Section 5

ELECTRICITY AND MAGNETISM

D. F. BLEIL, Editor

U.S. Naval Ordnance Laboratory, White Oak

CONTENTS

5a. Definitions, Units, Nomenclature, Symbols, Conversion Tables

W. R. SMYTHE

California Institute of Technology

5a-1. Fundamental Definitions Based on Mechanical Measurements

Capacitivity or Dielectric Constant. The capacitivity in farads per meter is the ratio of the force between two charged conductors measured in vacuum to that measured when the vacuum is replaced by a homogeneous fluid insulating medium, multiplied by 8.85434×10^{-12}. In a homogeneous solid it is the product of 8.85434×10^{-12} by the ratio of the force on a given small charge measured at the center of a thin disk-shaped evacuated cavity placed normal to a uniform electric field to that on the same charge measured at the center of a thin needle-shaped evacuated cavity aligned with the same field.

Charge. One coulomb is that charge which, when carried by each of two bodies whose distance apart r in meters is very large compared with their dimensions, produces in a vacuum a mutual repulsion of $8.98740r^{-2} \times 10^{9}$ newton. A charge of one coulomb is transported by a current of one ampere in one second. There are two kinds of charge. Electrons carry a negative charge and protons a positive charge.

Current. An ampere is that current which, flowing in the same direction in each of two identical coaxial circular loops of wire whose distance apart r in meters is very large compared with their radius a, produces in a vacuum a mutual attraction of $6\pi^2a^4r^{-4} \times 10^{-7}$ newton. A current of one ampere transports one coulomb of charge per second. Current direction is defined as that in which a positive charge moves.

Electric Intensity. The electric intensity in volts per meter is the vector force in newtons acting on a very small body carrying a very small positive charge placed at the field point, divided by the charge in coulombs. In a homogeneous solid the measurement is carried out at the center of a thin evacuated needle-shaped cavity aligned so that the force lies along the axis.

Electromotance or Electromotive Force. The electromotance in volts around a closed path is the work in joules required to carry a very small positive charge around that path, divided by the charge in coulombs.

Magnetic Induction or Magnetic Flux Density. The magnetic induction in webers per square meter is a vector whose direction is that in which the axis of a small circular current-carrying test loop that rests in stable equilibrium at the field point would advance if it were a right-hand screw rotated in the sense of the current circulation and whose magnitude equals the torque in newton meters on the loop when its axis is normal to the induction, divided by the product of loop current by loop area. In a homogeneous solid the measurement is carried out at the center of a thin evacuated disk-shaped cavity oriented so that the induction is normal to its faces.

Permeability. The permeability in henrys per meter is the ratio of the force between two linear circuits carrying fixed current measured in a homogeneous fluid insulating medium to that measured in a vacuum, multiplied by $4\pi \times 10^{-7}$. In a homogeneous solid it is the product of $4\pi \times 10^{-7}$ by the ratio of the magnetic induction at the center of a thin evacuated disk-shaped cavity oriented so that the induction is normal to its faces to that at the center of a thin evacuated needle-shaped cavity oriented so that the induction is directed along its axis.

Potential. The potential in volts at a point in an electrostatic field is the work in joules done in bringing a very small positive charge to the point from a point arbitrarily chosen at zero potential, divided by the charge in coulombs.

5a-2. Basic Laws

Ampère's Law. At any field point near a linear circuit, each circuit element contributes to the magnetic induction an amount inversely proportional to the square of the distance **r** from it to the point, directly proportional to its length, current, and the sine of the angle between **ds** and **r**, and in the direction of $\mathbf{ds} \times \mathbf{r}$.

Coulomb's Law. The force in a homogeneous isotropic medium of infinite extent between two point charges is proportional to the product of their magnitudes divided by the square of the distance between them.

Faraday's Law of Induction. The electromotance induced in a circuit is proportional to the rate of change of the magnetic flux linking the circuit.

Joule's Law. The rate of production of heat in a constant-resistance electric circuit is proportional to the square of the current.

Kirchhoff's Laws. (1) The algebraic sum of the currents flowing into any point in a network is zero. (2) The algebraic sum of the products of current by resistance around any closed path in a network equals the algebraic sum of the electromotances in that path.

Lenz's Law. The current induced in a circuit due to a change in the magnetic flux through it or to its motion in a magnetic field is so directed as to oppose the change in flux or to exert a mechanical force opposing the motion.

Ohm's Law. The current in an electric circuit is directly proportional to the electromotance in it.

5a-3. Definitions of Some Descriptive Terms. For quantitative terms, see Table 5a-1.

Anode. The positive electrode in such devices as the arc, vacuum tube, and electrolytic cell.

Antiferroelectric Materials. Those in which spontaneous electric polarization occurs in lines of ions; adjacent lines are polarized in an antiparallel arrangement.

Antiferromagnetic Materials. Those in which spontaneous magnetic polarization occurs in equivalent sublattices; the polarization in one sublattice is aligned antiparallel to the other.

Cathode. The negative electrode in such devices as the arc, vacuum tube, and electrolytic cell.

Coercive Force. The value of the reverse magnetic intensity needed to destroy the magnetic moment of the specimen.

Conductors. Bodies in which differences of potential, if not maintained by some driving electromotance, disappear rapidly with a flow of current.

