apparent paradoxes. At the same time it cannot fail to be instructive. LATIMER CLARK

May 7

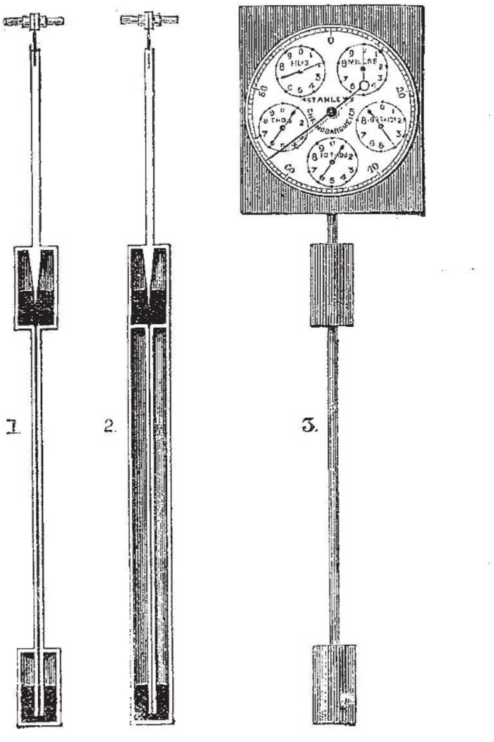
Cumulative Temperature

ATTENTION has been called in your valuable paper to the idea of registering cumulative temperatures by means of a pendulum, by M. von Sterneck, vol. xvii. p. 308, and this has called forth several letters. One gentleman has put forward my name as having devised means with some success. In an instrument exhibited at the Royal Society *soirée*, 1876, I could have left the matter resting at this point, but I am induced to write by the letter of your correspondent, "B," in vol. xvii. p. 486, who says, "The chief merit in this matter will belong to the person who puts the idea into a working form which can be proved capable of giving accurate results." As I think that I have fairly attained this end, or at least pointed out the way to it, with your permission I will describe the means which appears by the correspondence interesting to many of your readers. In my cumulative temperature clock the important element, the *pendulum*, is constructed as follows:—A steel cylindrical tube 32 inches long, 1¾ inch internal diameter, is hermetically closed at both ends. A rod is attached to one of the ends, which is placed uppermost, to connect this pendulum with the clockwork in the ordinary manner. An air-tight division is made across the tube or chamber at 5 inches from the upper end. A small tube leads from this division to the bottom of the chamber. A conical plug is inserted in the upper chamber, to be hereafter described. A screw plug is placed under the small tube in the outer tube to enable the upper chamber to be filled with mercury. When the pendulum is so constructed, the lower screw plug is removed, and the upper chamber and leading tube filled with mercury by means of a small funnel. In this full state the mercury is boiled, and the whole inverted. It then becomes a steel *barometer*. To convert it into a thermometer, a small air-hole is made in the outer tube (this is not shown in the engraving), and this hole is closed up with a small air-tight cock filled with a porous material. When this is screwed on and turned off, it is isolated from atmospheric pressure, and the mercury rises into the upper chamber by any increase of temperature causing expansion of air in the tube, and sinks in the same manner by loss of temperature, so that the pendulum becomes simply an air thermometer. The pressure of the air by expansion within the tube in the rising of the mercury changes the centre of oscillation of the pendulum and accelerates the clock, and *vice versâ*.

The clock is specially constructed to count beats only in units, tens, &c., up to ten millions, and the number of beats per day, week, month, or year, becomes the unit of temperature for the period. The exact length of time of each pendular oscillation being governed by the temperature at the time, the method becomes equal to one accurate observation at every second of time.

