

*TEXTBOOK OF
MEDICAL
PHYSIOLOGY*

SEVENTH EDITION

Arthur C. Guyton, M.D.

TEXTBOOK OF **MEDICAL PHYSIOLOGY**

SEVENTH EDITION

Arthur C. Guyton, M.D.

Chairman and Professor
Department of Physiology and Biophysics
University of Mississippi School of Medicine



1986

W. B. SAUNDERS COMPANY

Philadelphia London Toronto Mexico City
Rio de Janeiro Sydney Tokyo Hong Kong

W. B. Saunders Company: West Washington Square
Philadelphia, PA 19105

Library of Congress Cataloging-in-Publication Data

Guyton, Arthur C.

Textbook of medical physiology.

Includes bibliographies and index.

1. Human physiology. I. Title. II. Title: Medical physiology. [DNLM: 1. Physiology. QT 104 G992t]

QP34.5.G9 1986 612 85-18294

ISBN 0-7216-1260-1

Listed here is the latest translated edition of this book together with the language of the translation and the publisher.

Japanese (4th Edition)—Kirokawa Publishing Company, Tokyo, Japan

Serbo-Croatian (4th Edition)—Medicinska Knjiga, Belgrade, Yugoslavia

Italian (4th Edition)—Piccin Editore, Padova, Italy

Spanish (6th Edition)—Nueva Editorial Interamericana S.A. de C.V., Mexico City, Mexico

Persian (5th Edition)—Sherkat Sahami "TCHEHR," Tehran, Iran

Portuguese (6th Edition)—Editora Interamericana Ltda.,
Rio de Janeiro, Brazil

Editor: Dana Dreibelbis

Designer: Karen O'Keefe

Production Manager: Bob Butler

Manuscript Editor: Wynette Kommer

Illustrator: Karen McGarry

Illustration Coordinator: Peg Shaw

Textbook of Medical Physiology

ISBN 0-7216-1260-1

© 1986 by W. B. Saunders Company. Copyright 1956, 1961, 1966, 1971, 1976 and 1981 by W. B. Saunders Company. Copyright under the Uniform Copyright Convention. Simultaneously published in Canada. All rights reserved. This book is protected by copyright. No part of it may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without written permission from the publisher. Made in the United States of America. Press of W. B. Saunders Company. Library of Congress catalog card number 85-18294.

Last digit is the print number: 9 8 7 6 5 4 3 2 1

Preface

When I wrote the first edition of this textbook, I had the naive belief that once the book was completed, subsequent revisions would require only simple changes. However, with each new edition I find that progress in the field of physiology is so rapid that large portions of the text must be completely recast and rewritten, and even the emphasis of the subject matter must often be changed as our knowledge becomes more penetrating. Therefore, the reader will find hardly a chapter in this edition that has not been significantly altered. Also, most of the figures have been either changed in at least some feature or replaced, and new ones have been added. Especially important, many of the figures have been redrawn simply to increase their clarity.

As has been true of most of the past revisions, the major change in this edition reflects a striking trend toward more fundamental physiology. The reason for this is mainly the greater success of the research physiologist in probing deeper into basic mechanisms of function, especially cellular and molecular mechanisms, than was true a few years ago. Yet I have attempted still to present physiology as an integrated study of the body's functional systems, utilizing the new fundamental knowledge to build a better understanding of the mechanisms upon which life depends.

Also a serious attempt has been made to devise and achieve techniques of expression that will help bring the physical and chemical principles of the body's complexities into the medical student's realm of understanding. In pursuit of this goal, I have kept records of those types of material with which the student has difficulty; I have quizzed students in detail to determine their levels of comprehension; and I have attempted to note inconsistencies in logic that might appear in student discussions. All these data have been used to help choose the material and methods of presentation. Thus, it has been my desire to make this book a "teaching" text as well as one that covers essentially all the basic physiology required of a student of medicine.

A special emphasis of the book is a more detailed attention than given in most other textbooks of physiology to the body's many control systems. These are the basis of what physiologists call *homeostasis*. The reason for this special emphasis is that most disease conditions of the body result from abnormal function of one or more of the control systems. Therefore, the student's comprehension of "medical" physiology depends perhaps more on a knowledge of these systems than on any other facet of physiology.

Another goal has been to make the text as accurate as possible. To help attain this, suggestions and critiques from many physiologists, students, and clinicians throughout the United States and other parts of the world have been received and utilized in checking the factual accuracy of the text. Yet, even so, because of the likelihood of error in sorting through many thousands of bits of information, I wish to issue an

invitation—in fact, much more than merely an invitation, actually a request—to all readers to send along notices of error or inaccuracy. Indeed, physiologists understand how important feedback is to proper function of the human body; so, too, is feedback equally important for progressive development of a textbook of medical physiology. I hope also that those many persons who have helped already will accept my sincerest appreciation for their efforts.

A word of explanation is needed about two features of the text—first, the references, and, second, the two print sizes. The references have been chosen primarily for their up-to-dateness and for the quality of their own bibliographies. Use of these references as well as of cross-references from them can give the student almost complete coverage of the entire field of physiology.

The print is set in two sizes. The material presented in small print is of several different kinds; first, anatomical, chemical, and other information that is needed for the immediate discussion but that most students will learn in more detail in other courses; second, information that is of special importance to certain clinical fields of medicine but that is not necessary to fundamental understanding of the body's basic physiologic mechanisms; and, third, information that will be of value to those students who wish to pursue a subject more deeply than the average medical student. In contrast, the material in large print constitutes the major bulk of physiological information that students will require in their medical studies and that they will not obtain in other courses. Those teachers who would like to present a limited course of physiology can direct students' study primarily to the large type.

Again, I wish to express my deepest appreciation to many others who have helped in the preparation of this book. I am particularly grateful to Ivadelle Osberg Heidke, Gwendolyn Robbins, and Elaine Steed-Davis for their excellent secretarial services, to Tomiko Mita for her superb work on new illustrations, and to Dana Dreibelbis, Wynette Kommer, Robert Butler, Margaret Shaw, and the staff of the W. B. Saunders Company for continued editorial and production excellence.