Curie Point. The point, as the temperature increases, at which the transition from ferromagnetic to paramagnetic properties of a substance is complete.

Diamagnetic Bodies. Those which, when placed in an inhomogeneous magnetic field, tend to move toward its weaker regions.

Dielectric Bodies. Those which can support an electric strain and in which differences of potential disappear very slowly or not at all because of current flow.

Eddy or *Foucault Currents.* Circulating currents set up in conducting masses or sheets by varying magnetic fields.

Edison or *Richardson Effect.* The thermionic emission of electrons from hot bodies at a rate which increases rapidly with temperature.

Electric Circuit. The path taken by an electric current. Elements of the circuit which possess the properties of capacitance, inductance, resistance, etc. (Table 5a-1) are known as capacitors, inductors, resistors, etc., respectively.

Electric Lines of Force. Curves in an electric field whose tangents at any point give the direction of the field at that point.

Electric Tubes of Flux. Charge-free regions in isotropic space whose sides are everywhere tangent to the electric intensity and whose ends terminate on charges or charged areas or may meet to form closed rings.

Electrodes. Terminals by which current may enter or leave a region.

Electrolysis. The process of passing current through a substance when so doing liberates one or more of its constituents at the electrodes.

Electrolyte. A substance capable of electrolysis.

Electrostriction. The change of dimensions of a dielectric body when placed in an electric field.

Ettinghausen Effect. The phenomenon observed when a conductor carries current in a transverse magnetic field and a temperature gradient appears in a direction normal to both.

Ferrimagnetic Materials. Those in which spontaneous magnetic polarization occurs in nonequivalent sublattices; the polarization in one sublattice is aligned antiparallel to the other.

Ferroelectric Materials. Those in which the electric polarization (see Table 5a-1) is produced by cooperative action between groups or domains of collectively oriented molecules.

Ferromagnetic Materials. Those in which the magnetization is produced by cooperative action between groups or domains of collectively oriented molecules.

Gyromagnetic Effects. The phenomena of magnetization by rotation (Barnett effect) and rotation by magnetization (Einstein–de Haas effect).

Hall Effect. The production of a transverse potential gradient in a material by a steady electric current which has a component normal to a magnetic field.

Hysteresis Curves. These show the steady-state relation between the magnetic induction in a material and the steady-state alternating magnetic intensity (see Table 5a-1) that produces it.

Image Force. The force on a charge due to that charge or polarization which it induces on neighboring conductors or dielectrics.

Magnetic Lines of Force. Curves in a magnetic field whose tangents at any point give the direction of the magnetic intensity there.

Magnetic Saturation. A condition in which further increases in the magnetizing field produce no increase in magnetization.

Magnetic Tubes of Flux. Regions in space whose sides are everywhere tangent to the magnetic induction and whose ends may meet to form closed rings.

Magnetostriction. The change in dimensions of a body when placed in a magnetic field.

Nernst Effect. The production of a transverse electric field by a heat current.

Parallel Connections. These are so arranged that current divides between elements, no portion passing through more than one element.

Paramagnetic Bodies. When placed in an inhomogeneous magnetic field, these bodies tend to move toward its stronger regions.

Peltier Effect. The phenomenon of absorption or generation of heat according to the direction of passage of current across a junction of two conductors.

Permanent Magnets. Strongly magnetized bodies whose magnetization is little affected by the action of internal or external magnetic fields or by moderate mechanical shocks.

Photoconductivity. The property of a material which causes its resistivity (see Table 5a-1) to change when light falls upon it.

Photoelectric Effect. The liberation of electrons from a surface when light falls upon it.

Piezoelectric Effects. The phenomena of separation of charge in a crystal by mechanical stresses and the converse.

Proximity Effect. The distortion of alternating-current flow in one conductor due to that in neighboring conductors.

Pyroelectric Effect. The phenomenon of separation of charge in a crystal by heating.

Rectifiers. Devices which offer higher resistance (see Table 5a-1) to current passing in one direction than the other.

Seebeck or *Thermoelectric Effect.* The flow of current in a circuit consisting of two or more conductors caused by temperature differences at the junctions.

Semiconductor. A rather poor conductor whose conductivity may be changed radically by small changes in its physical condition.

Series Connections. These are so arranged that current must pass through all the elements in succession.

Skin Effect. The concentration of high-frequency alternating current near the surface of a conductor.

Thomson Effects. Phenomena in which potential gradients are produced in a material by differences of temperature.

Triboelectricity. The electric charges separated by friction between bodies.

Volta or *Contact-potential Effect.* The appearance of opposite charges on two dissimilar uncharged metals when placed in contact and the existence of a difference of potential between them.

Work Function. The energy needed to carry a charge across a metal vacuum boundary.

