

# Table of Contents

|                   |      |
|-------------------|------|
| Preface . . . . . | xiii |
|-------------------|------|

## SECTION I. INTRODUCTION

|                                     |   |
|-------------------------------------|---|
| 1. Physiologic Principles . . . . . | 1 |
|-------------------------------------|---|

|                                                 |                                                            |
|-------------------------------------------------|------------------------------------------------------------|
| Functional Morphology of the Cell 1             | The Capillary Wall 24                                      |
| Body Fluid Compartments 13                      | Sodium & Potassium Distribution & Total Body Osmolality 24 |
| Units for Measuring Concentration of Solutes 15 | pH & Buffers 25                                            |
| Composition of Body Fluids 16                   | Intercellular Communication 26                             |
| Forces Producing Movement of Substances         | Homeostasis 30                                             |
| Between Compartments 17                         | Aging 30                                                   |
| Cell Membrane & Resting Membrane Potentials 21  |                                                            |

Section I References: 31

## SECTION II. PHYSIOLOGY OF NERVE & MUSCLE CELLS

|                                      |    |
|--------------------------------------|----|
| 2. Excitable Tissue: Nerve . . . . . | 32 |
|--------------------------------------|----|

|                                           |                                 |
|-------------------------------------------|---------------------------------|
| Nerve Cells 32                            | Nerve Fiber Types & Function 42 |
| Electrical Phenomena in Nerve Cells 35    | Nerve Growth Factor 44          |
| Ionic Basis of Excitation & Conduction 40 | Glia 44                         |
| Properties of Mixed Nerves 41             |                                 |

|                                       |    |
|---------------------------------------|----|
| 3. Excitable Tissue: Muscle . . . . . | 45 |
|---------------------------------------|----|

|                                                 |                             |
|-------------------------------------------------|-----------------------------|
| Skeletal Muscle 46                              | Cardiac Muscle (cont'd)     |
| Morphology 46                                   | Mechanical Properties 57    |
| Electrical Phenomena & Ionic Fluxes 47          | Metabolism 58               |
| Contractile Responses 48                        | Pacemaker Tissue 58         |
| Energy Sources & Metabolism 52                  | Smooth Muscle 59            |
| Properties of Muscles in the Intact Organism 54 | Morphology 59               |
| Cardiac Muscle 55                               | Visceral Smooth Muscle 59   |
| Morphology 55                                   | Multi-Unit Smooth Muscle 61 |
| Electrical Properties 57                        |                             |

|                                                 |    |
|-------------------------------------------------|----|
| 4. Synaptic & Junctional Transmission . . . . . | 62 |
|-------------------------------------------------|----|

|                                               |                                             |
|-----------------------------------------------|---------------------------------------------|
| Synaptic Transmission 62                      | Neuromuscular Transmission 81               |
| Functional Anatomy 62                         | The Myoneural Junction 81                   |
| Electrical Events at Synapses 64              | Nerve Endings in Smooth & Cardiac Muscle 82 |
| Inhibition & Facilitation at Synapses 67      | Denervation Hypersensitivity 83             |
| Chemical Transmission of Synaptic Activity 71 |                                             |

|                                                     |    |
|-----------------------------------------------------|----|
| 5. Initiation of Impulses in Sense Organs . . . . . | 85 |
|-----------------------------------------------------|----|

|                             |                                           |
|-----------------------------|-------------------------------------------|
| Sense Organs & Receptors 85 | Electrical & Ionic Events in Receptors 87 |
| The Senses 85               | "Coding" of Sensory Information 89        |

