of heat—now unknown to us—are prepared in the great storehouse of creation.”

In the light of the discovery of radium and other radio-active substances, which in their changes are able to emit an enormous amount of energy, this remark seems almost prophetic. Assuming the average temperature gradient (1.50 deg. F. per foot descent from the earth's surface) and the conductivity of the rocks of the earth taken by Lord Kelvin, it can be calculated that the amount of heat conducted to the earth's surface each year and lost by radiation could be supplied by the presence of radium (or an equivalent amount of other radio-active matter) to the minute extent of about five parts in ten thousand million by weight. The observations of Elster and Geitel show that the amount of radio-active matter present in the soil is of this order of magnitude. Thus it does not appear improbable that the temperature gradient observed in the earth may be due to the heat liberated by the radio-active matter distributed throughout it. If this be the case, the present temperature gradient may have been sensibly constant for a long interval of time, and Lord Kelvin's computation may only supply the minimum limit to the age of this planet. Thus the earth may have been at a temperature capable of supporting animal and vegetable life for a much longer time than estimated by Lord Kelvin from thermal data. Similar considerations apply to the question of the sun's heat; for the presence of radium in the sun, to the extent of about four parts in one million by weight, would of itself account for the present rate of emission of heat. The discovery of the radio-active elements, which in their disintegration liberate enormous amounts of energy, thus increases the possible limit of the duration of life on this planet, and allows the time claimed by the geologist and biologist for the process of evolution.—Technics.

PROTECTION FROM LIGHTNING.*

By Prof. Dr. FR. NEESEN, of Berlin.

In laying down rules for protection from lightning, we have three classes of protectors to consider:

1. Lightning protectors for buildings.
2. Lightning arresters for low-potential circuits.
3. Lightning arresters for high-potential circuits.

In the first class direct connection of the whole construction with the earth is possible, in the other classes not.

Arresters for high-potential circuits must contain automatic means of breaking the short-circuit of the working current made by the escape of the lightning discharge to earth.

The construction of a protector depends on the definition of its duty. This would seem to be, obviously, protection from damage by lightning, but it is important to know how this protection can be given. Some regard the function of the protector as essentially preventive by rendering harmless, by so-called slow discharge, the electricity accumulated in the clouds before a flash can take place, but they concede that the protector, if it falls short of this duty, must be able to carry off the lightning from the apparatus to be protected. Others lay stress on the latter function, and regard the slow discharge as altogether subsidiary. The choice of one or the other view has more than theoretical interest. If the first is correct, as many points as possible must be employed and kept in perfect condition; if the second is the right one, the importance of points almost vanishes. A striking proof that points play a very unimportant rôle is given by the following experiment of Chwolson. (Fig. 1.)

The electricity accumulated in the clouds may be represented by the charge of the inner coating of a Leyden jar which is maintained by an electrical machine. The inner coating is connected with a metal rod provided with a movable arm, *b*, which ends in a cup *c*. Near the jar and within the sphere of influence

FIG. 1.

of the cup stands a little house provided with a high lightning rod, which is connected to earth. If the arm is so placed that the cup is directly over the lightning rod, *d*, no discharge of sparks occurs when the machine is turned, because the cup is slowly and continually discharged through the point. But if the

arm is turned away and brought back toward the point with a jerk, a spark discharge occurs. Indeed, the jerk need not be given, for the attraction between the charge of the cup and the induced charge of the point is enough to cause a sudden approach which makes the silent, sparkless discharge impossible. Now,

roofs of buildings to attract it. Two distinct plans are followed in the arrangement of these collectors—the old plan, based on Gay-Lussac's recommendations, and the new one, which rests on those of the Belgian Melsens. The first, easier to carry out in construction, is founded on the assumption that a

FIG. 2.

if the small charge of a Leyden jar cannot escape during the approach of the cup, the immensely greater charges of the air can surely not be dissipated in this way. Millions on millions of points, like the leaves and twigs of a forest, are needed. But even in a forest it often happens that a single tree is struck by lightning.

Hence the character of the points is unimportant, as conductors without points can draw the discharge to themselves from other parts of the building. In recognition of this fact, intelligent makers of light-

FIG. 3.

ning protectors have discarded the points of platinum, carbon, etc., once so highly esteemed.

