BIOCHEMISTRY:
FUNDAMENTALS AND BIOENERGETICS

Editors:
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Bentham Books

Biochemistry: Fundamentals and Bioenergetics

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Biochemistry: Fundamentals and Bioenergetics

Editors: Meera Yadav and H.S. Yadav

ISBN (Online): 978-1-68108-847-1

ISBN (Print): 978-1-68108-848-8

ISBN (Paperback): 978-1-68108-849-5

Bentham Science Publishers Ltd.
Executive Suite Y - 2
PO Box 7917, Saif Zone
Sharjah, U.A.E.
Email: subscriptions@benthamscience.net

CONTENTS

FOREWORD i

PREFACE ii

LIST OF CONTRIBUTORS iii

CHAPTER 1 SCOPE AND IMPORTANCE OF BIOLOGICAL CHEMISTRY 1

Nene Takio, Meera Yadav and *Hardeo Singh Yadav*

INTRODUCTION 1
CENTRE OF BIOCHEMICAL REACTIONS 2
BRANCHES IN BIOCHEMISTRY 2
Enzymology 2
Factors Affecting the Enzyme Activity 2
Endocrinology 4
Molecular Biology 5
Molecular Genetics and Genetic Engineering 5
Applications of Genetic Engineering 6
Structural and Metabolic Biochemistry 8
WHY UNDERSTANDING BIOCHEMISTRY IS IMPORTANT? 8
Importance of Biochemistry in Medicine 8
Drug Designing 8
Diagnosis 9
Nutrition 9
Importance of Biochemistry in Agriculture 10
Importance of Biochemistry in Nutrition 10
Importance of Biochemistry in Pathology 11
Importance of Biochemistry in Pharmacy 12
Drug Constitution 12
The Half-life 12
Drug Storage 12
Drug Metabolism 12
Importance of Biochemistry in Plants 12
Photosynthesis 13
Different Sugars 13
Plants Secondary Metabolites 13
RECENT TRENDS IN BIOCHEMISTRY 13
Human Genome Project 13
Application and Benefits of Human Genome Project (HGP) 14
Environmental Biochemistry 14
Biomarkers 15
Biosensors 16
Latest Developments in Environmentally Friendly Biosensors 17
Gene Therapy 21
CANCER 22
KEYWORDS 25
Genome 25
Biopsy 25
Genotype 25
Xenobiotics 25
Transgenes 26
SHORT-ANSWER TYPE QUESTION 26

LONG-ANSWER TYPE QUESTIONS 26
MULTIPLE CHOICE QUESTIONS 27
CONSENT FOR PUBLICATION 30
CONFLICT OF INTEREST 30
ACKNOWLEDGEMENTS 31
REFERENCES 31

CHAPTER 2 STRUCTURE OF WATER: ACID-BASE AND BUFFERS; HYDROGEN BONDING 33
Nivedita Rai, Shilpa Saikia, Meera Yadav and *Hardeo Singh Yadav*
INTRODUCTION 33
PHYSICAL AND CHEMICAL CHARACTERISTIC OF WATER 35
ACID AND BASE CONCEPT 36
Properties of Acids and Bases According to Robert Boyle 36
The Arrhenius Definition of Acids and Bases 36
Limitations of Arrhenius Theory 37
Bronsted Definition of Acids and Bases 38
Conjugate Acids and Bases 39
The Acid-Base Chemistry of Water 40
Lewis Acid-base Concept 41
pH Scale 43
HYDROGEN BONDING IN WATER 45
TYPES OF HYDROGEN BOND 46
HYDROPHOBIC 47
HISTORY 47
NOMENCLATURE 48
SUMMARY 48
LONG-ANSWER TYPE QUESTIONS 49
SHORT-ANSWER TYPE QUESTION 49
MULTIPLE CHOICE QUESTIONS 50
CONSENT FOR PUBLICATION 55
CONFLICT OF INTEREST 55
ACKNOWLEDGEMENTS 55
REFERENCES 56

CHAPTER 3 ELECTROSTATIC AND VAN DER WAALS FORCES 55
Nene Takio, Dencil Basumatary, Meera Yadav and *Hardeo Singh Yadav*
INTRODUCTION 55
FUNDAMENTAL FORCES IN BIOMOLECULES 55
Covalent Bonds 56
Non-Covalent Bonds 57
HYDROGEN BONDING 57
HYDROGEN BONDING AND ITS ROLE IN DNA 59
HYDROGEN BONDING IN PROTEINS 60
ELECTROSTATIC INTERACTIONS 61
ROLE IN PROTEIN FOLDING 64
MOLECULAR RECOGNITION 64
VANDER WAALS INTERACTIONS 64
Dipole-dipole/Keesom Interactions 67
Dipole Induced Dipole/Debye Forces 67
London Dispersion Forces 67
HYDROPHOBIC INTERACTION 68

Causes of Hydrophobic Interactions 68
Thermodynamics of Hydrophobic Interactions 69
Formation of Hydrophobic Interactions 69
Strength of Hydrophobic Interactions 69
Temperature 69
Number of Carbon Atoms on the Molecules 69
Shape of Hydrophobes 70
Hydrophobic Interactions in Protein Folding 70
Zwitterions 71
Glycine vs. Carbonic Acid 71
Titration Curves 72
Buffer Capacity and Buffer Intensity 72
ROLE OF FORCES IN BIOMOLECULES 72
SUMMARY 74
KEYWORDS 74
Vander Waals Contact Distance 74
Dipole-dipole Interactions 74
Thermophiles 75
Supramolecules 75
SHORT-ANSWER TYPE QUESTION 75
LONG-ANSWER TYPE QUESTIONS 75
MULTIPLE CHOICE QUESTIONS 76
CONSENT FOR PUBLICATION 88
CONFLICT OF INTEREST 88
ACKNOWLEDGEMENTS 88
REFERENCES 89