Section II References: 91

## SECTION III. FUNCTIONS OF THE NERVOUS SYSTEM

|                                                                                                                                                                                         |                                                                                                                                                                                                                    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>6. Reflexes</b>                                                                                                                                                                      | <b>92</b>                                                                                                                                                                                                          |
| The Reflex Arc 92<br>Monosynaptic Reflexes: The Stretch Reflex 92                                                                                                                       | Polysynaptic Reflexes: The Withdrawal Reflex 97<br>General Properties of Reflexes 99                                                                                                                               |
| <b>7. Cutaneous, Deep, &amp; Visceral Sensation</b>                                                                                                                                     | <b>101</b>                                                                                                                                                                                                         |
| Pathways 101<br>Touch 104<br>Proprioception 104<br>Temperature 104<br>Pain 105                                                                                                          | Differences Between Somatic & Visceral<br>Sensory Mechanisms 107<br>Visceral Pain 107<br>Referral & Inhibition of Pain 108<br>Other Sensations 110                                                                 |
| <b>8. Vision</b>                                                                                                                                                                        | <b>112</b>                                                                                                                                                                                                         |
| Anatomic Considerations 112<br>The Image-Forming Mechanism 116<br>The Photoreceptor Mechanism: Genesis of<br>Action Potentials 119                                                      | Responses in the Visual Pathways & Cortex 123<br>Other Aspects of Visual Function 126<br>Color Vision 128<br>Eye Movements 130                                                                                     |
| <b>9. Hearing &amp; Equilibrium</b>                                                                                                                                                     | <b>132</b>                                                                                                                                                                                                         |
| Anatomic Considerations 132<br>Hair Cells 136                                                                                                                                           | Hearing 137<br>Vestibular Function 142                                                                                                                                                                             |
| <b>10. Smell &amp; Taste</b>                                                                                                                                                            | <b>144</b>                                                                                                                                                                                                         |
| Smell 144<br>Receptors & Pathways 144<br>Physiology of Olfaction 145                                                                                                                    | Taste 146<br>Receptor Organs & Pathways 146<br>Physiology of Taste 147                                                                                                                                             |
| <b>11. Arousal Mechanisms, Sleep, &amp; the Electrical Activity of the Brain</b>                                                                                                        | <b>150</b>                                                                                                                                                                                                         |
| The Reticular Formation & the Reticular<br>Activating System 150<br>The Thalamus & the Cerebral Cortex 150<br>Evoked Cortical Potentials 151                                            | The Electroencephalogram 152<br>Physiologic Basis of the EEG, Consciousness, &<br>Sleep 154                                                                                                                        |
| <b>12. Control of Posture &amp; Movement</b>                                                                                                                                            | <b>160</b>                                                                                                                                                                                                         |
| Pyramidal System 160<br>Anatomy 160<br>Function 162<br>Extrapyramidal Mechanisms 164<br>Spinal Integration 164<br>Medullary Components 166<br>Midbrain Components 168                   | Extrapyramidal Mechanisms (cont'd)<br>Cortical Components 168<br>Basal Ganglia 169<br>Cerebellum 171<br>Anatomic & Functional Organization 171<br>Physiology 174                                                   |
| <b>13. The Autonomic Nervous System</b>                                                                                                                                                 | <b>178</b>                                                                                                                                                                                                         |
| Anatomic Organization of Autonomic Outflow 178<br>Chemical Transmission at Autonomic<br>Junctions 180                                                                                   | Responses of Effector Organs to Autonomic Nerve<br>Impulses 180                                                                                                                                                    |
| <b>14. Central Regulation of Visceral Function</b>                                                                                                                                      | <b>184</b>                                                                                                                                                                                                         |
| Medulla Oblongata 184<br>Hypothalamus 185<br>Anatomic Considerations 185<br>Hypothalamic Function 187<br>Relation of Hypothalamus to Autonomic<br>Function 187<br>Relation to Sleep 189 | Hypothalamus (cont'd)<br>Relation to Cyclic Phenomena 189<br>Hunger 189<br>Thirst 191<br>Control of Posterior Pituitary Secretion 192<br>Control of Anterior Pituitary Secretion 196<br>Temperature Regulation 199 |

|                                                                                      |            |
|--------------------------------------------------------------------------------------|------------|
| <b>15. Neural Basis of Instinctual Behavior &amp; Emotions</b> . . . . .             | <b>204</b> |
| Anatomic Considerations 204                                                          |            |
| Limbic Functions 205                                                                 |            |
| Sexual Behavior 206                                                                  |            |
| Fear & Rage 208                                                                      |            |
| Motivation 209                                                                       |            |
| Brain Chemistry, Behavior, & Synaptic Transmission in the Central Nervous System 210 |            |

|                                                                                                                                |            |
|--------------------------------------------------------------------------------------------------------------------------------|------------|
| <b>16. "Higher Functions of the Nervous System":<br/>    Conditioned Reflexes, Learning, &amp; Related Phenomena</b> . . . . . | <b>215</b> |
| Learning 216                                                                                                                   |            |
| Memory 218                                                                                                                     |            |
| Functions of the Neocortex 219                                                                                                 |            |