ARTHUR C. GUYTON

Contents

I INTRODUCTION TO PHYSIOLOGY: THE CELL AND GENERAL PHYSIOLOGY

1 FUNCTIONAL ORGANIZATION OF THE HUMAN BODY AND CONTROL OF THE "INTERNAL ENVIRONMENT"	2	Synthesis and Formation of Cellular Structures by the Endoplasmic Reticulum and the Golgi Apparatus.....	21
Cells as the Living Units of the Body.....	2	Extraction of Energy from Nutrients—Function of the Mitochondria.....	22
The Extracellular Fluid—The Internal Environment.....	2	Ameboid Locomotion of Cells.....	24
"Homeostatic" Mechanisms of the Major Functional Systems	3	Cilia and Ciliary Movements.....	25
Homeostasis	3		
The Extracellular Fluid Transport System—The Circulatory System.....	3	3 GENETIC CONTROL OF PROTEIN SYNTHESIS, CELL FUNCTION, AND CELL REPRODUCTION	27
Origin of Nutrients in the Extracellular Fluid	4	The Genes	27
Removal of Metabolic End-Products.....	4	The Genetic Code.....	28
Regulation of Body Functions.....	4	Ribonucleic Acid (RNA)—The Process of Transcription.....	29
Reproduction	5	Messenger RNA—The "Codons"	30
The Control Systems of the Body.....	5	Transfer RNA—The "Anticodons"	31
Examples of Control Mechanisms	5	Ribosomal RNA	31
Characteristics of Control Systems.....	5	Formation of Proteins on the Ribosomes—The Process of Translation	31
Automaticity of the Body.....	7	Synthesis of Other Substances in the Cell... ..	33
Appendix	7	Control of Genetic Function and Biochemical Activity in Cells	33
Basic Physical Principles of Control Systems.....	7	Genetic Regulation	33
		Control of Enzyme Activity	34
2 THE CELL AND ITS FUNCTION	11	Cell Reproduction.....	35
Organization of the Cell	11	Replication of the DNA.....	35
Physical Structure of the Cell.....	12	The Chromosomes and Their Replication	36
The Membranous Structures of the Cell.....	12	Mitosis.....	36
The Cytoplasm and Its Organelles	14	Control of Cell Growth and Reproduction	37
Comparison of the Animal Cell with Precellular Forms of Life	18	Cell Differentiation.....	37
Functional Systems of the Cell	19	Cancer	38
Ingestion by the Cell—Endocytosis.....	19		
Digestion of Foreign Substances in the Cell—Function of the Lysosomes	20		

II BLOOD CELLS, IMMUNITY, AND BLOOD CLOTTING

4 RED BLOOD CELLS, ANEMIA, AND POLYCYTHEMIA.....	42	Formation of Hemoglobin.....	46
The Red Blood Cells.....	42	Iron Metabolism	46
Production of Red Blood Cells.....	42	Destruction of Red Blood Cells.....	48
		The Anemias	48

Effects of Anemia on the Circulatory System	49	O-A-B Blood Groups	70
Polycythemia	49	The A and B Antigens—Called “Agglutinogens”	70
Effect of Polycythemia on the Circulatory System	49	The Agglutinins	71
5 RESISTANCE OF THE BODY TO INFECTION—THE LEUKOCYTES, THE MACROPHAGE SYSTEM, AND INFLAMMATION	51	The Agglutination Process in Transfusion Reactions	71
The Leukocytes (White Blood Cells)	51	Blood Typing	72
General Characteristics of Leukocytes	51	The Rh Blood Types	72
Genesis of the Leukocytes	52	The Rh Immune Response	72
Life Span of the White Blood Cells	52	Other Blood Factors	73
Properties of Neutrophils, Monocytes, and Macrophages	53	Transfusion	73
The Tissue Macrophage System (The Reticuloendothelial System)	54	Transfusion Reactions Resulting from Mismatched Blood Groups	73
Inflammation and Function of Neutrophils and Macrophages	56	Transplantation of Tissues and Organs	74
The Process of Inflammation	56	Attempts to Overcome the Antigen-Antibody Reactions in Transplanted Tissue	74
Neutrophilia Caused by Conditions Other Than Inflammation	57	8 HEMOSTASIS AND BLOOD COAGULATION	76
The Eosinophils	57	Events in Hemostasis	76
The Basophils	58	Vascular Spasm	76
Agranulocytosis	58	Formation of the Platelet Plug	76
The Leukemias	58	Blood Coagulation in the Ruptured Vessel	77
Effects of Leukemia on the Body	59	Fibrous Organization or Dissolution of the Blood Clot	77
6 IMMUNITY AND ALLERGY	60	Mechanism of Blood Coagulation	77
Innate Immunity	60	Conversion of Prothrombin to Thrombin	78
Acquired Immunity	60	Conversion of Fibrinogen to Fibrin—Formation of the Clot	78
Two Basic Types of Acquired Immunity	60	The Vicious Circle of Clot Formation ...	79
Antigens	60	Block of Clot Growth by Blood Flow ...	79
Role of Lymphoid Tissue in Acquired Immunity	61	Initiation of Coagulation: Formation of Prothrombin Activator	79
Preprocessing of the T and B Lymphocytes	61	Prevention of Blood Clotting in the Normal Vascular System—The Intravascular Anticoagulants	82
Specificity of Antibodies and T Lymphocytes—Role of Lymphocyte Clones	62	Lysis of Blood Clots—Plasmin	82
Origin of the Many Clones of Lymphocytes	62	Conditions That Cause Excessive Bleeding in Human Beings	83
Specific Attributes of the B Lymphocyte System—Humoral Immunity and the Antibodies	63	Decreased Prothrombin, Factor VII, Factor IX, and Factor X Caused by Vitamin K Deficiency	83
Special Attributes of the T Lymphocyte System—Activated Cells and “Cell-Mediated Immunity”	65	Hemophilia	83
Vaccination	67	Thrombocytopenia	83
Passive Immunity	67	Thromboembolic Conditions in the Human Being	84
Allergy	67	Femoral Thrombosis and Massive Pulmonary Embolism	84
An Allergy That Occurs in Normal People: Delayed-Reaction Allergy	68	Disseminated Intravascular Clotting ...	84
Allergies in the “Allergic” Person	68	Anticoagulants for Clinical Use	85
7 BLOOD GROUPS; TRANSFUSION; TISSUE AND ORGAN TRANSPLANTATION	70	Heparin as an Intravenous Anticoagulant	85
Antigenicity and Immune Reactions of Blood	70	Coumarins as Anticoagulants	85
		Prevention of Blood Coagulation Outside the Body	85
		Blood Coagulation Tests	85
		Bleeding Time	85
		Clotting Time	85
		Prothrombin Time	86