The difficulties of construction and refinement required upon this general description are of two kinds, mathematical and mechanical. The models that I exhibited at the Royal Society's *soirée* were imperfect, being of blown glass. The difference of oscillation per day for 1° Fahrenheit, was in these about 50, as taken at the Lambeth Observatory by the late Col. Strange. In the steel instruments described there would be about 100 oscillations additional per day for the rise of each degree centigrade. The mechanical difficulties are simply constructive. To obtain perfectly vacuum proof chambers, and to follow correctly the outline of the plug to be immersed in the vacuum-chamber. Also the adjustment of the correct volume of mercury, and the density of the contained air, by means of the cock, and the application of heat or cold to the outer case. The mathematical requirements are corrections. Thus: if the chambers were simply cylindrical, the mercury that rose by the pressure would have a different oscillation value for every point of space through which it rose. This might be corrected to equal scale value by making one or both the mercury-chambers conical, but it is much more simply done by inserting a conical plug in the upper chamber. There would also be a correction for the expansion of the mercury and the steel case, and from any irrationality in the expansion of the contained air. The whole of this correction being derived from heat might be made by one correction in the immersed plug. Prof. Stokes, Sec. R.S., kindly offered to calculate the exact form of this plug for me from data I was to supply. But I was ill shortly after this, and unable to attend to the matter, so I let it drop, but have the clocks and pendulums ready to complete some time hence.

I send a diagram engraving which shows the principle of the pendulum No. 2, for cumulative temperatures. No. 1 is for



taking cumulative pressures upon the same system, if the science of meteorology should require such exact means of obtaining permanent records of pressure and temperature for long periods as for months or years. WM. F. STANLEY

South Norwood, April 22

THE INTERIOR OF THE EARTH[1]

SIR GEORGE AIRY remarked that the nature of the subject was different from any upon which he ever lectured before, in regard to its indefiniteness and to the difficulty he should have if he considered it to be his duty to lead them definitely up to some point. He could only give them some idea of the theory to which he wished to lead them, and in doing so he would advert collaterally to a good many points which might be valuable. He proposed to divide his address into three parts. The first would relate to the measures of the earth; the second to observations on temperature; and the third to the manner in which they might suppose the earth to have been formed, especially with regard to the nebular hypothesis; and after that he would add some remarks on the conclusions to which these lead.

He described the process called triangulation, by which a large part of the contour of the globe is covered, and by which it is possible to lay down a map on which the distance between any one point and any other point is ascertained to within a few inches; how that this was valuable in ascertaining the dimensions and figure of the earth with the aid of the zenith sector, an instrument for measuring the apparent distances of stars from the point overhead. He showed on a large globe the principal lines of measurement which had up to this time

[1] Abstract of Address at the Cumberland Association for the Advancement of Literature and Science, by Sir George B Airy, K.C.B., F.R.S., Astronomer-Royal. Revised by the author.

