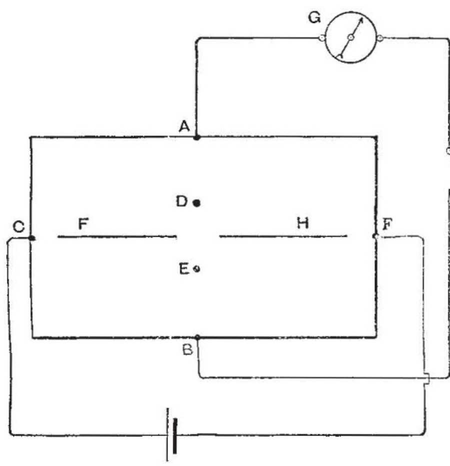
THE REVERSAL OF HALL'S PHENOMENON

In a recent communication to the Physical Society I mentioned among other things that I had succeeded in reversing the direction of the Hall effect in iron. It was, however, found to be so exceedingly difficult to keep the two points where the galvanometer connections were made at the same potential, even for a few seconds, that the extent of the deflections due to the Hall effect could only be roughly guessed at, and the experiment was hardly a satisfactory one. I believe this inconvenience arose from the fact that the iron, being a strongly magnetic metal, was slightly displaced whenever the polarity of the electromagnet was reversed, thus shifting the points of contact with the galvanometer wires. I have since repeated the experiment with gold, which turns out to be perfectly easy to work with, and altogether more suitable for the purpose. The following is an account of four experiments:—

Experiment 1.—A piece of nearly pure gold foil 5 cm. long and 3·5 cm. broad was cemented to a plate of glass and the whole placed between the flat pole pieces of an electromagnet. The middle points, A, B (see figure) of the longer sides of the foil were connected to a galvanometer, G, and the middle points, C, F, of the shorter sides to a battery. A current was passed through the metal from left to right, and the electromagnet



excited so that a south pole was beneath the glass and a north pole above it. The galvanometer was immediately deflected, indicating a current flowing in the direction B G A. If either the polarity of the magnet or the direction of the current through the foil was reversed, the transverse current was also reversed and flowed in the direction A G B. This is the ordinary "Hall effect," and the direction of the transverse currents agrees with that mentioned by Mr. Hall for gold. The extent of the deflections varied from about 50 to 70 scale divisions on each side of zero. Similar but smaller deflections occurred when the galvanometer was connected with points nearer to the middle of the plate.

Experiment 2.—Two longitudinal slits, F, H, about ¼ mm. wide, were then cut along the middle of the foil, leaving a connection 4 mm. wide between the two halves of the sheet, and the former experiment was repeated. The following are the details; and to understand them it must be remembered that the galvanometer is affected by two causes besides the transverse current: (1) by the direct action of the electromagnet upon the galvanometer needle, though 13 feet away from it; (2) by a small permanent current due to the fact that, however carefully adjusted, A and B are never (or hardly ever) at exactly the same potential.

The image of the galvanometer wire was brought as nearly as possible to zero of the scale before beginning the experiment, and the connections were made so that a current in the direction A G B caused a deflection to the left (−), and a current in the direction B G A caused a deflection to the right (+).

Upper pole of magnet north:—

Galvanometer key, K, raised, deflection + 25 divs.[1]
,, ,, depressed, ,, + 102 divs.[2]

[1] Due solely to the action of the magnet upon the galvanometer needle.
[2] Due partly to the action of the magnet on the galvanometer needle, partly to the permanent current above referred to, and partly to the transverse current resulting from magnetisation.

Upper pole of magnet south:—

Galvanometer key raised, deflection − 24 divs.
,, ,, depressed, ,, − 42 divs.

Net deflections due to current (subtracting effect of the magnet on the galvanometer needle):—

Upper pole north (102 − 25 =) + 77 divs.
,, south (− 42 + 24 =) − 18 divs.

Sum of opposite deflections due to transverse current, (77 + 18 =) 95, or deflection on each side of zero = 47·5 divs.

