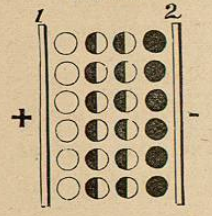
dielectric between two conducting surfaces, one of which is connected with the prime conductor of an electrical machine and the other with the earth, electricity may be strongly "condensed" on these surfaces. In Fig. 210, let the strip on the left represent a conductor, of tin-foil, positively charged from the machine, and that on the right a similar conductor connected with the earth, the intervening space being occupied by a plate of glass. This dielectric becomes polarized, the surface on the right attaining a negative charge which is bound there, while the corresponding positive electricity on the same side is neutralized by connection with the earth.

Fig. 210.

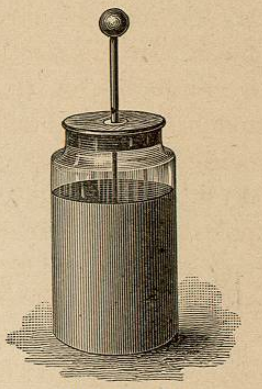


The negative charge in turn reacts through the dielectric, binding a positive charge on the left, whose energy thus becomes potential. The conductor can then receive a new charge from the machine, and the process is repeated until the greatest charge is accumulated that the condenser can carry. Its molecules are then in a condition of great strain.

14. The Leyden Jar consists of a glass jar, serving as dielectric, coated inside and outside, not quite to the top, with tin-foil. It is fitted with a cover of baked wood through which passes a metal rod with a knob at the top, and below a metal chain extending down to the inner coating. The jar is *charged* by bringing the knob near the prime conductor of the machine, while the outer coating communicates with the earth. The inner coating becomes charged

first from the machine, a succession of sparks being received until the two coatings acquire a large charge of bound electricity, positive within and negative without. To *discharge* it* one end of a conductor with an insulated handle is put on the outer coating, while the other is brought near the knob above. A sharp snap and a brilliant flash through the air announce that equilibrium is restored. Minute particles detached from the solid conductors are made momentarily white-hot, giving brilliancy to the spark.†

Fig. 211.



The Leyden Jar.

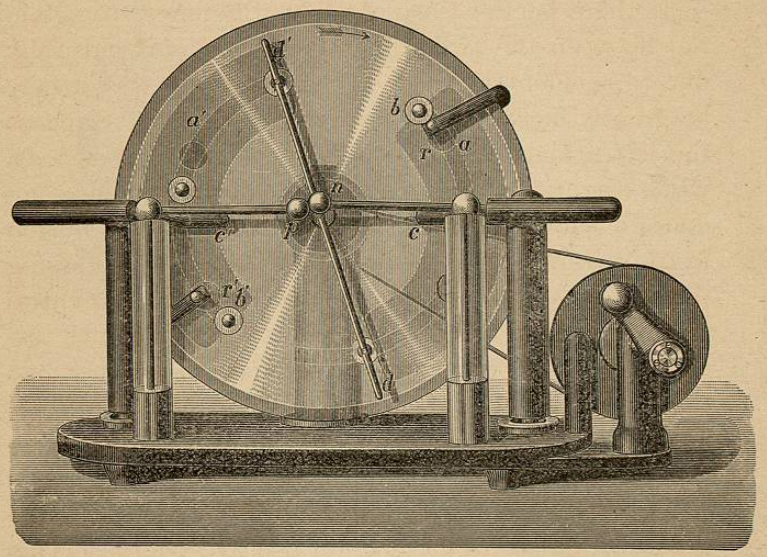
The tin-foil on a Leyden jar serves only as a conductor, and not as an accumulator, of the charge. The jar may be made with movable coatings. After it is charged these may be removed. Putting the same jar then into another set of coatings, it may be discharged in the usual manner.

* It is said that Cuneus, a pupil at Leyden, discovered the principle of the Leyden jar in the following curious way: While experimenting, he held a bottle of water to the prime conductor of his electrical machine. Holding the bottle with one hand, he happened to touch the water with the other, when he received a shock so unexpected, and so unlike any thing he had ever felt before, that he was filled with astonishment. It was two days before he recovered from his fright. A few days afterward, in a letter to a friend, the physicist innocently remarked, that he would not take another shock for the whole kingdom of France.

