clear to those who thought about such matters that the word 'star' in such a case is a misnomer from a scientific point of view, although no word would be better to describe it in its popular aspect. The word is a misnomer for this reason. If any star properly so-called were to become 'a world on fire,' were to 'burst into flames,' or, in less poetical language, were to be driven into a condition either of incandescence absolutely, or to have its incandescence increased, there can be little doubt that thousands or millions of years would be necessary for the reduction of its light to the original intensity."

Mr. Lockyer drew from this the remarkable conclusion that the body "*might only weigh a few tons or even hundredweights*," and be very near us. He accordingly wrote to Mr. Hind, to know whether any change in its position was noticeable; but up to the present time this has not been made known,

* *Nature*, vol. xvi. p. 400; 1877.
† *Nature*, vol. xvi. p. 413; Sept. 13, 1877.

though the positions given by the discoverer and Professor Litrow last year, and that just determined by Lord Lindsay, seem to afford grounds for the belief that a considerable proper motion will be detected.

M. Cornu considered that the spectrum of this body was similar to that of the solar atmosphere ("la lumière de l'étoile paraît posséder exactement la même composition que celle de l'envelope du soleil, nommé chromosphère"*); though Herr Vogel pointed out that the brightest line (the nebular line) of the star was unknown in the chromospheric spectrum. It will be shown presently how intimately the chromosphere and corona are connected with meteorites, and Mr. Lockyer thinks we must look for a body small enough to decrease in brilliancy as quickly as Nova Cygni, to "those small meteoric masses which an ever increasing mass of evidence tends to show occupy all the realms of space."† Now, if the observation of Dr. Copeland respecting the similarity of the spectrum of this star with those of three faint stars also in Cygnus be true, a physical connection is established between Nova and those stars, and it becomes a subject of great interest to determine whether these bodies have large proper motions, for if so Mr. Lockyer's suggestion will be greatly strengthened. However this may be, it certainly appears that there is so

* *Comptes Rendus*, t. 83, p. 1, 172.
† *Nature*, vol. xvi. p. 413.

intimate a connection between some stars and nebulæ, that a body may appear for a time as a star, and at another as a nebula. This conclusion was long since drawn from an examination of nebulæ, which brought to light the remarkable fact that a regular series can be traced from nebulæ to stars—that stars, in fact, are nebulæ in which the processes of cooling and condensation have gone on to a certain extent. Professors Tait and Thomson have shown that there are many points in common between nebulæ and comets. We shall presently see how close is the connection between comets and meteorites; and although there seem to me great difficulties in the way of accepting the opinion of the two professors just mentioned—that comets and nebulæ are clouds of meteorites—the fact nevertheless remains, that between meteorites, comets, nebulæ, stars, and (as will appear) the planets also, there are so many bonds of union, that we can no longer look upon these very dissimilar bodies as distinct entities, but must recognise a family connection between them. Once more, then, we are vividly impressed with the grandeur of the great law that "all are but parts of one stupendous whole."

Among the most wonderful of celestial objects are those faint, cloud-like bodies to which the name of nebulæ has been given. Some of these nebulæ are resolvable, in powerful telescopes, into clusters of stars; and it was hence concluded that those which are irresolvable are so by reason of their vast distances. It was, moreover, thought that the stars composing them formed systems comparable with the stellar system, from which they were supposed to be separated by vast regions of blank space. Sir William Herschel long ago showed that the nebulæ exhibit a "marked preference" for a certain district on the celestial sphere; and Mr. Proctor has shown that they form "streams of nebulæ over parts of the southern hemisphere corresponding to the two remarkable star-streams compared by the ancients to the river Eridanus, and to a stream of water from the can of Aquarius." That astronomer has propounded the following laws for the "nebulæ properly so-called" of Sir W. Herschel:—

1. The nebulæ show a marked avoidance of the galactic zone, or Milky Way.

2. The northern nebulæ form a somewhat irregular group, with faint indications of stream formation.

3. The southern nebulæ show a tendency to gather into streams with rich extremities—the very converse of the northern arrangement, the borders of the great northern cluster being sparsely strewn with nebulæ.

He remarks further that "clusters, on the other hand, as also planetary nebulæ, and irregular nebulæ (to be presently described), show a *preference* for the Milky Way, as marked almost as the *avoid-*

ance of this zone in the case of the irresolvable nebulæ. And, further, it is noteworthy that, taking the nebulæ in classes according to their resolvability, we find, with gradually diminishing resolvability, a gradually diminishing preference for the Milky Way, then neutral dispersion, and finally a gradually increasing avoidance of that zone."

In these phenomena of distribution we find the nebulæ repeating what we have learned respecting the stars. They are segregated into distinct areas, they form streams, and, moreover, these streams coincide with well-known star streams. The conclusion that must be drawn from these facts is patent: the nebulæ are not systems of stars immeasurably distant from the stellar system, but form an integral part of the sidereal system.

Some of the nebulæ are resolvable into irregular or globular clusters of stars. They seem to be of much the same nature, but the irregular clusters are less condensed, and do not show marked signs of condensation, as is the case with the globular nebulæ.

A second class are known as Resolvable Nebulæ. They are resolvable into bright points, and are generally circular in outline. They differ from the clusters in having no outlying branches; but this may be due to their being too distant for such portions to be visible.

The third kind are known as Irresolvable Nebulæ, and include three main divisions, the *elliptic*, *spiral*, and *irregular*. The elliptic variety are of all shades of ellipticity, and are always densest in the centre. The spiral kind are very remarkable objects from their fantastic shapes; and the irregular variety is also very singular.

A fourth class of nebulæ are called Planetary, because they appear as discs of faint light, which is sometimes equable all over the surface, sometimes mottled, and sometimes covered with curious branches of rather intenser light. Some of them are of a blue colour.

Double Nebulæ form a fifth class, and their components bear the same relation to each other as in the case of the double stars.

Spiral Nebulæ constitute a sixth class of nebulæ, which, however interesting they be, we must pass over, as we have the others, with but scanty notice.

A seventh class are known as Nebulous Stars, which are very singular. They consist of nebulæ intimately connected with stars. Some contain a bright star in the centre, some are double with a star in each, and others a pair of double stars associated with two nebulæ close enough together to form one system. Such close associations of stars and nebulæ point but to one conclusion, namely, that they are not only apparently but actually connected, and so clear did this seem that even Sir W. Herschel, who looked upon nebulæ as great sidereal systems beyond our own, not only recognised this as a necessary consequence, but regarded them as stars in process of formation, the nebulous matter having partially condensed. This seems to be a legitimate deduction, and its importance will be hereafter indicated.

An eighth class are formed by the Irregular Nebulæ, which, with one exception, lie in or near the Milky Way, and that, too, in such a manner as to lead Sir W. Herschel to remark that even the great nebula in Orion (of which we shall have more to say presently) is situated in a faint prolongation of the Milky Way.

The last and ninth class are the Variable and Temporary Nebulæ. Of the former one of the most remarkable is that which surrounds the variable star η Argûs, an association which of itself suggests an actual connection. This Sir J. Herschel was not inclined to admit, for he says that in "looking at the Argo nebula, we see through and beyond the Milky Way, far out into space through a starless region, disconnecting it altogether from our system." M. le Sueur, who discovered the variability of the nebula, was at first of opinion that it was nearer to us than the star, but he subsequently came round to Mr. Proctor's way of thinking, on finding that the spectra of both star and nebula were alike. Nebulæ have sometimes appeared where before no signs of them could be seen, and others which have been carefully examined have disappeared. In one case, indeed, a bright nebula diminished until it appeared as a small star, which faded away and was replaced by a nebula which eventually vanished; all these changes taking place within one month.

Such are the characteristics of the nebulæ as observed by telescopic power. Until the spectroscope was applied to them by Dr. Huggins, the opinion was pretty general that the irresolvable nebulæ would be resolvable into small stars by means of greatly increased magnifying powers. The spectroscopic examination of the nebulæ was, however, one of immense difficulty, for the light is so faint that Dr. Huggins estimates that a single sperm candle, burning 158 grains per hour, viewed at a distance of a quarter of a mile, is 20,000 times brighter than a nebula! And this faint glimmer has to be reduced in quantity, in passing through lenses and prisms, and then spread out, before the spectrum can be observed. Yet so skilfully were these difficulties surmounted that Dr. Huggins's researches upon the nebulæ are as reliable as the multiplication table. The first nebula examined was one of the Planetary variety. One cannot but envy the illustrious doctor the delicious excitement which he must have felt when, all arrangements complete, he knew that he had only to apply his eye to his spectroscope to settle once and for ever the question which had so long vexed the scientific world, as to whether it was possible for nebulæ to consist of incandescent gas. The spectrum would at once reveal whether the nebula was composed of solid or liquid matter, whether such matter was surrounded by an incandescent gaseous envelope, whether that envelope was of higher or lower temperature than the nucleus, or, finally, whether it consisted wholly of incandescent gas. Up to the final moment before bringing the image of the nebula on to the slit of the spectroscope all was uncertainty. One glimpse and that uncertainty was gone for ever. The spectrum showed three bright lines. The nebula consisted of incandescent gas; and thus this question was settled. Some of the Irregular Nebulæ were then examined, and were found to be characterized by the same spectrum of three bright lines. After examining about 70 nebulæ Dr. Huggins came to the conclusion that they could be divided into two great classes: one of which, comprising about one-third of the number, are truly gaseous, and give a spectrum of three bright lines; the rest give a continuous spectrum, but in some part of the spectrum is missing—in that of the nebula in Andromeda, for example, the red and part of the orange are wanting. To test the truth of the hypothesis that all resolvable nebulæ consist of small stars, this gentleman examined a number of them, and found to his astonishment that many gave the now well-known gaseous spectrum of three bright lines. Thus, the splendid nebula in Orion was found to present the same spectrum from the denser as from the more attenuated portions, although Sir J. Herschel had said (and quite justifiably at the time) that "there can, therefore, be little doubt as to the whole consisting of stars too minute to be discerned individually."

Of the three bright lines in the nebular spectrum the brightest is found to coincide with one of the nitrogen lines, the faintest agrees with the green line of hydrogen, but the middle line has not yet been referred to any known element. But hydrogen has a spectrum of three, and nitrogen of many lines. Inasmuch as only one of each of these has been detected in the nebular spectrum, are we justified in ascribing them to those elements? Dr. Huggins has settled this question in the affirmative by showing that when the intensity of the light from these spectra is diminished, the lines fade away, leaving finally only those which are found in the nebular spectrum. We have before remarked upon the exceeding faintness of the nebular light, and hence we are perfectly justified in saying that hydrogen and nitrogen exist in these nebulæ. The question of the nature and bearing of nebulæ upon the origin of the solar system will be dealt with in a future chapter.

It has now been shown that the sidereal system includes not only the stars but the nebulæ also, and that at present there are no grounds for the belief that in these latter bodies we see other stellar systems separated from that of which our sun is a member by vast regions of empty space. The system thus assumes a far greater complexity than it was of yore believed to possess. We find stars large and small aggregated in streams and clusters, and sweeping in systems along unknown paths; we see these stars variously coloured, and varying in their colour; we see them forming pairs, revolving about one another under the influence of gravitation, and we notice that many of them are variable in their magnitude, and some even disappear altogether. In like manner we observe the strange nebulæ segregated into clusters and gathered into streams, and, moreover, some of these are identical with prominent star-streams. We find nebulæ in every stage, from highly attenuated gas to bodies with signs of condensation, and from these to nebulæ enclosing stars; and the conclusions are forced upon us, firstly, that both stars and nebulæ form part of one great system, and, secondly, that the stars have in all probability once themselves been nebulæ. Our sun is a star, and a variable one, and we are hence enabled to sketch, roughly it is true, but still with some degree of certainty, the steps in the evolution of worlds.

Let us now epitomise this information.

1. The stars are so distant from us, that the distances of only a few have been determined, and these only approximately.
2. Stars are gathered into clusters and streams.
3. Many of the stars of small magnitude are

actually small, and do not owe their apparent size to their greater distance.

4. The stars are moving in unknown orbits.

5. Systems of stars are moving in the same directions.

6. Stars differ much in colour, and this colour in some cases varies periodically.

7. The colours of stars depend upon the nature of the gaseous envelopes that surround them, as shown by their spectra.

8. Stars may be grouped into four great classes according to the nature of their spectra.

9. Our sun belongs to one of the larger groups.

10. Some stars vary in magnitude. This, in two cases at least, is known to have been occasioned by a fearful outburst of burning hydrogen.

11. Certain stars under high powers are shown to be double, and these mutually obey the law of gravitation.

12. The nebulæ obey the same laws as stars, so far as regards their distribution.

13. They are part of the sidereal system.

14. They are of many kinds, and can be seen in all stages, from gaseous nebulæ to incipient stars.

15. Some of them are purely gaseous.

16. Others are solid or liquid.

17. The sidereal system is composed of the same kinds of matter, acted upon by the same laws, as terrestrial matter.

CHAPTER V.

THE SOLAR SYSTEM.

AT the commencement of the present century the solar system was looked upon as comparatively simple in structure; consisting, in fact, of little more than a series of seven planets circling in elliptic paths about the sun as a focus, and a few comets revolving in very eccentric orbits around the same luminary. All this is now changed, and we have to look upon our system as a complicated structure, including a vast number of planets, some very large and others exceedingly small, but all revolving pretty much in one plane and in one direction in orbits that do not vary much from circularity. An equally imposing array of comets is travelling in all sorts of planes, with all kinds of orbital inclinations, in different directions; some of which are permanent members of the system, some chance immigrants from space, which visit us but once to speed away for ever into illimitable distance; others are pulled into the system by the major planets to circle for a while and then be ejected from the scheme by the agents of their introduction. Besides these there are unknown numbers of systems of tiny meteors flying around the sun in orbits which vary from almost perfect circles to vastly elongated ellipses extending beyond the orbit of the most distant planet. All these have their perihelion passage pretty close to the sun, and the glorious crown of light which bursts forth from that body during a total eclipse is in all probability due to the presence of these systems of pocket planets, as, too, is most likely that varying pale and wonderful arch of light known as the zodiacal light. Some of these systems seem to fly after certain comets, following them in their ceaseless rounds. In addition to all this, the whole interplanetary space seems to be full of impalpable meteoric dust, varying in quantity in different parts of the system, and like the meteors just described, constantly being drawn into the sun and planets to add to their bulk, to a trifling but nevertheless important degree. The sun himself is now known to us, not merely as a great master ruling his subjects by the force of his incomparable gravitation, but influencing them in many ways. Further, he is known to be the seat of violent eruptions and cyclonic storms of incandescent matter. The rates of the one have been measured, the flames of the other are a matter of daily observation. His very origin, age, and duration have become matters of scientific speculation. Again, the planetary motions, once deemed so simple, are found to be full of recurring perturbations, whose effects come home to us in a very forcible manner, as influencing the climate of our globe and revealing the long hidden cause of those climatic revolutions which geology has unfolded. We will consider these points in rotation, dealing with them only so far as is essential to our purpose, and taking for granted that such elementary knowledge as is to be found in all geographical primers has formed part of the reader's studies.

Commencing with the planets, and starting from the sun, we encounter Mercury, Venus, Earth, and Mars, planets pretty much alike in size, and revolving upon their axes in about twenty-four hours. Then comes a system of very small orbs, known as asteroids, of which there are in all probability many thousands, but of which up to the present time (August, 1877) only 171 have been discovered, though every year adds to the number. Beyond the zone of asteroids we come consecutively to Jupiter, Saturn, Uranus, and Neptune, a splendid series of orbs very much exceeding the earth in magnitude, and all revolving upon their axes in about ten hours.

It thus appears that the planetary system is divided into two parts by the zone of asteroids, and that there are certain signs of similarity in the members of each group, to which signs may be added the fact that while all the large extra-asteroidal members possess satellites or moons, our earth is the only one so favoured in the intra-asteroidal series.*

* Two satellites have just been detected belonging to Mars

Although the planets are thus separable into three series, the intra-asteroidal, the asteroids, and the extra-asteroidal, they nevertheless constitute one system, whose members agree in many points, as in the direction of their axial and orbital motions and in the laws which regulate the velocities of their revolutions. The earth, as a planet, partakes of these peculiarities, and from the study of terrestrial movements we can determine those of its companions.

We will commence our examination of the planets with an account of the action of gravitation. A body as a whole must be in a state of rest or motion; we say as a whole, because we are not now concerned with those invisible molecular movements that have before passed under our consideration, but only with the motions of bodies which cause them to change their position in relation to other bodies. If a body, as a stone, could be placed in space out of the limits of the action of any force, it is evident that it would always remain at rest; and if it were then set in motion it would move on for ever in a straight line. But if we loosen our hold upon a stone at an elevation it does not remain stationary in the air but descends in a straight line to the earth. It is clear that some force is acting upon the stone; it is equally evident that the force was not imparted by us, and

(Aug. 1877). This interesting discovery was made by Prof. Asaph Hall, of Washington, U.S.A. They are very small, probably not exceeding ten miles in diameter.

it follows that the earth must have exerted the influence. Moreover, while the stone was held in the hand we were conscious of the existence of a force tending to drag it down, which force we call the weight of the stone, and which required a certain effort on our part to overcome. If the stone had been very large this force would have mastered our efforts to retain the stone, and it would have dropped in spite of us. If now, being upon the ground, we throw a stone directly upwards, the force we impart to it is sufficient to carry it onwards for ever with a certain velocity, provided no other force is acting upon it; but as a matter of fact, that velocity is only attained at the instant at which the stone leaves the hand, and it steadily decreases, at length is destroyed, and the stone descends with a gradually augmenting speed and finally reaches the spot whence it was projected with the velocity it had at starting. Why should the stone only travel a certain distance and then return? It is clearly no answer to say, the force originally imparted was only sufficient to carry it so far; because, were that the case, the stone having reached its farthest limit would stop and remain there, for evidently there is no reason why it should return. Two things seem to have happened. First, the original, or as it is termed the initial, force has been gradually destroyed. Secondly, the instant the stone stopped in its upward journey, a fresh force seems to have been imparted urging it downward. Now delicate experiment has shown that the gradually increasing speed at which it descends is exactly like the gradually decreasing speed at which it ascends, so that whether in rising or falling the speed at any one position is the same. How then can we explain this phenomenon? Let us try another simple experiment. Instead of throwing the stone vertically upwards, let us project it at an angle. If no other force than that we impart be acting upon it, the path will be a straight line at the given angle, and the stone will move on for ever. Instead of this the stone describes a curve, and finally reaches the earth at the same angle at which it was projected. In this case the stone has swerved from its normal path; in the former experiment it did not, the direction of the motion merely being reversed. The only path a body can follow under the influence of one force is a straight line; hence our stone in the last experiment has been influenced by some other force than that of projection, and the only source of that force is the earth. In the case of the stone let fall from a height, and of that thrown vertically upward, we are also justified in ascribing to the earth the force which in the one case caused the body to fall and in the other to gradually diminish the velocity and then reverse the motion. We can also see from these experiments that the force acts in a direction perpendicular to the earth's surface, otherwise the stone when thrown directly upwards would have swerved from its path. Now a force may act instantaneously as an impulse, or continuously as an attraction or repulsion. As the stone at a height was acted upon it is plain that the earth's attraction is not an impulse, or it would only have acted *on* the earth, and only for an instant; it is clearly continuous, for in the first experiment the speed was accelerated all the way to the ground, in the second it diminished the speed in the ascent and increased it as it descended, and in the third it clearly acted throughout, because the path of the stone was everywhere curvilinear. Again, the force is certainly an attraction, because it tended to draw the bodies downwards. Now this force is called gravity, and we have proved that it is an attraction acting in straight lines directed towards the earth's centre, and that it can act at a distance.

Magnetism exercises such an attraction upon iron. It will draw particles of iron to itself and hold them there, and the force necessary to draw them away is the measure of the force with which it holds them. It is only because the effects of gravity are matters of daily observation that its influence is unrecognised; but the weight of a body (leaving out of consideration the counteracting effects of the earth's rotation) is as truly the measure of the force of gravity as the power necessary to remove the bits of iron is the measure of the force of the magnet. But magnetism only attracts certain kinds of matter, and it is evident that, supposing the earth were a magnet and possessed no gravity, if we threw pieces of wood or stone into the air they would never fall, but travel onwards in the line of their projection. Pieces of iron, however, if thrown upwards, would fall under the influence of magnetism. Gravity, however, as daily experience teaches us, acts upon all kinds of matter, and it would assuredly surprise us if a body could be found which, when released at a height, would not descend, or which, if thrown upwards, would not fall; yet such would be the case if gravity did not act upon it.

Gravity, then, acts upon all kinds of matter; but it may be asked, does it act equally upon different materials? It would seem at first sight that it does not, for if a sheet of paper and a bullet be dropped from a balloon the bullet will reach the ground first. A little reflection will show us that this experiment is not to the point, for the bodies do not fall under the sole influence of gravity, but are acted upon by the air, and as the area of the paper is much greater than that of the bullet, it is much more impeded. If the bullet were beaten out into a sheet it would fall much slower than before; yet we here see that gravity is acting not only upon the same kind but upon the same quantity of matter. It can easily be proved, however, that it does act upon all materials alike, for if two bodies, say a coin and a feather, be let fall at the same time in a vessel from which the air has been exhausted, they will reach the bottom together.

This experiment leads to another inquiry. The mass of matter in the coin is clearly greater than in the feather, for a cubic foot of gold evidently contains much more matter than an equal bulk of feathers; yet, as both fell at the same rate, it appears that gravity acts upon each atom independently, as it were. Thus a great mass of matter, say iron, falls at the same rate as a small one, and if we broke up a mass into minute fragments they would fall through the same space in a given time as would the entire mass.

This phenomenon suggests another inquiry. Where does the source of gravity reside? Is it in the earth, as a whole, or does each particle attract every other? If each particle acts upon the other, it evidently follows that, inasmuch as everything we can project into the air is part of the earth, such fragments must not only be attracted by the earth but they must in turn react upon the earth. We have seen that the force of gravity acts in straight lines directed towards the centre of the earth. If, now, gravity acts only at the centre of the globe, it is clear that any portion of the earth's surface is inert in this respect. It has, however, been found that a plumb line which, by virtue of gravity, hangs perpendicularly to the surface of still water, is deflected from its position in the vicinity of mountains; the mountains, in fact, possess the power of attracting matter. Gravity, therefore, is a property of matter, and it has been found to act in the case of very small bodies; hence we are justified in saying that every particle of matter attracts every other particle.

This is very different from saying that every mass of matter attracts every other mass *equally;* and experiment and mathematical analysis have proved that the attraction is proportional to the mass—that a body having twice the mass of another will attract it with twice the force that the smaller one exerts upon the larger. It follows from this, that a body thrown upwards attracts the earth towards it, but as any such body bears but an infinitesimal proportion to the mass of the earth its influence is inappreciable. We shall return to this question when we have considered the effect of distance upon gravity.

It has already been stated that a falling body has an accelerated motion. If it attains a given velocity in one second it will possess twice that speed at the end of two seconds, three times at the end of three seconds, and so on. This, and the other laws relating to time and velocity, have been rigidly tested by experiment by means of a beautiful machine, which allows the speed to be diminished to any amount while still acting under the influence of gravity. By this machine it can be proved that the space fallen through is as the square of the time; that is to say, if it fall through a certain space in the first second, it will fall through $2 \times 2 = 4$ times that distance in the second second, through $3 \times 3 = 9$ times that space in the third, and so on.

This last experiment leads us to important conclusions. It shows us, firstly, that the force of gravity varies with the distance, growing very appreciably less as the distance increases. On the supposition that such is not the case, a body would fall with uniform motion; and if gravity increased only for a certain distance, bodies would fall very differently from what they do. Let a body, for example, fall for one second under the influence of gravity, and then suppose that force to be obliterated. The body will, of course, continue to fall, but its velocity will be uniform, and will be that acquired at the end of the first second. This will obviously be such as to carry it over twice the space fallen through in that second. Now we can apply this reasoning to every second of time with like results; hence we are justified in concluding that, as the velocity of falling bodies is uniformly accelerated, the force of gravity must diminish with the distance.

We can go further than this, and determine the law which regulates the force with respect to distance. We have shown that the space fallen through in successive seconds increases as the square of the units of time. Thus in the second unit it falls through twice the distance it did in the first, in the second four times, in the third nine times that distance, and so on. Now a body thrown vertically upwards obeys this law, and the distances passed through in successive seconds vary inversely as the square of the distance. Thus, if its velocity at starting be such as to carry it through 64 feet in 8 seconds, it will at the end of 4 seconds have a speed that would carry it through 16 feet in 4 seconds, and

4 is the square root of 16. It is thus evident that gravity varies inversely as the square of the distance.

Thus by reasoning from simple data we have learned the fundamental laws of gravity, and these laws are thus expressed by Newton, their discoverer: *Every particle of matter attracts every other particle with a force proportional directly to the product of the numbers representing their masses and inversely to the square of the distance separating one from the other.*

It must not be thought that the laws of gravity were deduced by Newton exactly by the method we have adopted to utilise them, for this was by no means the case. The present exposition has simply been adopted to show how from the study of simple phenomena the great principles of gravity can be deduced. It will presently be seen how gravity (or gravitation, as it is termed when applied to extra-terrestrial bodies) is one of the most important forces in nature, so far as the magnitude of its effects is concerned, and thus we again are impressed with the truth of our fundamental doctrine that the earth is indeed a type of the universe.

Newton's own proposition respecting gravitation differs from that above italicised in the addition of the words "in the universe" after the phrase "every particle of matter." This grand speculator first of all nobly guessed that the planetary motions were due to some such force, and then brought his great powers of mind to bear upon the question and demonstrate its truth. We, however, will proceed upon a lower but not less sure plan. It is now proved that gravitation can act at a distance, and there is no reason why any limit should be assigned to the distance at which it can act; so that we may assume that it does actually exert an influence upon bodies at immeasurable distances—that is, as Newton puts it, every particle of matter in the universe attracts every other particle. This will be conclusively proved in the sequel.

We have hitherto spoken of gravitation irrespective of the shape of the body exercising it. It is necessary to consider the case of a sphere. Suppose the earth to be a perfect sphere, and a plumb-line to be suspended over a given point, it will hang in the direction of the radius. But every particle of the earth is acting upon it independently. A particle, say one yard distant from the point towards the east, tends to pull it in that direction, but there is a corresponding particle one yard to the west which exercises an equal influence in a precisely opposite direction; and these two forces neutralise each other so far as their power to deflect the line is concerned. For every point not in the direction of the radius there is a corresponding and counteracting one, and consequently a plumb-line will hang in the direction of the radius no matter over what spot it be placed. A set of plumb-lines on a circle of longitude would clearly point inwards towards the centre of the sphere like the spokes of a wheel to the axle. In other words, the gravitation of a sphere acts as if it were all collected at the centre. For our present purpose we may consider the earth as a true sphere, and its gravity as stored at the centre.

The earth revolves upon its own axis, hence every particle of it is in motion. Let us consider a loose body upon the surface, say at the equator where the motion is greatest. This body has motion imparted to it, and from what has been said before, it therefore has a tendency to move in a straight line, and if there were no gravity it would pass away from the earth in a line tangent to the earth's surface at the point on which it rested. It cannot, however, take such a path because it is held back by the gravity of the earth. Upon such a body two forces are acting, one tending to carry it away tangentially, the other to drag it towards the earth's centre, and a stone can only lie upon the surface at the equator because the latter force is greater than the former. Roughly speaking, the earth's ~~diameter~~ circumference is 24,000 miles, and one complete rotation is performed in 24 hours; hence the velocity at which bodies at the equator are carried round is about 1,000 miles an hour, or 16·6 miles per second. Another way of viewing this question is to look upon the weight of a body as the measure of the force exercised upon it by gravity, which we have seen is really the case. Now the effect of the revolution of the earth is to counteract this force to a certain degree; hence the body in question weighs less than it would if the earth were at rest.

Now suppose the speed of rotation to be increased to such an extent that the effect of gravity is exactly counteracted,* and the body rendered weightless. Further, let us imagine the body to retain its position but the earth to diminish in size equably until it became a mere point, still retaining the gravity of the whole mass. The body has still the same tendency to fly away from its position and the same tendency to seek the centre, but it can do neither the one nor the other. It will, in fact, continue to follow the same path it pursued when lying upon the surface. That is, it will revolve with uniform velocity in a circular path about the centre at which the earth's mass is collected.

Moving bodies acted upon by a force tending to draw the bodies to a point are said to be under the influence of central forces. Such bodies of necessity describe curves; and Newton has shown that these curved paths must of necessity be either circles, ellipses, parabolas, or hyperbolas. They must, moreover, describe equal areas in equal times; that is, the triangles made by drawing straight lines from the positions of the body at equal intervals of time to the centre of force are equal in area, even though (as in the case of elliptic orbits) the velocity is far from uniform. If the body, as in our supposed case, be travelling in a circle its velocity is uniform, and it is self-evident that it describes equal areas in equal

* It would then have a velocity of 185·5 miles per second; *i.e.* 17·2 times its present speed.

times. But a body can only so travel if the direction of its motion at any moment be square or tangential to the line of central force. If it be otherwise, the path will be an ellipse, a parabola, or a hyperbola—an ellipse if its velocity be equal to or less than that which would entirely free the body from the control of the central force, and a parabola if the speed be increased beyond this quantity up to a certain rate, at which the path would become hyperbolic.

Let us consider the case of an elliptic orbit. At one point the body is nearest to, and at another farthest from, the focus towards which the central force is acting. The nearer the body approaches that focus the stronger is the influence of the central force upon it, and the quicker it will move; and the farther it is from the focus, the weaker is the influence, and the slower it will travel. As the distance increases the velocity diminishes; but it is always such that if at any point it were moving square to the line of force it would travel in a circle around the focus as centre with the velocity it then possessed, and in the same time or period. Consequently in dealing with a body travelling in an elliptic path under the sway of a central force, whether the maximum, minimum, or mean velocity be taken, it is always such as would carry the body at that distance and with that velocity in a circle around the centre of force. Some idea of the increase of velocity with decrease of distance can be obtained by means of a string, say four feet long, to one extremity of which a ball is attached, the other end being held in the hand. If the ball be swung round the head horizontally, it will move as under the influence of a central force. Let it be swung steadily so as just to keep the path horizontal, the motion will of course be uniform. Then let the string gradually coil round the finger, so that the distance is decreased though the actual force applied is the same; the ball will move quicker and quicker as the distance decreases, until by the time it reaches the finger it will be flying at a great speed.

It can be demonstrated mathematically that if a body describe an elliptic path under the influence of a central force, it will sweep through equal areas in equal times, and the force must act inversely as the square of the distance. We have shown that gravitation acts in this way, and long before the laws of gravitation were discovered Kepler showed that the planets travel about the sun as a focus in elliptic orbits, and that they do actually describe equal areas in equal times. These statements are known as Kepler's first and second laws. The same astronomer also worked out a third law of even greater significance, which will be discussed presently.

From observations upon bodies thrown upwards vertically and obliquely, and dropped from a height, we have now demonstrated not merely the existence of terrestrial gravity and the laws which relate to it, but the fact that it acts at considerable distances from the surface of the earth; and from the deportment of a stone lying at the equator, and carried round by the earth's rotation, we have deduced the doctrine of the action of central forces. It remains for us now to see whether we are justified in assuming that there is no limit to the distance at which gravitation can act. When Newton made his noble guess that the planetary motions were ruled by the force to which he gave the name of gravitation, he applied his theory to the motions of the moon; and not until he proved that they were amenable to these laws did he deem his theory established, although he had to wait nearly twenty years before the test could be satisfactorily applied, in consequence of the inexactness of the data when first his idea was worked out. Let us see how this can be effected. We know the size, mass, distance, and period of the moon. Taking the earth's radius as 1, the moon's distance is about 60, and she revolves about the earth in a little over 27 days; but if gravitation at her distance were as powerful as at the earth's surface, this speed would be far too small to enable her to retain her position; she would have to rotate in about 10 hours. Hence we see that if she is maintained in her position under the influence of gravitation, that force must be much less at the moon's distance than at the earth's surface; it must, in fact, be 3,600 times less energetic. But 3,600 : 1 :: $60^2 : 1^2$; that is, the diminution is inversely as the square of the distance, which is just the amount required by the theory. Not only in this simple matter does the law of gravitation hold good, but the moon's motions, owing to various circumstances, are very irregular; yet every variation is explicable on the theory of gravitation. It would, however, be beyond our purpose to enter upon this question, and the student who desires to master the subject must consult some special treatise.

Kepler discovered a third law relating to the planetary system, which is of immense interest as showing a real and intimate connection between the members of that system. If we tabulate the mean distances and periods of the planets, we find that as the distances increase the speeds diminish: the Earth, as an illustration, travels faster than Mars and slower than Venus. The decrease is not, however, directly proportional to the increase of distance, as is at once apparent; for the period of Mercury is roughly 88 days, and that of Venus 224 days, or in the proportion of 1 : 2·5, and the distance of the former is 35,392,000 miles, and of the latter 66,134,000 miles, or in the proportion of 1 : 1·8. Neither is the increase of period so fast as the squares of the distances; but if we take the *squares* of the periodic times and the *cubes* of the distances, we obtain the proportion. Thus the periods of the Earth and Mars are as 365·2564 to 686·9796, and their distances from the Sun as 100,000 to 152,369, and $(365{\cdot}2564)^2 : (686{\cdot}9796)^2 :: (100{,}000)^3 : (152{,}369)^3$. Kepler's third law may, therefore, be thus enunciated:—The squares of the periodic times of any two planets are to each other in the same proportion as the cubes of their mean distances from the sun. This remarkable law, as Sir John Herschel forcibly remarks, is "pregnant with important consequences. When we contemplate the constituents of the planetary system from the point of view which this relation affords us, it is no longer mere analogy which strikes us—no longer a general resemblance among them, as individuals independent of each other, and circulating about the sun, each according to its own peculiar nature, and connected with it by its own peculiar tie. The resemblance is now perceived to be a true *family* likeness; they are bound up in one chain—interwoven in one web of mutual relation and harmonious agreement —subjected to one pervading influence, which extends from the centre to the farthest limits of that great system, of which all of them, the earth included, must henceforth be regarded as members." *

Slowly and steadily the foundations of this great theory have been laid, and as certainly is the vast architecture of the solar and stellar systems being built thereon. As yet the pile is far from complete, but each year adds some portion, and the time may not be far distant when we shall be able to grasp with the assurance of truth not merely the anatomy of the scheme but its physiology also—not merely what it is, but how it works. We now recognise our earth as one of the family of planets ruled by

* "A Treatise on Astronomy," p. 264; 1851.

the sun; and ruled, moreover, by a force not peculiar to that great luminary but common to every atom of matter in the universe—common, therefore, to every atom of terrestrial substance; from which it follows that, from the study of the motions of such matter at or near the earth, we can deduce the laws which regulate the motions of every other particle and mass in the universe. Thus forcibly is brought home to us again the truth of our fundamental principle that the earth is a type of the universe.

Mr. Proctor, in his admirable work upon the sun, devotes a chapter to the ruling powers of that body; and, by a train of simple and elegant reasoning, shows how to calculate the maximum velocity a body at a given distance from the sun must have to free it from his control so far that it will no longer describe a closed path about the sun, but travel onwards for ever. He shows that if the earth's mean velocity (18·2 miles per second) be increased in the proportion of $\sqrt{1}$, or about as 1,414 to 1,000, it would possess sufficient energy to travel right onwards into space. This increase would only require to be from 18·2 miles per second to about 25·7 miles. It is further shown that this law holds good for all the planets, and by combining the mean distances with the velocities of the planets a most remarkable fact becomes apparent. In the annexed table this combination is made:—

Planet.		Mean distance in miles.	Mean velocity in miles per second.	Velocity increased as 1414 to 1000.
Mercury	..	35,392,000	29·3	41·4
Venus ..	..	66,134,000	21·4	30·3
Earth ..	..	91,430,000	18·3	25·9
Mars ..	..	139,311,000	14·7	20·8
Asteroids	..	250,000,000	11·0	15·5
Jupiter..	..	475,692,000	8·0	11·3
Saturn ..	..	872,137,000	5·9	8·3
Uranus..	..	1,753,869,000	4·2	5·9
Neptune	..	2,745,998,000	3·3	4·7

On comparing the velocities in the two last columns it is seen that the velocity a planet must acquire to free itself from complete solar control is roughly that which the next inner planet possesses. Thus Neptune would be almost freed if he had the velocity of Uranus, Uranus would be just freed with the speed of Saturn; and so on, the law becoming less evident as the sun is approached. Now, the velocity a planet requires for freedom is just that with which a body travelling towards the sun from an infinite distance along a parabolic orbit would pass the mean distance of the planet. Such a body would, of course, pass round the sun, and then speed away on its parabolic path for ever. Kepler's third law announces a certain relation between the distances and velocities of the planets; Mr. Proctor's curious illustration reveals the relation between the velocities of the planets at their mean distances and the controlling power of the sun. Looking for the present at distance alone, there is no *à priori* reason why the planetary distances should follow any regular law, but as a matter of fact they do. Bode long ago recognised this, and showed that the distance of any planet from the next inner one is about twice that of the inner planet from its next inner one; thus Mars is twice as far from the Earth as Venus is, Uranus twice as far from Saturn as Jupiter is, and so on. This duplication of distances does not, in all probability, directly result from any physical necessity; but when we find it associated so closely with the velocities, its signification becomes apparent, though its explanation may be hidden from us.

