# Medical Physics

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### PREFACE

Instrumental or mechanical science is the noblest and above all others the most useful, seeing that by means of it all animated bodies which have movement perform all their actions.

> -Leonardo da Vinci, in Sul Volo degli Uccelli (circa 1500).

MEDICAL PHYSICS is commonly regarded as a new branch of medicine. Many discoveries of fundamental physical phenomena in recent decades, combined with extraordinary developments of earlier discoveries, and successful application of numerous basic principles of physics in medical practice have fostered the notion that medical physics is a distinctive achievement of the twentieth century. That impression is not quite accurate. Although recent developments have led to a steadily increasing recognition of physics as one of the essential substructures of modern medicine, the fact is that progress in biology and medicine has always been significantly related to advances in physics. Before there could be any scientific bacteriology or pathology, there had to be a microscope to reveal the existence of micro-organisms and the structure of tissues. The science of physiology began with Harvey, who was the first to apply systematic measurements in biologic investigations and to attempt to correlate biologic phenomena with physical laws. Fundamental knowledge of blood pressure was dependent on development of suitable manometers, and many facts about the heart and circulation of the blood could not have been learned without the microscope, string galvanometer, stethoscope and roentgen rays. In short, physics has supplied instruments and methods of measurement that have led to many discoveries in physiology and medicine, and the methods of physical research have revolutionized many of the older approaches to the biologic sciences.

These facts have always been recognized to some extent. Evidence of that is furnished by such volumes as the able *Medizinische Physik*, by A. Fick of Zürich, published in 1856 by Vieweg of Braunschweig, or F. J. Brockway's *Essentials of Medical Physics*, one of the Saunders question-compends, published in 1891. The enthusiastic reception accorded by the medical profession all over the world to Röntgen's discovery of the x-rays in 1895 and the subsequent evolution of medical radiology vividly illustrate the close interrelationship between physics and medicine.

Yet the literature of medical physics as such has not kept pace with the expansion of the subject matter. Or perhaps it would be more precise to say that the literature has not been able to extricate itself from the established conventions of publication in medicine and the allied sciences, and to assert itself as a distinct entity, easily accessible to all physicians and surgeons who try to keep abreast of the advances that ultimately affect the welfare of their patients. Numerous physicists have interested themselves in the application of their researches to medicine, and many biologists, physiologists, clinicians and surgeons have studied the physical principles underlying their particular problems. The reports of such workers are scattered throughout the literature of physics and of medicine. Recently, more and more attempts have

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been made to concentrate such publications in special journals and books on biophysics. Yet most of these efforts have dealt with only limited aspects of medical physics; and no attempt seems to have been made to unify all the diverse information involved in a form useful alike to practitioners of medicine and physicists.

Twenty years ago I began to collect material bearing on the specialty of radiology alone, with the plan of organizing it as an encyclopedia. Numerous difficulties frustrated that plan. When it is recalled that the dosage unit for roentgen rays, the roentgen, was not internationally adopted until 1937, the nature of some of the difficulties will be appreciated. Thus, only the gist of that earlier idea eventually emerged in the volume, The Science of Radiology, written by twenty-seven authorities under my editorship and published by Charles C Thomas under the auspices of the American Congress of Radiology in 1934. But some of the groundwork of that project

remained as a point of departure for the present effort.

It took the vision and the courage of Mr. H. A. Simons, president of the Year Book Publishers, Inc., to see the need for a presentation of the subject matter of medical physics as a whole, and he and his associates provided the means and the enthusiasm necessary to realize the conception. Their first idea was to produce a small manual that would serve as a reference work for physicians and others dealing with medical physics. Later it was recognized that, because of the nature of the subject matter and its present status, the original proposal was inadequate. A mere assemblage of working formulas, unsupported by exposition of underlying principles, would be of limited use. It would not meet the fundamental need for a unified demonstration of the place of physics in medical practice. And it would leave untouched the requirement for a single text and reference book for teachers and students of medicine.

Out of these considerations evolved the final conception which this book attempts to embody: a combination of an encyclopedia, sufficiently comprehensive to serve as a reference for all those whose occupations involve any aspect of medical physics; a textbook, adequately detailed in exposition to serve students; and a working instrument. in which may be found the data necessary for actual application of the principles of physics to medicine. Readers will undoubtedly discover that this volume falls short of the attainment of that ideal. Though the work was not undertaken without some trepidation, unanticipated difficulties have been encountered during its progress. Many medical subjects naturally overlap each other, and in some instances proper classification has not been easy. Problems of straying too far afield into neighboring subjects, such as biochemistry, have arisen repeatedly. In the collection of material from many sources, as the scope of the undertaking required, it has been inevitable that, despite all efforts to eliminate them, some duplications, omissions and inconsistencies should have occurred. The approaches of various authors to their respective topics varied, of course; and it has been impossible to present all subjects with the same degree of detail. An earnest attempt has been made to compensate for some of these shortcomings by correlating the material as completely as possible in the index, which it is hoped will prove satisfactory for guiding the reader to the data in which he is particularly interested.

