forming a sort of ceiling directly over it, to help to diffuse the illumination. The whole of the shed is well lit; and a large quantity of light also penetrates into an adjoining one of similar dimensions, and separated by a row of columns. The light is used regularly all through the night, and has been so all through the winter. Messrs. Tate speak highly of its efficiency. To ascertain the exact cost of the light, as well as of the gas illumination which it replaced, a gas-meter was placed to measure the consumption of the gas through the jets affected; and also the carbons consumed by the electric illumination were noted. A series of careful experiments showed that during a winter's night of 14 hours' duration the illumination by electricity cost 1s. 9d., while that by gas was 3s. 6d., or 1½d. per hour against 3d. per hour. To this must be added the greatly increased illumination, four to five times, given by the electric light, to the benefit of the work; while this last illuminant also allowed, during the process of manufacture of the sugar, the delicate gradations of tint to be detected; and so to avoid those mistakes, sometimes costly ones, liable to arise through the yellow tinge of gas illumination. This alone would add much to the above-named economy, arising from the use of electric illumination in sugar works."

I am indebted for these facts to Mr. J. N. Shoolbred, under whose supervision the arrangements were made.

Some excellent experience has been gained at the shipbuilding docks in Barrow-in-Furness, where the Brush system has been applied to illuminate several large sheds covering the punching and shearing machinery, bending blocks, furnaces, and other branches of this gigantic business. In one shed, which was formerly lighted by large blast-lamps, in which torch oil was burnt, costing about 5d. per gallon, and involving an expenditure of £8 9s. per week, the electric light has been adopted at an expenditure of £4 14s. per week.

The erecting shop, 450 feet by 150 feet, formerly dimly lit by gas at a cost of £22 per week, is now efficiently lit by electricity at half the cost.

I am indebted for these facts to Mr. Humphreys, the manager of the works.

The Post-office authorities have contracted with Mr. M. E. Crompton, to light up the Post-office at Glasgow for the same price as they have hitherto paid for gas, and there is no doubt that in many instances this arrangement will leave a handsome profit to the Electric Light Company. They are about to try the Brockie system in the telegraph galleries, and the Brush system in the newspaper sorting rooms of the General Post-office in St. Martin's-le-Grand.

ON THE SPACE PROTECTED BY A LIGHTNING-CONDUCTOR.

By WILLIAM HENRY PREECE.*

ANY portion of non-conducting space disturbed by electricity is called an electric field. At every point of this field, if a small electrified body were placed there, there would be a certain resultant force experienced by it dependent upon the distribution of electricity producing the field. When we know the strength and direction of this resultant force, we know all the properties of the field, and we can express them numerically or delineate them graphically. Faraday (Exp. Res., § 3122 *et seq.*) showed how the distribution of the forces in any electric field can be graphically depicted by drawing lines (which be called *lines of force*) whose direction at every point coincides with the direction of the resultant force at that point; and Clerk-Maxwell (Camb. Phil. Trans., 1857) showed how the magnitude of the forces can be indicated by the way in which the lines of force are drawn. The magnitude of the resultant force at any point of the field is a function of the potential at that point; and this potential is measured by the work done in producing the field. The potential at any point is, in fact, measured by the work done in moving a unit of electricity from the point to an infinite distance. Indeed the resultant force at any point is directly proportional to the rate of fall of potential per unit length along the line of force passing through that point. If there be no fall of potential there can be no resultant force; hence if we take any surface in the field such that the potential is the same at every point of the surface, we have what is called an *equipotential surface*. The difference of potential between any two points is called an electromotive force. The lines of force are necessarily perpendicular to the surface. When the lines of force and the equipotential surfaces are straight, parallel, and equidistant, we have a *uniform field*. The intensity of the field is shown by the number of lines passing through unit area, and the rate of variation of potential by the number of equipotential surfaces cutting unit length of each line of force. Hence the distances separating the equipotential surfaces are a measure of the electromotive force present. Thus an electric field can be mapped or plotted out so that its properties can be indicated graphically.