been made for this purpose. From these measurements, there was no doubt that the earth is very nearly a sphere of 8,000 miles in diameter, or 25,000 miles in circumference. When he spoke of the surface of the earth, it must be understood that he spoke of the sea-level. Above that level stand mountains, and below are the depths of the sea. But although these inequalities of surface are taken into consideration by those who go accurately into calculations, they are comparatively very small. Suppose he were to make a sphere twenty-five feet in diameter, representing the earth, how much did they think the mountains would rise above the level? One-fifth of an inch. Well, of course that never could be seen; and it was a thing that in all ordinary calculations might be neglected. So that they might say that the earth was a sphere, with an exception he would mention presently. Then there was another thing which was important to their present subject, and that was the density of the matter of which the earth is formed; and this was a matter which had engaged the best experimenters in two or three ways. The first of the experiments of this kind is a very celebrated one known as the Schihallien experiment, so called from its being an experiment on a mountain in the Scottish Highlands (Perthshire) particularly adapted to these measurements, which are most favourably carried on in the north and south direction. It was found that the mountain Schihallien disturbed the plumb-line, causing a deviation from the vertical of 11″ or 12″. Then if that mountain, whose dimensions we can measure, turns the plumb-line so far, what is the proportion of its attracting mass to the attracting mass of the earth? And as we know the size of the mountain and the size of the earth, we can compare the density of the mountain and that of the earth. This process was gone through with great care, and it was found that, taking the density of the mountain as we could trace it by its constituent rocks, the density of the earth would be about four and a half times that of water, or about twice the average density of the surface rocks. The earth had density everywhere, but was more dense towards the centre than the outside. The next experiment is known as the Cavendish experiment. Here was a very light rod of deal, six feet long, suspended by a fine copper or silver wire (which is the most delicate suspension we can have) forty inches long, within a wooden case to defend it from currents of air. At each end of the lever was hung a ball two inches in diameter, and by a simple contrivance a pair of leaden spheres, weighing together perhaps 300lbs., were brought simultaneously into the neighbourhood of the balls (but outside the case), on opposite sides, so that they might attract the small balls; and the experiment was varied until, by a series of calculations, the density of the earth was ascertained, and gave a greater result than before, namely, that the average density of the earth was about 5½ times that of water. Then the third experiment was one which he made himself in the Harton colliery, near South Shields. That was by seeing how much the force of gravity was altered by going to a great depth, the force of gravity being ascertained and compared at the top and bottom by the swinging of a pendulum. From that a calculation was made, and it gave the density of the earth as six times that of water. He believed the best calculation was that founded upon the Cavendish experiment, and was quite willing to take something like 5½ times the density of water as the average density of the earth, including every part of it. There were consequences which followed from that which were certainly very striking. As this density was rather more than double that of the surface rocks, it showed that towards the centre the earth was more condensed than at the outside. But there was one result of the calculation which rather startled him when he made his own experiment on the subject. Since these rocks press upon each other more and more the further you go down, what is the pressure upon the square inch when you approach the centre of the earth? Many gentlemen there would have heard of a pressure of 50 lbs. or 100 lbs. on the square inch, and perhaps the greatest pressure we know is that by which tough Aberdeen granite is crushed—10,000 lbs. to the square inch. But it must be 30,000,000 lbs. to the square inch in the centre of the earth; and it is an astounding thing to imagine what consequences may follow. We have no idea of any such degree of pressure, and cannot therefore conceive what its consequences may be. Perhaps thereby gas may be squeezed into gold or platinum, and powder to solid, or solid to powder—we cannot tell what it does. That enormous pressure, and our total ignorance of it, is one of the difficulties and troubles of this case. He thought the general state of the earth would be understood from what he had said, and now he came to the rotation of the earth. The earth revolves, as everybody knows, in the course of a day; and everybody knows also, from the housemaid who whirls her mop to the greatest philosopher, that rotation will swell out the middle of the earth. Calculations have been made upon that, and the result is that the diameter of the earth in the equatorial direction is greater by about 1-300th part than the diameter in the polar direction. When they found that the measurement of the dimensions of the earth agreed so well with that conclusion, it led them to the further conclusion that the earth is, or has been, in a fluid state. In corroboration of this, he would mention a singular circumstance which occurred in our Indian Survey. In proceeding northward from Cape Comorin, the curvature of the earth agreed very well for many hundreds of miles with that found in other parts of the earth (with due reference to the elliptic form of the earth). On approaching the Himalaya Mountains, the plumb-line was sensibly attracted by the mountains. The late Archdeacon Pratt investigated, from the form of the mountains and the density of the rocks, the disturbance of the plumb-line, and found that it ought to be much greater than it really is. Sir George explained this by supposing that the whole of that country is floating upon a dense fluid, and that the thick mass of the lighter mountain-matter sinks deep in the fluid, and that the displacement of denser matter neutralises almost entirely the attraction of the lofty mountains. The form of the earth is not such as would be taken by a solid structure, but such as would be taken by a fluid mass with solids floating upon it.

In the second part of his address, Sir George Airy referred to what is known about the temperatures. They knew something of the rate at which temperature travels through the earth. The experiments on this point had begun, as many good experiments have begun, with the French, who fixed thermometers with very long stalks to the depth of twenty-five feet in the ground. These experiments were followed up, after some time, with similar thermometers at the Observatory at Edinburgh, and about the same time at the Observatory at Greenwich, and there the deeper thermometers were read every day. The first and most conspicuous result of these experiments is the retardation of the seasons. At the depth of twenty-five feet, high midsummer heat occurs at December, which shows that it takes five months for the heat to travel down that depth. If you compute it further, it takes 100 years to travel a mile; so that if the crust of the earth is 100 miles thick, it will take 10,000 years for the transmission of heat through it. This showed that really, after all, we may have a great deal of heat below us, and that it will not come to us for a very long time. It will come at last, but it will come travelling up slowly, and in the meantime the radiation from the surface of the earth will carry it off very rapidly. So that it is quite possible that with a cool surface there may be a great deal of heat below. In every part of the earth there is evidence of intense heat in former times.