**Section III References: 223**

## SECTION IV. ENDOCRINOLOGY & METABOLISM

|                                                                  |            |
|------------------------------------------------------------------|------------|
| <b>17. Energy Balance, Metabolism, &amp; Nutrition</b> . . . . . | <b>225</b> |
| Energy Metabolism 225                                            |            |
| Metabolic Rate 225                                               |            |
| Energy Balance 229                                               |            |
| Intermediary Metabolism 229                                      |            |
| General Considerations 229                                       |            |
| Carbohydrate Metabolism 231                                      |            |
| Intermediary Metabolism (cont'd)                                 |            |
| Protein Metabolism 238                                           |            |
| Fat Metabolism 244                                               |            |
| Nutrition 253                                                    |            |
| Essential Dietary Components 253                                 |            |

|                                                |            |
|------------------------------------------------|------------|
| <b>18. The Thyroid Gland</b> . . . . .         | <b>258</b> |
| Anatomic Considerations 258                    |            |
| Formation & Secretion of Thyroid Hormones 259  |            |
| Transport & Metabolism of Thyroid Hormones 262 |            |
| Effects of Thyroid Hormones 264                |            |
| Mechanism of Action of Thyroid Hormones 266    |            |
| Regulation of Thyroid Secretion 266            |            |
| Clinical Correlates 268                        |            |

|                                                                                                          |            |
|----------------------------------------------------------------------------------------------------------|------------|
| <b>19. Endocrine Functions of the Pancreas &amp; the Regulation of Carbohydrate Metabolism</b> . . . . . | <b>272</b> |
| Islet Cell Structure 272                                                                                 |            |
| Structure, Biosynthesis, & Secretion of Insulin 273                                                      |            |
| Fate of Secreted Insulin 274                                                                             |            |
| Consequences of Insulin Deficiency & Actions of Insulin 275                                              |            |
| Insulin Excess 282                                                                                       |            |
| Mechanism of Action of Insulin 282                                                                       |            |
| Regulation of Insulin Secretion 283                                                                      |            |
| Glucagon 286                                                                                             |            |
| Other Islet Cell Hormones 288                                                                            |            |
| Endocrine Regulation of Carbohydrate Metabolism 289                                                      |            |
| Hypoglycemia & Diabetes Mellitus in Humans 290                                                           |            |

|                                                                              |            |
|------------------------------------------------------------------------------|------------|
| <b>20. The Adrenal Medulla &amp; Adrenal Cortex</b> . . . . .                | <b>293</b> |
| Adrenal Morphology 293                                                       |            |
| Adrenal Medulla 294                                                          |            |
| Structure & Function of Medullary Hormones 294                               |            |
| Regulation of Adrenal Medullary Secretion 297                                |            |
| Adrenal Cortex 297                                                           |            |
| Structure & Biosynthesis of Adrenocortical Hormones 297                      |            |
| Transport, Metabolism, & Excretion of Adrenocortical Hormones 301            |            |
| Effects of Adrenal Androgens & Estrogens 303                                 |            |
| Adrenal Cortex (cont'd)                                                      |            |
| Physiologic Effects of Glucocorticoids 304                                   |            |
| Pharmacologic & Pathologic Effects of Glucocorticoids 307                    |            |
| Regulation of Glucocorticoid Secretion 308                                   |            |
| Effects of Mineralocorticoids 311                                            |            |
| Regulation of Aldosterone Secretion 313                                      |            |
| Role of Mineralocorticoids in the Regulation of Salt Balance 316             |            |
| Summary of the Effects of Adrenocortical Hyper- & Hypofunction in Humans 316 |            |

|                                                                                          |            |
|------------------------------------------------------------------------------------------|------------|
| <b>21. Hormonal Control of Calcium Metabolism &amp; the Physiology of Bone</b> . . . . . | <b>318</b> |
| Calcium & Phosphorus Metabolism 318                                                      |            |
| Bone Physiology 319                                                                      |            |
| Vitamin D and the Hydroxycholecalciferols 322                                            |            |
| The Parathyroid Glands 323                                                               |            |
| Calcitonin 326                                                                           |            |
| Effects of Other Hormones & Humoral Agents on Calcium Metabolism 328                     |            |