The slits therefore had the effect of reducing the amount of the Hall deflections; the direction was unaffected.

Experiment 3.—The galvanometer contacts were now moved from the edges to the points D, E, about 5 mm. from the middle line, and the experiment was repeated with the following result:—

Upper pole of magnet north:—

Key raised, deflection + 18 divs.
,, depressed, ,, + 165 divs.

Upper pole south:—

Key raised, deflection − 35 divs.
,, depressed, ,, + 180 divs.

Net deflections due to current:—

Upper pole north (165 − 18 =) + 147 divs.
,, south (180 + 35 =) + 215 divs.

Sum of deflections due to transverse current (215 − 147 =) 68.
Deflection on each side of zero = 34 divs.

Thus when the galvanometer contacts were near the middle of the plate the deflections were almost as great as when the galvanometer was connected to the edges. *But they were in the opposite direction*, showing that the Hall effect was reversed.

Experiment 4.—A repetition of the last.

Upper pole north:—

Key raised, deflection + 28 divs.
,, depressed, ,, + 170 divs.

Upper pole south:—

Key raised, deflection − 24 divs.
,, depressed, ,, + 170 divs.

Net deflections due to current:—

Upper pole north (170 − 28 =) 132 divs.
,, south (170 + 24 =) 194 divs.

Sum of deflections due to transverse current, (194 − 132 =) 62.
Deflection on each side of zero = 31 divs.

These results, curious as they are, were of course not unexpected, the experiment having been in fact devised for the purpose of testing in an absolutely conclusive manner the sufficiency of the explanation of Hall's phenomenon by strains and Peltier effects which I have recently proposed (see NATURE, p. 467).

Supposing the magnet and the battery to be so arranged that before the slits were made the points A and D were in stretched districts, and B and E in compressed districts of the metallic sheet, then the effect of cutting the slits will be practically to divide the plate into two independent plates, each of which undergoes strains similar to those originally existing in the whole. A and B therefore will still be in regions which are respectively stretched and compressed, while on the other hand the region in which D is will now be compressed, and that in which E is will be stretched. Thus as regards the points D and E the result of making the slits is to reverse the strain, and in consequence the Peltier effects and the galvanometer deflections. If Mr. Hall's own theory were correct, the existence of the slits should make no appreciable difference of any kind. That they should have the effect of *reversing* the action of the magnet upon the current is altogether inconceivable.

SHELFORD BIDWELL

DR. FEUSSNER'S NEW POLARISING PRISM

In a recent number of the *Zeitschrift für Instrumentenkunde* (iv. 42–50, February 1884), Dr. K. Feussner of Karlsruhe has given a detailed description of a polarising prism lately devised by him, which presents several points of novelty, and for which certain advantages are claimed. The paper also contains an account, although not an exhaustive one, of the various polarising prisms which have from time to time been constructed by means of different combinations of Iceland spar. The literature of this subject is scattered and somewhat difficult of access, and moreover only a small part of it has hitherto been translated into English; and it would appear therefore that a brief abstract of the paper may not be without service to those amongst the readers of NATURE who may be unacquainted with the original memoirs, or who may not have the necessary references at hand.

Following the order adopted by Dr. Feussner, the subject may be divided into two parts:—

I.—Older Forms of Polarising Prisms

In comparing the various forms of polarising prisms, the main points which need attention are:—the angular extent of the field of view, the direction of the emergent polarised ray, whether it is shifted to one side of or remains symmetrical to the long axis of the prism; the proportion which the length of the prism bears to its breadth; and lastly, the position of the terminal faces, whether perpendicular or inclined to the long axis. These requirements are fulfilled in different degrees by the following methods of construction.

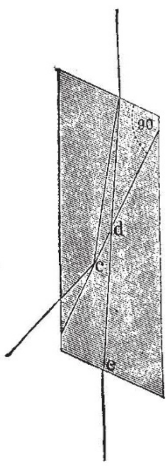


Fig. 1.

