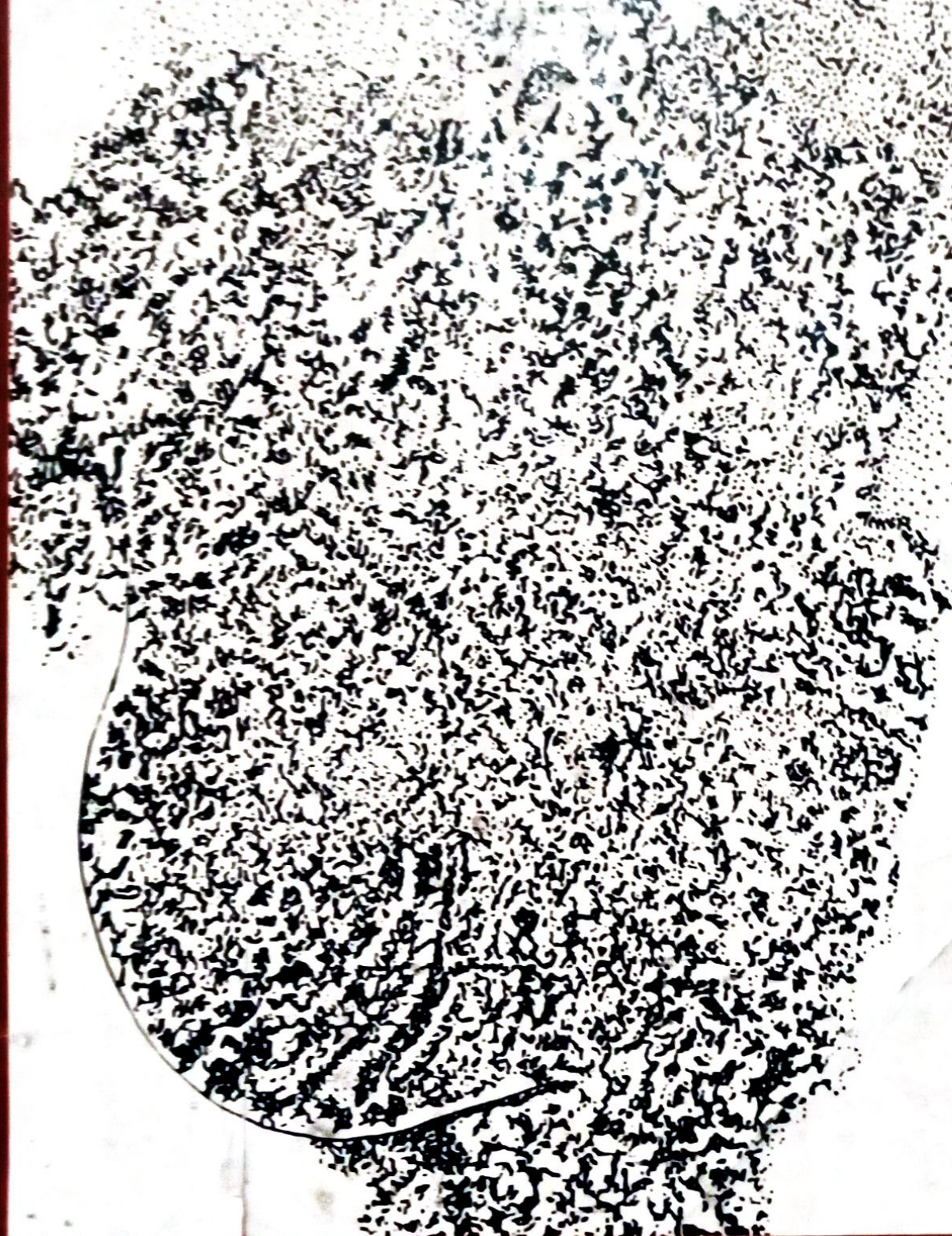


CELL PHYSIOLOGY

Fourth edition

ARTHUR C. GIESE, PH.D.