|                                                                                        |                                          |
|----------------------------------------------------------------------------------------|------------------------------------------|
| <b>22. The Pituitary Gland</b> . . . . .                                               | <b>329</b>                               |
| Morphology 330                                                                         | Physiology of Growth 337                 |
| Intermediate Lobe Hormones 331                                                         | Pituitary Insufficiency 339              |
| Growth Hormone 332                                                                     | Pituitary Hyperfunction in Humans 341    |
| <b>23. The Gonads: Development &amp; Function of the Reproductive System</b> . . . . . | <b>342</b>                               |
| Sex Differentiation & Development 342                                                  | The Male Reproductive System (cont'd)    |
| Chromosomal Sex 342                                                                    | Endocrine Function of the Testes 357     |
| Embryology of the Human Reproductive System 345                                        | Control of Testicular Function 359       |
| Aberrant Sexual Differentiation 348                                                    | Abnormalities of Testicular Function 360 |
| Puberty 349                                                                            | The Female Reproductive System 361       |
| Precocious & Delayed Puberty 350                                                       | The Menstrual Cycle 361                  |
| Menopause 351                                                                          | Ovarian Hormones 364                     |
| Pituitary Gonadotropins & Prolactin 352                                                | Control of Ovarian Function 369          |
| The Male Reproductive System 353                                                       | Abnormalities of Ovarian Function 371    |
| Structure 353                                                                          | Pregnancy 371                            |
| Gametogenesis & Ejaculation 354                                                        | Lactation 374                            |
| <b>24. Other Organs With Established or Suggested Endocrine Functions</b> . . . . .    | <b>376</b>                               |
| The Endocrine Functions of the Kidneys: Renin & Erythropoietin 376                     | Atrial Natriuretic Factor 381            |
|                                                                                        | Pineal 381                               |

**Section IV References: 382**

## SECTION V. GASTROINTESTINAL FUNCTION

|                                                              |                                        |
|--------------------------------------------------------------|----------------------------------------|
| <b>25. Digestion &amp; Absorption</b> . . . . .              | <b>384</b>                             |
| Carbohydrates 385                                            | Absorption of Water & Electrolytes 390 |
| Proteins & Nucleic Acids 387                                 | Absorption of Vitamins & Minerals 391  |
| Lipids 388                                                   |                                        |
| <b>26. Regulation of Gastrointestinal Function</b> . . . . . | <b>394</b>                             |
| Gastrointestinal Hormones 395                                | Exocrine Portion of the Pancreas 406   |
| Mouth & Esophagus 399                                        | Liver & Biliary System 408             |
| Stomach 401                                                  | Small Intestine 413                    |
| Regulation of Gastric Secretion & Motility 403               | Colon 416                              |
| Other Functions of the Stomach 405                           |                                        |

**Section V References: 420**

## SECTION VI. CIRCULATION

|                                                                                         |                                                                        |
|-----------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| <b>27. Circulating Body Fluids</b> . . . . .                                            | <b>421</b>                                                             |
| The Circulatory System 421                                                              | Blood (cont'd)                                                         |
| Blood 421                                                                               | Red Blood Cells 429                                                    |
| Bone Marrow 421                                                                         | Blood Types 434                                                        |
| White Blood Cells 423                                                                   | Plasma 437                                                             |
| Immune Mechanisms 424                                                                   | Hemostasis 438                                                         |
| Platelets 429                                                                           | Lymph 441                                                              |
| <b>28. Origin of the Heartbeat &amp; the Electrical Activity of the Heart</b> . . . . . | <b>442</b>                                                             |
| Origin & Spread of Cardiac Excitation 442                                               | Electrocardiographic Findings in Other Cardiac & Systemic Diseases 455 |
| The Electrocardiogram 444                                                               |                                                                        |
| Cardiac Arrhythmias 449                                                                 |                                                                        |

|                                                                         |                                            |
|-------------------------------------------------------------------------|--------------------------------------------|
| <b>29. The Heart as a Pump</b> . . . . .                                | <b>459</b>                                 |
| Mechanical Events of the Cardiac Cycle 459                              | Cardiac Output 463                         |
| <b>30. Dynamics of Blood &amp; Lymph Flow</b> . . . . .                 | <b>470</b>                                 |
| Anatomic Considerations 470                                             | Lymphatic Circulation & Interstitial Fluid |
| Biophysical Considerations 472                                          | Volume 481                                 |
| Arterial & Arteriolar Circulation 477                                   | Venous Circulation 483                     |
| Capillary Circulation 480                                               |                                            |
| <b>31. Cardiovascular Regulatory Mechanisms</b> . . . . .               | <b>485</b>                                 |
| Local Regulatory Mechanisms 485                                         | Systemic Regulatory Mechanisms 486         |
| <b>32. Circulation Through Special Regions</b> . . . . .                | <b>496</b>                                 |
| Cerebral Circulation 496                                                | Cerebral Circulation (cont'd)              |
| Anatomic Considerations 496                                             | Brain Metabolism & Oxygen Requirements 505 |
| Cerebrospinal Fluid 497                                                 | Coronary Circulation 506                   |
| The Blood-Brain Barrier 499                                             | Splanchnic Circulation 508                 |
| Cerebral Blood Flow 501                                                 | Circulation of the Skin 509                |
| Regulation of Cerebral Circulation 503                                  | Placental & Fetal Circulation 511          |
| <b>33. Cardiovascular Homeostasis in Health &amp; Disease</b> . . . . . | <b>514</b>                                 |
| Compensations for Gravitational Effects 514                             | Fainting 522                               |
| Exercise 516                                                            | Heart Failure 522                          |
| Hemorrhage & Hemorrhagic Shock 518                                      | Hypertension 524                           |
| Other Forms of Shock 520                                                |                                            |

