Medical Physics

VOLUME II

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PREFACE

THIS second volume of MEDICAL PHYSICS makes its appearance in an entirely different world from that which greeted the original work in the year before Hiroshima. The unleashing of atomic energy has affected every aspect of man's life and thought, but probably no field of learning has felt its impact more acutely and directly than medical physics. The stimulus of this development is being reflected in all areas of medical research, and consequently the field of medical physics has expanded more rapidly during the past five years than in all the preceding centuries. In 1944, when MEDICAL PHYSICS was first issued, only 200 of the 34 000 scientists listed in *American Men of Science* were designated as medical physicists or biophysicists. Today, it is estimated that, instead of 200 men, there are over 200 institutes or departments in universities, government agencies, private institutions and industry which are devoted to medical-physical and biophysical problems. In most of these, some research on the application of theories, methods and special physical instrumentation to practical medical problems is in progress. Many of these institutions carry out an educational program which ranges from occasional courses in special medical-physical problems to systematized courses in biophysics and even complete training of biophysicists.

These developments and the reception accorded the first volume of MEDICAL PHYSICS have more than corroborated the vision and justified the courage of the late H. A. Simons, who, as President of the Year Book Publishers, 10 years ago conceived the idea and initiated the effort that culminated in the appearance of the completed work in 1944. The unstinting co-operation of the authors who participated in that effort so far exceeded our first plans and expectations that the original volume was much larger and more comprehensive than had been contemplated. In turn, the fondest hopes of authors, editor and publishers have been greatly exceeded by the actual demand for and widespread use of this volume.

At the time of a second large reprinting in 1947, it was evident that a second edition was imperatively needed. Steps were then taken to revive the splendid co-operation of the authors who had participated in the preparation of the original volume for work on a revised second edition. The response on the part of the collaborators was, as in the case of the original volume, one of whole-hearted enthusiasm and extraordinary interest and effort. We had no idea when we embarked on the task of preparing a second edition that it would be possible to collect so much new and revised material of such outstanding excellence. During the process, it became apparent that if all the chapters, new and old, were to be printed in full, the book would have to be issued in several volumes. Because of soaring production costs, the publishers felt that this would not be at all feasible at this time. Hence, another solution of the problem became necessary and, after evaluation of several suggestions, it was decided to issue this volume as a complement and supplement to the first volume and to call it Volume II. Then, should there be need for further volumes, we could follow the same pattern.

The subjects in Volume II are arranged in alphabetical order, as in the original volume, with necessary changes in grouping and classification. In instances in which the chapter has been unchanged or not changed significantly in content, only the title is printed, with a reference to the complete article in the first volume. When the changes submitted consisted principally of additions, a page reference to the original article and the new additions are printed. Chapters which appeared in the original volume whose content has been significantly revised and those covering new subjects are printed in full. Thus this second volume of MEDICAL PHYSICS contains only new material to be added to or substituted for material in the original volume, without the repetition of subjects that remain essentially unchanged.

Even with this general scheme as a guide, some of the decisions regarding omission or inclusion of individual contributions have been difficult to make, and there no doubt will be some criticisms of the editor's judgment.

It must be thoroughly understood that the articles carried by title only are not represented as being up to date, but cover the status of the subject as of 1944. The supplements to some of the articles attempt to add the most significant developments since 1944. Unfortunately, stringent space restrictions did not permit inclusion of all such supplements that were prepared. In the final analysis of the material, the criteria for omission or inclusion had to be the adequacy of coverage in the first volume and the relative importance of the subject to medical physics as a whole.

No associate editors are listed for this volume, since valuable advice, suggestions and criticism were received from so many of the collaborating authors that it is fair to say that all of them were also associate editors. For additional space-saving, only the authors represented by complete chapters are listed in this volume. The list of authors whose work is not carried over in full from the original volume will be found on page vii of Volume I.

The editor is deeply indebted to Miss Jessie C. Tucker, who again gave invaluable assistance throughout the process of collecting the material and editing it, and to Mr. Barney Tautkins of the Cleveland Clinic, who executed the illustrative material.

Mr. Clarence M. Taylor, Executive Director of the Cleveland Clinic Foundation, generously put the resources of the Cleveland Clinic at our disposal. The editorial and production staffs of the Year Book Publishers were again of the greatest help in producing this volume. The Mack Printing Company co-operated most efficiently in the printing of the book. I wish to record my sincere thanks to everyone who collaborated in bringing this second volume of MEDICAL PHYSICS to issue.

OTTO GLASSER

January, 1950.

