

ART. XLVII.—*Address of Sir John Lubbock, President of the British Association at York.*

[Continued from page 289.]

\* \* IN Astronomy, the discovery in 1845 of the planet Neptune, made independently and almost simultaneously by Adams and by Le Verrier, was certainly one of the greatest triumphs of mathematical genius. Of the minor planets four only were known in 1831, whilst the number now on the roll amounts to 220. Many astronomers believe in the existence of an intra-mercurial planet or planets, but this is still an open question. The Solar System has also been enriched by the discovery of an inner ring to Saturn, of satellites to Mars, and of additional satellites to Saturn, Uranus and Neptune.

The most unexpected progress, however, in our astronomical knowledge during the past half-century has been due to spectrum analysis.

The dark lines in the spectrum were first seen by Wollaston, who noticed a few of them; but they were independently discovered by Fraunhofer, after whom they are justly named, and who, in 1814, mapped no fewer than 576. The first steps in "spectrum analysis," properly so called, were made by Sir J. Herschel, Fox Talbot, and by Wheatstone, in a paper read before this Association in 1835. The latter showed that the spectrum emitted by the incandescent vapor of metals was formed of bright lines, and that these lines, while, as he then supposed, constant for each metal, differed for different metals. "We have here," he said, "a mode of discriminating metallic bodies more readily than that of chemical examination, and which may hereafter be employed for useful purposes." Nay, not only can bodies thus be more readily discriminated, but, as we now know, the presence of extremely minute portions can be detected, the  $\frac{1}{8000000}$ th part of a grain being in some cases easily perceptible.

It is also easy to see that the presence of any new simple substance might be detected, and in this manner already several new elements have been discovered.

But spectrum analysis has led to even grander and more unexpected triumphs. Fraunhofer himself noticed the coincidence between the double dark line D of the solar spectrum and a double line which he observed in the spectra of ordinary flames, while Stokes pointed out to Sir W. Thompson, who taught it in his lectures, that in both cases these lines were due to the presence of sodium. To Kirchhoff and Bunsen, however, is due the independent conception and the credit of having first systematically investigated the relation which exists between Fraunhofer's lines and the bright lines in the spectra of incan-

descent metals. In order to get some fixed measure by which they might determine and record the lines characterizing any given substance, it occurred to them that they might use for comparison the spectrum of the sun. They accordingly arranged their spectroscope so that one-half of the slit was lighted by the sun, and the other by the luminous gases they proposed to examine. It immediately struck them that the bright lines in the one corresponded with the dark lines in the other—the bright line of sodium, for instance, with the line or rather lines D in the sun's spectrum. The conclusion was obvious. There was sodium in the sun! It must indeed have been a glorious moment when that thought flashed across them, and even by itself well worth all their labor.

But why is the bright line of a sodium flame represented by a black one in the spectrum of the sun? To Ångström is due the theory that a vapor of gas can absorb luminous rays of the same refrangibility only which it emits when highly heated; while Balfour Stewart independently discovered the same law with reference to radiant heat.

This is the basis of Kirchhoff's theory of the origin of Fraunhofer's lines. In the atmosphere of the sun the vapors of various metals are present, each of which would give its characteristic lines, but within this atmospheric envelope is the still more intensely heated nucleus of the sun, which emits a brilliant continuous spectrum, containing rays of all degrees of refrangibility. When the light of this intensely heated nucleus is transmitted through the surrounding atmosphere, the bright lines which would be produced by this atmosphere are seen as dark ones.

Kirchhoff and Bunsen thus proved the existence in the sun of hydrogen, sodium, magnesium, calcium, iron, nickel, chromium, manganese, titanium and cobalt; since which Ångström, Thalen and Lockyer have considerably increased the list.

But it is not merely the chemistry of the heavenly bodies on which light is thrown by the spectroscope; their physical structure and evolutionary history are also illuminated by this wonderful instrument of research.

