A paper presented at the 20th Annual Convention of the American Institute of Electrical Engineers, Niagara Falls, N. Y., July 2, 1903.

MAGNETIC UNITS AND OTHER SUBJECTS THAT MIGHT OCCUPY ATTENTION AT THE NEXT INTERNATIONAL ELECTRICAL CONGRESS.

BY A. E. KENNELLY.

The committee appointed by the British Association for the Advancement of Science for the selection and nomenclature of dynamical and electrical units, published its first report in 1873. That report recommended the adoption of the centimetre, gramme and second as the respective fundamental units of length, mass and time, on which the dynamic and electromagnetic systems of units should be based. The centimetre was selected in place of the metre, so as to make the density of water equal to unity.

The C. G. S. system of units thus promulgated, has become the recognized international scientific unitary system. It has met with almost universal satisfaction.

In constructing the C. G. S. basic units of electricity and magnetism, it is now easy to perceive that a bad selection was made. The unit magnetic pole was chosen as one which repelled its prototype at unit distance with unit force. A better selection would have been the pole which emitted unit magnetic flux, with a similar definition for the unit electric point-charge. The assumed system of electromagnetic units, thus amended, is sometimes spoken of as the "rational" system, in contradistinction to the existing system, which is then described as the "irrational system." The rational system would be more simple to express and to remember, for the reason that the numerical constant 4π or 12.566, which now appears in many fundamental electromagnetic equations, would have been eliminated and introduced into spherical problems, where the constant naturally belongs. For example, the m.m.f. in a magnetic circuit would become equal to the current-turns linked therewith, instead of 4π times the current-turns. Consequently, many spherical electromagnetic problems that would naturally expect the 4π constant, now exclude it, and plane or rectangular problems, that would be simpler without it, now embrace it.

This criticism could scarcely have been foreseen at the time the C. G. S. electromagnetic system was constructed. It has taken years of acquaintance with the system to make the defect apparent.

If we could go back with our present knowledge, and create the C. G. S. electromagnetic system afresh, it would probably be better to adopt the " rational " system. To make the change now would require changing the magnitudes of the ohm, volt, ampere and other magnetic units by some power of 4π. The only exceptions would be the watt and the joule. They would escape.

It would be very troublesome to change all our electromagnetic measures. The trouble would be felt by every electrical industry. The change could only be made effective by international agreement. The only compensation for the trouble and expense would be a certain amount of scientific simplification in the theory of electromagnetism, and a certain benefit to scientific computers. The electrical industries would not receive any practical benefit, and any benefit they could receive would be that small indirect amount derivable from the simplification in theory already mentioned.

It seems too late, therefore, to attempt reconstructing electromagnetic units upon the C. G. S. system on a more rational basis. The majority would be inconvenienced for the benefit of the minority. It seems better that the student minority should make a little more effort to work with the existing " irrational " uints, than to upset the existing order of electromagnetic measure in the hands of the many. In fact it is probably inadvisable for scientists to adopt the " rational " system in their writings, since the labor of reading electrotechnical papers is often greatly enhanced by the uncertainty as to which of the two systems is being employed.

The case is reversed as regards the rational use of the metric system of weights and measures. In this country, and in Great Britain, the system of customary weights and measures is a burdensome incoherent medley with absurd inconsistencies and ambiguities. The metric system is far simpler and better, besides being in otherwise international use. The change from the customary to the metric system would entail much trouble and some expense, but it would effect a great reduction of aggregate national labor in learning, employing, exchanging and computing. The change would be nationally economical, so far as can be judged from the internal evidence presented, as well as from the evidence of the various countries that have already made a similar change.

Several ingenious expedients have been proposed for effecting partial "rationalization" of the C. G. S. electric and magnetic units, without changing the values of the concrete practical units. All thus far proposed introduce a new factor into fundamental or defining equations in order to get rid of the 4π constant in other equations, so that the 4π difficulty is thereby not eradicated but merely transported. It is very doubtful whether such half-hearted expedients can succeed. It seems better to let the existing system alone.

In adapting the C. G. S. system of magnetic units to practical requirements, the inconvenient magnitudes of many C. G. S. units became apparent. The C. G. S. unit of e.m.f. was ridiculously small, since an ordinary Daniell cell showed 110 millions of them. A similar condition was found for the C. G. S. unit of resistance; since a Siemens unit, in extended use at that time, containing about a trillion C. G. S. units. In order, therefore, to aid practicians, the working unit of e.m.f. was selected as 10^8 C. G. S. units of e.m.f. under the name of the volt; while the working unit of resistance was selected as 10^9 C. G. S. units of resistance, under the title of the "ohm." These practical magnitudes having once been adopted, a practical system of units inevitably came into existence, one volt through one ohm producing one ampere; one ampere carried for one second delivering one coulomb, and so on. The practical units differed from their parents, the corresponding C. G. S. units, by differing multiples or powers of 10. In one instance, the ratio between a C. G. S. unit and its practical representative is 10, in another it is 10^9, in another 10^7, and so on. Moreover, the practical system of the ohm, volt, ampere, coulomb, joule, watt and henry, is such as would have been arrived at directly, if the unit of length had been an earth-quadrant, or 10^9 centimetres, instead of one centimetre, and the unit of mass 10^{-11} gramme, instead of the gramme, the unit of time being the second in both systems.

