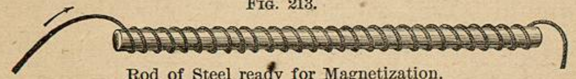
lightning, seem motionless; while a cannon-ball, in swift flight, appears poised in mid-air.

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.

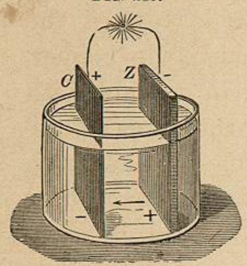
II. VOLTAIC ELECTRICITY.*

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.

platinum be immersed at the same time, and the upper ends of the two pieces of metal be touched together or connected by wires, many little bubbles of gas will be seen on the second strip, forming and rising to the surface. When the experiment is performed in the dark, an almost infinitesimal spark is perceived at the moment the wires are joined.*

Fig. 215.



A Voltaic Pair.

Two metal plates joined in this way form a *voltaic pair*. The exposed end of the copper or platinum plate is called the positive pole, and that of the zinc the negative pole of the pair.† Joining the wires, or otherwise connecting the poles, is termed *closing the circuit;* and separating them, *breaking the circuit.* A cup prepared for such an experiment is called a *voltaic cell.*

2. Action in the Voltaic Cell.—Zinc is far more easily acted upon by sulphuric acid than copper is. Each molecule of the acid is composed of two atoms of hydrogen, one of sulphur, and four of oxygen.‡ This may be expressed by the symbol, H_2SO_4. When the acid, mixed with water, acts on zinc (Zn), its hydrogen is set free, and a new substance, called zinc

* We can easily form a simple galvanic circuit by placing a silver coin between our teeth and upper lip, and a piece of zinc under our tongue. On pressing the edges of the two metals together, a peculiar taste will be perceived.

† These names may easily be remembered if we associate the p's with copper and positive, and the n's with zinc and negative.

‡ For the properties of these elements, refer to "Popular Chemistry," pp. 11, 38, and 103.

sulphate, is produced. Its symbol is $ZnSO_4$. It is at once dissolved in the water, leaving a fresh surface of metal to be attacked by the acid. It is thought that each molecule of liquid between the copper and zinc becomes polarized, then decomposed, giving up its H_2 to its neighbor on the side toward the copper, and its SO_4 to its neighbor on the side toward the zinc. The H_2 liberated, in contact with the copper, gathers in bubbles of gas; the SO_4, in contact with the zinc, unites with this metal. At the copper plate chemical energy is transformed into electrical energy. If the exposed ends of the two plates be examined with a sufficiently delicate electroscope, while they are still separate, it is found that the copper is electrically at higher potential than the zinc. When they are connected, neutralization instantly takes place, but the action of the acid renews the potential of the copper, so that the process is continuous as long as the zinc can be dissolved by the acid.*

3. The Electric Current.—The term "current" is applied to this continuous neutralization and renewal of electric potential in the closed voltaic circuit. The current is said to "flow" through the conducting wire from the copper at high potential toward the zinc at low potential, just as water flows from an

* With what inconceivable rapidity must these successive changes take place in an iron wire to transmit the electric energy, as in actual experiments, from Valentia, Ireland, across the bed of the Atlantic and the American continent to San Francisco and return, a distance of 14,000 miles, in two minutes! In fact, it far surpassed the velocity of the earth's rotation, by which we measure time, and leaving Valentia at 7:21 A.M., Feb. 1, it reached San Francisco at 11:20 P.M., Jan. 31.

elevated reservoir through a pipe toward a lower reservoir. There is no actual transfer of matter, no current of fluid; but only by analogy we may call it a current of energy transmitted through the entire thickness and length of the conducting wire. By analogy also the current is said to pass through the cell from zinc to copper, thus completing its circuit.

4. The Volt.—We measure the difference of temperature between two bodies in *degrees* on the thermometer scale, or the difference of level between the surfaces of two reservoirs in feet or meters. These are the accepted units of measurement. In like manner, for measuring the difference of potential between two bodies, a unit called the *volt* * has been selected. In the simple voltaic cell already described, when freshly set in action, the difference of potential between its poles is about one volt. The force due to difference of potential is called *electro-motive force*, and is always measured in volts. †

* Named in honor of Alessandro Volta, an Italian physicist, who was born in 1745. In 1793, he communicated to the Royal Society of London an account of his important experiments on which the modern science of electricity has been largely built.