It used to be supposed that the sun was a dark body enveloped in a luminous atmosphere. The reverse now appears to be the truth. The body of the sun, or photosphere, is intensely brilliant; round it lies the solar atmosphere of comparatively cool gases, which cause the dark lines in the spectrum; thirdly, a chromosphere,—a sphere principally of hydrogen, jets of which are said sometimes to reach to a height of 100,000 miles or more, into the outer coating or corona, the nature of which is still very doubtful.

Formerly the red flames which represent the higher regions

of the chromosphere could be seen only on the rare occasions of a total solar eclipse. Janssen and Lockyer, by the application of the spectroscope, have enabled us to study this region of the sun at all times.

It is, moreover, obvious that the powerful engine of investigation afforded us by the spectroscope is by no means confined to the substances which form part of our system. The incandescent body can thus be examined, no matter how great its distance, so long only as the light is strong enough. That this method was theoretically applied to the light of the stars was indeed obvious, but the practical difficulties were very great. Sirius, the brightest of all, is, in round numbers, a hundred millions of millions of miles from us; and, though as big as sixty of our suns, his light when it reaches us after a journey of sixteen years, is at most one two-thousand-millionth part as bright. Nevertheless as long ago as 1815 Fraunhofer recognized the fixed lines in the light of four of the stars, and in 1863 Miller and Huggins in our own country, and Rutherford in America, succeeded in determining the dark lines in the spectrum of some of the brighter stars, thus showing that these beautiful and mysterious lights contain many of the material substances with which we are familiar. In Aldebaran, for instance, we may infer the presence of hydrogen, sodium, magnesium, iron, calcium, tellurium, antimony, bismuth, and mercury; some of which are not yet known to occur in the sun. As might have been expected the composition of the stars is not uniform, and it would appear that they may be arranged in a few well marked classes, indicating differences of temperature, or in other words of age. Some recent photographic spectra of stars obtained by Huggins go very far to justify this view.

Thus we can make the stars teach us their own composition with light which started from its source before we were born—light older than our Association itself.

Until 1864, the true nature of the unresolved nebulae was a matter of doubt. In that year, however, Huggins turned his spectroscope on to a nebula, and made the unexpected discovery that the spectra of some of these bodies are discontinuous—that is to say, consist of bright lines only, indicating that “in place of an incandescent solid or liquid body we must probably regard these objects, or at least their photo-surfaces, as enormous masses of luminous gas or vapor. For it is from matter in a gaseous state only that such light as that of the nebulae is known to be emitted.” So far as observation has yet gone, nebulae may be divided into two classes: some giving a continuous spectrum, others one consisting of bright lines. These latter all appear to give essentially the same spectrum, consisting of a few bright lines. Two of them, in Mr. Huggins’s

opinion, indicate the presence of hydrogen: one of them agrees in position with a line characteristic of nitrogen.

But spectrum analysis has even more than this to tell us. The old methods of observation could determine the movements of the stars so far only as they were transverse to us; they afforded no means of measuring motion either directly towards or away from us. Now Döppler suggested in 1841 that the colors of the stars would assist us in this respect, because they would be affected by their motion to and from the earth, just as a steam-whistle is raised or lowered as it approaches or recedes from us. Everyone has observed that if a train whistles as it passes us, the sound appears to alter at the moment the engine goes by. This arises, of course, not from any change in the whistle itself, but because the number of vibrations which reach the ear in a given time are increased by the speed of the train as it approaches, and diminished as it recedes. So, like the sound, the color would be affected by such a movement; but Döppler's method was practically inapplicable, because the amount of effect on the color would be utterly insensible; and even if it were otherwise the method could not be applied, because, as we did not know the true color of the stars, we have no datum line by which to measure.

A change of refrangibility of light, however, does occur in consequence of relative motion, and Huggins successfully applied the spectroscope to solve the problem. He took in the first place the spectrum of Sirius, and chose a line known as F, which is due to hydrogen. Now, if Sirius was motionless, or rather if it retained a constant distance from the earth, the line F would occupy exactly the same position in the spectrum of Sirius, as in that of the sun. On the contrary if Sirius were approaching or receding from us, this line would be slightly shifted either toward the blue or red end of the spectrum. He found that the line had moved very slightly toward the red, indicating that the distance between us and Sirius is increasing at the rate of about twenty miles a second. So also Betelgeux, Rigel, Castor and Regulus are increasing their distance; while, on the contrary, that of others, as for instance of Vega, Arcturus and Pollux, is diminishing. The results obtained by Huggins on about twenty stars have since been confirmed and extended by Mr. Christie, now Astronomer Royal, in succession to Sir G. Airy, who has long occupied the post with so much honor to himself and advantage to science.

