province, so notorious for its turbulent braves, whose hostility to foreigners is proverbial. Mr. Dorward has however established the fact that a European, with two native assistants, can now traverse the province in safety. Near the city of Shênchi, some 450 miles from Wuchang, he had an opportunity of observing the processes used for extracting gold-dust from the sand, which consist in roughly sifting and afterwards using quicksilver.

THE Argentine Government has just despatched two officials to survey five thousand square leagues of country in the neighbourhood of the Neuquem, one of the chief tributaries of the Rio Negro. This extensive tract of country is close to the Andes, and is said to be extremely fertile. When the survey is completed the Government will dispose of the land with a view to its early colonisation.

THE Commercial Geographical Society of Bordeaux in its last *Bulletin* publishes a useful topographical note on the itinerary followed by the Upper Niger Surveying Expedition from Kita to Bamaku.

THE Department of the Interior in Canada has issued a new map of Manitoba and the North-West Territories, showing the country surveyed, &c., and in a later edition the line of the Canadian Pacific Railway will be shown.

WE hear that the Dépôt de la Guerre at Paris has just issued the first sheet of Col. Perrier's map of Tunis, drawn from his recent topographical survey of the country, which has been awaited with much impatience by French geographers.

PÈRE DUPARQUET, the well-known missionary traveller, who returned to South-West Africa early in October, has recently commenced the publication, in *Les Missions Catholiques*, of an account of a journey made by him through Ovampo Land as far as the River Cunene. He travelled in company with Mr. Erchison, one of the principal traders of Omaruru, who also had with him a son of the late Mr. C. J. Anderson. Père Duparquet's memoir is illustrated by a sketch-map of the region, on which is shown a singular connection between the River Cunene and Lake Etosha.

IN the new number (Heft 3, Band 4) of the *Deutsche geographische Blätter*, all the existing information on Wrangel Land and Herald Island has been collected, and will be of interest at present in connection with the missing *Jeannette*. Dr. Albrecht Penck of Munich contributes an interesting article on glaciation with special reference to Eschscholtz Bay in Kotzebue Sound on the north-west coast of America; and Herr G. Kreitner gives a detailed account of the Koko Nor and the surrounding region. There are besides a variety of notes on various points of geographical interest.

To the Austrian *Monatsschrift für den Orient* for October, M. Z. Janiczek of Port Saïd contributes a letter containing a good deal of valuable information on the trade of the Red Sea. In a letter from Herr Hansel of Khartoum we find some interesting information from Dr. Emin Bey. Among other things he tells us that there are three lakes to the north of Victoria Nyanza; that Beatrice Gulf certainly does not belong to Albert Nyanza, but to a lake lying from the south; that steamers now go regularly from Dufilé to Mahagi, a station on the west coast of Lake Albert; and that the only radical cure for the Central African slave-trade is the importation of free Chinese colonists. Prof. Blumentritt contributes notes on some important vegetable products and branches of industry in the Philippine Islands.

HEFT 1, for 1880–1, of the *Mittheilungen* of the Hamburg Geographical Society contains a paper of great interest on the distribution and relative value of cowrie shells by Herr John E. Hertz. These shells are used as money mainly in the region between the Niger and the coast of Africa, though they are also in use in other parts of the world. Herr Hertz gives the exchange value of these shells in the various regions where they are used, and traces their hi tory as a trading medium. A kindred paper, of much practical value and considerable interest, is on the barter-trade of Africa, by A. Wörmann. A long paper, with chart, on the paths of barometric minima in Europe and on the North Atlantic, and their influence on wind and weather in North Germany, by Dr. W. Köppen, is of considerable scientific interest. There is also a lecture by Dr. J. Classen on a visit to Olympia.

ACCORDING to the latest census the population of Japan on January 1, 1880, was 35,925,313. Of these 18,210,500 were males, and 17,714,813 females. When the numerous and destructive civil wars of the last twenty years are remembered, this relative proportion of the sexes will appear striking. Writers of the last century held very exaggerated notions of the population of Japanese towns, but the present census shows that some of them may properly rank among the most populous cities in the world. Tokio and its environs has a population of 957,121; Kioto, the old capital, of 822,098; and Osaka, 582,668. The smallest population of any district is that of the Bonin Islands, recently annexed to Japan, which contain only 156 inhabitants, composed of officials and descendants of Kanakas and deserters from English and American whaling vessels.

CAPT. JOHN MACKAY, of the ss. *Southern Cross* (Auckland), sends us, along with a note, an account by himself in the *Queenslander* of his discovery and settlement of the district of Mackay in Queensland. To the now flourishing town of Mackay we referred some time ago in connection with a special number of the *Mackay Standard*. The town bids fair to become one of the most flourishing in Queensland, though its discoverer does not seem to have met with the recognition he deserves.

SOLAR PHYSICS[1]

II.

AT the conclusion of my last lecture I stated my belief that those changes which are continually going on at the surface of the sun had their origin in currents of convection, and I illustrated the processes which are there going on by what we know to be going on on the surface of our own earth. I referred, but only historically, to a theory which was thrown out many years ago as to the origin of solar heat by Sir William Thomson, according to which it depended on the impact of meteoric bodies. I did not suppose at the time that he still retained that theory, regarding it as the most probable; in fact he gave it up many years ago, and I was glad to find, from conversation with him after the lecture, he is quite of the same opinion as I am, that these disturbances—the enormous disturbances which take place at the surface of the sun, have their origin in currents of convection. I stated my belief that the spots were produced by the downward rush of, comparatively speaking, cool portions of gas which had been in the first instance ejected during these eruptions. In speaking to Mr. Lockyer afterwards I found that he had obtained independent evidence from his spectroscopic researches that these spots consisted of down-rushes of gas, and not, as some have supposed, of up-rushes. He may have mentioned it to me before; if so I must apologise for it having passed from my memory. I will not however say anything about the evidence on which he was led to that conclusion, because he is going to lecture himself, and of course he will be the proper person to explain his own discoveries.

