transmission of sound through the water itself. The experiments of M. Colladon on the Lake of Geneva proved the great distance to which sound is transmitted through water, and the velocity and directness of its course.*

In his observations he employed a bell, let down into the water; but this is a bad instrument for signalling, as its vibrations are almost instantly stopped. Many arrangements would appear to be preferable. The Syren, which was so called by its inventor, M. Cagniard de la Tour, because it would sing under water, is well adapted to give any note that is found desirable.† Long glass tubes, vibrating longitudinally, are said to produce immense volumes of sound in water: and other means might be devised. As the sound remains in the water, it would be necessary to make some communication between it and the ear of the listener. M. Colladon employed an apparatus like a spoon, with a tube for handle. By this means a mariner might listen for signals made at any important station, such as the Lizard Point, and might not only hear them at a great distance, but determine approximately their direction, unaffected by the state of the atmosphere above.

[J. H. G.]

WEEKLY EVENING MEETING,

Friday, March 20, 1863.

MAJOR-GENERAL EDWARD SABINE, R.A. President R.S. D.C.L. Vice-President, in the Chair.

BALFOUR STEWART, Esq. F.R.S.

On the Forces concerned in producing Magnetic Disturbances.

WHEN a bar of steel has been magnetized, it has acquired a tendency to assume a definite position with respect to the Earth. Nothing is more widely known than this important fact, but at the same time there is nothing in Science more mysterious than its cause. We may endeavour to explain it by asserting that the Earth acts as a magnet; but whence it has acquired this magnetism, how it is distributed, and what are the causes of its many changes, are amongst the most perplexing and the most important of those problems in physical science which are yet unsolved.

* Mémoires de l'Académie des Sciences: Des Savans Etrangers.—Tome v.
† Ann. Chim. Phys. xii., page 171.

The force with which the Earth acts upon the needle is directive merely; that is to say, the needle is neither attracted nor repelled as a whole, but simply twisted round, and in this respect the Earth is similar to a very powerful magnet, the pole of which is placed at a great distance from the needle upon which it acts.

If we keep a magnetic bar constantly suspended in the same place, its position will be subject to many changes. In the first place, there is that change which goes on in the same direction for a great many years together, in virtue of which a needle suspended in this place 200 years ago would have assumed a position very much different from its present one. Secondly, there is a change of which the period is one year, and this is called the annual variation. Thirdly, there is a change of which the period is one day, and which is called the daily variation. Fourthly, there is a change which depends upon the moon's hour angle; and, fifthly, the needle is subject to sudden and abrupt changes in position, which are called magnetic storms and which form the subject of this discourse. During the prevalence of these unaccountable phenomena the needle is found to oscillate rapidly and capriciously backwards and forwards, being now on the one side and now on the other of its normal or undisturbed position.

It should be here remarked, that the Physicist regards the needle merely as a vane (similar to a wind-vane) which serves to render visible the direction and intensity of that mysterious force which operates through the Earth. It is really the Earth's magnetism with which he concerns himself.

Gauss, who has done so much to further the science of magnetism, showed, by means of a preconcerted system of observation, that magnetic storms affected the needle at Göttingen and at other stations in Europe at precisely the same moment of absolute time; and after the establishment of the colonial observatories, it was found by General Sabine that the needle was affected in Toronto at precisely the moment when it was disturbed at Göttingen. Nor is it too much to say, with our present knowledge, that these remarkable disturbances break out at the same moment over every portion of our globe.

Having thus shown that these phenomena are cosmical in their character, the next point of interest is their connection with the sun. This has been placed beyond doubt chiefly through the labours of General Sabine, who found at Toronto and elsewhere that magnetic disturbances obey a law of hours. Mr. Broun also showed the same thing from his observation of the needle at Makerstoun, in Scotland. It may be instructive to point out how this proof was deduced from the colonial observations; and to make the matter plain, let us refer to an imaginary case in the familiar science of meteorology. Suppose that, while an observer is watching his thermometer there is a sudden influx of cold weather, and that it is wished to estimate the influence of this upon the thermometer on a given day and at a given hour of that day, what must the observer do? He must endeavour to ascertain, by the best possible means, what indication the thermometer would have afforded at that specified day and hour had there been no cold weather. Comparing this with the actual height of the mercury, and deducting the one from the other, he would clearly obtain a measure of the effect of the cold weather upon the thermometer.

