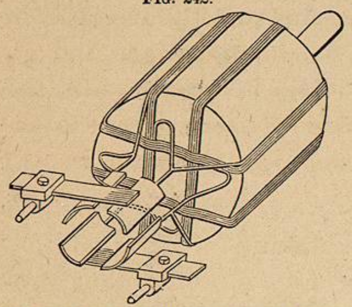
plied to a development of the magneto-electric machine that accomplishes this result. The armature coils, in one type of these machines, are wound lengthwise upon a drum or cylinder, Fig. 242, which is revolved between the poles of a powerful electro-magnet called the field-magnet. On this drum a large number of coils may be wound, each with its own pair of commutator plates, these being so close together that the interval between two successive currents is imperceptible. In Fig. 243, the end of the cylinder and of the group of commutator plates are seen between the large pole-pieces, *N* and *S*, of the field-magnets. The current is conducted off by the springs or "brushes," and passes through the coils of the field-magnet before reaching the main-line

Fig. 242.



Drum Armature and Four-part Commutator.

Fig. 243.

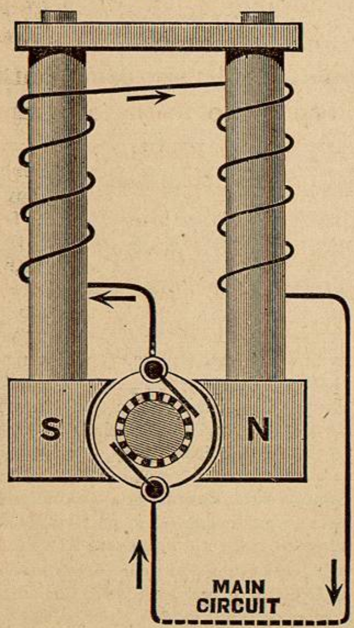


Diagram of a Series Dynamo.

wire. The pole-pieces never quite lose their magnetism, even after the machine is at rest. The energy of the induced current is at first wholly absorbed in exciting the field magnet. This action, even though almost infinitely weak at first, increases until the magnet is as strong as possible; after which the energy is expended in doing work on the main circuit.*

14. The Electric Light.—According to the method adopted in winding the armature, a dynamo-machine may give currents of high or of low electromotive force. Two corresponding kinds of lamp are used. To produce the *arc light*, a current of high electro-motive force is sent through a pair of carbon rods, which are then drawn slightly apart. Particles of carbon are made white-hot, and even turned into vapor, which is thrown from one rod to the other in the direction of the current. The path of the glowing vapor is curved, and hence this is called the voltaic arc. It is the most brilliant artificial light known, but unsteady because the arc leaps from side to side as the carbons become wasted away. An automatic regulator is employed to keep them at the proper distance apart. The arc light is excellent for lighting streets, halls, and other large public places. For domestic use, the *incandescent* lamp is better. In

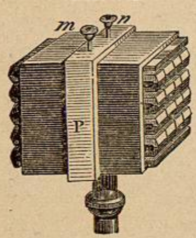
* In the frontispiece is a picture of the Weston Dynamo, such as is used for producing the electric lights on the great bridge between New York and Brooklyn. Each pole-piece is attached to two coils which are so wound that both have the same effect on it. The end of the drum armature is covered with radiating conductors, which connect the coils with the commutator plates. One of the brushes is seen pressing on these plates, and is connected with the insulated wire that conducts the current away.

this a current of low electro-motive force passes through a filament of carbon inclosed in a globe from which most of the air has been withdrawn. The filament glows with a soft and steady light, which is much inferior in brilliancy to the arc light. Although only $\frac{1}{1000000}$ of the air remains in the globe, the filament is slowly burned away, and has to be replaced with a new one.