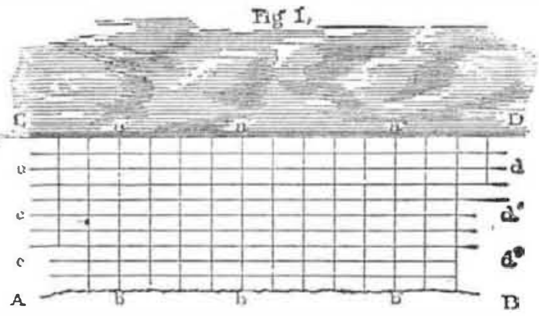
The air in an electric field is in a state of tension or strain; and this strain increases along the lines of force with the electromotive force producing it until a limit is reached, when a rent or split occurs in the air along the line of least resistance—which is disruptive discharge, or lightning.

Since the resistance which the air or any other dielectric opposes to this breaking strain is thus limited, there must be a certain rate of fall of potential per unit length which corresponds to this resistance. It follows, therefore, that the number of equipotential surfaces per unit length can represent this limit, or rather the stress which leads to disruptive discharge. Hence we can represent this limit by a length. We can produce disruptive discharge either by approaching the electrified surfaces producing the electric field near to each other, or by increasing the quantity of electricity present upon them; for in each case we should increase the electromotive force and close up, as it were, the equipotential surfaces beyond the limit of resistance. Of course this limit of resistance varies with every dielectric; but we are now dealing only with air at ordinary pressures. It appears from the experiments of Drs. Warren De La Rue and Hugo Muller that the electromotive force determining disruptive discharge in air is about 40,000 volts per centimeter, except for very thin layers of air.

If we take into consideration a flat portion of the earth's surface, A B (fig. 1), and assume a highly-charged thunder-cloud, C D, floating at some finite distance above it, they would, together with the air, form an electrified system. There would be an electric field; and if we take a small portion of this system, it would be uniform. The lines, *a b*, *a' b'* . . . would be lines of force; and *cd*, *c' d'*, *c" d"* . . . would be equipotential planes.

If the cloud gradually approached the earth's surface (Fig. 2), the field would become more intense, the equipotential surfaces would gradually close up, the tension of the air would increase until at last the limit of resistance of the air, *ef*, would be reached; disruptive discharge would take place, with its attendant thunder and lightning. We can let the line, *ef*, represent the limit of resistance of the air if the field be drawn to scale; and we can thus trace the conditions that determine disruptive discharge.

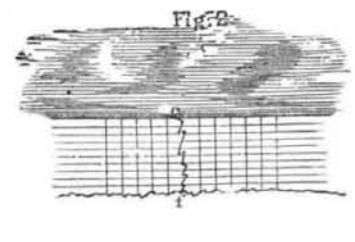
Fig 1.



If the earth-surface be not flat, but have a hill or a building, as H or L, upon it, then the lines of force and the equipotential planes will be distorted, as shown in Fig. 3. If the hill or building be so high as to make the distance H *h* or L *l* equal to *ef* (Fig. 2), then we shall again have disruptive discharge.

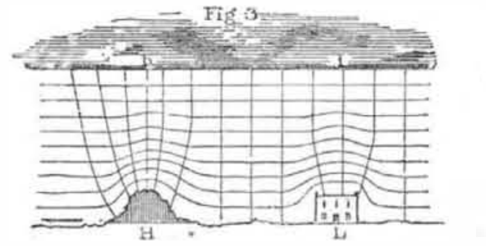
If instead of a hill or building we erect a solid rod of metal, G H, then the field will be distorted as shown in Fig. 4.

Fig 2.