A similar course was pursued by General Sabine in discussing the colonial magnetic observations, with the object of deducing the laws of disturbances. It was first necessary to ascertain by the best possible means what position the magnet would have assumed at any particular day and hour, had there been no disturbance. Calling this the normal value, the next course was to group together as disturbed, all those positions of the magnet which differed from the normal by more than a certain small quantity. The necessity for this separation will become evident when it is remarked that the disturbed and the regular observations have different hourly turning-points, and obey very different laws. Thus a disentanglement was effected, which was accomplished by the employment of a separating value. The selection of this value is to some extent arbitrary, but it was shown by reference to a diagram that the disturbance law at Kew was virtually the same, whether this were deduced (in the case of the declination) from 95 days of principal disturbances or from all disturbed observations which differ from the normal by more than 3′·3. It was also shown from the same diagram that easterly disturbances prevail at Kew during certain hours of the day, and westerly disturbances at certain other hours, thus exhibiting a daily law, and showing that disturbances are therefore connected with our luminary.

There is, however, a more interesting and mysterious connection than this. Professor Schwabe, of Dessau, has now for nearly forty years been watching the disc of the sun, and recording the groups of spots which have been visible, and he finds that these have a period of maximum nearly every ten years, two of these periods being the years 1848, 1859. Now it was likewise found by General Sabine, that the aggregate value of magnetic disturbances at Toronto attained a maximum in 1848, nor was he slow to remark that this was also Schwabe's period of maximum sun-spots, and it was afterwards found, by observations made at Kew, that 1859 (another of Schwabe's years) was also a year of maximum magnetic disturbance. This fact is eminently suggestive, and brings us at once into the presence of some great cosmical bond, different from gravitation, adding at the same time additional interest as well as mystery to these perplexing phenomena.

These are the grounds on which we suspect the sun to be the agent which causes magnetic disturbances, but there is also some reason to believe that on one occasion our luminary was caught in the very act. On the first of September, 1859, two astronomers, Messrs. Carrington and Hodgson, were independently observing the sun's disc, which exhibited at that time a very large spot, when about a quarter-past eleven they noticed a very bright star of light suddenly break out over the spot and move with great velocity across the sun's surface.

On Mr. Carrington sending afterwards to Kew Observatory, at which place the position of the magnet is recorded continuously by photography, it was found that a magnetic disturbance had broken out at the very moment when this singular appearance had been observed.

The next point to be noticed is, that magnetic storms are always accompanied by auroræ and by earth currents. With regard to the latter of these phenomena, a single word of explanation may be necessary. Earth currents are currents of electricity which traverse the surface of our globe, a portion of which is caught up by the telegraphic wires, which are often thereby seriously disturbed in their communications. A table was then referred to, which showed that auroræ and earth currents have the same ten-yearly period as sun-spots and magnetic disturbances, so that a bond of union exists between those four phenomena.

The question next arises, What is the nature of this bond? Now, with respect to that which connects sun-spots with magnetic disturbances we can as yet form no conjecture; but we may, perhaps, venture an opinion regarding the nature of that which connects together magnetic disturbances, auroræ, and earth currents. And here we may remark that this latter bond is the more definitely determined of the two, since the three phenomena which it embraces *invariably occur together*.

In order to exhibit the evidence upon which this hypothesis rests, it is necessary to refer to what is done at the Kew Observatory.