15. Thermo-electricity.—In the electric lamp the energy of a current is changed into heat and light. Conversely, heat and light (radiant energy) may be changed into electric energy. If the end of an iron wire be connected with that of a copper or German-silver wire, the other ends being attached to a galvanometer, the needle will swing aside when the joined ends are heated. This effect is increased if the junction be made with bismuth and antimony. A current flows at the junction from bismuth to antimony, thence through the galvanometer back to the bismuth.

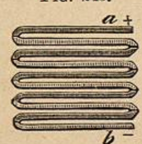
A Thermo-electric Pile consists of alternate bars of antimony and bismuth soldered together, as shown in Fig. 244. When mounted for use, the couples are insulated from each other and inclosed in a copper frame, *P*. If both faces of the pile are equally heated, there is no current. The least variation of temperature, however, between the two is indicated by the flow of electricity. Wires from *a*, the positive pole, and *b*, the negative, connect the pile with the galvanometer. This furnishes a test of change of temperature. A fly walking over the face of the pile by its warmth will move the needle, if the galvanometer be very delicate. When skillfully used, the thermopile serves as a very sensitive thermometer.

Fig. 244.



Thermopile.

Fig. 245.



The Bolometer is an instrument devised for the detection of very faint variations of temperature. A platinum or iron wire opposes much more resistance to the passage of an electric current when hot than when cold. The current is made to divide between two conductors. These are connected by a cross-wire, or "bridge," with a galvanometer interposed. If the current in the two branches be equal, the galvanometer is not affected; but, if unequal, a cross-current deflects the galvanometer needle. By heating one branch slightly the balance is disturbed, and the difference of temperature is read in the deflection of the needle.*

16. Animal Electricity.—The human body is often electrified. Many animals, especially when angry or otherwise excited, give evidence of being electrified.

* This instrument was invented by Professor Langley at the Alleghany Observatory near Pittsburg. It was used in examining the invisible parts of the solar spectrum, where lines and bands were discovered whose presence could not be detected with the most delicate thermopile. The invisible part of the spectrum was thus found to be much more extensive than the visible part, while the most intense heat as well as light is found in the region colored greenish-yellow. The bolometer is capable of revealing a change of temperature of .00001° C. Professor Langley has discovered by this means that the highest temperature of the moon scarcely, if at all, exceeds that of the human body, and that the temperature of outer space is nearly as low as the absolute zero of temperature, − 273° C.

Certain fish have the property of giving, when touched, a shock like that from a Leyden jar. The torpedo and the electrical eel are most noted. The former is a native of the Mediterranean, and its shock was anciently prized as a cure for various diseases. The latter is abundant in certain South American waters. A specimen of this fish, forty inches in length, was estimated by Faraday to emit a spark equal to the discharge of a battery of fifteen Leyden jars.

SUMMARY.

Electricity is a form of energy that may be manifested as an accompaniment of friction, of chemical action, of the motion of magnets, of variations in temperature, or of animal excitement. It exhibits a certain kind of duality in its effects, and hence the names positive and negative electricity are used to express the contrast. Many considerations point to the conclusion that the molecules of a charged body are in a condition of strain. This condition can be communicated by induction through a "dielectric," which itself becomes strained while thus acting as a medium. By taking advantage of a proper dielectric, such as glass, electrical energy may be stored up for subsequent use, as in the Leyden jar.

Voltaic electricity has its origin in chemical action, or in contact of different metals, or in both. The essentials of an ordinary battery for its development are two substances, which are unequally affected by a chemical agent. One of these is at higher potential than the other, and neutralization is effected by the passage of a current, continually renewed, from the body at high potential, through the best conductor, to the body at low potential. This difference of potential, however, is very slight in comparison with that developed by friction and induction, as in the Holtz or Voss machine. Voltaic electricity is more manageable, more reliable, more convenient, more generally available than frictional electricity. Electricity may be transformed, under appropriate conditions, into mechanical motion, magnetism, sound, heat, or light. Among its most important applications to the purposes of practical life are the telegraph, the electrotype, the telephone, and the electric light.

HISTORICAL SKETCH.