III—MEMBRANE PHYSIOLOGY, NERVE, AND MUSCLE**87**

9 TRANSPORT THROUGH THE CELL	Physiologic Anatomy of Skeletal Muscle ..	120
MEMBRANE.....	The Skeletal Muscle Fiber	120
Diffusion.....	Molecular Mechanism of Muscle	
Diffusion Through the Cell Membrane.....	Contraction	122
Net Diffusion Through the Protein	Molecular Characteristics of the	
Channels of the Cell Membrane and	Contractile Filaments	122
Factors That Affect It.....	Degree of Actin and Myosin Filament	
Osmosis Across Selectively Permeable	Overlap—Effect on Tension	
Membranes—Net Diffusion of Water... ..	Developed by the Contracting	
Active Transport.....	Muscle	125
Basic Mechanism of Active Transport..	Relation of Velocity of Contraction to	
Secondary Active Transport: Sodium	Load	126
“Cotransport” of Glucose and Amino	Initiation of Muscle Contraction:	
Acids	Excitation-Contraction Coupling	126
Active Transport Through Cellular	The Muscle Action Potential.....	127
Sheets	Release of Calcium Ions by the	
	Sarcoplasmic Reticulum	127
10 MEMBRANE POTENTIALS AND	The Source of Energy for Muscle	
ACTION POTENTIALS.....	Contraction	129
Basic Physics of Membrane Potentials	Characteristics of a Single Muscle	
Membrane Potentials Caused by	Twitch	130
Diffusion	Mechanics of Skeletal Muscle	
Membrane Potentials Caused by	Contraction	131
Active Transport—The Sodium-	The Motor Unit.....	131
Potassium “Electrogenic Pump”.....	Summation of Muscle Contraction	131
Measuring the Membrane Potential ..	Skeletal Muscle Tone.....	132
The Cell Membrane as an Electrical	Muscle Fatigue	133
Capacitor.....	The Lever Systems of the Body.....	133
The Resting Membrane Potential of	Special Features and Abnormalities of	
Nerves	Skeletal Muscle Function	133
Origin of the Normal Resting	Muscle Hypertrophy	133
Membrane Potential	Muscle Atrophy.....	134
The Nerve Action Potential.....	Prevention of Muscle Atrophy by	
The Voltage-Gated Sodium and	Electrical Stimulation	134
Potassium Channels	Physical Contracture of Muscle	
Summary of the Events That Cause	Following Denervation	134
the Action Potential	Rigor Mortis	134
Roles of Other Ions During the	Familial Periodic Paralysis	134
Action Potential	The Electromyogram.....	134
Initiation of the Action Potential.....		
Propagation of the Action Potential	12 NEUROMUSCULAR TRANSMISSION;	
“Recharging” the Fiber Membrane After	FUNCTION OF SMOOTH MUSCLE.....	136
Action Potentials—Importance of Energy	Transmission of Impulses from Nerves to	
Metabolism.....	Skeletal Muscle Fibers: The	
The Spike Potential and the After-	Neuromuscular Junction	136
Potentials	Myasthenia Gravis.....	139
Plateau in Some Action Potentials.....	Contraction of Smooth Muscle.....	139
Rhythmicity of Certain Excitable	Types of Smooth Muscle.....	139
Tissues—Repetitive Discharge.....	The Contractile Process in Smooth	
Special Aspects of Signal Transmission in	Muscle	140
Nerve Trunks.....	Membrane Potentials and Action	
Velocity of Conduction in Nerve	Potentials in Smooth Muscle.....	141
Fibers.....	Excitation-Contraction Coupling—	
Excitation—The Process of Eliciting the	Role of Calcium Ions.....	143
Action Potential.....	Neuromuscular Junctions of Smooth	
Inhibition of Excitability—	Muscle	144
“Stabilizers” and Local Anesthetics... ..	Smooth Muscle Contraction Without	
Recording Membrane Potentials and	Action Potentials—Effect of Local	
Action Potentials.....	Tissue Factors and Hormones	145
	Mechanical Characteristics of Smooth	
11 CONTRACTION OF SKELETAL	Muscle Contraction	146
MUSCLE.....		

IV THE HEART

149

13 HEART MUSCLE; THE HEART AS A PUMP	150	Control of Heart Rhythmicity and Conduction by the Autonomic Nerves	170
Physiology of Cardiac Muscle	150	Abnormal Rhythms of the Heart	171
Physiologic Anatomy of Cardiac Muscle	150	Heart Block	171
Action Potentials in Cardiac Muscle	151	The Phenomenon of "Re-Entry" and Abnormal Rhythms	172
Contraction of Cardiac Muscle	152	Premature Contraction—Ectopic Foci	175
The Cardiac Cycle	153	Cardiac Tachycardias	175
Systole and Diastole	153	Cardiac Arrest	175
Relationship of the Electrocardiogram to the Cardiac Cycle	154		
Function of the Ventricles as Pumps	155	15 THE NORMAL ELECTROCARDIOGRAM	177
Function of the Valves	155	Characteristics of the Normal Electrocardiogram	177
The Aortic Pressure Curve	156	Depolarization Waves Versus Repolarization Waves	177
Relationship of the Heart Sounds to Heart Pumping	156	Relationship of Atrial and Ventricular Contraction to the Waves of the Electrocardiogram	178
Work Output of the Heart	157	Voltage and Time Calibration of the Electrocardiogram	178
Energy for Cardiac Contraction	157	Methods for Recording Electrocardiograms	179
Regulation of Cardiac Function	157	The Pen Recorder	179
Intrinsic Regulation of Cardiac Pumping—The Frank-Starling Law of the Heart	157	Recording Electrocardiograms with the Oscilloscope	179
Control of the Heart by Parasympathetic and Sympathetic Nerves	160	Flow of Current Around the Heart During the Cardiac Cycle	179
Effect of Heart Debility on Cardiac Function—The Hypoeffective Heart	161	Recording Electrical Potentials from a Partially Depolarized Mass of Syncytial Cardiac Muscle	179
Effect of Chronic Increase in Heart Work Load—The Hypereffective Heart	161	Flow of Electrical Currents Around the Heart in the Chest	180
Effect of Various Ions on Heart Function	161	Electrocardiographic Leads	180
Effect of Temperature on the Heart	162	The Three Bipolar Limb Leads	180
The Heart-Lung Preparation	162	Chest Leads (Precordial Leads)	181
Assessment of Contractility	163	Augmented Unipolar Limb Leads	182
14 RHYTHMIC EXCITATION OF THE HEART	165		
The Special Excitatory and Conductive System of the Heart	165	16 ELECTROCARDIOGRAPHIC INTERPRETATION IN CARDIAC MUSCLE ABNORMALITIES—	
The Sinoatrial Node	165	VECTORIAL ANALYSIS	183
Internodal Pathways and Transmission of the Cardiac Impulse Through the Atria	167	Principles of Vectorial Analysis of Electrocardiograms	183
The Atrioventricular (A-V) Node and the Purkinje System	167	Use of Vectors to Represent Electrical Potentials	183
Transmission in the Purkinje System	168	Denoting the Direction of a Vector in Terms of Degrees	184
Transmission of the Cardiac Impulse in the Ventricular Muscle	168	"Axis" of Each of the Bipolar and Unipolar Limb Leads	184
Summary of the Spread of the Cardiac Impulse Through the Heart	169	Vectorial Analysis of Potentials Recorded in Different Leads	184
Control of Excitation and Conduction in the Heart	169	Vectorial Analysis of the Normal Electrocardiogram	185
The S-A Node as the Pacemaker of the Heart	169	Vectors Occurring During Depolarization of the Ventricles—the QRS Complex	185
Role of the Purkinje System in Causing Synchronous Contraction of the Ventricular Muscle	170		