ABBREVIATIONS, UNITS, NORMAL CLINICAL VALUES

Abbreviations, Signs and Symbols*

Otto Glasser

ABBREVIATIONS

A	acceleration; activity; Ångström unit; atomic weight; mass number
a-c	alternating current
amp	ampere
amp-hr	ampere-hour
amu	atomic mass unit
antilog	antilogarithm
atm	atmosphere
at. no.	atomic number
at. wt.	atomic weight
avdp	avoirdupois
bar	barometer
Bé	degree Baumé
Bev	billion electron volts
Btu	British thermal unit
C	degree centigrade; capacitance
c	velocity of light; cycle; curie
ca	candle
Cal	large calorie (kilocalorie)
cal	calorie (gram)
centi-	prefix meaning $^1/_{100}$ or 10^{-2}
cg	centigram
cgs	centimeter-gram-second (system of units)
c-hr	candle-hour
cl	centiliter
cm	centimeter
cm^2	square centimeter
cm^3	cubic centimeter
const	constant
cos	cosine
cosec	cosecant
cot	cotangent
CP	chemically pure
cp	candlepower
c_p	specific heat at constant pressure
cpm	counts per minute
cps	cycle per second
csc	cosecant
Ctu	centigrade thermal unit
cu	cubic
cu cm	cubic centimeter
cu ft	cubic foot
cu in.	cubic inch
cu m	cubic meter
cu mm	cubic millimeter
cu μ	cubic micron
c_v	specific heat at constant volume
cyl ax	cylinder axis
D	density; diameter; diffusion constant; diopter; dioptric power
d	day; density; spacing of Bragg planes
db	decibel
d-c	direct current
deci-	prefix meaning $^1/_{10}$ or 10^{-1}
deg or °	degree
deka-	prefix meaning 10 or 10^1
dg	decigram
DL	difference limen
dl	deciliter
doz	dozen
DS	dioptric strength
E	electric tension; electromotive force
e	base of natural or Naperian system of logarithms; electronic charge
e^-	gamma-ray conversion electron
eH	oxidation-reduction potential
e/m	charge-to-mass ratio of the electron
emf	electromotive force
emu	electromagnetic unit
Eq	equivalent weight
esu	electrostatic unit
ET	effective temperature
ev	electron volt
F	degree Fahrenheit; faraday; frictional loss
f	farad; frequency
f-number (e.g., f-2, f2, f:2, f/2)	focal length of photographic lens divided by its diameter
fpm	feet per minute
fps	foot-pound-second (system of units)
Fr	french (unit of catheter lumen)
ft	foot
ft-c	foot-candle
ft-L	foot-Lambert
ft-lb	foot-pound

* The list of abbreviations is based on the American Standard Abbreviations for Scientific and Engineering Terms, approved by the American Standards Association. Essential features of the style are omission of periods following abbreviations, except when such abbreviations form a word; omission of the comma in numerals of 5 digits or more, e.g., 10 000, 1 000 000, and omission of the degree sign (°) in temperatures, e. g., 72 F, 35 C.