Note on Tables 5a-2, 5a-3, *and* 5a-4. These tables are presented to facilitate transposition of formulas from one system of units into another. In such systems as the Gaussian, the formula to be transposed must be written for a medium in which μ and ϵ are not unity before using the tables. For example, the force on a moving charge in static fields is

$$\mathbf{F} = Q\mathbf{E} + c^{-1}Q(\mathbf{v} \times \mathbf{B}') \qquad \text{(Gaussian)}$$

where $\mathbf{F}$ is in dynes, Q and $\mathbf{E}$ in esu, $\mathbf{v}$ in cm/sec, $\mathbf{B}'$ in emu or gauss, and $c \approx 3 \times 10^{10}$ cm/sec. The equivalent formula in cgs emu is found from Table 5a-3, where, using primes for emu quantities, we write, according to directions, cQ' for Q, $c^{-1}\mathbf{E}'$ for $\mathbf{E}$ and obtain

$$\mathbf{F}' = Q'\mathbf{E}' + Q'(\mathbf{v} \times \mathbf{B}') \qquad \text{(cgs emu)}$$

For mks units, written with a double prime, we use the same table but write $10^{-5}\mathbf{F}''$ for $\mathbf{F}$, $10Q''$ for Q', $10^{-2}\mathbf{v}''$ or $10^{-2}l''/t$ for $\mathbf{v}$ or l/t, and $10^{-4}\mathbf{B}''$ for $\mathbf{B}'$, giving, after cancellation of 10^{-5} throughout,

$$\mathbf{F}'' = Q''\mathbf{E}'' + Q''(\mathbf{v}'' \times \mathbf{B}'') \qquad \text{(mks)}$$

In this formula $\mathbf{F}''$ is in newtons, Q'' in coulombs, $\mathbf{E}''$ in volts per meter, $\mathbf{v}''$ in meters per second, and $\mathbf{B}''$ in webers per square meter.

TABLE 5a-1. SYMBOLS. MKS[a] UNIT NAMES. SYMBOLIC DEFINITIONS. DIMENSIONS[b]

Quantity	Symbol[c]	Mks unit	Equivalents	Dimensions
Admittance	$\check{Y}$	mho	$\check{Z}^{-1} = G + jB$	$m^{-1}l^{-2}t^3I^2$
Attenuation	....	decibels	$10 \log (A_1/A_2)$	0
Attenuation constant	α a	parts/m	$(x_2 - x_1)^{-1} \ln (A_1/A_2)$	l^{-1}
Capacitance	C	farad	QV^{-1}	$m^{-1}l^{-2}t^4I^2$
Mutual	C_m,C_{rs}	farad	$Q_sV_r^{-1}$ if $V_t = 0,\ t \neq r$	$m^{-1}l^{-2}t^4I^2$
Self	C,C_{rr}	farad	$Q_rV_r^{-1}$ if $V_t = 0,\ t \neq r$	$m^{-1}l^{-2}t^4I^2$
Capacitivity	ϵ	farad/m	Defined in Sec. 5a-1	$m^{-1}l^{-3}t^4I^2$
Capacitivity of vacuum	ϵ_v ϵ_0	farad/m	8.85434×10^{-12}	$m^{-1}l^{-3}t^4I^2$
Capacitivity, relative	K_e,K	ratio	$\epsilon\epsilon_v^{-1}$	0
Charge	$Q,\check{Q},q$	coulomb	Defined in Sec. 5a-1	tI
Charge density, line	λ	coulomb/m	dQ/ds	$l^{-1}tI$
Surface	$\sigma,(\rho_s)$	coulomb/m²	dQ/dS	$l^{-2}tI$
Volume	ρ	coulomb/m³	dQ/dv	$l^{-3}tI$
Conductance	G	mho	$R^{-1} = IV^{-1}$	$m^{-1}l^{-2}t^3I^2$
Conductivity	$\gamma,(\sigma)$	mho/m	$\mathbf{i}\mathbf{E}^{-1}$	$m^{-1}l^{-3}t^3I^2$
Surface	$\gamma',(\sigma')$	mho	$\mathbf{i}'_s\mathbf{E}_s^{-1}$	$m^{-1}l^{-2}t^3I^2$
Current	$I,\check{I}$	ampere	Fundamental	I
Current density	$\mathbf{i},\check{\mathbf{i}},\mathbf{J}$	ampere/m²	$\gamma\mathbf{E},\gamma\check{\mathbf{E}}$	$l^{-2}I$
Surface	$\mathbf{i}',\check{\mathbf{i}}',\mathbf{J}'$	ampere/m	$\gamma'\mathbf{E}_s,\gamma'\check{\mathbf{E}}_s$	$l^{-1}I$
Dielectric constant	ϵ	farad/m	Defined in Sec. 5a-1	$m^{-1}l^{-3}t^4I^2$
Displacement, electric	$\mathbf{D},\check{\mathbf{D}}$	coulomb/m²	$\epsilon\mathbf{E},\epsilon\check{\mathbf{E}},\ \epsilon_v\mathbf{E} + \mathbf{P}$	$l^{-2}tI$
Elastance	S	daraf	C^{-1},VQ^{-1}	$ml^2t^{-4}I^{-2}$
Mutual	S_m,S_{rs}	daraf	$V_sQ_r^{-1}$ if $Q_t = 0,\ t \neq r$	$ml^2t^{-4}I^{-2}$
Self	S,S_{rr}	daraf	$V_rQ_r^{-1}$ if $Q_t = 0,\ t \neq r$	$ml^2t^{-4}I^{-2}$
Elastivitity	σ	daraf-m	ϵ^{-1}	$ml^3t^{-4}I^{-2}$
Electromotance (electromotive force)	$\mathcal{E},\check{\mathcal{E}}$ E	volt	Defined in Sec. 5a-1	$ml^2t^{-3}I^{-1}$
Electronic charge	e	coulomb	1.6020×10^{-19}	tI
Energy	W	joule	$I\Phi,QV,\frac{1}{2}\int\mathbf{E}\cdot\mathbf{D}\,dv$, $\frac{1}{2}\int\mathbf{H}\cdot\mathbf{B}\,dv$	ml^2t^{-2}
Flux, electric	ψ Ψ	coulomb	$\int\mathbf{n}\cdot\mathbf{D}\,dS$	tI
Flux, magnetic	Φ	weber	$\int\mathbf{n}\cdot\mathbf{B}\,dS$	$ml^2t^{-2}I^{-1}$
Force	$\mathbf{F}$	newton	$Q\mathbf{E},\ \int\mathbf{i}\times\mathbf{B}\,dv$	mlt^{-2}
Frequency	ν f	hertz	$v\lambda^{-1},\omega(2\pi)^{-1}$	t^{-1}
Frequency, angular	ω	radian/sec	$2\pi\nu,2\pi v\lambda^{-1}$	t^{-1}
Impedance	$\check{Z}$	ohm	$\check{\mathcal{E}}\check{I}^{-1},\ R + jX$	$ml^2t^{-3}I^{-2}$
Intrinsic, vacuum	η	ohm	$\mu_v^{\frac{1}{2}}\epsilon_v^{-\frac{1}{2}} \approx 120\pi$	$ml^2t^{-3}I^{-2}$
Mutual	$\check{Z}_m,\check{Z}_{rs}$	ohm	....	$ml^2t^{-3}I^{-2}$
Self	$\check{Z},\check{Z}_{rr}$	ohm	....	$ml^2t^{-3}I^{-2}$

