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# STANDARD HANDBOOK

## FOR

# ELECTRICAL ENGINEERS

PREPARED BY A STAFF OF SPECIALISTS

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NINTH EDITION



NEW YORK      TORONTO      LONDON  
McGRAW-HILL BOOK COMPANY, INC.

1957

STANDARD HANDBOOK FOR ELECTRICAL ENGINEERS

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MCGRAW-HILL BOOK COMPANY, INC.

First Edition (December, 1907)

First Printing, 5,200 copies

Second Edition (May, 1908)

Two Printings, 7,800 copies

Third Edition (September, 1910)

Three Printings, 14,000 copies

Fourth Edition (July, 1915)

Six Printings, 33,000 copies

Fifth Edition (June, 1922)

Nine Printings, 40,000 copies

Sixth Edition (January, 1933)

Six Printings, 30,000 copies

Seventh Edition (August, 1941)

Seven Printings, 70,464 copies

Eighth Edition (1948)

Four Printings, 49,932 copies

Total Issue, 250,396 copies

PRINTED IN THE UNITED STATES OF AMERICA

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Library of Congress Catalog Card Number: 56-6964

THE MAPLE PRESS COMPANY, YORK, PA.

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## PREFACE TO THE NINTH EDITION

Industrial expansion and intensification of the last decade have stepped up engineering techniques even beyond the pressured progress achieved during the Second World War. As a consequence this ninth edition of the "Standard Handbook for Electrical Engineers" has been prepared to record these advances for reference purposes. Meanwhile certain long-standing practices have become obsolescent, and measures were taken to reduce their treatment.

Opportunity has thus been afforded to recognize the essential advances in order to render a properly balanced portrayal of the electrical arts today. New international units have superseded the old. Nuclear physics has broadened into the pattern of nuclear power, and the subject has accordingly been shifted topically. The families of plastics and resins have been enlarged, and fresh values found for their usefulness to the electrical engineer. The conductor tables have been completely recomputed to conform to the latest ASTM standards. Electrical measurement of nonelectrical quantities has been expanded because it serves as foundation for industrial automation. Along with large-scale modernization of the rest of the measurement section, recognition has been given to the new methods of telemetering.

Illumination has been accorded a wholly new treatment with the application engineer in mind. Transportation has undergone rapid change with the emphasis swinging to automotive, aviation, and marine. These areas have been reframed in the book; the new 12-volt system in the automotive field is an instance of evolution. Magnetic amplifiers are treated more extensively in conjunction with control.

Transistors and television have come of age in the interval since the eighth edition. It is particularly hoped that the transistor text will be recognized as a distinctly lucid treatment of this new technique. Power distribution has been completely revamped, and the transmission section extended to embrace the new high-voltage levels and the increasing resort to cables. Needless to say the late developments in the field of cooling alternators, loading transformers, and protecting electric systems generally have been incorporated.

Despite the comprehensive revision every effort has been made to retain the characteristics that, in the past, have made the book acceptable to both the student and the matured practising engineer. In this era of specialization no one can follow in detail all that is developing across the broad art. The Handbook is aimed uniquely at serving the specialist in one field who seeks a clear understanding of the theory and established practice in a cognate field with which he has limited familiarity. Competence as an engineer seems to depend on ability to appraise new problems, break them into significant ingredients, and then analyze each by itself and with its companions until the conclusions can be translated into a solution. This type of analytical engineer has been dominantly in mind in establishing the scope, the level, and the penetration of this Handbook. Particular pains were taken with the index to include "doubled-up" terms both ways so that the items can be found under either approach. In fact, the nonengineering reader should be able to locate what he wants to know technically and then find it discussed in language that he should be able to understand so readily that his occasional disdain for utilitarian concepts might change to respect.

This book is a creation of a hundred collaborators minded with the editor to serve the busy engineer as directly, as simply, and as authoritatively as possible within the confines of a tolerably sized volume. The editor credits these recognized experts with meeting his prescriptions so accommodatingly that the book should continue to merit the regard with which previous editions have been received. R. M. Shoop, beyond being a contributor and collaborator, assisted in some of the editing. Miss

## *PREFACE TO THE NINTH EDITION*

Joan Armstrong assisted in the extensive correspondence, careful transcribing, and meticulous proofreading.