Fu	Finsen unit (for ultraviolet rays)
G	gravitation constant
g	gram
g	acceleration due to gravity
gamma	microgram
g-cal	gram-calorie
gal	gallon
giga-	prefix meaning 1 000 000 000 or 10^9
gpm	gallon per minute
gps	gallon per second
gr	grain
g r	gram roentgen
h	henry
h	Planck's quantum constant
hecto-	prefix meaning 100 or 10^2
hp	horsepower
hp-hr	horsepower-hour
hr	hour
hvl	half value layer
I	electric current
$_Z I^A$	symbol for isotope with atom number Z and atomic weight A
in.	inch
ips	inches per second
j	joule
K	degree Kelvin
K	orbital electron capture
kc	kilocycle
kcps	kilocycle per second
kev	kilo electron volt
kg	kilogram
kg-cal	kilogram-calorie
kg-m	kilogram-meter
kg per cu m	kilogram per cubic meter
kgps	kilogram per second
kilo-	prefix meaning 1000 or 10^3
kl	kiloliter
km	kilometer
kms	kilogram-meter-second (system of units)
kv	kilovolt
kvp	kilovolt peak
kw	kilowatt
kwhr	kilowatthour
L	Lambert
l	liter; lumen; length
λ, lambda	wavelength
λ_{eff}	effective wavelength
λ_{min}	minimum wavelength
lb	pound
lb per cu ft	pounds per cubic foot
Le	Lenard (unit for cathode rays)
l-hr	lumen-hour
lin ft	linear foot
ln (or $\log_e$)	natural or Naperian logarithm
log	common logarithm to the base of 10
lps	liter per second
lpw	lumen per watt
ly	langley (unit for sun's heating power)
M	molecular weight
M	atomic mass
m	meter; mass
m^2	square meter
m^3	cubic meter
ma	milliampere
mc	millicurie
mc-hr	millicurie-hour
mega-	prefix meaning 1000000 or 10^6
mel	unit of pitch
mEq	milliequivalent
Mev	million (or mega-) electron volts
mg	milligram
mg-hr	milligram-hour
mh	millihenry
mho	unit of electric conductance
micro-	prefix meaning $^1/_{1000000}$ or 10^{-6}
micromicro-	prefix meaning 10^{-12}
milli-	prefix meaning $^1/_{1000}$ or 10^{-3}
min	minute
m-kg	meter-kilogram
mks	meter-kilogram-second (system of units)
mL	millilambert
ml	milliliter
mM	millimolecular weight
mm	millimeter
mm^2	square millimeter
mm^3	cubic millimeter
mμ	millimicron
mol	gram molecule
mol. wt	molecular weight
mph	miles per hour
mr	milliroentgen
mrd	millirutherford
mrem	milliroentgen-equivalent-man (or mammal)
mrep	milliroentgen-equivalent-physical
mrhm	milliroentgen per hour at 1 meter
msec	millisecond
μ, mu	micron
μ^2	square micron
μ^3	cubic micron
μa	microampere
μc	microcurie
μf	microfarad
μg	microgram
μμ	micromicron
μμf	micromicrofarad
μr	microroentgen
μrd	microrutherford
μv	microvolt
μw	microwatt

μsec	microsecond
N	normal (solution)
N_0	Avogadro's number
NA	numerical aperture
ND	neutral density
n	index of refraction; neutron (unit for neutron rays)
ν, nu	frequency of radiant energy; unit of neutron dose
OD	oculus dexter or right eye
OS	oculus sinister or left eye
oz	ounce
P_{cc}	periscopic concave
P_{cx}	periscopic convex
PD	interpupillary distance
pH	hydrogen ion concentration
phon	loudness level
psi	pounds per square inch
Q	energy of nuclear reaction
qt	quart
R	degree Réaumur
r	roentgen (international unit for x-rays)
rd	rutherford
rem	roentgen-equivalent-man (or mammal)
rep	roentgen-equivalent-physical
r_γ	gamma roentgen
rhm	roentgen per hour at 1 meter
rms	root mean square
rpm	revolutions per minute
rps	revolutions per second
S	spherical
SE	spherical equivalent
sec	secant; second
SED	skin erythema dose
sigma	millisecond
sin	sine
sol.	solution
sone	loudness unit
sp gr	specific gravity
sp ht	specific heat
sq	square
sq cm	square centimeter
sq ft	square foot
sq in.	square inch
sq m	square meter
sq mm	square millimeter
sq μ	square micron
SR	sedimentation rate
T	temperature on absolute scale; half-life (radioactivity)
t	time; ton
tan	tangent
TED	threshold erythema dose
Ua	unit activity
v	volt
va	volt-ampere
w	watt
whr	watthour
X	unit for short-wave radiations
yr	year
Z	atomic number

Greek Alphabet

Greek		English	Meaning in Physics
alpha	Α	A	
	α	a	angle of optical rotation; angular acceleration; coefficient of thermal expansion; degree of dissociation into ions
beta	Β	B	
	β	b	coefficient of compressibility; flux density; specific heat constant
gamma	Γ	G	
	γ	g	conductivity; microgram; specific gravity; surface tension
delta	Δ	D	coefficient of diffusion; finite difference, increment; prism diopter
	δ	d	density; unit elongation; variation
epsilon	Ε	E	
	ε	e	base of natural system of logarithms; coefficient of extinction; dielectric constant; electrode potential; mean error
zeta	Ζ	Z	
	ζ	z	coordinates; impedance
eta	Η	Ē	
	η	ē	efficiency; viscosity
theta	Θ	Th	
	θ	th	angle (plane); angular phase displacement; Curie point; temperature in degrees above 0 C
iota	Ι	I	
	ι	i	
kappa	Κ	K	
	κ	k	dielectric constant; electric conductivity; Stefan-Boltzman constant; magnetic susceptibility; pair electrons
lambda	Λ	L	electric equivalent conductivity
	λ	l	microliter; radioactive decay constant; wavelength