[a] The meter, kilogram, second, and ampere (mksa) were adapted as the fundamental units by the members of the Tenth General Conference on Weights and Measures, Paris, October, 1954. The vote for the ampere was not unanimous but a strong three-fourths majority. *Compt. rend.* **239,** 64 (1954).

[b] Space vectors are printed in boldface. Phasors, which are complex numbers used in solving algebraically for the steady-state value of a sinusoidally time-dependent quantity, are designated by a flat v over the symbol. For conjugate phasors, an inverted flat v is used. The symbol j is used for $(-1)^{\frac{1}{2}}$.

[c] The symbols listed in the left-hand column are those recommended in "Letter Symbols for Physics," Z10.6 1948, American Standards Association, American Society of Mechanical Engineers, New York. Those symbols recommended by the "International Electrotechnical Commission (IEC)," Publication 27, Geneva, Switzerland, 1953, which are different from those of the ASA, are shown on the right-hand side of this column. **The ASA symbols have been used throughout Sec. 5 except for Sec. 5g, where the symbols are those recommended by the International Union of Pure and Applied Chemistry. Conversion to IEC symbols was not possible at this time because the Commission has not completed its list.**

TABLE 5a-1. SYMBOLS. MKS UNIT NAMES. SYMBOLIC DEFINITIONS. DIMENSIONS (*Continued*)