† The difference of potential between the discharging rods of a Voss electrical machine when giving long sparks is often several hundreds of volts. When passed through the body, such momentary currents are painful. The potential of the air during a thunder-storm quickly changes through thousands of volts. The voltaic cell furnishes a current that is exceedingly steady in comparison with the stream of sparks from an electrical machine, but of only small electro-motive force. Frictional electricity is sudden, noisy, convulsive; voltaic is gentle, silent, yet powerful. The one is like a quick, violent blow; the other like a steady, uniform pressure. The effect of the one is comparable to that of a blazing fire; the other, a summer breeze. Lightning leaps across miles of air; the voltaic current will pass through a conductor from England to California rather than spark across half an inch of air. The most powerful frictional machine would be insufficient for telegraphing; while signals have been sent across the ocean with a tiny battery composed of "a gun-cap and a strip of zinc, excited by a drop of water the bulk of a tear." "Faraday immersed a voltaic pair, composed of a wire of platinum and one of zinc, in a solution of four ounces of water and one drop of oil of vitriol. In three seconds this produced as great a deviation of the galvonometer needle as was obtained by 30 turns of the powerful plate-glass machine. If this had been concentrated in one millionth of a second, the duration of an electric spark, it would have been sufficient to kill a cat; yet it would require 800,000 such discharges to decompose a grain of water."

5. Electrical Resistance.—Every conductor opposes resistance to the electric current. A strong current at one end of a long telegraph wire is weakened at the other end. The liquid in the voltaic cell opposes resistance as well as the conducting wire. The strength of current increases in proportion to the electro-motive force and decreases in proportion to the resistance.

6. The Ohm.—To measure resistance, a unit called the *ohm* * has been selected. A piece of common copper wire, as thick as the band shown in Fig. 216, and fifty yards long, opposes a resistance of about one ohm. Coils whose resistance in ohms is known are much used in electrical measurement.

Fig. 216.

7. The Ampère.—To measure the effective current strength obtained from a voltaic cell, a unit called an *ampère* † has been selected. It is the

* Named in honor of Dr. G. S. Ohm, a German physicist, who determined the relation existing between current strength, electro-motive force, and resistance.

† Named for André Marie Ampère, a French physicist, born in 1775, whose splendid work in electricity was such as to give him the highest rank along with Volta.

The definitions of electrical units given in the text are not exact enough to furnish more than the most elementary ideas. The student will amount of current obtained when one volt of electro-motive force acts against one ohm of resistance.

With these units electricity can be measured with as much exactness as we measure quantities of grain or water.

8. A Battery consists of two or more voltaic cells so connected as to secure a stronger current than can be obtained from a single cell. According to Ohm's Law, the current strength (C) in ampères is equal to the electro-motive force (E) in volts divided by the resistance in ohms. The resistance is partly in the external conductor (R) and partly in the liquid of the battery (r). The law is expressed in a formula, thus,

$$C = \frac{E}{R + r}.$$

With a large number of cells a battery, therefore, can be arranged either to overcome a large external resistance, or, when this is small, to do a large amount of work within a liquid.

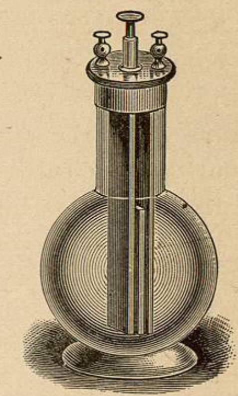
9. Polarization within the Battery.—As soon as the action of a battery is well begun, the electro-motive force becomes rapidly diminished because hydrogen tends to collect upon the plate in connection with the positive pole. The bubbles interfere with further action and start a counter electro-motive force which neutralizes much of that in operation. Many different devices have been em-

find them more accurately defined in any text-book devoted specially to Electricity, such as that of Thompson or Urbanitzky.

ployed to diminish this evil, and each gives rise to a special kind of battery. Only a few need be described.

10. The Potassium Bichromate Battery.—Instead of copper, a pair of plates of carbon are immersed, with a plate of zinc between them, arranged so as to slide into the liquid or out of it at will. A solution of potassium bichromate in sulphuric acid and water is used. The sulphuric acid acts on the zinc, and the hydrogen is prevented from forming in bubbles by being combined at once with some of the oxygen which the chromic acid yields.

Fig. 217.



Potassium Bichromate Cell.

Daniell's Battery. — In this battery there are two fluids separated by a cup of porous earthenware, which does not prevent the passage of the current. In the outer vessel of glass there is a strong solution of copper sulphate ($CuSO_4$) in which a split copper cylinder is immersed. Within this is placed the porous cup, containing a rod of zinc coated with mercury and a mixture of sulphuric acid with water. Zinc sulphate is produced, and the liberated hydrogen decomposes some of the copper sulphate, taking its SO_4 and causing a deposit of metal-

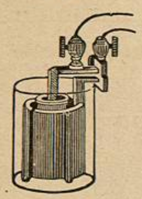
Fig. 218.