CHAPTER 4 INTRODUCTION TO PHYSICAL TECHNIQUES FOR DETERMINATION OF STRUCTURE OF BIOPOLYMERS 90
Nene Takio, Meera Yadav and *SonamTashi Khom*
INTRODUCTION 90
BIOPOLYMER TECHNIQUES 92
X-ray Crystallography 92
Diffraction in X-ray Crystallography 93
Applications 95
NMR (Nuclear Magnetic Resonance) 96
Electron Microscopy 98
Principle of Electron Microscopy 98
Types of Electron Microscopy 99
Transmission Microscopy (TEM) 100
SEM *VS*. TEM 101
SEM *vs*. TEM Advantages 101
Compared to SEMs, TEMs 101
Electron Tomography 103
SUMMARY 103
KEYWORDS 104
Mosaicity 104
Pleomorphism 104
Fourier Transforms 104
Synchrotrons 104
SHORT-ANSWER TYPE QUESTION 105

LONG-ANSWER TYPE QUESTIONS 105
MULTIPLE CHOICE QUESTIONS 105
CONSENT FOR PUBLICATION 116
CONFLICT OF INTEREST 116
ACKNOWLEDGEMENTS 116
REFERENCES 117

CHAPTER 5 STRUCTURE AND FUNCTION OF BIOLOGICAL BIOMOLECULES: CARBOHYDRATES, AMINO ACIDS, PROTEINS, NUCLEIC ACIDS, LIPIDS AND BIOMEMBRANES 118
Nagendra Nath Yadav, Saroj Yadav and *Archana Pareek*
CARBOHYDRATES 118
Synthesis of Carbohydrates 119
Function of Carbohydrates 120
Classification 120
Based on their Behavior Upon Hydrolysis 120
Based on their Taste 122
Based on their Reaction (Oxidation) 122
CLASSIFICATION OF MONOSACCHARIDES 122
STRUCTURE OF MONOSACCHARIDES 124
D & L CONFIGURATION (RELATIVE CONFIGURATION) 125
ENANTIOMER 125
Optical activity of sugars: (d+) or (l-) form 127
Racemic mixture: (±) or (d, l) form 127
ABSOLUTE CONFIGURATION (R, S - FORM) 127
FISCHER PROJECTION FORMULA OF CARBOHYDRATES 128
D-glyceraldehyde or R-(+)-Glyceraldehyde ($CHOCHOHCH_2OH$) 128
D-Glucose and D-Fructose 128
CYCLIC STRUCTURE OF MONOSACCHARIDES 128
PYRANOSE AND FURANOSE STRUCTURE 129
Structure of D-Fructose 130
HAWORTH PROJECTION FORMULA 130
ANOMERS AND MUTAROTATION 132
Structure of few monosaccharides 133
GLUCOSE (Dextrose or Grape Sugar or Blood Sugar) 133
Chemical Properties of Glucose (Tautomerization) 134
Formation of Glycosides 134
Oxidation Reaction 135
DISACCHARIDES (SUCROSE, MALTOSE AND LACTOSE) 138
Sucrose (table sugar, cane sugar, beet sugar) 138
Biological Importance 138
Inversion of Cane Sugar 138
Structure of Sucrose 139
Maltose (malt sugar) 139
Biological Importance 140
Structure 140
Lactose 141
Occurrence 141
Biological Importance 142
POLYSACCHARIDES (Starch, glycogen, and cellulose) 142
Starch (Homopolysaccharides from D-Glucose) 143

Occurrence 143
Biological Importance 143
Structure 143
Amylose 143
Amylopectin 144
Glycogen 144
Structure 144
Cellulose 145
Structure 145
AMINO ACIDS 146
Optical Isomerism in Amino Acid 147
Classification of Amino Acids 148
Non-polar Amino Acids having Hydrophobic R-groups 148
Polar Amino Acids with no Change on R-group 151
Polar Amino Acids with a Positive Charge on R-group 153
Polar Amino Acids with Negative R-group 154
Classification of Amino Acids Based on Nutritional Requirement 155
Chemical Properties 157
Reaction Due to –COOH Group 157
Reaction due to $-NH_2$ group 158
PROTEINS 160
Structure of proteins 162
Primary structure 162
β-pleated Sheet 164
Tertiary Structure of Protein 166
Quaternary Structure of Protein 167
Properties of Proteins 167
Colour Reactions 169
Xanthoprotic Test 169
Biuret Test 169
Millon's Reaction 169
Ninhydrin Reaction 169
Classification of Protein 169
Based on Biological Function 169
Simple Proteins 170
NUCLEIC ACIDS 172
Primary Structure 172
Bonding and Nomenclature of Nucleotides and Nucleosides 176
Nucleoside di- and tri-phosphate 178
Structure of polynucleotide (nucleic acid) 179
Secondary Structure 179
Tertiary Structure 180
Quaternary Structure 181
Structure of RNA 182
LIPIDS 184
Classification of Lipids 184
Derived Lipids 187
Nomenclature of Fatty Acids 190
Abbreviation of Nomenclature of Fatty Acids 190
Triacylglycerols (Triglycerides) 191
Structure of Acylglycerols 191