Effort has been made all along the way to exclude errors and to accord due credit to basic sources tapped for information. Some errors and omissions are almost certain to happen inadvertently and the editor will appreciate having them called to his attention for rectification.

ARCHER E. KNOWLTON

## PREFACE TO THE FIRST EDITION

In the preparation of the **STANDARD HANDBOOK** the publishers have adapted the "unit" system to bookmaking. The entire field of electrical engineering was divided into twenty sections or units, each complete in itself. These twenty sections were arranged in what seemed to be a logical order and each was assigned to a specialist. Each author was supplied with a detailed outline of all the sections, thus avoiding repetitions and duplication of material as far as desirable. All of the material thus brought together was carefully edited to obtain uniformity of style, symbols, abbreviations, units, etc., and to connect the various parts by cross-references.

Some repetitions are purposely made to save the time of the user. For instance, transformer oil is treated under Insulating Materials in Section 4, but a brief outline of its important qualities is again given in Section 6 under Transformers, with a cross-reference to guide the reader to the fuller treatment in Section 4.

The Index embodies some new features. All references are made to section and paragraph. In each section the paragraphs are numbered from one to the end, and the section and paragraph numbers are set at the head of the page; the page number appearing in an inconspicuous place at the foot, for the guidance of the printer only. Cross-references are always made through the index to avoid errors and to guide the user to *all* other parts of the book where that subject may be treated.

The studied use of **bold-face type** is also intended to save time by bringing out in a prominent way the real subject of each paragraph.

Recognized standards have been followed wherever possible. Those recommended by the national societies or organizations have usually been followed. Section 19 is entirely given up to Standardization Rules and Reports, including the full report of the American Institute of Electrical Engineers of June, 1907, and that of the American Street and Interurban Railway Engineering Association, ratified in October, 1907.

The publishers cannot hope for absolute accuracy in this first edition of a work containing such a mass of figures and data, although the greatest care has been exercised in its preparation. Any suggestions, criticisms, or corrections from users will be of great service in making the **STANDARD HANDBOOK** a standard in fact as well as in name.

*December, 1907*



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# SECTION 1

## UNITS AND CONVERSION FACTORS

BY

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## SECTION 1

### UNITS AND CONVERSION FACTORS

BY A. E. KNOWLTON  
AND FOREST K. HARRIS

#### MECHANICAL UNITS

**1. Nature of Units.** In engineering, quantities of many different kinds are involved, including mechanical, chemical, physical, thermal, and physiological quantities. In order to record or to compare magnitudes of quantities, some one magnitude of each kind must be taken as a basis or unit. Each unit either must be represented by a physical standard of some kind, natural or artificial, or else must be derived from a combination of other units represented by such standards. The magnitudes of derived units are fixed in some cases by simple relations between the basic or fundamental units; in other cases the magnitudes are determined by application of recognized physical "laws" which are more or less complicated.

**2. Systems of Mechanical Units.** There are two general systems of mechanical units used in engineering, the English (or United States Customary Units) and the metric. The use of the English system in the United States is based upon custom and the common law; there is no specific statutory authorization for it. The use of the metric system was legalized by the Act of July 28, 1866.

**3. Metric System.** The metric system, used throughout the world, is based on standards of length and mass recognized by the international Metric Convention signed in 1875 and ratified in 1878. These standards are preserved at the International Bureau of Weights and Measures at Sèvres, France. Metric units are derived in decimal steps from the basic units, the names being formed with the following prefixes:

tera = $10^{12}$ (T)	deci = $10^{-1}$ (d)
giga = $10^9$ (G)	centi = $10^{-2}$ (c)
mega = $10^6$ (M)	milli = $10^{-3}$ (m)
kilo = $10^3$ (k)	micro = $10^{-6}$ ( $\mu$ )
hecto = $10^2$ (h)	nano = $10^{-9}$ (n)
deka = $10$ (da)	pico = $10^{-12}$ (p)

**4. Meter.** The fundamental unit of length is the meter, defined as the distance between two specified lines on a bar of platinum-iridium kept at the International Bureau, when the bar is at the temperature of zero degree centigrade (0 C), at standard atmospheric pressure, and is supported at the two neutral points 28.5 cm from the center of the bar. (An alternative provisional definition is that the meter is 1,553,164.13 wavelengths of light of a red line in the spectrum of cadmium produced and measured under specified conditions.) The United States has two copies of the prototype meter bar; these are deposited at the National Bureau of Standards.