To examine the spectrum of a shooting star would seem even more difficult; yet Alexander Herschel has succeeded in doing so, and finds that their nuclei are incandescent solid bodies: he has recognized the lines of potassium, sodium, lithium and other substances, and considers that the shooting stars are

bodies similar in character and composition to the stony masses which sometimes reach the earth as *aërolites*.

Some light has also been thrown upon those mysterious visitants, the comets. The researches of Prof. Newton on the periods of meteoroids led to the remarkable discovery by Schiaparelli of the identity of the orbits of some meteor-swarms with those of some comets. The similarity of orbits is too striking to be the result of chance, and shows a true cosmical relation between the bodies. Comets, in fact, are in some cases at any rate groups of meteoric stones. From the spectra of the small comets of 1866 and 1868, Huggins showed that part of their light is emitted by themselves, and reveals the presence of carbon in some form. A photographic spectrum of the comet recently visible, obtained by the same observer, is considered by him to prove that nitrogen, probably in combination with carbon, is also present.

No element has yet been found in any meteorite, which was not previously known as existing in the earth, but the phenomena which they exhibit indicate that they must have been formed under conditions very different from those which prevail on the earth's surface. I may mention, for instance, the peculiar form of crystallized silica, called by Maskelyne, *Asmanite*; and the whole class of meteorites, consisting of iron generally alloyed with nickel, which Daubrée terms *holosiderites*. The interesting discovery, however, by Nordenskiöld, in 1870, at *Ovifak*, of a number of blocks of iron alloyed with nickel and cobalt, in connection with basalts containing disseminated iron, has, in the words of Judd, "afforded a very important link, placing the terrestrial and extra-terrestrial rocks in closer relations with one another."

We have as yet no sufficient evidence to justify a conclusion as to whether any substances exist in the heavenly bodies which do not occur in our earth, though there are many lines which cannot yet be satisfactorily referred to any terrestrial element. On the other hand, some substances which occur on our earth have not yet been detected in the sun's atmosphere.

Such discoveries as these seemed, not long ago, entirely beyond our hopes. M. Comte, indeed, in his "*Cours de Philosophie Positive*," as recently as 1842, laid it down as an axiom regarding the heavenly bodies, that "*Nous concevons la possibilité de déterminer leurs formes, leurs distances, leurs grandeurs et leurs mouvements, tandis que nous ne saurions jamais étudier par aucun moyen leur composition chimique ou leur structure minéralogique.*" Yet within a few years what he supposed to be impossible has been actually accomplished, showing how unsafe it is to limit the possibilities of science.

It is hardly necessary to point out that, while the spectrum

has taught us so much, we have still even more to learn. Why should some substances give few, and others many, lines? Why should the same substance give different lines at different temperatures? What are the relations between the lines and the physical or chemical properties.

We may certainly look for much new knowledge of the hidden actions of atoms and molecules from future researches with the spectroscope. It may even, perhaps, teach us to modify our views of the so-called simple substances. Prout long ago, struck by the remarkable fact that nearly all atomic weights are simple multiples of the atomic weight of hydrogen, suggested that hydrogen must be the primordial substance. Brodie's researches also naturally fell in with the supposition that the so-called simple substances are in reality complex, and that their constituents occur separately in the hottest regions of the solar atmosphere. Lockyer considers that his researches lend great probability to this view. The whole subject is one of intense interest, and we may rejoice that it is occupying the attention, not only of such men as Abney, Dewar, Hartley, Liveing, Roscoe and Shuster in our own country, but also of many foreign observers.