From these laws it is easy to calculate the maximum and minimum speeds that the sun can control at any distance, or it may be estimated directly from the law of the diminution of gravity with the distance. It can thus be shown that if the distance be reduced one-fourth the velocity will be doubled. At his surface the sun can control a speed of 378·9 miles per second; hence if a body be projected from his surface this is the least velocity that will carry it beyond his control. It also follows that no body can reach him with a greater velocity than this unless some share of its motion is due to other than solar gravitation. Now we have seen that the limits of solar control at the earth's mean distance is 25·9 miles; this, therefore, is the extreme velocity a body can have at that distance to travel in a closed orbit round the sun. Yet some of the meteors cross our orbit with a greater speed than this; hence they possess some extra-solar power, and will sweep round him and then fly away for ever. Moreover, the least velocity with which a body could travel so as to reach the earth, and then pass round the sun close to its surface is about 1·85 miles per second. No meteor, then, can reach our earth with a less motion than this without having been projected from the sun.

Here we must leave this interesting study, our object in treating it at such length being to show how from such simple observations as the motions of a ball tossed into the air, and the calculations based upon such observations, the mechanical principles which govern the universe can be established. Truly we are linked to every part of that universe by strong bands. Yet in this chapter we have only touched upon a few of the most obvious of these relations; and when we reflect that every perturbation in the orbits of the planets and their satellites is explicable and measurable by this method, we begin to perceive the majesty of our world.

Under the influence of gravitation the planets sweep round the sun in elliptical orbits. All travel in the same direction, which is also that of their rotations upon their respective axes. Those which possess satellites (the earth, Mars, and the extra-asteroidal planets) play the part of suns to them so far as gravitation is concerned, and compel them to describe elliptic paths around their primaries and in the same direction as they themselves rotate. Again, the planets all revolve pretty much in one plane and that not very different from the plane of the sun's equator. These, with the phenomena above described, are the sole evidences we possess of orderly sequence in the system; for, whether we regard their sizes or masses, the inclinations of their orbits or axes, or the eccentricities of their orbits, we fail to find any trace of law.

So far we have dealt only with the motions of the planets, and it remains for us to sketch a few of their physical relations. As respects their chemical constitution we know very little from spectroscopic research, and for the plain reason that they shine by reflected sunlight, and are not self-luminous, or if so to such a feeble extent that their light is overpowered by that which falls upon them from the sun. Nevertheless, it is perfectly legitimate to assume that they consist of the same kinds of matter as exists on the earth, and as have been detected in all the self-luminous orbs of heaven. If it were not so they must be different from all other bodies, and what is still more conclusive, different from the earth, which is part of the same family and obedient to the same laws.

The spectroscope, however, is not altogether silent, for the planetary atmospheres show absorption bands similar to those produced by the terrestrial atmosphere. In the spectrum of Jupiter one band corresponds with one in the earth's atmosphere, showing the presence of vapour, and another band is not referable to any known substance. Saturn's spectrum also shows the presence of atmospheric vapour. The spectrum of Uranus shows six absorption lines, of which one appears to be coincident with the F line of hydrogen. In the spectrum of Neptune the red end is missing, and three bands are seen which have not yet been referred to any known substance. The spectrum of Venus shows no particular features, but that of Mars is interesting. Dr. Huggins, who describes the spectrum, says he saw groups of lines in the blue and indigo, but was unable to fix their exact position owing to their faintness. The C line in the red of the solar spectrum was plainly visible, and in the less refrangible portions several dark lines were seen, of which one appears to be decidedly due to the action of the Martial atmosphere. Other lines on both sides of the sodium line D were also detected, and seem to show the presence of vapours in the atmosphere similar to those in our own. Meagre as these details at present are, they nevertheless enable us to pronounce a decided opinion that the constitution of the planets is similar to that of our earth.

The disc of Mars resembles that of the moon in being brightest at the edge, and it has been shown that this is a phenomenon observable only when the light is reflected from the actual surface of the planet. The light of Jupiter and Saturn, for instance, has come from their cloudy envelopes, and is less intense at the margin than at the centre of the disc. The light, moreover, of Mars varies as the planet increases and decreases in phase, and this with the increase of brightness of the limb has been accounted for by supposing the surface to be rugged. This, however, necessitates a series of slopes no less than 75° in inclination, and though this *may* be the explanation, such a peculiar landscape needs a great deal of confirmation before it is accepted. Mr. Proctor, who has studied the physical geography of Mars with great nicety, and has constructed an accurate map of the planet, suggests a simpler explanation of the phenomenon. The atmosphere of Mars, he points out, contains aqueous vapour, and variable white patches are now and then seen upon its disc, which are in all probability clouds. When our sky is thickly flecked with cumulus clouds, the blue interspaces seem to be largest overhead, and by the foreshortening towards the horizon the clouds seem more thickly spread there, although their distribution may be even. If, then, the atmosphere of Mars contains clouds, they will appear to be most thickly spread on the edges of the disc, and this would account for the brightness thereof. This feasible view of the matter is further borne out by the fact that the edges of the marks (considered to be continents and seas) become indistinct towards the edge of the disc, which is in accord with his explanation and at variance with the other.

Another very interesting feature of this planet is that a white patch is observable at each pole, and as they increase in the winter and decrease in the summer they are justly looked upon as polar snows. Mars does not differ much from the earth in size or density. His features can be more readily observed than those of any other planet, and hence he possesses singular interest to us. Moreover, his polar ice-caps are by some deemed to be types of what the earth must endure when the eccentricity of her orbit and the position of the solstices assimilate to his. We shall recur to this question; but it is absolutely essential that it be remembered that for Mars to be thus used as a test, his physical habitudes must be very similar to those of our earth. Yet it is easy to see that such could not be the case. If our earth were removed to the orbit of Mars all life would be destroyed in consequence of the intense cold that would prevail.

The mean distance of Mars is about twice that of the earth; consequently an equal area on the surface of Mars will only obtain one-fourth of the amount of heat received from the sun upon such an area on earth. We may take, for instance, the mean annual temperature of England at 50° F.; then at the distance of Mars its temperature would be 12·5° F., or 19·5° F. below freezing point, which is considerably below the mean temperature of any known place, and about equal to the temperature of south Greenland in January. Similarly the mean temperature of the equator is about 80° F.; at the distance of Mars it would be 20° F., or 12° F. below freezing point, which is about the mean temperature of Novaya Zemlia. Even the summer temperature of the Sahara, which is now 95° F., would fall to 23·7° F., or 8·3° below the freezing point.

But these calculations do not show the full extent of the cold we should suffer at the distance of Mars. As the oceans would be frozen, no currents could convey heat from the tropics to the polar regions, which would in consequence have their climates vastly more rigorous than has been assumed. If we are right, then, in calling the white polar patches on Mars ice-caps, it follows as a necessary consequence that the physical conditions of that planet are very different from those which prevail on earth. If his snows melt away under the influence of his summer heat, either the constitution of that snow is different from ours (which we have no right to assume), or he must possess a comparatively genial climate. But, to produce this, his atmosphere must be very different from our own; and if this be the case, we cannot, in the absence of any knowledge of the nature of his atmosphere, determine what train of consequences may flow from such a cause. It is, then, illogical to argue as to climatic changes from Mars to the Earth: firstly, because his physical conditions are very different from ours; secondly, because we are not sure that we are actually viewing ice or snow; thirdly, because we know nothing about the composition of his atmosphere.

It is not our province to describe what is known of the physical habitudes of each of the planets, but merely to call attention to a few points which have a direct bearing upon terrestrial affairs. We cannot, therefore, enter into descriptions of Jupiter, Saturn, or the other planets, much as such a subject would yield of surpassing interest. It is, however, necessary to state that the densities of these larger orbs are very small. Jupiter, for example, the most majestic member of the system, although more than twelve hundred times the size of the earth, only outweighs it 301 times, his specific gravity being only a little more than that of water. Saturn is even lighter, for though his magnitude is 696 times that of the earth, his mass only exceeds hers 89 times, and his specific gravity is only about half that of water. Now the only force we are cognisant of which would enable matter similar to terrestrial substances to exist under such conditions is heat; and just as we infer that the earth's interior is hot from its low specific gravity, so we may conclude that these orbs are also teeming with heat. But a body like the earth, if heated to such an extent as to reduce its density to that of Jupiter or Saturn, would glow, and if this reasoning be correct these orbs must act the part of minor suns to their trains of satellites, and this is the conclusion to which Mr. Proctor has arrived respecting all the larger planets. Mr. Bond has carefully studied the light of Jupiter, and has convinced himself that it really is self-luminous.

Saturn is a most remarkable planet, inasmuch as it presents to some extent a miniature copy of the solar system. Its eight satellites may be compared to the eight larger planets; and its marvellous rings, which appear to consist of vast numbers of tiny meteors, perhaps immersed in vaporous atmospheres, may be likened to the systems of meteors which circulate about the sun.

Jupiter and Saturn, however, possess a considerable interest to us, because from their immense masses they exercise a most important control over the earth's motions.* Inasmuch as every particle of matter attracts every other particle, and is attracted by them, the planets must mutually react upon each other. Suppose their orbits were to lie in one plane, and themselves to be so ranged that a line from the sun's centre to Neptune would pass through them all; and further, let them all revolve about the sun in the same time. The effect of all the outer planets upon the earth will be to draw it away from the sun, and that of the inner planets to bring it nearer to that body; but as these forces all act along one line, and as this will be the case in every position of the earth's orbit, the only effect will be slightly to modify the distance of the earth, and it, with its companions, will continue to revolve about the sun in truly elliptic paths. A similar train of reasoning will apply to all the planets.

* It need hardly be said that each planet is affected by every other planet.

But these conditions are not fulfilled: the planets never are all in one line, their orbits do not lie in one plane, and their periodic times are not equal. Nevertheless, their gravitation acts and must necessarily do so, and the result is that their paths are subject to slow periodic changes. The influence of the two largest planets is most severely felt, and hence they are often spoken of as the cause of these perturbations.

Now in estimating the disturbing effects of several bodies forming a system, it is found that unless exceedingly long periods are in question, we need not deal with each separate disturbing mass, but can treat the whole system as if it contained only three members—the central body, the disturbed body, and the disturber. The action of the disturber is to produce slight modifications of the movements of the disturbed; but this action is not directly as the power of the disturber, but as the difference between the central and disturbing forces; and as the power of the planets outside the earth's orbit is very small compared with that of the sun, the resulting perturbation is very small and very slow. It would be quite impracticable in a work of this nature to enter into the mechanics of this question, and we must content ourselves with the results, it being distinctly understood that these minor perturbations are not only rigidly measurable, but are the direct consequences of universal gravitation.

The action of the disturber, say Jupiter, upon the earth's motion about the sun is to modify the shape of the orbit, to make it more eccentric or more circular, according to the relative positions of the two planets. If Jupiter were stationary, this change would be permanent; but he revolves about the sun, and hence the perturbation is variable. The final result is that the eccentricity of the earth's orbit is constantly varying. At present it is growing more circular, and will continue to do so until A.D. 25,780. Since about 210,000 years ago it has decreased slowly and irregularly. The change of eccentricity, moreover, is not regular; that is to say, in one cycle from maximum to minimum neither the number of years in the cycle nor the amount of change is the same. It is as though we took a ring and slowly flattened it out, and then restored it almost to circularity, and continued this process at different rates and to different degrees. Besides this motion, the axis of the ellipse gradually changes its position, as though in the above experiment the ring was pulled out in different directions. The line joining the extremities of the elliptic orbit is known as the line of the apsides: the apsides, therefore, revolve, and a complete revolution would take place in 25,868 years if no modifying influence existed. In point of fact, the revolution is completed in about 21,000 years in consequence of a change known as the precession of the equinoxes, to be presently explained.

If the earth were a perfect sphere, the variations of the eccentricity and direction of the apsides would be the only perturbations to which it would be subjected. We know, however, that the earth is not spherical, but bulges towards the equator, and is flattened towards the poles. Now the moon does not circle the globe in the plane of her equator, and consequently her attraction is as it were sideways, or at an angle, and she obtains a kind of purchase upon the protuberant mass, the effect of which is to cause the axis of the earth to rotate about the pole of the ecliptic with a slow circular motion. The north end of the earth's axis at present is directed very nearly towards the Pole Star, whence the name, and if the axis were stationary that star would continue to lie in the direction of its continuation. But owing to the moon's action, the pole of the heavens describes a circle which would be completed in 25,868 years.

A good illustration of this motion is seen in the spinning of a peg top, which when revolving very rapidly *sleeps* or rotates evenly upon its axis; but when it begins to move more slowly the axis varies its inclination, and the top "wobbles," as the schoolboys say, and this motion is exactly like the one in question.

The immediate consequence of this is that the time occupied by the earth in travelling from any given position, say the vernal equinox to that position again, is diminished by about 20 minutes in each revolution, or, in other words, the earth does not have to travel through 360° to return to the same relative position to the sun, but only through 359° 59′ 49·0″. This is less than 360° by 50·10″, and 360° ÷ 50·10″ gives us 25,868 years as the time of one complete revolution.

From this perturbation an important result follows, namely, that the seasons do not always occur when the earth is in certain parts of its orbit; but summer in the northern hemisphere, for instance, has occurred, and will again occur, when the earth is nearest to the sun, and not when at its greatest distance as at present. In consequence of the equinoxes thus preceding their time, this movement is known as the *precession of the equinoxes.*

All this is only rigidly true on the assumption that the moon circles about the earth under its sole influence. This we know is not the case, for her path and velocity are being constantly modified by the sun. When she is between the earth and sun, he pulls her farther from her primary; when in the opposite position, the earth is pulled away from her satellite. Not only are her motions thus modified, but her revolution is so affected that her nodes (the points at which her path cuts the ecliptic) retrograde, producing a precession whose period is about 19 years. The effect of this upon the earth is to pull the protuberant parts in different directions, so that the pole of the earth would describe a small ellipse in 19 years. It cannot, however, act in this way, because, owing to the precession of the equinoxes, the pole is already revolving about the pole of th ecliptic; hence there arises a modification of the precessional circle, in the shape of a series of small undulations, so that the path of the polar axis is a waved line. It is as though our top when performing its oscillation had a tremor imparted to it. The small oscillations thus impressed upon the earth's precessional motion are called nutations, and they of course correspond exactly in period with the retrogressions of the moon's nodes.* One of the effects of this nutation is a periodical variation of the inclination of the ecliptic, which, however, is very slight, a larger degree of variation being effected by the planets through a very long cycle of years. Even this latter change is very slight, amounting to only a little over one degree on each side of the mean inclination.

In this transcendent force of gravitation we find another link which binds us to the celestial bodies. We see how every member of the solar system acts and is acted upon by every other, and the physical habitudes of the world, so far as they are influenced by planetary motion, are the result of this interaction. When we come to consider the climate of the earth it will, moreover, be shown that while the distribution of heat and the succession of the seasons are the result of the revolution about the sun, and of the obliquity of the ecliptic, those grand secular changes of climate which geology assures us have taken place—changes which have at one time inflicted upon England the rigours of arctic cold and

* Other nutations are described in Chapter ix.

anon brightened the polar regions with a genial climate—are the consequences of the secular changes of eccentricity, the revolution of the apsides, nutation and precession, and the variation of the ecliptic. If the earth were a solitary attendant upon the sun, and no moon accompanied her, the climate would remain steadfast as the globe itself; but the spheroidal moon-attended globe—one of a train of similar orbs—is ever passing through cycles of change, and the certain, though indirect, effect is seen in a corresponding cycle of climatic variation.

Knowing, as we now do, how very diverse are the motions of the earth and planets, it may fairly be asked whether this complicated system of motion may not contain the seeds of its own dissolution. Might not the earth be so far drawn away from the sun by the increase of eccentricity of the orbit as to free itself from his control; or might not a number of the disturbing causes so act together as to bring about some equally tremendous catastrophe? To these important questions the rigid laws of gravitation reply in no uncertain tone, for they assure us that the changes in question are really cycles of change comprised within definite though variable limits, and that those limits are of necessity small. The very cause which insures the uniformity and variability of the planetary motions, at the same time stamps their permanence; and so long as the sun enjoys his supremacy so long will his system remain such as we now know it.

Between Mars and Jupiter lies the zone of the small planets, known as asteroids, which probably are exceedingly numerous, although up to the present only 173* have been detected. Their mean position corresponds to that required by the "law of Bode" before described. Indeed it was the existence of a gap in the series between Mars and Jupiter that led astronomers to seek for a planet somewhere about the position in which the first asteroid (Ceres) was discovered. Their masses are small, and it has been estimated that the whole series, discovered and undiscovered, cannot much exceed, and probably falls below one-fourth of the mass of the earth. In the case of the larger planets we find the eccentricities small and varying within narrow limits, and the obliquity of their orbits to the ecliptic lie within a few degrees of each other. It is far otherwise with the asteroids, for amongst them are found eccentricities so great that their aphelion distance is more than double that of the perihelion distance, and inclinations of orbit so wide that the excursions above and below the ecliptic exceed the mean distance from the sun. When the distances of the asteroids are studied it appears that there are well-marked gaps in the series, as was pointed out by the American astronomer, Professor Kirkwood, who established a connection between the distribution of these bodies and the influence of the gigantic planet, Jupiter, their comparatively near neighbour. So

* August, 1877. Every year fresh members are discovered.

many proofs have now been advanced of the inter-dependence of the heavenly bodies upon each other, that we should have been justified in expressing great astonishment had not some definite action of so huge a planet been discernible. Jupiter lies outside the zone of asteroids, much as the Saturnian satellites lie beyond the rings, which are believed, on very strong grounds, to be systems of tiny meteors revolving about Saturn—they may, indeed, be considered Saturnian asteroids. This parallel is rendered still more exact by the fact that there are distinct gaps in the series, one of which, in fact, divides it into two complete rings. Saturn, with his eight moons and gapped rings, to a large extent reproduces in miniature the sun with his eight planets and zone of asteroids.

CHAPTER VI.

THE SOLAR SYSTEM (*continued*).

REVOLVING with still more eccentric orbits, and with still greater degrees of inclination than the asteroids, are those systems of tiny bodies called meteors, which, when passing through our atmosphere, are known familiarly as shooting stars. Of these systems a hundred and ninety-nine had been determined up to the year 1875.* The orbits of these known systems are so eccentric that they intersect the path of the earth, and only when they and the earth arrive near the same point simultaneously is their existence manifested. It would be most illogical to infer that the meteor systems known to us constitute a large proportion of the whole number, for it would be necessary to assume that every system cut the earth's path in the course of its revolution about the sun, and that the earth had encountered each one; neither of which suppositions is probable. It is far more philosophical to assume that there are many such systems included within

* Rep. Brit. Assoc. for 1875, p. 223.

the world's orbit, many without it, and many which intersect it, but have never been observed.* There may indeed be myriads of such systems.

The enormous length of some of their ellipses may be estimated from the established fact that the system which affords the magnificent display every now and then on the night of November 13—14th, has a period of no less than 33·25 years! Almost simultaneously with the calculation of this orbit by Professor Adams, it was shown that the August meteors crossed the earth's orbit exactly at the point where the great comet of 1862 made the same passage, and from this coincidence, Schiaparelli was led to inquire whether their paths were coincident. Such was found to be the case, and a similar connection was found to subsist between the course of the November meteors and Temple's comet of 1866. The meaning of this strange connection of dense meteor streams following the inconceivably attenuated comets will be pointed out when we deal with comets more particularly. The motions of the above comets are retrograde, that is to say they travel round the sun in a direction opposite to that taken by the planets.

The meteors themselves are not luminous under ordinary circumstances, but when they enter the

* It has been calculated that the earth annually encounters about 2,700 millions of meteors visible to the naked eye; and no less than 146,100 millions if the telescopic shooting stars are included.—Proctor's "Sun," 2nd ed. p. 374.

atmosphere, they are rendered so by reason of the resistance offered to them, and we see them as shooting-stars. But we can readily conceive them to become visible by reflected sun-light, not individually it is true, but collectively, just as the stars composing the Milky Way are too small to be visible independently, yet by reason of their proximity and great numbers they send to us a faint nebulous light. The myriads of meteor systems having their perihelion passage not far from the sun, coming in from space in continuous streams from different directions, and flying away again, would, it might be suspected, cause a faint light surrounding the sun to be apparent under favourable circumstances; and it might also be expected to be traceable, under certain circumstances, at a great distance from that body.

During a total eclipse one of the most magnificent spectacles that can be witnessed is the blaze of comparatively faint light that bursts forth when the solar face becomes obscured by the moon, to which light the appropriate name of corona has been given. General Myer, who witnessed the eclipse of 1869 from White Top Mountain, Virginia, thus describes this spectacle: "To the unaided eye, the eclipse presented, during the total obscuration, a vision magnificent beyond description. As a centre stood the full and intensely black disc of the moon, surrounded by the aureola of a soft bright light, through which shot out, as if from the circumference of the moon, straight, massive, silvery rays, seeming distinct and separate from each other, to a distance of two or three diameters of the lunar disc, the whole spectacle showing as upon a background of diffused rose-coloured light. This light was most intense and extended farthest at about the centre of the lower limb, the position of the southern prominence. The silvery rays were longest and most prominent at four points of the circumference, two upon the upper and two upon the lower portion, apparently equidistant from each other (and at about the junctions of the quadrants designated as limbs), giving the spectacle a quadrilateral shape. The angles of the quadrangle were about opposite the north-eastern, north-western, south-eastern, and south-western points of the disc. A banding of the rays, in some respects similar, has been noticed as seen at the total eclipse of July 18th, 1860. There was no motion of the rays, they seemed concentric."* These radial streams of pearly light, though invariable in any given eclipse, as might be expected, when it is remembered that they are only visible during totality which lasts but a few minutes, are of different shapes in different eclipses. Sometimes they are curved, sometimes at a considerable angle, and sometimes patches of brighter light are seen amidst the paler glare.

The light is of such a nature that it may very well arise from the presence of meteoric bodies in the sun's vicinity. It is certainly not due to an

* "The Sun," R. A. Proctor, ed. 2, 1872, p. 358.

extension of the solar atmosphere, yet it is certainly a solar phenomenon. It is certain that some such appearance would in all probability be formed by the continual influx of meteor systems, and it is a fair inference that some part, at any rate, of the coronal light is due to this cause.

When we examine the spectrum of the corona it appears as faint and continuous, and crossed by a few bright lines, one of which is coincident with a well-known iron-line in the solar spectrum; and it is suggestive to find that the spectrum is essentially the same as that of the zodiacal light and of the aurora borealis. Moreover, the light itself when studied with the polariscope is found to be partly reflected light, showing that solid matter forms a part of the corona, as certainly as gaseous material. From certain peculiarities in the polarising of the coronal light it would seem probable that a great many of the solid or liquid particles are of small size.

There is nothing in all this antagonistic to the theory of the corona being caused by the perihelion passage of myriads of meteors; but the eclipse of 1870 brought to light fresh facts, which demand a modification of that idea, though, as it seems to me, not a renunciation. We have before hinted that great eruptions of gaseous and other material are continually taking place in the sun, some of which are seen in profile at every eclipse, forming the well-known rose-coloured prominences, which will presently be described. It was observed during this eclipse that wherever these prominences were strongly marked the corona was correspondingly increased, and where the prominences were small or wanting the corona was depressed. Moreover, the inner brighter portion of the corona had been thought to be distinct from the fainter, outer, radial parts; but it was clearly demonstrated, both by direct observation and photography, that where a gap appeared in the outer part of the corona, a corresponding depression was observed in the brighter part, showing that the different parts of the corona form one phenomenon.

These observations prove not merely that the corona truly belongs to the sun, but that it is intimately connected with the prominences. Both prominences and corona are known to vary, and although as yet we are unable to observe the latter except during an eclipse, we may safely infer that any alteration in the size of the former is marked by a corresponding change in the corona.

By a process similar to that used in determining the limiting velocity a body must possess to travel round the earth, it can be shown that a body projected from the sun with a speed of 300 miles per second will pass entirely away from it. Now Professor Young has seen a hydrogen prominence reach a height of 200,000 miles in ten minutes, and if it were moving *in vacuo* it would have required an initial velocity of no less than 225 miles per second. ut the hydrogen did not move thus freely; it was retarded by having to pass through gaseous matter, and the amount of this retardation must have been very great. It is well known how vastly the speed of a shell is checked by the atmosphere, but we cannot form any estimate of the tremendous retardation a mass of gas must suffer under similar conditions; yet we may safely assume that the initial velocity necessary to drive a mass of hydrogen from a height of 100,000 to 200,000 miles from the sun's surface in ten minutes must have greatly exceeded 300 miles per second. But these airy hydrogen bombs are by no means the only ejections from the sun, for other and heavier vapours, and it may be liquids, are thrown up, iron among the rest; and having seen, firstly, the certainty of iron being largely present in the corona, probably in a liquid or solid condition, and, secondly, the intimate connection between the corona and the solar prominences, the conclusion is inevitable, that much of the matter of the corona is actually projected from the sun.

We are fairly justified, then, in looking upon this corona as formed chiefly of meteoric matter ejected from the sun, and partly of independent meteoric systems circulating about him, some of which may indeed have been derived from him. In this view we can understand why the corona is barred by dark lines, such as have been observed in the zodiacal light and in the aurora borealis. We have here, in all probability, myriads of bodies, some excessively minute, travelling with inconceivable velocity through a highly attenuated medium, and experiment has proved that under similar circumstances, as when steam rushes furiously from a vessel, conveying with it particles of solid matter, intense electrical action is set up. When an electrical discharge takes place in a highly rarefied medium the light evolved is always barred and streaked in a very singular manner, as is shown in experimenting with very attenuated gases in a Geissler tube. Here, then, we seem to meet with an explanation of all the phenomena, and we are compelled to look upon the corona as being formed by the perihelion rush of systems of meteors, by the storms of meteoric matter ejected by the sun, and by the fierce electric discharges attendant upon these motions. Mr. M. Williams, in his interesting work upon the "Fuel of the Sun," has ably advocated the solar origin of the coronal meteors; and, indeed, he carries his views further than there appears to me any ground for assuming, inasmuch as he considers all meteors, and even the asteroids themselves, are bombs fired from the stupendous artillery of the sun. Mr. R. A. Proctor no less ably demonstrated the action of the myriads of meteor systems, and, from the results of the eclipse of 1870, arrived at similar conclusions to those of Mr. Williams respecting the solar origin of much of the corona; but, in my opinion, justly distinguishes these new-born meteors from the independent systems.

The zodiacal light has been recognised by Messrs. Williams, Proctor, and others, as composed of meteors. Its peculiarities have been partly discussed already, and it remains only to be said that its mean position varies from the plane of the solar equator a few degrees on either side, and that its extension is variable, sometimes falling far short of the earth's orbit, and at others extending beyond it —phenomena which are easily accounted for when we remember that it is the light of meteor systems which are ever sweeping round in different paths. The light is constant, but the sources are constantly changing; just as a warm vapour-charged air-current caps a mountain with cloud that from below seems stationary, but which, when entered, is found to be driving mist. Bearing upon this question we may remark that Professor Serpieri, of Urbino, noticed a strong display of the zodiacal light on the evening of December 12th, 1873, and at the same time Professor Denza remarked a glow pervading the whole sky. Both observers recorded an unusual number of meteors (*Geminids*) on that night.*

We must now return to the meteors ejected by the sun with sufficient velocity to carry them beyond his complete control. It is in every way probable that some of these should reach, and even pass beyond, the earth's orbit, and it is also within the bounds of probability that some of them may

* Rep. Brit. Assoc. for 1874, p. 347.

strike the earth itself. If such be the case, the only phenomena we can look to in confirmation is found in the meteoric stones or aerolites that occasionally fall from the sky. The number of these we are very apt to under-estimate, because only such as fall near places where intelligent men are at hand to record the fact are known; and as there is only a very inconsiderable portion of the world where this is the case, by far the greater number pass unrecognised. Even in Britain it is possible for aerolites to fall unnoticed, and if this be the case, how much more probable is it that over the whole earth myriads may have descended unseen or unrecorded.

If the majority of these bodies have been hurled from the sun we should expect them to consist of such materials as would most readily cool, and they ought to be more plentiful by day than by night. Now the metals that would soonest cool are iron, nickel, cobalt, chromium, manganese, titanium, and aluminium; and these are (with the exception of titanium) exactly the materials of which the majority of aerolites are composed. It is also established that more aerolites fall in the daytime than at night. These two facts add great probability to the solar origin of these strange bodies; but there is still more weighty evidence. From microscopic investigations of the structure of meteoric stones, Mr. Sorby, so long back as 1864, arrived at the conclusion that "The most remote condition of which we have positive evidence, was that of small detached melted globules, the formation of which cannot be explained in a satisfactory manner, except by supposing that their constituents were originally in the state of vapour as they exist in the sun." *

Perhaps the most remarkable confirmation of the solar origin of aerolites is their chemical peculiarity. Professor Graham had shown that hydrogen possessed the singular property of uniting with metallic substances to form a kind of alloy. Iron possesses to a large degree the power of condensing this gas during the process of solidification, and as iron is a principal ingredient in most meteoric stones, and hydrogen exists in enormous quantities about the sun, it should follow, on the hypothesis we are examining, that a quantity of that gas ought to be imprisoned in meteoric iron. This is exactly what Professor Graham found. In his own words, speaking of an aerolite from Lenarto: "Hydrogen has been recognised in the spectrum of the fixed stars by Messrs. Huggins and Miller. The same gas constitutes, according to the wide researches of Father Secchi, the principal element of a numerous class of stars, of which α Lyræ is the type. The iron of Lenarto has, no doubt, come from such an atmosphere, in which hydrogen greatly prevailed. This meteorite may be looked upon as holding imprisoned within it, and bearing to us, the hydrogen of the stars.

"It has been found difficult to impregnate mal-

* Proc. Roy. Soc., 1864.

leable iron with more than an equal volume of hydrogen, under the pressure of our atmosphere. Now the meteoric iron (this Lenarto iron is remarkably pure and malleable) gave up about three times that amount without being exhausted. The inference is that the meteorite has been extended from a dense atmosphere of hydrogen gas, for which we must look beyond the light cometary matter floating about within the limits of our solar system." *

It is proved, then, that meteors have been observed to travel with a velocity sufficient to carry them beyond the reclaiming power of the sun; that they are composed of just those elements that might be expected to form such bodies; that they have solidified from a state of vapour; that they have been hurled through a dense atmosphere of vapour; and that they fall most frequently by day. The chain of evidence is so complete that there can be no escape from the conclusion that some, at least, of the aerolites have actually come to us from the sun. But clearly they need not all have come from our sun: there are myriads of similar orbs that may shoot their projectiles beyond their reclaiming power, and these must ever travel on, till compelled to circle around or fall upon some other body. But how few of these can reach our tiny earth! We are driven to the belief that there must be countless myriads of these bodies travelling in all sorts of

* Proc. Roy. Soc., 1864.

directions through space, of which but comparatively few are, or have been, or will ever be, gathered to earth by the power of her gravity.

If meteorites have come to us from other systems, we might expect some of them, at least, to give us a hint respecting Mr. Lockyer's theory of the comparative coolness of the stars with channelled-space spectra. Meteorites, from such sources, should contain compound bodies, and indeed we find a large class of stony meteors having such a composition. They often contain well-known minerals, such as olivine, and enclose spherules of glassy minerals; indeed, their structure is very like certain well-known volcanic rocks. Many observers have examined these interesting bodies; Dr. Flight, of the British Museum, has published a very admirable "History of Meteorites,"* dealing chiefly with their chemical and mineralogical composition. Mr. H. C. Sorby has examined them microscopically, and the following quotation from a recent lecture "On the Structure and Origin of Meteorites" expresses the conclusions at which he has arrived. "It appears to me that the conditions under which meteorites were formed must have been such that the temperature was high enough to fuse stony masses into glass; the particles could exist independently one of the other in an incandescent atmosphere, subject to violent mechanical disturbances; that the force of gravitation was great enough to collect these fine particles to-

* Geol. Mag. 1869—1876.

gether into solid masses, and that these were in such a situation that they could be metamorphosed, further broken up into fragments, and again collected together."*

Mr. A. W. Wright examined the occluded gases in a recently fallen stony meteorite, which was picked up warm near Iowa city. He found that at a temperature of 100° C. carbonic acid was freely given off, diminishing in quantity as the time went on and the temperature was raised. This gas formed 90 per cent. of the whole, whereas the hydrogen (which came off with greater freedom at the higher temperature) formed but a small proportion of the whole. Carbonic oxide and nitrogen were also present in small quantities. The spectrum, when the pressure was high, gave three conspicuous carbon bands, like those in certain cometary spectra. The hydrogen lines were weak in comparison. He draws the following conclusions from his researches on many meteorites: "1. The stony meteorites are distinguished from those which are metallic by occluding the oxides of carbon, chiefly carbonic acid, as their characteristic gases, in place of hydrogen. 2. The proportion of carbonic acid evolved is much greater at low than at high temperatures, and is sufficient to mask the hydrogen in the spectrum. 3. The amount of gas contained in a large meteorite, or in a cluster of such bodies forming a cometary nucleus, is sufficient to form the train as ordinarily observed.

* *Nature*, xv. p. 497; 1877.

4. The spectrum of these gases closely resembles that of several of the comets."*

Now, although these particular meteorites seem more closely connected with comets than stars, there is no reason why some of them may not be of stellar origin. Comets, nebulæ, and meteors are very closely allied in many of their phenomena, and stars and nebulæ are no less closely connected, as in the case of Nova Cygni, before described. Mr. Lockyer has shown that from meteorites we can get nebula-like spectra, and he has recently observed that "it is well known that within certain limits the lines in the spectrum of a compound body get brighter with *decrease* of temperatures; because at the higher one the compound almost entirely ceases to exist as such, and we get the lines of its constituents. It is a fair theory then to suggest that the famous nebula line may belong to a compound. Nay, the fact as it stands alone, further points to the possibility that the compound in question contains hydrogen as one of its constituents."†

The sizes of meteorites vary from several tons to a fine impalpable dust that helps to give the cerulean hue to the firmament, and the gorgeous tints of sunset.‡ In the splendid auroral displays we have

* Amer. Journ. Sci. ix. 459 and x. 44; also Rep. Brit. Assoc. for 1875, p. 242.

† *Nature*, xvi. p. 414, Sept. 1877.

‡ Professor A. E. Nordenskiold, from an examination of snow from various localities, such as Greenland and Spitzbergen, con-

evidence of the existence of extremely fine dust, of which iron is certainly a constituent, floating high above the appreciable limits of the atmosphere. These facts, taken in connection with the multitudes of meteors, lead us to a new conception of space, which must no longer be looked upon as void, but as charged with matter flung from all the suns in the heavens, and steadily gathered in again by those orbs and their attendant planets. We can picture the sun in the course of ages parting with a considerable portion of his bulk, but it is no less certain that he is as continually being recruited by drawing unto himself, not merely the major part of what he has thundered from his majestic artillery, but argosies of meteors that may have been dispatched from the confines of the universe. Whichever way we turn the grand truth we enunciated at starting comes home with ever-growing force—the earth is a type of the universe, and is linked by strong bands of affinity to every member of the great scheme.

The reason why we do not see the myriads of meteors which circle around our earth, the other planets, and the sun, is that they are solid, non-luminous bodies, which can only be rendered visible by reflecting sun-light, or by being heated to a glowing temperature in passing through our atmo-

cludes that small quantities of meteoric dust are brought to the surface of the earth by atmospheric precipitation. This dust contains metallic iron, cobalt, nickel, phosphoric acid, and organic matter.—Poggendorff's "Annalen," Bd. cli. p. 154; also Jour. prak. Chem., Bd. ix. p. 356.

sphere. It is, however, probable that some may be large enough to be visible by reflected sun-light, for a brief space, ere plunging into the earth's shadow; and M. Petit from observation, and calculation from formulæ given by Sir J. Lubbock for this purpose, arrived at the conclusion that at least one considerable meteor thus forms a small satellite, travelling at a distance of about 5,000 miles from the surface, and passing round the earth nearly seven times in a day.

M. Leverrier has pointed out that the motions of Mercury are inexplicable except on the supposition that between it and the sun matter exists of some kind. The hypothetical planet Vulcan was suggested as the cause of the Mercurial perturbations, but last year this body was sought for in vain under circumstances that were peculiarly favourable for its detection. We may conclude that Vulcan is a myth, and that the perturbations are due to numbers of tiny meteors between Mercury and the sun.

Professor Newcomb has detected certain irregularities in the moon's motion which may be due to the presence of some unseen body or bodies passing very near to her.

CHAPTER VII.

THE SOLAR SYSTEM (*continued*).

HAVING now dealt with planets, meteor systems, and aerolites, we must pass in review those remarkable bodies known as comets. Their appearance is too well known to need lengthy description; but it is as well to recall the facts that some comets seem to be hazy nebulous bodies without any brighter nucleus; that the tail, when present, is almost invariably turned from the sun, and that some comets have more than one such tail. The sizes of these curious bodies are often inconceivably great, being measurable in millions of miles, yet so exceedingly attenuated is the matter of which they are composed that they effect not the slightest disturbing influence upon any body they pass near, and consequently their mass is almost infinitely little. It has been estimated that some can only weigh a few ounces, and hardly any more than a few tons; yet the volume of such a comet may exceed that of the sun and all his family of planets and meteors.