Now with regard to these spots I have hitherto said nothing except as to their existence. The German astronomer Schwabe assiduously observed them in the beginning of 1826, and for about a quarter of a century he went on constantly observing them and making careful drawings of them. As the result of this long-continued and careful work, he was led to the conclusion that these spots as to their frequency and magnitude appear to be subject to a periodical inequality. The period appeared to be about ten years, during which, supposing you start with the maximum of spots, they dwindle away to the minimum, then after some years again rise afresh, and by the end of ten years or thereabouts you get to the maximum. M. Wolf of Berne has discussed the subject, and referred back to older observations, and was led to the conclusion that the period was longer than ten years. He makes it eleven years, or perhaps more exactly nine periods per century.

I will now come to some phenomena observed on the earth with which the solar spots would, at first sight, appear to have no possible connection. You are all, of course, familiar with the magnetism of the earth, by the aid of which our ships are navigated through the ocean. Now it has been long known that the magnetic needle is subject to disturbance; by the magnetic needle I mean the magnet suspended so as to turn freely round a vertical axis. For a long time after the discovery of magnetism that was the only kind of instrument used for the observation, and it had been observed that these disturbances were of two kinds. There was a regular diurnal movement of the needle to the west, and then to the east, of its mean position,

[1] Lecture by Prof. Stokes, Sec.R.S., in the South Kensington Museum Theatre, continued from p. 598.

and besides that there were from time to time irregular, or apparently irregular, disturbances following no observable law. It was known, too, that the diurnal fluctuation, which has now been known considerably more than a century, was greater in summer than in winter. It had been also observed that these apparently irregular fluctuations in the direction of the magnet are observed when an aurora is seen.[1] If there is an aurora there are sure to be these fluctuations, and if there are these fluctuations the probability is, if other circumstances permit, that we shall see an aurora. The connection between the two was made out about the year 1750, so that it is by no means new. Of course we cannot expect that for every magnetic disturbance we shall have a visible aurora; for in the first place the disturbance may take place in the day-time, in which case of course no aurora can be seen; then, supposing even it takes place at night, it may be that at the time the whole sky is covered with clouds, which prevent the aurora being seen; or again, it may be a bright night with the moon shining brightly, not far from the full, and then a faint aurora would not attract much notice. In fact I have often felt in doubt when I saw a luminous streak in the sky on a moonlight night whether it was an auroral streamer or merely a mare's-tail cloud illuminated by the light of the moon. After watching some time one can generally determine which it is, because if it be an auroral streamer it is pretty sure to be unsteady; but if the observer happens to have a small spectroscope in his pocket, or even a prism and a slit, the distinction can be made out at once, on account of the peculiar spectrum of auroral light.

There appears then to be evidently some intimate connection between magnetic disturbance and the aurora. The recent progress of telegraphy has caused us to be familiarly acquainted with another electrical phenomenon, or, if you like, magneto-electrical. (I assume here that the aurora is an electrical phenomenon—that, in fact, has long been admitted—for considerably more than a century.) I allude to the earth-currents. In telegraphy we have occasion to use insulated wire, the ends of which are placed, or may be placed, in connection with the earth. Now when that is done it frequently happens that, without sending any current from the battery at all through the line, there is a more or less powerful current transmitted along the wire, which is made evident by the deflection of the galvanometer. In fact, in certain cases these currents are so strong that they interfere with the working of the lines.

At the failure of the first Atlantic cable in 1865, Sir William Thomson (whom I am happy to see before me) made some experiments with these earth-currents, as they are called, transmitted through this cable. The failure was of such a nature as would have been caused if there was a breakage in the cable something like 300 miles off, and currents were transmitted through the cable, indicating an electromotive force, as it is called, amounting to one or two Daniell's cells; on one occasion to five or six; and currents more powerful even than those are observed from time to time.

Now it is well known that at times of magnetic disturbance we have these earth-currents powerful; and as I mentioned that magnetic disturbances and auroræ come together, we have here a third phenomenon, that of earth-currents, which accompanies the two former. These three are evidently intimately connected with one another, whatever be the cause of that connection. But at present I have said nothing whatever of the relation of these three phenomena to the sun. Of course any one would say there is the remote relation, that it is to the radiation from the sun that all the great changes that take place on the surface of the earth are due: the evaporation of moisture, the heating of the air, and consequent production of winds; and in a remote sense, therefore, there would in all probability be a relation between these three phenomena and the sun. But that relation is very far from remote. I forgot at the proper time to mention one circumstance connected with these earth-currents before I came to the sun, which, if you will allow me, I will do now. I mean the magnetic disturbances.