Quantity	Symbol	Mks unit	Equivalents	Dimensions
Inductance	L	henry	....	$ml^2t^{-2}I^{-2}$
Mutual	M, L_m, L_{rs}	henry	$(I_1I_2)^{-1}\int \mathbf{B}_2 \cdot \mathbf{n}\, dS_1$	$ml^2t^{-2}I^{-2}$
Self	L, L_{rr}	henry	$(\mu I^2)^{-1}\int B^2\, dv$	$ml^2t^{-2}I^{-2}$
Induction, magnetic	$\mathbf{B}, \check{\mathbf{B}}$	weber/m²	Defined in Sec. 5a-1	$mt^{-2}I^{-1}$
Intensity, electric	$\mathbf{E}, \check{\mathbf{E}}$	volt/m	Defined in Sec. 5a-1	$mlt^{-3}I^{-1}$
Intensity, magnetic	$\mathbf{H}, \check{\mathbf{H}}$	amp-turn/m	$\mu^{-1}\mathbf{B},\ \mu_v^{-1}\mathbf{B} - \mathbf{M}$	$l^{-1}I$
Length	l	meter	Fundamental	l
Magnetization (loop)	$\mathbf{M}$	amp-turn/m	$(K_m - 1)\mathbf{H}$	$l^{-1}I$
Magnetization (dipole) (See Polarization, magnetic)	$\mathbf{M}$			
Magnetomotance (magnetomotive force)	$\mathfrak{F}$ F	amp-turn	$\mu^{-1}\oint \mathbf{B} \cdot \mathbf{ds},\ \oint \mathbf{H} \cdot \mathbf{ds}$	I
Mass	m	kilogram	Fundamental	m
Moment, electric	$\mathbf{p}, \check{\mathbf{p}}$	coulomb-m	$Q\ \mathbf{ds}$	ltI
Moment, magnetic loop	$\mathbf{m}, \check{\mathbf{m}}$	amp-m²	$\pi a^2 I \mathbf{n}$	l^2I
Moment, magnetic (dipole)	$\mathbf{m}$	weber-m	$m\ \mathbf{ds}$	$ml^3t^{-2}I^{-1}$
Period	T	second	$\omega^{-1}2\pi, \nu^{-1}, \lambda v^{-1}$	t
Permeance	$\mathcal{P}$ Λ	henry	$\mathcal{R}^{-1}, \mathfrak{F}^{-1}\Phi$	$ml^2t^{-2}I^{-1}$
Permeability	μ	henry/m	Defined in Sec. 5a-1	$mlt^{-2}I^{-2}$
Vacuum	μ_v μ_0	henry/m	$4\pi \times 10^{-7}$	$mlt^{-2}I^{-2}$
Relative	K_m	....	$\mu_v^{-1}\mu$	0
Phase angle	φ	radian	....	0
Phase constant (see Wave number)				
Polarization, electric	$\mathbf{P}$	coulomb/m²	$(K_e - 1)\epsilon_v\mathbf{E}$	$l^{-2}tI$
Polarization, magnetic (Magnetization dipole)	$\mathbf{M}$ $\mathbf{J}$	weber/m²	$(K_m - 1)\mu_v\mathbf{H}$	$mt^{-2}I^{-1}$
Pole strength	m	weber	....	$ml^2t^{-2}I^{-1}$
Potential, electrostatic	V U	volt	Defined in Sec. 5a-1	$ml^2t^{-3}I^{-1}$
Electrodynamic	$\Phi, \check{\Phi}$	volt	$\mathbf{E} = -\nabla\Phi - d\mathbf{A}/dt$	$ml^2t^{-3}I^{-1}$
Vector magnetic	$\mathbf{A}, \check{\mathbf{A}}$	weber/m	$\mathbf{B} = \nabla \times \mathbf{A}$	$mlt^{-2}I^{-1}$
Power	P	watt	dW/dt	ml^2t^{-3}
Poynting vector	$\mathbf{\Pi}$	watt/m²	$\mu^{-1}\mathbf{E} \times \mathbf{B}$	mt^{-3}
Propagation constant	$\check{\Gamma}, (\check{\gamma})$	parts/m	$\alpha + j\beta$	l^{-1}
Quality factor	Q	a ratio	$\omega L R^{-1}$	0
Reactance	$\check{X}$	ohm	$\omega L - (\omega C)^{-1}$	$ml^2t^{-3}I^{-2}$
Reluctance	$\mathcal{R}$ R	amp-turn/weber	$\mathfrak{F}\Phi^{-1}$	$m^{-1}l^{-2}t^2I^2$
Reluctivity	ν	m/henry	μ^{-1}	$m^{-1}l^{-1}t^2I^2$
Resistance	R	ohm	VI^{-1}	$ml^2t^{-3}I^{-2}$
Resistivity	ρ	ohm-m	$\mathbf{E}\mathbf{i}^{-1}$	$ml^3t^{-3}I^{-2}$
Susceptance	B	mho	$\check{Y} = G + jB$	$m^{-1}l^{-2}t^3I^2$
Susceptibility, electric	χ_e κ_e	....	$K_e - 1$	0
Magnetic	χ_m κ_m	....	$K_m - 1$	0
Time	t	second	Fundamental	t
Time constant	τ	second	LR^{-1}, RC	t
Velocity of light	c	m/sec	2.99790×10^8	lt^{-1}
Wavelength	λ	meter	$2\pi\beta^{-1}, 2\pi v\omega^{-1}$	l
Wave number (phase constant)	β, k	radian/m	$2\pi\lambda^{-1}, \omega v^{-1}, \gamma = \alpha + j\beta$	l^{-1}
Work	W	joule	$\oint \mathbf{F} \cdot \mathbf{ds}$	ml^2t^{-2}

TABLE 5a-2. REDUCTION OF FORMULA TO CGS ESU[a]

Quantity	Esu	Emu	Practical cgs	Rationalized mks
Capacitance	C	$c^{-2}C$	$9^{-1}10^{-11}C$ farad	
Capacitivity	ϵ	$c^{-2}\epsilon$	$9^{-1}10^{-11}\epsilon(4\pi$ farad)/cm	$\epsilon_v\epsilon$ farad/m
Charge, quantity	Q	$c^{-1}Q$	$3^{-1}10^{-9}Q$ coulomb	
Conductance	G	$c^{-2}G$	$9^{-1}10^{-11}G$ mho	
Conductivity, area	γ'	$c^{-2}\gamma'$	$9^{-1}10^{-11}\gamma'$ mho	
Conductivity, volume	γ	$c^{-2}\gamma$	$9^{-1}10^{-11}\gamma$ mho/cm	$9^{-1}10^{-9}\gamma$ mho/m
Current	I	$c^{-1}I$	$3^{-1}10^{-9}I$ amp	
Current density, area	$\mathbf{i}'$	$c^{-1}\mathbf{i}'$	$3^{-1}10^{-9}\mathbf{i}'$ amp/cm	$3^{-1}10^{-7}\mathbf{i}'$ amp/m
Current density, volume	$\mathbf{i}$	$c^{-1}\mathbf{i}$	$3^{-1}10^{-9}\mathbf{i}$ amp/cm^2	$3^{-1}10^{-5}\mathbf{i}$ amp/m^2
Displacement	$\mathbf{D}$	$c^{-1}\mathbf{D}$	$3^{-1}10^{-9}\mathbf{D}$ (4π coulomb)/cm^2	$3\epsilon_v 10^4\mathbf{D}$ coulomb/m^2
Elastance	S	c^2S	$9 \times 10^{11}S$ daraf	
Electromotance	$\mathcal{E}$	$c\mathcal{E}$	$300\mathcal{E}$ volt	
Energy	W	W	W erg	$10^{-7}W$ joule
Force	$\mathbf{F}$	$\mathbf{F}$	$\mathbf{F}$ dyne	$10^{-5}\mathbf{F}$ newton
Impedance	$\check{Z}$	$c^2\check{Z}$	$9 \times 10^{11}\check{Z}$ ohm	
Inductance	L	c^2L	$9 \times 10^{11}L$ henry	
Intensity, electric	$\mathbf{E}$	$c\mathbf{E}$	$300\mathbf{E}$ volt/cm	$30{,}000\mathbf{E}$ volt/m
Length	l	l	l centimeter	$10^{-2}l$ meter
Mass	m	m	m gram	$10^{-3}m$ kilogram
Polarization, electric	$\mathbf{P}$	$c^{-1}\mathbf{P}$	$3^{-1} \times 10^{-9}\mathbf{P}$ coulomb/cm^2	$3^{-1} \times 10^{-5}\mathbf{P}$ coulomb/m^2
Potential, electric	V	cV	$300V$ volt	
Power	P	P	P erg/sec	$10^{-7}P$ watt
Reactance	X	c^2X	$9 \times 10^{11}X$ ohm	
Resistance	R	c^2R	$9 \times 10^{11}R$ ohm	
Resistivity, area	σ	$c^2\sigma$	$9 \times 10^{11}\sigma$ ohm	
Resistivity, volume	ρ	$c^2\rho$	$9 \times 10^{11}\rho$ ohm-cm	$9 \times 10^{9}\rho$ ohm-m