Section VI References: 526

## SECTION VII. RESPIRATION

|                                                                        |                                              |
|------------------------------------------------------------------------|----------------------------------------------|
| <b>34. Pulmonary Function</b> . . . . .                                | <b>528</b>                                   |
| Properties of Gases 528                                                | Pulmonary Circulation 538                    |
| Mechanics of Respiration 529                                           | Other Functions of the Respiratory           |
| Gas Exchange in the Lung 537                                           | System 540                                   |
| <b>35. Gas Transport Between the Lungs &amp; the Tissues</b> . . . . . | <b>542</b>                                   |
| Oxygen Transport 542                                                   | Carbon Dioxide Transport 547                 |
| Buffers in Blood 545                                                   |                                              |
| <b>36. Regulation of Respiration</b> . . . . .                         | <b>549</b>                                   |
| Neural Control of Breathing 549                                        | Chemical Control of Breathing 551            |
| Regulation of Respiratory Center Activity 551                          | Nonchemical Influences on Respiration 555    |
| <b>37. Respiratory Adjustments in Health &amp; Disease</b> . . . . .   | <b>558</b>                                   |
| Effects of Exercise 558                                                | Oxygen Treatment 566                         |
| Hypoxia 560                                                            | Hypercapnia & Hypocapnia 567                 |
| Hypoxic Hypoxia 561                                                    | Effects of Increased Barometric Pressure 568 |
| Other Forms of Hypoxia 565                                             | Artificial Respiration 569                   |

Section VII References: 571

## SECTION VIII. FORMATION & EXCRETION OF URINE

### 38. Renal Function . . . . . 572

|                           |                                                           |
|---------------------------|-----------------------------------------------------------|
| Functional Anatomy 572    | Acidification of the Urine & Bicarbonate Excretion 589    |
| Renal Circulation 575     | Regulation of $\text{Na}^+$ & $\text{Cl}^-$ Excretion 592 |
| Glomerular Filtration 577 | Regulation of $\text{K}^+$ Excretion 593                  |
| Tubular Function 579      | Diuretics 594                                             |
| Water Excretion 584       | Effects of Disordered Renal Function 595                  |

### 39. Micturition . . . . . 597

|                             |                                  |
|-----------------------------|----------------------------------|
| Filling of the Bladder 597  | Abnormalities of Micturition 598 |
| Emptying of the Bladder 597 |                                  |

### 40. Regulation of Extracellular Fluid Composition & Volume . . . . . 600

|                         |                                           |
|-------------------------|-------------------------------------------|
| Defense of Tonicity 600 | Defense of Specific Ionic Composition 601 |
| Defense of Volume 600   | Defense of $\text{H}^+$ Concentration 601 |

#### Section VIII References: 607

### Appendix . . . . . 609

|                                                         |                                                              |
|---------------------------------------------------------|--------------------------------------------------------------|
| General References 609                                  | Standard Respiratory Symbols 615                             |
| Normal Values & the Statistical Evaluation of Data 609  | Equivalents of Metric, United States, & English Measures 616 |
| Appendix References 612                                 | Greek Alphabet 616                                           |
| Abbreviations & Symbols Commonly Used in Physiology 612 |                                                              |

### Index . . . . . 617

#### Tables

|                                                                          |                    |
|--------------------------------------------------------------------------|--------------------|
| Atomic Weights . . . . .                                                 | Inside Front Cover |
| Ranges of Normal Values in Human Whole Blood, Plasma, or Serum . . . . . | Inside Back Cover  |