ELECTRICAL MEASUREMENTS: PART I - ELEMENTARY; INSTRUCTION PAPER

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ELECTRICAL MEASUREMENTS

PART I—ELEMENTARY

INSTRUCTION PAPER

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ELECTRICAL MEASUREMENTS

PART I—ELEMENTARY

SYSTEMS OF UNITS

Physical quantities are measured in terms of quantities called units. These units, as a rule, are related to one another and form systems; as, for example, the *British* system and the *C. G. S.* system.

Fundamental Units. The arbitrarily chosen units of a system are called *fundamental* in distinction to the related units depending on them, which are called *derived* units. The C. G. S. system, universally used in electrical measurements, takes its name from three of its fundamental units—the *centimeter*, the *gram*, and the *second of mean solar time*. Besides the three units from which it takes its name, the C. G. S. system includes other fundamental units; for example, the *degree centigrade*, the *calorie*, and the *unit magnetic pole*. Whenever the arbitrary choice of a property of a substance enters into the choice of a unit, the unit itself becomes fundamental. Thus the calorie depends on the thermal capacity of water; the unit magnetic pole depends on the magnetic property of air, etc.

Derived Units. Geometrical units, such as area and volume, are derived from the unit of length. That is, areas are measured in square centimeters, and volumes in cubic centimeters, involving units of the second and third degree with reference to the unit of length. We say that an area has a dimension of 2 and a volume of 3 in terms of a length. Put algebraically, an area may be expressed as L^2, and a volume as L^3 in terms of a length L. In mechanics we use derived units depending on length L, mass M, and time T. Thus velocity, which may be measured by the ratio of length and time, has as dimensions LT^{-1}, and acceleration LT^{-2}. Force is more complicated and may be defined in terms of the acceleration of a mass. The dimensions of force are then LMT^{-2}. The C. G. S. unit of force is called the *dyne*. Work and energy may be measured in terms of force exerted through space, and the unit, equal to one dyne acting through one centimeter, is called the *erg*. The dimensions of the erg are $L^2 M T^{-2}$. In the same way power (time rate of doing work) may be expressed in ergs per second. This unit of power is so small that for practical purposes we use the *watt* which is 10,000,000 ergs per second. Even the watt is small and so we frequently use the *kilowatt* (one thousand watts) for measurement of power. As we shall see later, the watt is used also for the measurement of power for electric circuits. Besides the C. G. S. units we use many units which are multiples or submultiples and so are related. For example, we use the meter (100 centimeters) and the kilometer (100,000 centimeters) and the millimeter (0.1 centimeter). Evidently the meter was intended to be the fundamental unit, the centimeter and the millimeter submultiples, and the kilometer a multiple; but in the C. G. S. system the meter becomes a multiple of the fundamental unit.

In electrical measurements the unit of resistance—the *ohm*—is practically taken as 1,000,000,000 C. G. S. units; the unit of electromotive force (e. m. f.)—the *volt*—is taken as 100,000,000 C. G. S. units; and the unit of current—the *ampere*—is taken as 0.1 C. G. S. unit. These units were originally recommended by a committee of the British Association for the advancement of science in 1873, and were internationally adopted at Paris in 1881. The watt is the practical unit of power and is equal to an e. m. f. of one volt multiplied by a current of one ampere. If the current is constant the product of current and e. m. f. gives the power. If the current is not constant, the average product of current and e. m. f. gives the average power. As we shall see later in the case of alternating currents, the readings of alternating-current voltmeters and ammeters cannot be multiplied together to get the power; but an instrument called a *wattmeter* must be used. The wattmeter gives the correct result. The watt is 10,000,000, *i. e.*, 10^7 C. G. S. units.

The unit of charge (or quantity)—the *coulomb*—is the quantity of electricity equal to a flow of one ampere for one second. The coulomb is 0.1 C. G. S. unit. The *farad* is the unit of capacity. A condenser has one farad capacity if it can store one coulomb with a potential difference of one volt at its terminals. Potential difference, like e. m. f., is practically measured in volts. At higher potential differences a condenser takes a proportionately higher charge. The farad is a very large capacity and condensers are practically rated in microfarads, *i. e.*, in millionths of a farad. The *henry* is the unit of inductance. When a current is started in a coil of wire a magnetic field is produced. This requires more e. m. f. than to maintain the current when once started. If the coil requires one volt more to increase the current at the rate of one ampere per second than to maintain it, we say the inductance of the coil is one henry. The henry is 1,000,000,000, *i. e.*, 10^9 C. G. S. units. These practical units are all related, as is seen above, to the C. G. S. units by factors, of powers of 10. There are other units in the electro-magnetic system for which the reader is referred to more advanced works.

Relation of C. G. S. to British Units. To reduce British to C. G. S. units and *vice versâ*, we make use of the relations between them. One inch equals 2.54 centimeters; one pound mass equals 453.59 grams mass; and a like relation between pounds weight (force) and grams weight. The second of mean solar time is the same in both systems. It should be kept in mind that for equal quantities the number of units is inversely proportional to the size of the unit.