Properties of Triacylglycerols 192
Phospholipids 194
Cholesterol 198
Brassinosteroids 199
Terpenes 199
Carotenoids 200
Chlorophyll 200
BIO-MEMBRANES 200
Composition 201
Functions 203
KEYWORDS 203
Eukaryotic Cells 203
Thylakoid Membrane 203
Integral Protein 203
Peripheral Protein 204
Endocytosis 204
SHORT-ANSWER TYPE QUESTION 204
LONG-ANSWER TYPE QUESTIONS 204
MULTIPLE CHOICE QUESTIONS 204
CONSENT FOR PUBLICATION 211
CONFLICT OF INTEREST 211
ACKNOWLEDGEMENTS 212
REFERENCES 212

CHAPTER 6 STRUCTURE AND BIOLOGICAL FUNCTION OF VITAMINS 214
Nagendra Nath Yadav, Archana Pareek and *Sonam Tashi Khom*
INTRODUCTION 214
HISTORY 215
CLASSIFICATION 217
VITAMIN A 217
Sources of Vitamin A 220
Deficiencies of Vitamin A 220
Health Benefits of Vitamin A 221
Side Effects due to Excess of Vitamin A 222
VITAMIN D 222
Sources of Vitamin D 224
Deficiencies of Vitamin D 224
Health Benefits of Vitamin D 225
Side Effects due to Excess of Vitamin D 225
VITAMIN E 225
Source of Vitamin E 226
Deficiencies of Vitamin E 227
Health Benefits of Vitamin E 227
Side Effects due to Excess of Vitamin E 227
VITAMIN K 228
Sources of Vitamin K 229
Deficiencies of Vitamin K 229
Health Benefits of Vitamin K 230
Side Effects due to Excess of Vitamin K 230
VITAMIN C 230
Sources of Vitamin C 230

Deficiencies of Vitamin C 231
Health Benefits of Vitamin C 232
Side Effects due to Excess of Vitamin C 232
VITAMIN B-COMPLEX 232
VITAMIN B1 233
Sources of Vitamin B1 233
Deficiencies of Vitamin B1 233
Health Benefits of Vitamin B1 234
Side Effects Due to Excess Vitamin B1 234
VITAMIN B2 235
Sources of Vitamin B2 235
Deficiencies of Vitamin B2 236
Health Benefits of Vitamin B2 236
Side Effects due to Excess of Vitamin B2 236
VITAMIN B3 236
Sources of Vitamin B3 237
Deficiencies of Vitamin B3 237
Health Benefits of Vitamin B3 238
Side Effects Due to Excess of Vitamin B3 238
VITAMIN B5 239
Sources of Vitamin B5 239
Deficiencies of Vitamin B5 239
Health Benefits of Vitamin B5 240
Side Effects Due to Excess of Vitamin B5 240
VITAMIN B6 240
Sources of Vitamin B6 241
Deficiencies of Vitamin B6 241
Health Benefits of Vitamin B6 241
Side Effects Due to Excess Vitamin B6 242
VITAMIN B7 242
Sources of Vitamin B7 242
Deficiencies of Vitamin B7 243
Health Benefits of Vitamin B7 243
Side Effects Due to Excess Vitamin B7 244
VITAMIN B9 244
Sources of Vitamin B9 245
Deficiencies of Vitamin B9 245
Health Benefits of Vitamin B9 245
Side Effects Due to Excess Vitamin B9 246
VITAMIN B12 246
Sources of Vitamin B12 247
Deficiency of Vitamin B12 247
Health Benefits of Vitamin B12 248
Side Effects Due to Excess Vitamin B12 249
KEYWORDS 249
Prosthetic Group 249
Collagen 249
Polyneuritis 249
Multiple Sclerosis 249
Ataxia 249
Skeletal Myopathy 249

Retinopathy ... 249
Bulimia ... 249
Korsakoff's Syndrome ... 249
Leigh's Disease ... 250
Maple Serum Urine Disease ... 250
Keratoconus ... 250
Glaucoma ... 250
Hartnup Disease ... 250
Megaloblastic Anemia ... 250
VERY SHORT ANSWER TYPE QUESTION ... 250
SHORT-ANSWER TYPE QUESTIONS ... 251
LONG-ANSWER TYPE QUESTIONS ... 251
MULTIPLE CHOICE QUESTIONS ... 251
CONSENT FOR PUBLICATION ... 257
CONFLICT OF INTEREST ... 257
ACKNOWLEDGEMENTS ... 258
REFERENCES ... 258

CHAPTER 7 ENZYMES (BIOCATALYST) ... 261
Nagendra Nath Yadav, Archana Pareek and *Kamlesh Singh Yadav*
INTRODUCTION ... 261
ENZYME STRUCTURE ... 262
NOMENCLATURE AND CLASSIFICATION ... 262
Recommended Name ... 262
Systematic Name ... 264
FACTORS AFFECTING ENZYME ACTIVITY ... 265
Concentration of Enzyme ... 265
Substrate Concentration ... 266
Effect of Temperature ... 267
Temperature of Coefficient (Q10) ... 267
Effect of pH ... 268
Effect of the Concentration of Product ... 268
ENZYME KINETICS ... 268
Mechanism of Enzyme Action ... 270
Enzyme-substrate Complex Formation ... 270
Fisher's Lock and Key Model or Fisher's Template Theory ... 271
Koshland's Induced Fit Model ... 271
ENZYME INHIBITION ... 272
Reversible Inhibition ... 272
Competitive Inhibition ... 272
Non-competitive Inhibition ... 273
Irreversible Inhibition ... 274
PHYSICO-CHEMICAL NATURE OF ENZYME ... 274
CHARACTERISTICS OF ENZYMES ... 274
COENZYMES ... 276
BIOLOGICAL FUNCTIONS OF COENZYME ... 277
Adenosine triphosphate (ATP) ... 278
Thymine Pyrophosphate (TPP) ... 278
Flavin mononucleotide (FMN) ... 278
Nicotinamide adenine dinucleotide (NAD^+) ... 278
Biocytin ... 278