The extent of volcanic action is partly lost on the earth by the effects of air and water; but when they looked at the old rocks, they found there had been volcanic action almost everywhere. In our limestone rocks, for instance, there are the basaltic veins, which in some parts go by the name of toadstone, which are certainly the result of volcanic heat enough to produce fluidity. Almost everywhere they found that there were volcanic streams intermixing with all the rocks; and even although the surface of the earth had been free from volcanoes in a given district for a time, yet there had always been volcanic action very near, enough to force in veins of lava from time to time. It seems, therefore, that we are entitled to say that we have always been near a great deal of heat—probably we have been much nearer it than at the present time, but still we are near enough to experience a great deal even in these countries. Repeated experiments have been made on the increase of temperature as you go down in mines, and the conclusion has been come to that the temperature rises one degree Fahrenheit, sometimes in sixty and sometimes in 100 feet. There is a mine in Cornwall in which he had walked in a stream of water at the bottom actually scalding to the legs! and everybody knows what quantities of water there are in the hot springs. And then there is the great display of the volcanoes, which come from a great deal of heat somewhere; and in places where volcanoes are extinct we can trace a sort of basaltic continent, so to speak, up to the very mouths of the craters from which the lava has come. So that there has been in all former ages undoubtedly much more heat than at present. There was another matter on which he would desire to speak, but with no great boldness, and that was the change in magnetism. The subject of terrestrial magnetism is one of the most obscure in the world; nevertheless, looking at the direction in which it always is towards the colder parts, and tracing its general phenomena, it may be effected by thermo-electricity, and that may be produced by the constant wear going on in the interior of the earth, where the fluid lavas are consolidating themselves. Within a few years the voyage of the *Challenger* has been made, and he had little hesitation in saying it was one of the most important in the scientific history of the world. In crossing the great seas they sounded to great depths, and measured in a satisfactory way the temperature of the water down to the depth of five miles. They always came to cold at the bottom; and there are great controversies whether the cold can come in deep sea streams from the frozen regions of the north. He thought that had some influence; but he thought the bottom of the water and the ground at those great depths is cold—he did not think that part of the earth partakes of the same heat as other parts; that he only expressed as his opinion, in which, of course, he might be met by the disbelief of a great many persons. That was the state of things as we know it regarding the temperature of the earth—that there is evidence everywhere that there has been enormous heat almost all over the earth. Some parts of the crust of the earth under the deepest seas are still perforated by volcanic islands. In some places the heat comes very near the surface. That he looked upon as an important fact, leading them to a theory of what the state of the earth really is.