The Electrocardiogram During Repolarization—The T Wave	187
Depolarization of the Atria—The P Wave.....	187
The Vectorcardiogram	188
The Mean Electrical Axis of the Ventricle	188
Determining the Electrical Axis from Standard Lead Electrocardiograms ...	188
Abnormal Ventricular Conditions That Cause Axis Deviation	189
Conditions that Cause Abnormal Voltages of the QRS Complex	191
Increased Voltage in the Standard Bipolar Limb Leads	191
Decreased Voltage of the Electrocardiogram.....	191
Prolonged and Bizarre Patterns of the QRS Complex	191
Prolonged QRS Complex as a Result of Cardiac Hypertrophy or Dilatation	191
Prolonged QRS Complex Resulting from Purkinje System Blocks	192
Conditions Causing Bizarre QRS Complexes.....	192
Current of Injury	192
Effect of Current of Injury on the QRS Complex.....	192
The J Point—The Zero Reference Potential of the Electrocardiogram....	193
Coronary Ischemia as a Cause of Current of Injury	194
Abnormalities in the T Wave.....	195

Effect of Slow Conduction of the Depolarization Wave on the T Wave.....	195
Prolonged Depolarization in Portions of the Ventricular Muscle as a Cause of Abnormalities in the T Wave.....	196

17 ELECTROCARDIOGRAPHIC INTERPRETATION OF CARDIAC ARRHYTHMIAS	197
Abnormal Sinus Rhythms.....	197
Tachycardia.....	197
Bradycardia.....	197
Sinus Arrhythmia.....	197
Abnormal Rhythms Resulting from Impulse Conduction Block	198
Sinoatrial Block	198
Atrioventricular Block.....	198
Incomplete Intraventricular Block—Electrical Alternans	199
Premature Contractions.....	199
Premature Atrial Contractions	200
A-V Nodal or A-V Bundle Premature Contractions	200
Premature Ventricular Contractions (PVCs).....	200
Paroxysmal Tachycardia	201
Atrial Paroxysmal Tachycardia	201
Ventricular Paroxysmal Tachycardia.....	202
Flutter and Fibrillation	202
Atrial Flutter.....	202
Atrial Fibrillation.....	202
Ventricular Fibrillation	203

V THE CIRCULATION

205

18 PHYSICS OF BLOOD, BLOOD FLOW, AND PRESSURE: HEMODYNAMICS....	206
The Circulatory System as a "Circuit".....	206
The Physical Characteristics of Blood	206
The Hematocrit.....	206
Plasma.....	208
Interrelationships Among Pressure, Flow, and Resistance.....	208
Blood Flow	208
Blood Pressure.....	210
Resistance of Blood Flow	211
Vascular Distensibility	214
Vascular Compliance (Or Capacitance)	214
Volume-Pressure Curves of the Arterial and Venous Circulations....	214
"Mean Circulatory Filling Pressure" and Volume-Pressure Curves of the Entire Circulatory System.....	215
The Mean Circulatory Filling Pressure	215

Volume-Pressure Curves of the Entire Circulation.....	215
Delayed Compliance (Stress-Relaxation) of Vessels.....	216
19 THE SYSTEMIC CIRCULATION.....	218
Physical Characteristics of the Systemic Circulation	218
Function of the Large Arteries	220
The Small Arteries, Arterioles, and Capillaries	220
Exchange of Fluid and Nutrients Through the Capillary Membrane	220
The Veins and Their Functions	221
Venous Pressures—Right Atrial Pressure (Central Venous Pressure) and Peripheral Pressures.....	221
Blood Reservoir Function of the Veins	224
Pressure Pulses in the Arteries	225
Factors That Affect the Pulse Pressure.....	225