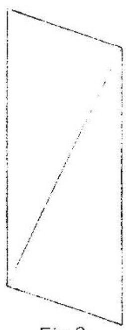


Fig.2.

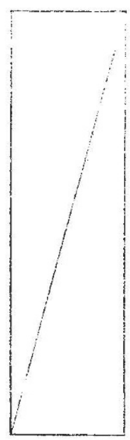


Fig.3.

1. *The Nicol Prism* (*Edin. New Phil. Journal*, 1828, vi. 83).—This (Fig. 1), as is well known, is constructed from a rhombohedron of Iceland spar, the length of which must be fully three times as great as the width. The end faces are cut off in such a manner that the angle of 72° which they originally form with the lateral edge of the rhombohedron, is reduced to 68°. The prism is then cut in two in a plane perpendicular to the new end surfaces, the section being carried obliquely from one obtuse corner of the prism to the other, in the direction of its length. The surfaces of this section, after having been carefully polished, are cemented together again by means of Canada balsam. A ray of light, on entering the prism, is separated by the double refraction of the calc-spar into an ordinary and an extraordinary ray: the former undergoes total reflection at the layer of balsam at an incidence which allows the extraordinary ray to be transmitted; the latter, therefore, passes through unchanged. This principle of obtaining a single polarised ray by means of total reflection of the other is common to all the forms of prism now to be described.

Dr. Feussner gives a mathematical analysis of the paths taken by the two polarised rays within the Nicol prism, and finds that the emergent extraordinary ray can include an angular field of 29°, but that this extreme value holds good only for rays incident upon that portion of the end surface which is near to the obtuse corner, and that from thence it gradually decreases until the field includes an angle of only about half the previous amount. He finds, moreover, that, although of course the ray emerges parallel to its direction of incidence, yet that the zone of polarised light is shifted to one side of the central line. Also that the great length of the Nicol—3·28 times its breadth—is not only an inconvenience, but, owing to the large pieces of spar thus required for its construction, prisms of any but small size become very expensive. To this it may be added that there is a considerable loss of light by reflection from the first surface, owing to its inclined position in regard to the long axis of the prism.

It is with the view of obviating these defects that the modifications represented in Figs. 2 to 6 have been devised.

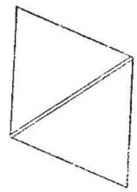


Fig.4.

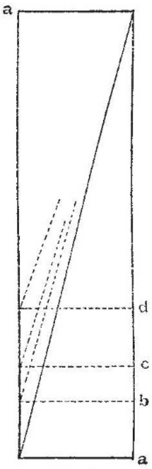


Fig.5.

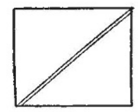


Fig.6.

2. *The Shortened Nicol Prism*.—This arrangement of the Nicol prism is constructed by Dr. Steeg and Reuter of Homburg v. d. H. For the sake of facility of manufacture, the end surfaces are cleavage planes, and the oblique cut, instead of being perpendicular, makes with these an angle of about 84°. By this alteration the prism becomes shorter, and is now only 2·83 times its breadth; but if Canada balsam is still used as the cement, the field will occupy a very unsymmetrical position in regard to the long axis. If balsam of copaiba is made use of, the index of refraction of which is 1·50, a symmetrical field of about 24° will be obtained. A prism of this kind has also been designed by Prof. B. Hasert of Eisenach (*Pogg. Ann.* cxiii. 189), but its performance appears to be inferior to the above.

3. *The Nicol Prism with Perpendicular Ends*.—The terminal surfaces in this prism are perpendicular to the long axis, and the sectional cut makes with them an angle of about 75°. The length of the prism is 3·75 times its breadth, and if the cement has an index of refraction of 1·525, the field is symmetrically disposed, and includes an angle of 27°. Prisms of this kind have been manufactured by Dr. Steeg, by Mr. C. D. Ahrens, and others.