CONTROL ACTIVITY OF ENZYMES 278
Regulation 278
Post-translational Modification (PTM) 278
Quantity 278
Subcellular Distribution 279
Organ Specialization 279
KEYWORDS 279
Catalyst 279
Dialysis 279
Denaturation 279
Biological Catalyst 279
SHORT-ANSWER TYPE QUESTIONS 279
LONG-ANSWER TYPE QUESTIONS 280
MULTIPLE CHOICE QUESTIONS 280
CONSENT FOR PUBLICATION 283
CONFLICT OF INTEREST 284
ACKNOWLEDGEMENTS 284
REFERENCES 284

CHAPTER 8 HORMONES 285
Nagendra Nath Yadav and *Archana Pareek*
INTRODUCTION 285
CLASSIFICATION OF HORMONES 288
According to the Chemical Nature 288
On the Basis of the Mechanism of Action 289
According to the Nature of the Action 289
According to the Effect 289
On the Basis of Stimulation of Endocrine Glands 290
Adrenocorticotropic Hormones (ACTH) 290
Thyroid-Stimulating Hormone (TSH) 291
Growth Hormones (GH) 292
Oxytocin 293
Vasopressin 293
Aldosterone 294
Adrenaline 295
Noradrenaline 296
Estrogen 296
Progesterone 297
Testosterone 298
Luteinizing Hormone (LH) 298
Follicle-stimulating Hormone (FSH) 299
Prolactin (PRL) 299
REGULATION OF HORMONES 299
HORMONES IN PLANTS 300
Type of Plant Hormones 300
Auxins 300
Cytokinins 301
Gibberellins 302
Ethylene 303
Abscisic Acid 304
HORMONES IN INSECTS 305

Brain Hormones 305
Molting Hormones 307
Juvenile Hormones 309
KEYWORDS 310
T-cells 310
Glucogenesis 310
Glycoprotein 310
Addison's Disease 310
Osteoporosis 310
Tonicity 310
Rosette Plant 310
SHORT-ANSWER QUESTIONS 310
LONG-ANSWER TYPE QUESTIONS 311
MULTIPLE CHOICE QUESTIONS 311
CONSENT FOR PUBLICATION 318
CONFLICT OF INTEREST 318
ACKNOWLEDGEMENTS 318
REFERENCES 318

CHAPTER 9 FUNDAMENTALS OF THERMODYNAMICS: PRINCIPLE APPLICABLE TO BIOLOGICAL PROCESSES 323
Nene Takio, Pratibha Yadav and *Anindita Hazarika*
INTRODUCTION 323
What is the Basic Concept of Thermodynamics? 324
STATE VARIABLES 325
ENERGY TRANSFER INTO HEAT & WORK 326
THE FIRST LAW: LAW OF CONSERVATION OF TOTAL ENERGY 327
ENTHALPY IS A USEFUL FEATURE FOR BIOLOGICAL SYSTEMS 328
THE SECOND LAW: SYSTEM TENDS TOWARD DISORDER AND RANDOMNESS 329
Attributes of the Entropy Function 330
THE THIRD LAW: ENTROPY CHANGE AT ABSOLUTE ZERO 331
GIBBS FREE ENERGY 332
THE STANDARD STATE FREE ENERGY CHANGE 332
THERMODYNAMIC PARAMETERS AFFECTING BIOCHEMICAL EVENTS 334
EFFECT OF PH ON STANDARD FREE ENERGIES CHANGE 335
REACTION OF CONCENTRATION AND FREE ENERGY CHANGE 335
COUPLED PROCESS 336
ATP (ADENOSINE TRIPHOSPHATE) 338
THERMODYNAMIC HYDROLYSIS OF ATP 339
Structure of ATP 339
FACTORS AFFECTING HYDROLYSIS OF FREE ENERGY OF ATP 340
HYDROLYSIS OF ATP AND EQUILIBRIA OF COUPLED REACTIONS 342
DAILY HUMAN REQUIREMENT FOR ATP 343
SUMMARY 344
KEYWORDS 344
Pyruvate 344
Denaturation 344
Calorimeter 345
Glycolysis 345
Phototrophs 345

SHORT-ANSWER TYPE QUESTION 345
MULTIPLE CHOICE QUESTIONS 346
CONSENT FOR PUBLICATION 359
CONFLICT OF INTEREST 359
ACKNOWLEDGEMENTS 359
REFERENCES 359

