LIGHTNING CONDUCTORS AND LIGHTNING GUARDS.

CHAPTER I.

GENERAL CONSIDERATIONS CONCERNING ATMOSPHERIC ELECTRICITY AND LIGHTNING.

ONE hundred and fifty years ago the nature of lightning was unknown. Several persons surmised that it had some connection with the phenomena excited in a piece of glass tube when rubbed, phenomena which were called electric; but no proof of the connection was attempted. The proof that lightning was in fact nothing but a large electric spark was given in 1751 by that comprehensive and common-sense genius, the Philadelphian printer, Benjamin Franklin.

This great man, a statesman of the first magnitude, might have made a leading experimental phrlosopher had he lived in quiet times instead of in the stirring period of the Declaration of Independence and the great American War. A space of some twelve years limits his active devotion to electrical matters, but in that time he acquired a masterly grip of the subject, expressing himself very accurately and precisely concerning electrical theory, his statement of which is far superior to a great deal that has quite lately passed current in text-books; indeed, it is only now becoming capable of improvement through the labour and the inspiration of some of the still greater giants of our own day.

From the time that Franklin flew his kite at Philadelphia and ascertained beyond cavil the true nature of lightning—from that time to the present, the protection of buildings and ships from its destructive agency has been mainly a matter of detail and application of the laws of electricity so far as they were known.

For a long time the erection of lightning conductors was opposed by the religious world as heretical and impious. But, first in some Protestant provinces in Germany, and later in France and England, the use of the heretical rods gradually extended. The extension of their use in England and their application to ships, were greatly aided by the labours of that enthusiastic worker, Sir W. Snow Harris. Their extension in our South African colonies, where violent thunderstorms are frequent, is largely due to the influence of the late Dr. Mann, who contributed important papers on the subject to the Society of Arts,[1] who edited the second edition of the hitherto standard British work on the subject, Anderson's "Lightning Conductors," and in whose honour the course of lectures which constitutes the foundation of the present volume were established by the Society of Arts.

Concerning the origin of atmospheric electricity, I have not much to say. It seems to me probably due to friction, as in Armstrong's hydro-electric machine. Faraday showed that the exciting cause in that apparatus of Armstrong's was the friction of water spray driven by steam over the solid surface of the jet; so also I picture winds in the atmosphere driving the spray of mist against

[1] "Journal of the Society of Arts," April 30, 1875, and March 15, 1878.

rock and ice surfaces, and thus gradually producing a certain difference of potential between the upper layers of the atmosphere and the surface of the earth.

It has been discovered by meteorologists that thunderstorms are often associated with curious V-shaped troughs or depressions among the isobars (see for instance Mr. Abercromby's book on "Weather," in the International Scientific Series, pp. 240-259), evidencing a whirl or cyclone with its axis horizontal. Now I would suggest that a horizontal cyclone is very like a cylinder electrical machine, with the earth acting as rubber and the upper regions of air acting as prime conductor; the air which has been charged by friction being discharged as soon as it is carried up to these higher regions, and thus electrifying them continually until they locally discharge. There are, however, various types of thunderstorm, and probably there are many varieties of cause to account for the electrification. Some variety of friction seems to me, however, most probable in all cases.

I have spoken as if I thought the friction had to be between mist globules and solid matter. It seems doubtful whether friction against *air* will suffice to render water electric. If it be efficient, then the constant slipping of mist or dust-particles through the upper layers of the atmosphere is one effective cause of atmospheric electrification; whatever may be the cause, it probably acts continuously, and a rain-shower probably carries down some of the charge to earth, so that after a spell of dry weather there is liable to be an accumulation of electricity, because it has had no recent opportunity of escape.

In the polar regions electrical discharges are mainly silent, or brush-like, giving the fantastic forms of aurora. But in our latitude these silent discharges in the upper semi-conducting rarefied layers of atmosphere are seldom visible. We see the effect in another form. The electrification gets occasionally conducted down by clouds into the lower and denser layers of atmosphere where silent discharge is impossible, until, when the potential rises high enough, they flash either into each other or into the earth, and the strain is partially relieved.

It may thus be that clouds play only a secondary part in the phenomena. The upper regions of atmosphere are at a different potential from the earth—cloud or no cloud. Clouds are able to conduct it down towards the earth, and thick dense clouds are therefore the usual prelude to a thunderstorm.