4. *The Foucault Prism* (*Comptes Rendus*, 1857, xlv. 238).—This construction differs from all those hitherto mentioned, in that a film of air is employed between the two cut surfaces as the totally reflecting medium instead of a layer of cement. The two halves of the prism are kept in position, without touching each other, by means of the mounting. The length of the prism is in this way much reduced, and amounts to only 1·528 times its breadth. The end surfaces are cleavage planes, and the sectional cut makes with them an angle of 59°. The field, however, includes not more than about 8°, so that this prism can be used only in the case of nearly parallel rays; and in addition to this the pictures which may be seen through it are to some extent veiled and indistinct, owing to repeated internal reflection.

5. *The Hartnack Prism* (*Ann. de Ch. et de Physique*, ser. iv. vii. 181).—This form of prism was devised in 1866 by MM. Hartnack and Prazmowski; the original memoir is a valuable one; a translation of it, with some additions, has lately been published (*Journ. of the R. Microscopical Soc.*, June, 1883, 428). It is considered by Dr. Feussner to be the most perfect prism capable of being prepared from calc-spar. The ends of the prism are perpendicular to its length; the section carried through it is in a plane perpendicular to the principal axis of the crystal. The cementing medium is linseed oil, the index of refraction of which is 1·485. This form of prism is certainly not so well known in this country as it deserves to be: a very excellent one supplied to the present writer by Dr. Steeg is of rectangular form throughout, the terminal surfaces are 19 × 15 mm., and the length 41 mm. The lateral shifting of the field is scarcely perceptible, the prism is perfectly colourless and transparent, and its performance is far superior to that of the ordinary Nicol. The field of view afforded by this construction depends upon

the cementing substance used, and also upon the inclination of the sectional cut in regard to the ends of the prism; it may vary from 20° to 41°. If the utmost extent of field is not required, the prism may be shortened by lessening the angle of the section, at the expense however of interfering with the symmetrical disposition of the field.

6. *The Glan Prism* (Carl's "Repertorium," xvi. 570, and xvii. 195).—This is a modification of the Foucault, and in a similar manner includes a film of air between the sectional surfaces. The end surfaces and also the cut carried through the prism are parallel to the principal axis of the calc-spar. The ends are normal to the length, and the field includes about 8°. This prism is very short, and may indeed be even shorter than it is broad. It is subject to the same defect as that mentioned in the case of the Foucault, although perhaps not quite to the same extent.

II.—The New Polarising Prism

This prism differs very considerably from the preceding forms, and consists of a thin plate of a doubly refracting crystal cemented between two wedge-shaped pieces of glass, the terminal faces of which are normal to the length. The external form of the prism may thus be similar to the Hartnack, the calc-spar being replaced by glass. The indices of refraction of the glass and of the cementing medium should correspond with the greater index of refraction of the crystal, and the directions of greatest and least elasticity in the latter must stand in a plane perpendicular to the direction of the section. One of the advantages claimed for the new prism is that it dispenses with the large and valuable pieces of spar hitherto found necessary; a further advantage being that other crystalline substances may be used in this prism instead of calc-spar. The latter advantage, however, occurs only when the difference between the indices of refraction for the ordinary and extraordinary rays in the particular crystal made use of is greater than in calc-spar. When this is the case, the field becomes enlarged, and the length of the prism is reduced.

The substance which Dr. Feussner has employed as being most suitable for the separating crystal plate is nitrate of soda (*natronsalpeter*), in which the above-mentioned values are $\omega = 1{\cdot}587$ and $\epsilon = 1{\cdot}336$. It crystallises in similar form to calcite, and in both cases thin plates obtained by cleavage may be used.