CHAPTER 10 BIOENERGETICS, METABOLISM OF BIOMOLECULES, PHOTOSYNTHESIS AND RESPIRATION, TRANSCRIPTION AND TRANSLATION, RECOMBINANT DNA TECHNOLOGY 361
Saroj Yadav, Kamlesh Singh Yadav and *Pratibha Yadav*
INTRODUCTION 361
BIOENERGETICS 364
Theory of Bioenergetics 364
Laws of Thermodynamics in Bioenergetics 364
Equilibrium Constant and Free Energy 366
Endergonic and Exergonic Reactions 367
Exergonic Reactions 367
Endergonic Reactions 368
Activation Energy 369
Coupled Reaction in Bioenergetics 370
METABOLISM OF CARBOHYDRATES 372
Glycolysis 372
Classification of Glycolysis 372
Glycolysis Pathway in Steps 373
Glucose Activation Phase 374
Step-1 374
Step-2 374
Step-3 374
Step-4 374
Step-5 375
Payoff Phase 375
Step-6 375
Step-7 375
Step-8 376
Step-9 376
Anaerobic Condition 377
Significance of the Glycolysis Pathway 377
LIPIDS METABOLISM 378
Biosynthesis of Lipid 379
Degradation of Lipid 381
METABOLISMS OF PROTEINS 381
Protein Synthesis 381
Chemical Synthesis of Protein 382
Protein Degradation 383
METABOLISM OF NUCLEIC ACID 384
Synthesis of Nucleic Acids 384
Decomposition of Nucleic Acid (DNA and RNA) 387
Catabolism of Pyrimidine 387
Purine Catabolism 388
PHOTOSYNTHESIS AND RESPIRATION 388

Similarities between Photosynthesis and Respiration ... 389
OXIDATIVE PHOSPHORYLATION ... 390
Electron Transport and Synthesis of ATP ... 390
DNA REPLICATION ... 392
TRANSCRIPTION ... 393
Formation of pre-mRNA ... 394
TRANSLATION ... 395
Transfer RNA ... 396
Protein Synthesis ... 397
RECOMBINANT DNA TECHNOLOGY ... 398
Instruments for Recombinant DNA Innovation: ... 399
Recombinant DNA Technology Steps ... 399
Application of Recombinant DNA Technology ... 400
SUMMARY ... 400
KEYWORDS ... 402
Glycolysis ... 402
The Cycle of Citric Acid ... 402
Ketosis ... 402
Oxidative Phosphorylation ... 403
Photosynthesis ... 403
Catabolism ... 403
Photorespiration ... 403
Recombinant DNA ... 403
LONG QUESTIONS ... 403
SHORT-QUESTIONS ... 404
MULTIPLE CHOICE QUESTIONS ... 405
CONSENT FOR PUBLICATION ... 409
CONFLICT OF INTEREST ... 409
ACKNOWLEDGEMENTS ... 409
REFERENCES ... 409

SUBJECT INDEX ... 411

FOREWORD

It is immense pleasure to write the forward of the book titled "Biochemistry: Fundamentals and Bioenergetics" edited by Dr. Meera Yadav and Prof. H.S. Yadav, which is comprehensive and highly informative for the students. I also believe that teachers and scholars at every level and stage of their careers can enrich and strengthen their knowledge of biological chemistry by updates and practices presented in this book. The initial interest in the area of biological chemistry became intense as new tools and techniques of biotechnology came into existence. Biological chemistry is continuously and steadily progressing at the laboratory level and at the computational level. The authors and editors have chosen the specific topics and details that are important and relevant to the chemistry behind life sciences.

This book discusses a wide range of topics related to the fundamental and applied aspects of the chemistry behind life sciences. The book contains a range of topics, including the scopes and importance of biochemistry, the latest physical techniques to determine structures of biomolecules, detailed classification, structure and function of biomolecules like carbohydrates, lipids , amino acids, proteins, nucleic acids, enzymes, hormones as well as the thermodynamics of life sciences and bioenergetics and metabolism of biomolecules. It also deals with photosynthesis and respiration, oxidative phosphorylation, DNA replication, transcription and translation, and recombinant DNA technology.

The book has contributions from scientists, teachers and research scholars. The editors have done a commendable job in bringing and collecting and compiling a wide range of excellent papers shared by expert researchers . The collection of expertise and knowledge has been shaped to provide a unique piece of work in the form of a book. I am very much confident that the book should prove to be a very useful source of knowledge to the students, teachers, research scholars, scientists, engineers and doctors in the disciplines of life sciences, microbiology, biochemistry, biotechnology and engineering.

I express my sincere appreciation to the editors for their contributions and I am sure that this book will be very handy and widely used especially by the aspiring young generation students who wish to create a niche in the field of biological chemistry.

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PREFACE

Based on progressive experimental achievements of biochemists and biologists, biochemical information is updated day by day and documented in the form of a book. Biochemistry is continuously and steadily progressing at the laboratory level to life sciences. We therefore have chosen specific topics and details that are important and relevant to understand the fundamentals of biological chemistry.

This textbook mainly aims to fulfill the requirement of undergraduates, postgraduates and research students having strong chemistry background with an ambition to enter into the biochemistry field. It is also helpful to instructors to get updates related to the field of biochemical sciences with little effort. The topics are explained, ranging from basics to a detailed knowledge in the area of biochemistry. To enable students to grasp the key points of chapters, keynotes have been included and a brief summary is given at the end of chapters.

We have attempted to integrate chemical concepts and details throughout the text. It includes the scope and nature of chemical forces, structural and mechanistic basis for the action of biomolecules, the thermodynamic basis for the folding and assembly of proteins and other macromolecules. Bearing specific functional groups, biomolecules are important intermediates for the synthesis of many chiral medicines and are widely used in the preparation of hormones, flavors, fragrances, liquid crystals and chiral auxillaries. These fundamental topics will help in understanding of all biological processes taking place. Our goal is to provide pricise and detailed view on specific topics concerning biological chemistry that will enable students to understand how the chemical features help to meet the biological needs.