Abnormal Pressure Pulse Contours ...	226
Transmission of the Pressure Pulse to the Periphery	227
The Radial Pulse	228
Pressure Pulses in the Veins	228
20 LOCAL CONTROL OF BLOOD FLOW BY THE TISSUES, AND NERVOUS AND HUMORAL REGULATION.....	230
Local Control of Blood Flow in Response to Tissue Need.....	230
Mechanisms of Blood Flow Control ...	231
Long-Term Blood Flow Regulation.....	235
Nervous Regulation of the Circulation ...	237
The Autonomic Nervous System	237
"Patterns" of Circulatory Responses Elicited by Different Central Nervous System Centers.....	240
Reflex Regulation of the Circulation..	241
Humoral Regulation of the Circulation....	241
21 ARTERIAL PRESSURE REGULATION: I. RAPID PRESSURE CONTROL BY NERVOUS REFLEXES AND OTHER MECHANISMS.....	244
Normal Arterial Pressures.....	244
The Mean Arterial Pressure	244
Relationship of Arterial Pressure to Cardiac Output and Total Peripheral Resistance.....	246
The Overall System for Arterial Pressure Regulation	246
Rapidly Acting Nervous Mechanisms for Arterial Pressure Control	247
The Arterial Baroreceptor Control System—Baroreceptor Reflexes.....	247
Control of Arterial Pressure by the Carotid and Aortic Chemoreceptors—Effect of Oxygen Lack on Arterial Pressure.....	250
Atrial and Pulmonary Artery Reflexes That Help Regulate Arterial Pressure and Other Circulatory Factors.....	250
The CNS Ischemic Response—Control of Arterial Pressure by the Vasomotor Center in Response to Diminished Brain Blood Flow.....	250
Special Features of Nervous Control of Arterial Pressure.....	251
Participation of the Veins in Nervous Regulation of Cardiac Output and Arterial Pressure.....	251
Role of the Skeletal Nerves and Skeletal Muscles in Increasing Cardiac Output and Arterial Pressure	252
Respiratory Waves in the Arterial Pressure	252
Arterial Pressure Vasomotor Waves—Oscillation of the Pressure Reflex Control Systems.....	252
Hormonal Mechanisms for Rapid Control of Arterial Pressure.....	253
The Norepinephrine-Epinephrine Vasoconstrictor Mechanism	253
Role of Vasopressin in Rapid Control of Arterial Pressure.....	253
The Renin-Angiotensin Vasoconstriction Mechanism for Control of Arterial Pressure	254
Two Intrinsic Circulatory Mechanisms for Rapid Arterial Pressure Regulation	255
22 ARTERIAL PRESSURE REGULATION: II. LONG-TERM CONTROL BY THE RENAL-BODY FLUID MECHANISM AND THE RENIN-ANGIOTENSIN SYSTEM: MECHANISMS OF HYPERTENSION.....	257
The Renal-Body Fluid System for Arterial Pressure Control	257
Role of the Renin-Angiotensin System and of Aldosterone in Long-Term Arterial Pressure Regulation	262
Hypertension (High Blood Pressure).....	264
Volume-loading Hypertension	264
Vasoconstrictor Hypertension.....	266
Types of Hypertension with Both Volume-Loading and Vasoconstrictor Components.....	268
Essential Hypertension.....	269
Effects of Hypertension on the Body..	270
23 CARDIAC OUTPUT, VENOUS RETURN, AND THEIR REGULATION	272
Normal Values for Cardiac Output at Rest and During Activity	272
Regulation of Cardiac Output	272
Role of the Heart in Cardiac Output Regulation—Its "Permissive" Role ...	272
Role of Total Peripheral Resistance in Determining Normal Venous Return and Cardiac Output.....	274
Effect of Arteriovenous Fistulae on Cardiac Output.....	275
Some Special Problems in Cardiac Output Regulation	275
Role of Blood Volume and the "Mean Systemic Filling Pressure" in Cardiac Output Regulation	276
Regulation of Cardiac Output in Heavy Exercise, Which Requires Simultaneous Peripheral and Cardiac Adjustments	276
Abnormally Low and Abnormally High Cardiac Outputs	277
Graphical Analysis of Cardiac Output Regulation	278
Cardiac Output Curves.....	279
Venous Return Curves	280
Analysis of Cardiac Output and Right Atrial Pressure, Using Cardiac Output and Venous Return Curves ...	282

Methods of Measuring Cardiac Output.....	284	Summary of the Changes That Occur Following Acute Cardiac Failure—"Compensated Heart Failure" ...	307
The Indicator Dilution Method.....	284	Dynamics of Severe Cardiac Failure— "Decompensated Heart Failure".....	308
24 THE PULMONARY CIRCULATION.....	287	Unilateral Cardiac Failure.....	309
Physiologic Anatomy of the Pulmonary Circulatory System.....	287	Unilateral Left Heart Failure	309
Pressures in the Pulmonary System.....	288	Unilateral Right Heart Failure	309
The Blood Volume of the Lungs.....	288	"High Cardiac Output Failure"— Overloading of the Heart.....	310
Blood Flow Through the Lungs and Its Distribution.....	289	Low Cardiac Output in Heart Failure—"Cardiogenic Shock"	310
Effect of Hydrostatic Pressure Gradients in the Lungs on Regional Pulmonary Blood Flow.....	289	Edema in Patients with Cardiac Failure..	311
Effect of Increased Cardiac Output on the Pulmonary Circulation During Heavy Exercise.....	290	Physiological Classification of Cardiac Failure.....	312
Function of the Pulmonary Circulation When the Left Atrial Pressure Rises as a Result of Left Heart Failure.....	291	Cardiac Reserve	312
Pulmonary Capillary Dynamics.....	291	Appendix.....	313
Capillary Exchange of Fluid in the Lungs.....	292		
Pathological Conditions That Obstruct Blood Flow Through the Lungs.....	293	27 HEART SOUNDS; DYNAMICS OF VALVULAR AND CONGENITAL HEART DEFECTS.....	316
25 THE CORONARY CIRCULATION AND ISCHEMIC HEART DISEASE	295	The Heart Sounds.....	316
Normal Coronary Blood Flow and Its Variations.....	295	Normal Heart Sounds	316
Physiologic Anatomy of the Coronary Blood Supply.....	295	Areas for Auscultation of Normal Heart Sounds	317
Normal Coronary Blood Flow.....	295	The Phonocardiogram	318
Control of Coronary Blood Flow.....	296	Valvular Lesions	318
Local Metabolism as the Primary Controller of Coronary Flow	296	Abnormal Heart Sounds Caused by Valvular Lesions	318
Nervous Control of Coronary Blood Flow	298	Abnormal Circulatory Dynamics in Valvular Heart Disease	319
The Substrates of Cardiac Metabolism.....	299	Dynamics of the Circulation in Aortic Stenosis and Aortic Regurgitation	319
Ischemic Heart Disease.....	299	Dynamics of Mitral Stenosis and Mitral Regurgitation.....	320
Myocardial Infarction.....	300	Circulatory Dynamics During Exercise in Patients with Valvular Lesions	321
Causes of Death Following Acute Coronary Occlusion	300	Abnormal Circulatory Dynamics in Congenital Heart Defects	321
The Stages of Recovery from Acute Myocardial Infarction.....	301	Patent Ductus Arteriosus—A Left-to-Right Shunt	322
Function of the Heart Following Recovery from Myocardial Infarction.....	302	Interventricular Septal Defect—A Left-to-Right Shunt	323
Pain in Coronary Disease	302	Tetralogy of Fallot—A Right-to-Left Shunt	323
Angina Pectoris	302	Pulmonary Stenosis.....	324
Surgical Treatment of Coronary Disease	303	Use of Extracorporeal Circulation During Cardiac Surgery	324
Measurement of Human Coronary Blood Flow	303	Hypertrophy of the Heart in Valvular and Congenital Heart Disease.....	324
26 CARDIAC FAILURE	305		
Dynamics of the Circulation in Cardiac Failure.....	305	28 CIRCULATORY SHOCK AND PHYSIOLOGY OF ITS TREATMENT	326
Acute Effects of Moderate Cardiac Failure.....	305	The Physiological Causes of Shock.....	326
The Chronic Stage of Failure.....	306	Shock Caused by Hypovolemia— Hemorrhagic Shock	327
		Relationship of Bleeding Volume to Cardiac Output and Arterial Pressure.....	327
		Nonprogressive and Progressive Hemorrhagic Shock	327