On entering upon a matter which was undoubtedly one of the boldest speculations in modern science, which was the formation of the earth—he could not say its creation, but the way it got into its present shape—he had to premise that the theory on which he had to speak, which is known as the nebular hypothesis, is the conception of a very bold and vigorous intellect indeed. Laplace it was who remarked that all the planets and satellites revolved in the same direction round the sun, and all of them turned on their axis in the same direction: and it was difficult to deny that there must be some general cause for this. It naturally occurred to Laplace that if we can find something which is contracting its dimensions, and which has a little rotation to begin with, then with every contraction of dimensions that rotation would become more rapid, till it might go to any degree, depending upon the condensation of its various parts and its density before. Then can we come to look at any matter which is being thus condensed, and which might so form systems such as ours, with sun, planets, and satellites? There are a series of bodies in the sky which did not attract much attention in former days, mainly because telescopes were not so large, but which are now catalogued by thousands. These are the nebulæ. The name denotes their cloudy appearance. They are small bodies among the stars, sometimes appearing to have stars in them, or to be connected with stars, and sometimes not. They have the strangest and most capricious shapes imaginable. If this nebula is contracting its parts together so as to form a world, that rotation in the course of condensation will become so rapid that it may form suns and planets and earths around it; and on this supposition there is no difficulty in making a complete solar system cut of such a mass as that of the nebula in Orion. Observations made lately by the largest telescopes—those of Lassell and Lord Rosse, both of which are remarkable telescopes of the largest class—have brought to light a number of nebulæ possessing a spiral appearance; and they seem to have some bearing on the supposition that the nebulæ are contracting and getting into a rotatory state. But these changes go on so slowly that they had not been able to answer with certainty for any of the changes of which he now spoke. The whole thing is theoretical, and yet, as it seemed to him, in the highest degree probable. Supposing this to be the case, these nebulæ would rotate, and in their compression would get very hot. There is no doubt that condensation would produce enormous heat, and it seems we have there sufficient explanation of the great heat we find below the surface of the earth and in other places. We suppose that the stars generally have been formed from the condensation of nebulæ; and there is a circumstance which was worthy mentioning. A series of observations founded upon optical experiments has come to light within late years which has done more to reveal the secrets of nature than anything before—this was by means of the spectroscope. By voltaic action sparks may be produced which derive their character—sparks like those of an electrical machine—in a great measure from the metals from which they spring. A spark springs from metal to metal, and the character of the metals gives different characters to the sparks. We have one set of these spectra produced by iron, another by nickel, others even by hydrogen gas, and so on, and these are observed and catalogued with great care. When we come to observe the light in the stars in the same manner, we find there are no two stars alike; some of them have the same spectra as that given from iron, and others have spectra from a number of different things; and we are actually able, by legitimate reasoning from this, to say from what the stars are made—what metals and other things they are made of, and, as a generat thing, there are no two stars alike. So that in this nebular hypothesis we are not bound to say that the nebulæ are all of the same materials, and we conceive that by comparing the bodies which we know in the solar system with those of the stars, we may arrive at an idea of the variety of materials of which the planets are composed. We cannot find anything different in comparing the light of the planets, because they all derive their light from the sun, and they do not present any difference of appearance in the spectrum. But we can draw conclusions from their relative density. As he had said to them, the average density of the earth is probably five and a half times that of water. They knew that the sun is only once that of water. What the sun is he could not tell, but it is a very poor light creature indeed. The density of Mercury is perhaps rather greater than that of the earth. The density of Venus is much the same as that of the earth, and the density of Mars is also much the same as that of the earth. Then after that comes a shower of little planets, about 200 of which have been observed up to the present time, and he could not tell what they are made of. Then there are Jupiter and Saturn, which are no heavier than water. So that it appears clear that, assuming the formation of these things by the condensation of nebulæ, on the theory he had mentioned, the different parts of the nebulæ which have contributed to the solar system are very different. Well, that being considered as established, it follows that in the constitution of our earth there may be parts of very different density. He should say that the high and prominent parts of the land are made of something light, and the heavy and dense parts are those covered by a considerable quantity of water, which have sunk deep into the central lava on which, he conceived, all things are resting.

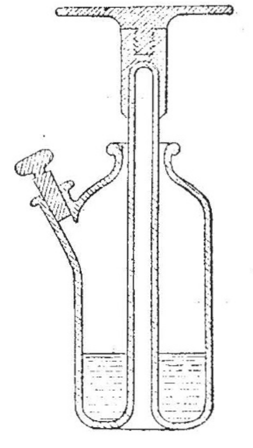
And now he had come pretty nearly to the end of his theory, and he would show them what he feared they would call an absurd representation of what he conceived the state of the earth to be. [The lecturer drew attention to a diagram of an "ideal earth," roughly showing his theory—some parts of the crust of the earth being thick and coloured darkly to indicate density; some thick and not so dense, and all admitting of volcanic eruptions from the interior, which was represented as lava.] Remember that everything here is exaggerated. It is not intended to be a correct representation. It is a caricature of the most extravagant kind; but if it conveyed to them the broad ideas that had impressed themselves upon his mind, it would be doing the right thing. He thought a large proportion of the centre of the earth is fluid and hot, and he thought that upon this there were certain divers classes of something like solid matter. In all these parts there are cracks or chinks through which volcanoes burst out where the cover of the earth is very thin. In some places you have two or three volcanoes together. There is one instance in Europe, where we have Etna, Stromboli, and Vesuvius. In this diagram he had condensed to the best of his conjectural power his supposition as to what the state of the earth really is; and if any one chose to find fault with it he would not quarrel with him. He only gave it as a sort of inference from a number of things he had said.