Some comets are observed to enter our system from the distant regions of space, sweep round the sun, and pass away for ever. It is easy to see how such a body approaching the sun might be so deflected from its course by the action of some large planet, such as Jupiter, that it should be compelled to travel about the sun in a closed orbit, and thus become a permanent member of the system. If such were the case the aphelion of the comet's orbit would be in the vicinity of Jupiter, the deflecting body. It is found, in point of fact, that many of the comets actually have their aphelia in the neighbourhood of the orbits of the larger planets; some being associated with Saturn, some with Jupiter, and so on. The obvious conclusion is that these bodies have actually been introduced into our system by those planets. It is equally probable that a comet circling the sun might, on the other hand, be expelled from the system by the same means. Both these processes were actually witnessed in the case of Lexel's comet, which, in the year 1777, was twisted by Jupiter into an orbit having a period of about five and a half years, and after making two complete revolutions again encountered that giant orb, was sent away into space, and it has never since been seen.

The inclinations of the cometary orbits are exceeding variable, for while those of the major planets lie within about 7° of the plane of the ecliptic, it is found that on an average about 26 per cent. of the cometary orbits lie between 0° and 30°, 27 from 30° to 50°, 39 from 50° to 89°, and 8 from 80° to 90°. In the degrees of eccentricity, the difference is even more striking; many comets taking several hundred years to complete a revolution, while the period of Coggia's comet of 1874 is believed to be no less than 9,000 years! Here, then, we lose all trace of that symmetry that was so striking in the case of the major planets. Even as we examined the smaller asteroids we began to lose sight of this uniformity, and now that meteors and comets have passed in review no community of motion or even of direction can be detected, for nearly half the comets move in the opposite direction to the planets—a circumstance that has only been detected among planets in the direction of the rotation of the satellites of Uranus.

The tails of comets are among the most marvellous phenomena in nature. These stupendous bodies, measuring millions of miles in length, are formed and dissipated in a few weeks, and as they almost invariably point away from the sun they sweep through enormous areas during the perihelion passage. It will be interesting to describe these remarkable productions and to endeavour to account for their formation; and although the subject is still far from being settled, I cannot but think that when the observations of Sir J. Herschel and M. Faye upon their motions, of Mr. N. Lockyer, Drs. Vögel and Huggins, and others upon their constitution, of Professor Tyndall upon the production of actinic clouds, and of Mr. Crookes upon radiation, are brought to bear upon the question collectively, instead of individually as heretofore, a fair idea of their nature may be formed.

The general phenomena of the production of the tail are as follows. The comet is first seen coming towards the sun from far beyond the limits of the planetary system, and only in that portion of their orbit are the comets visible. When first seen they appear like vague rounded nebulæ, generally with a brighter nucleus at or near the centre. As the comet comes nearer it begins to lengthen out, not as might be expected in the direction of the orbit, but in the direction of a line drawn from the sun's centre to the comet: such a line is called the radius vector. With the nearer approach of the comet, this lengthening becomes more marked, and forms a tail which gradually spreads out like a fan, and always bends backwards in the direction of its motion, so that it is more or less curved, but still its direction is roughly that of the radius vector. At the time of the perihelion passage, the elongation of the tail is most pronounced, and as the comet passes away from the sun the tail dies away to a mere elongation, and when last seen the comet has assumed its original rounded form. The sizes of these curious appendages are enormous; that of the comet of 1843, by no means one of the largest, was 180,000,000 miles long, or nearly twice the distance of the sun from the earth. When we remember that this gigantic body probably only weighed a few pounds, the inconceivable tenuity of the matter composing it can be partly appreciated.

The nucleus, as the comet approaches, grows brighter and brighter until it glows with star-like intensity, and envelopes of filmy consistency are formed around it and sweep back into the tail, as is well shown in a beautiful drawing of Coggia's comet, 1874, by Mr. Lockyer.* The light of both nucleus and tail is often not steady, but fitful, and pulses of light are propagated with great rapidity from nucleus to tail, like gigantic tremors.

When we come to consider the phenomenon, it appears most singular that the tail should sweep backwards along the radius vector, like smoke wreaths bent backwards by a strong wind from the sun, as Sir J. Herschel forcibly and accurately puts it. This direction, combined with the growth of the tail as it approaches the sun, its greatest extension when nearest to that orb, and its gradual diminution as it passes from its vicinity, clearly point to the sun as the cause of the prolongation. Now, as the comet's orbit is, as we have seen, the path along which it moves in obedience to the sun's gravitation, it follows that the tail cannot be caused by that force, or it would take the direction of the comet's path. It is, however, approximately projected in the line of the force of the sun's gravitation, and not in that curved path which it must assume under

* *Nature*, vol. x. p. 210; 1874.

the influence of a central force, as described previously.

If the comet moved directly towards the sun such a tail might perhaps be formed, but this is not the nature of a comet's path. Let us consider how a comet would be elongated under the influence of solar gravitation. When first observed the comet is a more or less spherical body, which may be described as consisting of a comparatively dense nucleus, surrounded by a vaporous envelope. Gravitation would act upon every part of the comet, but most powerfully upon the nearest portion, which, being vaporous, and therefore free to move, would be pulled away from the nucleus. The nucleus would in like manner be pulled away from the farthest part of the envelope, and the comet would assume an elliptical form, with the nucleus in the centre. The action, in fact, would be exactly similar to the formation of the tidal protuberances, which cause high-water simultaneously on opposite sides of the earth. As every portion of cometary matter is moving under the influence of a central force, the elongation would necessarily be in the direction of the orbit. As perihelion was approached the elongation would increase, still in the same direction; and after the perihelion passage the elongation would diminish, and at a certain distance become inappreciable.

It need hardly be said that no comet ever exhibited such phenomena. We are perfectly certain such would be the effect of gravitation, and hence we must look to some other source for an explanation. Let us now suppose that the sun, instead of merely possessing the attractive force of gravitation, is also the seat of a repulsive force. M. Faye, in a lecture delivered in the year 1874, at the Soirées Scientifiques de la Sorbonne, published in *La Revue Scientifique*, and translated in *Nature* for the same year, has adopted such a view, and adopts the idea that comets' tails are due to the repulsive action of the solar heat.* He points out that as bodies grow hotter they expand, and that the comet's temperature is raised as it approaches the sun. "In the case of comets," he remarks, "the solar heat produces an expansion comparable to that of gases. According to my calculations, this expansion dilates the radius of the concentric zones we can distinguish so well in the head of Donati's comet at the rate of 19 metres per second." It is also necessary to suppose, as M. Faye does, that this force acts more easily upon matter as its density grows less. Above a certain density gravitation will exert its full sway, at a certain less density these actions will be equal, and with a further rarefaction the repulsive energy of solar heat will prevail over the attractive force of gravitation. M. Faye estimates that in the case

* Sir J. Herschel held precisely similar ideas respecting the formation of comets' tails, and anticipated nearly all M. Faye's points. I have given M. Faye's account as embodying the most recent exposition, but the originator of the theory is certainly Sir J. Herschel, although M. Faye does not mention that fact.

of Encke's comet it would be necessary to diminish the density of the nucleus in the proportion of 1 to 1,000,000, to represent the observed excess of repulsion over attraction. That such a rarefaction actually does take place is clear, and our author justly remarks that "the nucleus [of Donati's comet] emits vapours which go on dilating more and more, so as to form around the nucleus envelopes having a radius of ten, or even a hundred times greater. But if the matter of a sphere, having a radius equal to 1, expands into a sphere having a radius equal to 100, it is sufficient to make the density become a million times less. In fact, all the matter of the nucleus is not thus disseminated in the head of the comet: this dilatation affects only a very small portion of the primitive mass, and we see how the density of the extreme layers of the head may fall much below the figure given by the above calculation."

Following out this hypothesis, we must look upon a comet as journeying under the attractive influence of gravitation, as steadily dilating under the influence of heat, and as having its rarefied envelopes driven backwards in the direction of the radius vector by the repulsion of solar heat with velocities dependent upon the density. It follows that the growth of the tail must increase in rapidity, as it approaches the sun, and this is in accordance with fact.

M. Faye further shows how the backward curvature of the tail is the direct result of such a repelling force. It is somewhat difficult to explain this without the aid of diagrams; but the following illustration may serve to give an idea of the nature of his argument, which is based upon strictly scientific grounds. Suppose a train to travel with uniform speed on a circular line of rails. It clearly moves much as a planet circling a sun would do, inasmuch as it has a tendency to move off tangentially, which is overcome by a force tending to draw it to the centre: it moves as if under the influence of a central force. Suppose the engine to emit at every yard a puff of smoke, with a constant force, and in a vertical direction. Also let the air be absolutely motionless. These puffs of smoke are clearly under the same influences as the engine, that is, they have a motion in a circle. Omitting the resistance of the air, the expansion of the puffs, and their vertical impetus, it is evident that they will follow the train on the same path, and complete the circle as the train completes it.

Now let a steady wind blow directly outwards from the centre of the circle, and with a force just sufficient to overcome the force towards the centre. A puff acted upon by this wind will no longer trace a circular path, but will take the line of a tangent to the point of emission. It will not move so fast as the train, because it is kept back by the wind. Call this puff A, and the distance it is left behind when the second puff, B, is emitted, 1. Now consider puff C to have been formed, and puff D to be just ejected. By this time puff A is at a distance 4 in the line of its tangent, puff B at a distance 3 on its tangent, puff C at a distance 2 on its tangent, and puff D is over the engine. Join all these puffs with smoke, and a curved line is produced bending backwards upon the train's path, and roughly in the direction of the radius vector.

Now let the force of the wind steadily increase. The stations 1, 2, 3, 4 of A, B, C, D will no longer be in the lines of the tangents, for the puffs will move in hyperbolic paths whose foci are directed to the centre. The curve will consequently be straighter, and closer approximating to the radius vector. As the wind grows stronger, this curve will grow straighter, though it can never quite attain to perfect straightness, because the smoke is emitted with a tendency to travel on the train's course.

The smoke-streams thus evolved will bear exactly the same relation to the train and central wind as the comet's tail does to the nucleus and central sun.

Another result follows from this method of viewing the question. If the material forming the comet's tail be of different densities, they will take different paths, and thus form separate tails; for the force of solar repulsion does not diminish with the distance, as does that of gravity, because heat travels with the velocity of light. Diminished density will act, therefore, just as increased velocity did upon the smoke puffs, by giving the repulsive force greater power upon the material, just as the constant velocity of a winnowing-machine drives the light chaff farther than the heavy corn. In accordance with this conclusion, we find that many comets have more than one tail. Donati's comet, for example, had three tails, the two smaller ones being nearly straight.

There remain three phenomena which, if explicable by this hypothesis, add largely to its probability—the envelopes that surround the nucleus and help to form the head of the comet, a dark space behind the nucleus, and the occasional formation of a tail directed towards the sun. These may be briefly disposed of. The envelopes are the direct result of the dilating power of the sun's heat; the dilation being checked in its forward portion by the sweeping back of the material to help to form the tail. Where several envelopes are seen, the inference is that they are of different densities, the outermost being the lightest. That the dark space behind the nucleus is not its shadow is proved in three ways: firstly, it exists even when the nucleus is transparent; secondly, it does not lie in the direct line of the sun; thirdly, it is far too long, being often traceable to the end of the tail at its greatest prolongation. If the repulsive energy of the sun's heat is the cause of the tail, the nucleus will screen the parts behind it from this action; for solar repulsion is a surface action, and does not depend upon mass, like gravitation, which would act *through* the nucleus. The rare phenomenon of a tail directed towards the sun would take place if the comet contained a large quantity of comparatively dense material, for this would, by gravitation, be drawn towards the sun and form a short tail.

The hypothesis of solar repulsion explains (1) the formation of a tail, which grows longer with the proximity of the comet to the sun; (2) the extension of the tail in the direction of the radius vector; (3) the backward curvature of the tail; (4) the formation of the envelopes on the head of the comet; (5) the origin of the dark space behind the nucleus; and (6) the occasional production of a short tail pointing towards the sun. It is, however, assumed that matter of almost inconceivable tenuity is capable of reflecting light; and, more important still, that solar radiation possesses the power of repulsion, and that this force is constant, and acts only on the surface. We must now see whether these assumptions are contrary to natural law.

On the first point the noble researches of Professor Tyndall upon the action of light upon vapours of extreme rarity are quite conclusive. That philosopher, by experiments as beautiful as they are refined, has shown how an utterly inappreciable trace of the vapour of certain substances, such as nitrite of amyl, grows into a magnificent cloud under the influence of the light of an electric lamp. Tyndall's explanation is that at first the particles of the vapour are exceedingly small, that they are caused to aggregate together, or condense by the action of the short invisible rays in the electric beam, and that, when so condensed, the particles are large enough to reflect light. That these short rapid waves are capable of exercising a powerful influence upon certain substances has long been known, and has given rise to the name of actinic rays, by which they are sometimes known. In the formation of these "actinic clouds" Professor Tyndall sees a possible explanation of cometary phenomena. His explanation is best made in the author's own words, and the interest of the question must compensate for the length of the quotation, if indeed any apology be needed for citing the expressions of so thoughtful an experimenter and so admirable an expounder.

"1. The theory is, that a comet is composed of vapour decomposable by the solar light, the visible head and tail being an actinic cloud resulting from such decompositions; the texture of actinic clouds is demonstrably that of a comet.

"2. The tail, according to this theory, is not projected matter, but matter precipitated on the solar beams traversing the cometary atmosphere. It can be proved by experiment that this precipitation may occur either with comparative slowness along the beam, or that it may be practically momentary throughout the entire length of the beam. The amazing rapidity of the development of the tail would be thus accounted for without invoking the incredible motion of translation hitherto assumed.

"3. As the comet wheels round its perihelion, the tail is not composed throughout of the same matter, but of new matter precipitated on the solar beams which cross the cometary atmosphere in new directions. The enormous whirling of the tail is thus accounted for without invoking a motion of translation.

"4. The tail is always turned from the sun for this reason,—two antagonistic powers are brought to bear upon the cometary vapour, the one an *actinic* power, tending to produce precipitation, the other a *calorific* power tending to effect vaporisation. Where the former prevails, we have the cometary cloud; where the latter prevails, we have the transparent cometary vapour. As a matter of fact, the sun emits the two agents here invoked. There is nothing whatever hypothetical in the assumption of their existence. That precipitation should occur behind the head of the comet, or in the space occupied by the head's shadow, it is only necessary to assume that the sun's calorific rays are absorbed more copiously by the head and nucleus than the actinic rays. This augments the relative superiority of the actinic rays behind the head and nucleus, and enables them to bring down the cloud which constitutes the comet's tail.

"5. The old tail, as it ceases to be screened by the nucleus, is dissipated by the solar heat; but its dissipation is not instantaneous. The tail leans towards that portion of space last quitted by the comet, a general fact of observation being thus accounted for.

"6. In the struggle for mastery of the two classes of rays a temporary advantage, owing to variations of density or some other cause, may be gained by the actinic rays, even in parts of the cometary atmosphere which are unscreened by the nucleus. Occasional lateral streamers, and the apparent emission of feeble tails towards the sun, may be thus accounted for.

"7. The shrinking of the head in the vicinity of the sun is caused by the beating against it of the calorific rays, which dissipate its attenuated fringe and cause its apparent contraction."*

This theory appears to me to be open to grave exceptions on certain points, but it merits very careful consideration. The author justly states that he has "dealt exclusively with true causes, and no agency has been invoked which does not rest upon the sure basis of observation or experiment." It is not, however, in the causes, but in the inferences therefrom that the theory appears faulty. Let us commence with paragraph 4. We are there shown that the precipitation occurs behind the nucleus, in the space which would be occupied by the shadow, because the head absorbs the calorific and transmits the actinic rays. Consequently, as the conditions

* "Heat a Mode of Motion," p. 550; 1870.

are here most favourable for the production of an actinic cloud, the tail should be brightest in that position. But as a matter of fact just in that particular part there is no tail at all, but a blank space, as before described, and as is beautifully shown in the drawings of Donati's comet by Secchi,* and of Coggia's comet by Lockyer.† Just at this crucial point the theory fails. Again, if the tail be a kind of actinic shadow (if such a term may be allowed), it should be conical in shape, the base being at the nucleus; whereas actually the tail invariably fans out as the distance from the head increases. Moreover, it is geometrically impossible that a body so comparatively small as the head of a comet should extend its shadow to such vast distances as the tails of comets do. The shadow-cone is determined by drawing lines from the sun's circumference to that of the shadow-producing body; these lines meet behind the body at a certain distance, beyond which there is no shadow, as the sun's rays illuminate the entire space. Now if in this way the shadow-cone of any comet's head be projected, its limits will fall very much nearer the head than the end of the tail; consequently not the slightest screening action will be experienced in the more distant parts, and this is quite opposed to the theory. Yet again, although, by paragraph 6, the formation of subsidiary tails may be explained, the difference of curvature of

* *Nature*, vol. x. p. 228; 1874.
† *Ib.* vol. x. p. 210.

those tails is utterly inexplicable, as is also the formation of the envelopes of the head. And, finally, inasmuch as, on this theory, we must look upon a comet as a vast nebulous mass of which only the nucleus and a streak behind it are visible, the "temporary advantage" spoken of in paragraph 7 ought occasionally to produce tails in quite other directions than that of the radius vector, yet no such appearance has ever been detected. It is the facility with which M. Faye's hypothesis explains, nay demands, these peculiarities that gives it such a strong basis of probability.

Professor Tyndall justly appreciates the improbability of so vast a body as a comet's tail being brandished through the heavens at such an inconceivable rate as is necessary to attribute to it if it be a permanent object. This is explained, in paragraphs 2 and 3, by the tail being composed of different materials in different parts of the comet's course. This is an equally necessary consequence of M. Faye's hypothesis, though he does not mention it. New matter is constantly being added, and goes to swell the size of the tail, but it is equally necessary that the peripheral portions, at any rate, cease to be luminous.

That this must be the case is evident from the following consideration. Let us follow a particle in its course from the head to the tail. It possesses a certain motion, of which a part is tangential movement, and this cannot be increased, but must in fact be diminished by the repulsive force of the solar beams. Suppose this particle to lie on the outside of the tail. As the comet approaches the sun other particles are constantly being driven off outside it, and our original particle becomes more and more centrally situated in the tail, and at the same time is continually increasing its distance from the head. It cannot keep up with the head, because its tangential velocity is diminished, and its initial speed would have to be increased in consequence of its greater distance from the sun if it had to maintain the same period; but this cannot be. Now unless the particles on the inner margin of the tail became non-luminous from some cause (probably by cooling), we should have a luminous fan stretching all round the perihelion of the cometary orbit; and unless the particles at the end of the tail likewise cease to be luminous, this fan would stretch outwards to an immense distance from the orbit of the head all round the perihelion position. These consequences must ensue on the above supposition, because such particles cannot keep up the speed of the head; and as they do not occur we must assume that the tail is continually wasting away, and as continually being recruited by fresh material.

Before passing to the consideration of the actual existence of a repulsive force, we must pause to consider a remarkable consequence of the action just described. *The comet must be constantly diminishing in size by this loss of material.* This has been noticed in many comets; Halley's comet, for instance, when seen in the fourteenth century was so large as to create the utmost consternation to beholders; but it has dwindled away steadily, and is now an inconsiderable body that might easily be passed over by casual observers. It is also probable that the repulsive action retards the motion of the whole comet, the effect of which would be to reduce the period, and also to bring it nearer to the sun. The final result would be that the comet, unless utterly dissipated beforehand, would fall into the sun. Such a diminution of period seems to have been detected in the case of certain comets, but the perturbations these bodies experience from the planets is so great, and the circumstances of the calculations so vague and intricate, that the detection of such a phenomenon is by no means an easy problem, or one that can be considered settled.

We must now examine the evidence adducible respecting the repulsive action of heat. M. Faye designed an apparatus to show this action, but the subject has only recently been placed beyond the regions of doubt by the invention of the radiometer, and the researches which have been carried out by its means by Mr. W. Crookes, F.R.S.

M. Faye, speaking of solar repulsion (whose laws he deduces, be it understood, not from experiment, but from the phenomena of comet's tails), says, "It is evidently a surface motion and not one of mass; and . . . it is natural to think that the surface of a heated body exerts its repelling action all round it, as well as towards the interior. Moreover, there is nothing opposed to the supposition that this force is propagated successively, since its cause, heat, is itself propagated successively in planetary space with a definite speed, that of light."* It is required, then, by M. Faye that the repulsion be a surface action propagated successively. These are exactly what Mr. Crookes finds, for he tells us "the repulsion by radiation only acts on the surface of bodies, and does not seem to act on the molecules which constitute thickness;"† and in the same paper makes the following singularly apt remark: "In the sun's radiation . . . we have the radial repulsive force, possessing successive propagation."‡ The nature of this repulsion being just what is required by the hypothesis advocated, let us see what the radiometer can tell us as to the probability of repulsion acting upon a comet.

The sun and the comet are two bodies in cold space; the sun is the hotter of the two, and its mass infinitely the greater. We have, then, two bodies, one hot, the other (comparatively) cold, in a cold space. Let us first assume (which is not the case) that the comet is of the same temperature as space, and (what is equally untrue) that its size and mass are the same as those of the sun. Now Mr. Crookes

* *Nature*, vol. x. p. 268, Aug. 1874. Herschel arrived at the same conclusions: see his "Familiar Lectures."

† "On Repulsion resulting from Radiation," Phil. Trans, clxiv. part ii. par. 76.

‡ *Ib.* par. 81.

has shown that in the case of two bodies, A hot and B cold, in a cold space, "the body A receives heat uniformly from all sides, even from that opposite B (B being of the same temperature as space). A will therefore not move; B receives heat uniformly from all sides except from that opposite A, on which side the influx of heat is more intense. The result will therefore be that A *remains stationary whilst* B *is repelled.*"* Call the sun A, and the comet B, and the repulsion of the comet is patent. Now let us take the actual case. The sun, surface for surface, is certainly much hotter than the comet,† and therefore the comet receives more heat from the sun than it imparts. Hence, although the sun receives more heat on the side opposite to the comet than elsewhere, the result is only such as would obtain if the temperature of space were that of the comet, but the repulsion is less in degree.

How is it, then, that the comet moves about the sun in obedience to his attraction? I think this difficulty is overcome by the following consideration. Imagine the comet to be stationary. The repulsive action of the sun would then drive it away; but as the comet is in motion (and that motion is not imparted, but only altered in direction by the sun), it sweeps on its course obedient to gravitation; but

* "On Repulsion resulting from Radiation," Phil. Trans. clxv. part ii. par. 89

† Mr. Lockyer believes comets to be comparatively cool, their temperature being sufficiently low to permit the existence of chemical compounds.

its motion is continuously modified by the solar repulsion. Solidify the comet and it will travel round the sun like a planet; partly volatilise it so as to decrease its density and increase its surface, and it will move as a comet ordinarily travels; completely volatilise it, and it will become, as it were, all tail, and, unless disintegration ensues, would eventually be driven from the system by the repulsive action of the sun.

Mr. Crookes, at the conclusion of his first paper, draws attention to the possible application of his results to celestial phenomena. "It is not unlikely that in the experiments here recorded may be found the key of some as yet unsolved problems in celestial mechanics. In the sun's radiation passing through the quasi-vacuum of space we have the radial repulsive force possessing successive propagation, required to account for the changes of form in the lighter matter of comets and nebulæ; and we may learn by that action, which is rapid and apparently fitful, to find the cause in those rapid bursts which take place in the central body of our system; but until we measure the force more exactly we shall be unable to say how much influence it may have in keeping the heavenly bodies at their respective distances.

"So far as repulsion is concerned, we may argue from small things to great, from pieces of pith up to heavenly bodies; and we find that repulsion, shown between a cold and warm body, will equally prevail, when for melting ice is substituted the cold surface of our atmospheric sea in space; for a lump of pith a celestial sphere, and for an artificial vacuum a stellar void.

"Attraction being developed by radiant heat under influences connected with air, it is not easy to conceive how it will be produced for cosmical purposes by heat. The upper surface of our atmosphere must present a very cold front, and from this we might argue repulsion by the sun, unless we fill space with a body acting like air, when we should have attraction. We might readily find conditions for both, but how to harmonize them is a difficulty.

"Although the force of which I have spoken is clearly not gravity, solely as we know it, it is attraction developed from chemical activity, and connecting that greatest and most mysterious of all natural forces, action at a distance, with the more intelligible acts of matter. In the radiant molecular energy of solar masses may at last be found that 'agent acting constantly according to certain laws,' which Newton held to be the cause of gravity." * Mr. Crookes is continuing his splendid researches, and in a letter informs me that he is about to bring before the Royal Society some recent discoveries which, he says, "will go far to confirm your idea that repulsion resulting from radiation may explain some astronomical phenomena."

* Phil. Trans. clxiv. part ii. par. 81; 1874.

Dr. Huggins first examined a small comet which appeared in 1866 and 1867, and found a faint continuous spectrum crossed by bright lines. In 1868 Brorsen's comet showed a similar faint continuous spectrum with three bright lines, which did not coincide with the three lines of the nebulæ, or indeed with any known spectra. With Winnecke's comet, in the same year, he was more fortunate, being able to refer three out of the six observed lines to some compound of carbon. The faint continuous spectrum, in all probability, shows that part of the cometary light is reflected, but the bright lines certainly indicate that they are self-luminous.* Dr. Vogel,† in an exhaustive paper, has examined the evidence of the spectroscope on this subject up to the year 1874, with the following results:—

1. Comet I. 1864 (the first observed spectroscopically) exhibited three bright bands, not coincident with any known carbon spectrum.

2. Tempel's comet I. 1866. Secchi observed three and Huggins one bright line, not coincident with carbon lines.

3. Comet II. 1867 had so bright a continuous spectrum, that it was difficult to determine the bright lines, but Huggins thought they were similar to the above.

4. Brorsen's comet I. 1868. Observed by Huggins

* Phil. Trans. 1868, p. 529 *et seq.*

† Poggendorff's "Annalen," 1874; *Nature*, vol. ix. p. 193, 1874.

and Secchi. Its three lines were not referable to nitrogen or carbon.

5. Winnecke's comet II. 1868. Both Huggins and Secchi found the spectrum apparently coincident with a hydrocarbon spectrum.

6. Comet I. 1870. Wolf and Rayet observed three bright lines, whose positions were not accurately determined.

7. Comet I. 1871. Observed by Huggins and Vogel. Three bright lines were seen similar to those in No. 4.

8. Encke's comet III. 1871. Observed by Huggins, Young, and Vogel. Three bright lines were seen, which the first gentleman thought were probably hydrocarbon lines, but the other observers failed to confirm the coincidence.

9. Tuttle's comet IV. 1871. Vogel found three lines not coincident with hydrocarbon spectra.

Dr. Vogel is doubtful whether the existence of carbon in any comet has been proved; but Dr. Huggins's observations upon Winnecke's comet seem to me to place the matter beyond reasonable doubt, and in this conclusion Professor Roscoe coincides.*

We are justified in saying that the cometary matter is self-luminous, and that probably it reflects feebly the solar rays also. The continuous

* "Spect. Analysis," p. 348, 1873. The discovery of carbonic acid and carbonic oxide in meteorites, and the identity of the spectra of these substances with the carbon lines of some comets, seem to place the matter beyond reasonable doubt. *Vide ante.*

spectrum *may* belong to the comet itself, but is not likely to do so when we remember the great rarefaction of the material. Moreover, it is a fair assumption that comets vary in their constitution—a conclusion in agreement with M. Faye's hypothesis; and that some of them contain carbon in some form or another. If, as we shall proceed to show, certain meteors are derived from cometary matter, the discovery of carbon in some meteoric stones derives an additional interest.

The spectroscopic observation of meteors is attended with great difficulty, owing to the transient nature of the light. Mr. Browning has designed a spectroscope especially adapted to this work, and to him and Professor Herschel we owe the initiation of this branch of knowledge. To the latter gentleman I am indebted for my information, he having kindly given me all the information available up to the present date. Herr von Konkoly is the only other observer on this subject. The results are necessarily meagre, but not the less interesting. Sodium and magnesium are very frequent, the latter especially so. Strontium, lithium, iron, and copper are also visible occasionally, and a carbon spectrum, like that observed in some comets, was detected by Von Konkoly in the streak of a fireball, observed in October 13th, 1873.*

* The following references to articles on meteor-spectroscopy were given me by Professor Herschel. They embrace all that has been achieved up to the present time (Sept. 1877):—Browning, J.,

Mr. Browning observed the spectra of the splendid meteoric shower of November 13—14th, 1866, but to Professor A. Herschel we owe much of our knowledge upon this subject. His observations prove, as might have been expected, that they are very variable in constitution.

The connection between certain meteor-streams and comets is a most important one. That these streams are not comets is so self-evident that it would be absurd to take up time in proving it. We have already hinted that, according to the theory of the origin of comets' tails here advocated, much of their matter must be left behind to follow on in the comet's path. Professor Kirkwood, of the State University, Virginia, U.S., in the year 1872,* communicated an interesting paper on the Disintegration of Comets, in which he maintains "(1) that meteors and meteoric rings are the *débris* of ancient but now disintegrated comets whose matter has become distributed around their orbits; (2) that the separation of Biela's comet as it approached the sun in December, 1845, was but one in a series of similar

"Spectra of Meteors," of Nov. 13—14, 1866, Phil. Mag. 4 S. xxxiii. p. 234; Herschel, A., "Spectra of Meteors," Intel. Observ. Oct. 1866; Konkoly, H. v., "Spectra of Meteors," Month. Not. R. Ast. Soc. xxxiii. p. 576, xxxv. p. 246; also B. A. Rep. for 1874, p. 345, for 1875, p. 256, for 1876, p. 165. The notices of this observer's work in Month. Not. R. A. S. xxxiv. p. 83, are incorrect. The B. A. Reports for 1874-6 contain admirable *résumés* of all that is known respecting this subject.

* *Nature*, vol. vi. p. 148.

processes which could probably continue until the individual fragments would become invisible; (3) that certain luminous meteors have entered the solar system from inter-planetary space, and that some may have originated within the system; (4) that the orbits of some meteors and periodic comets have been transformed into ellipses by planetary perturbations; (5) that numerous facts—some observed in ancient and some in modern times—have been decidedly indicative of cometary disintegration."

He leaves the question of repulsion as one for future discussion, and then proceeds to give ten cases of the observed breaking-up of comets into two or more separate masses. Amongst other illustrations he cites Professor H. A. Newton's determination of the identity of the comets of 1366 and 1866, pointing out that whereas in 1366 it was an object of considerable magnitude, in 1866 it was invisible to the naked eye, and draws the ready inference that the "meteor swarm" of November is the product of such disintegration. He also clearly recognises the fact that meteor systems, even when moving in elliptic orbits, are not necessarily permanent members of our system, being liable (like comets) to ejection therefrom by planetary influences.

Professor A. Herschel, of Newcastle, a great authority upon meteors, made a most important addition to our knowledge on this point, by an exhaustive examination of the history of Biela's comet, singularly confirmatory of the second proposition of

Professor Kirkwood above given.* He directs attention to its appearance in the years 1772, 1826, 1846, and 1852; to its separation into two portions in 1846, to the reappearance of the two comets in 1852 with increased distances apart, and lays great stress upon the remarkable fact that they were missing at the times of their expected return both in 1859, 1866, and 1872, although the period was well known, and the time of appearance accurately calculated. The telescopes of most of the observatories in the world persistently swept the heavens in the vain search for these singularly interesting bodies. Herschel further shows the probability of a similar separation having taken place previously—the telescopic comet discovered by M. Pons, at Marseilles, in 1818, having the same path as Biela's comet, although it was certainly not that body. He also shows that more than one telescopic comet is associated with the comet of 1866 and the November meteor shower. It is then pointed out that the meteor shower observed on December 7th, 1798, and subsequently, was proved by Dr. Weiss, of Vienna, and Dr. D'Arrest, of Copenhagen, to coincide with the orbit of the comet of 1818 and Biela's comet. It also appears that the meteor shower has advanced with the node of the comet from December 7th, as observed in 1798, to November 27th, as evidenced by the display of shooting stars on that date in 1872. It is highly pro-

* *Nature*, vol. vii. p. 77.

bable that in Biela's comet we have been able to observe the breaking-up of an original comet into at least three fragments, of which the first was dissipated early in this century, and the two last since 1852; and, moreover, that the cometary matter has been condensed into a well-known meteoric stream.

Professor Herschel's paper called forth a host of good work, and in the Report on Luminous Meteors, made by the British Association Committee (of which he is a member) for 1875, no less than 157 meteor showers are correlated with comets.* Of these a few of the more important are given below:—

Comet.	Date of Shower.	Name of Shower.
1861, I.	April 20.	Lyraïds.
Halley's, 1835, III.	May 4, 14, and 16.	None.
Winnecke's, 1858, II.	July 16, Aug. 26.	"
1862, III.	Aug. 10.	Perseïds.
Donati's, 1858.	Sept. 8.	None.
1866, I.	Nov. 13.	Leonids.
Biela's, 1852, III.	Nov. 27, 28.	None.
Lexell's, 1770, I.	July 8, Aug. 6, Sept. 17, Nov. 29.	"

Professor H. A. Newton, U.S.A., has shown that a stream of meteors accompanies Biela's comet, preceding it by 300,000,000 miles and following it for 200,000,000 miles—the stream being thus 500,000,000 miles long, or more than five times the distance of

* Report Brit. Assoc. for 1875, pp. 232—5.

the earth from the sun.* Professor Kirkwood has continued his observations on the disintegration of comets, and shows that there are two groups of November (Leonid) meteors indicating a former separation of the 1861 I. comet, and its subsequent disintegration.†

The conviction is thus forced upon us that in these cometary meteor-streams we see the disintegrated remains of comets, a conclusion at which I arrived from an independent analysis of the evidence. I have been unable to find any explanation of the breaking-up of comets into distinct portions; but, to my mind, the phenomenon is readily explicable on M. Faye's hypothesis. Comets are often composed of materials differing in density, and this gives rise to distinct tails. Now nothing is more probable than that during the perihelion passage, when the solar forces are exerting their utmost strength, the "winnowing" action of the repulsive forces should occasionally separate the particles differing widely in density, the lightest group being driven farthest away, and consequently lagging behind the others.

It is to be hoped that the great dearth of comets that has prevailed since the spectroscope has become so efficient an instrument in the hands of such men as Lockyer, Huggins, Draper, Secchi, and others, may speedily come to an end, and that

* Brit. Assoc. Rep. for 1875, p. 223.

† *Ib.* and *Nature*, Jan. 1875.

we may be favoured with one of these "visible nothings" sufficiently large to admit of accurate observations being made concerning the nature of its various portions.

In thus passing in review some of the most important relations of the solar system, we have been led to look upon it as a vast and complicated structure widely different from the simple arrangement that it presented to our ancestors. But from this almost chaotic assemblage there has gradually emerged a grander and truer simplicity than the light of bygone days could show. Everywhere throughout our system we have been struck with the interdependence between the various members. The major planets by their masses disturb the regularity of each other's motions; the minor planets, the meteor systems, and the comets undergo similar perturbations. All are obedient to the rule of the central sun; yet even he is not exempt from their influences. From his mighty mass are continually being hurled showers of meteors, some of which pass from his complete control and fly to other systems. Some fall back upon his surface, others are gathered in by his family of planets, and yet others circle round him in systems which help to crown him with the glorious nimbus that is only revealed to us during the few minutes of his obscuration by the moon. We have also been led to see that we are not isolated from other suns, but that they too send meteoric messengers to us, and reveal the identity of their constitution with ours. The weird comets have been compelled to yield their secrets, and we recognise them as casual visitants, and as more or less permanent members of our system. The mystery of their gradual decay has been cleared up, and we seem to be upon the confines of the knowledge which shall tell us of the origin of suns and planets, stars and nebulæ. Wonderful as all this is, we are still brought face to face with the grand mystery of being, concerning which we can only say, "Lo! these are but the beginning of His wisdom; they utter but a whisper of His glory."

Throwing our information into terse conclusions, we have shown—

1. That the planets all revolve about the sun, and upon their respective axes in one direction.

2. The satellites, excepting those of Uranus, have similar movements.

3. The planetary system is divided into two series by the zone of asteroids.

4. The intra-asteroidal planets revolve in about twenty-four hours.

5. The extra-asteroidal planets revolve in about ten hours.

6. The planets are under the influence of gravitation.

7. Every particle of matter attracts every other particle.

8. The earth's axial rotation causes bodies to weigh less at the equator than elsewhere.

9. If the speed of this rotation were increased seventeen times, bodies at the equator would have no weight.

10. Bodies moving under the influence of a central force describe circles, ellipses, parabolas, or hyperbolas, according to the direction and speed of their motion, and their distance from the central body.

11. The planets describe ellipses about the sun as one of the foci; therefore they are acted upon by a central force.

12. The earth is a planet obeying all the laws of planetary motion.

13. A planet at a given distance must have a certain velocity to enable it to maintain that distance.

14. A planet would be nearly, or quite, freed from complete solar control if it had the velocity of the next inner planet.

15. The distances of the planets from Mercury outwards are such that each is about twice as far from the next inner as from the next outer planet.

16. The planets play the part of suns to their satellites, so far as gravitation is concerned, and the larger ones probably afford light also.

17. The mutual reaction of the planets, &c., gives rise to perturbations known as the precession of the equinoxes, nutations, variation of orbital excentricity, and revolutions of the apsides.

18. The asteroids are small planets, whose inclinations and excentricities vary much more than those of the larger planets.

19. Multitudes of meteors travel about the sun in all sorts of directions, and with every imaginable degree of excentricity.