CONTENTS

INTRODUCTION / THE SCOPE OF CELL PHYSIOLOGY

Life Activities	1
Vitalistic and Mechanistic Interpretation of Life Activities	2
Experimental Approach in Cell Physiology	3
The Relation of Cell Physiology to Various Fields of Physiology	4
The Literature of Cell Physiology	4
Literature Cited and General References	5

1

APPLICATION OF THE LAWS OF THERMODYNAMICS TO THE CELL

Energy and Matter	7
The First Law of Thermodynamics: The Law of Conservation of Energy	7
The <u>Second Law of Thermodynamics</u>	8
Free Energy	9
Entropy and the Second Law of Thermodynamics	11
Coupled Reactions	13
Chemical Potential	13
The Cell and Thermodynamics	15
Energy Exchange and Life	15
The Law of Conservation of Matter and Life	17
Conversion of Mass to Energy	19
Literature Cited and General References	22
	23

Section I

Functional Organization of The Cell

2

CELL ORGANIZATION

Organelles Seen in Fixed and Stained Cells	25
Experimental Evidence for Cell Organelles in Living Cells	27
Variation in Organization of Animal Cells	28
Variation in Organization of Plant Cells	31
	34
	35
	xi

Variation in Organization of Prokaryotic Cells	36
The PPLO	37
Organization of Viruses	38
Appendix 2.1 Staining Techniques for Living and Fixed Cells	40
Appendix 2.2 Autoradiography	40
Appendix 2.3 Microscopical Techniques	41
Appendix 2.4 Microcinematography	49
Appendix 2.5 Micromanipulators	49
Literature Cited and General References	50

3

BIOCHEMISTRY OF THE CELL	53
Constituents of the Cell	53
Water, Free and Bound	57
Salts	57
Proteins	58
Colloidal Properties of Proteins	69
Nature of Structural Bonds Between Proteins	72
Lipids	73
Carbohydrates	75
Nucleic Acids—Deoxyribonucleic (DNA) and Ribonucleic (RNA)	77
Vitamins and Growth Factors	83
Chemical Composition of Cell Organelles	83
Chemical Composition of the Smallest Cells	85
Localization of Chemicals in Cell Organelles: Cytochemistry	86
Literature Cited and General References	89

4

THE STRUCTURE AND FUNCTIONS OF THE CELL ORGANELLES	92
The Endoplasmic Reticulum	92
The Ground Substance	95
Ribosomes and Ergastoplasm	95
Golgi Complex	99
Lysosomes	101
The Golgi-Endoplasmic Reticulum-Lysosome Complex	103
Mitochondria	103
Microtubules and Microfilaments	108
Plastids; Chloroplasts	110
Vacuoles	113
Cilia and Flagella	114
The Centrosome and the Centriole	115
Retinal Rod Cells	115
Summary	117
Literature Cited and General References	117

5

THE CHEMICAL ORGANIZATION AND FUNCTION OF THE CELL NUCLEUS

Relation Between Nucleus and Cytoplasm	121
Chemical Composition of the Nucleus—	
Cytochemistry	124
The Nucleolus	130
The Molecular Structure of the Chromosome	131
Deoxyribonucleic Acid Content of Nuclei	141
Ribonucleic Acid Content of Nuclei	141
Chemical Nature of the Gene	142
Comparison of the Genome in Bacteria,	
Viruses and Eukaryotic Cells	146
Summary	147
Appendix 5.1 Centrifugation for Separation and Study	
of Small Particles and Macromolecules	148
Literature Cited and General References	152

6

TEMPORAL ORGANIZATION OF THE CELL	157
Circadian Rhythms	158
Seasonal Circannual Rhythms	169
Literature Cited and General References	175

Section II

The Cell Environment	179
-----------------------------	-----

7

WATER, GASES AND PRESSURE IN THE CELL ENVIRONMENT	181
Water as a Factor in the Cell Environment	181
Carbon Dioxide in the Cell Environment	186
Oxygen in the Cell Environment	187
Pressure as an Environmental Factor	190
Literature Cited and General References	193

8

ELECTROLYTES IN THE CELL ENVIRONMENT	195
Acids, Bases and Hydrogen Ions	195
Dissociation of Weak Acids, Weak Bases and	
Water	196
The pH Scale	197
Measurement of the Strength of a Weak Acid by	
the pK_a	197

Buffers	208
Buffering Systems in the Cell Environment	209
Ampholytes in Electrophoresis	209
Resistance of Cells to pH Changes	209
Methods of Measuring pH	209
Relation Between Concentration and Activity of Electrolytes	209
Hydrogen and Hydrogen Ions	210
Salts	211
Halophilic Organisms	211
Organisms in Bacteria	212
Appendix 8.1 Buffer Mixtures Using a Weak Base and Its Salt	212
Literature Cited and General References	212