One of the first fruits of the establishment of regular magnetic observatories was the remarkable discovery that these magnetic storms occurred simultaneously over large tracts of the earth's surface; so that even the sudden and apparently capricious variations of say the direction of the declination needle would be observed simultaneously at the same moment of absolute, not local time, at places far separated from one another, such as London and Paris, and London and Lisbon even.[1] The cause of this magnetic disturbance, whatever it may be, must be one very widely spread. In discussing the results which have been obtained at the colonial magnetic observatories, Sir Edward Sabine made a remarkable discovery, namely, that whether you take the range of ordinary diurnal fluctuations of the magnet, or whether you take the frequency and magnitude of these magnetic disturbances that I spoke of, in both cases there appeared to be a decennial period, or a period nearly decennial, and that corresponded to the period of solar spots, corresponded not merely as to the duration of the period, but also as to the time of the maximum; so that in those years when the sun showed an unusual number of spots of unusual magnitude, both the regular diurnal variation of the magnet was greater than the average, and there were more numerous and more violent magnetic storms; on the other hand, when the sun was comparatively free from spots, the magnetic elements were, comparatively speaking, in a tranquil state. In the older observations the declination was the only one of the magnetic elements which had been observed, but all three components of the magnetic force were observed in these observatories, and accordingly the phenomena could be more searchingly investigated. Further research has fully confirmed this connection, so that there can be no doubt now that there is some intimate connection, whatever be its nature, between solar spots and magnetic disturbances.

I will mention one circumstance which is a remarkable corroboration of this observation. The late Mr. Carrington for many years was engaged in a series of most careful and elaborate measurements of the positions and magnitudes of the solar spots. The way he worked was by throwing a large image of the sun by means of an equatorially-mounted telescope, with its eyepiece suitably focussed, on to a fixed screen. One day he was engaged at this work when he saw two bright spots on the screen. His first impression was that the screen which was used to shut off the light of the sun, which otherwise would have passed down outside of the object-glass of the telescope, outside the tube, had got disarranged somehow or other, and that it was merely the sun shining through the holes, and coming on the screen. He moved the telescope a little, and these spots moved with the image of the sun, proving that it was not merely the sun shining through holes in the shading screen, but that they really belonged to the sun. They remained visible some minutes, during which they moved over a very sensible portion of the sun's disk at such a rate that the actual lineal motion of them must have been—I forget the figures, but I think it was something like 100 or 150 miles per second. Moreover one of them passed over a dark spot, which is confirmatory of the old observation of Wilson, that the spots are at a lower level than the general surface of the sun.

Now it so happened that on examining the records of the magnetic needle, which were kept automatically by a photographic process at Kew, just at the moment when these spots were seen, there was an unusually great magnetic disturbance. Well then, what can be the connection between these apparently so dissimilar, apparently so disconnected phenomena, and what is the cause in the first instance of the three terrestrial phenomena I first mentioned—magnetic disturbances, auroræ, and earth currents?

Different theories have been started as to this connection. Some have supposed that the disturbance of the magnetic needle was an electro-magnetic effect due to the earth currents; others have supposed, on the contrary, that the earth currents were due to the electro-magnetic induction produced by a change in the magnetism of the earth. But what of the auroræ? It has long been recognised that the aurora is an electrical phenomenon. It has been supposed to be imitated—and there can be no reasonable doubt that the supposition is a correct one—by sending an ordinary electric discharge through a highly-exhausted tube. But whence comes the electromotive force requisite to effect that discharge? My colleagues are not in any way responsible for what I am going to advance. I am going to suggest a cause for this phenomenon which, so far as I know, has not hitherto been broached,[2] and of course you must take it for what it is worth. It has not seen the light, and therefore has not had the opportunity of being subjected to the criticism of men of science. If laboratory experiments are to be any guide to us it requires no

[1] At least of the dancing kind; faint, steady auroræ do not seem to be accompanied by sensible magnetic disturbances.

[1] A number of photographic records from various magnetic observatories have recently been compared and discussed by Prof. W. G. Adams.

[2] This refers to the theory as a whole; the individual parts of it had mostly formed limbs, so to speak, of one or other of a set of theories which, taken in their entirety, must be regarded as quite different.

inconsiderable electromotive force to send an electric discharge through even a moderate length of rarefied air, though it passes far more freely through rarefied air than through air at the ordinary pressure. I will endeavour to show you that experimentally.

[An experiment was here exhibited in which the coatings of a Leyden jar were connected with the terminals of a Holtz machine, and also, by two branches, with each other, each branch involving an interruption by air. One branch led through a universal discharger, the brass knobs of which were separated half or three-quarters of an inch, the other through a long tube filled with rarefied air—a so-called aurora tube. The second branch being at first broken, the knobs were adjusted to a distance not too great to allow the spark of the jar to pass without fail. The connection with the terminals of the aurora tube being now restored, the discharge, which was at liberty to pass by either branch, chose the aurora tube.]