Greek		English	Meaning in Physics
mu	M	M	
	μ	m	coefficient of absorption; coefficient of viscosity; index of refraction; micron; electric molecular conductivity; magnetic permeability; meson
nu	N	N	
	ν	n	frequency of radiant energy; kinematic viscosity; refractive efficiency
xi	Ξ	X	
	ξ	x	
omicron	O	O	
	o	o	
pi	Π	P	pressure
	π	p	ratio of circumference of a circle to diameter, or 3.14149265 . . . ; osmotic pressure
rho	P	Rh	
	ρ	rh	coefficient of reflection; refractive power; specific resistance; volume density
sigma	Σ	S	summation of
	σ	s	coefficient of scattering; current density; 1/1000 second; standard deviation; surface density; surface tension
tau	T	T	
	τ	t	time constant; temperature; photoelectrons
upsilon	Υ	Ŭ	
	υ	ŭ	
phi	Φ	Ph	magnetic flux; radiant flux
	φ	ph	angular phase difference; potential
chi	X	Kh	
	χ	kh	
psi	Ψ	Ps	dielectric flux; luminous flux; phase difference
	ψ	ps	electrostatic flux
omega	Ω	Ō	Ohm
	ω	ō	angular frequency; angular velocity

SIGNS AND SYMBOLS

$+$	plus; add; positive; convex
$-$	minus; subtract; negative; concave
$\pm$	plus or minus; positive or negative
$\times$ or $\cdot$	times; multiplied by
$\div$ or : or /	divided by
= or : :	equals; as
$\doteq$ or $\approx$	approximately equals
$\ne$ or $\neq$	does not equal
$\equiv$	identical, congruent, with
$\not\equiv$	not identical, congruent, with
$>$	greater than
$\ngtr$	not greater than
$<$	less than
$\nless$	not less than
$\geqq$	equal to or greater than
$\geqq$ or $\geqslant$ or $\geq$	greater than or equal to
$\leqq$	equal to or less than
$\leqq$ or $\leqslant$ or $\leq$	less than or equal to
$\gtreqless$	greater than, equal to or less than
:	ratio of
$\propto$	varies as
∞	infinite
!	factorial product (4! $1 \times 2 \times 3 \times 4$)
$\frown$	combined with
$\sqrt{a}$ or $a^{1/2}$	square root of a
$\sqrt[3]{a}$ or $a^{1/3}$	cube root or third root of a
$\sqrt[n]{a}$ or $a^{1/n}$	nth root of a
a^1	the first power of a: a
a^2	a square or the second power of a: $a \times a$
a^3	a cube or the third power of a: $a \times a \times a$
a^n	the nth power of a: $a \times a \times a \times a \times \ldots .$
a^{-1}	$\frac{1}{a}$
a^{-2}	$\frac{1}{a^2}$
a^{-n}	$\frac{1}{a^n}$
Σ	summation of
Δ	finite difference; increment; prism diopter
∇	centrad
Δx	increment of x
$f(x)$	function of x
dx	differential of x
$\frac{dy}{dx}$ or $f'(x)$	derivative of y with respect to x
y' or $\dot{y}$	derivative of y, ordinarily with respect to time
$\frac{d^2y}{dx^2}$ or f''	second derivative of y with respect to x
y'' or $\ddot{y}$	second derivative of y, ordinarily with respect to time
$\frac{\partial z}{\partial x}$ or $\frac{\delta z}{\delta x}$	partial derivative of z with respect to x
$\int$	integral of
$\int_b^a$	integral to be taken between the value b of the variable and its value a

Units and Conversion Factors

E. C. Crittenden

To record results of any measurement or quantitative observation, *units* of some kind must be used. Obviously, also, to make recorded results useful the magnitude of the units must be known. In exact scientific work, therefore, one of the first essentials is agreement on units which can be used and understood by all concerned. Each important field of scientific work has developed special units suitable for its own needs, but fortunately most of them are based on a common general system of mechanical units, the metric system, used throughout the world.

English-speaking countries, however, have retained also their own peculiar systems of units. These do not have so definite a basis as metric units; units of the same name do not always have exactly the same size in different countries; for some of them there are no authoritative definitions, so that exact values used depend on assumed conditions with regard to which there is some diversity of practice. In general, however, these inconsistencies are minor and need to be taken into account only for measurements of the highest accuracy.

Conversion factors furnished in this section have been calculated in accordance with practical usage for which there is good authority. Only in a few instances would the uncertainties mentioned in the definitions affect even the last digit of the values given.