9	RADIATIONS IN THE CELL ENVIRONMENT	214
	Natural Radiations	214
	Photodynamic Sensitization of Cells	218
	Response in Photoreceptor Cells—Vision	220
	Effects of Ultraviolet Light on Cells	224
	Dark Recovery	230
	Characteristics of Different Kinds of Ionizing Radiations	231
	Effects of Ionizing Radiations on Cells	232
	Biological Effects of the Atomic Bomb	236
	Appendix 9.1 Absorption of Light in a Solution	236
	Appendix 9.2 Relation of X-Ray Wavelength to Voltage	239
	Appendix 9.3 The Range of an Electron	239
	Literature Cited and General References	240

10		
TEMPERATURE AS A FACTOR IN THE CELL ENVIRONMENT		243
The Biokinetic Zone		243
Heat Resistance and Heat Death of Active Cells		244
Cold Resistance and Cold Death of Active Cells		248
Thermal Resistance of Dormant Cells		252
The Rate of Thermochemical Reactions		253
Temperature Coefficients for Denaturation of Protein and Thermal Death of Cells		257
Temperature Effects on the Rate of Diffusion and Conductivity		258
Effect of Temperature on Photochemical and Photobiological Reactions		258
Temperature Coefficients and Limiting Reactions		258

Appendix 10.1 van't Hoff Equation for Q_{10}	259
Appendix 10.2 Calculation of Number of Activated Molecules	260
Appendix 10.3 Reaction Rate Theory	260
Literature Cited and General References	261

Section III

Exchange of Materials Across Cell Membranes 265

11

THE CHEMICAL NATURE AND STRUCTURE OF CELL MEMBRANES 267

Extraneous Membranes on Cells	267
Fine Structure of Cell Membranes	272
Chemical Content of Cell Membranes	274
Lipids in the Cell Membranes	275
Protein in the Cell Membranes	276
Thickness of Cell Membranes	277
Structure of Cell Membranes	279
The Nuclear Envelope	282
Cell to Cell Contacts	283
Compartmentalization of the Cell by Membranes	284
Literature Cited and General References	285

12

MOVEMENT OF WATER AND SOLUTES ACROSS CELL MEMBRANES IN RESPONSE TO A CONCENTRATION GRADIENT 289

WATER FLUX	292
Passage of Water Across Artificial Membranes:	
Osmosis	293
Permeability of the Plasma Membrane to Water	294
Osmotic Pressure of Nonelectrolytes	296
Osmotic Pressure of Electrolytes	297
Colligative Properties of Solutions	298
Movement of Fluids Due To a Difference in Hydrostatic Pressure	300
Cells As Osmometers	300
SOLUTE FLUX	302
Methods for Studying Permeability of Cell Membranes to Solutes	302
The Correlation of Permeability with Partition Coefficients	304
The Effects of Molecular Size Upon Permeability	306
Interaction Between Permeating Molecules	310

The Effect of Ionization Upon Permeability	310
Osmotic Relations in the Presence of Protein	311
Salt Antagonism	313
The Effect of Narcotics and Anesthetics Upon Permeability	315
The Effect of the Physiological State	316
Comparison of the Permeability of Different Kinds of Cells	316
Intracellular Movements of Water and Solutes	318
Exchange Diffusion	318
Countertransport	318
Appendix 12.1 The Staverman Reflection Coefficient	319
Appendix 12.2 The Kedem-Katchalsky Equation for Movement of a Solvent and Solute through a Cell Membrane	319
Literature Cited and General References	321
 13	
METABOLICALLY LINKED TRANSPORT THROUGH CELL MEMBRANES	324
Direct Measurement of Active Transport	327
Examples of Active Transport	328
Carriers	337
The Permease Carrier System	339
Applicability of the Michaelis-Menten Equation to Carrier Transport Kinetics	341
The Effect of Environment Upon Active Transport	341
Possible Mechanism of Active Transport	342
Literature Cited and General References	343
 14	
BULK TRANSPORT ACROSS CELL MEMBRANES	347
Endocytosis	347
Exocytosis	359
Conclusion	360
Literature Cited and General References	362
 Section IV	
Conversions of Energy and Matter in the Cell .. 365	
 15	
CELLULAR ENZYMES	367
Lowering the Energy of Activation by Enzymes	367
Classification of Enzymes	368

