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Edited by James Dredge
Excerpt
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ELECTRIC ILLUMINATION.

I.

ELECTRICAL UNITS.

THE principle of the conservation of energy, announced for the first time by Helmholtz, controls all problems in the measurement of force, and plays an important part in the application of the system of so-called absolute units, to which the British Association has lent its name, and to the consideration of which the Congress, at the recent Electrical Exhibition of Paris, devoted much attention, with the object of establishing it on an international basis.

The word "energy" is applicable to all physical manifestations —mechanical work, production of heat, light, &c. Conservation results from the important fact that energy expended is always to be found integrally in some other expressions of work—calories, chemical action, and so forth. It is an embodiment of the old aphorism, "Rien ne se perd, rien ne se crée." It is evident that the measure of the various forms of energy ought to be obtained by a system of units, intimately dependent one on another, but the establishment of such a system is the work of time; several centuries, for instance, were required, and a revolution, resulting in the sweeping away of prejudice, before a first series of geometrical units, for the measure of space and weight could be arranged in logical classification.

Nearly a century ago, a national convention in France marked a great era in progress by the creation of the metric system, which takes as a base for measures of length, area, volume, weight, and mass, the metre—equal to the forty-millionth part of the length of the terrestrial meridian.

Whether the metric units do, or do not, remain exact physical representations of a certain quantity in nature, is of no real importance, since, if they change, they enter into the system of universally accepted though arbitrary units. And this wide acceptation, apart from its practical convenience, constitutes the real value of the metric system, which has been tested by the experience of more than a century, and has been adopted by so many countries. The appreciation of this fact was demonstrated at the Paris Congress by an almost unanimous decision, to base all new international standard electric measurements on the metric system. A similar view had been taken a number of years before by a committee of the British Association, which co-ordinated the previous ideas of Weber, Gauss, and some other German *savants*, in electrical measurements, for, although the metric system is not generally adopted in this country and the United States, it has long served here as the basis of scientific calculation, and has thus become popularised to a certain extent. The British Association based its system of measurements on the three units of length, mass, and time, for which it adopted the centimetre, the gramme, and the second, whence the symbol, C. G. S., by which this system of units is commonly designated.

It was in 1873 that the C. G. S. unit was called into existence, and it was the result of the labour of the Committee that had been appointed to consider the question of absolute units. This Committee was composed of Sir W. Thomson, Professor G. C. Foster, Professor J. C. Maxwell, Mr. G. F. Stoney, Professor Fleeming Jenkin, Dr. Siemens, Mr. F. J. Bramwell, and Professor Everett, the latter acting as secretary. The principal work of this Committee was the selection and nomenclature of units of force and energy, and especially of electrical and magnetic units. In their report, to which it may be appropriate to refer in some detail, the selection of the fundamental units was definitely proposed, but their nomenclature was only provisionally suggested. The Committee pointed out that up to that date, when it was desired to specify a magnitude in absolute measure, three fundamental units were necessary to indicate length, mass, and time, and they considered that it would be highly desirable that one definite fundamental unit should be devised to express the three dimensions by a single term. "We think that in the selection of each kind of derived unit, all arbitrary multiplications and divisions by powers of 10, or other factors, must be rigorously avoided, and the whole system of fundamental units of force, work, electrostatic and electromagnetic elements must be fixed at one common level, that level, namely, which is determined by direct derivation from the three fundamental units once for all selected." Those recommended and adopted were, as stated above, the gramme, centimetre, and second. The peculiar fitness of the fundamental units chosen, will be recognised when it is remembered that an intimate relation exists between the centimetre and gramme, the latter being the weight of a cubic centimetre of distilled water measured at the temperature of its maximum density, viz., 4 deg. C. It was this connexion that led to the selection—despite their small values—of the C. G. S. units, by the British Association Committee, there being no such inter-dependent connection between the metre and the kilogramme.