† The incredibly small quantity of the metal volatized in this way is a striking proof of the divisibility of matter. During some experiments at the Philadelphia mint a gold pole lost in weight by a strong spark one millionth of a grain; and $\frac{1}{3\,850\,000}$ of a grain of nickel *signed its name* in the spectroscope brilliantly. See "Popular Science Monthly," May, 1877.

15. The Voss Electrical Machine.—Many improvements have been made on the plate electrical machine. One of the best is the Voss machine.* This consists of a fixed glass plate in front of which re-

Fig. 212.



The Voss Machine.

volves a smaller one provided with six metallic buttons (Fig. 212, *b*). On the rear of the fixed plate are two sheets of varnished paper, *a* and *a'*. Each covers a strip of tin-foil, called the armature, from which a metallic arm extends around to the front, ending in a rubber of brass filaments, *r*. Under this each button passes. A pair of combs, *c* and *c'*, connect with adjustable discharging rods, *p* and *n*. Another pair of combs and rubbers are attached to the brass rod, *dd'*; this extends across in front of the plate, which revolves in the direction shown by the arrows.

If there be the least possible difference of potential between the two armatures, such as is naturally due to accidental conditions on their surfaces, it may be greatly increased by revolving the plate. Suppose the left armature, *a'*, to be faintly charged positively, while the right armature, *a*, is neutral; then *a'* induces a slight negative bound charge on the button in front, which in revolving passes under *d'*. Passing from *d'* to *r*, the button comes opposite a neutral armature. Its negative bound charge at once becomes free and is conducted through the rubber *r* to the armature behind, charging it negatively. This at once acts inductively on the button, causing it to acquire a positive bound charge with which it passes *d*. This charge is freed at *r'* and conducted to the armature *a'*, strengthening its positive charge. This process continues, both armatures becoming soon strongly and oppositely charged. The comb, *c'*, by induction from *a*, is polarized. It discharges negative electricity, while the rod, *p*, acquires a strong positive charge. In like manner *c* discharges positive electricity and *n* acquires a strong negative charge. A succession of sparks soon passes between *p* and *n*, the strength of which is greatly increased by condensation in the Leyden jars, with which the discharging rods are connected.

* For a long time the best electrical machine was that devised by a German physicist, M. Holz. Two of his countrymen, Voss and Toepler, have improved it greatly. The one described in the text is often called the Toepler-Holz machine.

16. Lightning is only the discharge of a Leyden jar on a grand scale. If two clouds with opposite charges of electricity come near together, the intervening air reaches its limit of polarization, and a flash occurs like that between the discharging-rods of the Voss machine.* The air is never quite uniform in conducting power at all places, and the immense spark, moving along the line of least resistance, describes a zigzag course. It suddenly heats the air, which expands and instantly collapses. The concussion produces a series of air-waves from successive parts of the spark. These constitute thunder, which continues to roll because the sound is reflected many times from clouds, and from masses of air which differ among themselves in density. Often the charged cloud approaches the ground rather than another cloud. Discharge takes place, and exposed objects, such as tall houses or trees, are destroyed if included in the lightning's path.

LIGHTNING-RODS were invented by Franklin.† They are based on the principle that electricity always

* The air is constantly electrified. In clear weather it is in a positive state, but in foul weather it changes rapidly from positive to negative, and *vice versa*. Dr. Livingstone tells us that in South Africa the hot wind which blows over the desert is so highly electrified, that a bunch of ostrich feathers held for a few seconds against it becomes as strongly charged as if attached to an electrical machine, and will clasp the hand with a sharp, crackling sound.