[a] A formula given in emu, unrationalized practical cgs or rationalized mks units, in which the capacitivity or permeability, if relevant, appears explicitly, is expressed in cgs esu by replacing each symbol by the value given in the emu, practical cgs or rationalized mks column, respectively. Each line may be read as an equation relating the size of the units involved. Here c is 2.9979×10^{10}. For precise work the 3 and 9 factors should be replaced by 2.9979 and 8.9874. See inside cover for more precise values.

TABLE 5a-3. REDUCTION OF FORMULA TO CGS EMU[a]

Quantity	Emu	Esu	Practical cgs and rationalized mks	
Capacitance	C	c^2C^*	10^9C farad	
Charge, quantity	Q	cQ^*	$10Q$ coulomb	
Conductance	G	c^2G^*	10^9G mho	
Conductivity, area	γ'	$c^2\gamma'^*$	$10^9\gamma'$ mho	
Conductivity, volume	γ	$c^2\gamma^*$	$10^9\gamma$ mho/cm	$10^{11}\gamma$ mho/m
Current	I	cI^*	$10I$ amp	
Current density, area	$\mathbf{i}'$	$c\mathbf{i}'^*$	$10\mathbf{i}'$ amp/cm	$10^3\mathbf{i}'$ amp/m
Current density, volume	$\mathbf{i}$	$c\mathbf{i}^*$	$10\mathbf{i}$ amp/cm^2	$10^5\mathbf{i}$ amp/m^2
Elastance	S	$c^{-2}S^*$	$10^{-9}S$ daraf	
Electromotance	$\mathcal{E}$	$c^{-1}\mathcal{E}^*$	$10^{-8}\mathcal{E}$ volt	
Energy	W	W	W erg	$10^{-7}W$ joule
Flux, magnetic	Φ^*	$c^{-1}\Phi$	Φ maxwell	$10^{-8}\Phi$ weber
Force	$\mathbf{F}$	$\mathbf{F}$	$\mathbf{F}$ dyne	$10^{-5}\mathbf{F}$ newton
Impedance	$\check{Z}$	$c^{-2}\check{Z}^*$	$10^{-9}\check{Z}$ ohm	
Inductance	L	$c^{-2}L^*$	$10^{-9}L$ henry	
Induction, magnetic	$\mathbf{B}^*$	$c^{-1}\mathbf{B}$	$\mathbf{B}$ gauss	$10^{-4}\mathbf{B}$ weber/m^2
Intensity, electric	$\mathbf{E}$	$c^{-1}\mathbf{E}^*$	$10^{-8}\mathbf{E}$ volt/cm	$10^{-6}\mathbf{E}$ volt/m
Intensity, magnetic	$\mathbf{H}^*$	$c\mathbf{H}$	$\mathbf{H}$ oersted	$(4\pi)^{-1}10^3\mathbf{H}$ amp-turn/m
Length	l	l	l centimeter	$10^{-2}l$ meter
Magnetic moment (dipole)	$\mathbf{m}'^*$	$c^{-1}\mathbf{m}'$	$4\pi\mathbf{m}'$ maxwell-cm	$4\pi10^{-10}\mathbf{m}'$ weber-m
Magnetic moment (loop)	$\mathbf{m}^*$	$c\mathbf{m}$	$10\mathbf{m}$ amp-cm^2	$10^{-3}\mathbf{m}$ amp-m^2
Magnetization (dipole)	$\mathbf{M}'^*$	$c^{-1}\mathbf{M}'$	$4\pi\mathbf{M}'$ maxwell/cm^2	$4\pi10^{-4}\mathbf{M}'$ weber/m^2
Magnetization (loop)	$\mathbf{M}^*$	$c\mathbf{M}$	$10\mathbf{M}$ amp/cm	$1000\mathbf{M}$ amp/m
Magnetomotance	$\mathfrak{F}^*$	$c\mathfrak{F}$	$\mathfrak{F}$ gilbert	$(4\pi)^{-1}10\mathfrak{F}$ amp-turn
Mass	m	m	m gram	$10^{-3}m$ kilogram
Permeability	μ^*	$c^{-2}\mu$	μ gauss/oersted	$4\pi10^{-7}\mu$ henry/m
Pole strength, magnetic	m^*	$c^{-1}m$	$4\pi m$ maxwell	$4\pi10^{-8}m$ weber
Potential, electric	V	$c^{-1}V^*$	$10^{-8}V$ volt	
Potential, vector	$\mathbf{A}^*$	$c^{-1}\mathbf{A}$	$\mathbf{A}$ gauss-cm	$10^{-6}\mathbf{A}$ weber/m
Power	P	P	P erg/sec	$10^{-7}P$ watt
Reactance	X	$c^{-2}X^*$	$10^{-9}X$ ohm	
Reluctance	$\mathcal{R}^*$	$c^2\mathcal{R}$	$\mathcal{R}$ gilbert/max	$(4\pi)^{-1}10^9\mathcal{R}$ amp-turn/weber
Resistance	R	$c^{-2}R^*$	$10^{-9}R$ ohm	
Resistivity, area	σ	$c^{-2}\sigma^*$	$10^{-9}\sigma$ ohm	
Resistivity, volume	ρ	$c^{-2}\rho^*$	$10^{-9}\rho$ ohm-cm	$10^{-11}\rho$ ohm-m