In their report the committee pointed out, that the Ohm as represented by the original standard cell is approximately 10^9 C. G. S. units of resistance; the Volt is approximately 10^8 C. G. S. units of electromotive force; and the Farad is approximately 10^{-9} C. G. S. units of capacity. For defining quantities multiplied or divided by one million, the prefixes *mega* and *micro* were suggested, so that a Megohm denoted one million Ohms, and a Microfarad, one-millionth part of a Farad. Thus the sign 10^6 would represent the prefix "mega," and the sign 10^{-6} the prefix "micro;" or 1,000,000 and ·000001 respectively. The C. G. S. unit of force is that "force which acting on a gramme of matter for a second generates a velocity of one centimetre a second." This unit is named the *Dyne*. The weight of a gramme at any part of the earth's surface is about 980 dynes, or rather less than a kilodyne. The C. G. S. unit of work, or energy, represents the work done by the dyne in passing through the distance of a centimetre. This value was named the erg. The kilogrammetre is equal to 98,000,000 ergs, and the gramme centimetre is equal to 980 ergs. The C. G. S. unit of power is, the power of doing work at the rate of one erg per second. The equivalent given above assumes the value of g (the acceleration of a body falling *in vacuo*) to be 980 C. G. S. units of acceleration, but to obtain an exact result the value of g at the station where the calculation is made must of course be accurately ascertained.

It will be seen from the foregoing, which summarises the report of the Committee, that the features introduced by the British Association were the unit of force and the unit of work. As regards the former, the force most easily measured is the attractive force of the earth on bodies upon its surface. It is readily deduced from the weight of the object. Now, as is well known, this weight varies with the geographical position of the body, being greater near the poles than at the equator. On this account it was somewhat objectionable as a fundamental unit. An invariable unit was desired and was found in that force which acting on unit mass (one gramme) for unit time (one second) generates unit velocity (one centimetre per second). This force, as mentioned above, was called the *dyne*, and according to the preceding statement, it will be seen that taking p as the weight of a gramme, and g the acceleration, then $\frac{p}{g} = \frac{\text{dyne.}}{1}$ The weight of the gramme is thus equal to g dynes, and at Paris where $g = 981$ centimetres, it is equal to 981 dynes.

The idea of work follows as a necessary consequence on that of force. Work, it is needless to say, is the product of the intensity of the force by the distance through which it operates. The most generally employed expression of this energy is the horse-power. It was introduced by Watt, and is equal to 33,000 foot-pounds per minute, or 550 per second. This is equivalent to $7{\cdot}46 \times 10^9$ ergs per second. The horse-power is a very arbitrary unit; its continuance is justified only by its widely extended use. In France the horse power or "cheval vapeur" is measured in kilogrammetres—the unit of work which is equal to one kilogramme raised to a height of one metre; the foot-pound is one-seventh nearly of a kilogrammetre. The English horse-power is equivalent to 76 kilogrammetres, while the French "force de cheval" is only 75 kilogrammetres. These units, the foot-pound and the kilogrammetre, do not harmonise with the C. G. S. system, in which they are replaced by the *erg*, which is measured as the product of the dyne (the unit of force) by the centimetre (unit of length). An erg is therefore equal to a *dyne-centimetre.*

The practical fault of this unit is, that it is too small, so that work, such as is usually understood by the term, would have to be expressed in numbers altogether too large to be convenient. Thus the kilogrammetre, by the C. G. S. system, is equal (in Paris) to 98,100,000 ergs, and the horse-power (75 kilogrammetres) to 7,357,500,000 ergs. This difficulty was met, as has been stated, by devising a second unit—the meg-erg, equal to one million ergs. The kilogrammetre is therefore equal to 98·1 meg-ergs. A minor unit, the "ergten," equal to 10 ergs, was also introduced. This, Mr. W. H. Preece suggested, should be called a "Watt."

The heat units are based on the same system; they are—the *degree*, which measures temperature, and the *gramme-degree*, which is the quantity of heat necessary to raise one gramme of water from zero to 1 deg. (Centigrade). In the old system the kilogramme of water was employed, the new heat unit or *Calorie* is therefore one thousand times smaller than the old.