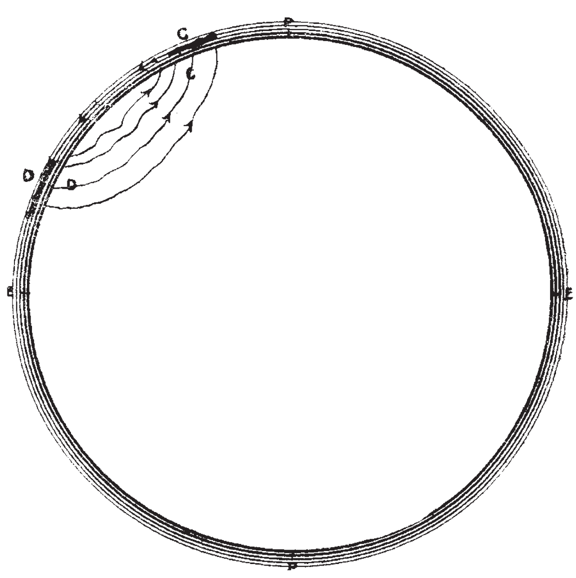
It appears then that the resistance to the passage of the electric discharge is greater across about three-quarters of an inch of air at ordinary pressure than across the whole length of the tube, which I suppose is somewhere about five feet, so that, although there is considerable resistance to the passage of the electric discharge through rarefied air, it is very much less than through air at ordinary pressure; but although it is very much less, it is very far indeed from being inconsiderable. Mr. De La Rue has a splendid battery of about 11,000 cells of chloride of silver. It required about 2000 of these to send electric discharges through tubes perhaps two or three-quarters the length of that, but not quite so broad, exhausted to such a degree as to oppose least resistance to the passage. We see then that, if one may judge by laboratory experiments, it requires a very considerable electromotive force to send an electric discharge through even a moderate distance in rarefied air.

Now attempts have been made to measure the height of the aurora, and very large figures have been brought out. It is said to be fifty or sixty, or even eighty miles high; I think some have made it even higher than that. It is a difficult matter of course to measure with much certainty, because you want a base to measure from; and the two stations must be distant a few miles, in order that you may get a sufficient angle of parallax. Then with observers situated a few miles apart it is a difficult matter, with such a variable and indefinite phenomenon as aurora, to fix on what they should observe. Possibly in the future, when such observers may be put in connection by telephone and be able to speak to one another and tell each other what sort of aurora they see, and settle by conversation at that distance what particular part they shall observe, we shall get more certain results. However, there can be no doubt that, although there may be some uncertainty as to the precise height of the aurora, it is very high indeed.

Now, even in spite of this great height, the auroral streamer subtends a very considerable angle at the eye of the observer. If this be a discharge, the length of that discharge must be very considerable, probably many miles. Where shall we get the electromotive force sufficient to send a discharge through so great an interval of air, rarefied though it be, and that not too highly? I say "and that not too highly," because experiments with exhausted tubes have shown that the resistance to the passage of the spark through the tube goes on diminishing as you make the exhaustion higher, until you reach a certain point, after which it goes on increasing again, and this exhaustion, at which the resistance to the passage of the discharge is least, is by no means very considerable as exhaustions go nowadays. Tubes have been so exhausted that rather than strike across a millimeter within the tube from terminal to terminal, the discharge would pass some inches outside in air. Well, then, it would appear from that that we do not gain so very much as regards facility of passage for an electric discharge by going up to a tremendous height in the air. Where then can we get an electromotive force sufficient to send an electric discharge through such a length? Sir William Thomson, in the case of the Atlantic cable which failed the first time, as I said before, obtained earth-currents indicating an electromotive force of a few Daniell cells; but a few Daniell cells, or a few scores of Daniell cells, or a few hundreds of Daniell cells would be quite insufficient for sending a discharge through such a space as I have spoken of, if laboratory experiments are to be any guide. There is, however, one instance of electric phenomena where we have tremendous tensions to deal with—I mean atmospheric electricity. In the case of the atmosphere we may have the electric spark striking all the distance from a cloud to the earth, perhaps half a mile or a mile. I need not say that the electric spark I refer to is a flash of lightning. Here I found some difficulty in getting the discharge to strike through air of ordinary density, across more than about three-quarters of an inch, but in lightning it strikes all that distance that I mentioned. Atmospheric electricity of tension sufficient to strike across a mile of air at ordinary density (or at least slightly reduced as you go up) might have an opportunity of striking across many miles of rarefied air, and if the experiment which I have showed you just now with that tube is to be any guide, then it would be competent to do so. In atmospheric electricity it is conceivable that we may have a sufficient tension to cause the electric discharge to strike across that great distance which the length of an auroral streamer must be.

It has long since been remarked that displays of auroræ seem in some way or other in high latitudes to take the place of thunderstorms in low latitudes. Well, then, I will endeavour to explain what I imagine takes place. I do not enter into any speculation as to the cause of atmospheric electricity. We know as a fact from its manifestation that it exists, and that is sufficient for my purpose. Suppose now that the air, especially the higher portions of the air, over a large tract of country, say to the north of us, were more or less highly electrified—positively or negatively, as the case may be—we will suppose positively—if the electric tension were sufficient, although, considering that the air is a non-conductor, we might not have a flash of lightning, which gathers into itself in one moment the electricity from an entire cloud and sends it down into the earth (we might not have tension enough to produce such a discharge, the resistance to the passage of electricity from one portion of the air to another, which at any rate would be comparatively dry compared with what we have in warm latitudes, would prevent it by itself alone), we might nevertheless have a discharge taking place in the higher regions of the atmosphere where the air is rarefied, and accordingly opposes less resistance to the discharge.