Metric System

The metric system is based on standards of length, the meter, and of mass (or "weight"), the kilogram. The primary standards are deposited at the International Bureau of Weights and Measures located at Sèvres, France. Each important country has similar standards which have been compared with the primary or international prototypes. The earth serves as the standard for a third quantity, time, involved in defining some units. The second is taken as $1/86\,400$ of the mean solar day.

Larger and smaller units (except units of time) are derived from the basic ones in decimal steps, and names for them are formed with prefixes as follows:

Multiples		Sub-multiples	
Mega =	1 000 000	Deci =	0.1
Kilo =	1 000	Centi =	0.01
Hecto =	100	Milli =	0.001
Deka =	10	Micro =	0.000001

Meter.—The meter is defined as the distance between 2 specified lines on a particular bar of platinum-iridium at the International Bureau, when the bar is at the temperature of 0 C, at standard atmospheric pressure, and is supported at the 2 neutral points 28.5 cm from the center of the bar. (As an alternative, the meter may be taken as 1553164.13 wavelengths of light of a certain red line in the spectrum of cadmium.)

Kilogram.—Nominally the fundamental unit of mass should be the gram, but the actual fundamental standard is a cylinder of platinum-iridium at the International Bureau, the mass of which is taken as the kilogram.

TABLE 1.—Conversion Factors: Linear Measure

Unit	Mm	Cm	M	In.	Ft	Yd	Rods
1 millimeter (mm) =	1	0.1	0.001	0.03937	0.00328	0.00109	0.000199
1 centimeter (cm) =	10	1	0.01	0.3937	0.03281	0.01094	0.001988
1 meter (m) =	1000	100	1	39.37	3.28083	1.09361	0.198838
1 inch (in.) =	25.4	2.54	0.0254	1	0.08333	0.02778	0.005051
1 foot (ft) =	304.8	30.48	0.3048	12	1	0.33333	0.060606
1 yard (yd) =	914.4	91.44	0.9144	36	3	1	0.181818
1 rod =	5029.2	502.92	5.0292	198	16.5	5.5	1

TABLE 2.—Conversion Factors: Units Used for Micromeasurement and Wavelengths of Radiation

Unit	Mm	Microns	Millimicrons	Micromicrons	Angstroms	X-units
1 millimeter (mm) =	1	10^{3}	10^{6}	10^{9}	10^{7}	10^{10}
1 micron (μ) =	10^{-3}	1	10^{3}	10^{6}	10^{4}	10^{7}
1 millimicron ($m\mu$) =	10^{-6}	10^{-3}	1	10^{3}	10	10^{4}
1 micromicron ($\mu\mu$) =	10^{-9}	10^{-6}	10^{-3}	1	10^{-2}	10
1 Angstrom (A) =	10^{-7}	10^{-4}	0.1	10^{2}	1	10^{3}
1 X-unit (X) =	10^{-10}	10^{-7}	10^{-4}	0.1	10^{-3}	1

Note: More exactly, the X-unit (derived from spacing of atoms in the calcite crystal) equals 1.00202 times the values given in the bottom line of the table.

Liter.—The liter, the volume occupied by 1 kilogram of pure water at its temperature of maximum density and under standard atmospheric pressure, is the metric unit of capacity.

The gram was intended to be the mass of 1 cubic centimeter of water under these conditions. The liter would then be the same as the cubic decimeter, and 1 milliliter would equal 1 cubic centimeter. Experimental errors in establishing the original standards, however, made the milliliter slightly too large. It is equal to 1.000028 cu cm and the use of the name cubic centimeter ("cc") as synonymous with milliliter is not precisely correct.

Centimeter-Gram-Second System.—The centimeter-gram-second (cgs) system of units is a form of the metric system widely used in scientific work. It is made up by taking as a basis the 3 units named and making the defining equations of other physical quantities have a one-to-one relation, so far as possible.

Dyne.—The dyne, the cgs unit of force, is the force required to give a mass of 1 g an acceleration of 1 cm per second per second.

Erg.—The erg, the cgs unit of work or energy, is the work done when a force of 1 dyne acts a distance of 1 cm.