As the cementing substance for the nitrate of soda, a mixture of gum dammar with monobromonaphthalene was used, which afforded an index of refraction of 1·58. In the case of thin plates of calcite, a solid cementing substance of sufficiently high refractive power was not available, and a fluid medium was therefore employed. For this purpose the whole prism was inclosed in a short glass tube with air-tight ends, which was filled with monobromonaphthalene. In an experimental prism a mixture of balsam of tolu was made use of, giving a cement with an index

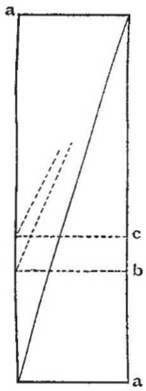


Fig.7.

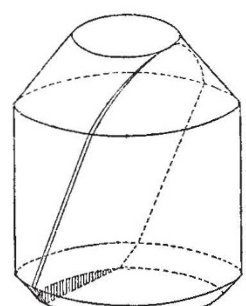


Fig.8.

of refraction of 1·62, but the low refractive power resulted in a very considerable reduction of the field. The extent and disposition of the field may be varied by altering the inclination at which the crystal lamina is inserted (Fig. 7), and thereby reducing the length of the prism, as in the case of the Hartnack.

In order to obviate the effects of reflection from the internal side surfaces of the prism, the wedge-shaped blocks of glass of which it is built up may be made much broader than would otherwise be necessary; the edges of this extra width are cut obliquely, and suitably blackened.

The accompanying diagram (Fig. 8) represents a prism of cylindrical external form constructed in this manner, the lower surface being that of the incident light. In this the field amounts to 30°, and the breadth is about double the length.

Dr. Feussner remarks that a prism similar in some respects to his new arrangement was devised in 1869 by M. Jamin (*Comptes Rendus*, lxviii. 221), who used a thin plate of calc-spar inclosed in a cell filled with bisulphide of carbon; and also by Dr. Zenker, who replaced the liquid in M. Jamin's construction by wedges of flint glass.

Amongst others, the carefully considered modifications of the Nicol prism which have recently been devised by Prof. S. P. Thompson (*Phil. Mag.*, November, 1881, 349; and *Journ. R. Micros. Soc.*, August, 1883, 575), and by Mr. R. T. Glazebrook (*Phil. Mag.*, May, 1883, 352), do not appear to have been known to Dr. Feussner.

The following tabular view of different forms of polarising prisms is taken from the conclusion of Dr. Feussner's paper:—

	Field	Inclination of section in regard to long axis	Ratio of length to clear width	Fig.
I. The Old Polarising Prisms	°	°		
1. Nicol's prism	29	22	3·28	1
2. Shortened Nicol prism—				
a. Cemented with Canada balsam	13	25	2·83	2
b. ,, ,, copaiba ,,	24	25	2·83	2
3. Nicol with perpendicular ends—				
a. With Canada balsam	20	15	3·73	3
b. With cement of index of refraction of 1·525	27	15	3·73	3
4. Foucault's prism	8	40	1·528	4
5. Hartnack's prism—				
a. Original form...	35	15·9	3·51	5 *ab*
b. With largest field	41·9	13·9	4·04	5 *aa*
c. With field of 30°	30	17·4	3·19	5 *ac*
d. With field of 20°	20	20·3	2·70	5 *ad*
6. Glan's prism	7·9	50·3	0·831	6
II. The New Polarising Prism				
1. With calc-spar: largest field ...	44	13·2	4·26	5 *aa*
2. ,, field of 30° ...	30	17·4	3·19	5 *ac*
3. ,, field of 20° ...	20	20·3	2·70	5 *ad*
4. With nitrate of soda: largest field	54	16·7	3·53	7 *aa*
5. ,, ,, field of 30°.	30	24	2·25	7 *ab* and 8
6. ,, ,, field of 20°.	20	27	1·96	7 *ac*

As an analysing prism of about 6 mm. clear width, and 13·5 mm. long, the new prism is stated by its inventor to be of the most essential service, and it would certainly appear that the arrangement is rather better adapted for small prisms than for those of considerable size. Any means by which a beam of polarised light of large diameter—say 3 to 3½ inches—could be obtained with all the convenience of a Nicol would be a real advance, for spar of sufficient size and purity for such a purpose has become so scarce and therefore so valuable that large prisms are difficult to procure at all. So far as an analyser is concerned, the experience of the writer of this notice would lead to the opinion that improvements are to be looked for rather in the way of the discovery of an artificial crystal which absorbs one of the polarised rays than by further modifications depending upon total reflection. The researches of Dr. Herapath on iodosulphate of quinine (*Phil. Mag.*, March, 1852, 161, and November, 1853, 346) are in this direction; but crystals of the co-called herapathite require great manipulative skill for their production. If these could be readily obtained of sufficient size, they would be invaluable as analysers.