† Franklin's plan was opposed by many men of his day, who declared it was as impious to ward off Heaven's lightning, "as for a child to ward off the chastening rod of its father." There was much discussion as to whether the conductors should be pointed or not. Wilson persuaded George III. that the points were a republican device to injure His Majesty, as they would certainly "invite" the lightning, and so the points on the lightning-rods upon Buckingham Palace were changed for balls.

seeks the best conductor. The rod should be pointed at the top with some metal which will not easily corrode. If constructed in several parts, they should be securely jointed. The lower end should extend into water, or else deep into the damp ground, beyond a possibility of any drought rendering the earth about it a non-conductor, and be packed about with ashes or charcoal. If the rod is of iron, it needs to be much larger than one of copper, which is a better conductor. Every elevated portion of the building should be protected by a separate rod. Chimneys need especial care, because of the ascending column of vapor and smoke. Water conductors, tin roofs, etc., should be connected with the damp ground or the lightning-rod, that they may aid in conveying off the electricity.*

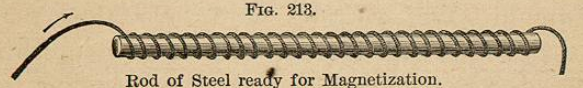
DURATION OF THE FLASH.—The duration of the flash from a Leyden jar has been found to vary from two thousandths to forty billionths of a second. When the plate of the Voss machine is revolving at the highest speed, each button can be momentarily seen, as if it were still, when illuminated by the spark. The trees swept by the tempest, or a train of cars in rapid motion, when seen by a flash of

* The value of a lightning-rod consists, most of all, in its power of quietly restoring the equilibrium between the earth and the clouds. By erecting lightning-rods, we thus lessen the liability of a sudden discharge. Every drop of rain, and every snow-flake, falls charged with electric energy, and thus quietly disarms the clouds of their terror. The balls of electric light, called by sailors "*St. Elmo's fire*," which sometimes cling to the masts and shrouds of vessels, and the flames said to play about the points of bayonets, indicate the quiet escape of electricity from the earth toward the clouds.

lightning, seem motionless; while a cannon-ball, in swift flight, appears poised in mid-air.

17. Effects of Frictional Electricity.—(1.) PHYSICAL.—Discharges from a large battery of Leyden jars will melt metal rods, perforate glass, split wood, magnetize steel bars, etc.—Let a person stand upon an insulated stool and become charged from the prime conductor. His hair, through repulsion, will stand erect in a ludicrous manner. On presenting his hand to a little ether contained in a warm spoon, a spark leaping from his extended finger will ignite

FIG. 213.



Rod of Steel ready for Magnetization.

it. If he hold in his hand an icicle, the spark will readily dart from it to the liquid.*—A card held between the knob of a Leyden jar and that of the discharger, will be punctured by the spark.—A piece of steel may be magnetized by the discharge from a Leyden jar. Wind a covered copper wire around a steel bar, as in Fig. 213, or inclose a needle in a small glass tube, around which the wire may be wound. On passing the spark through the wire, the needle will attract iron filings.—When strips of tin-foil are pasted on glass, and figures of various patterns cut from them, the electric spark leaping from

* This experiment can be more surely performed by using disulphide of carbon. The insulating stool may be merely a board laid on four dry flint-glass bottles or goblets, and the electricity be developed by rubbing a glass tube.

one to the other presents a beautiful appearance.—If a battery be discharged through a small wire the electricity will be changed to heat, and the wire, if sufficiently small, will be fused into globules or dissipated in smoke.

FIG. 214.

Illuminated Pane.

(2.) CHEMICAL EFFECTS.—The "electric gun" is filled with a mixture of oxygen and hydrogen gases. A spark causes them to combine with a loud explosion and form water.—The sulphurous smell which accompanies the working of an electrical machine, and is noticed in places struck by lightning, is owing to the production of ozone, a peculiar form of the oxygen of the air. (See "Popular Chemistry," p. 23.)

(3.) PHYSIOLOGICAL EFFECTS.—A slight charge from a Leyden jar produces a contraction of the muscles and a spasmodic sensation in the wrist. A stronger one becomes painful and even dangerous.

II. VOLTAIC ELECTRICITY.*

1. Simple Voltaic Circuit.—If a strip of zinc, coated over with mercury, be put into a mixture of sulphuric acid and water, no perceptible chemical action will be noticed. But if a strip of copper or

* This name is given in honor of the Italian physicist who made the first discoveries in this branch of electricity.