Meter-Kilogram-Second System.—The meter-

TABLE 3.—CONVERSION FACTORS: SQUARE MEASURE

UNIT	SQ MM	SQ CM	SQ M	SQ IN.	SQ FT	SQ YD	SQ RODS	ACRES
1 sq millimeter (sq mm) =	1	0.01	0.000001	0.00155	10.764×10^{-6}	1.196×10^{-6}	3.954×10^{-8}	2.471×10^{-10}
1 sq centimeter (sq cm) =	100	1	0.0001	0.155	10.764×10^{-4}	1.196×10^{-4}	3.954×10^{-6}	2.471×10^{-8}
1 sq meter (sq m) =	1 000 000	10 000	1	1 550	10.764	1.195985	3.954×10^{-2}	2.471×10^{-4}
1 sq inch =	645.16	6.45	0.000645	1	6.944×10^{-3}	7.716×10^{-4}	25.508×10^{-6}	15.942×10^{-8}
1 sq foot =	92 903	929.03	0.092903	144	1	0.111111	3.673×10^{-3}	2.296×10^{-5}
1 sq yard =	836 131	8 361.31	0.836131	1 296	9	1	33.058×10^{-3}	2.066×10^{-4}
1 sq rod =	$25\,293 \times 10^{3}$	252 930	25.293	39 204	272.25	30.25	1	6.25×10^{-3}
1 acre =	$40\,469 \times 10^{5}$	$40\,469 \times 10^{3}$	4046.9	6 272 640	43 560	4840	160	1

NOTE: The *barn*, which is equal to 10^{-24} sq cm, is a unit of area used in stating the effective cross-section of atoms.

TABLE 4.—CONVERSION FACTORS: VOLUMES

UNIT	CU MM	CU CM	CU M	CU IN.	CU FT	CU YD
1 cubic millimeter (cu mm) =	1	10^{-3}	10^{-9}	6.1023×10^{-5}	3.5314×10^{-8}	1.30794×10^{-9}
1 cubic centimeter (cu cm) =	10^{3}	1	10^{-6}	6.1023×10^{-2}	3.5314×10^{-5}	1.30794×10^{-6}
1 cubic meter (cu m) =	10^{9}	10^{6}	1	61 023.4	35.314	1.30794
1 cubic inch (cu in.) =	16 387	16.387	16.387×10^{-6}	1	5.787×10^{-4}	2.1433×10^{-5}
1 cubic foot (cu ft) =	$28\,317 \times 10^{3}$	28 317	0.028317	1728	1	3.7037×10^{-2}
1 cubic yard (cu yd) =	$764\,559 \times 10^{3}$	764 559	0.764559	46 656	27	1

TABLE 5.—CONVERSION FACTORS: CAPACITY (LIQUID MEASURE)

UNIT	ML	L	MINIMS	FL DR	FL OZ	GILLS	PT	QT	GAL
1 milliliter (ml) =	1	0.001	16.231	0.27052	0.033815	0.008454	0.002113	0.001057	0.000264
1 liter (l) =	1000	1	16 231	270.52	33.815	8.454	2.1134	1.0567	0.26418
1 minim =	0.0616	0.0000616	1	0.01667	0.002083	0.000521	0.000130	0.000065	0.000016
1 fluid dram (fl dr) =	3.697	0.003697	60	1	0.125	0.03125	0.007812	0.003906	0.000977
1 fluid ounce (fl oz) =	29.57	0.02957	480	8	1	0.25	0.0625	0.03125	0.007812
1 gill =	118.29	0.11829	1920	32	4	1	0.25	0.125	0.03125
1 pint (pt) =	473.17	0.47317	7680	128	16	4	1	0.5	0.125
1 quart (qt) =	946.33	0.94633	15 360	256	32	8	2	1	0.25
1 gallon (gal) =	3785.33	3.78533	61 440	1024	128	32	8	4	1

NOTE: One milliliter is approximately 1 cubic centimeter; 1 ml = 1.000028 cu cm.

TABLE 6.—CONVERSION FACTORS: MASS (WEIGHT), METRIC AND AVOIRDUPOIS

UNIT	MG	G	KG	GRAINS	DR	OZ	LB
1 milligram (mg) =	1	0.001	0.000001	0.015432	0.000564	0.000035274	0.000002205
1 gram (g) =	1 000	1	0.001	15.432	0.564383	0.035274	0.002204622
1 kilogram (kg) =	1 000 000	1000	1	15 432	564.383	35.274	2.204622
1 grain =	64.8	0.0648	0.0000648	1	0.036571	0.0022857	0.000142857
1 dram (dr) =	1 771.8	1.7718	0.0017718	27.344	1	0.0625	0.00390625
1 ounce (oz) =	28 349.5	28.3495	0.0283495	437.5	16	1	0.0625
1 pound (lb) =	453 592.4	453.5924	0 4535924	7000	256	16	1

NOTE: For the microgram, 0.000001 gram, the name gamma (symbol γ) is sometimes used.