By means of an apparatus arranged by the late Mr. Welsh, the values of the *components* of the earth's magnetism, are there recorded continuously by photography. Now there is a proposition which goes by the name of the parallelopiped of forces and which asserts that if three forces acting at a point be represented in magnitude, and in direction by the three sides of a parallelopiped, the resultant of these forces shall be represented in magnitude and direction by the diagonal of the parallelopiped. These three forces may be said to be *components* of the whole resultant force, since the joint action of the three is the same as that of the resultant.

To refer to a familiar case, suppose that there is a gust of wind which (as sometimes happens) is not horizontal, but blows downwards in a slanting direction from above. How shall we estimate the direction and the force of this wind? Let us have three pressure plates, one north and south, one east and west, and one up and down; then the north and south component of the wind will be given by the first, the east and west component by the second, and the up and down component by the third, and exhibiting the indications of these three pressure-plates by the three sides of a parallelopiped, the diagonal will represent the wind in magnitude and in direction.

Something of this kind must be done, if it be wished to record the disturbing force which acts upon the needle. Let there be three magnets free to move, two in a horizontal plane and one in a vertical direction; one swinging freely and pointing to magnetic north and south, one compelled by torsion to point to magnetic east and west, and a third balanced on a knife-edge so as to move up and down; the first will be sensitive to an east and west disturbing force, which will act at right angles to it, and tend to twist it round; the second will on the other hand be affected by a north and south force, and the third by a vertical force. It is easily seen how these three magnets will take the place of the three pressure plates, in the meteorological problem. Now if a mirror be attached to each of these magnets, it may be made to reflect the image of a dot of light upon a sheet of photographic paper, so that a small motion of the mirror shall cause a large motion of the dot, and if the paper itself move by clock-work, in a direction at right angles to that in which the dot moves on the paper, the photographic impression of the dot during a day's motion of the paper will be a curved line, and this being obtained for each of the three magnets, we shall be able to record continuously the changes which are taking place in the three components of the earth's magnetic force.

Reference was then made to a diagram in which these three curved lines were exhibited for September 1–2, 1859; and it was seen that about four o'clock in the early morning of September 2, the three components of the earth's magnetism at Kew were simultaneously and abruptly disturbed, and were kept at one side of their normal or undisturbed positions for many hours. During this time there were vivid auroræ which extended over the greater part of the globe, and even to as low a latitude as Cuba, and strong earth currents were also observed by Mr. C. V. Walker, on the various telegraphic lines. These currents were found to change their direction every two or three minutes, going alternately from positive to negative, and back again to positive. It is therefore evident that currents varying in this manner could not have been the *cause* of magnetic disturbances in which the needle was kept on one side of its nominal position for many hours. But the curves of magnetic disturbance further exhibit sharp peaks and hollows, or wavelets, superimposed upon the great disturbance wave, and these wavelets change their direction every two or thre minutes, in which respect they are comparable with earth currents. May not these wavelets be connected with earth currents and auroræ, and may not this connection be of the following kind? A peak denotes a small but rapid change of the earth's magnetic force in one direction, and a hollow, a similar change in the opposite direction. Now in a Ruhmkorff's coil we have—1st, a soft iron core, with a current circulating round it; 2nd, an insulator round the current; 3rd, a secondary coil above the insulator, containing perhaps several miles of fine wire. In this arrangement we have a discharge between the terminals of the secondary coil every time contact with the primary current is made, and one of an opposite character every time this contact is broken.

But the chief use of the primary current is to reverse the magnetism of the iron core, and could we reverse this, or even change it rapidly without a primary current, we should have the same effect, that is to say, we should have a secondary current in one direction, when the magnetism of the core was rapidly increased, and one an opposite direction, when this was rapidly diminished. An experiment was made, showing the mode of action of the Ruhmkorff's coil, and the following comparison was instituted between this instrument and our earth. The body of our earth may be likened to the soft iron core of a Ruhmkorff's machine, in which one of the small curve-peaks already alluded to denotes a rapid change of magnetism in one direction, and a hollow, a change of the opposite character. The lower strata of the atmosphere again resemble the insulator of the Ruhmkorff's machine, and the upper and rarer strata, the secondary conductor; again, the crust of the earth being permeated with moisture, becomes a conductor, and may therefore also be likened to the secondary coil. Whenever therefore we have a curve-rise, that is to say, a sudden change of the earth's magnetism in one direction, we should have in the upper strata of the atmosphere and in the crust of the earth currents of one kind; and when we have a curve-fall or a sudden change of magnetism in the opposite direction, we should have similar currents of an opposite description.