Now, it is quite evident that whatever be the relative distance of the cloud and earth, or whatever be the motion of the cloud, there must be a space, *g g'*, along which the lines of force must be longer than *a' a* or H H'; and hence there must be a circle described around G as a center which is less subject to disruptive discharge than the space outside the circle; and hence this area may be said to be protected

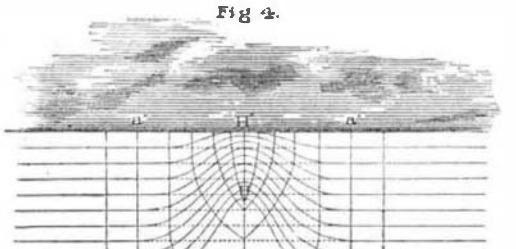
Fig 3.



by the rod, G H. The same reasoning applies to each equipotential plane; and as each circle diminishes in radius as we ascend, it follows that the rod virtually protects a cone of space whose height is the rod, and whose base is the circle described by the radius, G *a*. It is important to find out what this radius is.

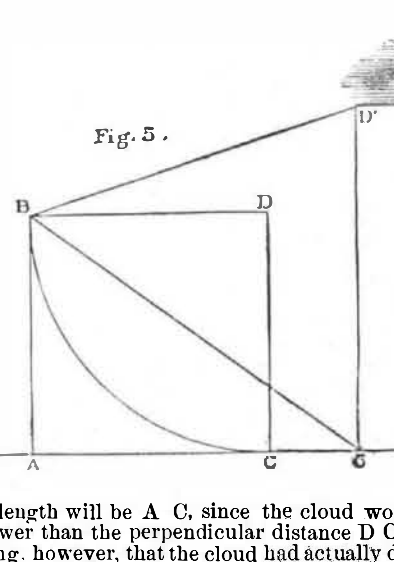
Let us assume that a thunder-cloud is approaching the

Fig 4.



rod, A B (Fig. 5), from above, and that it has reached a point, D', where the distance, D' B, is equal to the perpendicular height, D' C'. It is evident that, if the potential at D be increased until the striking-distance be attained, the line of discharge will be along D' C or D' B, and that the length, A C', is under protection. Now the nearer the point D' is to D the shorter will be the length A C' under protection; but the

Fig. 5.



minimum length will be A C, since the cloud would never descend lower than the perpendicular distance D C.

Supposing, however, that the cloud had actually descended to D when the discharge took place. Then the latter would strike to the nearest point; and any point within the circumference of the portion of the circle, B C (whose radius is D B), would be at a less distance from D than either the point B or the point C.

Hence a lightning-rod protects a conic space whose height is the length of the rod, whose base is a circle having its radius equal to the height of the rod, and whose side is the quadrant of a circle whose radius is equal to the height of the rod.

I have carefully examined every record of accident that was available, and I have not yet found one case where damage was inflicted inside this cone when the building was properly protected. There are many cases where the pinnacles of the same turret of a church have been struck where one has had a rod attached to it; but it is clear that the other pinnacles were outside the cone; and therefore, for protection, each pinnacle should have had its own rod. It is evident also that every prominent point of a building should have its rod, and that the higher the rod the greater is the space protected.

* From the *Philosophical Magazine* for December, 1880.

PHOTO-ELECTRICITY OF FLUOR-SPAR CRYSTALS.

HANTZEL has communicated to the Saxon Royal Society of Science some interesting observations on the production of electricity by light in colored fluor-spar. The centers of the fluor-spar cubes become negatively electric by the action of light. The electric tension diminishes toward the edges and angles, and frequently positive polarity is produced there. With very sensitive crystals a short exposure to daylight is sufficient; by a long exposure to light the electric current increases. The direct rays of the sun act much more powerfully than diffused daylight, and the electric carbon light is more powerful even than sunlight. The photo-electric action of light belongs principally to the "chemically active" rays; this is shown by the fact that the production of electricity is extremely small behind a glass colored with cuprous oxide, and behind a film of a solution of quinine sulphate; while it is not appreciably diminished by a film of a solution of alum. The photo-electric excitability of fluor-spar crystals is increased by a moderate heat (80° to 100° C.).