ELECTRICAL MEASURING APPARATUS

Galvanometers. In the year 1819 Oersted discovered that a current flowing through a conductor produced an effect on a magnet. This effect is now explained by saying that lines of force surround the conductor, and that the north pole of the magnet tends to move along the lines of force in one direction and the south pole in the opposite direction. In other words the magnet, if free to move, tends to take a direction across the conductor. In the case of a long, straight wire the lines of force are circumferences of circles with the conductor at the center. The force on the magnet pole in this case falls off in proportion to the increase in the distance from the center of the conductor; *i. e.*, the force is inversely proportional to the distance. If the magnet is already in a magnetic field, such as that of the earth for instance, a current in a north and south wire above or below the magnet, tends to turn the magnet away from the

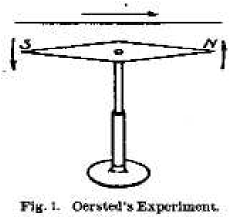

Fig. 1. Oersted's Experiment.

magnetic north and south, the tangent of the angle through which it turns being proportional to the current, Fig. 1. The effect of a single wire is small unless the current is very large.

Tangent Galvanometer. If the conductor is wound in a coil whose plane is north and south and vertical, the effect on a magnet at the center is multiplied many times, Fig. 2. Such an instrument is called a *tangent galvanometer*. If the thumb of the right hand is placed along the outside of the conductor pointing in the direction

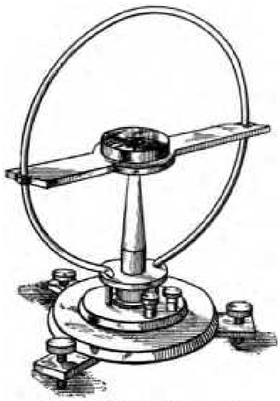

Fig. 2. Tangent Galvanometer.

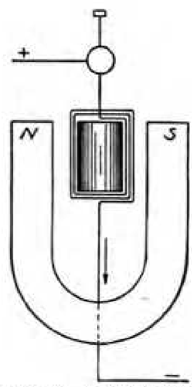

Fig. 3. Diagram of D'Arsonval Galvanometer.

of the current, the fingers of the hand may be curled around the conductor and will point in the direction toward which the north pole of the magnet will be urged by the field produced. A similar arrangement of the left hand will indicate the direction in which the south pole will be urged.

D'Arsonval Galvanometer. If the magnet is fixed and the coil free to turn, the latter will turn in the reverse direction. If the magnet is of the horse-shoe type with the coil of wire between the poles a similar rule will determine the direction of motion. Galvanometers of the moving coil type were invented by D'Arsonval and Deprez, and are usually called *D'Arsonval galvanometers*, Fig. 3.

Astatic Galvanometer. An improvement may be made in the tangent galvanometer, if greater sensitiveness is desired, by mounting on the same support two magnets of nearly but not quite equal strength, care being taken to turn the poles in exactly opposite directions. This is very important. One magnet is placed at the center of the coil through which the current is sent and the other magnet is above or below the coil and influenced relatively little by the current, Fig. 4. The directive action of the earth's magnetic field is little on such a system—called *astatic*—and a small current consequently turns the system more easily from the magnetic meridian. A similar effect is produced if part of the coil is about one magnet and the rest, with reversed direction of the current, about the other magnet. Another way to produce an equivalent effect on a single, suspended magnet is to mount a powerful control magnet near by (above, below, or behind) so as to reduce to a very small amount the magnetic field due to the earth and the control magnet at the center of the coil.

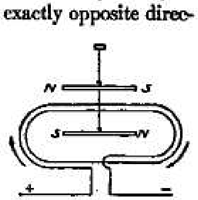

Fig. 4. Astatic System.

An extremely sensitive galvanometer may be made by combining the control magnet with the astatic system of magnets. The magnet (or system of magnets) of tangent and astatic galvanometers is suspended generally either by a fine silk or quartz fiber. The current is led into and out of the coil of the D'Arsonval galvanometer through two wires, both above in the bifilar suspension, one above and one below in the unifilar suspension.

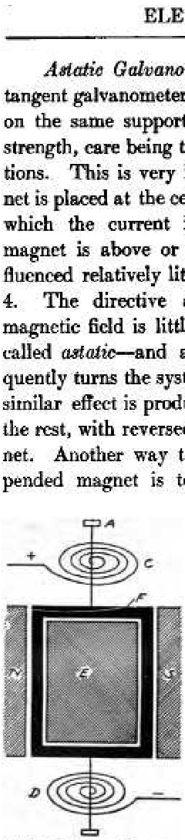

Fig. 5. Section of Suspension of Portable Galvanometer.

Less sensitive galvanometers may have their moving parts mounted on pivots or other bearings, and in such galvanometers of the D'Arsonval type the current is brought in and out through spiral springs which tend to hold the coil in its zero position, Fig. 5. Galvanometers of this type are used for ammeters—to measure amperes of current; or for voltmeters — to measure e. m. f. in