Thus there has been created the fundamental centimetre-gramme-second system in which the theory of electromagnetics is learned, and to which all science is referred. Side by side with the C. G. S. system is the practical, or quadrant-eleventh et gramme-second system, or Q. E. S. system, in which most of the units have been christened for industrial use. The C. G. S. system is thus the language of the esoteric; while the Q. E. S. system is the electrical vernacular.

The divorce of the practical from the scientific system was a grave mistake, although it was probably hard to foresee. After years of experience it is now easy to see that the correct original course would have been to christen the C. G. S. magnetic units, without regard to their particular magnitudes, and, at the same time, to adopt a suitable series of prefixes for decimal multiples and submultiples, in extension of the existing micro-milli-kilo-mega system. If, for example, the C. G. S. magnetic unit of current-strength (10 amperes), had been originally christened the ampere, our present ampere would have been known as the deci-ampere, and in a few days we should have become as familiar with such a deci-ampere as we are with the existing ampere. This is shown by the case of the *microfarad*, which is as simple and convenient a term as if this standard capacity had been originally called the farad. We should then have retained the C. G. S. system for both the esoteric and the vernacular, but would have adopted for practical work certain multiples with their apporpriate prefixes.

It is probably now too late to retrace our steps. We cannot annul the Q. E. S. system and exclusively adopt the C. G. S. system for practical work. Nor is it worth while upheaving decimal relationships. Thus, it has been suggested that the existing dekavolt might be changed in name to the volt, by increasing the volt to ten times its present magnitude, in order to make the new ampere agree with the C. G. S. unit of current. This would entail a slight advantage over the existing practical system. It would, however, effect a confusing hiatus in technical literature and would still leave a practical system divorced from the C. G. S. system with numerical ratios of 10^{-9} and 10^{9}. The Q. E. S. system is in satisfactory industrial use all over the world, so far as it goes; viz., through the eight units: volt, ampere, ohm, farad coulomb, henry, joule, and watt. But we can with advantage stop further unnecessary divergence, by refraining from christening any more units in the Q. E. S. system, and by bestowing all future names on the C. G. S. system. A start in this direction has already been made. The international electrical Congress at Paris in 1900 christened the C. G. S. magnetic units of flux and flux-density, under the names of maxwell and gauss respectively. These terms have already come into fairly extended use in America and into somewhat more limited use in Europe.

It is very desirable that the next international electrical congress should complete the units of the magnetic circuit by bestowing names upon the C. G. S. units of m.m.f. and of reluctance. The AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS has for several years provisionally recommended the names " gilbert " and " oersted " for these two units. They are already in some use in America. If they should be adopted, we would have the relations:

$$\frac{\text{gilberts}}{\text{oersteds}} = \text{maxwells}$$

$$\frac{\text{maxwells}}{\text{sq. cms.}} = \text{gausses}$$

The ampere-turn is a very convenient unit of m.m.f. close to the C. G. S. unit in order of magnitude; but a name for the C. G. S. unit is very desirable.

By rights, every C. G. S. electromagnetic unit should have a name. There is not even a recognized weed, or germ, that does not have a name. Practically all the fifteen hundred millions of people inhabiting the world have names. It would seem that a fundamental C. G. S. electric or magnetic unit is of as much importance as a weed or a bacillus. Moreover, it is fortunately unnecessary to learn the names for units, or commit them to memory, if the units are rarely used. It would be sufficient to have authorized names accessible and definite, ready for use when required.

Moreover, our minds are so constituted that until we possess a name for a thing, the thing remains more or less symbolical, and is not fully realized as concrete. Thereby the C. G. S. system of electromagnetic units, which is necessary and fundamental becomes hampered and retarded. It is desirable for scientific purposes, for educational purposes, and in the interests of progress, that these international C. G. S. units should have recognized names.

For example, the fundamental rule for the electromotive force of a direct-current bipolar dynamo is

$$e = \phi\, n\, w. \quad \text{C. G. S. magnetic units of e.m.f.}$$

where ϕ is the useful flux from pole to armature in maxwells, n the speed of rotation in revolutions per second and w the number of wires on the surface of the armature. If we divide e in this equation by 10^8, we get the result in volts; but the *C. G. S. magnetic unit of electromotive force* is worthy of a name, if only to avoid the objectionable periphrasis.