[a] A formula given in esu, Gaussian (starred), unrationalized practical cgs, or rationalized mks units, in which the capacitivity or permeability, if relevant, appears explicitly, is expressed in cgs emu by replacing each symbol by the value given in the esu, starred, practical cgs, or rationalized mks columns, respectively. Each line may be read as an equation relating the size of the units involved. Here c is 2.9979×10^{10}. (See inside cover.)

TABLE 5a-4. REDUCTION OF FORMULA TO RATIONALIZED MKS UNITS[a]

Quantity	(a) Practical cgs (b) mks	Emu	Esu
Capacitance	C farad	$10^{-9}C$	$9 \times 10^{11}C^*$
Capacitivity	(a) ϵ (4π farad)/cm	$10^{-9}\epsilon$	$9 \times 10^{11}\epsilon^*$
	(b) ϵ farad/m	$4\pi 10^{-11}\epsilon$	$\epsilon_v^{-1}\epsilon^*$
Charge, quantity	Q coulomb	$10^{-1}Q$	$3 \times 10^{9}Q^*$
Conductance	G mho	$10^{-9}G$	$9 \times 10^{11}G^*$
Conductivity, area	γ' mho	$10^{-9}\gamma'$	$9 \times 10^{11}\gamma'^*$
Conductivity, volume	(a) γ mho/cm	$10^{-9}\gamma$	$9 \times 10^{11}\gamma^*$
	(b) γ mho/m	$10^{-11}\gamma$	$9 \times 10^{9}\gamma^*$
Current	I ampere	$10^{-1}I$	$3 \times 10^{9}I^*$
Current density, area	(a) i' amp/cm	$10^{-1}\mathrm{i}'$	$3 \times 10^{9}\mathrm{i}'^*$
	(b) i' amp/m	$10^{-3}\mathrm{i}'$	$3 \times 10^{7}\mathrm{i}'^*$
Current density, volume	(a) i amp/cm²	$10^{-1}\mathrm{i}$	$3 \times 10^{9}\mathrm{i}^*$
	(b) i amp/m²	$10^{-5}\mathrm{i}$	$3 \times 10^{5}\mathrm{i}^*$
Displacement, electric	(a) **D** (4π coulomb)/cm²	$10^{-1}\mathbf{D}$	$3 \times 10^{9}\mathbf{D}^*$
	(b) **D** coulomb/m²	$4\pi 10^{-5}\mathbf{D}$	$(3\epsilon_v)^{-1}10^{-4}\mathbf{D}^*$
Elastance	S daraf	$10^{9}S$	$9^{-1}10^{-11}S^*$
Electromotance	$\mathcal{E}$ volt	$10^{8}\mathcal{E}$	$(300)^{-1}\mathcal{E}^*$
Energy	(a) W erg	W	W
	(b) W joule	$10^{7}W$	$10^{7}W$
Flux, magnetic	(a) Φ maxwell	Φ^*	$3^{-1}10^{-10}\Phi$
	(b) Φ weber	$10^{8}\Phi^*$	$(300)^{-1}\Phi$
Force	(a) **F** dyne	$\mathbf{F}$	$\mathbf{F}$
	(b) **F** newton	$10^{5}\mathbf{F}$	$10^{5}\mathbf{F}$
Impedance	$\check{Z}$ ohm	$10^{9}\check{Z}$	$9^{-1}10^{-11}\check{Z}^*$
Inductance	L henry	$10^{9}L$	$9^{-1}10\ ^{11}L^*$
Induction, magnetic	(a) **B** gauss	$\mathbf{B}^*$	$3^{-1}10^{-10}\mathbf{B}$
	(b) **B** weber/m²	$10^{4}\mathbf{B}^*$	$3^{-1}10^{-6}\mathbf{B}$
Intensity, electric	(a) **E** volt/cm	$10^{8}\mathbf{E}$	$(300)^{-1}\mathbf{E}^*$
	(b) **E** volt/m	$10^{6}\mathbf{E}$	$3^{-1}10^{-4}\mathbf{E}^*$
Intensity, magnetic	(a) **H** oersted	$\mathbf{H}^*$	$3 \times 10^{10}\mathbf{H}$
	(b) **H** amp-turn/m	$4\pi 10^{-3}\mathbf{H}^*$	$12\pi 10^{7}\mathbf{H}$
Length	(a) l centimeter	l	l
	(b) l meter	$10^{2}l$	$10^{2}l$
Magnetic moment (dipole)	(a) **m′** maxwell-cm	$(4\pi)^{-1}\mathbf{m}'^*$	$(12\pi)^{-1}10^{-10}\mathbf{m}'$
	(b) **m′** weber-m	$(4\pi)^{-1}10^{10}\mathbf{m}'^*$	$(12\pi)^{-1}\mathbf{m}'$
Magnetic moment (loop)	(a) **m** amp-cm²	$10^{-1}\mathbf{m}^*$	$3 \times 10^{9}\mathbf{m}$
	(b) **m** amp-m²	$10^{3}\mathbf{m}^*$	$3 \times 10^{13}\mathbf{m}$
Magnetization (dipole)	(a) **M′** maxwell/cm²	$(4\pi)^{-1}\mathbf{M}'^*$	$(12\pi)^{-1}10^{-10}\mathbf{M}'$
	(b) **M′** weber/m²	$(4\pi)^{-1}10^{4}\mathbf{M}'^*$	$(12\pi)^{-1}10^{-6}\mathbf{M}'$
Magnetization (loop)	(a) **M** amp/cm	$10^{-1}\mathbf{M}^*$	$3 \times 10^{9}\mathbf{M}$
	(b) **M** amp/m	$10^{-3}\mathbf{M}^*$	$3 \times 10^{7}\mathbf{M}$