When geology so greatly extended our ideas of past time, the continued heat of the sun became a question of greater interest than ever. Helmholtz has shown that, while adopting the nebular hypothesis, we need not assume that the nebulous matter was originally incandescent; but that its present high temperature may be, and probably is, mainly due to gravitation between its parts. It follows that the potential energy of the sun is far from exhausted, and that with continued shrinking it will continue to give out light and heat, with little, if any, diminution for several millions of years.

Like the sands of the sea, the stars of heaven have ever been used as effective symbols of number, and the improvements in our methods of observation have added fresh force to our original impressions. We now know that our earth is but a fraction of one out of at least 75,000,000 worlds.

But this is not all. In addition to the luminous heavenly bodies, we cannot doubt that there are countless others, invisible to us from their greater distance, smaller size, or feebler light; indeed we know that there are many dark bodies which now emit no light or comparatively little. Thus in the case of Procyon, the existence of an invisible body is proved by the movement of the visible star. Again I may refer to the curious phenomena presented by Algol, a bright star in the head of Medusa. This star shines without change for two days and thirteen hours; then, in three hours and a half, dwindles from a star of the second to one of the fourth magnitude; and

then, in another three and a half hours, reassumes its original brilliancy. These changes seem certainly to indicate the presence of an opaque body, which intercepts at regular intervals a part of the light emitted by Algol.

Thus the floor of heaven is not only "thick inlaid with patines of bright gold," but studded also with extinct stars; once probably as brilliant as our own sun, but now dead and cold, as Helmholtz tells us that our sun itself will be, some seventeen millions of years hence.

The connection of Astronomy with the history of our planet has been a subject of speculation and research during a great part of the half century of our existence. Sir Charles Lyell devoted some of the opening chapters of his great work to the subject. Haughton has brought his very original powers to bear on the subject of secular changes in climate, and Croll's contributions to the same subject are of great interest. Last, but not least, I must not omit to make mention of the series of massive memoirs (I am happy to say not yet nearly terminated) by George Darwin on tidal friction, and the influence of tidal action on the evolution of the solar system.

I may perhaps just mention, as regards telescopes, that the largest reflector in 1830 was Sir W. Herschel's of 4 ft., the largest at present being Lord Rosse's of 6 ft.; as regards refractors the largest then had a diameter of  $11\frac{1}{4}$  in., while your fellow townsman Cooke carried the size to 25 in., and Mr. Grubb, of Dublin, has just successfully completed one of 27 in. for the Observatory of Vienna. It is remarkable that the two largest telescopes in the world should both be Irish.

The general result of astronomical researches has been thus eloquently summed up by Proctor:—"The sidereal system is altogether more complicated and more varied in structure than has hitherto been supposed; in the same region of the stellar depths coëxist stars of many orders of real magnitude; all orders of nebulæ, gaseous or stellar planetary, ring-formed, elliptical, and spiral, exist within the limits of the galaxy; and lastly, the whole system is alive with movements, the laws of which may one day be recognized, though at present they appear too complex to be understood."

We can, I think, scarcely claim the establishment of the undulatory theory of light as falling within the last fifty years; for though Brewster, in his "Report on Optics," published in our first volume, treats the question as open, and expresses himself still unconvinced, he was, I believe, almost alone in his preference for the emission theory. The phenomena of interference, in fact, left hardly any—if any—room for doubt, and the subject was finally set at rest by Foucault's celebrated

experiments in 1850. According to the undulatory theory the velocity of light ought to be greater in air than in water, while if the emission theory were correct the reverse would be the case. The velocity of light—186,000 miles in a second—is, however, so great that, to determine its rate in air, as compared with that in water, might seem almost hopeless. The velocity in air was, nevertheless, determined by Fizeau in 1849, by means of a rapidly revolving wheel. In the following year Foucault, by means of a revolving mirror, demonstrated that the velocity of light is greater in air than in water—thus completing the evidence in favor of the undulatory theory of light.

The idea is now gaining ground, that, as maintained by Clerk-Maxwell, light itself is an electro-magnetic disturbance, the luminiferous ether being the vehicle of both light and electricity.