One of the principal inspirations sustaining the efforts of editorship has been that the subject grew to unexpected proportions during the progress of the work. A second, and indeed greater, inspiration has derived from the readiness of the authors to collabo-

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rate and the excellence of their contributions. Planning of the book and discussions of its organization began in April, 1940. Invitations to contributors were issued in that year, and the first manuscripts were received early in 1941—though the last of them were not completed until October, 1943. War conditions required some alterations of the original plans, notably in regard to aviation medicine, biologic effects of high and low pressures, and some new electronic devices that may play important rôles in medicine. Among those invited to participate, enthusiasm for the program of comprehensively presenting the relation of physical principles to medical diagnosis and therapy was remarkable from the beginning. No praise would be excessive of the loyal work of the authors who, often despite serious obstacles created by the war, executed their commitments. Because of their conscientious co-operation, an astonishingly small number of the articles originally planned (on such subjects as anesthesia, fractures, physical biochemistry, physical factors in psychologic measurements, plastic surgery and speech correction) were not finally received.

The enthusiasm and generosity of the collaborating authors have been matched by similar qualities in the associate editors. Their help has been of inestimable value in the collection and organization of material and in many other phases of the work, but they cannot be held responsible for possible errors of omission or commission in their respective departments. The exigencies of publication, especially under the conditions of war, inhibited their freedom in attending to details of their parts of the book, so that final responsibility for possible shortcomings rests with the editor-

in-chief.

Miss Jessie C. Tucker, assistant editor, also gave invaluable assistance throughout the process of collecting the material, organizing, editing and indexing it. Without her faithful co-operation this book could not have been brought to issue.

Mr. Edward C. Daoust, president of the Cleveland Clinic Foundation, generously put the resources of the Cleveland Clinic at our disposal. Miss Bernardine Lufkin, research secretary of the Foundation, contributed valuable services to the work. Most of the drawings for the illustrations were executed by Mr. Bernard Tautkins of the Cleveland Clinic and Mr. Charles M. Jeffries of the Victoreen Instrument

Company.

The editorial and production staffs of the Year Book Publishers, Inc., were invariably helpful in connection with numerous editorial and other problems. In particular, the work of Mr. Paul Perles, production manager, Mrs. Anabel Ireland Janssen, head of the editorial department, and Miss Jean Husted, chief proofreader, deserves grateful acknowledgment. A major contribution, in the solution of mechanical problems, was made by the Mack Printing Company; and I wish to record my sincere thanks to the heads of that company, the publishers and the Cleveland Clinic Foundation for the splendid co-operation of their respective organizations.

-OTTO GLASSER

# COMMENTS, ABBREVIATIONS, SYMBOLS

Organization.—Subjects in this book are arranged in alphabetical order. The editor recognizes that this may not be an ideal method of presenting the material, but no better system suggested itself. To facilitate search for any given subject, the following suggestions are offered:

The Table of Contents, in alphabetical order, may be found on pages xvii-xxii, and the Classified Tables of Contents on pages xxiii-xlii. The Subject Index begins on page 1729

References to literature beyond the scope of the original articles presented in this book are numbered in sequence in the articles, but arranged in alphabetical order according to authors at the end of the articles. Bibliographies are also arranged in alphabetical order according to authors at the end of the articles.

Cross-References to other articles appearing in this book are listed as (see Author); e.g. (see Trump) on page 28 refers to the article, Roentgen Rays: Supervoltage Generators, by John G. Trump, on page 1391.

Style.—Certain rules of style have been followed in an effort to achieve the greatest possible uniformity in material from such widely different sources.

Units and Conversion Factors.—These are furnished in the article of this title by E. C. Crittenden, on page 1596.

Abbreviations and Symbols.—A list of abbreviations is herewith presented. It 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, and omission of the comma in numerals of five digits or more, e.g., 10 000, 1 000 000, etc.