LIGHTNING PROTECTORS FOR BUILDINGS.

In order to review the laws governing the construction of lightning protectors, it is necessary to have a clear understanding of what takes place on the approach of an electrically-charged cloud.

All objects on the surface of the earth become charged oppositely, especially objects in which the induced electricity can move without delay or resistance, namely, conductors. Where differences of potential exist between a cloud and particular parts of

vertical metal rod protects everything within a certain cone of which the rod forms the axis. The cone was determined by the rule that a cloud in any possible position must be nearer to the tip of the rod than to any part of the building.

Many sad experiences have shown that no reliance can be placed on this rule, and it was found necessary to contract the cone more and more, until the diameter of its base was reduced to three times the height of the rod. This rule is still followed by a number of constructors, partly no doubt because it gives a simple plan for the arrangement of the rods.

But this method of calculation is not justified by the differences in the distance of the cloud from various parts of the building, differences very small in comparison with the length of the flash, which may be several kilometers. Even in experiments with sparks a few decimeters long, we see that the spark does not follow the straight and shortest line, but always shows the zigzag form characteristic of lightning. A number of other phenomena come into play which affect the path of lightning, above all air currents and motions of the electrical charges of different parts of the building, which may lead to the formation of dangerous modes of vibration. For it must always be remembered that in view of the rapid motion of clouds, we have to do, not with conditions of equilibrium, but with currents. Hence it was a happy thought of Melsens to enunciate the principle that instead of tall rods of heights computed from the rule of the protected cone, short rods should be attached to all exposed places such as chimneys and ventilators, and that the metallic connections between these rods should also serve as collectors and cover and protect the roof. The construction is more complicated, but the cost of erecting high rods is saved, and their absence improves the appearance of the building.

But the task is not completed with the construction of a good collecting device. This alone would act like the spangled tube of the lecture room, for though the rods or roof wires would receive the actual lightning stroke, sparks would pass from them to neighboring conductors and thence to earth. For the electricity of

FIG. 4.

the same sign as the cloud's charge, which is repelled by this in the process of induction, also produces differences of potential which give rise to secondary discharges.

The charge accumulated on the roof conductors must therefore find immediate escape to a reservoir large enough to minimize electrical tension. Such a reservoir is the earth, hence the roof conductors are connected by wires running down the walls to special conductors, the earth connections, whose function it is to distribute the accumulated charge through the soil. In computing the dimensions of these ground and intermediate conductors, it must be remembered that the escape of a charge through a conductor occupies an interval of time, during which differences

* A lecture delivered before the Electrochemical Society of Leipzig.

of potential between the conductor and neighboring objects may be developed and cause secondary discharges. Hence several paths of escape, several wires, and ground connections are needed—how many is hard to say. Here a sort of feeling of instinctive comprehension must be the guide. As a rough estimate we may take one escape wire and ground connection for every hundred square meters. The multiplication

FIG. 5.

of earth wires also offers the advantage, strongly emphasized by Melsens, of shielding the interior of the building from electrical tension, as the conductors form a sort of Faraday's cage.

There are many forms of ground connections. The commonest and most effective are plates of copper or galvanized iron buried, or gas pipes driven, below the ground-water level. But the ground water is often so difficult to reach that other devices must be employed. In such cases wires radiating in various directions

FIG. 6.

from the end of the conductor and about ten meters long may be buried very near the surface, preferably under sod or in a damp place. A narrow trench filled with small coke surrounding a strip of lead connected with the conductor has also proved satisfactory.

An example of the absurd constructions which often result from following a fixed rule is given by an Alpine shelter where, to make connection with the ground water, a wire has been led to a spring several kilometers away. Special ground connections may, and to

FIG. 7.

some extent must, be replaced by metal gas or water pipes, which favor the distribution of the charge better than any artificial arrangement. But as these pipes may be cut off there should always be an independent earth connection as well.

A complete Faraday's cage is generally impracticable, hence there will be electrical tension in the interior parts, particularly toward extended conductors such as gas and water pipes. Smoke pipes and heating flues should be connected at the bottom with the

FIG. 8.

protective system. Whether this should or should not be done when these pipes do not reach the upper story is another matter for electro-technical instinct. If they are ten meters below the lightning protector, and this is well grounded, they need not be connected. Regard must be paid also to the distance between water pipes and the wires which connect the roof with

the ground. If this distance is only a few meters at any point, the pipe and wire should be connected at that point unless they are connected at the ground.