**5. Kilogram.** Although nominally the fundamental unit of mass is the gram, the actual fundamental unit is the kilogram, defined as the mass of a cylinder of platinum-iridium kept at the International Bureau. The United States has two similar standards of mass at the National Bureau of Standards.

**6. Second.** The third fundamental mechanical unit is the second, defined as the 86,400th part of the mean solar day. The fundamental standard is, therefore, the earth.

**7. Liter.** The metric unit of capacity (volumetric) is the liter, defined as the volume occupied by one kilogram of pure water at the temperature of maximum density and under standard atmospheric pressure.

Originally, the gram was intended to be the mass of one cubic centimeter of water under these conditions; then the liter would be equivalent to one cubic decimeter, and one milliliter would equal one cubic centimeter. On account of experimental errors in establishing the standards, this equivalence was not exactly obtained. The milliliter is 1.000028 cubic centimeters. The name "cubic centimeter" ("cu cm") is often erroneously used for the milliliter.

**8. Centimeter-gram-second System.** The centimeter-gram-second (cgs) system of units is a development of the metric system in which the three units named are taken as fundamental and the proportionality constants in the equations representing physical relations between quantities are, so far as possible, made unity. It is used in scientific work throughout the world.

**9. Dyne.** The dyne is the cgs unit of force. It is that force which will give a mass of one gram an acceleration of one centimeter per second per second.

**10. Erg.** The erg is the cgs unit of work or energy. It is the work done when a force of one dyne acts for a distance of one centimeter.

**11. Meter-kilogram-second (mks) system** of units is a metric system similar to the cgs system, except that the larger fundamental units are used as indicated by the name, and the magnitudes of many derived units are therefore more convenient for engineering purposes than the corresponding cgs units.

**12. Newton.** The mks unit of force is the force that will give a mass of one kilogram an acceleration of one meter per second per second. The International Electrotechnical Commission has recommended the name *newton* for this unit. The newton is equal to  $10^6$  dynes.

**13. Joule.** The joule is the mks unit of work or energy. It is the work done when a force of one newton acts for a distance of one meter. The joule is equal to  $10^7$  ergs.

**14. Watt.** The watt is the mks unit of power. It is the power required to do work at the rate of one joule per second or  $10^7$  ergs per second.

**15. Basis of United States Customary Units.** No fundamental standards were ever set up to represent explicitly the units commonly used in the United States. The Act of July 28, 1866, however, specified relations between those units and the metric units; and in 1893 the U. S. Coast and Geodetic Survey announced that certain ones of the ratios in that act would be taken as exact and would thus define the precise value of the customary units. The units so defined are still used.

**16. Yard.** The United States yard is 3,600/3,937 meter. This makes the inch equal to 25.40005 + millimeters. For engineering purposes, however, standardizing bodies throughout the world, including the American Standards Association, have adopted the simpler relation, 1 inch = 25.4 millimeters. This is equivalent to taking the yard as 0.9144 meter.

**17. Pound.** The United States avoirdupois pound is 453.5924277 grams.

**18. Pound (Force)—Gravitational Constant ( $g$ ).** The pound as defined above is a unit of mass. In engineering mechanics, the name pound is commonly used for a unit of force that is the gravitational force acting upon a mass of one pound. Gravitational force varies from place to place,<sup>1</sup> and the magnitude of this unit depends upon the value assigned for the acceleration due to gravity: The generally accepted value for the acceleration due to gravity is (for testing purposes)  $g_c = 980.665$  cm per sec per sec. This value of  $g$  was used in computing the conversion factors given in the tables of this section.

**19. Foot-pound.** The foot-pound is a unit of work or energy equal to the work done in lifting a mass of one pound one foot vertically against the attraction of gravity at the surface of the earth. Its exact magnitude depends upon the value of the gravitational constant assumed.

**20. Horsepower.** The horsepower is a unit of power representing the ability to do work at the rate of 550 foot-pounds per second.