The expedient suggests itself of attaching the prefix *ab* or *abs* to a practical or Q. E. S. unit, in order to express the absolute or corresponding C. G. S. magnetic unit. The advantages of the plan are that it is almost self-explanatory, and requires no effort of memory to acquire; also that it is self-suggesting in all the important European languages. According to this plan the

C. G. S. magnetic unit of e.m.f.	would be the	abvolt
" " " " resistance	" "	absohm
" " " " current	" "	absampere
" " " " quantity	" "	abcoulomb
" " " " capacity	" "	abfarad
" " " " inductance	" "	abhenry or centimetre
" " " " energy	" "	abjoule or erg
" " " " power	" "	abwatt

We would also have the following ratios:

1 abvolt	= 0.01 microvolt	= 10^{-8} volt	
1 absohm	= 1 bicrohm	= 10^{-9} ohm	
1 absampere	= 1 dekampere	= 10 amperes	
1 abcoulomb	= 1 dekacoulomb	= 10 coulombs	
1 abfarad	= 1 begafarad	= 10^{9} farads	
1 abhenry	= 1 bicrohenry	= 10^{-9} henry	= 1 cm.
1 abjoule	= 0.1 microjoule	= 10^{-7} joule	= 1 erg
1 abwatt	= 0.1 microwatt	= 10^{-7} watt	

On such a basis the preceding equation would be written

$$e = \phi\, n\, w \text{ abvolts},$$

with great advantage in clearness and comprehensibility.

In a comprehensive system of electromagnetic terminology, the electric C. G. S. units should also be christened. They are sometimes referred to in electrical papers, but always in an apologetic, symbolical fashion, owing to the absence of names to cover their nakedness. They might be denoted by the prefix *abstat*. Thus, the

C. G. S. electric unit of e.m.f.	would be the	abstatvolt
" " " " resistance	" "	abstatohm
" " " " current	" "	abstatampere
" " " " quantity	" "	abstatcoulomb
" " " " capacity	" "	abstatfarad
" " " " inductance	" "	abstathenry

The abstatjoule and abstatwatt are the same as the abjoule and abwatt respectively. These units would almost also be self-explanatory in any European language and would call for no appreciable effort of memory.

We should then have the following ratios ($v = 3 \times 10^{10}$ approximately):

1 abstatvolt	$= v$ abvolts	$= 300$ volts
1 abstatohm	$= v^2$ absohms	$= 9 \times 10^{11}$ ohms
1 abstatampere	$= v^{-1}$ absampere	$= 3.3 \times 10^{-10}$ ampere
1 abstatcoulomb	$= v^{-1}$ abcoulomb	$= 3.3 \times 10^{-10}$ coulomb
1 abstatfarad	$= v^{-2}$ abfarad	$= 1.1 \times 10^{12}$ farad
1 abstathenry	$= v^2$ abhenrys	$= 9 \times 10^{11}$ henrys*

It is desirable that such system of christening the C. G. S. magnetic and static units, without burdening the memory, should be adopted by an international electrical congress.

It seems also desirable that an international electrical congress should sanction the use of the Hefner Alteneck Reichsanstalt standard amyl-acetate lamp as a secondary standard of light or luminous intensity. The lamp is in extended use for determining the intensity of incandescent lamps, and as such should receive recognition.

It is also desirable that steps should be taken by an international electrical congress to establish a uniform international basis for the standardization of electrodynamic machinery. The American Institute of Electrical Engineers has already formulated, through the work of a committee, a series of standardization rules, relating to nearly all classes of dynamo-electric machinery. A similar series of rules differing from the last named in various details has been promulgated in Gèrmany by the Verband der Deutcher Electroteckniker. Still other rules are extant locally in other countries. It is perhaps possible to carry the principal of international standardization too far into detail, since many details depend in each country upon local,

*The abstat henrys regarded as a length according to the conventional system of dimensions contains 9 x 10^{11} earth quadrants, a distance that light would take nearly one thousand years to cross.

commercial and industrial conditions; but, on the other hand, there are many underlying physical and electrotechnical conventions that might receive international consent among electrical engineers. For example, a dynamo machine ought to have the same rating, based on temperature-elevation under load, all over the world, and the rules by which the rating of a dynamo is experimentally determinable might well be adopted by an international electrical congress, together with many similar matters, under this general title of standardization. Such a concensus of opinion would probably take time to evolve and an international electrical congress might appoint a standing committee to confer upon the question of standardization with instructions to report at a future time. Much scientific and engineering benefit might be hoped for from the efforts of such a standing committee on international standardization.