Wünsch, as long ago as 1792, had clearly shown that the three primary colors were red, green, and violet; but his results attracted little notice, and the general view used to be that there were seven principal colors—red, orange, yellow, green, blue, indigo and violet; four of which—namely orange, green, indigo and violet—were considered to rise from mixtures of the other three. Red, yellow and blue were therefore called the primary colors, and it was supposed that in order to produce white light these three colors must always be present.

Helmholtz, however, again showed, in 1852, that a color to our unaided eyes identical with white, was produced by combining yellow with indigo. At that time yellow was considered to be a simple color, and this, therefore, was regarded as an exception to the general rule, that a combination of three simple colors is required to produce white. Again, it was, and indeed still is, the general impression that a combination of blue and yellow makes green. This, however, is entirely a mistake. Of course we all know that yellow paint and blue paint make green paint: but this results from absorption of light by the semi-transparent solid particles of the pigments, and is not a mere mixture of the colors proceeding unaltered from the yellow and the blue particles: moreover, as can easily be shown by two sheets of colored paper and a piece of window glass, blue and yellow light, when combined, do not give a trace of green, but if pure would produce the effect of white. Green, therefore, is after all not produced by a mixture of blue and yellow. On the other hand, Clerk-Maxwell proved in 1860 that yellow could be produced by a mixture of red and green, which put an end to the pretension of yellow to be considered a primary element of color. From these and other

considerations, it would seem, therefore, that the three primary colors—if such an impression be retained—are red, green, and violet.

The existence of rays beyond the violet, though almost invisible to our eyes, had long been demonstrated by their chemical action. Stokes, however, showed in 1852 that their existence might be proved in another manner, for that there are certain substances which, when excited by them, emit light visible to our eyes. To this phenomenon he gave the name of fluorescence. At the other end of the spectrum, Abney has recently succeeded in photographing a large number of lines in the infra-red portion, the existence of which was first proved by Sir William Herschel.

From the rarity, and in many cases the entire absence, of reference to blue, in ancient literature, Geiger—adopting and extending a suggestion first thrown out by Gladstone—has maintained that, even as recently as the time of Homer, our ancestors were blue-blind. Though for my part I am unable to adopt this view, it is certainly very remarkable that neither the *Rig-veda*, which consists almost entirely of hymns to heaven, nor the *Zendavesta*, the Bible of the Parsees or fire-worshippers, nor the Old Testament, nor the Homeric poems, ever allude to the sky as blue.

On the other hand, from the dawn of poetry, the splendors of the morning and evening skies have excited the admiration of mankind. As Ruskin says, in language almost as brilliant as the sky itself, the whole heaven, “from the zenith to the horizon, becomes one molten, mantling sea of color and fire; every black bar turns into massy gold, every ripple and wave into unsullied shadowless crimson, and purple, and scarlet, and colors for which there are no words in language, and no ideas in the mind—things which can only be conceived while they are visible; the intense hollow blue of the upper sky melting through it all, showing here deep, and pure, and lightness; there, modulated by the filmy, formless body of the transparent vapor, till it is lost imperceptibly in its crimson and gold.”

But what is the explanation of these gorgeous colors? why is the sky blue? and why are the sunrise and sunset crimson and gold? It may be said that the air is blue, but if so how can the clouds assume their varied tints? Brücke showed that very minute particles suspended in water are blue by reflected light. Tyndall has taught us that the blue of the sky is due to the reflection of the blue rays by the minute particles floating in the atmosphere. Now if from the white light of the sun the blue rays are thus selected, those which are transmitted will be yellow, orange and red. Where the distance is short

the transmitted light will appear yellowish. But as the sun sinks towards the horizon the atmospheric distance increases, and consequently the number of the scattering particles. They weaken in succession the violet, the indigo, the blue, and even disturb the proportions of green. The transmitted light under such circumstances must pass from yellow through orange to red, and thus, while we at noon are admiring the deep blue of the sky, the same rays, robbed of their blue, are elsewhere lighting up the evening sky with all the glories of sunset.