Irreversible Shock.....	331	Control of Blood Flow Through the	
Hypovolemic Shock Caused by		Skeletal Muscles	337
Plasma Loss.....	331	Circulatory Readjustments During	
Hypovolemic Shock Caused by		Exercise	337
Trauma.....	332	The Cerebral Circulation.....	338
Neurogenic Shock—Increased Vascular		Normal Rate of Cerebral Blood	
Capacity.....	332	Flow	338
Anaphylactic Shock	332	Regulation of Cerebral Blood Flow....	338
Septic Shock	333	The Splanchnic Circulation	340
Effects of Shock on the Body.....	333	Blood Flow Through the Liver.....	340
Physiology of Treatment in Shock	334	Blood Flow Through the Intestinal	
Replacement Therapy.....	334	Vessels.....	342
Treatment of Shock with		Portal Venous Pressure.....	342
Sympathomimetic and Sympatholytic		The Splenic Circulation	343
Drugs	334	Circulation in the Skin.....	343
Other Therapy.....	334	Physiologic Anatomy of the	
Circulatory Arrest	335	Cutaneous Circulation.....	343
Effect of Circulatory Arrest on the		Regulation of Blood Flow in the	
Brain	335	Skin.....	344
		Color of the Skin in Relation to Skin	
		Temperature	345
		Physiology of Vascular Diseases of the	
		Limbs	345
		Raynaud's Disease	345
		Peripheral Arteriosclerosis.....	346

29 MUSCLE BLOOD FLOW DURING	
EXERCISE; CEREBRAL, SPLANCHNIC,	
AND SKIN BLOOD FLOWS	336
Blood Flow Through Skeletal Muscles	
and Its Regulation in Exercise	336
Rate of Blood Flow Through the	
Muscles.....	336

IV THE BODY FLUIDS AND KIDNEYS

347

30 CAPILLARY DYNAMICS, AND		The Lymphatic System	361
EXCHANGE OF FLUID BETWEEN		The Lymph Channels of the Body....	361
THE BLOOD AND INTERSTITIAL		Formation of Lymph.....	363
FLUID.....	348	Total Rate of Lymph Flow	363
Structure of the Capillary System	348	Control of Interstitial Fluid Protein	
Flow of Blood in the Capillaries—		Concentration.....	365
Vasomotion	349	Regulation of Interstitial Fluid	
Average Function of the Capillary		Protein by Lymphatic Pumping	365
System.....	349	Control of Interstitial Fluid Pressure.....	365
Exchange of Nutrients and Other		Edema	366
Substances Between the Blood and		Pressure-Volume Curve of the	
Interstitial Fluid	350	Interstitial Fluid Spaces.....	366
Diffusion Through the Capillary		Positive Interstitial Fluid Pressure as	
Membrane.....	350	the Physical Basis for Edema.....	367
The Interstitium and the Interstitial		The Concept of an "Edema Safety	
Fluid.....	351	Factor".....	368
Distribution of Fluid Volume Between the		Edema Resulting from Abnormal	
Plasma and Interstitial Fluid.....	352	Capillary Dynamics.....	368
Capillary Pressure	353	Edema Caused by Kidney Retention	
Interstitial Fluid Pressure—Intragel		of Fluid.....	370
Pressure and Free Fluid Pressure.....	354	The Presence and Importance of Gel in	
Plasma Colloid Osmotic Pressure	356	the Interstitial Spaces	370
Interstitial Fluid Colloid Osmotic		Pulmonary Interstitial Fluid Dynamics .	371
Pressure	357	Pulmonary Edema	372
Exchange of Fluid Volume Through			
the Capillary Membrane	357	32 THE SPECIAL FLUID SYSTEMS OF	
The Starling Equilibrium for		THE BODY—CEREBROSPINAL,	
Capillary Exchange.....	358	OCULAR, PLEURAL, PERICARDIAL,	
		PERITONEAL, AND SYNOVIAL	374
		The Cerebrospinal Fluid System	374
		Cushioning Function of the	
		Cerebrospinal Fluid.....	374

31 THE LYMPHATIC SYSTEM,	
INTERSTITIAL FLUID DYNAMICS,	
EDEMA, AND PULMONARY FLUID	361

Formation, Flow, and Absorption of Cerebrospinal Fluid.....	375	Effect of Dehydration	391
Cerebrospinal Fluid Pressure.....	376	Effect of Adding Saline Solution to the Extracellular Fluid	391
Obstruction to the Flow of Cerebrospinal Fluid.....	376	Glucose and Other Solutions Administered for Nutritive Purposes...	391
The Blood-Cerebrospinal Fluid and Blood-Brain Barriers.....	377		
The Intraocular Fluid.....	377	34 FORMATION OF URINE BY THE KIDNEY: GLOMERULAR FILTRATION, TUBULAR FUNCTION, AND PLASMA CLEARANCE	393
Formation of Aqueous Humor by the Ciliary Body	378	Physiologic Anatomy of the Kidney...	393
Outflow of Aqueous Humor from the Eye.....	378	Basic Theory of Nephron Function...	395
Intraocular Pressure	378	Renal Blood Flow Through the Kidneys...	395
Fluid Circulation in the Potential Spaces of the Body.....	379	Blood Flow Through the Kidneys	395
Fluid Exchange Between the Capillaries and the Potential Spaces	379	Pressures in the Renal Circulation ..	396
The Pleural Cavity.....	380	"Intrarenal Pressure" and Renal Interstitial Fluid Pressure	396
The Pericardial Cavity	380	Function of the Peritubular Capillaries	396
The Peritoneal Cavity	380	Glomerular Filtration and the Glomerular Filtrate.....	397
The Synovial Cavities	381	The Glomerular Filtration Rate.....	398
		Dynamics of Glomerular Filtration ..	398
33 PARTITION OF THE BODY FLUIDS: OSMOTIC EQUILIBRIA BETWEEN EXTRACELLULAR AND INTRACELLULAR FLUIDS.....	382	Factors That Affect the Glomerular Filtration Rate.....	399
Total Body Water.....	382	Reabsorption and Secretion in the Tubules.....	400
Intake Versus Output of Water.....	382	Basic Mechanisms of Absorption and Secretion in the Tubules	400
Body Fluid Compartments.....	383	Absorptive Capabilities of Different Tubule Segments.....	402
The Intracellular Fluid Compartment	383	Reabsorption and Secretion of Individual Substances in Different Segments of the Tubules	404
The Extracellular Fluid Compartment	383	Concentrations of Different Substances at Different Points in the Tubules.....	406
Blood Volume	383	The Concept of "Plasma Clearance"	407
Measurement of Body Fluid Volumes.....	384	Inulin Clearance as a Measure of Glomerular Filtration Rate	407
The Dilution Principle for Measuring Fluid Volumes	384	Para-Aminohippuric Acid (PAH) Clearance as a Measure of Plasma Flow Through the Kidneys.....	408
Determination of Blood Volume	385	Calculating the Filtration Fraction from Plasma Clearances.....	408
Measurement of the Extracellular Fluid Volume	386	Effect of "Tubular Load" and "Tubular Transport Maximum" on Urine Constituents	408
Measurement of Total Body Water.....	386		
Calculation of Interstitial Fluid Volume.....	386	35 RENAL MECHANISMS FOR (1) CONTROLLING GLOMERULAR FILTRATION, (2) EXCRETING DILUTE OR CONCENTRATED URINE, AND (3) EXCRETING UREA, SODIUM, POTASSIUM, AND FLUID VOLUME	410
Constituents of Extracellular and Intracellular Fluids	386	Autoregulation of Glomerular Filtration Rate.....	410
Osmotic Equilibria and Fluid Shifts Between the Extracellular and Intracellular Fluids	387	Mechanism of Autoregulation of Glomerular Filtration Rate—Tubuloglomerular Feedback	411
Basic Principles of Osmosis and Osmotic Pressure	387	Autoregulation of Renal Blood Flow ..	413
Osmolality of the Body Fluids	388	The Mechanism for Excreting Excess Water: Excretion of a Dilute Urine	413
Maintenance of Osmotic Equilibrium Between Extracellular and Intracellular Fluids	389		
Changes in the Volumes and Osmolalities of the Extracellular and Intracellular Fluid Compartments in Abnormal States.....	390		
Calculation of Fluid Shifts Between the Extracellular and Intracellular Fluid Compartments	390		
Effect of Adding Water to the Extracellular Fluid	390		