Daniell Cell.

lic copper. Polarization is thus prevented, and this is one of the most constant batteries known.

Grove's Battery.—In this the outer cup contains the zinc and dilute sulphuric acid. Within the porous cup a strip of platinum dips into strong nitric acid. The hydrogen decomposes some of the nitric acid, taking oxygen from it to produce water and liberating red fumes of nitric oxide, which are unpleasant and hurtful. This battery gives very high electro-motive force.

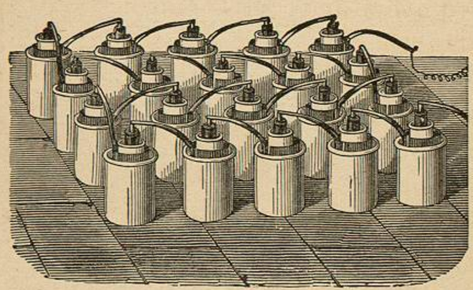
Fig. 219.



Grove Cell.

Bunsen's Battery.—In this rods of carbon are substituted for the strips of platinum used in the Grove battery. Sometimes potassium bichromate

Fig. 220



Bunsen Battery.

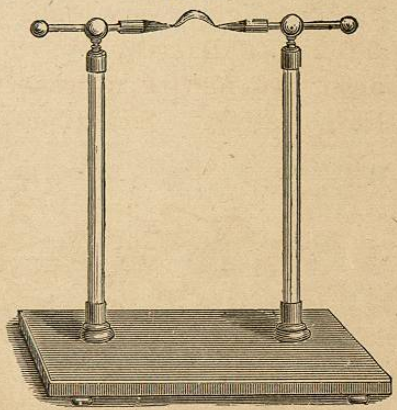
solution is substituted for nitric acid in order to avoid the production of nitrous fumes. Fig. 220 shows a Bunsen battery arranged in series.

11. Effects of Voltaic Electricity.—(1.) Physical.—If a current of electricity is passed through a wire too small to conduct it readily, it is converted into

heat. The poorer the conducting power of the wire, and hence the greater the resistance, the more marked the effect. With ten or twelve Grove's cups several inches of fine steel wire may be fused; and with a powerful battery, several yards of platinum wire may be made to glow with very brilliant effect, giving a steady light.*

In closing or breaking the circuit, we produce a spark, the size of which depends on the electro-motive force and current strength of the battery. With several cells, beautiful scintillating sparks are obtained by fastening one pole to a file and rubbing the other upon it. When charcoal or gas-carbon electrodes are used with a powerful battery, on slightly separating the points, the intervening space is spanned by an arch of the most dazzling light (Fig. 221). The flame, reaching out from the positive pole like a tongue, vibrates around the negative pole, licking now on this side and now on that. The heat is intense. Platinum melts in it like wax

Fig. 221.



The Arc Light.

* Torpedoes and blasts are fired on this principle. Two copper wires leading from the battery to the spot are separated in the powder by a short piece of small steel wire. When the circuit is completed, the fine wire becomes red-hot and explodes the charge.

in the flame of a candle,* the metals burn with their characteristic colors; and lime, quartz, etc., are fused. The effect is not produced by burning the charcoal points, since in a vacuum it is equally brilliant.

(2.) Chemical Effects.—*Electrolysis* (to loosen by electricity) is the process of the decomposition of compound bodies by the voltaic current. If platinum electrodes be held a little distance apart in a cup of water mixed with sulphuric acid, tiny bubbles will immediately begin to rise to the surface. When the gases are collected, they are found to be oxygen and hydrogen, in the proportion of two parts of the latter to one of the former.† In the electrolysis of

* To show the varying conducting power of the different metals, fasten together alternate lengths of silver and platinum wire and pass the current through them. The latter will glow, while the former, conveying the electricity more perfectly, will scarcely manifest its presence.