20. The zodiacal light and part of the light of the solar corona are due to the passage of such systems near to the sun.

21. Meteoric stones are fallen meteors.

22. The earth encounters about 144,100 millions of meteors in a year.

23. Meteoric stones are of two kinds—metallic and stony.

24. Many of the former have been ejected by the sun and by stars of similar structure.

25. Many of the latter have been ejected from dusky, cool stars.

26. Much of the light of the solar corona is derived from material ejected by the sun.

27. Myriads of meteors belonging to our own and other systems are gathered in by the planets and the sun.

28. Similarly, many solar meteors pass from our own to other systems.

29. Comets describe elliptic or hyperbolic paths about the sun.

30. Many comets come to us from space and pass away again for ever.

31. Many comets are made permanent members

of our system by the influence of the major planets.

32. Some comets are ejected from the system by the same causes.

33. The orbits of periodic comets are often of very great excentricity.

34. The inclinations of cometary orbits are of all degrees.

35. Many comets have a retrograde movement.

36. The mass of a comet is inconceivably small, though their size is often immense.

37. The tails of comets are formed during their perihelion passage.

38. The tails are always turned away from the sun in the direction of the radius vector, and they are bent backwards.

39. Some comets have more than one tail.

40. The tail is formed by the repulsive action of solar heat.

41. When a comet has more than one tail, each differs from the others in density.

42. The densest tails are most curved.

43. Tyndall has shown that matter of cometary attenuity can reflect light.

44. Crookes has proved that heat can repel bodies.

45. Some comets split up into two or more pieces.

46. All comets are undergoing disintegration by the loss of matter from their tails.

47. Such matter forms streams of meteors along the cometary orbit.

48. Nearly 200 such cometary meteor-streams are already known, or suspected.

49. The chemical constitution of comets is not known.

50. One seems to contain carbon, and carbon is found in some meteorites.

CHAPTER VIII.

THE SUN.

CONCERNING the glorious orb which sways the movements and in many other ways influences the family of bodies which constitute our system, a vast amount of information has been collected, which only to epitomise would require several volumes such as this. The present chapter must be deemed merely a very slight sketch introductory to the study of the many and admirable works which deal with the sun. It is not even possible to mention the names of the noble army of philosophers who have won undying fame in this field of research, for they are happily to be numbered by scores, and are to be found wherever civilisation has established its sway.

Much has already been said respecting the gravitation of the sun; and, regarding its geometrical characters, it must suffice to enumerate some of them as briefly as possible.

The distance of the sun from the earth is a most important factor in astronomical measurements; and, although we do not know accurately what that distance is, the limits of error are so small that for all ordinary purposes it may be considered exact. At present the best determinations give, in round numbers, 91,850,000 miles*. We cannot as yet determine the exact distance within about four or five hundred thousand miles; and inasmuch as this is twenty times the circumference of the earth, some persons unacquainted with the nature of the problem have spoken as if astronomy, in spite of its vaunted "mathematical accuracy," had lamentably failed in the solution of a fundamental measurement, and was in consequence unreliable. Such is by no means the case; for it is forgotten by, or was unknown to, such objectors that to detect a difference of five hundred thousand miles at the distance of the sun, is much the same as measuring accurately the height of a man at the Cape of Good Hope by an observer stationed in London. An error of four millions of miles in the sun's distance would be equal to mistaking the height of an ordinary sized woman for that of a moderately tall man.

Until recently the sun's distance was given as about 95,274,000 miles; but more exact calculations from known data have shown that a more probable estimate is, as above stated, about 91,850,000 miles, giving a difference of about 3,414,000 miles. This difference, be it remembered, was not detected by those who cavil at what they term the "pretentiousness of science" (if it had been they might have had

* The report of the Astronomer Royal upon the results of the English Transit Expeditions gives 92,393,000 for the sun's mean distance. This measurement may require modification.

grounds for their remarks), but by the astronomers themselves; and, so far from being a subject for shame, it is one of the triumphs of modern mathematics. To go back to our illustration, the observer himself discovered that it was a woman's and not a man's height he had measured. Similarly the task that astronomers are now at work upon is a correction equivalent to about one inch in the stature of the person at the Cape as viewed from London.

In round numbers the sun's diameter is 850,000 miles, so that it would take 108 earths ranged side by side to stretch across its disc. The area of his surface is two billion two hundred and eighty-five thousand millions of square miles, or 11,650 times that of the earth. His volume, as compared with the earth, is 1,250,000 times greater, and his mass 318,000. If his density were as great as the earth's, his mass would exceed it, of course, by the same amount as his volume; that is, he would be 1,250,000 times as heavy. But such is not the case, his density being only one quarter of that amount; in fact, whereas the density of the earth is about 5½ times that of water, the sun's is only 1·42 times as heavy as water. Consequently the sun, *as a whole*, is composed of lighter materials than the earth. It, however, by no means follows that some parts (say near the centre) of the sun may not be denser than any terrestrial matter. The force of gravity at the sun's surface is 27·1 times greater than on earth; hence, while a body under the influence of terrestrial gravity falls 16 feet in a second, at the sun's surface it would fall 436·3 feet.

The general features of the sun may be thus summarised. The blazing disc, or *photosphere,* to which we usually apply the term sun, is not uniformly illuminated. Over the whole surface are scattered intensely bright areas, which we will call *granules,* between which darker spaces or *pores* are visible. Besides the pores there are generally to be seen dusky areas, or *spots,* of greater or less extent, which come and go in a seemingly capricious manner, but which certainly belong to the sun as they revolve with him. In the neighbourhood of these weird spots, especially when they are seen on the edge of the sun, are frequently to be observed extensive bright areas or *faculæ,* which are quite distinct from the granules above mentioned. The spots are confined to two zones—one on each side of the solar equator, and the faculæ generally lie behind the spots, or in the direction from which the spots have been carried by the sun's rotation.

During an eclipse, or at any time by means of a special application of the spectroscope, remarkable *prominences,* generally like rose-coloured flames, are seen projecting from the photosphere, which consist chiefly of glowing hydrogen. Sometimes these are linked into a mountain-like chain, to which the appropriate name of *sierra* has been applied. The entire photosphere is immersed in an atmosphere of glowing gas, several thousands of miles in depth, which at its outer limits is mainly composed of hydrogen, other materials being associated with that gas as the photosphere is approached. To this layer, which gives a spectrum of bright lines, Mr. Lockyer has given the name *chromosphere* (*chroma*, colour), or, more rigidly, the *chromatosphere*. Outside the chromatosphere comes the magnificent glory, known as the corona, concerning which so much has been said in the previous pages.

We must now examine these phenomena in somewhat greater detail, commencing with the spots. It is, nevertheless, necessary to remind the reader that only a very meagre sketch can here be given.

These singular appearances have been most carefully studied since their first discovery by Galileo and others. Generally speaking, they consist of a very dark central *nucleus*, surrounded by a less dark area or *umbra*, between which and the edge of the spot is a lighter *penumbra*. Suppose a spot to be just appearing on the edge of the disc as the sun revolves upon his axis. The dusky penumbra on the side nearest the edge appears wider than the opposite side. As the revolution brings the spot nearer to the centre of the disc the central side (as we may call it) of the spot broadens, and attains its maximum development when the spot is centrally situated on the disc. As the spot is carried towards the opposite side of the sun, the spot's central side diminishes in breadth. Now this is just the appearance that would result if the spot were a basin-shaped depression below the general level of the photosphere; and such was the conclusion drawn by Dr. Wilson, of Glasgow, in 1769, the first observer of the phenomenon. All subsequent research has confirmed the justice of this deduction, and although very many modifications and irregularities have been observed from time to time, we are now quite sure that sun spots are areas of depression.

The formation and dissolution of spots have been watched with great care, and although every imaginable variety of aspects and degree of rapidity have been noticed, certain distinctive features appertain to the various stages of development. Mr. Proctor thus admirably summarises the phenomena: "The formation of a spot is usually preceded by the appearance of a facula. Then a dark point makes its appearance, which increases in size, the penumbral fringe being presently recognised around it, and the distinction between the umbra and the penumbra being well defined. The same clearness of definition continues ordinarily until and after the spot has reached its greatest development. But when the spot is about to diminish there is a change in this respect. The edges seem less sharp, and an appearance is presented as though there floated over them a luminous cloud-veil, brighter in some places than others, and not unfrequently attaining a brightness which seems to exceed even that of the faculæ.

At certain parts of the spot's circumference, this bright matter projects, hiding the whole width of the penumbra and forming a sort of cape or promontory, with sharply serrated edges, singularly well-defined against the dark background of the umbra. It is usually in this manner that the formation of a bridge begins—two promontories on opposite sides of a spot, or even on the same side, joining their extremities, so as to form either a bridge of light across the umbra, or a curved streak having both its extremities on one side of the spot. But indeed no strict law or sequence has yet been assigned to these processes of change. In a large spot the wildest and most fantastic variations will take place, and often when the spot seems approaching the stage of disappearance it will seem to renew its existence, as though fresh forces were at work in disturbing the region it belongs to."*

The sizes of spots are very variable. Some are so minute as to require high magnifying powers for their detection, others are readily visible to the naked eye. In the year 1858 some remarkably large spots were observed, of which one had a breadth of 143,500 miles. Into such a basin as this (as Mr. Williams observes) worlds like ours could be poured like peas.

The duration of spots is as inconstant as their other phenomena. Some have been observed to travel round with the sun seventeen times; others

* "The Sun," p. 229.

are short-lived. Their destruction is sometimes very rapid. Dr. Wollaston saw a large spot burst into pieces, as it were, like "a piece of ice when dashed on a frozen pond, which breaks in pieces and slides on the surface in different directions." Sir W. Herschel has seen a spot-group disappear almost instantly, and other records of a similar kind could be produced.

It has already been remarked that sun-spots are variable phenomena, the disc being sometimes quite free from them, and at others very rich in the particular regions they affect. We owe the recognition of their periodicity to the indefatigable researches of Herr Schwabe, of Dessau, whó, for over forty years, daily examined the sun, tabulating the numbers, sizes, and positions of the spots. From these researches we learn that the spot-frequency varies through a cycle, to which Schwabe ascribed a period of 10 years, Professor Wolf, of Zurich, a period of 11·11 years, and Messrs. De La Rue, B. Stewart, and Loewy 11·07 years. The progression from minimum to maximum is more rapid than the passage from maximum to minimum, as is shown in the following table: *

Year.	No. of spot-groups.
1855	38
1856	34
1857	98
1858	188
1859	205
1860	210

* *Nature*, vol. xvi. p. 11; 1877.

Year.	No. of spot-groups.
1861	204
1862	160
1863	124
1864	113
1865	93
1866	45
1867	17

Besides this principal cycle, minor peculiarities appear to exist. Thus there are generally more spots between the months September to January than in the rest of the year; and it seems probable that a minor cycle occupying 0·627 of a year, or 7·65 months, is herein shown; and as this period closely corresponds with the periodic time of Venus, it would show a disturbing influence of that planet upon the sun.

Mr. De La Rue, Professor Balfour Stewart, and Mr. Loewy have since examined this question at great length. In commencing their investigations they argued that there certainly is a periodicity of sun-spot frequency, the cause of which lies either in the sun or outside it. It is difficult to understand how any internal actions could give rise to such a cycle of changes; and, on the other hand, it is not easy to see how such comparatively small bodies as the planets could cause such vast disturbances. We cannot, they pointed out, conceive any internal cause; but in the relative positions of the planets we have at least a possible cause, and this they diligently investigated. All the most accurate measurements and photographs were examined, and the results plotted, so as to represent the behaviour of the spot-groups as they travel across the sun's disc from left to right. If a spot retains the same magnitude during its passage, its path is represented by a horizontal line; if it becomes smaller in the centre of its course, the line is curved so that the middle is lowest. In this way it was found that when Venus or Mercury is between the earth and the sun's centre, the spots diminish as they approach the centre and then increase again. When these planets are at the extreme right of the sun the spots diminish all the way across. When either planet is exactly opposite the earth the spots have their maximum at the centre. Finally, when either planet is at the extreme left of the sun the spots increase all the way across. In fact it is demonstrated that the spots are greatest when Mercury or Venus are farthest away, and smallest when they are nearest. Moreover, it appears that when two planets are on the same side of the sun more spots than usual are formed, and when they are on opposite sides fewer than ordinary are observed.

It is also well known that the movements of the magnetic needle are greatly influenced by sun-spots. A freely suspended magnetic needle oscillates daily, but at certain times great fluctuations of a most erratic nature take place, which are known as magnetic storms. These are much more frequent in seasons of great sun-spot richness than at others, and on one occasion the connection was verified in a remarkable manner. Sir J. Herschel has described this occurrence so graphically that, although his words have been quoted again and again, I may be pardoned for reproducing them once more.

"There occurred on September 1st, 1859, an appearance on the sun which may be considered an epoch, if not in the sun's history, at least in our knowledge of it. On that day great spots were exhibited, and two observers, far apart and unknown to each other, were viewing them with powerful telescopes, when suddenly, at the same moment of time, both saw a strikingly brilliant luminous appearance, like a cloud of light far brighter than the general surface of the sun, break out in the immediate neighbourhood of one of the spots, and sweep *across* and *beside* it. It occupied about five minutes in its passage, and in that time travelled over a space on the sun's surface which could not be estimated at less than 35,000 miles.

"A magnetic storm was in progress at the time. From the 28th of August to the 4th of September many indications showed the earth to have been in a perfect convulsion of electro-magnetism. When one of the observers I have mentioned had registered his observation, he bethought himself of sending to Kew, where there are self-registering magnetic instruments always at work, recording by photography at every instant of the twenty-four hours the positions of three magnetic needles differently arranged. On examining the record for that day it was found that at that very moment of time (as if the influence had arrived with the light) all three had made a strongly marked jerk from their former positions. By degrees, accounts began to pour in of great auroras seen on the nights of those days; not only in these latitudes, but at Rome, in the West Indies, in the tropics within 18° of the equator (where they hardly ever appear), nay, what is still more striking, in South America and in Australia, where, at Melbourne, on the night of the 2nd of September the greatest aurora ever seen there made its appearance. These auroras were accompanied with unusually great electro-magnetic disturbances in every part of the world. In many places the telegraphic wires struck work. They had too many private messages of their own to convey. At Washington and Philadelphia, in America, the telegraph signalmen received severe electric shocks. At a station in Norway the telegraphic apparatus was set fire to; and at Boston, in North America, a flame of fire followed the pen of Bain's electric telegraph, which, as my hearers perhaps know, writes down the message upon chemically prepared paper."*

Nor is it alone the violent magnetic storms and auroral displays which are thus influenced by the sun-spot frequency; for it has been demonstrated by Professor Loomis, of the United States, and even more rigidly by Professor Balfour Stewart, that the

* "Popular Lectures on Scientific Subjects," p. 79; 1876. London: Daldy, Isbister & Co.

fluctuations of the magnetic daily range also occur in cycles corresponding in length with the sun-spot period. The latter authority, moreover, points out that though this magnetic period is equal to the spot cycle, it is not contemporaneous therewith, but lags behind, as it were, about six months. May not this be a fortuitous coincidence? To this Professor Stewart has given a conclusive negative. If, he reasons, the sun-spot frequency is directly influenced by the planets, and if, again, the magnetic fluctuations depend upon the sun-spots, then the magnetic fluctuations ought to show a similar dependence upon the planetary positions—not that the planets influence the magnetic needle directly, but indirectly through their disturbing action on the sun. He made the necessary investigation, and the result was indisputable. There is a striking resemblance between the magnetic and sun-spot inequalities dependant upon the positions of the planets, and the former lag behind the latter, as theory demanded. "It is," he remarks, "unquestionably a very strange and striking conclusion that the daily range of the magnet, freely suspended in a vault of the Kew Observatory, should be sensibly greater about the times when Mercury and Venus, or Venus and Jupiter, come together in position, and also about the times when Mercury is nearest the sun." *

Not alone in the apparently obscure fluctuations of the earth's magnetism is the periodicity of sun-spots

* *Nature*, vol. xvi. p. 28; 1877.

influential, for Professor B. Stewart has shown that the mean daily range of temperature shows a very close agreement with the range of the magnetic changes, and this discovery is pregnant with momentous consequences, for as the latter lag behind the sun-spot periods of activity, so do the former. Who can tell but that ere long many meteorological changes will be capable of prediction from a careful, continuous, and enlightened study of the solar surface? Such a scheme was carried on at Kew for years, but a penny-wise parsimony has prevented its continuance.

We do indeed, even now, begin to see an intimate connection between sun-spot cycles and various meteorological phenomena. Thus the winds seem peculiarly influenced, and Mr. Meldrum, of Mauritius, has shown that the fearful cyclones that sweep over the Indian region are most frequent during sun-spot maxima. This comes out very clearly from an examination of the following table: *

Character as regards sun-spots	Years.	Total number of cyclones.	No. of cyclones in max. and min. periods.	Character as regards sun-spots.	Years.	Total number of cyclones.	No. of cyclones in max. and min. periods.
Max.	1847	5	23		1853	8	
	1848	8		Min.	1854	4	13
	1849	10			1855	5	
	1850	8			1856	4	
	1851	7			1857	4	
	1852	8			1858	9	

* *Nature*, vol. xvi. p. 45; 1877.

Character as regards sun-spots.	Years.	Total number of cyclones.	No. of cyclones in max. and min. periods.	Character as regards sun-spots.	Years.	Total number of cyclones.	No. of cyclones n max. and min. periods.
Max.	1859	15	39		1868	7	31
Max.	1860	13		Max.	1869	9	
Max.	1861	11		Max.	1870	11	
	1862	10		Max.	1871	11	
	1863	9			1872	13	
	1864	5			1873	12	
Min.	1865	7	21				
Min.	1866	8					
Min.	1867	6					

A similar connection has been shown to subsist between sun-spot frequency and the cyclones of central Africa.

The winds are the vehicles of the rain, and if the former are influenced by the sun-spot cycle we might expect the latter to be so likewise; but, for this action to manifest itself clearly, we must seek our evidence in the tropical regions of periodic rains rather than in the temperate zones of variable rains. Our only reliable data are from India, where the question is still under scrutiny, but sufficient evidence is already collected to prove that such a connection really exists. Dr. Hunter, Director-General of Statistics for India, first called attention to the periodicity of famines in Southern India (caused by a failure of the rice crop through defective rainfall), and their coincidence with the minima of sun-spot cycles. Since then several gentlemen have worked at the question, the most important (to my mind) being the researches of Messrs. S. A. Hill and E. D. Archibald,* whose results, independently arrived at, are suggestively coincident. It seems quite clear that the rainfall of India varies with the sun-spot cycle, and that in years of maximum sun-spots the summer rainfall is above and the winter rainfall below the average, while in years of minimum sun-spots the cases are reversed. The practical importance of this question cannot be over-estimated, for in future we may be able to guard the districts of summer rain from drought and consequent famine during sun-spot minima, and districts of winter rains from similar catastrophes during sun-spot maxima. Let us hope such a time is close at hand, and that the heartrending scenes of misery such as now prevail in the Madras presidency may become things of the past. How could a government render itself more cherished of the people than by removing gaunt famine from their midst ! †

We are far from knowing the extent to which this periodicity of sun-spots influences us. Dr. A. Schuster has shown that the good wine years of

* See *Nature*, 1877, several papers.

† It has been suggested, and is indeed maintained, by several meteorologists, that there is a cyclical variation of solar radiation corresponding to the spot period. Be this as it may (it does not seem to me to be proved), I cannot see how a *general* lowering or heightening of the temperature can give rise to variations in the great convection currents (trades and anti-trades) so as to give one supremacy over the other. These currents depend upon *differences* of temperature at any given time, hence a *general* lowering or heightening of temperature could not cause one wind to preponderate over another, as has been assumed.

Germany correspond to the sun-spot minima. Mr. G. W. Dawson has shown an apparent connection between the seemingly capricious fluctuations of the water-level of the great American lakes and the same cycle. It has even been suspected that periods of commercial panic are periodic, and run through the same cycle! This may be fanciful, it is true, but at any rate in this singular epoch we have come upon another link in the chain which unites the earth and sun.

We must, after this long excursion, return to the question of sun-spots themselves. One of the first results of their discovery was the recognition of the rotation of the sun upon his axis. That the period was about twenty-five days was at once disclosed; but when accurate measurements of the time taken by spots to traverse the disc were compared, considerable discrepancies appeared, amounting in some cases to hours, and as they were clearly of too glaring a nature to be due to errors of observation, it was suspected that some spots, at any rate, had proper motions. The late Mr. Carrington commenced a splendid series of observations for the purpose of determining this, among other points, and his researches continued until 1861, with results amply justifying the immense expenditure of labour. He found that some spots actually possess proper motions, although such a phenomenon is comparatively rare; but the remarkable result clearly manifested itself that in different solar latitudes the sun-spots rotate in different periods. The velocity is greatest near the equator and diminishes regularly towards the poles, the speed in southern latitudes being in all cases less than in the corresponding northern latitudes. The mean period of rotation, as determined by Carrington, is 25·38 days; Spörer, on a re-examination of these and other data, gives it as 25·23 days. The inclination of the solar equator as determined by these two astronomers is 7° 15′ in the one case, and 6° 57′ in the other.

We have before stated that spots often exhibit such an appearance in crossing the disc as to suggest the idea of great basin-shaped depressions. This phenomenon is by no means constant, for many spots exhibit no such changes, and in others the appearances are of an exactly opposite nature. Nevertheless, it is now considered proved that spots are areas of depression, caused by a downrush of comparatively cool gases, which in some cases assume the nature of great cyclones, infinitely greater than the still terrible cyclones they influence in corresponding tropical portions of the earth. It will presently appear, from the evidence of the spectroscope, that the points above mentioned as the results of telescopic observations have been definitely settled, Mr. J. Norman Lockyer having devoted much attention to this question.

Leaving the subject of spectroscopy for the present we will pass on to the study of the *faculæ,* those grand areas of intense brightness which are so frequently associated with spot-groups, and are most often visible towards the edge of the disc. Considerable discussion, foreign however to our purpose, has taken place respecting the faculæ; but the opinion that they are elevations rising above the general level of the photosphere (just as spot regions are depressed below it), advanced long since by Sir W. Herschel, is now generally accepted. Mr. Dawes, indeed, has seen a facula actually projecting beyond the edge of the disc. Messrs. De La Rue, Stewart, and Loewy examined the evidence of 1,137 spots and their accompanying faculæ, with very satisfactory results. Some physical connection between faculæ and spots is patent from their associated positions—the elevations and depressions are connected in some way or other. The three gentlemen above mentioned found that out of 1,137 spots, 584 had their faculæ to the left or behind them as respects the sun's rotation, and only 45 on the right hand, or in front. They conclude that "the faculæ of a spot have been lifted from the very area occupied by the spot, and have fallen behind to the left from being thrown up into a region of greater velocity of rotation."* They also think it probable that the faculæ (and perhaps the whole photosphere) are composed of solid or liquid matter slowly sinking or

* Many facts seem more in accordance with densely gaseous matter than with solid or liquid substances.

suspended in a gaseous medium. The bridges of luminous matter that sometimes span a spot, and the fragments that shoot across a spot, are also cited as proving the spots to be below the general luminous surface.

It is as well here to point out that, in speaking of the influence of the spot cycles upon terrestrial phenomena, it is not meant that the spots actually exercise any action upon the earth; but that spots and faculæ show that vast disturbances are occurring in the sun, and that these disturbances are of a periodic nature. It is this agitation of the sun that influences the earth, and, it may be added, the other planets also.

We must now consider those luminous portions of the solar disc which we shall call *granules.* Unlike the faculæ they are scattered over the entire surface of the sun, the spaces between them appearing as comparatively dark specks or pores. Different observers have variously described the granules as mottlings, granulations, crystals, clouds, straws, rice-grains, willow-leaves, ridges, waves, and what not; and they have been and still are subjects of animated discussion. Their importance was first recognised by the announcement of Mr. Nasmyth, that the photosphere was covered with a multitude of brilliant bodies of definite size and shape, crossing each other in every direction, but generally more or less isolated around the spots, across which they sometimes link themselves to form bridges. From their shape, Mr. Nasmyth denominated them willow-leaves, and ascribed the pores to the interspaces between these singular bodies. Other observers, while admitting a sort of definite shape in the vicinity of the spots, failed to see any evidence of uniformity upon the solar disc, but described the more brilliant portions as a general mottling of the surface.

The question, which is of the highest importance, resolves itself into this: if these granules are mere irregular mottlings, they may be referred to known phenomena, but if they are definitely shaped bodies swarming over the photosphere and uniting to span the spots, as South American monkeys bridge a stream, then we are at a loss to understand what their nature can be; not that such difficulty of explanation necessitates the rejection of the idea, for we are still ignorant of many of the processes of nature, but that ere accepting such a view very strong corroborative testimony must be forthcoming. Sir J. Herschel accepted the willow-leaf theory (as we may call it), and sees that "nothing remains but to consider them as separate and independent sheets, flakes, or scales, having some sort of solidity."* He further states that they must be the "immediate sources of the solar light and heat," and draws the astounding conclusion that "we cannot refuse to regard them as *organisms* of some peculiar and amazing kind"! Peculiar and amazing such fiery

* "Pop. Lectures," p. 83; 1876.

monsters must be indeed, when we bear in mind, that, to be visible at all, they must be at least a thousand miles in length and some hundreds in breadth. Surely before we can accept such conclusions every source of doubt as to their existence ought to be removed.

Accordingly we find these granules have received the closest scrutiny, and the independent testimony of such trained and careful observers as Dawes, Huggins, Lockyer, Secchi, and others, is dead against the willow-leaf theory. To the best of my judgment the balance of evidence is in favour of these gentlemen and those who side with them.*

When we come to a spot region the granules do often assume a more or less definite shape. They are seen surrounding the penumbra and projecting on to and in some cases quite across the umbra. Secchi has described certain of these as consisting of parts like willow-leaves, or like the crystallizations of salammoniac. Mr. Lockyer has seen these luminous masses gradually dying away in the sun-spots, and Secchi, speaking of a particular spot, says that the rest of the nucleus is due to the rarefaction of these "leaves."

In considering the nature of these granules it must be remembered that when we view the sun's

* Since the above was written M. Janssen has proved by means of large photographs that the interlacing does not exist. The granules in some places are clear and distinct, in others distorted and confused.

disc the objects are seen more or less foreshortened, or in plan, whereas when we examine the margin, bodies are seen in profile, or in elevation. Hence a body, say a projection, at the centre of the photosphere would appear like a spot of greater or less magnitude, which would lengthen out as it approached the edge, where it would be apparent in its full height. Now it has been suggested, indeed it is pretty certain, that the photosphere is in a continual state of violent commotion. If we look upon the photosphere as liquid, we must consider it to be ruffled with waves, or to have jets of luminous vapour bursting through it. If, on the other hand, as appears from Mr. Lockyer's researches most probable, the photosphere is densely gaseous, we must ascribe the commotion to flames or erupted luminous gases, or both. On either supposition the appearance of the granules can be accounted for. The tongues of flame or jets of vapour, foreshortened on the disc, would give it just such an appearance as it presents. In the spots we have violent downrushes of comparatively cool vapour, and we can easily see how such flames as are here suggested would be drawn inwards, and might present every one of those multifarious aspects which have been described as rills, bridges, veils, and so forth. The gradual dissipation of such flames within a spot is at the same time explained. Mr. M. Williams thus explains not only the granules, but the faculæ also, attributing them to "currents," "tides," and "groundswells," as it were, of the flaming photosphere, and the suggestion seems a probable one.*

When the sun is totally eclipsed, strange shaped, rose-coloured prominences shine forth from his edge. During successive eclipses they are seen to be of different shapes, and to occupy distinct positions on the sun's edge; but the period of totality is so short, and total eclipses are so rare, that the observations on prominences were comparatively meagre. Messrs. Norman Lockyer and Janssen independently made the brilliant discovery that by a suitable arrangement of the spectroscope (described in the chapter on light) the prominent spectra can be seen at any time. Our knowledge of them has consequently largely increased since 1868, the year of the discovery. Dr. Huggins has since shown us how to obtain accurate images of the prominences themselves by means of the spectroscope,† so that we are now able to study daily not merely the line spectra of the prominences, but their forms also, and to watch the changes they undergo. To Messrs. Lockyer, Secchi, Zöllner, Respighi, Young, and others, we

* Dr. Janssen has recently produced remarkably fine photographs of the solar disc, which bring to light facts that cannot be directly observed. His researches are quite in accordance with the view taken above.

† Dr. Huggins's plan is to so greatly disperse the general light of the sun, by means of a powerful train of prisms, as to render it practically *nil*, and then to open the slit of the spectroscope so wide that the image of the prominence is projected instead of the image of the slit.

are especially indebted for our information upon this subject.

The general results of observations on the prominences may be thus stated. The photosphere is surrounded to a depth of about 5,000 miles by a luminous envelope, generally of a red colour, to which Mr. Lockyer has given the name *chromosphere* (*chroma*, colour), or more correctly *chromatosphere*, from its giving a spectrum of bright lines. It presents, as Secchi points out, four aspects. It may be smooth with a definite outline, or smooth with an indefinite outline, or it may be fringed with filaments, or irregularly varied with small flames.

Rising above the chromatosphere are the prominences, which the same observer groups under three heads—*heaps*, *jets*, and *plumes*. The heaps are, as their name indicates, mere elevations of the chromatosphere. The jets are essentially eruptive phenomena. They are fitful and fleeting, often passing away in a few minutes and seldom lasting an hour; and it is a suggestive fact that they are seen wherever faculæ approach the sun's margin. It is difficult to describe these jets without illustrations, for they assume every variety of shape: sometimes shooting up in immense columns, 40,000 miles high and more, with evident signs of a twisting motion, then spreading out like the pine-shaped smoke of Vesuvius in eruption, and gradually subsiding; sometimes they appear bent and swayed about as if by violent winds; at others they break up into lovely coloured clouds which slowly sink towards the chromatosphere. It would seem from Secchi's observations that in these jets part of the photosphere itself is upthrown. The plumes differ materially from the jets, in not showing signs of eruptive formation, in being scattered indifferently over the solar surface, and in lasting longer, though they change much in figure. They extend to enormous heights (200,000 miles in one case), and appear to be due to the uplifting of chromatospheric matter.

The most wonderful prominence probably ever witnessed came under the observation of Professor Young, of America. His description, from the *Boston Journal of Chemistry*, for October, 1871, though long, may be here aptly reproduced, as affording the most vivid idea of these wonderful phenomena. "On the 7th of September last, between half-past twelve and two P.M., there occurred an outburst of solar energy remarkable for its sudden violence. Just at noon the writer had been examining with the telespectroscope an enormous protuberance of hydrogen, close on the eastern limb of the sun. It had remained with very little change since the preceding noon—a long, low, quiet-looking cloud, not very dense or brilliant, nor in any way remarkable except for its size. It was made up mostly of filaments nearly horizontal, and floated above the chromatosphere with its lower surface at a height of some 15,000 miles; but was connected with it, as is usually the case, by three or four vertical columns brighter and more active than the rest. Lockyer compares such masses to a banyan grove. In length it measured 3′ 45″, and in elevation about 2′ to its upper surface, that is, since at the sun's distance 1″ measures 450 miles nearly, it was about 100,000 miles long by 54,000 high.

"At 12.30, when I was called away for a few minutes, there was no indication of what was about to happen, except that one of the connecting stems at the southern extremity of the cloud had grown considerably brighter, and was curiously bent to one side; and near the base of another, at the northern end, a little brilliant lump had developed itself, shaped much like a summer thunderhead.

"What was my surprise, then, on returning in less than half an hour (at 12.55) to find that in the meantime the whole thing had been literally blown to shreds by some inconceivable uprush from beneath. In place of the quiet cloud I had left, the air, if I may use the expression, was filled with flying *débris*—a mass of detached vertical fusiform filaments, each from 10″ to 30″ long, by 2″ or 3″ wide, brighter and closer together where the pillars had formerly stood, and rapidly ascending.

"When I first looked, some of them had already reached a height of nearly 4′ (100,000 miles), and while I watched them they rose with a motion almost perceptible to the eye, until in ten minutes (1.5) the uppermost were more than 200,000 miles above the solar surface. This was ascertained by careful measurement. The mean of three closely accordant observations gave 3′ 49″ as the extreme altitude attained, and I am particular in the statement, because, so far as I know, chromatospheric matter (*red hydrogen* in this case) has never before been observed at an altitude exceeding 5′. The velocity of ascent also—166 miles per second—is considerably greater than anything hitherto recorded. As the filaments rose they gradually faded away like a dissolving cloud, and at 1.15 only a few filmy wisps, with some brighter streamers low down near the chromatosphere, remained to mark the place.

"But in the meanwhile the little 'thunder-head,' before alluded to, had grown and developed wonderfully into a mass of rolling and ever-changing flame, to speak according to appearances. First it was crowded down, as it were, along the solar surface; later it rose almost pyramidally 50,000 miles in height; then its summit was drawn out into long filaments and threads which were most curiously rolled backwards and downwards, like the volutes of an Ionic capital; and finally it faded away, and by 2.30 had vanished like the other.

"The whole phenomenon suggested most forcibly the idea of an explosion under the great prominence, acting mainly upwards, but also in all directions outwards, and then after an interval followed by a corresponding inrush; and it seems far from impossible that the mysterious coronal streamers, if they turn out to be truly solar, as now seems likely, may find their origin and explanation in such events.

"The same afternoon a portion of the chromatosphere on the opposite (western) limb of the sun was for several hours in a state of unusual brilliance and excitement, and showed in the spectrum more than 120 bright lines whose position was determined and catalogued—all that I had ever seen before, and some 15 or 20 besides."

The phenomena of the subsiding clouds succeeding these tremendous eruptions seem clearly to show that though the chromatosphere is not itself a true solar atmosphere, an atmosphere exists around it, though invisible, in which these fiery clouds are suspended, and through which they sink.

The features of the *corona* having been already described, it remains for us, now that the telescopic revelations have been summarised, to direct our attention to the teachings of the spectroscope respecting the condition of the sun. It is necessary here to remind the reader of a few important points in spectroscopy. Mr. Lockyer's discoveries respecting the spectra of compounds and elements, and the variations they exhibit under different conditions of pressure and temperature, are of the highest interest in this connection, and must lead to most important results. He has shown us that the spectra of elements are more simple than those of compounds, that the spectra of metalloids are channel-spaced, that the spectra of compounds differ from both. Moreover, he points out that, especially in the case of metalloids, the character of the spectrum changes with an increase of temperature, from a continuous spectrum to one with general absorption in the blue, thence into a channelled-space and finally at the temperature of the electric spark to one of bright lines. He has also shown that in certain cases the lines thicken out as the pressure increases (that is as the number of molecules becomes greater), and that new, shorter lines sometimes make their appearance. Lastly, he has made it clear that a continuous spectrum may be produced from a line spectrum by increase of density. This takes place in two ways: firstly, by thickening of the bright lines, as in the case of aluminium and other metals with low specific gravity and melting point; secondly, by an increase in the actual number of lines, as in the case of iron and other heavy metals difficult to fuse.

The spectroscope may be used in two ways. For instance, in examining the solar system, we may allow the general light of the sun to fall upon the slit, in which case the light comes indifferently from spots, faculæ, chromatosphere, and corona; or we can allow only the light from a small portion of the solar surface to impinge upon the slit, and so study independently the spectrum of the corona, or any other part of the sun, such as a spot. The first method gives us an *integrating*, the latter an *analysing* spectroscope: the one gives a general spectrum, the latter a particular one.

We will commence with the integrating instrument. The general solar spectrum is continuous, and traversed by a multitude of dark lines, which, from having been first mapped by Fraunhofer, are known as Fraunhofer's Lines. Now such a spectrum we know, from what has been said before, must be caused by incandescent matter (which may be solid, liquid, or densely gaseous) shining through incandescent gas at a lower temperature. The *intensity* of light (as distinguished from its colour) depends upon the height or amplitude of the vibration; colour depends upon the length of the vibration. A heated body, the amplitude of whose vibrations may be either so small as not to produce light, or so great that light is emitted, absorbs light of the same wave-length and greater amplitude. Hence, if there be a cooler gaseous envelope surrounding the sun, through which the hotter matter giving the continuous spectrum shines, the cooler gas will absorb from the light of the hotter matter those vibrations whose wave-length is the same as its own, but whose amplitude is greater. This is just what happens in the sun. The elements at present known to exist there are arranged according to their atomicities in the following list:

Monads.	Dyads.	Triads.	Tetrads.	Hexads.
Hydrogen	Oxygen	Gold (?)	Titanium	Chromium
Lithium	Calcium		Cobalt	Manganese
Sodium	Strontium		Nickel	Iron
Potassium (?)	Barium		Platinum (?)	Rubidium
	Lanthanium		Aluminium	
	Didymium		Cerium	
	Magnesium		Uranium	
	Zinc		Lead	
	Cadmium			
	Copper			

It will be noticed that this list is essentially one of metals, the only exceptions being hydrogen and oxygen. Even these exceptions vanish on closer scrutiny; for hydrogen is certainly a metal, although it is only known to us in the gaseous state, and oxygen has quite recently been added to the list by Professor Henry Draper, of New York, who finds it gives *bright* lines on the solar spectrum, the lines of all the other elements being dark. Hydrogen being a metal, we are justified in asserting that, so far as our knowledge goes, the dark lines in the solar spectrum are metallic lines. That the metalloids exist in the sun all analogy justifies us in assuming, but as yet (with the single exception of Professor Draper's discovery) their presence has not been demonstrated.* Now it is a very suggestive fact that in the Bessemer flame, although we know that metalloids exist there, their presence is not shown by the spectroscope; because, as Mr. M. Williams points out, they give rise to a continuous spectrum. The spectrum of the Bessemer flame

* Mr. Lockyer has since detected the presence of carbon.

being, in fact, continuous with bright bands. The remarkable discovery of Professor Draper opens out to us quite a fresh field of observation, inasmuch as he shows that the presence of metalloids may be detected in the spectrum as bright bands: the reason why they were not before seen being that bright lines are not so easily seen upon a bright ground as are dark ones, though when attention is directed to them they are apparent enough.* This discovery, indeed, forces us to look upon the solar spectrum as being continuous, with both bright and dark lines.† Indeed, it may be that the photosphere is a sort of gigantic Bessemer flame, the dark lines being due to the presence of its metallic constituents, and the continuous spectrum and bright lines to its metalloidal components. However this may be, Professor Draper's brilliant discovery affords strong grounds for the hope that metalloids may be detected almost as readily as metals.‡

* May we not hope that on re-examination, metalloidal spectra may be detected in the Bessemer flame? If such be found it will afford another blow to those who ask, What is the use of abstract science?