<sup>1</sup> Value of  $g$  at sea level varies from 978.039 at 0 deg latitude to 983.217 at 90 deg latitude. To obtain value of  $g$  for any particular locality, refer to "International Critical Tables"; Vol. I, pp. 395-402.

**21. Gallon.** The United States gallon is equal to 231 cubic inches. Other units of liquid capacity are derived from the gallon.

**22. Bushel.** The United States bushel is equal to 2,150.42 cubic inches. Other units of dry measure are derived from the bushel.

### ELECTRIC AND MAGNETIC QUANTITIES

**23. Quantity of Electricity ( $Q$  or  $q$ ).** The amount of electricity present in an electric charge or passed through a circuit by an electric current during a time interval. The practical unit is the coulomb.

**24. Electromotive Force ( $emf$ ,  $E$ , or  $e$ ).** The characteristic of a device that tends to produce current in a circuit. The practical unit is the volt.

**25. Potential Difference ( $E$  or  $V$ ).** A measure of the work done in moving unit charge from one point to another. The practical unit is the volt.

**26. Potential Gradient.** The rate of change of potential with distance. Units such as volts per meter or kilovolts per centimeter may be used.

**27. Current ( $I$  or  $i$ ).** The rate of flow of electricity in a circuit. The practical unit is the ampere, which is one coulomb per second.

**28. Current Density.** The ratio of a current to the cross-sectional area of its path in a plane perpendicular to the direction of the current.

**29. Resistance ( $R$  or  $r$ ).** The property of a circuit or element which determines for a given current the rate at which electrical energy is converted to heat in accordance with the formula  $W = I^2R$ . The practical unit is the ohm.

**30. Resistivity ( $\rho$ ).** The ratio of potential gradient in a conductor to the density of the unvarying current that produces it. Also, the resistance of a unit cube of a substance measured between parallel faces. Units such as ohm-centimeter or microhm-centimeter may be used.

**31. Conductivity ( $\gamma$ ).** The reciprocal of resistivity. Units such as mho per centimeter or micromho per centimeter may be used.

**32. Inductance ( $L$ ).** The property of a circuit (or circuits) that causes an emf to be induced by a change in current. It is a measure of the flux-linkages per unit current. The practical unit is the henry.

**33. Capacitance ( $C$ ).** The property of a system of conductors and dielectrics that permits the storage of electricity when a potential difference exists between conductors. Its value is the ratio of charge to potential difference. The practical unit is the farad. Other units commonly used are the microfarad ( $10^{-6}$  farad) and the picofarad ( $10^{-12}$  farad).

**34. Permittivity.** The property of a dielectric that determines its energy storage per unit volume for unit potential gradient. In the cgs electrostatic system, the permittivity of vacuum is unity and the permittivity of any substance is numerically equal to its dielectric constant. In the mksa rationalized system, the permittivity of vacuum is  $8.85 \times 10^{-12}$  and the permittivity of a substance is its dielectric constant multiplied by this value.

**35. Dielectric Constant ( $K$  or  $\epsilon_r$ ).** The ratio of the permittivity of a dielectric to the permittivity of vacuum. The ratio of the capacitance of a capacitor when the substance in question is the dielectric to the capacitance of a capacitor having an identical electrode system but with vacuum as the dielectric.

**36. Frequency ( $f$ ).** The number of periods of a repetitive function per unit time. Common units are cycles per second (cps), kilocycles per second (kcps), and megacycles per second (Mcps). The hertz is synonymous with cps.

**37. Impedance ( $Z$  or  $z$ ).** The ratio of the effective (rms) potential difference across a portion of a circuit to the effective (rms) current through it, there being no source of emf in this portion of the circuit. The practical unit is the ohm.

**38. Reactance ( $X$  or  $x$ ).** For a sinusoidal voltage and current (at a particular frequency), the reactance of a circuit element is the ratio of the effective voltage across the element to the effective current multiplied by the sine of the angle between them, there being no source of emf in the element. The reactance is different for each separate frequency component of a nonsinusoidal alternating current. There are two species of reactance of mutually opposite signs, *viz.*, inductive reactance, developed in an inductance  $L$ , given by the formula  $x = 2\pi fL$  and denoted in the complex notation with the sign  $+jx$  or  $+\sqrt{-1}x$ , and capacitive reactance, developed in a capacitor,



given by the formula  $x = 1/2\pi fC$ , and denoted by the sign  $-jx$  or  $-\sqrt{-1}x$ . The practical unit is the ohm.