Expense may be saved and the protective system improved if this is constructed simultaneously with the building and utilizes its metallic structural elements. Metal ridge plates, roof, gutters, and leaders are excellent substitutes for special constructions. But this cheapening must not be carried too far. In some buildings pointed out as models of safety metal parts have been incorporated in the protector without having good contact with each other. This has been

FIG. 9.

defended on the assumption that the high tension of lightning discharges can easily spring over such small gaps. This is quite true, but the sparks which necessarily occur may, and in one instance did, cause a conflagration and, besides, they retard the discharge and produce electrical oscillations, both of which effects increase the danger of lateral discharges. In the construction of a first-class protector all such defects which may impair its efficiency should be avoided. If, on the other hand, we are content with a less degree of security, or a second-class protector,

FIG. 10.

we may disregard small gaps. It is perfectly legitimate to speak of different degrees of protection. Even an imperfect conductor gives better protection than none. Except in very special cases, there is no ground for the common saying that a poor lightning rod only increases the danger of being struck. The approaching cloud charges not only the rod, but the whole building, and the ground. The capacity of the latter is always extremely great compared with that of the building, and their ratio is not affected by the small metallic surface of the rod. But the building itself

FIG. 12.

offers more favorable points for discharge than the ground does, and is as likely to be struck without a rod as with one.

Some establishments, such as oil tanks, powder mills, and, above all, dynamite factories, need especially careful protection because of the great danger of ignition from sparks. Several recent explosions caused by lightning have recalled attention to the

protection of such structures. The Berlin Electro-technical Union is now diligently working at this problem and, let us hope, will soon make known its conclusions.

The vapor which rises from an oil tank is very liable to ignition by a stroke of lightning. Except for this special danger the metal tank would need no further protection than an earth connection. To protect the vapor, however, a fine-meshed wire netting should be stretched high above the tank and well grounded, so that the lightning cannot reach the densely vapor-laden air immediately over the tank. The manholes should also be always protected by self-closing Davy safety gratings. A similar arrangement is employed in the dynamite factory at Krimmel, and is illustrated in Figs. 2 and 3. A meter above

FIG. 13.

the building to be protected wires are stretched lengthwise and crosswise at intervals of a meter and attached to iron posts on the surrounding wall, from which the earth connections extend. The poles have also, perhaps unnecessarily, branching Melsens collectors. The building is further protected by a second coarse net, such as is used in powder mills.

LIGHTNING ARRESTERS FOR LOW-POTENTIAL CIRCUITS.

In electrical establishments the danger from lightning to which the line is exposed is added to that which threatens the building directly. The line is

FIG. 11.

charged to a varying extent by atmospheric electricity, and these varying charges result in currents which must become very strong when the line is struck by lightning. The apparatus is exposed to danger from these currents, which may destroy it and kill men who are near it even when the line is not actually struck.

In devising methods of protection it should be borne in mind that these currents, usually, are not constant but intermittent, or even consist of electrical oscillations which must occur on the line, even if the

FIG. 14.

lightning flash itself is not an oscillating discharge, as it is often asserted to be, though, so far, without the slightest proof. Aside from cutting out the apparatus from the line on the approach of a storm, immunity from damage has been sought in two ways. Arresters of the first class automatically disconnect the apparatus from the line when the current becomes too strong, while those of the second seek to provide

for the lightning discharge a way of escape which the working current cannot follow. To the first class belong especially safety fuses, strips of easily fusible metal which form part of the circuit and are melted by a strong current. An example is the so-called cartridge arrester, much employed in telephone stations. (Fig. 4.) A glass tube, *g*, contains two spiral wires which hold between them a piece of easily fusible alloy, *d*. The tube is inserted between springs, *b*, *b*, which are connected respectively with the apparatus and the line. It is evident that this device cannot protect the apparatus from an actual lightning stroke, in which the electrical tension increases so suddenly that the apparatus is in danger before it is cut out by the fusing of the plug. Such devices are of value only as safeguards against the weaker and less sudden currents due to fluctuations in the charge of the air, and as complements to arresters of the second class.