A NEW INSULATING STAND[1]

SIR WILLIAM THOMSON has frequently dwelt on the great importance of insulating, with the utmost care, any apparatus intended for researches relating to static electricity; he has shown that the atmosphere and other gases have but little effect in dissipating an electric charge, even when moist, and that it escapes mainly in consequence of the deposition of a layer of moisture upon the insulating supports which renders their surface conducting. In all Sir W. Thomson's electrometers there is an arrangement for drying the insulating surfaces by means of sulphuric acid, either free or absorbed by pumice. This method admits of very general application:—Any body, as for example apparatus constructed for the observation of atmospheric electricity, may be most perfectly insulated by supporting it on glass rods inserted in glass cylinders containing free sulphuric acid or pumice moistened with it. In order to do this the lower end of the rods must be either inserted into cylinders of lead or else fixed to the bottom of the jar by means of a substance not acted upon by sulphuric acid, for example, melted sulphur or paraffin; melted sulphur is liable, on account of its temperature, to crack the jars, notwithstanding the precaution of previous heating; paraffin, on the other hand, softens in the course of time, and the glass rods do not retain their vertical position. Notwithstanding these disadvantages excellent insulators may be thus extemporised as occasion may require.

[1] By M. E. Mascart, Professor of Physics, Collége de France, Paris.

For permanent use it is advantageous to employ insulators specially constructed, as shown in the accompanying figure; it consists of a bottle having a narrow neck,



through which passes a tubular continuation of the bottom, about 4 mm. less in diameter than the internal diameter of the neck, so as to leave a space of 2 mm. (about) between them. The top of this hollow rod is closed, in order that a brass tube may be cemented upon it, into which may be screwed any apparatus, as, for example, a disc as shown in the figure, a sphere, a crutch on a hoop, &c., &c. In the shoulder of the bottle is a neck, closed with a ground-glass stopper, through which sulphuric acid may be poured, in the first instance, and renewed from time to time. As the space between the hollow rod and the neck of the bottle is very small, the air in the bottle does not change very rapidly, and the sulphuric acid remains efficient for a long time. It is only necessary to run off a portion of it occasionally by means of a siphon, and to add fresh; as this may be done without disturbing the apparatus, the insulation may be maintained for any length of time. Moreover, for an insulator to be used occasionally, an addition is made of a vulcanised rubber cap, which slides on the glass rod to close the neck of the bottle when not in use.[1]

A double pendulum of pith balls supported by such an apparatus maintains its divergence, after being charged with electricity, for a very long time, even in a theatre filled with an audience. One may show by a simple experiment the great efficacy of this apparatus in comparison with insulators of glass exposed to the air, even when carefully varnished with shellac. If a pair of pith balls, suspended by a thread of cotton, is hung upon the latter support, and the metallic foot is placed on an insulator, and connected with a charged condenser, no divergence of the pith balls occurs in the first instance, but little by little the electricity is propagated along the glass rod, and then the threads near the support begin to separate, and soon after the balls diverge and remain at a certain distance from each other.

The electrometers of Sir Wm. Thomson are sometimes so perfectly insulated that the loss of a charge of electricity does not amount to $\frac{1}{100}$th part in twenty-four hours. By means of the insulator described above, one may obtain an insulation of like order for *bodies supported in the open air*, and thus diminish to a great extent one of the chief sources of error usually met with in experimenting with static electricity.

[1] These may be obtained of various sizes, one litre, half-litre, quarter-litre capacity, at Alvergniat Frères, 10, Rue de la Sorbonne, Paris.