The Mechanism for Excreting Excess Solutes: The Countercurrent Mechanism for Excreting a Concentrated Urine	414
Osmolar Clearance: Free Water Clearance	417
Urea Excretion	417
Sodium Excretion	419
Potassium Excretion	420
Fluid Volume Excretion	421
Summary of the Control of Fluid Volume Excretion	424
36 REGULATION OF BLOOD VOLUME, EXTRACELLULAR FLUID VOLUME, AND EXTRACELLULAR FLUID COMPOSITION BY THE KIDNEYS AND BY THE THIRST MECHANISM.....	425
Control of Blood Volume	425
Basic Mechanism for Blood Volume Control	426
Role of the Volume Receptors in Blood Volume Control	426
Other Factors That Help Control Blood Volume.....	427
Control of Extracellular Fluid Volume	428
Control of Extracellular Fluid Sodium Concentration and Extracellular Fluid Osmolality	428
The Osmosodium Receptor—Antidiuretic Hormone Feedback Control System	429
Thirst, and Its Role in Controlling Sodium Concentration and Extracellular Fluid Osmolality	431
Combined Roles of the Antidiuretic and Thirst Mechanisms for Control of Extracellular Fluid Sodium Concentration and Osmolality	432
Effect of Aldosterone on Sodium Concentration.....	433
Control of Sodium Intake—Appetite and Craving for Salt	433
Regulation of Potassium Ion Concentration.....	433
Other Factors That Affect Potassium Ion Concentration	435
Control of the Extracellular Concentration of Other Ions	435
37 REGULATION OF ACID-BASE BALANCE	438
Defense Against Changes in Hydrogen Ion Concentration.....	439
Function of Acid-Base Buffers	439
The Bicarbonate Buffer System	439
The Buffer Systems of the Body Fluids.....	441
The Isohydric Principle.....	442
Respiratory Regulation of Acid-Base Balance	442
Renal Regulation of Hydrogen Ion Concentration.....	444
Tubular Secretion of Hydrogen Ions ..	444
Renal Correction of Acidosis—Increase of Bicarbonate Ions in the Extracellular Fluid	445
Renal Correction of Alkalosis—Decrease of Bicarbonate Ions in the Extracellular Fluid.....	446
Combination of Excess Hydrogen Ions with Tubular Buffers and Transport into the Urine	446
Rapidity of Acid-Base Regulation by the Kidneys.....	447
Renal Regulation of Plasma Chloride Concentration—The Chloride to Bicarbonate Ratio	448
Clinical Abnormalities of Acid-Base Balance	448
Respiratory Acidosis and Alkalosis ...	448
Metabolic Acidosis and Alkalosis.....	448
Effects of Acidosis and Alkalosis on the Body.....	449
Respiratory Compensation of Metabolic Acidosis or Alkalosis	449
Renal Compensation of Respiratory Acidosis or Alkalosis.....	449
Physiology of Treatment in Acidosis or Alkalosis	450
Clinical Measurements and Analysis of Acid-Base Abnormalities	450
38 RENAL DISEASE, DIURESIS, AND MICTURITION.....	452
Renal Disease.....	452
Acute Renal Failure	452
Chronic Renal Failure—Decrease in Number of Functional Nephrons	453
Hypertensive Kidney Disease.....	457
The Nephrotic Syndrome—Increased Glomerular Permeability.....	457
Specific Tubular Disorders	458
Renal Function Tests	458
Diuretics and Mechanisms of Their Actions	459
Micturition.....	460
Physiologic Anatomy and Nervous Connections of the Bladder	460
Transport of Urine Through the Ureters	461
Tone of the Bladder Wall, and the Cystometrogram During Bladder Filling	461
The Micturition Reflex	461
Abnormalities of Micturition	462