Now let me refer to this figure. This great circle, P E *p e*, I suppose to represent a section of the earth by a plane passing



through its centre. This blue [faint in cut] outside represents the atmosphere, the height, of course, being enormously exaggerated, in order to make it visible at a distance. Suppose in some way or other a portion of this upper atmosphere, as C, got considerably charged positively or negatively, say positively; it would act by induction on the earth below. The opposite electricity, negative in that case, would be accumulated underneath, as at C, and this portion of the earth would form, as it were, a portion of a Leyden jar, the lower atmosphere being the di-electric or glass of the jar, the upper atmosphere being partly, you may say, the di-electric and partly also the charged coating. It would be represented more precisely by an imaginary coating outside composed not of tinfoil, but of some badly-conducting substance. The positive electricity about C would be bound down in part by the negative electricity about C, which it induces. In another portion of the atmosphere—it may be at some considerable distance from the former—you may have the atmosphere charged in an opposite way, and of course if this were negative there would be induced positive electricity below, or it might be that the whole of the atmosphere from C to D is charged positively, but at D the negative charge is much feebler than at C. The end-result would be the same; but for facility of explanation I will suppose that the upper portion in one place is actually charged with electricity of the opposite kind to what the charge is at the other. If the tension were sufficient, then there might be a striking across of the electricity of this name in the atmosphere from C to D, and in the earth in the reverse direction. Compared with the atmosphere, the earth would be an exceedingly good conductor, so that the electromotive force concerned in sending the currents from one part of the earth to the other would be, comparatively speaking, trifling, and therefore the electromotive force represented perhaps by a few scores of the elements of a Daniell's battery. Well, then, in atmospheric electricity we appear to have the tension requisite to send the discharge through a considerable space of rarefied air. Now if a discharge took place, and if it were night, and the sky were clear, it would, at least where sufficiently concentrated, be visible to us just in the same way as the discharge passing through the exhausted tube is visible, by the light it produces. It would produce in fact an aurora. The air is not a comparatively good conductor, like a thunder-cloud, from which a great quantity of electricity strikes in one moment, but is, after all, a bad conductor, so that the electricity can only pass in a spitting sort of way. We may conceive here that we have a sort of double current, yet not forming a complete circuit; nevertheless a discharge would go on nearly of the same nature as if the circuit were complete, and the effect of such a discharge on the magnetic needle would be nearly the same as that of a circuit which was complete. I will endeavour to produce a discharge in a circuit which is doubly incomplete.

[An experiment was here shown in which two Leyden jars were charged, one positively, and the other negatively, and were laid on the same wire resting on a table. On connecting the knobs the jars were discharged, and that almost completely, as it happened that the charges were almost exactly equal. The inner coatings here represent two portions of the upper atmosphere, the outer coatings the opposed portions of the earth's surface, and the glass of the two jars the intervening portions of the lower atmosphere.]

As I said, although the circuit is not complete, the electro-magnetic effect of the whole system would be nearly the same as if you had a complete circuit with an electric current passing through it. Now if there be only a sufficient quantity of electricity, we have here the elements necessary for producing a disturbance of the magnetic needle. Moreover, those disturbances, as the instruments show, are of a most fitful and apparently capricious character. They resemble in that the fitful character of electric discharges through air. I need hardly say that according to this theory the earth-current consists in the return currents produced by the statically-induced change on the surface of the earth, induced by the charged atmosphere above. When there is a neutralisation of the electricity from one part to another of the atmosphere above, the induced electricity in the earth is set free, and we have earth-currents to bring about the redistribution of the electricity on the surface of the earth.

It seems to me that this theory not only accounts for the connection between the phenomena, which could be otherwise accounted for, but enables us to conceive how it is that electricity strikes across such enormous distances in the upper regions of the air, and I think, further, it will account for some interesting features of the electric discharge which constitutes no doubt itself the aurora. I have here a sheet of blotting- or filtering-paper, and I will suppose this to represent an electrified tract of air lying over, it may be, an extensive tract of country, say somewhere to the north of us. Suppose that this air is charged positively, it will induce negative electricity on the earth below. This metallic coating on this sheet of glass [over which the blotting-paper was held horizontally at a little distance] may be supposed to represent the surface of the earth on which this negative electricity is induced. The two may be quietly in equilibrium. Suppose, however, that from some cause or other the tension becomes sufficient to enable the electricity from some point in this stratum of air to strike across higher up—because the streamers are found to be parallel to the direction of the dipping-needle, and parallel accordingly to the lines of magnetic force—higher up in the first instance; from thence I do not know where the discharges go, but I should suppose that in our country they generally go somewhere to the south of us. Now if a tract of air were pretty uniformly electrified, it would induce electricity of the opposite name underneath it, pretty uniformly distributed except about the edges, where the electrified air which was the inducing body would tend rather to overlap the electrified portion of the earth below, and where accordingly, if the charge were the same throughout, there would be the greatest tendency for the electricity to strike off and pass into the upper regions of the atmosphere, and thence probably to the south. Well, suppose now that a discharge begins anywhere, say somewhere along this edge of the paper, which I will suppose to be the northern edge. The paper which I hold in my hand is really touch-paper (such as boys use for amusement), and I will light the edge of it. Now this smouldering away of the touch-paper I conceive to represent the mode in which the rarefied air becomes successively discharged. Suppose that a discharge takes place somewhere about the edge of this sheet of electrified air covering a large tract of country, then if once a hole (so to speak) were formed, the tendency would be for the discharge to continue along that edge, because, as I said, as soon as the electricity at the edge was discharged the electricity of opposite name which had been induced on the surface of the earth below would be set free, the earth-current would be set up; and then again, what now is the edge of the electrified tract of air would be left exposed, no longer protected in the same manner as before by the induction of the electricity of opposite name beneath; the electricity would fly off from it in turn, and so on, so that there would be formed a sort of curtain composed of auroral rays, and gradually advancing, in our country usually in the direction from north to south; because we live in a sort of neutral region not too far south to see the aurora from time to time, and not far enough north to be exempt from thunder-storms. This auroral discharge, which takes the place of thunder-storms in lower latitudes in some way or other, usually occurs to the north of us, and accordingly the aurora is called the Northern Lights; but when there is a fine display it sometimes reaches down to us and goes south of us. So I say the discharge would usually begin from a place north of us, and would creep along the edge of the electrified stratum of air, forming a sort of luminous curtain, and passing from north to south, just as the smouldering edge of the touch-paper passes along the paper gradually. When we are just under the edge at which the discharge takes place we have, as I conceive, an auroral arch passing, it may be, through the zenith, generally stretching also east and west, and generally moving with a slow motion from north to south.