The latter offer to the lightning a way of escape to earth over a spark gap which allows the high-tension lightning, but not the working current, to pass. With this object a piece of metal connected with earth is placed about a millimeter away from another piece of metal attached to the line. These pieces are of various forms, including points, plates, continuations of both, and simple wires. The employment of opposed points or edges rests on the theory that the pointed form facilitates discharge. This is the case, however, only when the point is made the positive electrode, and even then it must be remembered that the discharge of the great quantity of electricity involved in lightning cannot be confined to the point, but must take place over the whole surface. Hence the plate form is preferable. To avoid the danger of short-circuiting by fusion in plate arresters, it is advantageous to make them of carbon instead of metal. The carbon must, of course, be of excellent quality, not easily disintegrated.

Some arresters contain cylindrical conductors and present themselves as earth-connected electrodes surrounding the line. Saunders's arrester (Fig. 5) is employed to advantage on ocean cables. A wire, *s*, connected with the line, *L*, is surrounded by a metal cylinder, *a*, *m*, *a*, which is connected to earth.

The ends of the cylinder are furnished with transverse sharp points which almost touch the wire. The other end of the wire is connected with the apparatus through a fusible plug arrester, *d*, which cuts out the apparatus if a very strong current flows through the line.

In the spiral arrester used in telephone stations, on the other hand, a fine insulated wire is wound on an earth-connected metal core. Powerful atmospheric discharges spring from the wire to the core and, at the same time, melt the fine wire and thus produce a short circuit through which the charge of the wire passes directly to earth, without affecting the apparatus.

Arresters of this sort are attached to the line wire inside the station and also at poles along the line, where, however, the attachment is made in a manner open to serious objection. The same objection applies to the customary arrangement of the arresters for high-potential circuits, to be described presently.

The arrester plate does not form a part of the line, but is inserted on a shunt, as shown in Fig. 6. A branch wire, *b*, leads from the line, *a*, to one plate of the arrester, the other plate of which is the cover, *D*, which is connected to earth through *V*. The space between the plates is protected from moisture, which would ground the line, by a porcelain shield, *G*.

The attachment of the arrester to a shunt constitutes the defect, as will appear from a comparison with a water circuit which gives, in essentials, a good image of an electrical one. (Fig. 7.) After a permanent state of flow is established, the branch, *b*, will carry off from the main channel, *a*, a quantity of water conditioned by the cross sections and slopes of the two. The result is very different when a mass of water falls suddenly and with great velocity into *a*. The branch channel, at first, takes but very little of the flow. Again, a calmly-flowing stream passes the bend in the channel *c*, without injuring the dike at *d*, but a sudden flood endangers the dike despite the open channel beyond. Similar conditions exist in the action of a lightning arrester. If it is on a branch wire it does not take the full charge imposed on the line by a sudden electrical impulse.

If, however, the arrester is inserted directly in the line, the desired rupture of the dike, the discharge to earth, follows in accordance with the analogy just given. Hence it appears to be more correct also to connect plate arresters to the line or apparatus in the manner shown in Fig. 8. Here the current enters the plate at right angles and leaves it in the same manner, but in the opposite direction.

For the facilitation of such electrical breaking of bounds use is made of the resistance which the current offers to change of direction by inserting spirally-wound wires between the arrester and the apparatus to be protected. These are called inductance coils, and the peculiar and great resistance which they oppose to sudden impulsive discharges is termed inductance. This apparent resistance proceeds in reality from a counter electromotive force developed in the coil by the sudden disturbance. The arrester and its ground connection, on the contrary, must have as little inductance and hence as little curvature as possible.

There is another defect common to nearly all in-

stallations, including those of high-potential circuits. This also may be illustrated by a hydraulic analogy. Often, to save a threatened district from flood, a dam is broken at some other point. A small opening will not suffice; the break must be large enough to carry off the water. Just so must the break through which the electrical charge is to escape to earth be large enough for its purpose. In technical language the arrester must possess sufficient capacity. In lightning we have to do, not with thin sparks, but with flashes meters wide. The conditions of discharge in an electrical machine are not a safe guide.

LIGHTNING ARRESTERS FOR HIGH-POTENTIAL CIRCUITS.