**39. Admittance ( $Y$  or  $y$ ).** The reciprocal of impedance. The practical unit is the mho.

**40. Susceptance ( $B$  or  $b$ ).** The quadrature component of admittance. For a sinusoidal current and voltage (at a particular frequency), the susceptance of a circuit element is the product of the sine of the angle between voltage and current times the ratio of the current to the potential difference, there being no source of emf in the element. The practical unit is the mho.

**41. Conductance ( $G$  or  $g$ ).** The in-phase component of admittance. For a sinusoidal current and voltage (at a particular frequency), the conductance of a circuit element is the product of the cosine of the angle between voltage and current times the ratio of the current to the potential difference, there being no source of emf in the element. In d-c applications conductance is the reciprocal of resistance. The practical unit is the mho.

**42. Magnetic Moment.** A measure of the maximum torque exerted on a magnet (or current loop) in a particular magnetic field in vacuum. There are two species of magnetic moment: **Magnetic dipole moment ( $j$ )** is equal to the torque in a field in which the magnetizing force ( $H$ ) has unit value; **magnetic area moment ( $m$ )** is equal to the torque in a field in which the magnetic induction ( $B$ ) has unit value. For a plane current loop the area moment is equal to the product of the area and the current. In the cgs em system of units these moments are equal. In the mksa rationalized system of units  $m$  is larger than  $j$  by the factor  $1/(4\pi \times 10^{-7})$ .

**43. Magnetic Induction ( $B$ ).** A vector point function describing a magnetic field. It is measured either by the mechanical force experienced by an element of a conductor carrying current or by the emf induced in a conductor element that moves with respect to the field. The cgs em unit is the gauss; the mksa unit is the weber per square meter or the tesla.

**44. Magnetic Flux ( $\Phi$ ).** The surface integral of the normal component of induction over an area. The cgs em unit is the maxwell; the mksa unit is the weber.

**45. Magnetizing Force ( $H$ ).** A vector point function which measures the ability of currents or magnetized bodies to produce magnetic induction at a point. The cgs em unit is the oersted; the mksa rationalized unit is the ampere-turn per meter.

**46. Magnetomotive Force ( $\mathcal{F}$ ).** The line integral of magnetizing force around a closed path in a magnetic field. The cgs em unit is the gilbert; the mksa rationalized unit is the ampere-turn.

**47. Magnetic Constant ( $\gamma_m$ ) or Space Permeability ( $\mu_0$ ).** The ratio of the magnetic induction to the corresponding magnetizing force in vacuum. In the cgs em system this ratio is unity; in the mksa rationalized system it is  $4\pi \times 10^{-7}$ .

**48. Normal Permeability ( $\mu$ ).** The ratio of normal induction in a material to the corresponding magnetizing force. It is smaller by the factor  $4\pi \times 10^{-7}$  in the mksa rationalized system than in the cgs em system. In the latter system it is numerically equal to the specific permeability.

**49. Specific Permeability or Relative Permeability ( $\mu_r$ ).** The ratio of the normal permeability of a material to the magnetic constant (or to space permeability). It is a pure number independent of the system of units.

**50. Permeance ( $\mathcal{P}$ ).** In a portion of a magnetic circuit bounded by two equipotential surfaces and by a surface everywhere tangent to the direction of the magnetic induction, it is the ratio of the flux through any cross section to the magnetomotive force acting between the two equipotential surfaces under consideration.

$$\mathcal{P} = \Phi/\mathcal{F}$$

**51. Reluctance ( $\mathcal{R}$ ).** The reciprocal of permeance.

## ELECTRICAL UNITS

**52. Systems of Electrical Units.** Various systems of electrical units differ chiefly in the choice of the constants used in the equations relating the electrical and magnetic quantities to each other and to mechanical quantities. The cgs electrostatic, cgs electromagnetic, Gaussian, mks (Giorgi), and mksa (rationalized) systems have all

been used widely in theoretical work. In addition two so-called "practical" systems have been used for engineering and other practical purposes. The International electrical units were used throughout the world and constituted the legal units in the United States until Dec. 31, 1947. Beginning on Jan. 1, 1948, the legal basis in the United States and throughout the world has been the *mksa* Absolute system of electrical units.