Now supposing that that is the explanation of the three phenomena—magnetic disturbances, earth-currents, and auroræ—can we in any way connect their occurrence with changes going on at the surface of the sun? I think we can. We know that a tube containing rarefied air, supposing the density of the air in it is given, opposes less resistance to the electric discharge through it when it is warm than when it is cold. The conducting power of a wire for electricity decreases if you heat the wire, but it is the reverse with air. The passage of electricity through rarefied gases is very different in its nature from the passage of electricity through a wire or through an electrolyte. Mr. De La Rue has shown in the course the researches made by means of his splendid battery, that in these highly exhausted tubes the electric discharge, be it ever so steady to all appearance, obeys laws connecting it rather with a series of disruptive discharges, with a rapid succession of sparks, than with a discharge passing through a wire. Now connected with that difference, or at least accompanying it, there is that opposite action of heat which, as I say, in the case of gases renders the passage of electricity more easy instead of less easy. We may imagine that if from any cause the sun gives out greater radiation than usual, the upper regions of the atmosphere may thereby become heated to a certain extent[1] and oppose less resistance to the passage of the electric

[1] The rays of the visible spectrum, and even the invisible rays for some considerable distance beyond the extreme violet, pass freely through clear air, which could not therefore be sensibly heated by them. But there is reason to think that the atmosphere, or some of its constituents, are more or less opaque to rays of very high refrangibility; and it is just for copious emission of these that sources of radiation of an excessively high temperature are so remarkable. The substance, which is opaque to the rays of excessive refrangibility, and consequently enables them to heat upper regions of the atmosphere, is probably not nitrogen or oxygen, but some gas or gases present in very small quantity.

discharge through it than they did before. In this way we may conceive that in a great outbreak like that observed by Mr. Carrington, where the hot interior of the sun is turned up, as it were, and radiates towards the earth, the facility for the passage of the electric discharge is increased, and it may be very rapidly increased. So that according to this theory the foundation of these three phenomena lies in atmospheric electricity, which forms as it were the magazine, and the solar radiation, as it were, supplies the match, and allows it to be discharged. Of course, over and above that, when solar radiation is active, all the phenomena which depend on solar radiation may be expected to be active too; and therefore beyond its influence in firing the match, to speak metaphorically, this solar radiation, when more active than usual, and lasting, will also produce a more rapid development of all those processes at the surface of the earth which depend on solar radiation, among others, no doubt, the generation of atmospheric electricity, although we are not at present able to explain with certainty the manner in which it is produced. So that in two ways, by applying the match to the train already laid and by gradually manufacturing the powder, the increased solar radiation may cause an increase in those electric discharges and earth-currents as the result of the redistribution of the induced electricity at the surface of the earth, and thereby a disturbance of the magnetic elements. I do not know of any other theory than that of atmospheric electricity which furnishes anything like sufficient electromotive force to account for these auroral discharges, if they are really electric discharges analogous to those which take place in exhausted tubes. As I said, it has been supposed by some that the magnetic disturbances are due to earth-currents; according to the theory which I have advanced, they are due rather to a vast assemblage of currents, partly atmospheric and partly terrestrial. An objection has sometimes been taken to the supposition that the magnetic disturbances are due to earth-currents arising from the consideration of the electro-magnetic effect which the earth-current actually observed would have upon the needle. But this, I think, is obviated when you remember that an earth-current actually observed is merely what results from the examination of a very small portion of this vast electric system, stretching it may be over hundreds of miles of country. At Greenwich, for instance, there are now wires by which earth-currents are regularly observed. The coincidence between photographic traces left by the earth-currents and those left by the magnetic storms is most remarkable. Every peak of the one, you may say, answers to a peak of the other. It has been noticed, however, that there appears to be a slight difference in the time of the occurrence. It would appear as if the disturbances preceded the earth-currents. Well, that may very well be, because, according to the theory which I have advanced, the effect on the magnet is the resultant effect of a vast series of currents, partly terrestrial and partly atmospheric, stretching over a very large region of country, whereas the earth-currents observed are merely obtained by tapping the earth at a couple of places at no great distance, so that the two do not by any means necessarily correspond exactly.

I forgot to mention at the proper time a diagram which Capt. Abney has kindly prepared for me. This is a copy of the diagram made by Mr. Ellis of the Royal Observatory, giving the result of his discussion of the Greenwich observations on two out of the three magnetic elements, namely, the declination and horizontal force, as compared with sun-spot frequency. [Mr. Ellis's diagram in Part ii. of the *Philosophical Transactions* for 1880 was then referred to.]