Another remarkable triumph of the last half-century has been the discovery of photography. At the commencement of the century Wedgwood and Davy observed the effect produced by throwing the images of objects on paper or leather prepared with nitrate of silver, but no means were known by which such images could be fixed. This was first effected by Niepce, but his processes were open to objections, which prevented them from coming into general use, and it was not till 1839 that Daguerre invented the process which was justly named after him. Very soon a further improvement was effected by our countryman Talbot. He not only fixed his "Talbotypes" on paper—in itself a great convenience—but, by obtaining a negative, rendered it possible to take off any number of positive, or natural, copies from one original picture. This process is the foundation of all the methods now in use; perhaps the greatest improvements having been the use of glass plates, first proposed by Sir John Herschel; of collodion, suggested by Le Grey, and practically used by Archer; and, more lately, of gelatine, the foundation of the sensitive film now growing into general use in the ordinary dry-plate process. Not only have a great variety of other beautiful processes been invented, but the delicacy of the sensitive film has been immensely increased, with the advantage, among others, of diminishing greatly the time necessary for obtaining a picture so that even an express train going at full speed can now be taken. Indeed, with full sunlight  $\frac{1}{100}$  of a second is enough, and in photographing the sun itself  $\frac{1}{10000}$  of a second is sufficient.

We owe to Wheatstone the conception that the idea of solidity is derived from the combination of two pictures of the same object in slightly different perspective. This he proved in 1833 by drawing two outlines of some geometrical figure or other simple object, as they would appear to either eye respectively, and then placing them so that they might be seen, one by each eye. The "stereoscope," thus produced, has been greatly popularized by photography.

For 2,000 years the art of lighting had made little if any progress. Until the close of the last century, for instance, our lighthouses contained mere fires of wood or coal, though the

construction had vastly improved. The Eddystone lighthouse, for instance, was built by Smeaton in 1759; but for forty years its light consisted in a row of tallow candles stuck in a hoop. The Argand lamp was the first great improvement, followed by gas, and in 1863 by the electric light.

Just as light was long supposed to be due to the emission of material particles, so heat was regarded as a material, though ethereal, substance, which was added to bodies when their temperature was raised.

Davy's celebrated experiment of melting two pieces of ice by rubbing them against one another in the exhausted receiver of an air-pump had convinced him that the cause of heat was the motion of the invisible particles of bodies, as had been long before suggested by Newton, Boyle and Hooke. Rumford and Young also advocated the same view. Nevertheless, the general opinion, even until the middle of the present century, was that heat was due to the presence of a subtle fluid known as "caloric," a theory which is now entirely abandoned.

Melloni, by the use of the electric pile, vastly increased our knowledge of the phenomena of radiant heat. His researches were confined to the solid and liquid forms of matter. Tyndall studied the gases in this respect, showing that differences greater than those established by Melloni existed between gases and vapors, both as regards the absorption and radiation of heat. He proved, moreover, that the aqueous vapor of our atmosphere, by checking terrestrial radiation, augments the earth's temperature, and he considers that the existence of tropical vegetation—the remains of which now constitute our coal-beds—may have been due to the heat retained by the vapors which at that period were diffused in the earth's atmosphere. Indeed, but for the vapor in our atmosphere, a single night would suffice to destroy the whole vegetation of the temperate regions.

Inspired by a contemplation of Graham Bell's ingenious experiments with intermittent beams on solid bodies, Tyndall took a new and original departure; and regarding the sounds as due to changes of temperature he concluded that the same method would prove applicable to gases. He thus found himself in possession of a new and independent method of procedure. It need perhaps be hardly added that, when submitted to this new test, his former conclusions on the interaction of heat and gaseous matter stood their ground.

The determination of the mechanical equivalent of heat is mainly due to the researches of Mayer and Joule. Mayer, in 1842, pointed out the mechanical equivalent of heat as a fundamental datum to be determined by experiment. Taking the heat produced by the condensation of air as the equivalent of

the work done in compressing the air, he obtained a numerical value of the mechanical equivalent of heat. There was, however, in these experiments, one weak point. The matter operated on did not go through a cycle of changes. He assumed that the production of heat was the only effect of the work done in compressing the air. Joule had the merit of being the first to meet this possible source of error. He ascertained that a weight of 1 lb. would have to fall 772 feet in order to raise the temperature of 1 lb. of water by  $1^{\circ}$  Fahr. Hirn subsequently attacked the problem from the other side, and showed that if all the heat passing through a steam-engine was turned into work, for every degree Fahr. added to the temperature of a pound of water, enough work could be done to raise a weight of 1 lb. to a height of 772 feet. The general result is that, though we cannot create energy we may help ourselves to any extent from the great storehouse of nature. Wind and water, the coal-bed and the forest, afford man an inexhaustible supply of available energy.