### ABBREVIATIONS

	ADDAL	VIATIONS	
A a-c amp amp-hr antilog atm at. no. at. wt. avdp	angstrom unit alternating current ampere ampere-hour antilogarithm atmosphere atomic number atomic weight avoirdupois	c-hr cl om cm² cm³ const cos cot	candle-hour centiliter centimeter square centimeter cubic centimeter constant cosine cotangent
bar Bé bev Btu C c ca cal centi- cg cgs	barometer degree Baumé billion electron volt British thermal unit  degree centigrade; capacitance velocity of light; cycle candle calorie (gram) prefix meaning 1/100 centigram centimeter-gram-second (system of units)	cp cp cps cps csc Ctu cu cu cm cu ft cu m cu mm cu μ cc cyl ex	chemically pure candlepower specific heat at constant pressure cycle per second cosecant centigrade thermal unit cubic cubic centimeter cubic foot cubic meter cubic millimeter cubic mieron specific heat at constant volume cylinder axis

### ABBREVIATIONS

dioptric power decided decibel decider	D	density; diffusion constant;	lionter:	keps	kilocycle per second
de- de- decidirect current decide of direct current decide of direct current decide of direct current decide of deci			nopuci,		
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degro deka- prefix meaning 10 decigram deciliter dose dosen DS dioptric strength  E electric tension base of natural or Naperian system of logarithms; charge of electron oxidation-reduction potential emn electromedite in potential emn electromagnetic unit esu electrostatic unit esu electrostatic unit effective temperature ev electron volt  F degree Fahrenheit f-2, 12, 12, 12, 12 f-number (e.g., f-2, 12, 12, 12 f-t-1 f-b foot-pound gram a ceeleration due to gravity gram gallon per minute prefix meaning 100 make helich horu hor hore prefix meaning 100 kms kiliorman per second (system of unita) prefix meaning 100 kms kiliorman per second kilioth kw kiliowath kur kiliowath kur liter; lumen lifer; lumen lifer; lumen lefectronoth later; lumen lifer; lumen lifer; lumen lifer; lumen lifer; lumen lofe offective wavelength liter; lumen lifer; lumen lifer; lumen lofe offective twavelength liter; lumen lifer; lumen lifer; lumen lofe offective twavelength lifer; lumen lifer; lumen lifer; lumen lofe offective twavelength lifer; lumen lifer; lumen lofe offective twavelength lifer; lumen lifer; lumen lofe offective twavelength lifer; lumen lofe offective twavele					
deks- dg decigram  deciliter dos dosen dl deciliter dos dosen dl deciliter dos dosen dloptrie strength  E electric tension e base of natural or Naperian system of logarithms; charge of electron eH oxidation-reduction potential esu electromative force emu electromative force eve electron volt electron volt for farad; frequency f-number (e.g., f-2, 12, f-2, f-2) fpm feet per minute fips foot-pound-second (system of units) ft foot ft-L foot-Lambert ft foot-pound ft-L foot-Lambert ft foot-pound ft-L foot-Lambert ft foot-pound ft-L foot-Lambert ft foot-pound gravitation constant gram g a acceleration due to gravity grain grain grain grain gallon per minute per second horsepower-hour herry hecto- herry herry horsepower-hour half value layer  H degree Kelvin  K degree Kelvin  M molar; molecular weight miner milliumper miner milliumper miner milliumper miner milliumper minitate miner minitate miner minitate miner minitate miner minitate miner minitate miner milliumper minitate					
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	tasper las			mμ	millimicron
ke kilocycle mph miles per hour	K	degree Kelvin		mol. wt	molecular weight
	ke .	kilocycle		mph	miles per hour

μ, inu	micron	rpm	revolutions per minute
μ2	square micron	rps	revolutions per second
μ3	cubic micron		
ha	microampere	S	spherical
μf	microfarad	SE	spherical equivalent
		sec	secant; second
Irtr	micromicrofarad	SED	skin erythema dose
μμί	microvolt	sin	sine
μν	microwatt	sol.	solution
μW	microsecond	sp gr	specific gravity
µsec .	niicrosecona	sp ht	specific heat
NA	numerical aperture	sq	square
ND	neutral density	sq cm	square centimeter
n	index of refraction; neutron (unit	sq ft	square foot
	for neutron rays)	sq in.	square inch
ν, nu	frequency of radiant energy	sq m	square meter
r, uu		sq mm	square millimeter
OD	oculus dexter or right eye	sq µ	square micron
OS	oculus sinister or left eye	SR	sedimentation rate
02	ounce		
		T	temperature on absolute scale
Pee	periscopic concave	t	time
Pes	periscopic convex	tan	tangent
PD	interpupillary distance	TED	threshold erythema dose
pH	hydrogen ion concentration		
psi	pounds per square inch	V	volt
	The state of the s	V8	volt-ampere
qt	quart		
SHANNER WAS	degree Réaumur; Solomon roentgen	W	watt
R		whr	watthour
	(unit for x-rays)		
r	roentgen (international unit for x-	X	unit for short-wave radiations
	rays)		appeter the same and the same a
rγ	gamma roentgen (unit for radium-	yr want or de	year
	gamma rays)	Z	atomic number
rms	root mean square	L	GOOTHIO HIGHSWAY
			The state of the s