The preceding remarks serve to introduce the consideration of the new electrical units which have been created by the decisions of the Paris Electrical Congress. In obtaining a view of the phenomena attending the propagation of an electric current, it is necessary to be familiar with certain primary ideas. Unfortunately the definitions of these are somewhat unsatisfactory, owing to our very imperfect knowledge of the nature of the electric current itself.

These ideas are (1) *Potential*, or the condition of a body with respect to electricity; (2) *Electromotive force*, or that mysterious power which tends to produce a transfer of electricity from one point to another of a conductor; (3) *Conductivity*, or the facility which a body offers to the flow of electricity; (4) *Resistance*, or the degree of difficulty experienced by a current in its passage through a body; (5) *Intensity*, or strength of a current which must be directly proportional to the electromotive force and inversely to the resistance; (6) *Quantity*, which is plainly the product of the current strength by the time that it lasts; (7) *Capacity*, or the quantity of electricity necessary to raise the potential of a conductor from zero to unity.

The discussion of an international system of electrical units was one of the chief occupations of the Congress at Paris. The first sitting, on the 15th of September, 1881, was devoted to the organisation of the work; the second, on the 20th of September, was abruptly dissolved by the reception of the news of the death of President Garfield. At the third sitting, on the 21st of September, M. Mascart, secretary of the Commission charged with the investigation of the question, informed the Congress of the points that had been discussed, and the decisions that had been arrived at No time had been lost in this important work. Under the presidency of M. T. B. Dumas, the Commission held four important *seances*—on the 16th, 17th, 19th, and 21st of September. England was represented by Sir W. Thomson, Messrs. Warren de la Rue, Spottiswoode, Ayrton, Everett, and Moulton; France by MM. Mascart, Levy, Raynaud, and Lippmann; Germany by Dr. Siemens, MM. Helmholtz, Clausius, Widemann, and Förster; Italy by M. Govi, and Russia by M. Stoletow. The results of the four sittings of the Commission are contained in the following resolutions, which were moved at the third meeting :—

1. In electrical measurements, the three fundamental units shall be adopted : Centimetre, Gramme and Second (C. G. S.)

2. The practical units, the Ohm and the Volt, will preserve their actual values : 10^9 for the Ohm and 10^8 for the Volt.

3. The unit of resistance, the Ohm, will be represented by a column of mercury of one square millimetre section, at the temperature zero Centigrade.

4. An international commission shall be appointed to ascertain, by new experiments, the length of the column of mercury of one square millimetre section at the temperature of zero Centigrade, which will represent the value of the Ohm.

5. The current produced by a Volt through an Ohm shall be called an *Ampère*.

6. A *Coulomb* shall be the quantity of electricity defined by the condition that an Ampère gives a Coulomb per second.

7. A *Farad* shall be the capacity defined by the condition that a Coulomb in a Farad gives a Volt.

These conditions were unanimously adopted by the Congress, after an explanation by Sir W. Thomson on their meaning and value.

It may be useful now to consider these units one by one, and to endeavour to make their meaning clear by a few elementary considerations.

The term *Electrical Potential* was introduced into our scientific nomenclature in 1828 by Mr. George Green, of Nottingham. Potential, in mechanics, means the power of doing work; the electrical potential of any point in a body, or in space, is defined as the quantity of work done in bringing unit electrification from an infinite distance up to that point. Thus the potential at A may be different from that at B. If A be higher than B, then, on connecting them by a conductor, a current will flow from A to B, and continue until the potentials are equalised. There is an analogy in the flow of water through pipes, where there is necessarily a difference of level, that corresponds to the difference of potential; this difference of level produces a hydrostatic pressure, that is electromotive force; when the tap is turned, the water flows out, that is the current. We then conclude that, wherever there is a difference of potential, there is electromotive force, and on completing the circuit (the analogue of opening the tap), a current will be established.

The terms, *Electromotive Force* and *Difference of Potential*, are thus not exactly synonymous, and it is useful to distinguish between them.