† Secchi and Janssen had previously discovered in the spectra of spots lines identical with those of aqueous vapour, which, of course, necessitates the existence of oxygen; but the presence of oxygen itself had never before been detected.

‡ Dr. Schuster has just announced the discovery that oxygen has two spectra, one corresponding with a high, and the other with a lower temperature. The former is the one detected by Draper. Mr. R. Meldola is working out the question of the explanation of these and other bright lines in the solar spectrum, and his conclusions are anxiously awaited.

It is to the analysing spectroscope, however, that we must look for most of our knowledge, and even here we are met at the threshold with an insurmountable difficulty. It is easy enough to view the chromatosphere or the corona without the conflicting evidence of the photosphere, for we have only to direct our instrument to the sun's limb, and the photospheric light is shut off; but, clearly, we can no more see the photosphere without at the same time viewing the chromatosphere, than an observer could see the earth without looking through the atmosphere. When, therefore, bright lines are seen in the spectrum of the photosphere, we must, ere referring them to that body, assure ourselves that they do not belong to the chromatosphere.

Let us first turn our attention to the spot regions. The analysing spectroscope teaches us much respecting this subject; for if we bring upon the slit a line of light passing from one side to the other of a spot, we can (by observing those lines whose deportment under various conditions is known) at once determine whether we have there any matter not found in the photosphere; whether the pressure increases or diminishes in their abysses; whether there is an upward or downward current; and, finally, whether the spot region as a whole is cooler or hotter than the photosphere. To take the simplest case of a spot showing an unbroken penumbra and umbra; it is found that throughout the whole length of the spectrum, from red to violet, there is a diminution of light corresponding to the penumbra, and a still greater decrease of intensity corresponding to the umbra. This decrease of light at once informs us that the spot is a region of absorption, and as it affects every part of the spectrum, it is a case of general and not selective absorption. A spot, therefore, is a region of comparative coolness.

The dark lines are still visible; and if we choose the F (green) line of hydrogen, the sodium or magnesium lines, we learn still more, for these Mr. Lockyer has shown thicken and become indistinct at the edges under great pressure. Now these very lines are seen so to behave in the spots, so that we are certain that the density of the vapours increases as we spectroscopically sound the depths of these mysterious cavities. Moreover, these lines are often seen to be bent towards the red, and (as has been already explained) this indicates that the hydrogen, &c., are rushing downwards. The speed of this rush can also be measured, and we have learned that a velocity of thirty-five miles per second is sometimes attained. Again, the thickening of these lines indicates a selective absorption or cutting out of light corresponding to them.

In the darkest portion of the umbra light is present; the darkness only being relative—just as a rushlight seems dark in front of a limelight. In the depths of a spot, then, we still have a continuous spectrum with dark lines: a spectrum showing that some incandescent solid, liquid, or dense gas is shining through incandescent vapour. Whence comes this light? Apparently, from lower depths still than the deepest spot gulf we have fathomed. If it were not so, it appears to me that the spot-spectrum would be a bright-line one, because the down-rushing vapours are themselves incandescent. This consideration, amongst others, leads me to venture the following suggestion respecting the light we obtain from the photosphere. Professor H. Draper has just shown us that the solar spectrum must henceforth be looked upon as continuous, with both bright and dark lines, and that the bright lines are, in all probability, those of metalloids. The central portions of the sun must be hotter than the parts nearer the surface; they must also be of greater density. Let us suppose they give a continuous spectrum—the question whether they are solid, liquid, or gaseous does not affect the argument. Let the photosphere be gaseous, so that by itself it would give a spectrum of bright metallic lines, and bright metalloidal lines and bands. Then if the central body shines through the photosphere we shall have the metallic lines reversed (or turned into dark lines), and the metalloidal lines will remain bright. Both bright and dark lines will then be seen superposed upon a continuous spectrum, which is just what we have in the solar spectrum.

It may be objected to this that the bright-metalloidal lines ought also to be reversed. To this it may be replied: These lines certainly *are not* reversed. However they may be accounted for, *they exist.* We know very little about the deportment of these lines, but we do know they stand out as bright lines on the spectrum. Professor Draper on this point writes: "At first sight it seems rather difficult to believe that an ignited gas in the solar envelope should not be indicated by dark lines in the solar spectrum, and should appear not to act under the law—'a gas when ignited absorbs rays of the same refrangibility as those it emits.' But in fact the circumstances hitherto investigated in the sun are really metallic vapours—hydrogen probably coming under that rule. The non-metals obviously may behave differently. It is easy to speculate on the causes of such behaviour; and it may be suggested that the reason of the non-appearance of a dark line may be that the intensity of the light from a great thickness of ignited oxygen overpowers the effect of the photosphere, just as if a person were to look at a candle-flame through a yard thickness of ignited sodium vapour, he would only see bright sodium lines and no dark absorption lines. Of course, such an explanation would necessitate the hypothesis that ignited gases, such as oxygen, give forth a relatively large proportion of the solar light. In the outburst of T. Coronæ, Huggins showed that hydrogen could give bright lines on a background of spectrum analagous to that of the sun." * Pro-

* *Nature*, vol. xvi. p. 365; Aug. 30, 1877.

fessor Draper's words in one point are liable to misapprehension; for in speaking of the oxygen lines in the "solar envelope," and of their overpowering the light of the photosphere, it might be inferred that he considered the oxygen to belong to the chromatosphere. This is obviously not so, for if these intensely bright lines—brighter than the general blaze of the sun—were chromatospheric, *they would be the brightest lines in the chromatosphere spectrum;* but clearly they are not so, or they would have been long since recognised. The meaning is that the oxygen lines are brighter than the continuous spectrum.

It may be urged against my view that the continuous spectrum in the depths of the spot may be due to the light of the photosphere shining inwardly and being reflected by the vapours themselves. This objection is only apparent, not real; for the vapours could only reflect light corresponding to that which they emit. Only a solid, liquid, or very dense gas could reflect light of all refrangibilities; and if we admit the presence of such matter below the spot my argument remains intact, for then a continuous spectrum is shining through vapour: in the one case the matter is self-luminous, in the other it shines with borrowed light.

The usual explanation is as follows—I quote from one of Mr. Lockyer's admirable lectures: "We find in the case of the sun, that surrounding the visible sun there extends to a very considerable distance an atmosphere of an element that we have not here* [the corona], which is probably lighter than hydrogen. Immersed in this, and therefore extending to a small distance from the sun, is another envelope, which has been called the chromosphere, consisting, in the main, of hydrogen. The brightest part of this lies pretty close to the sun. This region is excessively bright—so bright that by a certain method it can be seen without any eclipse whatever. Immersed in this hydrogen, and therefore still nearer the sun is an enormous quantity of vapours of the different elements existing in the sun, in what we term a reversing layer, and it is to the absorption of the elements in this layer that the absorption of the sunlight, and therefore, so to speak, the creation of the spectrum of the sun, is in the main due." †

No one can dispute the justice of this view. The bright-line-giving vapours of the chromatosphere must assuredly act in the manner stated. But they can only reverse light of wave-lengths of their own period, and, inasmuch as the dark lines of the photosphere are far more numerous than the bright lines of the chromatosphere, only part of the absorption is accounted for. This view by itself fails also to

* Allusion is here made to the 1474 K line of the corona, which, as it does not coincide with any line of a known element, has been suspected to belong to an unknown one. It may now turn out to be a metalloid line. Similar remarks apply to the D3 line of the chromatosphere, to which supposed element the name of *Helium*, "sun-stuff," has been given.—See Draper's paper, *op. cit.*

† *Nature*, vol. ix. p. 431; 1874.

account for the continuous spectrum in the spot depths. My suggestion does not impair its validity in a single point, it merely supplements it.

To return to the spot spectrum. In describing the telescopic appearance of spots it was stated that in many instances bright photospheric matter was seen in patches, wisps, and other forms upon the darker penumbra and umbra, and that these in many cases have been seen to fade away. The spectroscope supplements these observations, and renders it certain that portions of the photosphere are carried down into the spot depths by the rush of cooler vapours, and there become cooled. The cyclonic appearances that have been detected are also verified.

We must, then, look upon a spot region as one in which there is a kind of precipitation of comparatively cool matter, often accompanied with cyclonic motions, which break through the photosphere.

The faculæ, on the other hand, with their associated jet prominences, are the exact opposites of the spots. In them we see vast eruptive forces at work, hurling glowing gases and metallic vapours many thousands of miles upwards, and with sufficient velocity (as has been already explained) to drive portions beyond the reclaiming power of the sun, and thus to give rise to meteors.

The chromatosphere, as its name implies, gives us a bright-line spectrum, which can be studied day by day by the method devised by Lockyer and

Janssen. The determination of the lines is a comparatively easy task, for they can be seen simultaneously with the dark lines of the photosphere. The most abundant element is hydrogen, shown by its red, green, blue, and violet lines; and these lines extend farthest from the sun's limb, showing that hydrogen, the lightest known element, has the greatest extension in the chromatosphere. Immersed in this hydrogen are the vapours of numerous metallic elements, which grow more plentiful as the sun's edge is approached, and Mr. Lockyer has made the interesting discovery that these elements occur in a definite order. "This region contains, besides hydrogen, and dealing with known elements, magnesium, sodium, titanium, calcium, nickel, chromium, iron, manganese, aluminium, copper, zinc, barium, cobalt, and so on; and, latterly, we have had reason to suppose that some six or seven new elements must be added to the list—potassium, lead, cerium, uranium, strontium, and cadmium. Further, if instead of the new 'atomic weights' of the elements we take the old 'combining weight,' we find that the arrangement of these layers round the sun follows the vapour densities of the various substances either absolutely or very closely." *

From the broadening of the hydrogen and other lines, it has been calculated that the pressure at or near the photosphere is less than one atmosphere,

* "Celestial Chemistry," *Nature*, vol. ix. p. 432; 1874.

the limits lying between 2 and 20 inches of the mercurial barometer.

Vast cyclonic storms travel through this chromatosphere, and their course can be tracked and their velocities gauged by the spectroscope. Some of them occupy areas of many thousands of miles, and travel with inconceivable velocity. Mr. Lockyer has measured a speed of 100 miles per second. Here, again, the spectroscope has come to the aid of the telescope, confirming and supplementing its revelations. The facts just cited, when compared with Professor Young's description of a solar outburst, will fix this fact more vividly in the mind than any description.

Having already dealt with the corona, the outermost solar envelope, it only remains for us briefly to summarise the results attained.

1. The sun's mean distance is about 91,850,000 miles.

2. His diameter is about 850,000 miles.

3. His density, as compared with the earth, is 0·25.

4. His mass, as compared with the earth, is 318,000.

5. The temperature of the sun is so high that all metallic substances are vaporised, and compounds dissociated.

6. We know nothing, certainly, of the central parts of the sun. They are probably solid, liquid, or densely gaseous, and emit a continuous spectrum.

7. The brilliant disc of the sun is known as the photosphere.

8. It is very probably gaseous.

9. It is certainly the seat of violent commotions, far transcending all terrestrial cylones.

10. The photosphere is covered with flame-like granules.

11. It contains two regions of spots: one zone lying to the north, the other to the south of the solar equator.

12. The spots revolve at different speeds depending upon their latitude.

13. The speeds in the northern zone are greater than those in corresponding latitudes in the south.

14. Spots are very variable in duration.

15. They also come and go in a cycle of about 11·07 years.

16. This cycle influences terrestrial magnetism, temperature, rainfall, and other phenomena.

17. The cycle depends upon the planetary positions.

18. Spots are comparatively cool regions caused by a downrush of vapour.

19. The motion of the vapours is often cyclonic.

20. In the neighbourhood of the spots bright faculæ occur.

21. They are generally behind the spots, as if they had been uplifted from the spot region and dropped behind.

22. In their neighbourhood vast jet prominences often occur.

23. Around the photosphere is a region of glowing vapours, chiefly hydrogen, called the chromatosphere.

24. The elements occur, as it were, in layers, those whose combining weights are heaviest occupying the lowest positions. The lowest layer of the chromatosphere contains the most elements, and they diminish in number with the height.

25. The chromatosphere is the seat of violent commotions; jet, plume, and heaped prominences revealing their existence.

26. Some of these are of eruptive, others of cyclonic nature.

27. The pressure of the vapours at the level of the photosphere is less than ordinary atmospheric pressure.

CHAPTER IX.

THE EARTH'S INTERNAL HEAT.

It used confidently to be asserted that the interior of the earth was in a molten condition, and pictorial diagrams illustrative of this idea to this day adorn the walls of village schools, and other institutions of higher scientific pretensions. It will presently be shown how untenable this hypothesis is; but it was a legitimate deduction from observed phenomena, which more extensive knowledge has shown to be inconsistent with the idea of internal fluidity.

That the interior of the earth is hot is proved by the increase in the temperature of rocks, as we penetrate beneath the surface, and by the widespread phenomena of hot springs and volcanoes. The similarity of the lavas or volcanic rocks in different parts of the globe has been appealed to in favour of a molten interior; the low specific gravity of the earth has likewise been cited in support of this opinion; and, finally, the shape of the earth is such as would be assumed if it were now, or once was, in a liquid condition. Let us examine these arguments in detail.

The shape of the earth affords the first argument on this question. As is well known, it is not a perfect sphere, but an oblate spheroid, flattened about the poles, or in the direction of the axis of rotation. It is not quite exact to speak of polar compression merely, for at the same time the equatorial regions bulge. If it were not so those regions would possess a spherical instead of a spheroidal curvature. This being made clear, we may speak of the polar compression, or the equatorial protuberance, as suits our convenience. The amount of compression is 26½ miles; that is to say, the polar radius is shorter than the mean equatorial radius by 13¼ miles.

Suppose the earth to be a sphere at rest, and to be covered with a uniform ocean. Then let a quantity of solid matter be taken from the polar regions, and piled about the equator so as to bring the earth's shape into its present form. This would clearly be equivalent to building a mountain over the equator whose height was 13¼ miles, or about 70,000 feet, and whose base is equal to the surface of the original sphere. Under such circumstances the water could no longer occupy any portion of the tropics, but would run every way down the slopes towards the poles; forming two polar seas separated by an equatorial continent. We know that this is not actually the case. We know that the ocean *does* occupy the tropics, and that the water at the equator actually stands 70,000 feet above the polar sea-level without manifesting any tendency to flow to the lower regions of the earth. There must, consequently, be some cause for this phenomenon, and we find the explanation in the rotation of the earth about its axis. Stop the earth, and the ocean will gather around the poles, and a great equatorial continent be formed.

Again, if the solid earth were a sphere covered with a uniform ocean, and were then set revolving, the sphericity would be destroyed by the gathering of the waters about the equator, and we should thus have an oblate spheroid formed. Next, let the whole ocean be converted into solid granite. The oblate spheroid will then retain its shape, whether the earth rotate or be at rest; for the solid particles, unlike the liquid ones, are not free to move.

We are certain that the solid earth has such an oblate spheroidal form, and it becomes a question of surpassing interest to inquire how that shape has been brought about. We cannot, of course, form any conclusion upon this matter directly; but in this, as in so many instances in deductive science, the evidence is cumulative: and when, as in this case, we find several lines of argument pointing to the same conclusion, the credence we are justified in placing therein becomes so strong as to amount to conviction. Let us, therefore, assume for the present that the world was once in a molten condition.

It would then act as a whole in the same manner as the ocean has been shown to; that is, the fluid particles would move away from the axis of rotation and thus give rise to an oblate spheroid. Now, knowing as we do the velocity of rotation, the amount of compression can be calculated; indeed it was so estimated by Newton before it had been actually measured; and it is significant that the observed and calculated quantities closely agree with each other.

Very momentous consequences accrue from this compression, some of which (such as *precession*) have been already discussed. A perfect sphere would revolve as well upon one axis as upon another; it would indeed be in a state of unstable equilibrium. But an oblate spheroid is in stable equilibrium only when, like the earth, it revolves about its shorter axis. The protuberant equatorial mass gives it stability, just as a heavy rim gives stability to a revolving disc, as is seen in the beautiful toy known as the chamæleon top. The magnitude of this protuberance is often lost sight of, because we are accustomed to hear it spoken of as affecting the sphericity of the globe to so slight an extent as to be inappreciable in diagrams and models. It is, however, quite as essential that we remember that its bulk is no less than an eighty-fourth of that of the entire globe; and I have estimated that it exceeds the volume of the entire land (measured from sea-level) as much as 18,000 times.

The earth, then, may be looked upon as a revolving body heavily weighted at the rim, in consequence of which its axis of revolution is unchangeable, *so long as this rim-weight remains unchanged.* If, however, by any cause the earth changes its figure, the axis of rotation must shift to accommodate itself to the new condition of things; and, further, if this change be of considerable magnitude, it must be the source of great changes in the climate of given areas. To this question we shall return in the sequel, merely remarking here that, to bring about appreciable change, the displacement of matter must bear some considerable proportion to the quantity of the protuberance, and that, so far as our knowledge at present goes, we have no adequate grounds for believing that the earth's axis has materially changed within geological times.

To return to our subject. It has been shown that the earth's shape is such as would result if the globe was once in a fluid condition. This supposition receives additional weight from the fact that the oldest known rocks are all of igneous origin, or at any rate show traces of having been subjected to intense heat; and this is true of all parts of the world. Hence we are justified in assuming that in all probability the earth actually was at one time in a molten condition.

If so, it must have cooled; and we must now ask whether this cooling has proceeded so far that all traces of original heat have been dissipated; or whether, on the other hand, the interior is still hot. Science here speaks in no uncertain tones, but emphatically declares that the interior of the earth is still very hot. The most patent evidence upon this point is the almost universal distribution of volcanoes, by which molten rock and heated water are brought to the surface from beneath. Speaking broadly, the vast basin of the Pacific Ocean is fringed with these terrific proofs of internal heat; the Atlantic shows similar phenomena in Iceland and the West Indies; and in the Mediterranean, Red Sea, and Indian Ocean we again come upon like proofs of the earth's high internal temperature.

Hot springs, again, afford similar proofs of a heated interior, and they lead us a step farther, inasmuch as they are of wider distribution than volcanoes, being found in districts, such as England, where at present there are no volcanoes.

But the most complete answer to this question is yielded by accurate measurements taken in mines, wells, and borings. Delicate self-registering thermometers are used to determine the temperature of the rocks; and, wherever observations have been taken at successive depths, the temperature is invariably found to increase after a certain depth has been reached. The influence of summer's warmth and winter's cold is appreciable in the rocks for a depth which may be roughly taken as 100 feet. At this limit the temperature is that of the mean annual temperature of the locality. Below this the rocks grow warmer continuously, but not always regularly. The rate of increase may be taken roughly at about 1° Fah. for every 60 feet; but it varies with the nature of the rock, the dip of the strata, the quantity of contained water, and other causes. The great fundamental fact, however, comes out clearly, that the temperature everywhere increases with the depth below the surface. From what we have learned in our second chapter it is certain from this, firstly, that the interior of the earth is hot; secondly, that the earth is cooling; thirdly, that it was once much hotter than now. Here, then, we find another train of reasoning pointing to a time when the whole earth was molten.

Having established the fact of the earth's high internal temperature, let us attack the question of the fluidity or solidity of the interior, leaving for a future chapter the consideration of the rate of cooling, which is intimately connected with the age of the globe.

Taking the increment of heat at 1° Fah. for every 60 feet it is apparent that, other things being the same, a temperature will be attained at a moderate depth sufficiently high to melt every known rock. Thus, at about 35 miles from the surface, the heat would be sufficient to melt platinum, the most refractory of metals. Hence it was assumed that the interior of the globe must be molten, and fearful pictures still adorn the walls of "Literary and

Scientific Institutions" portraying a section through the earth, a thin black line marking the thickness of the "crust," while all within is filled with "hideous fire." Upon this insignificant and utterly unstable film we were supposed to be stationed; truly, life in a powder-mill would be safe in comparison!

Unfortunately for this highly coloured effort of scientific sensational imagination, this perilous bomb is a myth, as we shall proceed to show.

It is true that we have no grounds for denying that at the depths in question the assigned temperature exists, indeed it must necessarily be so; but the conclusion that the interior is therefore molten by no means follows.

The internal parts of the globe are subjected to the immense pressure of the superincumbent matter, and pressure exercises a most important influence upon the fusing-points of bodies. Most substances contract on solidifying, and although I know of no extended experiments on the deportment of rocks in general in this respect, yet so far as they have been investigated they obey this general law, and are not to be classed among those exceptional materials (such as water) which expand on solidifying. Experiments on this point would be very interesting. The fusing-points of substances which expand on melting are raised by pressure, as might be expected; sulphur, for example, has its fusing-point raised from 237° Fah. at the ordinary atmospheric pressure to 285° Fah. at 519 atmospheres.

If the fusing-points of rocks are thus raised by pressure, it must follow that solid rocks must exist at great depths below the surface, at temperatures far higher than would be sufficient to liquefy, or even vaporise, them under ordinary atmospheric pressures.

The mean density of the earth, which is about $5\frac{1}{2}$ times that of water, has also been appealed to in support of internal fluidity. The average density of rocks is about twice that of water; hence the earth as a whole is twice as heavy as the material forming the solid surface. If the earth were composed throughout of similar materials it would be vastly heavier than this, in consequence of the compression arising from the weight of the superincumbent rock. To take a simple illustration: water is one of the most incompressible of substances, and was, indeed, for a long time deemed to be absolutely rigid. Refined experiments have shown, however, that the pressure of an atmosphere (16 pounds on the square inch) reduces the bulk of sea-water one 44-millionth. Now a column of water 32 feet high, and of one inch sectional area, weighs 16 pounds. Suppose the earth to be made entirely of sea-water, having the ordinary density at the surface, which density we will call 1. Taking the earth's radius at 4,000 miles we have 660,000 times 32 feet, which gives us a pressure of 660,000 atmospheres at the centre. The water at the centre will consequently be compressed into ($660{,}000 \times 0{\cdot}000044 = 29{\cdot}040$) one twenty-ninth of its bulk at the surface. Half this will give the mean density. The earth's specific gravity would be 14·520 instead of 5·5, if it were composed of sea-water, and possessed a temperature of 60° Fah. throughout.

Or to vary this illustration: if we take the area of the ocean at 146,000,000 square miles, and the mean depth at 2 miles, it could be poured into a cavity $2\frac{1}{4}$ miles square, reaching from the surface to the centre of the globe.

Knowing, as we do, that the surface of the earth is made of matter more than twice as dense as water, and of much greater incompressibility, we are driven to the conclusion that its low specific gravity is due either to the internal parts being made of very light matter, or that some force exists which to a large extent overcomes the compression that would otherwise ensue.

There are strong reasons for believing the earth's interior is composed of matter having a *greater* specific gravity than the ordinary surface rocks. We find, for instance, that the denser igneous rocks have been formed at greater depths than the lighter kinds; and that while the surface rocks are mostly compounds of the light easily oxidizable metals such as calcium, the eruptive rocks that have welled up from the depths below contain larger quantities of the heavier less oxidizable metals.

Furthermore, a comparison of meteoric stones with terrestrial rocks leads to the same conclusion. These remarkable bodies, which have already taught us so much, consist chiefly of combinations of iron, oxygen, and silicon, and these are the most abundant terrestrial elements. Moreover, the minerals contained in meteorites are well-known constituents of volcanic rocks, and they are for the most part heavy. The consideration of these and kindred phenomena long since induced Reichenbach to infer that deep in the earth there exists (beneath the lighter granite rocks) matter similar in composition to that which is so frequent in stony meteorites, and that beneath this, heavy metals, such as iron, may exist in a native (or pure) condition.*

This conclusion is further strengthened by the phenomenon so often observed during volcanic eruptions, namely, that the lighter acidic lavas are first ejected, and then the heavier basic matter, as if the latter came from profounder depths. The mode of occurrence of such heavy metals as platinum and gold further tend to confirm the supposition that the earth increases in density downwards.†

Nor is it alone from geological reasoning that this opinion has arisen, for the phenomena of precession and nutation are only explicable on the supposition that the earth increases in density from the surface downwards.

We are, therefore, obliged to abandon any theory

* Poggendorff's "Annalen," vol. cv. p. 560.

† This question was admirably discussed by Mr. Warrington Smyth, F.R.S., in his Presidential Address to the Geological Society in 1867.

which accounts for the low specific gravity of the earth on the grounds of an interior composed of lighter matter than the surface rocks.

Knowing, then, that the earth's interior has such a composition that the material, at the surface and at ordinary temperatures, would be heavier than the rocks with which we are familiar, we are driven once more to the conclusion that the interior must be intensely hot; but we have advanced a step farther, and now ascribe the low density of the globe to the expansive action of that heat upon the (otherwise) dense matter.

It is difficult to understand how the lavas in volcanic craters can stand at such very different levels as they do if volcanoes are orifices communicating with a liquid interior. The great volcano of Mauna Loa, in the Sandwich Islands, for example, has one crater at its summit 13,760 feet above the sea, and another on its flank 10,000 feet lower. If both these communicated with the same reservoir it would be impossible for the upper one to overflow while the liquid lava in the lower lay placid; yet this has been observed.

Again, it is a well-known law of hydrostatics that pressure is communicated, without diminution, through liquids. Let us suppose that a pressure is exerted on one portion of the liquid interior, which causes the lava in a neighbouring volcano to overflow. Then this pressure will be communicated to every other portion of the liquid interior, and, consequently, all the volcanoes will be influenced. It is needless to observe that no such terrible universal convulsion has been experienced.

Perhaps the most conclusive evidence in favour of the earth's solidity is that afforded by the motions of precession and nutation. Hopkins* long ago showed that a thin shell, say 100 miles in thickness, would not permit these motions to take place as they do. Sir William Thomson has admirably developed this phase of the discussion, and, as I think, finally set it at rest.†

Precession and nutations, as we have already shown, arise from the influence of the sun, moon, and planets upon the earth, as a whole, causing in the one case an alteration in the orbit, and in the others variations in the axial revolution. The principle of Hopkins's and Thomson's argument is that if the earth were not rigid it would not accept these perturbations, for it would then be modified in shape instead. They then examine the effects of a rigid shell of (say) 100 miles in thickness upon an internal liquid, and show that it would be utterly inadequate to resist the influences which would modify precession and nutation.

* Phys. Geol. Researches, 1839-42; Phil. Trans. 1839; and Brit. Assoc. Rep. 1847.

† See his final work on "The Physical Condition of the Earth;" Rep. Brit. Assoc. 1876 (Glasgow meeting); Trans. of Sections, p. 3.

The nutations of the earth are, first, a planetary influence which has a period of 26,000 years; second, a lunar nutation of 19 years; third, a solar semi-annual, and fourth, a lunar fortnightly nutation.

Sir William Thomson has shown that if (as must be assumed) the internal surface of the solid shell be elliptical, the earth as a whole would act as if it were rigid throughout, with respect to motions of long period such as precession (with a cycle of 26,000 years), but would sensibly affect nutations of very short period. He proves:—

1. That an ellipticity of inner surface equal to $\frac{1}{26,000 \times 365}$ would be too small, but that an ellipticity of one or two hundred times this amount would not be too small, to compel approximate equality of precession throughout liquid and shell.

2. That with an ellipticity of $\frac{1}{300}$, if the precessional motion were 26,000 times as great as it is (that is, if it occupied one year), the motion of the liquid would be very different from that of a rigid mass rigidly connected with the shell.

3. That with the actual forces and the supposed interior ellipticity of $\frac{1}{300}$, the lunar nineteen-yearly nutation might be affected to about five per cent. of its amount by interior ellipticity.

4. Lastly, that the solar semi-annual nutation must be largely, and the lunar fortnightly nutation enormously, affected by interior liquidity.

With an ellipticity of $\frac{1}{300}$ the effect upon the precessional period of 26,000 years would be to reduce the annual precession of 51″ by one-sixtieth of a second, a quantity that would be utterly inappreciable. The nineteen-yearly lunar nutation would be reduced by one twenty-third, a quantity which might escape detection, but which would be easily detected if sought for.

When we deal with the solar semi-annual and lunar fortnightly nutations the cases are very different, for the periods are commensurate with the ellipticity, the one being about one-half and the other one-twentieth of 300. In the former case the earth's axis would be shifted about an ellipse, having semi-axes of 0·86″ and 0·81″, instead of 0·55″ and 0·51″ as is actually the case, and this discrepancy would be very patent. In the latter case the discrepancy would be very much greater. The semi-axis of the nearly circular ellipse described by the pole is 0·0325″. If the crust were infinitely thin the semi-axis would be nineteen times this quantity, or 1·7″. Between this and a thickness of crust about a hundred miles, it would lie between that amount and infinity.

It is certain, then, that although in the case of precession and the two nutations of long period we cannot form any just estimate of the condition of the earth's interior, yet in the two nutations of short period we have a powerful means of testing the two hypotheses of solidity or fluidity. The amounts calculated upon the theory of solidity agree with the observed movements, but entirely disagree with calculations based upon the theory of a solid shell surrounding a liquid interior.

Sir William Thomson points out, however, that in the above investigations the solid crust is supposed to be absolutely rigid, which is impossible. If the crust were of solid steel, five hundred miles thick, it would yield to the attractions of the sun and moon almost as readily as if it were indiarubber. The earth would thus be distorted in figure. It would, for example, heap up under the moon like the waters of the sea, which it would carry with it, and thus nullify the tides by preventing any relative change of level between land and water.

Moreover, the same authority shows that the equilibrium of the crust would be unstable. The secular cooling causes upheavals and depressions, and any portion of the crust rent from its continuity with the rest would behave like a ship that has been rammed, one portion would rise up, another would sink down, and then all would go down. Thus the crust could not maintain its integrity, but would inevitably shatter and sink piecemeal through the lighter lava to build up a solid framework from below.

Such being the physical results of the shrinkage of the crust it is interesting to find that in such a process we find a ready and sufficient explanation of the broad features of volcanic action. The earth, though now solid, must once have been in a molten condition. Its surface, exposed to the coldness of space, must, in all probability, have become covered with a scoriacious crust which frequently broke up under the overpowering throes of the seething mass below. Sinking through the liquid matter, these solid fragments would partly melt and partly retain their solidity; and so in time would be built up a more or less solid globe, honeycombed in structure, with liquid rock filling the cavities.

Shrinkage continuing, in consequence of the cooling, we find an explanation of those gradual subsidences and elevations presently to be described, as well as of the terrific phenomena of volcanoes and earthquakes. The roofs and walls of the subterranean caverns may fall in and cause earthquakes, or if the superior rocks are rent volcanic eruptions may ensue.

We see, too, how it has happened that volcanic action has taken place in a certain area, then ceased for ages, to break out again once or many times; and we can as readily understand how volcanoes have become extinct. It is only necessary to suppose that in a region of active volcanoes there is an area of liquid rock of greater or less extent beneath; that this area may become enlarged or diminished, or annihilated for a time or for ever, through the changes ever taking place in the cooling, shrinking globe.

We can understand, moreover, how limited volcanic areas can exist, and why eruptions are not synchronous and universal.

Our own land, as an example, though now happily free from these grandly terrible phenomena, teems with relics of former igneous action in Devon, Somerset, Staffordshire, Warwickshire, Leicestershire, Derbyshire, Northumbria, Wales, Scotland, and Ireland—relics which belong to all ages of geologic time, from the oldest known stratified rocks (Laurentian) to the comparatively recent Middle Tertiary period. From this last epoch we have been free from volcanic eruptions, and the vast cones have gradually wasted under the silent influences of rain and frost, rivers and seas. Some of these volcanic mountains rivalled Etna in magnitude, but now all is quiet in their vicinity, an occasional earthquake of very moderate dimensions alone attesting that the subterranean fires are not quite extinct.

The imprisoned rocks below are held in a state of compulsory solidity by pressure, which needs only to be relieved to free them from their bondage, and permit the assumption of the liquid condition. This may, nay, must, often have taken place, and may occur again; and in this way new areas of volcanic eruption may arise.

The earth, then, must be looked upon as a solid orb, probably as rigid as if made of steel. Its interior is intensely hot, and in all probability composed of matter, such as the metals, which at the surface are heavier than the rocks which form the bulk of the accessible crust. Vast cavernous hollows exist beneath the surface in which, from lack of pressure, liquid rock exists. These spaces are not persistent, but, owing to the incessant changes in the earth, due to the shrinkage (arising from cooling), become constricted or enlarged, and at times entirely obliterated, while new hollows are formed from time to time.

It is to the internal changes taking place in the earth's interior that volcanoes and earthquakes are due. They also bring about those successive elevations and depressions of the land with which geology makes us familiar. Briefly, these geological phenomena are the result of the secular (that is, slow) cooling of the earth. When, in the last chapter, we come to consider the origin of the heat which is the source of the movements in question, and find that it is the same as the heat of the sun—in other words that the sun's heat and the earth's internal temperature have one and the same origin—we shall again be struck with the intimate relations subsisting between the different members of our system.

Throwing this knowledge into short sentences, it has been shown:—

1. The interior of the earth is intensely hot.

2. The shape is such as to lead to the belief that it was once in a molten condition.

3. Its spheroidal shape insures practical steadiness in the axis of rotation.

4. The earth is cooling, and consequently shrinking.

5. The mean density of the earth is about $5\frac{1}{2}$ times that of water.

6. The interior is probably metallic.

7. The earth, as a whole, is very rigid, and cannot be molten in the interior.

8. It contains great cavernous spaces more or less full of liquid rock.

9. The changes in these spaces give rise to the phenomena of volcanoes, earthquakes, &c.

10. Volcanic action has been far more extensive than at present.

CHAPTER X.

EFFECTS OF INTERNAL HEAT.

LEAVING the phenomena of volcanoes and earthquakes out of sight for the moment, and confining our attention to the earth as a whole, it is apparent that the continued shrinkage will give rise to movements of the surface on the grandest scale.

A sound ripe apple has a perfectly smooth skin, but towards the end of winter, when its internal juices are to some extent destroyed, the skin becomes wrinkled and crumpled; the apple as a whole shrinks, and the skin, preserving its continuity, is finally too large to cover the interior smoothly. Similarly in the case of the earth, the interior is perpetually losing heat and shrinking; and the exterior, shrinking with it unequally, becomes wrinkled and crumpled to a large extent; and hence, even if the surface had ever been smooth, it would assume a rugged character in the lapse of ages.

But the crust* of the earth, unlike the skin of

* The term *crust* is a convenient one to apply to the rocks at the surface. It was invented when the earth was supposed to be

the apple, is too rigid to bear the wrinklings due to contraction, and frequently becomes rent across. These fracture-lines are called *faults*, and are of very frequent occurrence in all parts of the world. The rocks on the one side are upheaved, and on the other depressed below the normal level. The amount of the "throw," as it is called, is sometimes very considerable. To mention a few cases in Great Britain, there is a fault running from the Mersey, west of Stockport, to the north of Bolton, having a throw of upwards of 3,000 feet. Near Snowdon a great fault displaces the rocks 5,000 feet. In Arran a fault with a throw of 7,000 feet has been described, and between Aran Mowddwy and Careg Aderyn another upheaves the rocks about two miles. The great fault which crosses Scotland from Dunbar to the Ayrshire coast has a throw, in some parts, of 15,000 feet, or about three miles!

These being facts of the most indisputable nature, it follows that at the time the faults were produced the rocks in the last-mentioned district, for instance, must have stood three miles higher on the one side of the fracture than on the other. That they do not is a circumstance that needs no demonstration. How, then, is it that these tremendous dislocations do not modify the landscape to a great degree? Twenty faults, each of no inconsiderable

molten within, but may be appropriately used, without any theoretical meaning being attached, to designate the rocks accessible to man.

throw, may be passed over in a morning's stroll across a plain. There is but one answer. The upheaved portions have been removed. The mode in which this has been effected will be described, when we consider the effects of water in modifying the face of the globe.

Faults are of every conceivable magnitude, from tiny dislocations that only shift the rocks a fragment of an inch, to vast disruptions such as we have above indicated.

They affect beds of every age, excepting the most recent, and, as might have been expected, they are most frequent in the oldest rocks. Upon the maps of the Geological Survey faults are laid down, and no more striking illustration of the shattered condition of the earth's crust can be afforded than the inspection of some of these publications.

The geological ages of faults are often determinable. When we find undisturbed rocks lying upon faulted ones, as is often the case, we know that the fault took place after the lower rocks had been formed, and before the newer ones were laid down. In this manner we have learned that faults are of all ages.