On such a circuit the arrester, after carrying off the atmospheric electricity, must break the short circuit of the working current caused by the discharge. For when a large spark passes between the arrester plates, it heats the air so greatly that the ordinary high-potential current is able to follow, and is thus diverted to earth, or short-circuited.

There are a great many high-potential arresters, based on diverse theories the validity of which can be proved by experience alone.

A simple means of preventing the short circuit consists in the multiplication of sparks in the arrester, so that the tension of the working current cannot bridge the gap, even after the way has been prepared by the lightning stroke. In plate arresters this is effected by means of a series of plates with a gap between each pair. But this form has not stood the test of practice, for though it prevents short-circuiting it does not entirely equalize the tension on the line, so that in many cases apparatus lying beyond it has been injured.

An improved form is the cylinder arrester (Fig. 9) which is based upon the fact that the passage of a spark between certain metals, such as zinc or aluminum, so increases the resistance of the gap that the passage of a second spark becomes much more difficult. The cause of this increased resistance is not yet clearly understood. It is assumed that a non-conducting coating of oxide is formed, but this could occur only at the point where the spark passes, and at other points the path would still be open.

The number of cylinders used depends upon the working voltage. Cylinder arresters appear to be used chiefly in America. In Germany they have proved satisfactory on alternating, less so on direct-current circuits.

Electromagnetic spark extinguishers are very largely used for the automatic rupture of the short circuit. In some of these the short-circuit current traverses a coil with a movable iron core, by the action of which the plates between which the spark passes are separated so widely that the short circuit is broken. (See Figs. 10 and 11.) By surrounding the plates with oil the suddenness of the rupture is greatly increased. The oil vessel is shown in *d*, Fig. 11. If the coil were inserted in the main line, its inductance would hinder the discharge to earth. It must, therefore, be put on a branch wire, as in Fig. 10, so that the greater part of the discharge can pass by to earth. This form has stood the test of experience better than the simple plate arrester, but only for comparatively low voltages. It is, furthermore, easily destroyed. Sixteen such arresters were rendered useless last year in Rottenburg, where the magnetic extinguishers of another class, since introduced, have as yet suffered no damage. These are based upon a direct action of the magnetic field due to the short circuit upon the path of the spark. The lines of force projected by a magnet have the same effect on a spark as on any other conductor, but as the ends of the spark are fixed, the magnetic action involves a lengthening of the spark, which at last breaks because the working voltage is too low to maintain a spark of the increased length. The spark is blown away from the magnet which, therefore, is termed a blow magnet. Fig. 12 shows the arrangement.

The short-circuit spark is formed between the pieces 1, 2, 3, 4 and blown by the electromagnet *A* upward along their curved edges to their points. These pieces are usually horn-shaped, as in Fig. 13, whence the name horn arrester. In this form, even without an iron magnet, the spark is driven upward and therefore lengthened partly by the upward current of heated air, partly by electromagnetic action. Fig. 14 shows an arrester constructed on this principle by Siemens & Halske. Two wires, one connected with the line, the other with earth, approach each other from opposite directions, gradually become parallel and then bend sharply away from each other. Their distance can be varied, but is usually one millimeter at the point of closest approach. Of all forms these horn arresters have best stood the test of experience, at least in Germany.

A serious inconvenience is the frequent connection of the wires by snow, rain, or dust and the resultant short-circuiting of the current even without a lightning stroke. Inclosing the apparatus in a box is suggested as a remedy.

In the attachment of all arresters for high-potential circuits the error of putting them on shunts is made. Another general defect is the smallness of the surface of discharge, the so-called capacity. To these two circumstances, probably, is due the occasional failure of every one of the forms described to afford protection.

That with proper regard to these two points protection may be assured is shown by the example of the electrical equipment of the Baltic and North Sea Canal. Here the protector is a barbed wire stretched

parallel to the cable and grounded at intervals of two hundred meters. The discharge takes place directly from the line and over a large surface. No damage from lightning has yet occurred to lamps or dynamos, though the cable has been slightly injured.

Experience like this is the best guide in the construction of lightning arresters. Thanks to the initiative of the Berlin Electrotechnical Union, it has been possible to found a collection of results of practice from which, though only two years old, very valuable conclusions have been drawn. It does not seem too bold to hope that through the co-operation of all interested as secure protection for both low and high voltage circuits as we now have for buildings will eventually be found.