Hydrolytic Enzymes—Hydrolysis	368
Specificity of Hydrolytic Enzymes	370
The Chemical Nature of Enzymes	372
Activation of Hydrolytic Enzymes	373
Enzymes Involved in Cellular Metabolism	374
Effect of Environment on Enzyme Activity	378
Mechanism of Enzyme Action	382
The Michaelis-Menten Equation	384
Inhibition of Enzymes by Poisons	388
Literature Cited and General References	391

16

THE RELEASE OF ENERGY IN CELLS	393
The Nature of Oxidation-Reduction Reactions	393
Stepwise Release of Energy During Oxidation-Reduction Reactions	394
Pathway of Oxidation-Reduction Reactions in the Cell	394
Anaerobic Decomposition of Glucose	397
Aerobic Decomposition of Glucose	401
The Metabolic Mill	402
Hydrogen and Electron Transfer in the Main Line of Oxidation-Reduction Reactions	405
Alternate Pathways of Glucose Oxidation	408
Hydrogen Peroxide Formation as an End Product in Cellular Oxidation	412
Methods for Investigating Intermediary Metabolism	412
Enzymes in the Organelles of the Cell	413
Dynamic Nature of Cell Constituents	417
Literature Cited and General References	417

17

OXIDATION-REDUCTION POTENTIALS IN CELLULAR OXIDATION	420
Redox Potentials at Electrodes Immersed in Electrolytes	420
Measurement of Redox Potentials of Organic Compounds	423
The Effect of pH on Redox Potentials	425
Potentials Developed by Biological Redox Systems	426
Coupling of Univalent and Divalent Enzymatic Redox Systems	428
Detection of Free Radicals by Their Magnetic Properties	429

Determination of Redox Potentials in the Living Cell	432
Appendix 17.1 Derivation of Peter's Equation for Oxidation-Reduction Potentials	432
Appendix 17.2 Equation for the Effect of pH on Oxidation-Reduction Potentials	434
Appendix 17.3 Measurement of pH by the Quinhydrone Electrode	435
Appendix 17.4 Use of a Calomel Electrode Instead of a Hydrogen Electrode	435
Literature Cited and General References	435

18

CELLULAR RESPIRATION, FERMENTATION AND LUMINESCENCE

Aerobic Metabolism: Oxygen Consumption of Cells	437
The Effect of Temperature on Respiratory Rate	441
The Effect of Oxygen Partial Pressure on Respiration	441
Respiratory Inhibitors	443
The Effect of Water on Respiration	443
Respiratory Quotient (R.Q.) and Reduction Level (R.L.)	444
Heat Evolved During Respiration	446
Indirect Calorimetry	447
Anaerobic Metabolism: Glycolysis and Fermentation	448
Cell Oxidations with Emission of Light	450
Appendix 18.1 Various Methods for Measuring Respiration	454
Appendix 18.2 Relative Sensitivities of Various Methods	460
Literature Cited and General References	461

19

PHOTOSYNTHESIS

Photosynthesis as an Oxidation-Reduction Reaction	464
Light (Photochemical) Reactions in Photosynthesis	465
The Photosynthetic Unit	466
Photophosphorylation	467
The Function of Pigments in Photosynthesis	468
Evidence for Two Systems of Photochemical Reactions	469

Coupling Between Electron Transport and Phosphorylation	479
The Dark Reactions in Photosynthesis	480
C ₄ -Dicarboxylic Acid Photosynthesis	486
Crassulacean Plant Photosynthesis	488
Appendix 19.1 Quantum Efficiency of Photosynthesis	489
Appendix 19.2 Paper Chromatography	491
Literature Cited and General References	492

20

BIOSYNTHESIS	495
Nutritional Patterns	495
Biosynthesis of Small Molecules	496
Biosynthesis of Lipids	498
MACROMOLECULAR SYNTHESIS	499
Biosynthesis of DNA: Replication	499
RNA-Directed DNA Synthesis	506
Biosynthesis of RNA: Transcription	507
Biosynthesis of Protein: Translation	511
The Genetic Code	518
Extrachromosomal Inheritance	522
Coding for mRNA, rRNA and tRNA on DNA	522
Biosynthesis of Polysaccharides	523
Rate of Biosynthesis	524
Changes in Biosynthesis—Mutations	525
Development of Cell Organelles	526
Abiotic Organic Syntheses and the Origin of Life	527
Literature Cited and General References	530