You see that an examination of the phenomena going on at the solar surface itself leads us to the conclusion that there are vast currents up and down, by means of which the comparatively speaking cool upper portions are continually replaced by hotter matter from beneath. Mr. Lockyer, in the lectures he is about to give, I have no doubt will have a great deal of very interesting evidence derived from spectroscopic study of the phenomena to lay before you, bearing out that same conclusion We have seen that the supposition that there is extra radiation when the interior portions of the sun are ejected and come to the surface, falls in very well with the known relationship between the occurrence of sun-spots and the three terrestrial phenomena I have mentioned—magnetic disturbances, auroræ, and earth-currents. I say between the sun-spots, although it is not, strictly speaking, the sun-spots themselves, but the tremendous disturbances which are their precursors, and of which they form the most easily-observed manifestation.

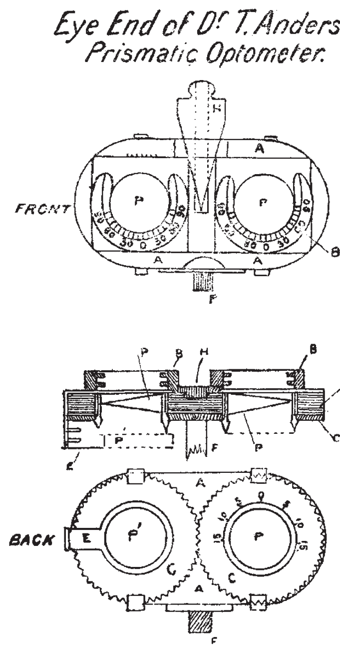
Now if there is reason to believe that, when the sun is in a state of activity in this manner, there is increased radiation from it, it may well be that the meteorology of the earth is affected by the changes which take place at the surface of the sun; but the meteorology of the earth forms an exceedingly complicated problem. We have, so to speak, to deal here with a very complicated integral of a differential equation. I am speaking somewhat metaphorically, but my words will be understood by the mathematicians who happen to be present. We cannot very directly connect that integral with the disturbing forces. One thing, however, we may say: supposing that there is a system of any kind subject to periodic disturbing forces—and we have seen reason to believe that these great eruptions which take place on the surface of the sun are, perhaps somewhat roughly, periodic—if, I say, we have a periodic system of disturbing forces, then the system which is acted upon by these forces will show a periodic disturbance which may be more or less concealed by apparently capricious disturbances, but which yet may be expected to come out in the long run; and it has been supposed by those who have studied meteorological phenomena that there are indications of a decennial, or nearly decennial period in some of the meteorological elements, for instance, the mean temperature of the air and the fall of rain. Again, in some observatories thermometers have been sunk to a considerable depth in the earth, and observations of such thermometers were carried out for a great number of years by the Astronomer-Royal of Scotland, Prof. Piazzi Smyth, and they are regularly carried out now at Greenwich. Connected with the annual variation of temperature between summer and winter there are, so to speak, waves of heat and cold slowly propagated down from the surface of the earth to the interior, rapidly decreasing in amplitude as they descend, and by going a suitably moderate depth you get these fluctuations, indicating the annual fluctuation of the atmospheric temperature, and free in a great measure from the fluctuations which take place at much shorter periods. When you go a little way down the results given by these thermometers seem to indicate something of a decennial or nearly decennial period. Conflicting statements, however, have been made by different observers as to the time of maximum of the meteorological elements which were supposed to have such a period, and some have argued from the results that when the sun was in a highly spotted condition we had a higher temperature than usual, and some the reverse. Now this is an important matter to attend to. Suppose we had such a system acted on by periodic disturbing forces; it will show at least in the mean a corresponding periodic fluctuation, corresponding however only as regards the length of the period. The epoch of maximum of the element observed, whatever it may be, has no necessary relation to the epoch of maximum of the disturbing forces, excepting that they are separated by a constant interval, and the epoch of maximum of the element observed may be different at one locality from what it is at another. So that it is only the period and not the epoch of maximum which you can expect to arrive at possibly by an observation of such elements as I have spoken of. It is very difficult indeed to say, even if a ten-yearly period be observed, what ought to be the year of greatest solar radiation if we have given the observed results.

Is there any way in which we may hope to attack that problem? I think there is. It is by no means hopeless to attempt to measure by a direct process the solar radiation. Instruments have been devised for the purpose, called actinometers. One was devised by the late Sir John Herschel, and goes by his name, and it is a very beautiful instrument; but unfortunately it is excessively fragile, and if the instrument has got rough travel or rough work at all to go through, it is pretty sure to be broken. Other instruments have been devised for the purpose, and among them I may mention one by Prof. Balfour Stewart. He has lately devised a new actinometer, and one of his construction has recently been sent out to India, and is at present under trial. In these cases heat is observed by a thermometer. Another has been devised by Prof. Roscoe, depending on the chemical action of radiation. I think none of these have yet had a thoroughly complete trial, because in such a climate as ours a fair trial can hardly be made, since there are so many disturbing elements in the lower atmosphere. An exceedingly slight cirrus-haze makes an enormous difference in the amount of heat radiated from the sun as received by us without being deflected from its course. If there be the slightest haze a good deal of the heat rays are deflected from their course, perhaps not much deflected, so that if we take in the direction of the sun itself and the neighbouring directions from the sun for some considerable distance all round it, the totality of radiation from that portion of the heavens may not be so much inferior to what it is when there is none of that slight cirrus haze there. But still we have haze enough in the lower regions, and besides that we have water in an invisible state of vapour, and Dr. Tyndall has shown that that absorbs with great avidity a portion of the heat rays. Those, however, are mainly rays of very low refrangibility. Still the absorption of these may very sensibly affect the totality of radiation received from the sun. How then shall we, if possible, get rid of these sources of disturbance? The best plan seems to be to take observations at a considerable altitude, where if possible you may get many thousand feet above the level of the sea and get rid of the lower, dustier, hazier portion of the atmosphere, and get rid also of by far the greater portion of the aqueous vapour, which by itself alone would absorb a portion of the heat. That is what the Committee on Solar Physics have attempted to do. We contemplate having actinometric observations made in the north of India. Of course, if observations are to be continued, it is not sufficient to go to some high mountain. You must go to some habitable place where the observer can live and be in some sort of comfort. Now in the Himalayas you may get up to many thousand feet and yet be still within reach of human habitations; or what is better still, if you cross the range and go over into Thibet, you have there a high table-land many thousand feet above the level of the sea, with a sky usually cloudless, and where observations of this kind may, it is hoped, be made with success for a considerable period together, and the result may, we hope, in time throw light on the question whether or no there is in reality a change in the amount of radiation received from the sun, and whether the amount of that change is sufficient to make any material difference in the meteorological conditions of our globe.