[a] A formula given in cgs emu, cgs esu, or Gaussian (starred) units, in which the capacitivity or permeability, if relevant, appears explicitly, may be expressed in (a) unrationalized cgs practical units or (b) rationalized mks units by replacing each symbol with its value in the emu, esu, or starred column, respectively. Each line may be read as an equation relating the size of the units involved. In precise work, replace 3 by 2.9979 and 9 by 8.9874.

TABLE 5a-4. REDUCTION OF FORMULA TO RATIONALIZED MKS UNITS (*Continued*)

Quantity	(a) Practical cgs (b) mks	Emu	Esu
Magnetomotance	(a) $\mathfrak{F}$ gilbert	$\mathfrak{F}^*$	$3 \times 10^{10}\mathfrak{F}$
	(b) $\mathfrak{F}$ amp-turn	$4\pi 10^{-1}\mathfrak{F}^*$	$12\pi \times 10^{9}\mathfrak{F}$
Mass	(a) m gram	m	m
	(b) m kilogram	$10^{3}m$	$10^{3}m$
Permeability	(a) μ gauss/oersted	μ^*	$9^{-1}10^{-20}\mu$
	(b) μ henry/m	$(4\pi)^{-1}10^{7}\mu^*$	$(36\pi)^{-1}10^{-13}\mu$
Polarization, electric	(a) $\mathbf{P}$ coulomb/cm²	$10^{-1}\mathbf{P}$	$3 \times 10^{9}\mathbf{P}^*$
	(b) $\mathbf{P}$ coulomb/m²	$10^{-5}\mathbf{P}$	$3 \times 10^{5}\mathbf{P}^*$
Pole strength	(a) m maxwell	$(4\pi)^{-1}m^*$	$(12\pi)^{-1}10^{-10}m$
	(b) m weber	$(4\pi)^{-1}10^{8}m^*$	$(1200\pi)^{-1}m$
Potential, electric	V volt	$10^{8}V$	$(300)^{-1}V^*$
Potential, vector	(a) $\mathbf{A}$ gauss-cm	$\mathbf{A}^*$	$3^{-1}10^{-10}\mathbf{A}$
	(b) $\mathbf{A}$ weber/m	$10^{6}\mathbf{A}^*$	$3^{-1}10^{-4}\mathbf{A}$
Power	(a) P erg/sec	P	P
	(b) P watt	$10^{7}P$	$10^{7}P$
Reactance	X ohm	$10^{9}X$	$9^{-1}10^{-11}X^*$
Reluctance	(a) $\mathfrak{R}$ gilbert/max	$\mathfrak{R}^*$	$9 \times 10^{20}\mathfrak{R}$
	(b) $\mathfrak{R}$ amp-turn/weber	$4\pi 10^{-9}\mathfrak{R}^*$	$36\pi \times 10^{11}\mathfrak{R}$
Resistance	R ohm	$10^{9}R$	$9^{-1}10^{-11}R^*$
Resistivity, area	σ ohm	$10^{9}\sigma$	$9^{-1}10^{-11}\sigma^*$
Resistivity, volume	(a) ρ ohm-cm	$10^{9}\rho$	$9^{-1}10^{-11}\rho^*$
	(b) ρ ohm-m	$10^{11}\rho$	$9^{-1}10^{-9}\rho^*$