The rocks do not always break under the strain of the imprisoned forces beneath. They are to a certain extent flexible, as is shown, for instance, in the waves into which they are thrown by earthquake shocks. Owing to this flexibility they have often been tilted up, and even thrown into folds without dislocation. Some of these folds are of huge dimensions, measuring many miles from crest to crest; others are almost microscopic in their minuteness, a score existing within a hand's-breadth. There is no more impressive proof of the vast power of the subterranean forces than to see solid, intensely hard rocks thus squeezed and crumpled like sheets of paper in a strong man's hand.

The greater portion of the rocks which form the dry land are sediments that have accumulated in the beds of seas and lakes, and their present position is proof positive of the upheavals and depressions which the crust has undergone. Very few rocks retain the more or less horizontal positions in which they must have been deposited, and as they often form even the summits of high mountains, we are obliged to admit that such oscillations of level have occurred, even if collateral evidence were not overwhelming.

It is certain, therefore, that in past times the earth has been the seat of gigantic throes, by which sea-beds have been upheaved and land surfaces depressed, and all these effects are explicable on the theory that the earth is a cooling, shrinking body—a theory which has already been proved to be true.

At first sight it may appear difficult to explain how elevations can be the result of shrinkage. A little consideration will render this plain. Let us refer to our homely illustration of the dry apple. Suppose it, when ripe and sound, be covered with a film of liquid. Then, when old and withered, this liquid will be crowded into the lowest parts, and the wrinkles will stand up above it. The apple as a whole has shrunk, but some parts of the skin have been elevated relatively to the liquid. Just so with respect to the earth. It has shrunk as a whole, but portions have been elevated relatively to the sea.

If the earth thus shows conclusive signs of the upheaving and depressing forces of internal, gradually declining heat, it may be asked whether such changes have taken place during the more recent ages of geological history, and whether they are still in operation. The researches of many geologists in many parts of the globe give a most satisfactory answer to these momentous questions. Such movements *have* taken place during recent geological times, and are indeed in operation to this day.

To take first the case of the prehistoric changes of level, we find abundant evidence around the coasts of England and Wales that since the human occupancy of our land considerable changes have taken place in the relative levels of land and sea. Ireland affords us similar evidence, and Scotland is exceedingly rich in these records of bygone changes.

The evidence is of two kinds, the one relating to elevations and the other to depressions: in the one case the extent of land was greater, and in the other less than now.

The proofs of elevation are both direct and indirect; and interesting as this question is, we can do little more than allude to it; but the reader will find ample proofs in two works already issued by the publishers of this treatise, and still greater detail in one that is in preparation.*

Of the direct proofs perhaps the most striking are the lines of beaches, containing such common shells as cockles and mussels, which fringe some parts of the coast-line high above the reach of the sea. They are known as *raised beaches,* and conclusively show that at one time the sea stood at the level they mark. These raised beaches in our kingdom do not rise to greater heights than 100 feet above the present sea-level. They are plentiful about our south coast, especially in Devon and Cornwall, but are shown to perfection in many parts of Scotland, where they may be traced along the coast for miles. Nor is it on the mainland alone that raised beaches are found, for many of the beautiful islands of the Hebrides, especially the inner group, show them admirably. The shores of the "desolate Coll" and the coasts of the "wild Tyree" may be cited as examples, together with the "green island of Lismore."

Indirect proofs of former elevations are of many kinds, of which we will mention a few. The earliest recognised human inhabitants of Britain were a savage race of hunters and fishers, who knew not the simple arts of pottery or weaving, who had no

* "The Great Ice Age," J. Geikie, LL.D., F.R.S.; "Climate and Time," J. Croll, LL.D., F.R.S.; and "Prehistoric Europe," by the former.

metal, no domestic animals, or cultivated plants, and whose general cultus was of a lower stamp than that of the degraded Fuegians of to-day. How did they get here? They had no boats sufficiently large to carry them across from the nearest land, and they certainly were not Webbs or Cavills who make the channel passage *in puris.* They must have come across on dry land. In other words, England must have been united with the continent.

Again these Old Stone Folk occupied the land together with races of animals such as lions, hyænas, rhinoceri, and hippopotami, which must also have come from the mainland, and they clearly had to walk. The remains of these animals have been found in such isolated spots as Lundy Island, which they could not reach by swimming, and which even had they done so is far too small to have afforded them food. We know they lived there in numbers and thrived, and we cannot explain this occupation except by supposing that England stood higher above the waves than now, and that what is at present the Bristol Channel was then a broad and fertile plain, tenanted with herds of wild animals, on which the predaceous species preyed.

In like manner we might take the present fauna and flora of our land, and by showing how the species diminish in numbers as we journey westwards towards Ireland and the Hebrides, prove that they have actually slowly spread from the continent, and that the separation of the islands took place before the whole of the species had time to cross.

The above considerations lead us naturally to the subject of depressions; for clearly if the British Isles have been united to each other and to the continent, we ought to find some proofs of the depression which has separated them. This evidence is not merely forthcoming, but is exceedingly weighty. Between the tide-marks in many parts of the coast are found the remains of old land-surfaces, which are generally exposed only at low spring-tides; in other places fragments of trees, peat, &c., are thrown ashore after heavy gales. These old land-surfaces consist for the most part of peat and remains of ancient forests. They can be traced at intervals all round our shores; and, moreover, even the open sea yields relics of the same kind. Cornwall, Devon, Dorset, Sussex, Kent, Essex, Suffolk, Norfolk, Lincolnshire, and Yorkshire all possess submarine forests or peat-beds along their coasts; and we might go on enumerating county after county all round Great Britain whose sea-shores are fruitful in these records of the past. The German Ocean too gives up treasures of the same nature, fishermen frequently bringing up in their nets fragments of peat, stools of trees, and the bones of land animals. From the English Channel and the Irish Sea the same story reaches us, and there can no longer exist a doubt that these shallow marges of the great ocean mark the site of a wide and fertile land now sunk beneath the waves.

It is not our province to work out the dates of these movements, nor to trace their history, for these questions belong to pure geology. Suffice it that we have proved that within very recent geological times considerable oscillations of level have occurred. It is, however, necessary to remind the reader that these comparatively minute changes need not of necessity be due to movements of the land. Several phenomena appear to be more readily explicable on the hypothesis that the sea itself has altered, in a manner to be explained hereafter. Nevertheless, although this may apply to some of the cases in point it cannot explain them all, and we must still admit the existence of this mighty silent force, as will be now made clear.

Hitherto we have dealt solely with prehistoric changes of level, and we must here direct our attention to those which are now taking place. If changes of relative level be due to movements of the sea, we should find the raised beaches, for example, along a given line of coast, occupying pretty much the same level; the only departures from which would occur in such spots as narrow gulfs, or fiords, where the tidal water being pent up might give rise to beaches at a higher elevation than would be the case along the exposed coast. Unless such a general parallelism of deposits obtains, we must refer the movement to subterrene action, and this must clearly be the case if under similar conditions, along the same coast, we find elevation and depression taking place simultaneously.

This is exactly what we do find in some places. The Scandinavian peninsula is a case in point, for a raised beach can be traced from near the present water-line, which ascends higher and higher as we travel northwards, until at the North Cape it stands 600 feet above the waves. Throughout its entire length it contains the remains of shells of extinct species. The southern portions of the peninsula exhibit no such beach. It is clearly impossible to explain such appearances as this by a change in sea-level.

Scandinavia is peculiarly interesting as being the area in which it was first proved that slow movements of the land are still taking place. Along the northern shores of the Baltic the pilots and fishermen have long recognised the fact that the land is imperceptibly rising. Channels in hard rock along which their forefathers took their craft in safety have shoaled so as to afford no passage to the smallest boats. Rocks which of yore were known only as dangerous sunken reefs now show boldly above the waves. Landing-places used long since are now far from the shore. Such are the signs which have taught these toilers of the sea one of the most interesting facts in nature.

In the southern Baltic the signs are of a precisely opposite nature. Craft of large size can traverse channels that once were hazardous to little boats. Rocks that stood aloft as warning beacons now form dangerous hidden reefs. Landing-places, and even buildings, that once stood upon the shore are now laved by the waters of the sea.

We have here, then, evidences of exceedingly slow movements of opposite kinds taking place along a coast-line far removed from volcanic seats. The rate of motion has been roughly calculated, and is found to be about two or three feet in a century. To us how slow, how utterly insignificant such a movement appears! A veteran fisherman might stand upon such a shore at seventy years of age and see scarcely any change from the scene he gazed upon as a boy. But make that man's span of life commensurable with the age of the world, and then how patent would be the signs! It is only when in imagination we thus look upon the processes of nature that we are able to realise how all-important these seemingly puny efforts really are.

Nor is it alone in Scandinavia that such movements are going on. Siberia, from the Obi far eastwards beyond the Sena, appears to be rising. Spitzbergen, North Greenland, Kamtschatka, Japan, the Philippine Islands, the Solomon Isles, the Mexican Gulf, the West Indies, and Venezuela all exhibit similar evidences. Even Scotland and our own south coast appear to be undergoing gradual upheaval. Southern Greenland, parts of the Atlantic coast of the United States, Brazil, and Patagonia, on the other hand, seem to be as slowly sinking.

In the vast Pacific basin some of the grandest proofs of these slow movements were culled by Mr. Darwin during the memorable voyage of the *Beagle*. He pointed out with singular astuteness that in coral-reefs we have a certain criterion of changes of level. Sometimes the reefs merely fringe the coast at a short distance from it; sometimes they form vast barriers parallel with the coast but miles out to sea; sometimes they appear as little islets, often more or less ring-shaped, unconnected with any other land. These various reefs are not indiscriminately mixed, but occur in groups, barriers by themselves, atolls (ring-shaped reefs) by themselves, and fringes again by themselves. Moreover the thickness of the coral in barrier-reefs and atolls is often very great, though the reef-building coral polyps can only exist within a few fathoms of the surface. The bases of barrier-reefs and atolls are consequently composed of dead coral. When that coral lived it must have been close to the surface. So argued Mr. Darwin, and so grew up his magnificent theory of the formation of coral-reefs.

Suppose, then, a coral-fringed land to be sinking beneath the waves with a slow motion like that of Southern Sweden. The ever-busy coral polyps will keep on growing upwards, and those below will be killed as the land goes down. But as the greatest vigour is attained on the outside edge of the reef where the clear waves break incessantly, the reef will not retreat with the shore-line, but will maintain almost the same position, thus always growing farther from the shore, until at length the fringing reef is converted into a barrier-reef. If the land be an island, and the depression continue until the whole is submerged, the coral will stand just above the sea as an atoll.

The districts in which barrier-reefs or atolls occur are areas of depression, and Mr. Darwin has pointed out that in the Pacific there are two such areas, the one stretching from Pitcairn's Island and the Low Archipelago to the Caroline and Pellew Islands, a distance of 7,000 miles; the other including New Guinea and N.E. Australia, on which latter coast the grandest barrier-reef in the world runs for 1,200 miles. Between these depressed areas there is an area of elevation, marked by the presence of active volcanoes, and to the north a similar district occurs in which the splendid volcanoes of the Sandwich Islands are found. Between India and Madagascar is another area of depression 1,500 miles long, mapped out by atolls.

Fringing reefs do not afford much evidence of changes of level, for they may be forming upon land either stationary, rising, or sinking. But in many cases fringing reefs have been elevated above the sea, where they stand as unmistakable proofs of change. This I found to be very commonly the case in certain parts of the Red Sea, where I have seen the white coral a mile inland glistening in the tropic sunlight, and skirting the black volcanic hills as with a snow-white girdle. In this district the movements have been irregular, clear proofs of elevation appearing at one spot, indisputable evidence of depression at another. Sometimes two or three lines of reef mark successive movements, but speaking broadly the north and south show signs of elevation, and the central portions of depression.

Dubious as some of the evidence might have appeared as illustrating movements of the land when we were dealing with our own country, the great fact is now established by various lines of evidence, culled from many parts of the globe, that the subterrene force is not spent, but that it is still operating even in places where it might be least expected. The dreary regions of the north, the fervent tropics, as well as the milder zones, have only one story to tell—that the "solid ground of nature" is ever wavering—that the everlasting hills are passing away.

Let us now briefly glance at the more palpable effects of internal heat as manifested in the cognate phenomena of volcanoes and earthquakes. How mighty these forces are and how terribly they affect our welfare is perfectly well known. But it is not so generally understood that the seat of this energy, in every case in which it has been possible to measure it, is but a very few miles below the surface.

Dr. Mallet, to whom our knowledge of this matter is due, has estimated that even in the great earthquake of Calabria, in the year 1857, during which 40,000 lives were lost and untold property destroyed, the centre of disturbance was little more than five miles below the surface, and extended over a space only nine miles long and three miles in depth. The terrific earthquake of Riobamba, in 1797, which hurled its victims a hundred feet into the air across wide streams, was generated at a depth of about 30·6 miles, and this he conceives to be about the maximum depth at which they can originate.

We cannot, of course, determine rigidly the depth of the seats of volcanic activity, but the intimate connection between volcanoes and earthquakes justifies us in assuming, in the absence of more accurate knowledge, that a similar limit must be accorded.

Here, then, we have a forcible argument against the hypothesis of a molten interior, with which volcanic vents communicate. If changes taking place at so slight a depth as thirty miles, in an area of but a few square miles, can so affect the solid crust as to urge it into waves, to rend it open, to upheave and depress considerable areas, how utterly incompetent must a slight crust be to resist the incomparably grander influences of the sun, and moon, and planets!

The lamentable earthquake which happened in Peru on May 9th, 1877, affords us a telling illustration of the effects of these mighty throes. It must be still fresh in the minds of all how vast was the destruction of property—how about half-past eight in the evening a fearful shock was felt along the entire coast, lasting about five minutes, and was succeeded by others of less intensity—how the sea was then observed to recede, and the startled inhabitants, warned by former experiences, fled for safety to the neighbouring hills—how the angry water, heaping itself up, rushed upon the devoted land, and swept southwards with ungovernable fury, destroying everything in its track—how a steamer, stranded by the earthquake of 1868, was lifted bodily up and carried two miles inland. These are details still too well remembered. Yet, terrific though they be, they are the result of an action perfectly puny in comparison with those slow mighty movements we have been describing. The suddenness alone makes them so hideous; and what pen could depict the wreck that would ensue if those grander movements which are uplifting and depressing continents did their work at one great effort!

This earthquake, by no means the greatest experienced in that land or elsewhere, thrilled the great ocean through a million of square miles, and so mighty was the throe, that in Hawaii, 5,000 miles away, the sea rose and fell in waves thirty-six feet in height.

It is not our purpose to describe the various phenomena of volcanoes and earthquakes, for that is the province of physical geography and geology. It is merely necessary for us to duly appreciate the effects they have upon the world at large. By earthquakes considerable areas of land are suddenly upheaved or depressed, but the amount seldom exceeds ten feet during any one earthquake. But if these movements are many times repeated in one direction the result in the course of ages may be very great. The mean elevation of the land is about one thousand feet, and if a series of earthquakes occurred once a century, and elevated the land ten feet each time, ten thousand years would suffice to raise our continents to their present average height.

To these actions—the spasmodic convulsions of earthquakes and the slow movements above described—the elevations and depressions of the surface are primarily due; and they are, in all probability, the effects of the cooling and shrinking of the globe.

The surface of the land and the bed of the ocean are not uniformly level, but are diversified by hill and dale, mountain and plain. The forces of upheaval and depression do not act uniformly, and it is a question of high importance as to how far the present features are due to these deep-seated forces.

This much we may safely aver—that the broad modelling of the land and sea-bed have been determined by upheaval and depression. Continents are areas of elevation, oceans of depression. The fact that the greater portion of the land is occupied by rocks which must have been deposited in the sea is conclusive evidence of this; and the bendings and contortions and dislocations the rocks exhibit are equally convincing proofs.

We must now ask ourselves whether mountains and hills are areas of greater elevation than plains and valleys. At first sight such would seem necessarily to be the case, but when we look closely into the actual phenomena doubts begin to arise as to whether this is all the truth, and eventually we are driven to believe that the features of a landscape are only dependent to a very slight degree upon the direct action of the internal forces.

The very existence of land is, as we have seen, proof of elevation, and mountain ranges are as certainly illustrations of great local upheaval; but the actual undulations of the surface of the one and the peaks and crags of the other are in almost every case due to secondary causes. The internal forces upheave the mass of the land, other forces fret it into diversified shapes. Occasionally the main features of a mountain range are determined by the flexures impressed upon the rocks during their elevation, as may be seen in the Jura and Alleghany Mountains (although even here they are much modified); but many a plain is formed upon rocks as highly contorted as the most complex mountain-system. Illustrations of these and other peculiarities will be given in the chapter on Earth Sculpture.

Epitomizing the results arrived at in this chapter, we see—

1. That both upheaval and depression may result from the shrinkage of the crust.

2. Rocks have been bent, twisted, and broken or faulted by the action of the internal forces.

3. These actions have occurred in all geologic ages, in every part of the world and are still in operation.

4. The upheaval of land masses and the broad features of the continents, &c., are due to their movements,

5. Their effects have been much modified by secondary actions.

CHAPTER XI.

THE EARTH'S EXTERNAL HEAT.

Having determined the effects of the earth's internal heat in broadly mapping out the elevations of continents and the depressions of ocean-basins, we must direct our attention to the heat received from external sources, and study the results which accrue therefrom.

The whole of the heat derived from external sources is practically the gift of the sun; for the quantity received from other sources, such as the moon and stars, is so insignificant that the most refined experiment alone can reveal its existence.

The first question that arises relates to the quantity of heat supplied to us by our great master, the sun. Accurate experiments upon this subject have been made by Sir J. Herschel, at the Cape of Good Hope, and by M. Pouillet, in Paris, and the close agreement of their results justifies us in accepting them as proved.

The instrument by which these curious researches were carried out is the *pyrheliometer*. It consists essentially of a thin metallic box of known area containing water. One surface of the box is blackened and exposed perpendicularly to the sun's rays. The increase of temperature of the water which the impact of the solar rays induces is registered by means of a thermometer.

This, however, does not give the entire thermal effect, because the instrument is not only receiving heat but parting with it by radiation, as explained in our second chapter.

To determine the actual quantity of heat received, the pyrheliometer is first turned to an unclouded part of the sky, where it radiates its heat freely for, say, five minutes, the decrease of temperature showing the amount of radiation. For an equal space the instrument is then directed towards the sun, and then for a like period once more exposed to a clear sky. These three processes constitute one experiment. The mean of the first and last exposures gives the amount of heat radiated in five minutes, which, added to the increment of temperature during the second exposure, gives the total amount of heat received on the instrument from the sun in five minutes.

Sir John Herschel summarises the results of these interesting experiments by saying that, if the direct solar heat were "received on a surface capable of absorbing and retaining it, it would suffice to melt an inch of ice in thickness in 2h. 13m." On a square mile of surface no less than 26,000 tons could in this way be melted in one hour, and fifty million times this quantity on the entire surface of the earth. Pouillet's experiments gave very nearly the same result.

From this we can readily estimate the quantity radiated into space, knowing the size of the earth, and taking the sun's distance at 91,730,000 miles. From these data it follows that the earth only receives one 2,138,000,000th of the solar emission. All the planets of the solar system, Proctor points out, intercept but one 227-millionth part of the heat, the rest being dissipated into space, excepting what is absorbed by meteors and comets.

M. Pouillet conducted experiments at different times from sunrise to sunset, and was thereby able to calculate the quantity absorbed by the atmosphere. He estimated that if the instrument received the rays direct from the zenith about one-quarter would be absorbed, and that of the total amount received by the illuminated hemisphere nearly one-half is cut off by the atmosphere.

We have already shown (p. 48) that dry air is nearly diathermous, but that water vapour opposes a strong obstacle to the transmission of heat. The absorption of the solar rays above described is due to the presence of aqueous vapour in the atmosphere.

The solar heat, after streaming through space, impinges upon the atmosphere, from which part is reflected back again into space. The rest passes on and finally reaches the earth, minus the quantity absorbed by the vapour. Reaching the earth, part of the heat is radiated back through the atmosphere, the rest is absorbed by the solid earth, which is thereby warmed. Traces of solar heat can be detected in the ground to a depth of about a hundred feet. The warmed earth imparts heat to the air above it by conduction, as shown in Chapter II.; and if there were no vapour or other adiathermous matter in the atmosphere this is the only way in which it could be warmed, for the solar heat would not be checked by pure air.

Only a small quantity of the heat received from the sun is absorbed and retained by the earth; but it is easy to calculate what would be the result if all the heat were so absorbed. Tyndall estimates that if the earth were covered with an ocean of ice-cold fresh-water, 66 feet deep,* it would be raised to the boiling-point in one year.

Pouillet's experiments show that when the sun's rays fall vertically upon the earth the minimum of absorption ensues; and, consequently, the greater the thickness of air they have to traverse the greater is the absorption. Over every part of the tropical zones the sun is vertical at some part of the year, and except on the tropics themselves this occurs twice annually; and, moreover, the sun at mid-day is always very high in the heavens, never being more than 47°

* By an error the amount is printed *miles* instead of feet in Tyndall's "Heat a Mode of Motion." It is perhaps necessary to point this out.

from the zenith in any place. Hence it is that the tropical regions are so hot. The degree of obliquity with which the sun's rays strike any part of the earth determines primarily the temperature of that place, and though many modifications arise through local causes, the earth is broadly divided into one torrid, two temperate, and two frigid zones. The main divisions of climate are thus determined by the direct influence of the earth's external heat.

Nearly the whole of this area is in a condition to support life; for, with few exceptions, only the extreme north and south are too cold to support existence of some kind. The habitability of the earth is, therefore, the result of the external heat.

This is, however, far more forcibly illustrated if we consider the vertical range of temperature in the atmosphere. The air receives the greater part of its heat by conduction direct from the earth, and a much lesser amount by the heating of the aqueous vapour, both directly from the sunbeams, and indirectly from the terrestrial radiations. As already explained, the transmission of heat by conduction necessitates a fall of temperature as the distance from the source of heat increases, hence the air will be colder as we ascend from the surface. In the case of the vapour a similar condition is brought about in consequence of the atmosphere being moistest in its lowest portions. It is important to bear in mind the fact that the atmosphere is chiefly warmed from the earth, and not from the sun.

That the atmospheric regions above us are colder than the surface is known to all. The daily experience of mountaineers proclaims it; the rarer experiences of aeronauts enforce it; and the snow-capped mountains in all parts of the globe bring it visibly before us. We shall in the sequel learn that in recent geologic times the earth has passed through a period of intense cold, known to geologists as the glacial period. It strikes us with wonder, that familiarity does not lessen, when in our now-favoured land we see engraven upon the rocks the marks of the icy hand that bound us in chill fetters like the polar regions of to-day. But we do not, as a rule, realise the startling fact, that though the glacial epoch is removed from us in time by thousands of years, a glacial climate hovers a few thousand feet above us. Yet such is the case.

We may, to simplify matters, take it as true that life cannot exist where the temperature never rises above the freezing-point. No matter in what part of the globe we may be stationed the cold region of the atmosphere (as we will call the region in question) is never so much as four miles above us. The limits of perpetual snow mark the lower boundary of this region in unmistakable handwriting upon the mountains, and this limit we call the *snow-line*. But it must be impressed upon every mind that the cold region is everywhere present, whether there be or be not mountains high enough to penetrate it. The fleecy, cirrus clouds that give such beauty to a summer day are icy particles floating in it.

This region is farthest from us in the tropics, and approaches the earth as we journey towards either pole. It is, indeed, like a dome above our heads, whose rims (taking the earth's mean temperature) rest upon the surface in the northern hemisphere about lat. 80, and in the southern about lat. 60. Taking the polar semi-circumference at 12,000 miles and the greatest elevation of the snow-line at 4 miles, we have 1-3,000th for the vertical as compared with the horizontal limit of life. On a globe eight feet in circumference a film of 1-1,600th of an inch would mark the vertical limit of life at the equator, and this inappreciable space must be made to diminish in all directions to illustrate the life-limits for the entire sphere.

As the sun draws away from our hemisphere after the summer solstice, the cold region settles closer to us and creeps southwards over the land, while in the southern hemisphere it is lifted higher and its earth-boundary retreats. As the sun comes back again this process is reversed, the cold settling nearer to the earth south of the equator.

The tiny film of warm air is preserved about the globe practically by the presence of aqueous vapour in the atmosphere. Remove this, and although by day the air would be somewhat warmed by conduction and push the cold region back, each night we should be enveloped in its folds, and life as we know it could not exist. Until Prof. Tyndall demonstrated the adiathermity of aqueous vapour, as stated in our second chapter, we were ignorant of the vital importance of this exceedingly attenuated matter. On the arid plains of Africa and Australia the quantity of vapour is reduced to a minimum, and the nearest approach to the above hideous state of things is found. The sun's untempered rays beat fiercely down and heat the parched sand to such a degree that lucifer matches have been known to ignite on contact with it. By radiation this heat is given up at night, and the traveller is fain to wrap himself in his warmest clothing to escape the cold. I have shivered by night in the deserts of Africa, and in a few hours I have been blistered by the sun.

The aqueous vapour may be likened to a spring cushion, which by its elasticity holds in check the cold region. Its elasticity is imparted by the solar heat, and as this increases the cold is pushed back; as it diminishes the cold draws near.

The solar heat does far more than this. It gives rise to great movements of the air and water which affect the economy of nature in an important degree. We will take the case of the atmosphere first.

Let us suppose the earth to be a perfect sphere, either covered entirely with water or entirely consisting of land. The average difference of temperature between the tropics and the poles is about

80° F. The air in the torrid zone is therefore heated to a much greater extent than elsewhere. Consequently it expands, and thus becoming lighter, rises and continues to ascend until it reaches an elevation at which the air is of about the same density. Thence it will flow away northwards or southwards, as the case may be, as an upper current.

The ascent of the heated air tends to produce a vacuum, and the cooler, denser air from the temperate and polar regions flows in towards the equator. In this way arise two regular winds, one from the north, the other from the south, each travelling towards the equator. But in their journey they are continually passing over places in which the earth's diurnal rotation is greater than whence they have come, and as the rotation is from west to east, the winds seem to lag behind, and those in the northern hemisphere become N.E., and those in the southern hemisphere S.E. winds. They are well known as the Trade-winds.

The heated air which rises from the tropics flows away northwards and southwards, as upper currents, known as the *Anti-trades.* As they set out with a rotary motion greater than that of any place over which they pass they get in advance of the earth, as it were, and so become S.W. winds in the northern hemisphere, and N.W. winds in the southern hemisphere.

It might be expected that the earth would thus be swept at its surface by N.E. and S.E. trade-winds, and that everywhere above these would flow the anti-trades in an opposite direction.

As a matter of fact this is not the case, for the anti-trades dip down to the surface north of the tropic of Cancer and south of that of Capricorn, and so form regions of prevailing S.W. winds in the northern temperate zone, and prevailing N.W. winds in the south temperate zone.

The trade-winds in like manner are upper currents in the temperate zones, and dip to form surface winds near the tropics.

The zones in which these crossings of the winds take place are known as the *zones of calms*, for there the winds more or less neutralise each other's effects. In like manner there is a zone of calms just north of the equator where the two trade-winds meet, and probably cross.

In the neighbourhood of large masses of land the trade-winds become modified into periodical winds known as *monsoons*, especially where, as in the Indian Ocean, the land trends east and west.

The mechanism of the winds is therefore due to the influence of the sun's heat, and their force and direction depend in the main upon the difference of temperature between two localities. Thus the N.E. trades are due to the difference of temperature between the arctic and the tropic zones. If that difference be diminished the force of the trades will be lessened; if it be increased the force will be enhanced.

If the whole earth were equally heated by the sun there would be no winds whatever. If one hemisphere be more or less heated than the other the trades of the cooler hemisphere will be the stronger; for the difference of temperature between the polar regions of that hemisphere and the zone of maximum heat will be greater than in the opposite hemisphere.

Now the southern hemisphere is colder than the northern, and consequently we find the S.E. trades are stronger than the N.E. Were the two hemispheres equally warmed the trades would meet, and the zone of calms be formed, at the equator. But as the southern hemisphere is the cooler, the S.E. trades invade the northern hemisphere and the zone of calms lies a few degrees north of the equator. This is of the utmost importance in the economy of nature, as we shall see when we discuss the phenomena of climate.

Inasmuch as the S.W. wind brings warmth to our land, and as it had its origin in the tropics, it has been inferred that it conveys to us some of the heat of those fervid regions. A little consideration will show that this is not strictly true. It is certain that as the heated tropic air expands and rises it carries with it a large amount of heat, which is thus removed from the tropics. But as it ascends it must continually part with heat by conduction to the cooler air around, and still more by direct radiation into space from the elevated, chill, almost moisture-less regions to which it reaches. Moreover, as it flows towards the poles at least 2,000 miles of its journey is performed in the cold region of the atmosphere, above the snow-line. It must, consequently, have parted with by far the greater portion of its original heat long before it descends to the earth.

Nevertheless this wind (which we select as an example) *does* bring so large an amount of heat to Western Europe as to convert Britain into a genial home, instead of leaving it frost-bound like dreary Labrador, in the same latitude, on the opposite side of the Atlantic.

Whence does it derive this heat? The answer is very simple. The S.W. wind flows over a portion of the ocean abnormally heated by warm currents. From this body of warm water it gathers heat by conduction, and distributes it far over the land beyond the influence of the waters.

Let us now turn to the no less important currents of the ocean. It is well known that the sea is intersected almost everywhere by currents—"rivers in the ocean," as Maury calls them—some of which flow along the surface, and some travel beneath as under-currents. It is unnecessary to describe in detail the general system of ocean currents since they are fully expounded in all manuals of physical geography. Neither will there be any occasion to discuss the various theories that have been advanced by different authors concerning their causes.

Dr. Croll has, in my opinion, completely set this matter at rest in a very simple manner. He devotes two hundred pages to this question in his work on "Climate and Time," and has most ably advocated the theory that the currents are produced by the prevailing winds—not the trade-winds alone, but the prevailing winds of the whole world regarded as a general system. In illustration of this theory he has constructed a map whereon he has laid down the sources of the winds (from Johnston's "Physical Atlas") and the directions of the ocean currents (from the Admiralty Current Charts). *In every case the direction of the main currents agrees exactly with that of the prevailing winds.* This, it seems to me, sets this vexed question at rest, for no amount of argument can explain away this universal law, which, if it does not prove the winds to be the originators of the currents, would stand as an unparalleled instance of fortuitous coincidences. Accepting, then, the wind origin of the currents as established, let us take the Atlantic Ocean, and the North Atlantic in particular, to illustrate the action of currents in distributing heat.

The N.E. and S.E. trade-winds give rise to currents flowing towards the equator. These currents meeting near the equator originate an equatorial current which flows from east to west.

Impinging upon the American coast this equatorial current must bifurcate. If the two trade-winds were equal in power, and the configuration of the coast were such as to exercise no influence, half the stream would flow northwards and half southwards. But, as we have already learned, the S.E. trade-wind is the more powerful; consequently the currents it gives rise to are the stronger, and hence much of the southern water is carried north of the equator. There it unites with the current due to the N.E. trade, and swinging northwards along the coast sweeps at length across the Atlantic in a N.E. direction as the Gulf Stream. If South America were separated from North America by a broad channel this would not take place, but the equatorial current would enter the Pacific.

It is patent that the northern course of the Gulf Stream is primarily due to the S.E. trade-wind being stronger than the N.E. trade-wind. We have already shown that this is due to the comparative coolness of the southern hemisphere. If by any cause the N.E. trade-wind were to become the stronger, the Gulf Stream would be deflected into the southern hemisphere. In the chapter on Climate we shall show how this can be, and doubtless has been, brought about, and what important consequences ensue.

Now the water of the Gulf Stream is derived from the tropics and flows towards the cooler regions of Western Europe. Its temperature is considerably higher than that of the surrounding water in the North Atlantic, and it may therefore be looked upon as a gigantic hot-water apparatus for warming the western part of the North Atlantic area.

If this be the case we should expect to find that the climate of Western Europe was milder than that of corresponding latitudes on the opposite American shores. This is indeed the case. England is in the same latitude as Labrador, and the temperature of eastern Ireland in winter is as high as that of New York, 28° farther south.

We are very apt to under-estimate the influence of this gigantic current, and a few statistics, taken from Dr. Croll's work, will be of interest. He estimates that the quantity of heat conveyed by the Gulf Stream is equal to all the heat received from the sun by 1,560,935 square miles at the equator, and to all the heat received by 2,062,960 square miles of the temperate regions. Again, the area of the Atlantic from the latitude of the Florida Straits to the Arctic Circle is 8,500,000 square miles, and one-fourth of all the heat possessed by that area (even supposing every solar ray to be absorbed) is derived from the Gulf Stream! Deflect that current, and by the above amount will the temperature of the Atlantic be reduced.

Now it must be remembered that this quantity of heat is not merely conveyed to temperate and arctic regions, but that it is lost by the tropics. The Gulf Stream, therefore, tends not merely to increase the temperature of the north-eastern regions but to lower that of the tropics, and in this it is assisted by the compensating cold currents which flow down the east coast of America. Heat is, therefore, removed from the tropics in two ways: by the uprising of heated air, and by currents. But the results in the two cases are very different. In the former the heat is radiated into space, and so lost to earth; in the latter case it is distributed to the cooler regions.

The winds are directly due to the sun's heat; ocean currents are directly due to the winds; hence they too are manifestations of the solar rule.

Indeed, without ocean currents the globe would not be habitable. The present difference of temperature between the poles and the equator is in round numbers 80° F.; the temperature of the equator being about 80° and of the poles 0°. This is the result of all the causes which modify climate, of which currents are by far the most important.

If we imagine all the aerial and oceanic currents to be stopped, the various parts of the earth would possess temperatures depending directly upon the amount of heat received from the sun.* If all the solar heat were destroyed the earth would acquire the temperature of space, which several trains of reasoning show to be about —239° F. This quantity

* There are certain phenomena which make this statement not rigidly true, but these to a great degree compensate each other, and the above is consequently practically true.

added to the observed temperature gives the total heating effect of the sun.

If all the currents were stopped and the temperature were dependent solely upon the direct solar rays, the equatorial temperature would be 374° above that of space, and the polar 156°. The observed temperature of the equator would then be 135°, and of the poles —83°. That is to say, the equatorial regions would be 55° warmer and the polar regions 83° colder, and their difference would be 218°, instead of 80° as at present. It is needless to say that under such conditions the present forms of life could not exist.

So great is the influence of the Gulf Stream upon England, that it raises the temperature of London 40°, in spite of the counteracting effects of the colder currents.

Immense as is the influence of currents in thus distributing the warmth of the tropics over temperate regions, it is nevertheless true that of themselves they would merely warm the coasts, and the interior of the continents would still be perishingly cold.

It is here that the influence of the winds comes into play. Blowing steadily across the heated waters of the Gulf Stream the air becomes warmed, and owing to the high specific heat of water, as explained before (p. 39 *et seq.*), and the comparatively low specific heat of air, which is less than a fourth that of water, vast volumes of air can be warmed.

Taking the specific heat of air as unity, that of water is 4·2, and the density of the latter is 770 times greater than that of the former. Consequently the same amount of heat which will only raise a cubic foot of water 1° will raise 770 cubic feet of air 4·2°, or 3,234 cubic feet 1°. In other words, the Gulf Stream can warm 3,234 times its own volume of air by giving up its own heat. Of course the whole of the heat is not so yielded, but we can see how enormous a volume of air can be warmed by a comparatively small quantity of warm water.

Climate, then, is vastly ameliorated by the action of ocean currents—that of the sea directly, of the land indirectly, through the intervention of the winds. Owing to the high specific heat of water enormous volumes of air can be warmed, and the warm winds sweeping over continents render their interiors habitable.

One other effect of the earth's external heat calls for notice, namely, evaporation and precipitation. As climate is largely modified by the influences of the currents of air and water, so the physical aspect of the land is moulded by the effects of these two phenomena.

We have already shown how all important the adiathermous vapour in the atmosphere is *—how it

* Pages 10 and 48.

alleviates the fierce splendour of the solar rays, and checks the no less baneful radiation which would freeze to death every living thing. This vapour is lighter than hydrogen, and the quantity contained in the atmosphere (about 1 part in 200 in England) appears almost ridiculously small when we consider the effects attributed to it.

As might have been expected, the quantity of vapour in the atmosphere diminishes as we ascend above the earth—at first rapidly, and then more slowly. The blue tint of the sky, one of the most beautiful sights in nature, is due to its presence, and is deep and pure in tint where the vapour is plentiful, and pales and assumes a steely hue where the atmosphere is dry. Thus whether we gaze into the summer sky or the ocean depths we are peering into water.

The vapour is the result of evaporation, and this process takes place at all observed temperatures, whether from the surfaces of water, snow, or ice. It goes on simultaneously with condensation, and hence appears to cease, and then become negative in quantity, when saturation and precipitation take place.

As yet no reliable data exist relating to evaporation at different temperatures, but Mr. S. H. Miller and myself are at work upon this question and hope shortly to publish our results. It is certain, however, that, other things being equal, evaporation is increased with the temperature. Evaporation takes place from every exposed moist surface, and increases with the area of the surface; hence a stretch of forest land or pasture will evaporate more than an equal area of rock, or even, under some circumstances, than a similar area of water.

Nevertheless, taking the whole world, it is certain that the ocean yields more vapour to the atmosphere than the land. If there were no winds or ocean currents the quantity of vapour in the atmosphere would remain constant at all places. Suppose evaporation to commence, it would go on until the air was saturated, after which there would be no more accession of vapour. The quantity of vapour would be greatest in the hottest regions, and least in the coldest. Neither would there be any precipitation of vapour as rain or snow, nor even condensation into cloud, fog, or mist.