So much might be said whatever the type of storm ; but when it is the type associated with an isobaric "trough," or whirl round an horizontal axis, then the formation of electrified cloud at the summit of the whirl is a simple and natural consequence ; the ascending air becoming chilled by expansion and condensing its vapour in the ordinary way. And this visible cloud being a semi-conductor, whereas invisible vapour is a good insulator, we have all the ingredients necessary for an accumulation of electricity by frictional electric-machine-like action without postulating an ascent into the still higher conducting layers of atmosphere. For remember the great height at which these must exist. Air can hardly be called conducting at a greater pressure than about 1 inch of mercury, or say $\frac{1}{30}$ atmosphere ; now such a pressure exists at about $3\frac{1}{2}$ times "the height of the homogeneous atmosphere" appropriate to the temperature ; and at the freezing point the homogeneous atmosphere is 8 kilometres high. The average temperature will be lower, but one cannot suppose the conducting layers to be much less than 20 miles high, except in excessively cold regions. But the clouds caused by a horizontal whirl may be readily found at a height of a mile or two, or even less.

It is often asserted and believed that the coalescence of small charged globules into larger globules is competent to raise their potential enormously,[1] but Dr. Everett has shown ("Nature," vol. 38, p. 343) that so long as the charge adheres to the individual globules their aggregation makes no difference to the average potential. The mistake arose by forgetting that what would be true for any one isolated globule would not be true of an assemblage; the potential of any one of a crowd being $\Sigma\left(\frac{q}{d}\right)$, which is independent of size, instead of the simple $\frac{q}{r}$ for an isolated sphere.

The converse phenomenon, or the tendency to coalescence of globules produced by feeble electrical charges in their neighbourhood, is, however, a real and important phenomenon, and is best illustrated as discovered by Lord Rayleigh, by means of a very simple experiment with a water-jet and sealing-wax.

A vertical jet about one-twentieth of an inch in diameter and three or four feet high does best, but almost any fairly vertical jet of clean water will serve. A little vertical fountain can be easily arranged at any water-tap by help of a bit of india-rubber tubing and a glass nozzle. It spreads out at the top in the well-known brush of spray, and the drops fall as a scattered shower, like fine rain, until a stick of excited sealing-wax is held a yard or two away; the jet then at once shrinks

[1] See a lecture on "Thunderstorms," by Prof. Tait, in "Nature," August, 1880.

upon itself in width, changing its appearance entirely; its drops collect into large globules and fall as a thunder-shower.

Lord Rayleigh has shown, by examining what goes on by means of intermittent illumination, and by other experiments on jets impinging on each other, that the scattering is due to collisions among the particles, and that two colliding drops or two colliding jets do not unite, but rebound from each other, so long as their surfaces are clean and so long as they are at the same electric potential. But a difference of potential of even one or two volts is sufficient to affect the joint boundary surface during a collision sufficiently to cause a puncture, as it were, or at any rate to unite the surfaces and stop any rebound. Thus it is, that under feeble electrical influences drops accidentally striking each other unite, and thus rapidly grow in size. The obvious connection between this experiment and the notably large drops of thunder-showers need not be insisted on. Every detail of the explanation may not be considered perfectly clear, but the facts are undeniable, and the same kind of explanation which serves for the small-scale experiment must serve also for the large-scale observation.

A process of electrical aggregation of a somewhat analogous kind was detected also by the writer, in conjunction with the late Mr. J. W. Clark, when examining the behaviour of dust-laden air.[1] They found that on electrifying such air by a brush discharge all the particles rushed together, and grew rapidly into flakes and streamers, and rapidly cleared away, either by reason of attraction to the walls of the vessel, or by simple gravitational subsidence. The same thing was found to occur

[1] It has since been pointed out that the first discoverer of this effect was a Mr. C. F. Guitard; in the "Mechanics' Magazine" for 1850,

with the water-dust of visible steam-like cloud or fog, as with any form of solid smoke or dust particles. A cloud exposed in this way to a non-uniform electric field can, therefore, be made to rain. For remember, that in one sense clouds are always raining: the water globules are always sinking through the air, only the rate of sinking is so slow that up-currents more than counterbalance the descent, or else the drops dry up on the way. To make them reach the earth it is only necessary to accelerate their descent by increasing their size, and this is exactly what neighbouring electrification can accomplish: first aggregating the minute globules into drops, which begin to fall as a fine shower, rebounding against each other as they fall; but being liable to further electric influence if they pass anywhere near an electrified body, whereby their collisions result in coalescence, and their rapidity of fall becomes violent.

These experiments throw light on the connection between rain and electrical states of the atmosphere, and render probable the assumption that the weather is more affected by electrical condition than may have been supposed, and that if ever the weather is to be in any sort artificially controlled it must be by the agency of extensive works for the supply of high-tension electricity of definite sign. Perhaps for neighbouring supplies of opposite sign, in order to secure the needful inequality of field. Perfect uniformity of field would tend to keep globules separate, and would result in fog.