Chemical insight often depends on a clear understanding of the structures of biochemical molecules. We have taken considerable care in preparing structures of stereochemically biomolecules. These structures should make it easier for the student to develop an intuitive feel for the shapes of molecules and comprehension of how these shapes affect reactivity *i.e* structure function relationship.

This edition of Biochemistry: Fundamentals and Bioenergetics offers a wide selection of high-quality supplements to assist students and instructors.We are optimistic to see the satisfaction of students and teachers aspiring to have clear concepts and knowledge in the area of biological chemistry. The editors and authors confirms that this book content has no conflict of interest.

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CHAPTER 1

Scope and Importance of Biological Chemistry

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Abstract: Biochemistry allows us to understand how various chemical processes in all living organisms interact and function to support life. It covers a wider range of scientific disciplines, which are sub-categorised into different branches. In this unit, the importance of biochemistry in medicine, health sectors, nutrition, and the living system has been discussed in detail. It also helps to understand biological phenomena of the environment and its conversation, genetic manipulations of genes *via* recombinant DNA technology and gene sequencing *via* human genome project. The knowledge of biochemistry has advanced tremendously and in forthcoming years, it has a potential role in unravelling the mystery of life processes.

Keywords: Biomarkers, Biopsy, Genome, Genotype, Transgenes, Xenobiotics.

INTRODUCTION

Biochemistry, as an interdisciplinary subject, includes a wide range of scientific disciplines like life sciences, forensics, chemical sciences, plant sciences, and medicine. It focuses on the chemical processes occurring within the living system at the molecular level. Therefore, there is a need for a biochemical approach because biochemistry attempts to understand the chemical composition, structure, biological functions and metabolism of biomolecules and in this process, it goes much deeper into the problem of life than any other branch of science. The term 'Biochemistry' was first coined in 1903 by a German chemist named Carl Neuberg. During the last two decades, knowledge of biochemistry has advanced tremendously and in forthcoming years, it is predicted to have a potential role in unraveling the mystery of the processes of life [1].

The concept of biochemistry is very old; its knowledge and understanding have been applied for exploring and investigating components of a living system for more than a thousand years. Modern biochemistry will help in a better understanding of enzymes, molecular biology and their functions in the body.

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Cells and tissues in the human body are made up of chemical elements like H_2, C, N, O, Ca and P, which play a pivotal role in overall body functions and form a vital part of biochemistry [2].

CENTRE OF BIOCHEMICAL REACTIONS

DNA is the core part where genetic material stores data, directs and controls all biochemical reactions. It directs the cell to release chemicals like enzymes to perform various mechanical functions like replication, synthesis, digestion, catalysis, *etc*., which occur in a regulated manner. The information is contained long sequences of nucleic acid subunits and each subunit is made up of four nucleotides. The sum of weak interactions between molecules affects the overall stability of the biological structures and functions. All the biochemical reactions follow the 2nd law of thermodynamics, stating that all systems with spontaneous reactions run “downhill,” motion with an increase in entropy or randomness [3, 4].

BRANCHES IN BIOCHEMISTRY

Biochemistry is a diverse subject quite useful in all other branches of science. Nowadays, it has been sub-categorised into different branches to study different biological functions involving RNA and DNA, protein synthesis, cell membrane and much more. Some of these have been discussed below:

Enzymology

It is a study of properties and biological functions of enzymes like enzymatic activity, kinetics, enzyme-substrate complex, the kinetics of the reaction, enzymatic regulation, and transition state, *etc*. They fulfill a multitude of functions in living organisms. They are essential for signal transmission and cellular control, usually by kinases and phosphatases. They also produce movement with ATP, which hydrolyzes myosin to induce muscle contraction as well as moves cargo in and out of the cell. Other cell membrane ATPases are active transport ion pumps [5]. Enzymes like amylases and proteases present in the intestine participate in the digestive system and breakdown of large molecules like starch and proteins into smaller ones.

Factors Affecting the Enzyme Activity

Clinical enzymology is another sub-branch of biochemistry that deals with the studies of enzymes responsible for prolonged diseases and their diagnosis. Enzymes are highly specific and selective, therefore required in small quantities with high purity.The reaction rate is the maximum when an enzyme gets fully saturated with substrate, designated as Vmax. The affinity of an enzyme with substrate influence the relationship between the reaction rate and concentration of substrate normally represented as the Km (Michaelis-Menten constant) of an enzyme. For practical purposes, Km is defined as the concentration of substrate at which the enzyme achieves its half Vmax. A high Km value represents the low affinity of the enzyme with a substrate and to achieve Vmax, a higher concentration of substrate is required. The favoured kinetic properties of these enzymes are low Km and high Vmax for maximum efficiency at low enzyme and substrate concentrations, as shown in Fig. (**1**). Thus, to avoid contamination from incompatible materials, the enzyme source is selected with utmost care to get a purified enzyme. Enzymes have huge potential in the therapeutic application for treating cancer [6], such as Asparaginase, has proved to be efficient in treating acute lymphocytic leukaemia. Its action relies upon the fact that tumour cells have poor aspartate-ammonia ligase activity,which limits their potential to synthesize the typically non-essential amino acid L-asparagine [7]. Table **1** shows various applications of enzymes in clinical diagnosis.