The unit of electromotive force was called the Volt by the British Association, in honour of the great Italian physicist Volta. It is a close approximation to the electromotive force of a Daniell's cell (about ·95 of it). In other words, a Daniell's cell is a little more than a Volt (1·106 according to Siemens, and 1·079 according to Latimer Clark). At the General Post-Office in London, a standard cell has been adopted, consist- of a Daniell's element arranged as in the annexed sketch, (Fig. 1), in which A A is a vessel with two compartments. In the first is placed to half the depth a saturated solution of sulphate of zinc, and a plate of zinc descending almost to the level of the liquid. In the second compartment is a porous jar V, filled with crystals of sulphate of copper, into which is plunged the copper plate C. A small cylinder of zinc D is placed as shown at the bottom of the compartment B of the vessel. In the position shown in the sketch, the cell is inoperative. To make it work, the jar V is lifted from the second compartment and placed in the first, raising the level of the solution and submerging the zinc, thus setting the cell in action. When the experiment has been concluded, the jar V is restored to its original position. The rod D receives the deposit of copper from the sulphate which has percolated through the porous jar V; the solution in B is thus always kept clear. The Latimer Clark element is also sometimes employed as a standard, its electromotive force being 1·457 Volts.

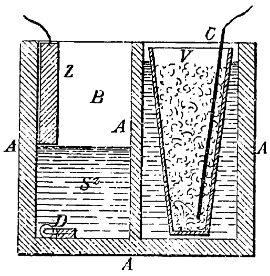

Fig. 1.

The *Resistance* of a circuit to the passage of an electric current varies directly as its length and inversely as its cross section. The unit employed to measure resistance is the Ohm, which is represented approximately by the resistance of a telegraph wire of galvanised iron 100 metres in length and 4 millimetres in diameter, or by a column of mercury 1·05 metres long and one square millimetre section, or again by 48 metres of pure copper wire 1 millimetre in diameter. The first standards for resistance were made in 1867 of wire coils, composed of alloys of gold and silver, platinum and silver, and platinum and iridium, the conductivity of which is but little affected by changes of temperature. These wires were from five to eight-hundredths of a millimetre in diameter and from 1 metre to 2 metres long; they were insulated from one another by a casing of silk and paraffin. Nine years later these coils were subjected to a series of comparative tests, when it was found, with the exception of the platinum and iridium alloy which had changed, they remained absolutely unaltered from their original condition. Even admitting, however, the absolute permanence of these alloys, which was practically shown by experiment, the adoption of such standards is open to objection. The paraffin insulator prevents the metallic thread from placing itself easily in equilibrium with the temperature of the surrounding air. Besides that, the paraffin, especially when the coil is plunged in ice, may become affected by moisture and render the measurements unreliable. These defects in practical working led to the design of other standard resistances of silver platinum wire, the coils of which are separated from each other by sheets of hard rubber pierced with holes, the insulation being effected by the air. The coils thus composed are placed in a cylindrical box formed of two copper capsules stamped out of the solid and screwed one into the other; this apparatus can be submerged in water without any detriment.

In addition to the unit of resistance adopted by the British Association, there existed until the decision of the Paris Congress, the Siemens unit, measured by the resistance of a column of mercury of one square millimetre section, and one metre in length, at the temperature of zero Centigrade. This unit was equivalent to ·955 Ohm. Though this unit may have been officially abandoned, it will be observed that its principle has been substantially retained, since the Congress expressed the hope that the value of the Ohm should be represented by a column of mercury. It is true, as Professor Helmholtz remarked, that the mercury has to be contained within a glass tube, which forms a fragile measuring apparatus, and one liable to destruction; and, moreover, that it is impossible to be certain that some want of truth may not exist in the tube, which would affect the value of the standard. On the other hand, Sir W. Thomson called attention to the unavoidable imperfections in solid metal standards, and Dr. Siemens reminded the Commission that the mercury standard could be reproduced geometrically in all parts of the globe, and that in any case an approximation, much superior to that possible with wire standards, would be obtained. These considerations determined the decision of the Congress.