CONTEMPORARY ELECTRICAL SCIENCE.*

ARC BETWEEN METALLIC OXIDES.—J. Stark has found that in certain circumstances an arc is more easily established between metallic oxides than between the metals themselves. He uses a vacuum tube in which the main current passes between the anode and the cathode and produces the ordinary glow phenomena, while the secondary current passes between electrodes at right angles to the primary electrodes, and is extinguished as soon as the main current is interrupted. At a pressure of over 50 volts and a vacuum of less than 0.5 millimeter, the presence of a film of metallic oxide, or of a few fragments of it, facilitates the production of an arc between the secondary electrodes. The author gives the following explanation of this effect. The lines of electric force proceed straight from the anode to the cathode, but if the latter bears a fragment of metallic oxide, they curve round it and enter the cathode at some other point. Nevertheless, the positive ions, having acquired a certain amount of momentum, go straight on, and impinge upon the oxide, thus increasing its temperature, and causing it not only to conduct electricity, but to evolve electrons in large quantities. Wehnelt has already shown that metallic oxides project more electrons than pure metals at high temperatures, and hence the arc, which requires a liberal supply of electrons, is more easily formed at the oxide than at the pure metal. At atmospheric pressure, the author obtained a small arc between a carbon anode and a cathode of thorium oxide at a pressure of 1,800 volts and with a current of 7 milliamperes. The anode remained quite dark.—J. Stark, *Physikal. Zeitschr.*, February 1, 1904.

COMPARISON OF HEAT AND N-RAY EFFECTS.—R. Blondlot found recently that the effect of N-rays upon a faintly luminous fluorescent screen consists not so much in an increase of the luminosity as in a change in the direction of emission. Thinking that the well-known effect of heat in increasing the luminosity of fluorescence might show a similar behavior, he observed the emission of heated screens in various directions. He found, however, that the emission increased in the same proportion in all directions, and thus obtained a valuable criterion for distinguishing between the effects of N-rays and those of heat. He describes a striking experiment which serves to clearly bring out the essential difference between heat and N-rays. He covers a screen measuring 5 centimeters by 12 centimeters uniformly with calcium sulphide, and makes it feebly luminous. He heats a portion of it, whereupon it becomes brighter than the rest. After that, he exposes one-half of the same screen to the action of N-rays given out by a Nernst lamp. The intensity of the rays is so feeble that no visible effect is produced upon the screen. Then he brings a small metallic object, such as a key or a perforated sheet of metal, in front of the screen where the N-rays impinge upon it. The shadow of the object is then clearly seen on the screen. On moving it toward that part of the screen which is not exposed to the rays, the outline becomes dim and indefinite. On moving the object to and fro over the screen, the transition from the portion illuminated by N-rays to the portion not so illuminated is clearly marked. On looking at the screen in a tangential direction the phenomena are reversed.—R. Blondlot, *Comptes Rendus*, March 14, 1904.

ATMOSPHERIC RADIO-ACTIVITY IN HIGH LATITUDES.—G. C. Simpson has obtained some remarkably high values for the radio-activity induced by the atmosphere in the extreme north of Norway, at Karasjoh. He used the method described by Elster and Geitel. A wire was stretched between an insulator in the open air and another in a room. The part exposed to the open air, 10 meters long, could be detached from the rest. The wire was charged to a negative potential by means of a small influence machine, and the potential of the wire was regulated by a variable resistance made of a piece of ebonite with a pencil line drawn on it. The potential was maintained at about 2,250 volts. The wire after being charged for two hours was wrapped round a cylinder of wire netting and its radio-activity determined by means of a dissipation electrometer. The radio-activity was estimated by the arbitrary unit devised by Elster and Geitel, unit radio-activity being possessed by the air when, after a two hours' exposure, a meter of the wire reduces the potential of the dissipation cylinder by 1 volt in one hour. The mean value of the radio-activity at Wolfenbüttel in 1902 was 18.6, the extreme values being 64 and 4. The numbers for Karasjoh are very much higher than the corresponding ones for Germany, the mean for the month being 102, which is nearly six times as great as the German mean (for the year); and the highest value, 432, being nearly seven times greater than the German

* Compiled by E. E. Fournier d'Albe in the *Electrician*.