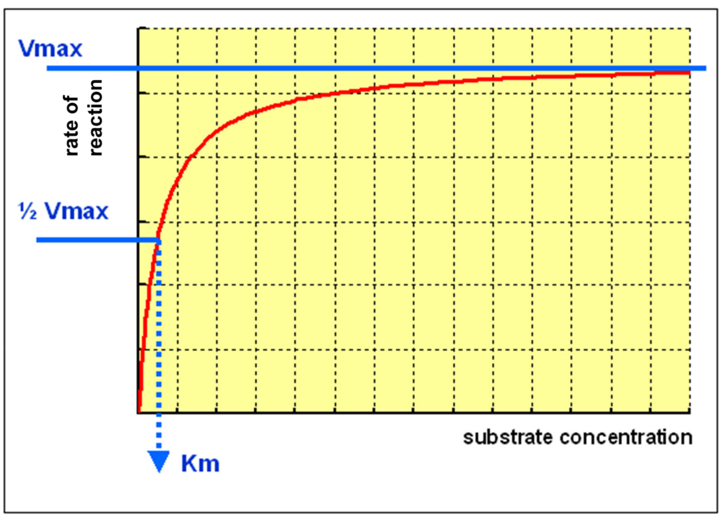

Fig. (1). Rate of reaction *vs* substrate concentration.

Table 1. Uses of enzyme for diagnostic purposes.

S.No.	Enzyme for diagnostic purpose	Estimation of	Method of estimation
1	Urease	Urea	Rapid Ureate Test(RUT)
2	Uricase	Uric acid	A colorimetric method
3	Glucose oxidase	Glucose	Glucose oxidase method

CHAPTER 2

Structure of Water: Acid-Base and Buffers; Hydrogen Bonding

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Abstract: Water, being a universal solvent, makes up to 70% of the weight of living organisms. The amphoteric nature of water is explained by Lewis and Bronsted acid-base theory. Hydrogen bonding is crucial in many chemical processes. It is accountable for having water's unique solvent capabilityand also for hydrophobic effect. This chapter discusses in detail the hydrogen bonding between neighbouring water molecules and theirrole in physical and chemical changes in the water molecule. It also discusses the relationship between pressure and temperature in water *via* a phase diagram.

Keywords: Acids, Bases, Buffer, Hydrogen bonding.

INTRODUCTION

Water (H_2O) is the basic need of every single living being, making up to 70% or a greater amount of the weight of most life forms. Water comprises little polar V-shaped particles with molecular formula H_2O. It is viewed as the widespread universal solvent for reasons including its basic, synthetic, and physical properties. These properties bring about numerous extraordinary attributes of water [1].

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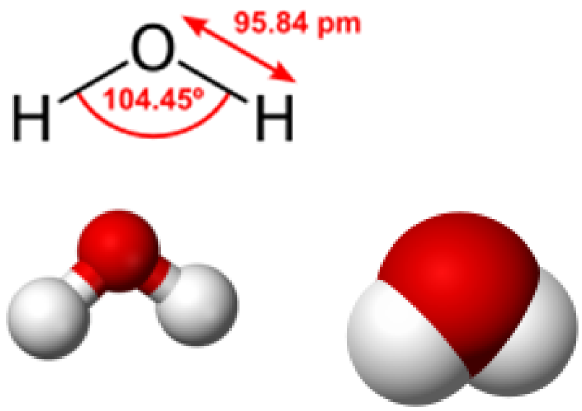

Water is a very small bent molecule, consisting of two hydrogen atoms connected to a heavier oxygen atom. Water molecule possesses a neutral charge, but polarity lies with the center of positive and negative charges located oppositely. Each hydrogen atom has a core comprising a unit positively charged and proton encircled by a 'cloud' of a unit negatively charged electron. Oxygen atom similarly has a core comprising of eight positively charged protons and eight uncharged neutrons encircled by a 'cloud' of eight negatively charged electrons.

The water molecule contains ten paired electrons in five 'orbitals'; one pair of the electron is connected with the oxygen atom, the other two pairs of electrons are associated as 'outer' electrons on the oxygen atom and the remaining two electron pairs form each of the two similar hydroxyl (O-H) covalent bonds.

Water molecules are polar in nature and form a hydrogen bond with other water molecules. The polarity of water permits it to isolate particles of salts and get strongly bonded to other polar substances, for example, acids, alcohols, *etc*., consequently dissolving them.

Hydrogen bonding of water is responsible for its various unique properties, like the density of its solid form (ice) is less compared to its liquid form; it generally possesses a high boiling point of 100 °C and has a high molar heat capacity.

Water is amphoteric in nature, *i.e.* it has both an acidic and a basic character, and self-ionizes to H^+ and OH^- ions. At a fixed temperature, the product of the concentrations of H^+ and OH^- ions is constant. Since water is an excellent solvent, it is rarely pure. There are numerous other compounds that are not soluble in water, like oils, fats and other nonpolar substances [2].