It need hardly be remarked, that those currents which take place in the upper strata of the atmosphere will form auroræ, while those in the crust of the earth will constitute earth currents.

Now, if this be the nature of that connection which subsists between magnetic disturbances, earth currents, and auroræ, may we not extend our inquiries, and ask, "If the sun's action is able to create a terrestrial aurora, why may he not also create an aurora in his own atmosphere? It occurred independently to General Sabine, Professor Challis, and the speaker, that the red flames visible during a total eclipse may, indeed, be solar auroræ. In support of this hypothesis it may be remarked that, during the late total eclipse in Spain, Mr. De la Rue, by means of the Kew photoheliograph, proved that these red flames belong to the sun, and that they extended in one case to the distance of 70,000 miles beyond his photosphere. But, considering the gravity of the sun, we are naturally unwilling to suppose that there can be any considerable amount of atmosphere at such a distance from his surface; and we are therefore induced to seek for an explanation of these red flames amongst those phenomena which require the smallest possible amount of atmosphere for their manifestation. Now the experiments of Mr. Gassiot, and the observed height of the terrestrial aurora alike convince us that this meteor will answer our requirements best. And besides this, the curved appearance of these red flames, and their high actinic power in virtue of which one of them, not visible to the eye, was photographed by Mr. De la Rue, are bonds of union between these and terrestrial auroræ.

It has been remarked by General Sabine, that an auroral outburst in the sun may perhaps be responded to simultaneously by the different planets. If this be true, our whole solar system would seem to thrill almost like a living being under the excitement of this mysterious force. It has been likewise found by Mr. Gassiot, that electricity cannot pass through a perfect vacuum, so that perhaps we have only to observe the greatest height attained by a terrestrial aurora and by a solar red flame, in order to be able to assign the limit, not only of our own atmosphere, but also of that of our luminary.

One other point remains to be noticed in connection with magnetic disturbances, and this is, that there appear to be two separate disturbing forces, nearly opposite in character, both connected with the sun, which act simultaneously upon the magnet; the position which the latter assumes being due to the combined effect of both. This has been shown to be true by General Sabine, who has observed that the curve which exhibits the daily range of the east component of the disturbing force, is in many places very different in character from that which exhibits the same for the west component. And this difference between the two curves is of one kind at one station, and of another kind at another station. This duality of the disturbing forces may also be observed directly in the Kew disturbance-curves. Here it was shown, by means of models, kindly constructed by Mr. Beckley, and also by reference to the parallelopiped of forces, that whenever the corresponding peaks and hollows for the different components continue to bear a definite proportion to one another, these then denote the action of a disturbing force, varying in intensity, but always preserving the same type.

A set of curves were exhibited in which this proportion held, and in which the disturbing force, whose variations were denoted by the peaks and hollows, was one which affected the north and south component twice as much as the other two. It was then shown by reference to the normal line, or line of no disturbance, that there was also in action at that time another disturbing force, which was not however of the same variable character as that which caused the peaks and hollows.

The attention of foreign men of science has been much directed to the problem of terrestrial magnetism, and five sets of magnetographs, similar to those in operation at the Kew Observatory, have been already procured by foreign governments. These, however, will be placed in the northern hemisphere, and it is to be desired that some of our colonies in the southern hemisphere may come forward in order that by the next epoch of maximum disturbance (1869), there may be such a network of magnetic observatories as may enable us to obtain the solution of this interesting and important problem.

[B. S.]