This opinion is supported by the existence of an inconvenience which attends every form of analysing prism. It is frequently, and especially in projecting apparatus, required to be placed at the focus of a system of lenses, so that the rays may cross in the interior of the prism. This is an unfavourable position for a prismatic analyser, and in the case of a powerful beam of light, such as that from the electric arc, the crossing of the rays within the prism is not unattended with danger to the cementing substance, and to the surfaces in contact with it.

PHILIP R. SLEEMAN

ON VARIOUS SUGGESTIONS AS TO THE SOURCE OF ATMOSPHERIC ELECTRICITY[1]

WE have seen that, taking for granted the electrification of clouds, all the ordinary phenomena of a thunderstorm (except *globe* lightning) admit of easy and direct explanation by the known laws of statical electricity. Thus far we are on comparatively sure ground.

But the case is very different when we attempt to look a little farther into the matter, and to seek the source of atmospheric electricity. One cause of the difficulty is easily seen. It is the scale on which meteorological phenomena usually occur; so enormously greater than that of any possible laboratory arrangement that effects, which may pass wholly unnoticed by the most acute experimenter, may in nature rise to paramount importance. I shall content myself with one simple but striking instance.

Few people think of the immense transformations of energy which accompany an ordinary shower. But a very easy calculation leads us to startling results. To raise a single pound of water, in the form of vapour, from the sea or from moist ground, requires an amount of work equal to that of a horse for about half an hour! This is given out again, in the form of heat, by the vapour when it condenses; and the pound of water, falling as rain, would cover a square foot of ground to the depth of rather less than one-fifth of an inch. Thus a fifth of an inch of rain represents a horse-power for half an hour on every square foot; or, on a square mile, about a million horse-power for fourteen hours! A million horses would barely have standing room on a square mile. Considerations like this show that we can account for the most violent hurricanes by the energy set free by the mere condensation of vapour required for the concomitant rain.

Now the modern kinetic theory of gases shows that the particles of water-vapour are so small that there are somewhere about three hundred millions of millions of millions of them in a single cubic inch of saturated steam at ordinary atmospheric pressure. This corresponds to 1/1600 or so of a cubic inch of water, *i.e.* to about an average raindrop. But if each of the vapour particles had been by any cause electrified to one and the same potential, and all could be made to unite, the potential of the raindrop formed from them would be fifty million million times greater.

Thus it appears that if there be any cause which would give each particle of vapour an electric potential, even if that potential were far smaller than any that can be indicated by our most delicate electrometers, the aggregation of these particles into raindrops would easily explain the charge of the most formidable thundercloud. Many years ago it occurred to me that the mere *contact* of the particles of vapour with those of air, as they interdiffuse according to the kinetic theory of gases, would suffice to produce the excessively small potential requisite. Thus the source of atmospheric electricity would be the same as that of Volta's electrification of dry metals by contact. My experiments were all made on a small scale, with ordinary laboratory apparatus. Their general object was, by various processes, to precipitate vapour from damp air, and to study either (1) the electrification produced in the body on which the vapour was precipitated; or (2) to find on which of two parallel, polished plates, oppositely electrified and artificially cooled, the more rapid deposition of moisture would take place. After many trials, some resultless, others of a more promising character, I saw that experiments on a comparatively large scale would be absolutely necessary in order that a definite answer might be obtained. I communicated my views to the Royal Society of Edinburgh in 1875, in order that some one with the requisite facilities might be induced to take up the inquiry, but I am not aware that this has been done.