As the rivers are constantly discharging into the sea, and as they are only recruited by rain and snow, they would dwindle away to nothing, and the whole of the land would soon become a desert.

One of the most important functions of the winds is the diffusion of vapour over the land. To us the S.W. wind is the rain-bearer. It has travelled over the warm waters of the Gulf Stream and become heated. This elevation of temperature enables it to hold a large quantity of vapour, which, as the winds become chilled in passing over the land, becomes precipitated as rain and snow.

To the sea, then, we must look for our supply of terrestrial water; and the tropics are the great reservoirs.* Water is continually passing through a great cycle of events. The course of a drop of water on its longest journey may be thus sketched. Evaporated from the surface of the sea it passes into the state of vapour, and ascends through the air, until meeting with the colder atmosphere it is condensed into cloud, swept over the land, further condensed and falls as rain or snow. Here we may suppose it to sink into the earth and travel onwards and downwards until it reaches the surface again in a spring, the source of a river, from which point it flows on until it is again poured into the sea, to commence again a similar cycle. Of course precipitation may occur almost anywhere, and the water be almost immediately evaporated again, but as a rule, the great round is pursued as indicated. Hence it is that "all the rivers run into the sea, yet the sea is not full," for "unto the place from whence the rivers come, thither they return again."

It is very important to understand clearly that this great process of evaporation and condensation is a grand distillery. The tropic or other heat is the furnace, the cold air and land are the condensers. If we uniformly increase the temperature of the whole earth, we may enhance the evaporation but

* This is only true indirectly. Most of the water evaporated in the tropics is precipitated in those regions. But the heat of the Gulf Stream is of tropic origin, and this gives us our rain and snow.

not the precipitation. If we cool uniformly the whole earth we shall diminish evaporation at the same time. To obtain a greater precipitation of rain or snow, we must increase the difference of temperature between the furnace and the condenser. In other words, we require greater heat in low, and greater cold in high, latitudes. No general increase or decrease of temperature is of any avail. This important consideration has often been lost sight of in speculating upon the causes of change of climate.

In concluding this most meagre sketch of the action of solar heat upon the earth, we are again compelled to recognise the truth of our fundamental doctrine, that the past and present conditions of the globe depend upon the action of internal and external heat upon solid, liquid, and gaseous matter.

If internal heat has been instrumental in determining the shape of the globe, and the broad features of its surface, the external heat is no less important, not merely in giving rise to the broad climatic zones, but in originating the winds and ocean currents without which the earth would not be habitable, and in distributing the vapour from which all our terrestrial water is derived. The great cycle of the waters from the ocean as liquid, through the air as vapour, and through the rocks and over the land as springs and rivers, are thus determined. The power of the sun as a ruler is beginning to dawn upon us, and will appear clearer and yet clearer as we advance.

Epitomizing the contents of this chapter, we have learned:—

1. The earth only receives a two-billionth of the heat emitted by the sun.

2. This would be sufficient to melt 26,000 tons of ice hourly on every square mile of surface, if it were all absorbed.

3. One-half of the heat never reaches the ground, being cut off by the atmosphere.

4. A considerable portion of the heat which reaches the surface is radiated back into space.

5. Solar heat determines the broad climatic zones.

6. The atmosphere is warmed almost entirely from the earth, the vapour being the material which absorbs the heat.

7. This warm vapour acts like a spring cushion in pushing back, as it were, the cold region above us.

8. The winds are caused by differences of temperature in different parts of the globe.

9. The stronger trade-winds blow from the cooler hemisphere.

10. Ocean currents are caused by the prevalent winds.

11. They are the most powerful agents in distributing heat over the surface of the earth.

12. They heat the winds which warm the land.

13. Heat is lost in the tropics by radiation. That

heat passes away from the earth. Much heat is also transferred from the tropics to higher latitudes by currents.

14. If all currents were stopped the temperature of the tropics would be about 135°, and of the poles −83°.

15. Owing to its high specific heat warm water can heat over three thousand times its own volume of air, to its own temperature.

16. Clouds, fog, rain, snow, springs, and rivers are the results of evaporation and precipitation.

17. The winds distribute moisture over the earth.

18. Water is constantly circulating from the sea through the air, on to the land, and into the sea again.

19. Winds, ocean currents, and the distribution of moisture, and hence the rain, snow, and rivers, are the result of differences of temperature.

CHAPTER XII.

EFFECTS OF THE EARTH'S EXTERNAL HEAT.—EARTH SCULPTURE.

WE have already learned, from the study of faults and the structure of mountains, that although the internal forces of upheaval and depression have broadly mapped out the features of the land, some other cause has been simultaneously at work modifying the original contours, and removing great masses of solid rock. This force we must proceed to investigate.

It will be well to recall some of the proofs of this re-modelling of the surface—this wearing away of the rocks which has given to the land its diversity of landscape. To this action the name of *denudation* is given.

The first proof to be noticed is derived from faulted strata. It has been shown that the crust has been very frequently rent across, and one side of the fracture upheaved, in some cases as much as three miles, as in Scotland. Yet all this upheaved material has somehow been removed, and the surface of the ground affords no evidence of the break. Faults of several hundred feet throw are daily passed over without attracting any notice, for the landscape may be quite flat, or broken only by gently swelling undulations. Of this nature may be cited the fault in the Ashby-de-la-Zouch coal-field, with a throw of 500 feet, which occurs in an almost flat country.

In mountain districts proofs of denudation often exceed the tokens of elevation, the bulk of rock thus removed sometimes being greater than that which remains. Magnificent examples of this are seen in North Wales, as was first pointed out by Prof. Ramsay. If Snowdon, for example, owed its external form to upheaval, we should find it occupying the ridge of one of the great folds into which the strata have been thrown, and the Menai Straits would lie in one of the troughs. Instead of this the mountain occupies the trough of a gigantic flexure, and the Straits are hollowed out of a ridge. The quantity of material removed is in round numbers about 21,000 feet, and as the height of Snowdon is only 3,500 feet, a thickness of rock seven times as high as Snowdon has been removed from that area.* Replace the strata that have been denuded away, and the Menai district would tower

* The reader should consult the classic essay of Prof. A. C. Ramsay on "The Denudation of South Wales." Mem. Geol. Survey, vol. i., 1846. The sections there given, showing the quantity of material removed from that hilly country, tell a more forcible story than any words.

in gigantic mountains higher than the Alps or Rocky Mountains.

This example, though it may be extreme in the amount of denudation indicated, illustrates a very frequent phenomenon, for mountains and hills very commonly occupy the troughs (or synclinals), and valleys the ridges (or anticlinals), of the folds of strata. The reason for this will be presently expounded.

Even in those comparatively rare cases in which mountains occupy the anticlinals, and valleys the synclinals, there is always proof of a vast amount of denudation. Of this class of hills are the Jura and the Appalachians, and our own Derbyshire hills.

If these hills maintained their original contours the newest rocks (being uppermost) would run right over the summits. It would hardly be stating the case too strongly to say this never occurs. The newer rocks flank the sides of the hills, and the older ones crop out at and near the summit. Now the newer rocks must originally have run right across the ridge, but since that time they have been denuded away, and so exposed the underlying rocks.

In other cases hills bear no relation whatever to their internal structure, which may be exceedingly complicated, while the outline is simple. On the other hand, hills cut out of horizontal, or nearly horizontal, strata are of the very commonest occurrence, the hills round London being all more or less of this character.

Nor is it alone in hills and valleys that these proofs of denudation are to be found. Plains may exhibit them in an equally forcible manner, for they may be carved out of highly-inclined, or even crumpled strata, as in the central plains of Ireland.

It has now been made clear that while the land itself has been upheaved by forces from below, the external aspect of the land has been produced by forces from above, that is by surface agencies.

Denudation is the wearing away of rocks, and the consequent exposure of rocks which were before hidden. The question naturally arises as to whether we can see evidence of this waste going on in our own days. A little consideration will enable us to answer in the affirmative.

Those who witnessed the erection of the Houses of Parliament, and admired the beauty of the Perpendicular tracery and mouldings with which they were decorated, must often linger mournfully over the traces of decay, which even in this short space of time appear but too prominently. The hard magnesian limestone is succumbing to the fell influence of the acid-laden atmosphere of the metropolis. These acids attack the stone, and convert its exterior into a soluble salt, which the rain washes away, and which sooner or later finds its way into the Thames and is carried off to sea.

Even in the pure country air every old building bears the marks of time's ravages; and the very tombstones, erected to perpetuate the memory of the dead, have had their inscriptions smoothed out by the same impartial hand.

If upon these monuments of stone selected especially for its durability, the traces of slow dissolution are apparent, how much more rapid must be the decay of the numberless softer and less durable rocks that constitute the land!

Nor is it alone in the chemical action of acid-laden waters, vast as that action is, that the denudation of rocks is brought about. Far more powerful are the mechanical effects of frost, of rain, and of rivers. Every shower that falls washes away at least a few grains of sand, and carries it onwards, always downwards, until at last it reaches a stream, and is transported into the sea, or into some lake.

The stratified rocks have all been formed in this way. They are sediments washed from the land, and attest by their magnitude the power of the seemingly puny efforts of atmospheric agents. Every ounce of these rocks, twenty-one miles in thickness in Britain, has been washed from off pre-existing land.

The waters of the clearest rill are laden with solid matter in suspension, and in solution; besides which a considerable burden is rolled onward and downward along its bed. Every one must have noticed the turbidness of rivers in times of flood; the deposit of rich fertilising matter on the land that has been submerged; the banks of mud and sand that gather in the channels; and the great delta deposits formed at the mouths of large rivers, which form great fertile plains, and sometimes whole countries, as in the case of Lower Egypt, which Herodotus long since recognised as "the gift of the Nile." These are some of the tokens of river-work. So too are the broad flats that fringe their valleys, and form the best meadow-lands in the kingdoms. The water-meadows, straths, and carses are all of this nature, and represent so much material moved from elsewhere.

The rain, falling upon the ground, sinks into the crannies of the rocks; the winter's cold causes the water to expand as it freezes; the rocks are thus rent, and so crumble, and are easily carried away. The action of vegetation, and perhaps quite as much the imperceptible agency of worms, all tend to wear away the rocks. The loose fragments are then moved downwards by the rains (except in the case of loose sand which may be sometimes blown upwards); the motion is always to lower levels, and finally into streams.

In ice-bound regions where glaciers exist this degradation of the rocks goes on with even greater force. The ice grinding over the rocks abrades and smooths them, and the particles so removed, becoming frozen into its base, are converted into most powerful agents of destruction.

In countries, such as our own, which have in recent geological times been smothered in ice, the denuding effects are very striking. In the mountain regions all the asperities have been smoothed and rounded, in the plains the abraded material has been deposited in beds of boulder-clay, which sometimes attain a thickness of several hundred feet. Since the ice retreated the ordinary atmospheric forces have been busy in removing this comparatively loose matter, and in breaking up the smoothed rocks into more angular forms; but sufficient time has not elapsed to do more than modify these relics, though in many places there is clear evidence of boulder-clay having been almost entirely removed from large areas.

At the present time this action of the ice refers only to high mountain regions and to polar lands; and it is to frost, rain, and rivers that we must look for the elucidation of the phenomena of denudation as witnessed in our day.

Mr. A. Tylor, in the year 1850, first directed serious attention to this important question,* and made the luminous remark that "the mere consideration of the number of cubic feet of detritus annually removed from any tract of land by its rivers, does not produce so striking an impression upon the mind as the statement of how much the mean surface-level of the district in question would be lowered by such removal." This indeed is the key to the whole question.

* Phil. Mag. Ser. 4, vol. v. p. 268. I would earnestly suggest the study of this paper, together with one by Prof. A. Geikie on "Modern Denudation" (Trans. Geol. Soc., Glasgow, vol. iii.), the chapter on this subject in Dr. Croll's "Climate and Time," and Whitaker's important paper in the Geol. Mag. for 1867.

At first sight the quantity of sediment carried by the rivers seems too inconsiderable to have effected such gigantic changes as have taken place in the configuration of the land. We islanders turn our eyes naturally to the sea. We can watch the untiring energy with which it frets away the shore, and are hence apt to attribute greater importance to it than to the quite imperceptible effects of rain and rivers. Yet we shall presently see how much more important this latter action is.

Given the area of a river basin, the discharge of water per annum, and the quantity of material held in solution, carried in suspension, and pushed along the bed, and we have the requisite data for calculating by how much the general level of the land is lowered in a year.

For instance, the Mississippi basin is 1,147,000 square miles in area, the annual discharge of water is 19,500,000,000,000 cubic feet, the sediment amounts to one 2,900th part of this quantity, consequently the land is lowered by the six thousandth part of a foot per annum.

Now, if we knew the mean height of the continent of North America, we could estimate approximately the length of the time it would take to reduce it to the sea-level, taking the Mississippi as our standard of denudation.* This has been laboriously calculated

* The Mississippi is admirably suited for such an application, as it flows from north to south, from temperate to tropic regions, and is not, like the St. Lawrence, connected with great lakes which would collect much sediment.

by Humboldt and by Arago, but an unfortunate error has crept into the subject. As it is of vital importance to the present question we will deal with it at once and in detail. Humboldt gives the following as the height of the mean centres of gravity:—

Europe	671 feet.
Asia	1,132 „
N. America	748 „

Unfortunately he uses the terms *mean height* (hauteur moyenne) and *centre of gravity of the volume* (centre de gravité du volume) as synonymous, and Sir J. Herschel, misled by this, doubled these heights to find the mean height of the surface, and his figures have been accepted by every succeeding writer. Nevertheless, the method employed by Humboldt clearly proves that by *hauteur moyenne*, &c., he intended to indicate *centre de gravité de la surface*, and Arago's computations also prove this, for they give practically the same results for the centre of gravity of the surface, which he correctly designates in all cases the *hauteur moyenne*, avoiding the misleading phrase *centre de gravité du volume.** It is clear that by doubling the mean height of the continents, we at the same time double the time required for their destruction.

The mean height of the surface of North America must, therefore, be taken at 748 feet, and as it is being lowered by denudation at the rate of one foot

* This was pointed out by the late Mr. J. Carrick Moore. *Nature*, vol. v. p. 479; 1872.

in six thousand years, it follows that in less than four and a half million years the continent would be reduced to the sea-level by its present rivers. This is the inevitable result unless, by upheaval, the destruction is counteracted.

The Mississippi, however, is by no means the most powerful of rivers as a denuding agent. The Ganges is wearing away its basin at the rate of a foot in 2,358 years; and the Hoang Ho denudes the rocks one foot in 1,464 years. Taking the mean of these rates as the speed of denudation for Asia, the continent would be worn down to the level of the sea in about 2,160,000 years.

Of European rivers the Rhone, Danube, and Po are known to be working at the rates of a foot in 1,528, 6,846, and 729 years respectively. The enormous erosion of the Po is such that at the same rate of denudation Europe would be worn down to sea-level in less than 500,000 years.

Prof. Geikie points out another way of arriving at approximate estimates of the quantity of material removed by streams. Taking the average rainfall of the British Isles at 36 inches per annum, the area at 120,000 square miles, and the amount of discharge by the rivers as one-fourth of the rainfall, we have about 17 cubic miles of water discharged from the land in a year. Assuming that the amount of suspended and dissolved matter is only one five thousandth part of the volume of water, we still have $\frac{1}{8800}$ of a foot of rock worn down per annum. The mean height of the land is under 650 feet, and at the above rate it would be reduced to the sea-level in about five and a half millions of years.

It is perfectly certain, from these considerations, that the land is constantly wearing away under the influences of frost, rain, and rivers, but it may be asked whether this action is not confined to the immediate neighbourhood of flowing water. Does it prove that the land *as a whole* is being lowered?

A little thought will show that the denudation is not confined to the stream-channels, and that the entire land is being degraded. The ultimate source of all river water, as we have seen, is the rain. Now the rain falls upon every part of the land, and by its mechanical and chemical actions will wear away the rocks. Mechanically it will remove loose or soft material, and will even shiver hard rocks, by freezing in the crevices and rending the particles asunder. It is also clear that the transport of matter is always downwards. A grain of sand detached from a hill top may be carried but a fraction of an inch downwards by a passing shower, every succeeding rain will convey it onwards, and the path must ever be a descending one. As Col. Greenwood quaintly puts it, the sand will be carried on by the nex-t-rain, and there are no return tickets. Chemically the rain will dissolve any soluble matter upon which it falls, and this dissolved waste must also journey downwards. Hence we may be sure that the whole country is constantly being lowered.

But this action is evidently very unequal in different places, being clearly more marked in valleys than on plains. The lie of the rocks also to a large extent influences the rate of denudation. Anticlinals, or dome-shaped folds, by shedding the water outwards are peculiarly favourable to denudation. Synclinals, or troughs, on the other hand, as sturdily oppose it; and hence we see why so many hills and mountains are synclinals, or geological valleys, as remarked before.

The old school of geologists ascribed the major part of denudation to the sea—and very naturally, for its action is patent to all. But if we compare its power with that of the sub-aërial agents (as they are called) frost and rain, and rivers, its importance is readily shown.

Let us, following Dr. Croll, take the length of sea-coast of the globe at 116,531 miles, its average height at 25 feet, and the mean rate at which the sea encroaches at a foot in a hundred years, which is most probably far too much. The total amount of land is 57,600,000 square miles, and at the above rate 15,382 millions of cubic feet are removed in a century. Now, if we take the Mississippi as giving the mean rate of subaërial denudation, that is one foot in 6,000 years, we have 26,763,000 millions of cubic feet as the waste, or 1,740 times as much as is performed by the sea. For the sea to work as fast as subaërial agents are known to do, it would have to advance upon the land at a rate of more than 17 feet annually, and this, it need hardly be said, we know is not the case.

Having then established the fact of the supremacy of subaërial over marine denudation, let us briefly consider the only argument of any weight that has been brought forward in opposition to the silent action of atmospheric agents. It has been vigorously urged that as from year to year the soil remains practically constant in quantity it cannot be wearing away. The refutation of this objection is very simple. It assumes that the same soil continually lies upon any given spot, which is not the case. It ignores the fact that rivers *do* carry the quantity of matter above indicated. The fact that the soil is not all washed away only proves that *the rocks are disintegrating faster than the rivers can carry the decomposed matter away.* In some places, as in the Hebrides, where the rainfall is excessive and the rocks are very hard, the country is almost bare of soil.

In these subaërial agents, aided to a lesser degree by other forces, we have a tremendous engine capable of wearing away whole continents. The stratified rocks are themselves tokens of its workmanship, for they indicate so much matter worn from the land, and carried out to sea by rivers. When we reflect that, in Britain alone, these rocks attain a thickness of over twenty miles, we feel that we are not ascribing too great a task to subaërial denudation in sculpturing the face of the land into mountain and glen, into hill and valley. We find here the key to the mystery that even high mountain ranges speak more forcibly of the loss they have suffered than of the upheavals they have experienced—we learn how it is that plains may have been the seat of violent earth-throes. In fine, we have arrived at the conclusion that the features of the land have been carved out, instead of being thrust up, as at first sight appears natural, by the internal forces of the earth.

Coming back once again to our first proposition we have proved that, inasmuch as the rain is due to the sun's heat, and the features of the land to the rain, the very landscapes around us are due to the action of heat.

Epitomizing this information it appears:—

1. The land everywhere shows evidence of immense denudation.

2. Even mountain ranges are carved out rather than upheaved.

3. This is chiefly the result of subaërial denudation.

CHAPTER XIII.

CLIMATE.

In the course of our inquiry we have already arrived at certain fundamental principles respecting climate which it may be as well to recall. We have learned that while the broad climatal zones are directly due to the impact of the sun's rays, the climate of temperate and polar regions is very considerably modified by the action of ocean-currents and winds. This embraces the entire question of climate at any given period of the earth's history.

But climate is not stable; it is, viewed upon a broad scale, as variable as weather. The testimony of the rocks reveals that great and startling changes have taken place—that Britain has been so hot as to lure southern species of plants and animals to its seas and shores, and that it has also been cold enough to drive, it may be, all life away; it has sweltered under a tropic-like heat, and shivered beneath an all-shrouding mantle of ice. Into the cause of these changes of climate it is now our duty to inquire.

This question has of late years attained to the first ranks of scientific importance, in consequence of the proofs that have steadily accumulated of a cold period having occurred within quite recent geological times. Nearly the whole of the northern hemisphere shows evidence of this; and similar indications of like vicissitudes in the south are plentiful. To this Glacial Epoch, as geologists term it, very much attention has recently been directed, and when its history is completely elucidated we shall probably be in possession of the key that will unlock the chief mysteries of geological time.

Now this glacial period is supposed by some to have been contemporaneous in both hemispheres: that is to say, the whole earth was colder then than now. Others hold that while a glacial period existed in one hemisphere the other was enjoying more than usual mildness. Others, again, believe that the epoch was one undivided period of cold, which gradually came on, culminated, and passed away. While yet another class of geologists maintains that it was a great period of alternate cold and warm periods, or, as they express it, of alternate glacial and interglacial periods.

Nor is opinion less divided respecting the cause of the glacial epoch. Some look to changes in the distribution of land and sea, others to astronomical causes. Of the astronomical explanations there are three only which demand attention. One ascribes the changes of climate to changes in the obliquity of the earth's orbit; another to changes in the position of the earth's axis of revolution; and yet others to the indirect effects of the well-known movements of the variation of the eccentricity of the orbit, precession, nutations, &c.

Each of the above views has its strenuous advocates; but a close study of the question for some years forces me to confess that those most intimately acquainted with the geological and astronomical facts of the case are steadily approaching unanimity, and are believers in alternate glaciations of opposite hemispheres, in alternate glacial and interglacial periods, and in the potency of the astronomical phenomena of eccentricity, &c.

Before entering into a consideration of the various theories advanced, it will be as well to clear the ground of extraneous facts and indicate those which, being firmly established, must be explicable by a theory if it merits acceptance.

The great fact of a glacial period is universally accepted. The alternation of cold and warm periods is equally well proved, though not so generally accepted. The proofs lie in the occurrence of several beds of distinct ages which are by all admitted to be the result of the action of ice;* and of other beds between these indicating by their nature and the character of their fossils the existence of mild

* These are known as boulder-clays, or tills; and consist generally of tough clay stuck full of sub-angular boulders, which are often covered with scratches.

periods. This at once disposes of the theory of a single period of cold.

It is also perfectly well known to all who have studied the question that during the glacial period the land had very much the same configuration as at present. Hence the cold was not caused by geographical changes.

It cannot, however, be directly shown that the glaciation of the two hemispheres was not contemporaneous.

The true theory of the cause of changes of climate must explain the fundamental facts of geology. A very brief sketch of these may be of use to the reader in following out the different lines of argument in this interesting problem. Let us take the east of England as a type, and show what changes it has undergone in quite recent times, premising that almost any other district would afford similar evidence. The following is a table of the beds arranged in natural order.

9. Recent Beds	Post-glacial.	
8. Hessle Boulder Clay . . .	Glacial	Glacial Epoch.
7. Gravels, &c.	Interglacial	
6. Purple Boulder Clay . .	Glacial	
5. Gravels, &c.	Interglacial	
4. Chalky Boulder Clay . .	Glacial	
3. Sands, Clays, &c. . . .	Interglacial	
2. Lower Boulder Clay, &c. .	Glacial	
1. Norwich Crag	Pre-glacial.	

Commencing with the lowest beds, the Norwich Crag, their constitution shows that no glacial conditions had yet set in, but the fossils prove that the climate was growing colder and colder. At last the glacial epoch began, and the ice spread far down into Suffolk. This finally passed away, and the climate gradually grew mild and warm; then it slowly changed back again to cold. Ice again set in (No. 4) and covered the land, at least as far south as the Thames. This passed away; another mild interglacial period occurred (No. 5), to be again succeeded by ice (No. 6), less extensive than before. This was once more followed by a mild interglacial period (No. 7), and finally the last cold period took place (No. 8) of still less intensity than No. 6. The ice passed away, and the climate has gradually ameliorated up to the present time, as shown by beds 9.

These alternations of warm and cold periods have taken place within quite recent geological times, and throughout the whole cycle Britain has remained much as at present. Sometimes it was united to the continent, at others it was slightly submerged, but as a whole the aspect of the land was such as we are familiar with in these days.

It is essential, then, that a theory, to be accepted, must explain these alternations of climate, rapidly succeeding each other (geologically speaking); and it must do so without requiring great upheavals and depressions of the earth's surface in these or other latitudes. Only one theory has, as yet, succeeded in doing this without violating either geological or astronomical facts, and that is the one expounded by Dr. Croll.

Before describing this theory let us glance at the other opinions which have been brought forward. Two theories have been advanced dependent upon considerable variations in the obliquity of the ecliptic. Lieutenant-Colonel Drayson and Mr. T. Belt are their originators and champions; and though the conclusions they draw are very different, it will be sufficient for our purpose to see —(1) whether variations in the obliquity of the ecliptic could produce a glacial period, and (2) whether there are any just grounds for believing such changes of obliquity have or ever can have taken place.

If climate be largely influenced by changes of obliquity the greatest effects will be produced, in the one case when the obliquity is reduced to nothing, the axis being perpendicular to the plane of the orbit, and, in the other case, when the obliquity is at its maximum of 90°, the axis being then in the plane of the orbit.

Let us suppose the obliquity to be reduced to nothing. Mr. Belt concludes that spring would reign around the arctic circle, and consequently, "under such circumstances, the piling up of snow, or even its production at sea-level, would be impossible, excepting perhaps in the immediate neighbourhood of the poles, where the sun's rays would have but little heating power from its small altitude." *

It is quite true that an equinox would prevail all over the earth so long as this state of things continued, but this is very different from perpetual spring. At present the equinox is marked with snow and frost in the polar regions, and so it would be then. Moreover, the polar regions would then be colder than now. Their heat depends upon distance from the equator, and not upon obliquity, and under the above conditions the long summer days, which prevent loss by excessive radiation, would be replaced by days and nights of twelve hours each, and during the darkness the arctic regions would lose nearly all the heat they acquired by day. It is clear then that, contrary to what is above affirmed, the arctic regions would be colder than now.

Let us now see what would be the result of the maximum of obliquity, which both the authors above mentioned would deem the very acme of glacial possibilities. The arctic circle would then reach to the equator.

Dr. Croll has so admirably treated this question that we will state the case in his own words. "A square foot of surface at the poles would then be receiving as much heat per annum as a square foot at the equator at present, supposing the sun remained on the equator during the entire year. Less heat,

* Quart. Journ. Sci. October, 1874.

however, would be reaching the equatorial regions than now. At present . . . the annual quantity of heat received at either pole is to that received at the equator as 42·47 is to 100; but at the period under consideration the poles would be actually obtaining one-half more heat than the equator. The amount received per square foot at the poles, to that received per square foot at the equator, would be in the ratio of half the circumference of a circle to its diameter, or as 1·5708 to 1. But merely to say that the poles would be receiving more heat per annum than the equator is at present, does not convey a correct idea of the excessive heat which the poles would then have to endure; for it must be borne in mind that the heat reaching the equator is spread over the whole year, whereas the poles would get their total amount during the six months of their summer. Consequently, for six months in the year the poles would be obtaining far more than double the quantity of heat received at present by the equator during the same length of time, and more than three times the quantity then received by the equator. The amount reaching the pole during the six months to that reaching the equator would be as 3·1416 to 1.

"At the equator twelve hours' darkness alternates with twelve hours' sunshine, and this prevents the temperature from rising excessively high; but at the poles it would be continuous sunshine for six months without the ground having the opportunity of cooling for a single hour. At the summer solstice, when the sun would be in the zenith of the pole, the amount of heat received there every twenty-four hours would actually be nearly three and a quarter times greater than that presently received at the equator. Now what holds true with regard to the poles would hold equally true, though to a lesser extent, of polar and temperate regions. We can form but a very inadequate idea of the condition of things which would result from such an enormous increase of heat. Nothing living on the face of the globe could exist in polar regions under so fearful a temperature as would there prevail during summer months. How absurd would it be to suppose that this condition of things would tend to produce a glacial epoch! Not only would every particle of ice be dissipated in polar regions, but the very seas around the pole would be, for several months in the year, at the boiling point." *

The above argument appears to me irrefutable, and we must, therefore, admit that increase of obliquity, so far from producing a glacial period, would produce precisely the opposite effect.

We must now turn to the astronomical aspect of the question, and see whether great variations of the obliquity of the ecliptic are possible.

Laplace and Leverrier have both examined the question of the limits of oscillation of the ecliptic, and Mr. Stockwell has subsequently re-examined the

* "Climate and Time," p. 412.

problem. The results are almost identical. The mean value of the obliquity of the ecliptic to the equator is 23° 17′ 17″, its extreme limits being 24° 35′ 58″ and 21° 58′ 36″: "whence it follows that the greatest and least declinations of the sun at the solstices can never differ from each other to any greater extent than 2° 37′ 22″."* Laplace and Leverrier also showed that the plane of the ecliptic would oscillate to the extent of 4° 53′ 33″ on each side of its mean position, but as the position of the equator varies along with it, the recession of the ecliptic cannot exceed 1° 22′ 34″, according to Laplace. This is important, for both Colonel Drayson and Mr. Belt have supposed that the obliquity of the ecliptic in relation to the equator might amount to 4° 53′, a very different statement from that made by astronomers.

Astronomy therefore assures us, that so long as the earth retains its present figure, the obliquity of the ecliptic will only vary through about a degree and a quarter. Colonel Drayson accounts for the great degree of obliquity required on his hypothesis by an assumption which no astronomer ever yet admitted, namely, that the pole of the heavens describes a circle round a point 6° distant from the pole of the ecliptic and 29° 25′ 47″ from the pole of the heavens (23° 25′ 47″ + 6°). Calculating on this supposition, he arrives at the conclusion that about

* "Secular Variations of the Elements of the Orbits of the Planets." Smith. Cont. Know. vol. xvii.

13,700 years B.C., the angular distance between the two poles was 35° 25′ 47″. The arctic circle was then in latitude 54° 34′ 15″, with which amount of obliquity he supposes a glacial epoch would ensue.

We have already shown how a high degree of obliquity would produce quite an opposite result, for though the winters would be colder and the summers hotter, the increment of heat would be greater than that of cold. Colonel Drayson admits the heat of summer would be intense, and supposes it would be sufficient to melt all the ice. Undismayed by this conclusion, he affirms that "each winter the whole northern and southern hemispheres would be one mass of ice; each summer nearly the whole of the ice of each hemisphere would be melted and dispersed." * It seems hardly worth while to refute such a strange hypothesis, which begins by supposing astronomical data which have, to put it as mildly as possible, never been recognised by any one, and finishes by ignoring all the laws of terrestrial physics. Its refutation can be gathered from the foregoing chapters, and will be sufficiently made clear when we speak of the action of heat upon ice and snow.

Mr. Belt does not call in any secret astronomical peculiarities, but considers the astronomers have lost sight of certain phenomena which may give rise to considerable changes in the obliquity of

* "Last Glacial Epoch," p. 150.

the ecliptic. Such are upheavals and depressions, the unequal distribution of land and sea, the irregularity of the equatorial protuberance, and the heaping up of the ice about the poles during the glacial epoch.

The last phenomenon may be at once dismissed, as it cannot be both the cause and the effect of the obliquity. The inequality of the equatorial bulge, if it had been brought about within recent geological times, might have appeared to be a cause of alteration of obliquity; but it so happens that the longer diameter passes through the deepest part of the Pacific, and the shorter through the continents of Asia and America. The result is that the solid portions of the earth are pretty evenly distributed about the axis of rotation. Respecting the effects of upheavals and depressions, and the re-arrangement of land and sea, *it would be necessary to show that great disturbances had ensued just before and during the glacial period to produce that epoch, and equally great oscillations since to account for the passing away of the ice age, besides intermediate disturbances of equal magnitude to account for successive glacial deposits.* Not only is it impossible to show this, but it is quite certain that no such disturbances took place either just preceding, during, or after the glacial epoch. Indeed, Mr. Belt's own papers, like those of all glacialists, suppose the land to have stood much as at present. This consideration is fatal to the hypothesis.

Closely related with the effect of disturbances of the earth's surface upon obliquity, is the hypothesis that the axis of revolution may change owing to such disturbances, so as to alter the latitude of places. If, for instance, to take the extreme case, the poles so changed that the axis passed through two points of the present equator, it is clear that what are now polar regions would then constitute portions of the tropics; any lesser change would produce similar, but less pronounced, effects. The ablest advocate of this view is Dr. J. Evans, who has written largely on the subject, and definitely expressed his views in his Presidential Address to the Geological Society in 1876.

Supposing for the moment that this hypothesis is true, it in reality does away with changes of climate as affecting the whole earth—the climate remains the same, but different parts of the surface are brought into polar or other regions; the glacial period need not have been one of great cold; there is a glacial period now in the north, move Britain there, and it will be again glaciated.

Dr. Evans lays great stress upon the character of the fossil plants of tertiary and newer dates, that have been discovered in the polar regions. It is indeed a remarkable proof of change of climate to find in these dreary regions beds of coal, for example, teeming with the remains of pines and cypresses which grew and perished there. Still more striking are the vegetable remains of cretaceous age, for they indicate a climate similar to that of the Canary Isles, ferns, cycads, and conifers being abundant. In yet older rocks are entombed nautili, ammonites, and great saurians, such as, being found at home, we look upon as proof of warmer conditions than prevail in our latitudes. Can there be any more vivid proof of change of climate than the occurrence of such forms in the arctic regions? The glaciated rocks of Britain do not impress us so forcibly as the preservation of these warmth-loving species in lands bound fast in rigid ice.

The deductions drawn by Dr. Evans are as follows:—"1. That for vegetation such as has been described there must, according to all analogy, have been a greater aggregate amount of summer heat supplied than is now due to such high latitudes; 2. That there must have been a far less degree of winter cold than is in any way compatible with the position on the globe; and 3, That in all probability the amount and distribution of light which at present prevail within the arctic circle are not such as would suffice for the life of the trees." *

It is certain that a greater degree of warmth was necessary to nourish these plants, but to say that such is not "in any way compatible with the position on the globe," is to beg the very question at issue; and, as we shall see, is not borne out by facts. The argument as to the necessity for light as well as warmth is a more difficult one to answer, and before

* Quart. Journ. Geol. Soc. vol. xxxii. p. 104, 1876.

being called upon to do so it would be as well for its propounders to ascertain whether it is sound. At present there are no facts to support such an assumption, and something can even be said upon the other side, for it is well known that "palms and other plants actually brought from the tropics survive the winter in St. Petersburg, matted down in absolute darkness for more than six months." *

In the address above quoted, Dr. Evans says, "I should like to inquire of mathematicians what would be the theoretical result of such a slight modification geologically speaking, as the following:—Assume an elevation to the extent, on an average, of 4,000 feet over the northern part of Africa, the centre of the elevation being, say, in 20° N. lat. Assume that this elevation forms only a portion of a belt around the whole globe, inclined to the equator at an angle of 20°, and having its most northerly point in the longitude of Greenwich, and cutting the equator at 90° of E. and W. longitude. Assume that along this belt the sea-bottom and what little land besides Africa it would traverse were raised 4,000 feet above its present level over a tract 20° in width. Assume further that the elevation of this belt was accompanied by corresponding depressions on either side of it, so as to leave the total volume of the mineral portion of the earth unaffected. Would

* Prof. H. G. Seeley, in discussion on Twisden's paper on Displacements of the Earth's Axis of Figure, Quart. Journ. Geol. Soc. vol. xxxiv. p. 48; 1878.

not such a modification of form bring the axis of figure about 15° or 20° south of the present, and on the meridian of Greenwich—that is to say, midway between Greenland and Spitzbergen? And would not, eventually, the axis of rotation correspond in position with the axis of figure?"*

Here we have a clear and unmistakable assertion of the kind of change that is desiderated, and a plain question answerable in definite terms. The answer was supplied in an admirable paper by Professor J. F. Twisden.† The conclusions at which he arrived, after a careful mathematical investigation, are best stated in his own words.

"1. That the displacement of the earth's axis of figure from the axis of rotation that would be effected by the elevations and depressions of the kind suggested would be less than 10′ of angle.

"2. That a displacement of as much as 10° or 15° could be effected by elevations and depressions of the kind suggested only if their heights and depths exceeded by many times the heights of the highest mountains.

"3. That under no circumstances could a displacement of 20° be effected by a transfer of matter of less amount than about a sixth part of the whole equatorial bulge.

"4. That even if a transfer of even this enormous amount of matter were to take place, it would not

* Address, Quart. Journ. Geol. Soc. vol. xxxii. p. 108; 1876.

† *Op. cit.* vol. xxxiv. p. 35; 1878.

of necessity produce any effect, and might only produce a small effect on the position of the axis of figure."

Prof. Twisden's investigation thus answers in the negative the question put by Dr. Evans.