Still more recently another effect, possibly a distinct effect, has been observed by the late Robert von Helmholtz, viz., that a cloud of visible steam was darkened and rendered much more opaque by the discharge of electricity into it from a point.

The experiment has been several times exhibited by

Mr. Shelford Bidwell; and it is certainly very striking to see the instantaneous change from a light fleecy cloud of steam, issuing from an orifice of a vessel of boiling water, into an opaque, dark, lurid cloud, the instant it is electrified. The peculiar heavy colour of a thunder-cloud is exactly reproduced, and it is impossible not to suppose the two things connected, though the precise cause of the extra opacity is not specially clear. It seems most likely that extra condensation goes on, and more vapour is condensed, by means of the presence of an extra number of nuclei, in accordance with the discoveries of Mr. Aitken. But whether these nuclei are dust-nuclei, *i.e.*, are fragments of metal torn off by the brush discharge, or whether the chemical dissociation going on in such discharge has itself a nucleus-like power, such as Mr. Aitken found dry flame to have, are matters not yet quite settled.

We have now to think of ourselves as living always between the coatings of a large condenser or Leyden jar, the upper coating of which is the sky, the under coating the earth, while the common air is the dielectric between. Ordinarily the sparking distance is far too great. Every now and then portions of the upper coating protrude down as clouds, and we are then liable to a disruptive discharge. Some square miles of cloud and some square miles of land are the two coatings, and the interval of separation need not be extremely great. If the cloud and the earth were perfect conductors, all this great area would be relieved in a single flash of awful size; but, fortunately, the conduction of cloud is a slow process, and it usually takes a good many flashes from different parts to remove its charge.

The total maximum energy of a given area of cloud at a given height from the earth is easily estimated, for it is well known that as soon as the electric tension of air reaches the limit of about half a gramme weight per square centimetre, disruption occurs. Supposing it all equally on the verge of giving way, the energy of the dielectric per cubic centimetre is therefore $\frac{981}{2}$ ergs, and per cubic mile is $\frac{4{,}110 \times 10^{12}}{2 \times 3 \times 10^{\prime}}$ foot-tons $=$ 70,000,000 foot-tons.

Given, then, the whole area of cloud facing the earth, and its height when on the point of discharging at every point, and you have the number of cubic miles of strained dielectric, and an approximation to the energy of the storm, at the rate of 70,000,000 foot-tons per cubic mile.

The potential needed to give a spark a mile long is so enormous [1] that the quantity of electricity required to give this energy need not be very great; 217 million electrostatic units of quantity per square mile would give a bursting tension. Now, 217 million electrostatic units is just about 70 coulombs, or not enough to decompose one-hundredth of a gramme (1-7th of a grain) of water. Faraday stated this, but it is often disbelieved.

The energy of any ordinary flash can be accounted for by the discharge of a very small portion of charged cloud, for an area of 10 yards square at the height of a mile would give a discharge of over 2,000 foot-tons energy.

One is not, however, to suppose that because the total quantity is small therefore the current caused by it is weak. Two factors enter into strength of current,

[1] The difference of potential for a spark a mile long, between flat plates, is roughly sixteen million electrostatic units, each one of which is equal to 300 volts; that is, nearly 5,000 million volts.

quantity and time, and if the time of passage of a given quantity be short, as in the case of lightning it is, the current may be furiously strong.

Thinking now of a cloud and of the earth under it as forming the two coats of a Leyden jar, in the dielectric of which houses and people exist, we have now to consider what determines a discharge, and what happens when the discharge occurs. The maximum tension which air can stand is ½ gramme weight per square centimetre. At whatever point the electric tension rises to this value, smash goes the air. The breakage need not amount to a flash, it must give way along a great length to cause a flash; if the break is only local, nothing more than a brush or fizz need be seen. But when a flash does occur it must be the weakest spot that gives way first—the place of maximum tension—and this is commonly on the smallest knob or surface which rears itself into the space between the dielectrics.

If there be a number of small knobs or points, the glows and brushes become so numerous that the tension is greatly relieved, and the whole of a moderate thunder-cloud might be discharged in this way without the least violence. This is by far the best way of protecting anything from lightning; do not let the lightning flash occur if you can possibly avoid it. But one cannot always prevent it, even by a myriad of points. Sometimes a cloud will descend so quickly, or it will have such a tremendous store of energy to get rid of, that no points are sufficiently rapid for the work, and crash it all comes at once. One specially noteworthy case when points are no protection occurs when one cloud sparks into another, and thence to the ground; or, in general, whenever electric strain is thrown quite suddenly upon a layer of air. (See Chaps. IX. and XVI. for details.)