Thales (6th cent. B.C.), one of the seven wise men, knew that when amber is rubbed with silk it will attract light bodies, as straw, leaves, etc. This property was considered so marvelous that amber was supposed to possess a soul From the Greek name of the substance (elektron) our word electricity is derived. This simple phenomenon constituted all that was known until the 16th century, when William Gilbert, physician to Queen Elizabeth, made many valuable experiments. He discovered that amber was by no means the only substance which can exhibit electrical manifestations when rubbed, and he examined into the conditions favorable to electrical phenomena. Among the most important of these he found to be the dryness of the atmosphere. Francis Hawksbee called attention to the resemblance between the electric spark and lightning, and invented an electric machine, in which the hands were used as rubbers. Stephen Gray, in the 18th century, discovered the difference between conductors and non-conductors, that an electric charge is at the surface, and that the human body can be electrified. Dufay discovered that there are two manifestations of electricity, which he called vitreous and resinous, and considered them to be fluids. Kinnersley, the friend and associate of Franklin, recognized that these two electricities were nothing else than what Franklin had already called positive and negative charges. The Leyden jar was invented in 1745, probably by several persons about the same time; it was first exhibited and used in experiment by Muschenbroeck, at Leyden, in Holland. By the use of it students of electricity were able to gather the mysterious "virtue" or "effluvia" in much larger quantities, and to produce effects never imagined before, such as the firing of gunpowder. Experiments were made about this time to ascertain the rate of transmission of electricity from a Leyden jar through a metallic conductor. A wire more than two miles long was employed; through this the discharge appeared to be absolutely instantaneous.

In 1749, Benjamin Franklin wrote from Philadelphia to Peter Collinson at London, as follows:

"Chagrined a little that we have hitherto been able to produce nothing in this way of use to mankind, and the hot weather coming on, when electrical experiments are not so agreeable, it is proposed to put an end to them for this season, somewhat humorously, in a party of pleasure on the banks of the *Skuylkil*. Spirits, at the same time, are to be fired by a spark sent from side to side through the river, without any other conductor than the water; an experiment which we some time since performed, to the amazement of many. A turkey is to be killed for our dinner by the *electrical shock*, and roasted by the *electrical jack* before a fire kindled by the electrical bottle (Leyden jar); when the healths of all the famous electricians in England, Holland, France, and Germany are to be drank in *electrified bumpers*, under the discharge of guns from the *electrical battery*."

About 1752, Franklin proved the identity of lightning and frictional electricity by means of a kite made of a silk handkerchief and with a pointed wire at the top. He elevated this during a thunder-storm, tying at the end of the hemp string a key, and then insulating the whole by fastening it to a post with a long piece of silk lace. On presenting his knuckles to the key, he obtained a spark. He afterward charged a Leyden jar, and performed other electrical experiments in this way. These attempts were attended with very great danger. Prof. Richman, of St. Petersburg, drew in this manner from the clouds a ball of blue fire as large as a man's fist which struck him lifeless. Shortly after the famous experiments of Franklin, the Frenchman, Coulomb, established the law of electric attraction and repulsion, showing that it was the same as that of gravitation, light, and heat, the law of inverse squares.

In the year 1790, Galvani was engaged in some experiments on animal electricity. For this purpose he used frogs' legs as electroscopes. He had hung several of these upon *copper* hooks

from the *iron* railing of the balcony, in order to see what effect the atmospheric electricity might have upon them. He noticed, to his surprise, that when the wind blew them against the iron supports, the legs were convulsed as if in pain. After repeated experiments, Galvani concluded that this effect was produced by what he termed animal electricity, that this electricity is different from that caused by friction, and that he had discovered the agent by which the will controls the muscles. Volta rejected the idea of animal electricity, and held that the contact of dissimilar metals was the source of the electricity, while the frog was "only a moist conductor, and for that purpose was not as good as a wet rag." He applied this view to the construction of "Volta's pile," which is composed of plates of zinc and copper, between which are laid pieces of flannel moistened with an acid or a saline solution (Fig. 246). This theory is substantially the one held at the present time, though we now know that there must be chemical action to continue the supply.