I may briefly mention some of the more prominent attempts which have been made to solve this curious and important problem. Some of them are ludicrous enough, but their diversity well illustrates the nature and amount of the difficulty.

[1] By Prof. Tait. Read at the meeting of the Scottish Meteorological Society on March 17, and communicated by the Society.

The oldest notion seems to have been that the source of atmospheric electricity is aërial friction. Unfortunately for this theory, it is *not* usually in windy weather that the greatest development of electricity takes place.

In the earlier years of this century Pouillet claimed to have established by experiment that in all cases of combustion or oxidation, in the growth of plants, and in evaporation of *salt* water, electricity was invariably developed. But more recent experiments have thrown doubt on the first two conclusions, and have shown that the third is true only when the salt water is boiling, and that the electricity then produced is due to friction, not to evaporation. Thus Faraday traced the action of Armstrong's hydro-electric machine to friction of the steam against the orifice by which it escaped.

Saussure and others attributed the production of atmospheric electricity to the condensation of vapour, the reverse of one of Pouillet's hypotheses. This, however, is a much less plausible guess than that of Pouillet; for we could understand a particle of vapour carrying positive electricity with it, and leaving an equal charge of negative electricity in the water from which it escaped. But to account for the separation of the two electricities when two particles of vapour unite is a much less promising task.

Peltier (followed by Lamont) assumed that the earth itself has a permanent charge of negative electricity whose distribution varies from time to time, and from place to place. Air, according to this hypothesis, can neither hold nor conduct electricity, but a cloud can do both; and the cloud is electrified by conduction if it touch the earth, by induction if it do not. But here the difficulty is only thrown back one step. How are we to account for the earth's permanent charge?

Sir W. Thomson starts from the experimental fact that the layer of air near the ground is often found to be strongly electrified, and accounts for atmospheric electricity by the carrying up of this layer by convection currents. But this process also only shifts the difficulty.

A wild theory has in recent times been proposed by Becquerel. Corpuscles of some kind, electrified by the outbursts of glowing hydrogen, travel from the sun to the upper strata of the earth's atmosphere.

Mühry traces the source of electricity to a direct effect of solar radiation falling on the earth's surface.

Lüddens has recently attributed it to the friction of aqueous vapour against dry air. Some still more recent assumptions attribute it to capillary surface-tension of water, to the production of hail, &c.

Blake, Kalischer, &c., have lately endeavoured to show by experiment that it is not due to evaporation, or to condensation of water. Their experiments, however, have all been made on too small a scale to insure certain results. What I have just said about the extraordinary number of vapour particles in a single raindrop, shows that the whole charge in a few cubic feet of moist air may altogether escape detection.

And so the matter will probably stand, until means are found of making these delicate experiments in the only way in which success is likely to be obtained, viz. on a scale far larger than is at the command of any ordinary private purse. It is a question of real importance, not only for pure science but for the people, and ought to be thoroughly sifted by means which only a wealthy nation can provide.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE

CAMBRIDGE.—The General Board of Studies propose to appoint, early in Easter Term, a number of Readers and University Lecturers, including the following: a Reader in Comparative Philology, stipend 300*l.* per annum; a Reader in Botany, stipend 100*l.*; University Lecturers in Sanskrit, in Comparative Philology, in Mathematics (one in each group of the Tripos, Part 3), in Applied Mechanics, in Botany, in Animal Morphology, in Advanced Physiology (three), in Geology, in History (five), and in Moral Science; all at 50*l.*, except in Animal Morphology and in Geology, to which 100*l.* is assigned. The University Lecturers will for the most part be chosen from such College Lecturers as open their lectures to the University generally; but the Board is not necessarily restricted to such; nor to persons who may apply. Candidates are to send in their names and testimonials (if any) to the Vice-Chancellor not later than April 25. It is understood that two lectures a week during