Quite independently, Mr. G. H. Darwin attacked a somewhat similar problem,* his object being to "investigate the results of the supposition that the earth is slowly changing its shape from internal causes." He shows that the obliquity of the ecliptic must have remained constant throughout geological history, and that even gigantic ice-caps cannot alter the position of the arctic circle by so much as three inches, though this is the most favourable redistribution of matter for producing such an effect. Further, he concludes that from $\frac{1}{10}$ to $\frac{1}{20}$ of the whole earth's surface may have undergone consentaneous rise or fall to the extent of 10,000 feet. These movements would cause a deflection of the pole, and so far seem to favour Dr. Evans's views. Taking the elevation at 10,000 feet it is shown that—

A rise of	$\frac{1}{200}$	of the earth's	surface	would deflect the pole	11⅓′
"	$\frac{1}{20}$	"	"	"	1° 46½′
"	$\frac{1}{10}$	"	"	"	3° 17′
"	$\frac{1}{2}$	"	"	"	8° 4½′

Whence he concludes no single geological change

* "On the Influence of Geological Changes on the Earth's Axis of Rotation."—Proc. Roy. Soc. vol. xxv. p. 328. This paper singularly confirms the general conclusions of Prof. Twisden, though the object was quite different.

could alter the position of the pole more than 3° of latitude, and if the rise be due to intumescence (*i.e.* if the land be upheaved like a blister) the result would be quite insignificant.

Finally, and this is most important to our subject, under certain circumstances these effects may be cumulative, "and the pole may have wandered some 10° or 15° from its primitive position, or have made a smaller excursion and returned to near its old place." He in conclusion very dubiously suggests "that possibly the glacial period may not have been really one of great cold, but that Europe and North America may have been then in a much higher latitude, and that on the pole retreating they were brought back again to the warmth." But with inherited caution he remarks, "There seem to be, however, certain geological objections to this view."

These objections, to my mind, are insuperable, and I feel sure that if the author investigates the geological facts he will arrive at a similar conclusion.

Let us suppose that a displacement of the pole to the extent of 15° would bring about a glacial period in Britain. It has been shown that no single geological change can deflect the pole more than about 3°, and that to do this one-tenth of the whole surface of the earth must have been upheaved 10,000 feet. Then, as the result is cumulative, there must have been five such changes to move the pole 15°, and this is equivalent to the upheaval of one-tenth of the earth's surface to a height of 50,000 feet, or one-half the surface to the height of 10,000 feet.

Ignoring the fact that there is no such evidence of enormous change having taken place in Tertiary times, and supposing a glacial epoch to have been brought about in this way, we may possibly explain the formation of the Lower Boulder Clay (p. 326) which marks the first glaciation of Britain.

But we must suppose no less than four such enormous changes to have occurred during the great cycle of the glacial period, in order to account for the four successive glaciations as recorded by the four boulder clays. It is needless to remark that such a demand upon geology cannot for a moment be admitted. In fine, the interglacial periods afford an unerring test of the truth or fallacy of any theory of the cause of change of climate. We have applied this test to all the prominent theories but one, and have found them wanting. Let us now bring it to bear upon the remaining one.

Dr. Croll's theory is that changes of climate are the indirect results of variations in the eccentricity of the earth's orbit, to the precession of the equinoxes, &c.

These astronomical phenomena we have already described (p. 139), but it may be as well to recall the fact that in consequence thereof the orbit is being continually elongated and being brought back almost to circularity again, and that summer and winter, in the course of a long series of years, occur in all parts of the orbit. At present the eccentricity is small, and the northern winter occurs in perihelion, or when the earth is nearest to the sun. The theory we are about to elucidate affirms that when the northern winter is in aphelion at a time when eccentricity is high, the northern hemisphere will be glaciated, and the southern hemisphere be enjoying an interglacial climate; but this result is brought about by secondary causes. We will proceed to show, first, that a glacial period would not result directly from these causes; and, secondly, how a glacial period is produced indirectly.

The first point can be settled in a few words. The total quantity of heat received from the sun during one revolution is inversely proportional to the minor axis of the orbit; and as the difference of the minor axis at the periods of maximum and minimum eccentricity is only as 997 to 1000, the quantity remains practically the same, and can have little or no influence upon climate.

It is quite otherwise when we consider the indirect effects of variations of eccentricity. Taking the mean distance of the sun as 91,400,000 miles, as we have done throughout the volume, we find that when the eccentricity is at its superior limit (0·07775) the aphelion distance is 98,506,350 miles, the perihelion distance 84,293,650 miles, and the difference, consequently, 14,212,700. The amount of heat received by the earth in these two positions is as 19 to 26.

Let winter in the northern hemisphere (and for the future, when winter alone is mentioned the northern winter will be understood) happen in aphelion, when the eccentricity is at its superior limit, as it must have done owing to precession. The earth will then be 8,641,870 miles farther from the sun in winter than at present, and the direct heat received will be one-fifth less, and during summer one-fifth more than now.

Next let winter occur in perihelion while the eccentricity is at its greatest. The earth will then be 14,212,700 miles nearer the sun in winter than in summer. The winter will then be comparatively warm, and in our latitude the difference of temperature between summer and winter will be almost annihilated.

Now as winter in one hemisphere corresponds with summer in the other, it follows that while one hemisphere would be enduring the extreme of summer heat and winter cold (as in our first illustration) the other would enjoy a perpetual summer.

From this we gather (1) that the effect of high eccentricity with winter in aphelion is to induce extremes of heat and cold in that hemisphere, and to minimise the difference of summer and winter temperature in the other; and (2) that while the one hemisphere is being glaciated the other is passing through an interglacial epoch—provided, as we are about to show, that a glacial period is so caused.

It must not be forgotten, however, that both hemispheres receive the same annual amount of heat; the effect of high eccentricity with the solstices at aphelion and perihelion, being merely to alter the distribution of that heat throughout the year.

Let us now see how a glacial period results from such a combination of astronomical causes. We will recall some of the fundamental laws of climate.

1. The *relative* temperature of a country depends upon the amount of heat received from the sun per annum. That is to say the climate grows colder as we pass from the equator to the poles (p. 289).

2. The air is chiefly warmed by conduction from the surface, and not by direct impact of the solar beams upon the air (p. 289).

3. The temperature of the tropics is lowered (*a*) by radiation, this heat passing away from the earth; (*b*) by the influx of cold currents of air and water; (*c*) by the efflux of warm currents (pp. 295-302).

4. The temperate and polar regions are warmed by the influx of warm ocean-currents, and by the winds which blow over them (p. 301).

5. The influence of the currents of air and water depends upon the *difference* of temperature between the poles and the equator in either hemisphere (p. 294).

6. The specific heats of water, snow, and ice are very high (p. 44).

7. The temperature of the air cannot be raised above 32° F. over extensive fields of ice and snow (p. 27). Therefore the temperature of a snow-clad

region must always be low, although the quantity of heat received may be large.

With these data firmly fixed in the mind, we are in a position to determine the influence of great eccentricity with winter in aphelion in modifying climate.

The first effect is to lower the temperature of that hemisphere and raise that of the opposite one. At present our winter is nearly eight days shorter than the summer, but at that time the winter would be thirty-six days longer than the summer. Winter would, therefore, be both colder and longer than now. Both these causes would give rise to an increased snow-fall; much of what now falls as rain would be precipitated as snow, and this would lower the temperature of that hemisphere.

The accumulation of snow lowers the summer temperature in three ways, namely, by direct radiation, by reflection of heat into space, and by giving rise to fogs.

Firstly, by direct radiation. No matter how fierce the sun's rays may be, their effect is entirely expended in melting the snow, and not in raising the temperature (p. 45). Hence the temperature of the air cannot rise above 32° F., and the snow tends by direct radiation to reduce surrounding bodies to the freezing point. That this is still the case in snow-clad regions, the testimony of arctic and Alpine travellers attests. In Greenland the direct sunshine will raise a thermometer to 100° F., while the temperature of the air is only 20° F. (p. 34). Were it not for the snow the summers of Greenland would be as warm as those of England.

Secondly, snow lowers the temperature by reflecting back again into space much of the heat which would otherwise go to warm the ground, and indirectly the air. Moreover that which is absorbed is used up in melting the snow instead of warming the air, as we have already pointed out. Now the latent heat of ice is 142° F., consequently the heat necessary to melt one pound of ice would raise 142 pounds of water 1°, and as the density of air is to that of water as 1 is to 770, and its specific heat as 1 is to 4·2, it follows that the heat used in melting a cubic foot of ice would raise the temperature of no less than 459,388 cubic feet of air by one degree.

Thirdly, the snow and ice lower the temperature by cooling the air, and condensing the moisture into fog. The sun's heat causes evaporation, the snow condenses it into fogs, and this, of course, would take place with greatest vigour in summer, when the solar power is greatest. These fogs would cut off much of the direct sunshine, and so prevent so much snow being melted as would otherwise be the case. Accordingly we find that voyagers in arctic regions invariably record such a state of things.

It is now established that the climate of the hemisphere whose winter occurred in aphelion will be colder than the opposite one, and that the conditions will be peculiarly favourable for the accumulation of snow and ice.

But this is not all. The difference of temperature between the pole of the glaciated hemisphere and the equator will be very much more than in the opposite hemisphere. Consequently the trade-winds of that hemisphere will be the stronger, and hence the equatorial current will be deflected towards the warmer side of the equator. If the northern hemisphere be the glaciated one the Gulf Stream will be turned into the Southern Atlantic and the north temperate regions robbed of the heat it distributes. How great a change this would bring about we have already shown (p. 299); indeed this deflection of the currents is the chief cause of the great change of climate during the glacial period.

It is very remarkable that the above physical causes react upon each other, so that their effect is cumulative. The snow and ice which gather cool the air; the cooled air encourages the precipitation of snow; the fogs cut off the sun's rays, and also encourage the formation of snow as well as diminish the rate of melting. The snow by reflecting much of the solar heat tends to cool the earth, and the cooler the earth grows the greater the fall of snow. The warm currents of the ocean are deflected, and so tend to cool the northern hemisphere, and the temperature being thus lowered, the winds grow stronger and still more vehemently deflect the currents. And so in this singular state of affairs each cause tends to cool the glaciated hemisphere, and the effects being cumulative are far greater than might have been suspected.

We have already pointed out that no general lowering of the temperature could produce a glacial period (p. 305). It would make the earth colder, but could never pile snow and ice upon the land, for these require an immense amount of heat for their formation (p. 305). It is hence just as necessary that some parts of the earth should be hot as that others should be cold in order to bring about a glacial period. This could not have been the case had both hemispheres been glaciated at once.

Croll's theory shows us that while one hemisphere was cooled the other was heated, for all the cooling processes were reversed. A strong wind from the north necessitates an equally strong upper-current to the north, and this coming from the warm regions would be laden with moisture, which would be deposited as snow. The theory thus provides us with the boiler and condenser in this great still, without which the machinery cannot work.

We are now in a position to apply our inter-glacial test. Let the author state his own case. "The primary cause that set all those various physical agencies in operation which brought about the glacial epoch was a high state of eccentricity of the earth's orbit. When the eccentricity is at a high value snow and ice begin to accumulate, owing to the increasing length and coldness of the winter on that hemisphere whose winter solstice is approaching towards the aphelion. The accumulating snow then begins to bring into operation all the various agencies which we have been describing; and, as we have just seen, these, when once in full operation, mutually aid one another. As the eccentricity increases century by century, the temperate regions become more and more covered with snow and ice, first by reason of the continued increase in the coldness and length of the winters, and secondly, and chiefly, owing to the continued increase in the potency of those physical agents which have been called into operation. This glacial state of things goes on at an increasing rate, and reaches a maximum when the solstice point arrives at the aphelion. After the solstice passes the aphelion, a contrary process commences. The snow and ice gradually begin to diminish on the cold hemisphere, and to make their appearance on the other hemisphere. The glaciated hemisphere turns, by degrees, warmer, and the warm hemisphere colder, and this continues to go on for a period of ten or twelve thousand years, until the winter solstice reaches the perihelion. By this time the conditions of the two hemispheres have been reversed, the formerly glaciated hemisphere has now become the warm one, and the warm hemisphere the glaciated. The transference of the ice from the one hemisphere to the other continues as long as the eccentricity remains at a high value."*

* "Climate and Time," p. 76. Daldy, Isbister & Co., 1875.

Here we have a complete explanation of the cause of interglacial periods. The eccentricity may, and indeed actually does, remain high for periods which may be numbered by hundreds of thousands of years, during which time the solstitial points will many times complete their revolution, and thus give rise to alternate glacial and interglacial periods in each hemisphere.

But the theory does more for us even than this. It gives us the date of the glacial period, which began about 200,000 years ago and terminated about 80,000 years since. During this long era glacial and interglacial periods, of greater or less intensity, alternated at intervals of from 10,000 to 15,000 years.

It is perhaps as well to remark that the presence of plant life in arctic regions such as we have noticed is as strong proof of an interglacial period as the scored rocks of Scotland are of a glacial period. Croll's theory accounts for all the facts hitherto brought to light; it deals solely with perfectly well-known causes, and moreover it has been the means of pointing the way to new discoveries.

The opinion, long held by some of us, is gaining ground, that our earth has suffered many glacial periods. When these are properly elucidated we shall be able to measure geological time in years.

In concluding this chapter it is hardly necessary to direct attention to the wonderful proofs of our original proposition, and we may now rest assured that the great changes of climate which geology has revealed are the results of the perturbations which our fellow-members in the solar system impose upon us, and upon the action of the sun's heat.

We have now proved:—

1. That great changes of climate have taken place.

2. That cold and warm periods alternated in comparatively rapid succession during the glacial period.

3. That they are due to the indirect results of a high eccentricity combined with the position of the solstitial points in aphelion and perihelion.

CHAPTER XIV.

LIFE.

The question as to whether life has been known to arise directly from inorganic matter is still the subject of searching inquiries; some maintaining the affirmative, others struggling to establish the negative, a far more difficult task. To follow this important discussion does not come within the scope of the present work. It seems difficult to escape the conviction that sooner or later the evolution of living from dead matter will be an acknowledged fact.

The whole tendency of modern philosophical inquiry is to establish the great theory of Evolution. The preceding pages have shown us many of the steps in this scheme: the concluding chapter will reveal others. It shows us how each phenomenon of nature is linked together in the inorganic world. In the organic world the labours of Mr. Darwin and his followers have established a no less close affinity between all the forms of life. Is there in this great scheme a sudden break? Is the distinction between living and lifeless matter so distinct as has been asserted? Certainly from a chemical point of view no such differences exist; for not merely are the constituents of living beings identical with those of the mineral world, but the latter supplies every particle of matter to the former.

When we study those lowly beings whom to call organisms is almost a misnomer, such as *Protogenes*, which are mere lumps of shapeless jelly, destitute of every trace of organization, without even a somewhat harder layer on the exterior to serve as a skin, it does indeed seem strange to endow them with attributes of so high an order as those who see a grand distinction between the living and lifeless worlds confer upon them. To my mind, I must confess, the contemplation of the process of crystallization is at least as wonderful. To watch the molecules gathering together, and building themselves up into definite geometrical forms, from out of a transparent solution, is a process that may well elevate one's views of nature. It is as if from a quarry the stones hewed themselves into well-shaped blocks, and then built themselves into a temple. In the face of all that modern science has achieved it becomes daily more difficult to believe in so great a break in the scheme of nature as is here contemplated.

Leaving this unsolved problem, and returning to the accomplished deeds of science, it has been abundantly proved that the vast assemblage of living forms which people the earth are the modified descendants of those bygone races some of whose relics are entombed in the rocks. A very few examples can alone be given here in support of this doctrine, which is treated at great length and with great power by Mr. Darwin and a brilliant host of naturalists.

One of the most striking facts of geology is the story of development told by the fossil remains. In the more recent rocks we have a wealth of species not widely differing from existing forms. As we go lower in the series of strata we find the forms of life growing more and more distinct from those of today. Gradually, too, the higher types are lost sight of, until, finally, in the oldest known rocks the very lowest organisms alone testify to the existence of life. Here, then, we have, in its broadest sense, evidence of the gradual production of higher forms.

Equally striking are the proofs that the present forms are the blood-relations of the fossil species. No one would deny, for example, that the living shells in our seas are allied in blood to the remains of identical species in the most recent rocks. But even when the species are not the same, but only allied, the proof is equally strong. To cite a few cases: Australia is peopled by a peculiar type of animals—the marsupials—of which the kangaroo is a sample, and in the caves of that country the mammals are without exception of the same type. South America, again, possesses peculiar forms, such as the armadillo, and there, accordingly, we find fossil armadilloes. In New Zealand, throughout the Old World, and even in islands like Madeira, the same law holds good; and there is no philosophical explanation thereof excepting the theory of descent with modification.

It is clear, from the above, that the broad features of the geographical distribution of life were determined before the present species had been produced.

The geographical distribution of life tells us much respecting the blood-relationship of different species, and also brings this question within the scope of our inquiry by showing the dependence of that distribution, and also of the production of new species, upon geological and climatal changes.

Mr. Darwin has admirably pointed out that three great facts are brought to light by a consideration of the present distribution of life.

Firstly, that *neither the similarity nor the dissimilarity of the inhabitants of various regions can be wholly accounted for by climatal and other physical conditions.* For example, both the climatal and physical features of the Old World can be paralleled in the New. We have similar climatic zones, similar plains, forests, and deserts, yet the fauna and flora are quite distinct.

Secondly, *barriers of any kind, or obstacles to free migration, are related in a close and important manner to the differences between the productions of various regions.* Deep seas, great deserts, and high mountain-ranges are the most formidable of barriers, and we accordingly find that the countries they separate have distinct species, and even great rivers sometimes serve to separate different floras and faunas.

Thirdly, *there is a marked affinity in the productions of the same continent or of the same sea, though the species themselves are distinct at different points and stations.* Every continent and sea produces numerous illustrations of this law. Even our own land, small as it is, affords proofs of this kind; for every botanist knows how in the north species exist which are distinct from, though allied to, forms whose abode is in the south.

These three laws are explicable solely on two grounds, namely, that the species of a district are united to those which have preceded them by the bond of inheritance, and that they have spread over their present habitats by migration. We shall now proceed to show how great a part climatic and geologic changes have played in the diffusion of species and in their modification.

It is, however, most important to bear in mind that the above agents do not directly give rise to changes of character, although it is highly probable that they exercise some slight influence. But they are of the first importance in bringing about alterations in the distribution of life and the characters of species indirectly, just as we have seen that changes in the earth's position relative to the sun determine indirectly the changes of climate discussed in our last chapter. The direct agent in modifying species is the struggle for existence which takes place everywhere in nature. Any circumstance which alters the conditions of this struggle tends to induce a corresponding change in the species affected. Changes of climate induce migration; by migration species are brought into collision with fresh foes, and mutual modification is the result. With these few preliminary remarks we will enter upon the question of the influence of changes of climate upon the distribution of life in time and space.

We have already remarked that the fossils of North America are more closely allied to living North American species than to those of Europe; and that in like manner the fossils of Europe have a decidedly European *facies*. It is, however, a very suggestive fact that this difference is less marked in the fossils of Tertiary age than in the living forms. So marked, indeed, is the connection between the Miocene flora of Europe and the recent flora of the southern United States that certain geologists have suggested that in Tertiary times a continent occupied what is now the bed of the Atlantic, across which the American plants travelled. This theory, in the present state of knowledge, cannot for a moment be admitted, for it is certain that our oceans have been oceanic areas ever since the Silurian rocks were deposited. Nevertheless the botanist is entitled to ask of the geologist an explanation of such peculiarities.

Another instructive phenomenon is exhibited in the distribution of certain living plants which from their general occurrence upon mountains are known as Alpine plants. This Alpine flora is distinguished from all others by its identity all over the world. On the mountains of Wales and Scotland, on the Alps and Pyrenees, on the Altai and Himalayas, on the mountains of Abyssinia and Japan we find a similar flora. If we cross to America upon the Rocky Mountains and the Alleghanies, and even upon the Andes, we again come upon it. Even the isolated peaks of the tropics, such as the Cameroons of West Africa, yield these curious plants, and they have found their way to solitary Kerguelen and antipodal Australasia.

How can this remarkable uniformity of Alpine plants be explained? It is no answer to reply, as was once done, that they were created at these different points to occupy a certain climatal zone; for the temperate and tropic regions beneath are just as similar in different regions, yet their floras are utterly distinct.

The explanation must account (1) for the isolation of groups of animals and plants by barriers such as mountain-ranges and deep seas; (2) for the existence of distinct forms in places similarly situated as respects climate and soil; (3) for the connection subsisting between the fossil and living species of any area; and (4) for the similarity of the Alpine flora over the globe. This explanation is afforded by the effects of such changes of climate as we discussed in the last chapter.

The readiest way of applying this explanation is to suppose a gradual change from a warm interglacial period to a cold glacial period, and back again to such an epoch as the present. We must, in carrying out this investigation, remember that glacial and interglacial epochs alternated at intervals of from 10,000 to 15,000 years during a period of high eccentricity, and that before and after the culmination of the cold considerable submergence took place, owing to the elevation of the sea-level; and, on the other hand, during the interglacial periods by a lowering of the sea-level the extension of the land was largely increased. These oscillations were probably as much as 600 feet on either side of the present sea-level.

Let us commence with the warm middle tertiary period, called the Miocene, which has left such bountiful records of its presence in the plant-bearing strata of Europe, America, and the arctic regions; and let us pre-suppose that it marks a mild interglacial period.

From what has already been said about climate we may feel sure that during an interglacial period the climate of temperate regions would be more equable, and on the whole somewhat warmer, than now. This would result (1) from the proximity of the sun in winter preventing the formation of snow; (2) from the great amount of heat brought by the warm currents; (3) from the northerly winds being warmer than now in consequence of the small amount of ice in the arctic regions.

Very different would be the effects upon the polar lands, for there all the causes which re-act upon each other to produce the rigour of the climate would be removed. Greenland would have its temperature raised, firstly, by the removal of the ice, which would permit the solar rays to exert their full influence; secondly, by the length of the summer; and, thirdly, by the influx of warm water from the south. If the theory here advocated be true we ought to find a much more marked difference between the present and the Miocene temperatures in the polar latitudes than in our own.

Prof. O. Heer, of Zurich, is our great authority upon the flora of Tertiary times, and his testimony upon the point under consideration is the more valuable because he is a hostile witness both as regards Darwin's and Croll's views. He concludes from an exhaustive examination of Miocene plant-remains that the climate in the tropics "was then the same as in our times," for the Miocene plants of southern Java are closely allied to the living indigenous flora. The climate of Switzerland he estimates was, in Lower Miocene times, "probably 16° ·22 F. hotter than at present; and in the Upper Miocene period the climate had an elevation of temperature of 12° ·66 F. above" that of the present day. From an examination of numerous species from

Spitzbergen and North Greenland (lat. 70°) he concludes that the excess of temperature amounted to no less than from 28° ·33 to 30° ·66 F., and he pertinently remarks that, "The difference of temperature between the Miocene and the existing floras is therefore much more considerable in the arctic than in the temperate zone; and the change has been greatest in the extreme north." * An examination of the plants brought home by Captain Feilden, of the English Arctic Expedition, from Grinnell Land, in lat. 81° 45′, gives additional testimony to the correctness of the Professor's views, which are indeed very carefully deduced.

Turning now to the character of the flora, we find in the Lower Miocene of Europe a preponderance of American forms, and in the Upper Miocene a large number of American species, although the European plants are here more common. Of these American forms the fan palms (*Sabal*), the cypress (*Taxodium*), the planes (*Platanus*), and the huge pines (*Sequoia*) allied to the "big trees" of California may be cited. The palms are not found farther north in Europe than lat. 50°, but the other American forms range into the arctic regions, even as far as Grinnell Land, in lat. 82°.

It is not difficult to understand this fusion of the American and European forms; for, at the interglacial period in question, the almost continuous

* "Primeval World of Switzerland," vol. ii. p. 145. 1877. English Translation by J. Heywood.

land about the pole would be tenanted by a mixed flora of temperate and sub-tropic species which had migrated with the increasing warmth from the more southern latitudes of both hemispheres. We must also bear in mind that at such times the islands would be more or less united.

While this was going on the purely arctic species would be driven from the low to the high grounds of the polar regions. Their habitat would be restricted, they would have to struggle with fresh competitors, some would inevitably succumb, and others would be more or less modified.

Now let us imagine the climate to grow gradually colder. The sub-tropic and temperate forms would retreat to more congenial climes to the southward in America and Eurasia. The colder the climate became the farther they would have to travel, and from the configuration of the land, the more widely separated the floras would become. They would meet with different competitors in each continent, and so, in course of ages, and as the result of many such climatic oscillations, the differences of the European and American floras would be brought about. In this way we can understand why the living floras of Europe and America are so distinct, why they nevertheless show certain resemblances, and why in the far-off Tertiary era the distinctions were less marked.

As the cold came on the arctic and cold-temperate species would creep from the polar highlands to the plains, and as the gathering ice pressed southwards they would retreat before it until at the culmination of the ice age they would people the lowlands of the temperate zones and the moderately high lands of the tropics.

The ice then began to pass away. The sub-tropic and temperate species would gradually be driven towards the cold. This they would find not merely to the north but upon the mountains, up which they would creep.

Finally, when such a state of affairs as the present was attained, we should find the mountain regions of the whole world peopled with plants similar to those which occupy the plains of the still icy north; and this flora would present a remarkable uniformity of type. The Alpine flora so formed would appear even on isolated ranges like the Pyrenees and Alps, though they could not now cross the intermediate plains.

The great epoch of the glacial period terminated about 80,000 years ago, after enduring about 160,000 years. During this long epoch there were twelve or thirteen glacial and interglacial periods of more or less pronounced nature, some only of which have as yet been detected. A dozen times, therefore, both fauna and flora had to migrate, and at each migration the arctic and tropic forms suffered most, from their habitats being restricted at the times of greatest cold and heat.

It seems to me that during such an epoch the modification of species must have been more rapid than now when the climate is comparatively steady. But it must not be inferred that during the glacial epoch all the alternations of climate were sufficiently pronounced to cover England with ice, for instance. It was only when the eccentricity was very high that very severe glacial periods were formed; and during the 160,000 years in question there were two long spells of comparatively low eccentricity. Nevertheless the climatic changes were throughout more intense than would occur under present conditions, and this would be sufficient to insure considerable mutation of species.

If winter in the northern hemisphere occurred in aphelion instead of in perihelion, with the present amount of eccentricity, the climatic change would be comparatively slight. But it is a suggestive fact that the present low eccentricity is exceptional. For 800,000 years it has been invariably higher, and for a million years it has only four times been as low, and if we take the last three million years the eccentricity has been as low only 10 times, and the whole of these periods do not exceed 160,000 years.

During all this period of high eccentricity migration must have been greater than at present, the species were oftener brought into fresh conditions both physically and as regards the struggle for life with other species; and hence I believe that changes of form are abnormally slow just now, a conclusion that is of great interest.

In conclusion it is only necessary to point out how dependent the forms of life and their distribution are upon climatic change, how climatic change depends upon the influence of the heavenly bodies, how this influence brings us into new relations with the solar heat, and hence how once more we find how important a control is exercised upon life by the action of external heat. This simple result precludes the necessity of epitomizing our knowledge, inasmuch as from the apparent complexity of physical motion we have arrived at the simplicity of life.

CHAPTER XV.

THE PAST AND THE FUTURE.—THE NEBULAR HYPOTHESIS, ETC.

In treating of the internal heat of the earth we were led by several lines of thought to the conception of a time when the earth was in a molten condition. The method pursued was an inductive one: the evidence was cumulative. Applying a similar train of reasoning, let us see what the probabilities are that it was at one time in the state of gas. From the earth to the planets is a very simple step, and in some of them we have already recognised signs of a temperature so hot as to cause them to glow. These planets act the part of suns to their satellites, and from them to the sun himself is another easy gradation. The sun we know to be not merely glowing, but to consist in great part of incandescent vapours, even such refractory elements as iron being vaporised.

The sun is a star, and there can be no doubt that if it could be observed from some other system it would appear as such. It yields a spectrum like that of certain bright stars, and not like the dusky ones. These latter appear to be cooler than the brighter stars, and thus form a connecting link between the shining planets and the sun.

From the sun we pass to brilliant stars, like Sirius, which are still hotter, and there we must stop for the present. A regular gradation can thus be formed, which, starting from a colder body than the earth, we may thus range, choosing suitable examples:

Moon. Earth. Saturn. A Herculis. Sun. Sirius.

Such a table gives us a series of orbs of different temperatures, commencing with the moon with little or no heat of its own, and ending with Sirius, a star so hot as to be almost entirely gaseous. If we wish to advance a step farther in this series we must appeal to those irresolvable nebulæ, which have been shown to consist entirely of gas.* The intimate connection which subsists between certain stars and nebulæ has already been pointed out, hence the leap is not so wide a one as at first sight appears.

Nebulæ are seen to be condensing into stars; stars of different kinds show successive degrees of condensation; the passage from the sun to the planets is a very gradual one. These appear like steps in a

* Attempts have been made, not very successfully, in my opinion, to show that the nebulæ are comparatively cool bodies. I shall, however, continue throughout this chapter to treat them as excessively hot, a supposition which will not affect the present argument, even if it be proved to be an incorrect one.

process. Therefore it is no far-fetched idea to suppose that the earth was once in a gaseous condition: it is merely putting farther back the time when it began that process of cooling and contracting which is still going on.

We may go a step farther and inquire into the probabilities of the entire solar system having once been in the condition of a nebula stretching far beyond its present limits.

Imagine such a nebula rotating and contracting. As the contraction progressed the rotation would increase, and at length the speed would become so great that the peripheral matter would separate from the rest in consequence of the velocity; and so a ring of nebular matter would be formed. This process would be several times repeated.

The rotating ring would almost certainly break up, and the different parts thus attain a rotation of their own, the direction of which, like that of the ring and of the parent nebula, would be in one direction.

In the majority of cases the fragments would unite into a single mass, the embryo planets of the system; and these would in most instances, by similar methods, throw off minor rings which would become satellites.

Occasionally the broken rings would fail to coalesce, in which case a zone of small planets would be formed.

Such is the skeleton of the Nebular Hypothesis propounded by Laplace. It is essentially an hypothesis of development or evolution, and it is based upon sound mechanical and mathematical research. It explains the general agreement in the planes of the planetary orbits, the identity of the direction of periodical and axial rotation, the formation of the zone of asteroids and of Saturn's rings, and it explains the heat of the sun and of the planets.

The hypothesis was propounded at a time which may be looked upon as the dawn of modern physical knowledge; and although our space does not permit us to follow the steps, every advance of science has rendered it more and more probable, until it may be said that the nebular hypothesis, in some form or another, affords the true explanation of the mechanism of the solar system.

As Laplace expounded it, the hypothesis fails to account for much that has since been discovered. The retrograde motion of the Uranian satellites, the enormous inclination of the orbits of certain meteor streams, and some of the results of spectroscopic analysis, necessitate a modification of the hypothesis; but the broad fact remains that the members of our system are linked by absolute bonds of unity; and again to recur to our grand principle, the internal heat of the earth and that of the sun have had a common origin.

Very reluctantly we are compelled to pass by the indications that a combination of the nebular hypothesis with the effects of myriads of meteor systems, seems to be gathering shape, and to suggest that science is nearly ripe for developing a theory of the origin of our system which shall not merely account for known facts, but suggest new lines of investigation, certain to be fruitful in great discoveries.

The result of all our investigations has been to show how all the features of nature are dependent upon differences of temperature in various parts; and that the most powerful cause of natural phenomena is high-temperature heat, such as that of the sun and of the earth's interior.

We may indeed look upon our system "not as a collection of matter, but rather as an energetic agent—in fact, as a lamp."* If this lamp were not alight we might conceive that it had so existed for ever and might so continue without end. But this lamp is burning, and hence must have had a beginning, as it will assuredly have an end.

What that beginning was we are coming to see as through a glass darkly; what the end will be is more clearly ascertainable. When the beginning was, or when the end will be, are questions to which we cannot as yet assign time-limits.

But although it is as yet impossible to ascertain when our system, as such, had its origin, we can form some definite idea as to the length of time during which our earth has been habitable.

* "The Conservation of Energy." By Prof. Balfour Stewart. London. 1874. P. 153.

It is an important fact that high-temperature heat is constantly being dissipated. The energy of fuel cannot be entirely restored as high-temperature heat, for friction and other causes always necessitate a loss. So, too, with the energy of the sun and of the earth: it is being gradually dissipated, and we can look forward to the time when all the parts of the system will be reduced to one dead level of temperature, and when all natural phenomena will cease.

We know the rate at which the sun is parting with his heat: that to maintain his present rate of radiation by combustion, a supply equal to 1,500 tons of coal per hour on every square foot would be necessary. This cannot have gone on for ever, any more than a lighted lamp can have been burning for aye. Neither can the heat of the sun be due to combustion, for if his sphere were of coal it would supply but 5,000 years of heat. Nor does the suggestion of Mr. Lockyer that the elements are in a state of dissociation, and by their chemical reactions produce heat, relieve us from our difficulty; for this source will supply us with but a few thousand years of additional heat.

Physicists have, therefore, turned their attention to gravitation, and Dr. Mayer, the eminent doctor of Heilbronn, whose decease we are just lamenting, first suggested that the storms of meteors which batter the sun may supply him with his source of heat. This idea has been developed by several eminent philosophers, but has been abandoned as being quite inadequate, though it is doubtless a *vera causa*. A pound of matter falling into the sun from infinite distance would generate 6,000 times the amount of heat that would arise from its combustion.

Another form of the gravitation theory has been propounded by Helmholtz, and has received the sanction of some of our most distinguished men of science. This author looks to the condensation of the sun from a nebular mass to its present state as affording a solution of the problem of the age of the sun. The heat generated by this process would supply the solar radiation for about twenty million years. If this be the sole origin of the sun's heat geological time must be comprised within this limit. Nay, more; this period must be reduced to a large extent, for only that heat which has been so produced since the earth was formed is available; and we should be far within the truth if we halved the time above indicated.

Such a period would appear to most geologists far too short, and Dr. Croll, in a remarkable paper recently published, has come to the rescue of his brethren of the hammer.*

He justly objects that physicists assume this theory to be the only one they can suggest, and expect that geologists will accept the results as if no

* "On the Probable Origin and Age of the Sun." By J. Croll, LL.D., F.R.S. Quart. Journ. Science. July, 1877.

other cause were possible. But, he goes on to say, the fundamental truths of geology are demonstrated facts, and if they show that the earth *is* more than twenty million years old it is clear the gravitation theory is at fault.

The geological proofs of the earth's antiquity upon which Dr. Croll chiefly relies are the evidences of vast denudation in different geological epochs. We have already shown that denudation is in progress, and that its rate depends upon the carrying power of rivers. Applying this principle, that author shows that since the Old Red Sandstone period three miles of rock have been removed; and this would require for its removal forty-five million years, supposing denudation to have taken place twice as fast as in the Mississippi basin at the present time. But the rocks below the Old Red Sandstone are far thicker than those above it, and during all that prior time denudation was in progress. Hence we may feel certain that the habitable globe is much more than twenty million years old.

This disposes of the gravitation theory as the sole cause of solar heat. Dr. Croll then proceeds: "Are we really under any necessity of assuming that the sun's heat was wholly, or even mainly, derived from the condensation of his mass by gravity? According to Helmholtz's theory of the origin of the sun's heat by condensation, it is assumed that the matter composing the sun, when it existed in space as a nebular mass, was not originally possessed of temperature, but that the temperature was given to it as the mass became condensed under the force of gravitation. It is supposed that the heat given out was simply the heat of condensation. But it is quite conceivable that the nebulous mass might have been possessed of an original store of heat previous to condensation.

"It is quite possible that the very reason why it existed in such a rarefied or gaseous condition was its excessive temperature, and that condensation only began to take place when the mass began to cool down. It seems far more probable that this should have been the case than that the mass existed in so rarefied a condition without temperature. For why should the particles have existed in this separate form when devoid of the repulsive energy of heat, seeing that, in virtue of gravitation, they had such a tendency to approach one another?"

In reply to the question as to how the nebula could obtain its heat, Croll suggests the following answer. The energy in the form of heat may have been derived from motion in space. In other words, it may have resulted from the collision of two swiftly-moving bodies, each, say, one half the mass of the sun. With a velocity of 476 miles per second, such a collision would instantaneously generate heat which would cover the present rate of solar radiation for 50 million years. The reader must be referred to the original for the discussion of this question in its entirety. Sufficient, however, has been said to show that the question of the origin of the system is within the limits of scientific research.

It has already been pointed out that in some form or another the nebular hypothesis is almost universally accepted as true. One difficulty I do not remember to have seen discussed. Suppose the solar system once more to be dissipated into vapour, and an observer in space to examine its light spectroscopically. We should expect to find the spectra of all the known elements. No known nebula exhibits any such appearance, and hence it might be inferred that none of them could condense into a system like ours. This conclusion is not, however, a necessary one, for we know so little of the deportment of matter at exceedingly high temperatures that it would be rash to suggest that the nebulæ consist only of hydrogen, nitrogen, and the unknown "nebula stuff" which their spectra reveal. Some of Mr. Lockyer's magnificent researches appear to help us out of the difficulty, for he considers that many of the substances which we call elements, from our inability to decompose them, are in reality compounds, which higher temperatures than we can command might break up.

Another explanation I would venture with much diffidence. It may be that at excessively high temperatures most of the vibrations are too rapid to emit light, and hence, even if our elements are truly such, they might fail to yield a spectrum under nebular conditions.

All our knowledge tends to strengthen belief in the nebular hypothesis, under some form or another. But it may be asked, if this be true of our system, are we to stop there? The stars are suns and move in systems. Our sun is a member of one of these. Was that grander scheme evolved from a yet grander nebula? Who can tell? If so, how infinitely more simple would appear the Unity of Creation!

INDEX.

THE END.

PRINTED BY VIRTUE AND CO., LIMITED, CITY ROAD, LONDON.