It used to be considered that there was an absolute break between the different states of matter. The continuity of the gaseous, liquid and solid conditions was first demonstrated by Andrews in 1862.

Oxygen and nitrogen have been liquefied independently and at the same time by Cailletet and Raoul Pictet. Cailletet also succeeded in liquefying air, and soon afterwards hydrogen was liquefied by Pictet under a pressure of 650 atmospheres, and a cold of  $170^{\circ}$  Cent. below zero. It even became partly solidified, and he assures us that it fell on the floor with "the shrill noise of metallic hail." Thus then it was shown experimentally that there are no such things as absolutely permanent gases.

The kinetic theory of gases, now generally accepted, refers the elasticity of gases to a motion of translation of their molecules, and we are assured that in the case of hydrogen at a temperature of  $60^{\circ}$  Fahr. they move at an average rate of 6,225 feet in a second; while as regards their size, Loschmidt, who had since been confirmed by Stoney and Sir W. Thomson, calculates that each is at most  $\frac{1}{80000000}$  of an inch in diameter.

We cannot, it would seem at present, hope for any increase of our knowledge of atoms by any improvement in the microscope. With our present instruments we can perceive lines ruled on glass  $\frac{1}{300000}$ th of an inch apart. But, owing to the properties of light itself, the fringes due to interference begin to produce confusion at distances of  $\frac{1}{74000}$ , and in the brightest part of the spectrum at little more than  $\frac{1}{90000}$ th they would make the obscurity more or less complete. If indeed we could use the blue rays by themselves, their waves being much shorter,

the limit of possible visibility might be extended to  $\frac{1}{120000}$ ; and as Helmholtz has suggested, this perhaps accounts for Stinde having actually been able to obtain a photographic image of lines only  $\frac{1}{100000}$ th of an inch apart. It would seem then that, owing to the physical characters of light, we can, as Sorby has pointed out, scarcely hope for any great improvement so far as the mere visibility of structure is concerned, though in other respects no doubt much may be hoped for. At the same time, Dallinger and Royston Pigott have shown that, so far as the mere presence of simple objects is concerned, bodies of even smaller dimensions can be perceived.

Sorby is of opinion that in a length of  $\frac{1}{80000}$ th of an inch there would probably be from 500 to 2,000 molecules—500, for instance, in albumen and 2,000 in water. Even, then, if we could construct microscopes far more powerful than any we now possess, they would not enable us to obtain by direct vision any idea of the ultimate molecules of matter. Sorby calculates that the smallest sphere of organic matter which could be clearly defined with our most powerful microscopes would contain many millions of molecules of albumen and water, and it follows that there may be an almost infinite number of structural characters in organic tissues, which we can at present foresee no mode of examining.

The Science of Meteorology has made great progress; the weather, which was formerly treated as a local phenomenon, being now shown to form part of a vast system of mutually dependent cyclonic and anti-cyclonic movements. The storm-signals issued at our ports are very valuable to sailors, while the small weather-maps, for which we are mainly indebted to Francis Galton, and the forecasts, which anyone can obtain on application either personally or by telegraph at the Meteorological Office, are also of increasing utility.

Electricity in the year 1831 may be considered to have just been ripe for its adaptation to practical purposes; it was but a few years previously, in 1819, that Oersted had discovered the deflective action of the current on the magnetic needle, that Ampère had laid the foundation of electro-dynamics, that Schweizer had devised the electric coil or multiplier, and that Sturgeon had constructed the first electro-magnet. It was in 1831 that Faraday, the prince of pure experimentalists, announced his discoveries of voltaic induction and magneto-electricity, which, with the other three discoveries, constitute the principles of nearly all the telegraph instruments now in use; and in 1834 our knowledge of the nature of the electric current had been much advanced by the interesting experiment of Sir Charles Wheatstone, proving the velocity of the current in a metallic conductor to approach that of the wave of light.