VII RESPIRATION

465

39 PULMONARY VENTILATION	466	Oxygen Concentration and Partial Pressure in the Alveoli	485
Mechanics of Pulmonary Ventilation	466	CO ₂ Concentration and Partial Pressure in the Alveoli	485
Basic Mechanisms of Lung Expansion and Contraction	466	Expired Air	485
Respiratory Pressures	467	Diffusion of Gases Through the Respiratory Membrane	
Expansibility of the Lungs and Thorax: "Compliance"	468	Factors That Affect Rate of Gas Diffusion Through the Respiratory Membrane	485
The "Work" of Breathing	469	Diffusing Capacity of the Respiratory Membrane	485
The Pulmonary Volumes and Capacities ..	470	Effect of the Ventilation-Perfusion Ratio on Alveolar Gas Concentration	490
Recording Changes in Pulmonary Volume—Spirometry	470		
The Pulmonary "Volumes"	470	41 TRANSPORT OF OXYGEN AND CARBON DIOXIDE IN THE BLOOD AND BODY FLUIDS	493
The Pulmonary "Capacities"	470	Pressures of Oxygen and Carbon Dioxide in the Lungs, Blood, and Tissues	493
Significance of the Pulmonary Volumes and Capacities	471	Uptake of Oxygen by the Pulmonary Blood	493
Abbreviations and Symbols Used in Pulmonary Function Studies	471	Transport of Oxygen in the Arterial Blood	494
Determination of Functional Residual Capacity—The Helium Dilution Method	472	Diffusion of Oxygen from the Capillaries to the Interstitial Fluid ...	494
The Minute Respiratory Volume—Respiratory Rate Times Tidal Volume	472	Diffusion of Oxygen from the Capillaries to the Cells	495
Alveolar Ventilation	472	Diffusion of Carbon Dioxide from the Cells to the Tissue Capillaries, and from the Pulmonary Capillaries to the Alveoli	495
Rate of Alveolar Ventilation	473	Transport of Oxygen in the Blood	496
Functions of the Respiratory Passageways	474	The Reversible Combination of Oxygen with Hemoglobin	496
The Trachea, Bronchi, and Bronchioles	474	The Tissue Oxygen Buffer Function of Hemoglobin	497
Maximum Expiratory Flow	476	Shift of the Oxygen-Hemoglobin Dissociation Curve and Its Significance	498
Forced Expiratory Vital Capacity and Forced Expiratory Volume	477	Metabolic Use of Oxygen by the Cells	499
Respiratory Functions of the Nose ...	477	Transport of Oxygen in the Dissolved State	499
Vocalization	477	Combination of Hemoglobin with Carbon Monoxide	500
Artificial Respiration	478	Transport of Carbon Dioxide in the Blood	500
Mouth-to-Mouth Breathing	478	Chemical Forms in Which Carbon Dioxide Is Transported	500
Mechanical Methods of Artificial Respiration	479	The Carbon Dioxide Dissociation Curve	501
40 PHYSICAL PRINCIPLES OF GASEOUS EXCHANGE; DIFFUSION OF OXYGEN AND CARBON DIOXIDE THROUGH THE RESPIRATORY MEMBRANE	481	Effect of the Oxygen-Hemoglobin Reaction on Carbon Dioxide Transport—The Haldane Effect	501
Physics of Diffusion and Gas Pressures ...	481	Change in Blood Acidity During Carbon Dioxide Transport	502
The Molecular Basis of Gaseous Diffusion	481	The Respiratory Exchange Ratio	502
Gas Pressures in a Mixture of Gases—Partial Pressures of Individual Gases	482		
Pressures of Gases in Water and Tissues	482		
The Vapor Pressure of Water	482		
Diffusion of Gases Through Fluids—The Pressure Gradient for Diffusion ..	483		
Diffusion of Gases Through Tissues ...	483		
Composition of Alveolar Air—Its Relation to Atmospheric Air	483		
Rate at Which Alveolar Air Is Renewed by Atmospheric Air	484		

42 REGULATION OF RESPIRATION.....	504
The Respiratory Center.....	504
Control of Overall Respiratory Center Activity.....	506
Chemical Control of Respiration.....	506
Direct Chemical Control of Respiratory Center Activity by Carbon Dioxide and Hydrogen Ions...	506
The Peripheral Chemoreceptor System for Control of Respiratory Activity—Role of Oxygen in Respiratory Control.....	508
Composite Effects of PCO_2 , pH, and PO_2 on Respiratory Activity.....	511
Regulation of Respiration During Exercise.....	511
Other Factors That Affect Respiration...	513
Abnormalities of Respiratory Control.....	514
Respiratory Center Depression.....	514
Periodic Breathing.....	514
43 RESPIRATORY INSUFFICIENCY—PATHOPHYSIOLOGY, DIAGNOSIS, OXYGEN THERAPY.....	516
Additional Methods for Studying Respiratory Abnormalities.....	516
Study of Blood Gases and pH.....	517

Physiologic Types of Respiratory Insufficiency.....	517
Abnormalities That Cause Alveolar Hypoventilation.....	518
Diseases That Decrease Lung Diffusing Capacity.....	518
Abnormalities of Oxygen Transport from the Lungs to the Tissues.....	518
Physiologic Peculiarities of Specific Pulmonary Abnormalities.....	518
Chronic Pulmonary Emphysema.....	518
Pneumonia.....	520
Atelectasis.....	520
Asthma.....	521
Tuberculosis.....	521
Hypoxia.....	522
Cyanosis.....	522
Dyspnea.....	522
Hypercapnia.....	523
Effects of Hypercapnia on the Body...	523
Oxygen Therapy in the Different Types of Hypoxia.....	523
Danger of Hypercapnia During Oxygen Therapy.....	524
Absorption of Entrapped Air.....	525

VIII AVIATION, SPACE, AND DEEP SEA DIVING PHYSIOLOGY

527

44 AVIATION, HIGH ALTITUDE, AND SPACE PHYSIOLOGY.....	528
Effects of Low Oxygen Pressure on the Body.....	528
Alveolar PO_2 at Different Elevations.....	528
Effect of Breathing Pure Oxygen on the Alveolar PO_2 at Different Altitudes.....	529
The "Ceiling" When Breathing Air and When Breathing Oxygen in an Unpressurized Airplane.....	529
Effects of Hypoxia.....	529
Acclimatization of Low PO_2	530
Natural Acclimatization of Natives Living at High Altitudes.....	531
Work Capacity at High Altitudes: The Effect of Acclimatization.....	532
Chronic Mountain Sickness.....	532
Acute Mountain Sickness and High Altitude Pulmonary Edema.....	532
Effects of Acceleratory Forces on the Body in Aviation and Space Physiology...	532
Centrifugal Acceleratory Forces.....	532

Effects of Linear Acceleratory Forces on the Body.....	534
Perception of Equilibrium and Turning in Blind Flying.....	534
Problems of Temperature in Aviation and Space Physiology.....	534
Radiation at High Altitudes and in Space.....	535
"Artificial Climate" in the Sealed Spacecraft.....	535
Weightlessness in Space.....	536
45 PHYSIOLOGY OF DEEP SEA DIVING AND OTHER HYPERBARIC CONDITIONS.....	537
Effect of High Partial Pressures of Gases on the Body.....	537
Decompression of the Diver After Exposure to High Pressures.....	539
Some Physical Problems of Diving.....	541
Scuba Diving (Self-Contained Underwater Breathing Apparatus).....	542
Special Physiological Problems in Submarines.....	543
Hyperbaric Oxygen Therapy.....	543

IX THE NERVOUS SYSTEM

545

46 ORGANIZATION OF THE NERVOUS SYSTEM; BASIC FUNCTIONS OF SYNAPSES.....	546
---	-----

General Design of the Nervous System....	546
The Sensory Division—Sensory Receptors.....	546