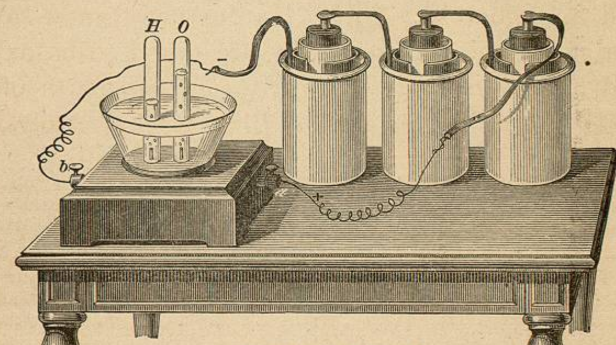
There are two forms of the electric light now used—the *arc* (shown in Fig. 221), where the current passes between two carbon points; and the *incandescent*, where the current heats to a dazzling white a carbon strip placed in the circuit. The former is employed in lighting streets, railroad stations, and large halls; the latter is generally used in dwellings, etc., as it gives a softer light, and is much more steady. Edison's Lamp consists of a tiny carbon loop placed in a glass globe from which the air has been so completely exhausted as to leave only $\frac{1}{1000000}$ of an atmosphere. When exposed to the air, the voltaic arc rapidly wastes the carbon points. Electric lamps have therefore been devised that, by a self-acting apparatus, keep the points at a proper distance from each other.

† If the copper poles be inserted, bubbles will pass off from the negative, but none from the positive pole, since the oxygen combines with the copper wire. That gas has no effect on platinum. The burning of an atom of zinc in the battery develops enough electricity to set free an atom of oxygen at the positive pole. It is interesting to notice that in the battery there is zinc burning, *i. e.*, combining with oxygen, but without light or heat; in the electric light the real force of the combustion is revealed. We may thus transfer the light and heat to a great distance from the place where they take their origin. The transmission of energy thus to a distance is better effected through electricity than through any other agency. Much ingenuity has been expended on machines for this purpose.

compounds, their elements are found to be in different electrical conditions. Hydrogen and most of the metals go to the negative pole, and are *electro-positive*. Oxygen, chlorine, sulphur, etc., go to the positive pole, and are therefore *electro-negative*.

Any battery-cell subjected to electrolysis is called a secondary cell. Several such cells form an *accumulator* or storage battery. Faure's accumulator

Fig. 222.

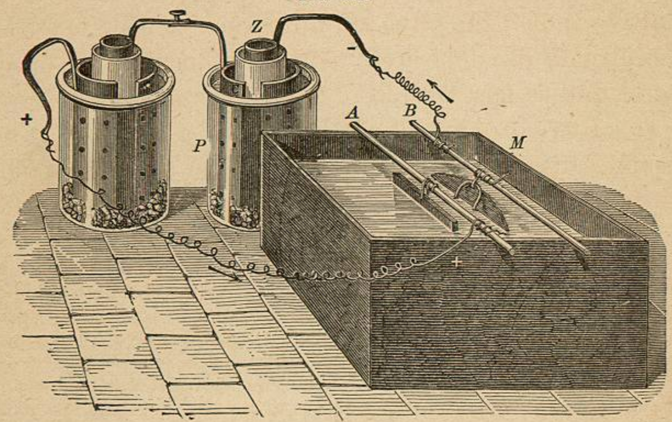


Electrolysis of Water.

consists of two lead plates coated with red lead, rolled together with flannel between them, and immersed in dilute sulphuric acid. A current of electricity passed through such a cell changes a part of the red lead on the positive plate into peroxide of lead; and a part of the red lead on the negative plate into spongy metallic lead. A battery of these cells when freshly charged will retain its energy and produce a sustained current when desired.

Electrotyping is the process of depositing metals from their solution by electricity. It is used in copying medals, wood-cuts, types, etc. An impression of the object is taken with gutta-percha or wax. The surface to be copied is brushed with black-lead to render it a conductor. The mold is then suspended in a solution of copper sulphate, from the negative pole of the battery, and a plate

FIG. 223.



Electrotyping.

of copper is hung opposite on the positive pole. The electric current decomposes the copper sulphate; the metal goes to the negative pole and is deposited upon the mold, while the acid, passing to the positive pole, dissolves the copper, and preserves the strength of the solution.*

* While the plate is hanging in the solution there is no noise heard or bubbling seen. The most delicate sense fails to detect any movement. Yet the mysterious electric force is continually drawing particles of *ruddy, solid* copper out of the *blue liquid*, and, noiselessly as the fall of snow-flakes, dropping them on the mold; producing a metal purer than any chemist can manufacture, spreading it with a uniformity no artist can attain, and copying every line with a fidelity that knows no mistake.