I have spoken of meteorological elements in which various observers suspected that they saw some indications at least of a decennial, or nearly decennial, period. Speculations have been made as to whether there is not a decennial period, or something of the kind, traceable even in the occurrence of Indian famines. If so, there may be some very close relationship between the solar spots and these famines. At first sight one would be disposed to say, "What possible connection can sun-spots and famines have with one another? You might as well speak of the connection between comets and wars!" But when we go deeper below the surface, and study carefully the phenomena presented to our view, we see that a possible connection between such apparently remote things as sun-spots and famines may not be chimerical; and there is no saying what practical application may in the end result from a study of solar phenomena undertaken in the first instance for a purely scientific object.

A PRISMATIC OPTOMETER[1]

It is well known that in the normal eye, with its accommodation relaxed, parallel rays of light, that is, those from distant objects, are brought to a focus on the retina. Rays from near objects are divergent, and if they enter such an eye they are not brought to a focus on the retina, but would be at some point behind it. In order that they may be so brought to a focus and form a distinct image on the retina, an effort of accommodation is necessary. This is performed by a small muscle called the ciliary muscle, inside the eyeball, the ultimate effect of whose contraction is an alteration in the shape and perhaps the condition of the lens, which causes the rays to be more strongly refracted, and brings them to a focus on the retina. The effect is in fact the same as if a convex lens were added to the optical system of the eye. As age advances, the muscle and lens become stiffer, and work with difficulty. They are relieved of part of their work by putting a convex glass in front of the eye. Hypermetropia is a condition in which the axis of the eyeball is too short, compared with the refracting power of the lens. In it an effort of accommodation is necessary to see even distant objects clearly, and a still stronger effort to see near objects. A person suffering from it requires convex glasses. When both eyes are used together, the optic axes of both are directed to the object, so that in looking at a distant object they are directed parallel, and in looking at a near one they converge. These movements are effected by the external muscles of the eyeball, which are supplied by branches of the same nerve as the ciliary muscle. As a fact these movements of the ciliary muscle and of the external muscles of the eyeball are associated, or habitually performed in conjunction; that is, the brain has become accustomed to send an impulse to the one set of muscles proportionate to that sent by the other. Any disturbance of this association can only be accomplished by a distinct effort which, if severe or long continued, is apt to be painful. Suppose a man has become presbyopic, *i.e.* his accommodation has gradually become stiff, and its range reduced. In order to accommodate for rays from an object at the ordinary reading distance of ten or twelve inches, he has now to exert an effort equal perhaps to what he would have employed when young on one four inches off, but the change has been gradual, and the convergence of the eyes for twelve inches has become associated with this amount of effort. If he now use convex glasses of suitable power, the want of refracting power is supplied, the effort of accommodation is reduced to its natural amount, but the amount of convergence which has become associated with this small effort is now insufficient, and the eyes, instead of converging to twelve inches, converge on a point several feet distant, so that double vision would be produced, unless by a distinct effort the eyes were converged more, and



A, main frame carried by F, graduated rod; C, rotating frame carrying P P, prisms; E, frame carrying P', third prism; H, wedge to separate B B frames for lenses.

this effort is often painful, and is expressed by the term that the spectacles "draw" the eyes. After a time new associations are formed, and the spectacles can be used comfortably; but this does not happen in all cases, and for these it is necessary to grind the lenses on glasses of prismatic section. The action of the prism is so to bend the pencils of rays coming to the eyes that they appear to diverge from a point corresponding to the new focal distance of the eyes provided with the spectacles. Sometimes the amount of prismatic effect required is calculated, but the calculation, being based on general considerations, does not always suit individual persons; at other times prismatic glasses from a trial case, are combined with the calculated spherical, or spherical and cylindrical glasses, until one is found with which vision is comfortable. In many cases it is not necessary to use glasses specially ground on prisms, but sufficient to move the centre of the glasses nearer together. The glass being thicker in the centre, looking through the part near the edge produces an amount of prismatic effect which is often sufficient. If concave glasses are used, as in cases of short sight, then they must be further apart than the distance of the eyes, in in order to produce this effect. The object of the instrument exhibited is to find experimentally the amount of prismatic power, and the distance of the centre of the lenses which is

[1] "On a Prismatic Optometer," by Tempest Anderson, M.D., B.Sc., read at the York meeting of the British Association.