TABLE 7.—CONVERSION FACTORS: MASS (WEIGHT), METRIC AND APOTHECARIES'

UNIT	MG	G	KG	GRAINS	SCRUPLES	DR	OZ	LB
1 milligram (mg) =	1	0.001	0.000001	0.015432	0.000772	0.000257	0.00003215	0.000002679
1 gram (g) =	1 000	1	0.001	15.432	0.7716	0.2572	0.03215	0.002679
1 kilogram (kg) =	1 000 000	1000	1	15 432	771.6	257.2	32.15	2.679228
1 grain =	64.8	0.0648	0.0000648	1	0.05	0.01667	0.002083	0.0001736
1 scruple =	1 296	1.296	0.001296	20	1	0.33333	0.04167	0.003472
1 dram (dr) =	3 888	3.888	0.003888	60	3	1	0.125	0.010417
1 ounce (oz) =	31 103	31.103	0.031103	480	24	8	1	0.083333
1 pound (lb) =	373 242	373.242	0.373242	5 760	288	96	12	1

kilogram-second (mks) system of units is similar to the cgs system, but larger basic units are used as indicated by the name, so that the derived units are in general much larger than the corresponding cgs units.

NEWTON.—The newton, the mks unit of force, is the force required to give a mass of 1 kg an acceleration of 1 m per second per second. It is equal to 10^5 dynes.

JOULE.—The joule, the mks unit of work or energy, is the work done when a force of one newton acts for a distance of 1 m. The joule is equal to 10^7 ergs.

WATT.—The watt, the mks unit of power, is the power required to do work at the rate of one joule per second or 10^7 ergs per second.

UNITED STATES CUSTOMARY UNITS

The mechanical units commonly used in the United States were never definitely established by statute. However, relations between those units and the metric units were specified by law in 1866, and precise values of the customary units have been established in accordance with that law.

Yard.—The United States yard is taken as $^{3600}/_{3937}$ m. This makes the inch equal to 25.40005 mm. For most purposes, however, the simpler relation, 1 in. = 25.4 mm, is used. This is equivalent to taking the yard as 0.9144 m, or the foot as 30.48 cm.

Pound.—The United States avoirdupois pound is taken as 453.5924277 g.

Gallon.—The United States gallon contains 231 cu in. Other units of liquid capacity are derived from the gallon.

Bushel.—The United States bushel contains 2150.42 cu in. Other units of dry measure are derived from the bushel.

Foot-pound.—The foot-pound is a unit of work, or of energy, equal to the work done in lifting 1 lb 1 ft vertically. Its exact magnitude depends on the value of the gravitational force, which is somewhat different at different places.

Horsepower.—The horsepower is a unit of power defined as the ability to do 550 ft-lb of work per second.

ELECTRICAL UNITS

Many different systems of electrical units have been proposed, but only 3 have been extensively used. These are the cgs electromagnetic, the cgs electrostatic and the ordinary practical, or mks, system. In all these systems, the magnitudes of the units are fixed by using accepted laws or equations which represent relations between the electrical and magnetic quantities and mechanical forces or movements. In these equations it is necessary to use constants which may be considered as representing electrical and magnetic properties of space. These properties have a definite relation to each other. Consequently, in defining a system of units one may choose simple constants for one of the properties but cannot do so for both.

Cgs Electromagnetic System.—The cgs electromagnetic system of units is derived from the 3 fundamental mechanical units, centimeter, gram and second, by taking the magnetic permeability of space as unity, i.e., by making the constant μ_0 (permeability for empty space) equal to 1 wherever it occurs in the electromagnetic equations.

Cgs Electrostatic System.—The cgs electrostatic system of units is derived from the centimeter, gram and second by taking the dielectric constant of space as unity. No specific names have been generally adopted for the various units of the 2 cgs systems, but an accepted practice is to form names from those of the practical system by adding the prefix "ab" for cgs electromagnetic units and "stat" for cgs electrostatic units.

TABLE 8.—CONVERSION FACTORS: FLOW RATES

UNIT	GAL/HR	CU FT/HR	ML/SEC	L/MIN
1 gallon per hour (gal/hr) =	1	0.1337	1.051	0.0631
1 cubic foot per hour (cu ft/hr) =	7.48	1	7.866	0.4719
1 milliliter per second (ml/sec) =	0.951	0.1271	1	0.0600
1 liter per minute (l/min) =	15.85	2.119	16.667	1

Practical (Mks) Electrical Units.—The name "practical" has been commonly used for a system of units (*ampere, volt, ohm,* etc.) which are decimal multiples of the cgs electromagnetic units and are of more convenient magnitude for ordinary use. It happens also that these practical electrical units, together with the mks units of force, energy and power (newton, joule and watt), fit into a complete system. This is similar to the cgs electromagnetic system, except that, as basic mechanical units, the meter, kilogram and second are used and the value assigned to the permeability of space is 10^{-7} instead of 1. Being derived from fundamental units and principles these units are also called *absolute*.