Electro-plating is the process of coating with silver or gold by electricity. The metal is readily deposited on German silver, brass, copper, or nickel silver (a mixture of copper, zinc, and nickel). The objects to be plated are thoroughly cleansed, and then hung from the negative pole in a solution of silver, while a plate of silver is suspended on the positive pole. In five minutes a "blush" of the metal will be deposited, which conceals the other metal and is susceptible of polish.*

(3.) PHYSIOLOGICAL EFFECTS.—With a single cell no special sensation is experienced when the two poles are held in the hands. With a large battery a sud-

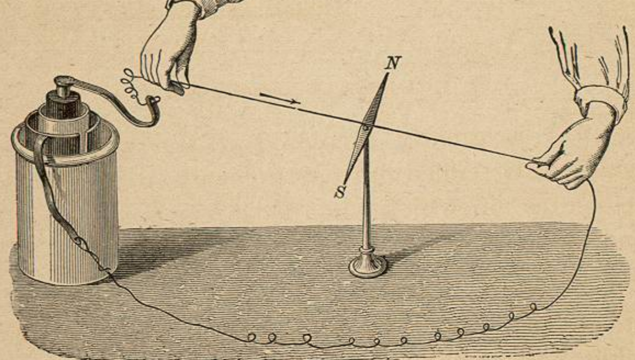
* Place in a large test-tube a silver coin with a little nitric acid. If the fumes of the decomposed acid do not soon rise, warm the liquid. When the silver is dissolved, fill the tube nearly full of soft water. Next drop hydrochloric acid into the liquid until the white precipitate (silver chloride) ceases to fall. When the chloride has settled, pour off the colored water which floats on top. Fill the tube again with soft water; shake it thoroughly; let it settle, and then pour off as before. Continue this process until the liquid loses all color. Finally, fill with water and heat moderately, adding potassium cyanide (the pupil will remember that this substance is exceedingly poisonous) in small bits as it dissolves, until the chloride is nearly taken up. The liquid is then ready for electro-plating. Thoroughly cleanse a brass key, hang it from the negative pole of a small battery, and suspend a silver coin from the positive pole. Place these in the silver solution, very near and facing each other. When well whitened by the deposit of silver, remove the key and polish it with chalk. In the arts the polishing is performed by rubbing with "burnishers." These are made of polished steel, and fit the surfaces of the various articles upon which they are to be used. It is said that an ounce of silver can be spread over two acres of surface. A well-plated spoon receives about as much silver as there is in a ten-cent piece. The only method of deciding accurately the amount deposited is by weighing the article before and after it is plated.—A vessel may be "gold-lined" by filling it with a solution of gold, suspending in it a slip of gold from the positive pole of the battery, and then attaching the negative pole to the vessel. The current passing through the liquid causes it to bubble like soda-water, and in a few moments deposits a thin film of gold over the entire surface.

den twinge is felt, and the shock becomes painful and even dangerous, especially if the palms are moistened with salt or acid water to increase the conduction. Rabbits which had been suffocated for half an hour, have been restored by an application of a strong voltaic current.

III. TRANSFORMATIONS OF ELECTRIC ENERGY.

1. Effect of a Voltaic Current on a Magnetic Needle.—If a wire conducting an electric current be placed over a poised magnetic needle, this tends to place itself at right angles to the wire.

Fig. 224.

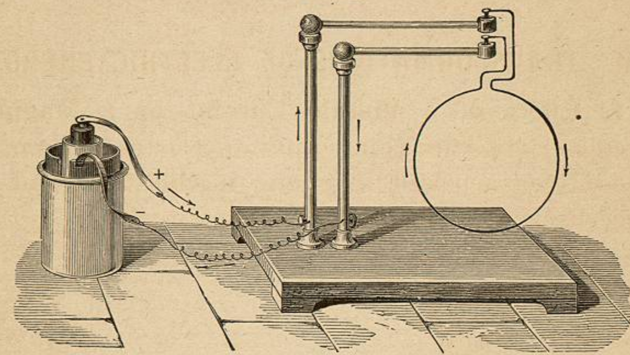


Effect of Current on Needle.

Assuming the direction of the current to be northward, the north pole of the needle will be turned toward the left. The same effect will be produced if the current pass southward under the

needle, or vertically downward on the north side of it, or vertically upward on the south side of it. By reversing these conditions, the north pole of the needle will be turned toward the right. The play of the needle becomes thus a test of the presence and direction of an electric current.* The delicacy of

Fig. 225.



Pivoted Hoop of Conducting Wire.

this test is greatly increased if the wire, properly insulated, be coiled into a ring with many turns, at the center of which the needle is pivoted or suspended.

2. A Wire bearing a Current acts like a Magnet.—Let a copper-wire hoop be pivoted, as shown in Fig. 225, so that its plane is in a north and south

* Ampère gave a very convenient rule for determining the direction of the current from the motion of the magnetic needle. Imagine the current to be like a stream of water, with a little swimmer in it, facing the needle and swimming along with the current. The north pole of the needle will always turn *toward his left*. The pupil should try the experiment and test it in all possible ways.