THE AURORA BOREALIS AND TELEGRAPH CABLES.

THE January and February numbers of the *Elektrotechnische Zeitschrift* contain a number of articles on this interesting subject by several eminent electricians. Professor Foerster, director of the observatory in Berlin, points out the great importance of the careful study of earth currents, first observed at Greenwich, and now being investigated by a committee appointed by the German Government. He further points out, according to Professor Wykander, of Lund, in Sweden, that a close connection exists between earth currents, the protuberances of the sun, and the aurora borealis, and that the nearly regular periodical reappearance of protuberances in intervals of eleven years coincides with similar periods of excessive magnetic earth currents and the appearance of the aurora borealis. The remarkable disturbing influences on telegraph wires and cables of the aurora borealis observed from the 11th to 14th of August, 1880, have been carefully recorded by Herr Geh. Postnath Ludwig in Berlin, and a map of Europe compiled, showing the places affected, with the extent to which telegraph wires and cables were influenced and disturbed. Although the aurora w s but faintly visible in England and Germany, and in Russia only as far as 35° north, disturbing influences were reported from all parts of Europe, the Mediterranean, and Africa, and even Japan and the east coast of Asia. As far south as Zanzibar, Mozambique, and Natal disturbances were also noticed. They were in Europe most intense on the morning of August 12, when they lasted the whole day, and increased again in intensity toward eight o'clock in the evening, while they suddenly ceased everywhere almost simultaneously. Scientific and careful observations were only taken at a few places, but the existence of earth currents in frequently changing direction and varying intensity, was noticed everywhere. Long lines of wires were more affected than short ones, and although some lines—for instance the Berlin-Hamburg in an east-west direction—were not at all influenced, no general law was noticed according to which certain directions were freed from the disturbing influence. While, for instance, the Red Sea cable was not noticeably affected, the land line to Bombay, forming a continuation of this cable, was materially disturbed. The Marseilles-Algiers cable, so seriously influenced in 1871, showed no signs at all, but as may be expected, the north of Europe suffered more than the south, and in Nystad, Finland, the galvanometer indicated an intensity of current equal to that of 200 Leclanché cells.

Since thunderstorms are generally local, it is only natural that their effect upon telegraph cables should also be confined to one locality. Numerous careful observations, carried out over considerable periods of time, show that the disturbing influences of thunderstorms on telegraph lines are of less duration and more varying in direction and intensity than those of the aurora borealis. Long lines suffer less than short lines; telegraph wires above ground are more easily and more intensely affected than underground cables. It is, however, possible, that this is mainly due to the fact that in the districts where strict records were kept, in the German Empire, most of the long lines are underground cables, while most of the short local lines are overground wires. The results of the disturbances varied; in Hughes's apparatus the armatures were thrown off, lines in operation indicated wrong signs, dots became dashes, and the spaces were either multiplied in size or number, according to the direction of the earth currents induced by the thunderstorms. Since these observations extended over nearly 2,000 cases, some conclusions might fairly be drawn from them. For the purpose of a more complete knowledge on this subject, Dr. Wykander recommends a series of regular observations on earth currents to be carried out at different stations, well distributed over the whole surface of the globe, these observations to be made between six and eight A.M., and at the same time in the evening. Special arrangements to be made at various stations to record exceptionally intense disturbances during the phenomena of the aurora borealis, notice to be taken of time, direction, intensity, and all further particulars. Since this question appears to bear a considerable amount of influence on underground cables, it is one that deserves serious attention before earth cables are more generally introduced; there can, however, be little doubt that they are not nearly so much exposed as overhead wires to disturbing influences of other kinds, such as snow, rain, wind, etc., while they certainly do suffer, though perhaps in a less degree, by electrical disturbances.—*Engineering.*