Practical applications of these discoveries were not long in coming to the fore, and the first telegraph line on the Great Western Railway from Paddington to West Drayton was set up in 1838. In America Morse is said to have commenced to develop his recording instrument between the years 1832 and 1837, while Steinheil, in Germany, during the same period was engaged upon his somewhat super-refined ink-recorder, using for the first time the earth for completing the return circuit; whereas in this country Cooke and Wheastone, by adopting the more simple device of the double-needle instrument, were the first to make the electric telegraph a practical institution. Contemporaneously with, or immediately succeeding these pioneers, we find in this country Alexander Bain, Breguet in France, Schilling in Russia, and Werner Siemens in Germany, the latter having first, in 1847, among others, made use of gutta-percha as an insulating medium for electric conductors, and thus cleared the way for subterranean and submarine telegraphy.

Four years later, in 1851, submarine telegraphy became an accomplished fact through the successful establishment of telegraphic communication between Dover and Calais. Submarine lines followed in rapid succession, crossing the English Channel and the German Ocean, threading their way through the Mediterranean, Black and Red Seas, until in 1866, after two abortive attempts, telegraphic communication was successfully established between the Old and New Worlds, beneath the Atlantic Ocean.

In connection with this great enterprise and with many investigations and suggestions of a highly scientific and important character, the name of Sir William Thomson will ever be remembered. The ingenuity displayed in perfecting the means of transmitting intelligence through metallic conductors, with the utmost despatch and certainty as regards the record obtained, between two points hundreds and even thousands of miles apart, is truly surprising. The instruments devised by Morse, Siemens, and Hughes have also proved most useful.

Duplex and quadruplex telegraphy, one of the most striking achievements of modern telegraphy, the result of the labors of several inventors, should not be passed over in silence. It not only serves for the simultaneous communication of telegraphic intelligence in both directions, but renders it possible for four instruments to be worked irrespectively of one another, through one and the same wire connecting two distant places.

Another more recent and perhaps still more wonderful achievement in modern telegraphy is the invention of the telephone and microphone, by means of which the human voice is transmitted through the electric conductor, by mechanism that imposes through its extreme simplicity. In this connection the

names of Reiss, Graham Bell, Edison and Hughes are those chiefly deserving to be recorded.

Whilst electricity has thus furnished us with the means of flashing our thoughts by record or by voice from place to place, its use is now gradually extending for the achievement of such quantitative effects as the production of light, the transmission of mechanical power, and the precipitation of metals. The principle involved in the magneto-electric and dynamo-electric machines, by which these effects are accomplished, may be traced to Faraday's discovery in 1831 of the induced current, but their realization to the labors of Holmes, Siemens, Pacinotti, Gramme, and others. In the electric light, gas-lighting has found a formidable competitor, which appears destined to take its place in public illumination, and in lighting large halls, works, &c., for which purposes it combines brilliancy and freedom from obnoxious products of combustion, with comparative cheapness. The electric light seems also to threaten, when subdivided in the manner recently devised by Edison, Swan, and others, to make inroads into our dwelling-houses.

By the electric transmission of power, we may hope some day to utilize at a distance such natural sources of energy as the Falls of Niagara, and to work our cranes, lifts, and machinery of every description by means of sources of power arranged at convenient centres. To these applications the brothers Siemens have more recently added the propulsion of trains by currents passing through the rails, the fusion in considerable quantities of highly refractory substances, and the use of electric centres of light in horticulture as proposed by Werner and William Siemens. By an essential improvement by Faure of the Planté Secondary Battery, the problem of storing electrical energy appears to have received a practical solution, the real importance of which is clearly proved by Sir W. Thomson's recent investigation of the subject.

It would be difficult to assign the limits to which this development of electrical energy may not be rendered serviceable for the purposes of man. \* \* \*