21

REGULATION AND CONTROL OF CELL METABOLISM	533
Types of Regulation	533
Mass Action in Reversible Reactions	534
Competition for Shared Substrate	534
Allosteric Inhibition and Activation	534
Regulation of Nucleic Acid Synthesis	537
Regulation of Protein Synthesis	538
Enzyme Induction, Repression and Activation	538
Cyclic Adenosine Monophosphate As a Regulator	541
Regulation by Isozyme Formation	542
Regulation of Protein Degradation	543
Compartmentation	543
Regulation by Hormones—Intercellular Regulation	544
Literature Cited and General References	545

Section V

Excitability and Contractility 549**22****ACTION POTENTIALS OF CELLS** 551

The Nature of the Nerve Impulse	551
The Rate of Conduction of the Nerve Impulse	555
The Strength-Duration Relationship	557
Core Conductor Theory of the Nerve Impulse	558
Saltatory Conduction of the Nerve Impulse	560
Resting Metabolism of Nerve Cells	561
Activity Metabolism of Nerve Cells	562
Heat Production During Nerve Activity	563
Effects of Various Factors on the Action Potential of Nerve Cells	563
Action Potentials in Muscle Fibers	564
Action Potentials in Excitable Plant Cells	566
Literature Cited and General References	568

23**DEVELOPMENT, PROPAGATION AND TRANSMISSION OF THE ACTION POTENTIAL** 571

Resting Potentials Across the Cell Membrane	571
Origin of the Propagated Action Potential	578
Theory of the Propagation of the Action Potential	582
Sensory Fiber Action Potentials	585
Synaptic Transmission of Action Potentials	587
Appendix 23.1 Chemical Chain Potentials	594
Literature Cited and General References	595

24**CONTRACTILITY** 599

Cytoplasmic Streaming	599
Ameboid Movement	599
Movement of Pigment Granules in Chromatophores	600
Ciliary and Flagellar Movements	604
Muscular Movement	605
Contraction of Smooth Muscle Cells	608
Contraction of Cardiac Muscle Cells	608
Contraction of Skeletal (Body) Muscle Fibers	610
Fatigue	615
Development of Muscle Cells	620
Literature Cited and General References	622

25

THE CHEMICAL BASIS OF CONTRACTILITY	625
Evidence of Molecular Orientation in Muscle	625
Fibers	630
The Structural Proteins of Muscle Cells	633
Actomyosin	635
Source of Energy for Contraction	637
The Sliding Filament Mechanism of Muscular Contraction	638
Work and Heat Relations in Muscle Contractions	641
Excitation of Muscular Contraction	644
Relaxation of Muscle Cells	645
Mechanism of Contraction in Nonmuscular Cells	648
Literature Cited and General References	

Section VI

Growth and Cell Division	651
---------------------------------------	-----

26

CELL GROWTH	653
The Virus as a Model Replicating System	653
Life Cycle of a Cell Culture	656
Measuring Growth Rates of Cells	657
Growth of Cells in Tissue Culture	659
Growth of Cells in Tumors	664
Regulation of Form and Size in Cells	665
Unbalanced Growth	666
Regulation of Growth	667
Growth Studies on Single Cells	669
Literature Cited and General References	

27

CELL DIVISION	672
Cell Division Cycle	674
Synchronized Cell Division	681
DNA Synthesis During the Cell Cycle	682
RNA Synthesis During the Cell Cycle	682
Protein Synthesis During the Cell Cycle	684
Source of Energy for Cell Division	686
Blocking Cell Division	690
The Initiation of Cell Division	

xxii / CONTENTS

The Nature and Formation of the Mitotic	691
Apparatus	693
Cytokinesis in Animal Cells	696
Cytokinesis in Plant and Bacterial Cells	698
Literature Cited and General References	

Section VII

Trends in Cell Physiology	703
--	-----

28

TRENDS IN CELL PHYSIOLOGY: AN OUTLINE	705
--	-----

Literature Cited and General References	712
---	-----

Index	713
--------------------	-----