TABLE 9.—CONVERSION FACTORS: ELECTRICAL UNITS OF 3 SYSTEMS

PRACTICAL UNIT	VALUE OF PRACTICAL UNIT EXPRESSED IN	
	Cgs Electromagnetic Units	Cgs Electrostatic Units
1 ampere (amp) =	0.1 abampere	3×10^9 statamperes
1 volt (v) =	10^8 abvolts	$1/300$ statvolt
1 ohm =	10^9 abohms	$1/(9 \times 10^{11})$ statohm
1 coulomb =	0.1 abcoulomb	3×10^9 statcoulombs
1 farad (f) =	10^{-9} abfarad	9×10^{11} statfarads
1 henry (h) =	10^9 abhenries	$1/(9 \times 10^{11})$ stathenry
1 joule (j) =	10^7 ergs	10^7 ergs
1 watt (w) =	10^7 ergs per sec	10^7 ergs per sec

NOTE: The values are for the absolute "practical" units. Those involving the factors 3 and 9 are approximate. More exactly these factors are 2.99776 and $(2.99776)^2$. The ratio of the 2 cgs units of current is equal to the velocity of light in vacuum in cm per second, which is approximately 3×10^{10} (or more exactly 2.99776×10^{10}) cm per second.

Definitions of electrical units may be set up on the basis of various interrelations with the mechanical units. The following set of illustrative definitions has been proposed by the International Committee on Weights and Measures.

AMPERE.—The ampere is an electric current of such magnitude that when maintained in 2 straight parallel conductors of infinite length and of negligible cross-section, at a distance of 1 m from each other in vacuum, it would produce between the conductors a force of 2×10^{-7} newtons per meter of their length.

VOLT.—The volt is the difference of electrical potential between 2 points in a conductor carrying a constant current of 1 amp when the power dissipated between these points is 1 w.

OHM.—The ohm is the electrical resistance between 2 points of a conductor when a constant difference of potential of 1 v maintained between these points produces a current of 1 amp in the conductor, provided that no source of electromotive force is included.

COULOMB.—The coulomb is the quantity of electricity transported in 1 sec across any cross-section of a circuit by a current of 1 amp.

FARAD.—The farad is the capacitance of an electric condenser in which a charge of 1 coulomb produces a difference of potential of 1 v.

HENRY.—The henry is the inductance of a circuit in which an electromotive force of 1 v is produced when an electric current in the circuit changes uniformly at the rate of 1 amp per second, or the inductance between 2 circuits when a uniform change of 1 amp per second in one of them produces an electromotive force of 1 v in the other.

WATT.—From the above definitions it follows that the power required to maintain a current of 1 amp through a resistance of 1 ohm is 1 watt.

KILOWATT.—The kilowatt is 1000 watts.

KILOWATTHOUR.—The kilowatthour is the energy supplied when a power of 1 kw is used for 1 hr.

FARADAY.—The faraday, also called faraday constant, may be considered a subsidiary unit of electric charge. It is the quantity of electricity carried in electrolysis by 1 gram-equivalent of an element. Its value is somewhat doubtful but is approximately 96 500 coulombs per gram-equivalent.

Reference Standards.—In actual practice the magnitudes of the electrical units have been established by using (1) current balances for weighing the forces exerted between coils carrying measured currents, and (2) coils of which the inductance can be calculated from mechanical dimensions. The basic units for which these 2 kinds of apparatus give values are the ampere and the henry; for convenience in regular use, however, values of the ohm and the volt, derived from these basic units, are preserved by resistance coils and standard cells. The national standardizing laboratories of various countries maintain groups of such reference standards and calibrate standards and instruments for other laboratories and for manufacturers of instruments.

UNITS OF HEAT AND OF LIGHT

Units of Heat.—Because water is a most convenient substance to use in measuring or comparing quantities of heat it has long been customary to define units of heat by reference to the rise in temperature of a mass of water. The calorie and British thermal unit are the common units.

CALORIE.—The calorie is the amount of heat required to raise the temperature of 1 gram of water 1 cen-