### GREEK ALPHABET

GREEI	c	English	MEANING IN PHYSICS	GREEK		ENGLISH	Meaning in Physics
alpha	A	A		epsilon	E	E	4860 080 0
atpria	α	a	angle of optical rotation; angular acceleration; coefficient of		E	е	base of natural system of loga- rithms; coefficient of extinc- tion; dielectric constant; elec-
		Har were	thermal expansion; degree of dissociation into ions				trode potential; mean error
SUMMERS OF	-	D	TO ALL OFFICE STORE				
beta	В	В	coefficient of compressibility;	zeta	Z	Z.	and the second second second
	β	b	flux density; specific heat con-		3	Z	coordinates; impedance
			stant		7		
gamma	r	G	the light language of the 1890 of	eta	H	Ē	
	Y	g	conductivity; microgram; spe- cific gravity; surface tension		η	ē	efficiency; viscosity
			veria inita initali				
delta	Δ	D	coefficient of diffusion; finite dif- ference, increment; prism	theta	Θ	Th	on Sections 17
			diopter		0	th	angle (plane); angular phase dis-
30,1204 W/s	δ	d	density; unit elongation; varia-				placement; Curie point; tem- perature in degrees above 0 C

		4	3 / M	BOLS		
GREE	K	ENGBISH	MEANING IN PHYSICS	GREEN	K	English Meaning in Physics
iota	I	I		rho	P	Rh
	L	1			p	
kappa	K	K				coefficient of reflection; refractive power; specific resistance volume density
	Λ.	k	dielectric constant; electric con- ductivity; Stefan-Boltzman constant; magnetic suscepti-	sigma	Σ	S summation of
1 11			bility magnetic suscepti-		σ	s coefficient of scattering; current
lambda	λ	1 1	electric equivalent conductivity microliter; wavelength			density; 1/1000 second; standard deviation; surface density; surface tension
mu	M	M		tau	T	T
	μ	m	coefficient of absorption; coefficient of viscosity; index of re-		T	t time constant; temperature
			fraction; micron; electric molecular conductivity; mag-	upsilon	Y	Ů
nu	N	M	netic permeability		U	to Angelon and the second
nu .	ν	N n	fraintanas of -1	phi	Ф	Ph magnetic flux; radiant flux
			frequency of radiant energy; kinematic viscosity; refractive efficiency		9	ph angular phase difference; poten- tial
xi	7	X		ehi	X	Kh
	ξ	X			X	kh
omicron	0	0				
	0	0		psi	Ψ	Ps dielectric flux; luminous flux; phase difference
pi	11	n			4	ps electrostatic flux
þi	Π π	DISTRICT TO SELECT THE PARTY OF	pressure	omega	Ω	Ō Ohm
		P	ratio of circumference of a circle to diameter, or 3.14149265; osmotic pressure	· · · · · · · · · · · · · · · · · · ·	ω	Ohm angular frequency; angular ve-
						locity
			SYM	BOLS		
+			ld; positive; convex	a <sup>1</sup>		the first power of a:a
=k=		minus;	subtract; negative; concave	a²		a square or the second power of a:
× or			minus; positive or negative multiplied by	a3		a × a a cube or the third power of a:
+ or :		divided				$a \times a \times a$
= or:		equals;		an		the nth power of a:
= or		approxir	nately equals	Σ		a×a×a×
+ or	#	does not	equal	Δ		summation of finite difference; increment; prism
===			, congruent, with			diopter dinerence; increment; prism
×			tical, congruent, with	$\nabla$		centrad .
>		greater t		Δx		increment of x
<		not grea less than		f(x)		function of x
*		not less		dx		differential of x
5		equal to	or greater than	$\frac{\mathrm{d}y}{\mathrm{d}x}$ or $f'(x)$		derivative of y with respect to x
₹	or ≥	equal to	han or equal to or less than	y' or ý		derivative of y, ordinarily with respect to time
≦ or ≤	or <		han, equal to or less than	$\frac{d^2y}{dx^2}$ or f"		second derivative of y with respect to x
:		ratio of				
oc co		varies as infinite		y" or y		second derivative of y, ordinarily with respect to time
!			product (4! $1 \times 2 \times 3 \times 4$ )	δz δx		partial derivative of z with respect to x
√a or a	1/2	square ro		5		integral of
√a or a			or third root of a	ſa.		integral to be taken between the value
∜a or a	1/n	nth root		Jo		b of the variable and its value a

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