Fig. 246.

Volta's Pile.

From the earliest times in which the knowledge of electricity began to be definite, impostors and half-educated people circulated marvelous stories about its value as a panacea for all kinds of disease. Many supposed that deafness and dimness of sight might be cured by the use of the electric spark. Franklin remarked of this, "it will be well if perfect blindness be not the consequence of the experiment." In the hands of experienced physicians electricity has been used with good effect, but to-day, as in Franklin's time, the name often serves as a cloak for ignorance or trickery.

Electricity and magnetism were studied as distinct branches until 1820, when Oersted of Copenhagen discovered the phenomenon shown in Fig. 224. This was published every-where, and excited the deepest interest of scientific men. In the fruitful mind of Ampère the experiment bore abundant fruit. He discovered that two parallel wires conveying an electric current in the same direction attract each other, and when in opposite directions, repel each other. From this he generalized the entire subject. Prof. Henry next exhibited the wonderful power of the electro-magnet, and invented the electro-magnetic engine. Scientific men in all parts of the world were now gathering the material necessary for the invention of the electric telegraph. It fell to Samuel F. B. Morse to make this knowledge practical, and in 1837 he exhibited in New York a working instrument. An experimental line between Washington and Baltimore was completed in 1844, and, on May 27th of that year, was sent the first message ever forwarded by a recording telegraph.

Consult Maxwell's "Electricity and Magnetism"; Tyndall's "Lessons in Electricity"; "Faraday's "Lectures on the Physical Forces" and "Researches in Electricity"; Noad's "Manual of Electricity"; Art. on the Microphone, in "Scribner's Monthly," Vol. XVI., p. 600; Prescott's "The Speaking Telephone, Talking Phonograph," etc.; Foster's "Electrical Measurements," in "Science Lectures at South Kensington," Vol. I., p. 264; Thomson's "Papers on Electrostatics and Magnetism"; Guillemin's "The Forces of Nature" and "The Applications of Physical Forces"; "American Cyclopedia," Articles on Electricity, Magnetism, Electro-magnetism, etc.; Smith's "Manual of Telegraphy"; Jones' "Historical Sketch of Electric Telegraph"; Watts' "Electro-metallurgy"; "Barnes' Hundred Years of American Independence," Sec. on Morse, p. 442; "Fourteen Weeks in Zoology," Sec. on Torpedo, p. 186; Gordon's "Electricity and Magnetism"; Hospitalier's "Modern Applications of Electricity" (specially commended for latest discoveries); Urbanitzki's "Electricity in the Service of Man"; Mendenhall's "A Century of Electricity"; Thompson's "Dynamo-electric Machinery"; Daniell's "Principles of Physics," and Anthony and Brackett's "Text-book of Physics."

CONCLUSION.

"Science is a psalm and a prayer."—PARKER.

NOWHERE in nature do we find chance. Every event is governed by fixed laws. If we would accomplish any result or perform any experiment, we must come into exact harmony with the universal system. If we deviate from the line of law by a hair's breadth, we fail. These laws have been in operation since the earliest beginnings of the development of our world, and all the discoveries of science prove them to extend to the most distant star in space. A child of to-day amuses itself with casting a stone into the brook and watching the widening curves; little children of ten thousand years ago may have done the same. A law of nature has no force of itself; it is but *the manner in which force acts.*

We can not create force. We find it every-where in Nature; so that matter is not dumb, but full of inherent energy. A tiny drop of dew sparkling on a spire of grass is instinct with power: Gravity draws it to the earth; Chemical Affinity binds together the atoms of hydrogen and oxygen; Cohesion holds the molecules of water, and gathers the drop into a globe; Heat keeps it in the liquid form; Adhesion causes it to cling to the leaf. If the water