**53. Absolute Units.** Those derived from the basic mechanical units by the application of accepted laws stating the relations among the various quantities.

**54. Cgs Electrostatic System.** An absolute system based on the centimeter, gram, and second as the fundamental mechanical units. The permittivity of vacuum ( $\epsilon_0$ ) is taken as unity in Coulomb's law of force between electric charges ( $F = q_1 q_2 / \epsilon_0 d^2$ ), where  $d$  is their separation. These units are commonly designated by using the prefix *stat* with the name of the corresponding practical unit, e.g., *statampere*.

**55. Cgs Electromagnetic System.** An absolute system based on the centimeter, gram, and second. The permeability of vacuum ( $\mu_0$ ) is taken as unity in Ampere's law of force per unit length between infinite, parallel current-carrying conductors ( $dF/dl = 2\mu_0 i_1 i_2 / d$ ), where  $d$  is their separation. These units are commonly designated by using the prefix *ab* with the name of the corresponding practical unit, e.g., *abampere*.

**56. Gaussian System.** A mixed system in which electrical quantities are stated in cgs electrostatic units and magnetic quantities in cgs electromagnetic units.

**57. Mks (Giorgi) System.** An absolute system in which the fundamental mechanical units are the meter, kilogram, and second and the permeability of vacuum is assigned the value  $\mu_0 = 10^{-7}$ .

**58. International Units.** These units were an approximation of a "practical" system based on certain decimal multiples of the corresponding cgs electromagnetic units. Actually they differed slightly in magnitude from the "absolute" units they were intended to represent. The International ohm was defined as the resistance at 0°C of a column of mercury having a mass of 14.4521 grams, a constant cross section, and a length of 106.3 centimeters. The International ampere was defined as the unvarying current which would deposit 0.001118 gram of silver per second from a specified silver nitrate solution. The International volt was defined (1910-1948) by assigning the value 1.01830 volts for the average emf of the Weston normal cell at a temperature of 20°C. This value was assigned as the result of experimental determinations which made use of the ohm and ampere as defined above. The International coulomb, henry, farad, watt, and joule were defined in terms of appropriate combinations of the ohm, ampere, and volt. These units formed the basis of all scientific and engineering measurements and constituted our legal electrical units until Jan. 1, 1948.

**59. Absolute Mksa Units.** Since Jan. 1, 1948, our legal electrical units have been based on the absolute meter-kilogram-second system, with the ampere as the fourth basic unit.<sup>1</sup> A modification of this system, the rationalized *mksa* system, is generally used by engineers. This modification, in which the permeability of vacuum is assigned the value  $4\pi \times 10^{-7}$  instead of  $1 \times 10^{-7}$ , does not change the values of the electrical units but does change the units of magnetomotive force, magnetizing force, and certain others. (See Pars. 42 to 51.) Various electrical quantities, defined in a manner consistent with Public Law 617 but in terms of the *mksa* system, are given in the following paragraphs.

**60. Ampere.** An electrical current of such magnitude that when maintained in two straight parallel conductors of infinite length and negligible cross section, at a distance of one meter from each other in vacuum, would produce between the conductors a force of  $2 \times 10^{-7}$  newton per meter of length.

**61. Volt.** The difference of potential between two points (or equipotential surfaces) in a conductor carrying a constant current of one ampere when the power dis-

<sup>1</sup> The change was authorized by the 80th Congress in HR 4113 introduced on July 8, 1947. The legal basis of our present system is Public Law 617, enacted by the 81st Congress on July 21, 1950, which formally repealed the Act of July 12, 1894, Public Law 105 (53d Congress), and redefined the units in terms of an absolute system. (The earlier act, PL 105, had defined the legal units in terms of the International units described in Par. 58.) It is interesting to note that the language of PL 617 followed the precedent of the earlier law and defined the ohm and ampere as  $10^9$  and  $10^{-1}$  cgs electromagnetic units, respectively. The units of PL 617 are, of course, identical with the corresponding *mksa* units.