Names	
IUPAC name	Water, oxidane
Other names	Hydrogen hydroxide(HH or HOH), Hydrogen oxide, Di-hydrogen monoxide(DHMO), Hydrogen monoxide, Di-hydrogen oxide, Hydric acid, Hydroxic acid, Hydrol. μ-oxido dihydrogen

Water nomenclature table

PHYSICAL AND CHEMICAL CHARACTERISTIC OF WATER

- Water has no taste and has no odour at the standard condition of temperature and pressure. It is colorless when present in small quantities, however, the color of water and ice appears to a very light blue. Additionally, ice also appears colorless and the vaporized form of water essentially appears invisible as a gas.
- It is translucent, and as daylight can enter the aquatic plants, they can survive within the water. UV light isrelatively less absorbed.
- The shape of the water molecule is nonlinear V-shaped. The electronegativity of the oxygen atom of the water molecule is higher than the electronegativity of the hydrogen atoms and hence there is a small -ve charge on the oxygen atom and +ve charge on the hydrogen atom. Therefore water is a polar molecule having a net dipole moment. Likewise, water can form a remarkably large number of intermolecular hydrogen bonds (four) for a particle of its size. Because of these unique factors of water, there is a strong attractive force between the molecules of water as a result of which water develops a very high capillary force and high surface tension. With capillary movement, water goes up against the force of gravity through small capillary tubes. All vascular plants, for example, trees, depend on this property.
- It is a very good solvent and hence it is considered a universal solvent. Substances thatcan dissolve in water, *e.g*. sugars, acids, alkalis salts and few gases such as oxygen and carbon dioxide (carbonation) are called hydrophilic which means water-loving in nature and those substances which don't dissolve well in water (*e.g*. oils and fats), are called as hydrophobic which means water-hating in nature.
- All the biomolecules which are found in the cells are also soluble in water.

For example, DNA, proteins, polysaccharides, *etc*.

- Water in its pure form conducts very low electricity but conductivity can be greatly improved by dissolving a small quantity of ionic solid such as NaCl.
- The boiling point of water depends upon the barometric pressure. At the top of Mt. Everest, for example,water boils at 68°C, while at sea level, it boils at

CHAPTER 3

Electrostatic and Van Der Waals Forces

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Abstract: Non-covalent intermolecular interactions are the fundamental forces which defines all the shape and structural stability of the biomolecules. Hydrogen bonds hold strands of DNA together and also responsible for determining the three-dimensional structure of folded proteins, whereas electrostatic and vander waals interactions are found to be a dominant factor in determining conformation of biomolecules. Noncovalent forces are individually weak relative to covalent bonds, but the cumulative effect of such interactions in a protein or nucleic acid can be very significant. They all play a fundamental role in fields as diverse as supramolecular chemistry, structural biology, polymer science and nanotechnology.

Keywords: Covalent and non covalent forces, Dipole-Dipole interactions, Ionic bonds, Thermophiles: Supramolecules, Vander waals contact distance.

INTRODUCTION

Molecular interactions, also known as non-covalent interactions, are attractive or repulsive forces involving atoms and molecules. These are significant for the determination of structural biomolecules, drug designing, material science, sensors, nanotechnology, and chemical sciences. In the biological processes, non-covalent interactions allow protein and ribosomal RNAs folding to form globular structures, and also help the formation of the DNA double-helical structure. These stabilize the assembly of proteins with DNA, RNA and other proteins, and help in the formation of phospholipids in the membrane. Hence, understanding the forces behind the interactions between biomolecules is essential, providing a better perspective on how a living system functions.

FUNDAMENTAL FORCES IN BIOMOLECULES

Covalent bonds with high energy formation are considered to be much stronger than the bonds in biomolecules, but still, they manage to hold the complex mole-

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cular structure with great ease since all these small non-covalent forces have a very strong cumulative effect on bimolecular stability. A double-stranded helical DNA with thousand base pairs held by different stacking forces is considered, as shown in Fig. (**1**).

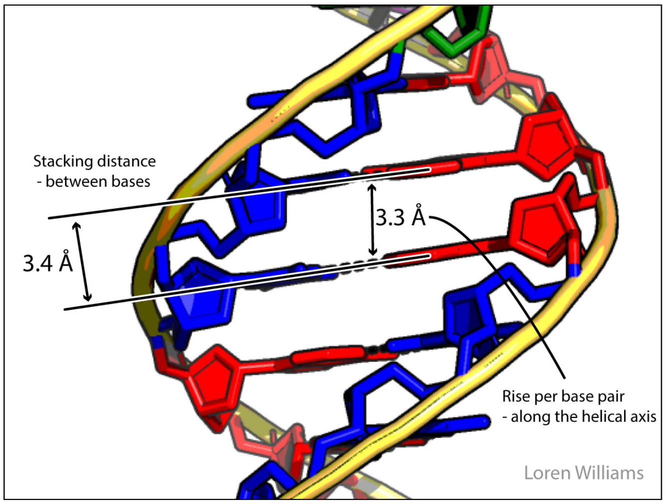

Fig. (1). Base pair stacking in B-DNA. Short range repulsion sets a distance of 3.4 Å between base pairs. Major stacking forces- Hydrophobic Interactions Van der Waals forces. https://ww2.chemistry.gatech.edu/~lw26/structure/molecular_interactions/mol_int.html.

The base pair energy of the average base pair, which is about 0.5 kJ/mol, is not very large, but the energy range of 1000 base pairs is 500 kJ/mol, which is equal to the range of many covalent bonds. It also has important implications for the mobility of individual base pairs. These can be easily opened when whole molecules are held together. These weak and uncoordinated forces play an important role in DNA replication, 3-dimensional protein synthesis, enzyme-substrate complex formation, and also in molecular signals identification. Infact, all biological compositions and processes are interdependent on covalent and non-covalent interactions. Some of the forces responsible for the structural determination of proteins have been discussed below (Fig. **2**).

These include:

Covalent Bonds

1. The breakdown of protein-peptide bonding with the respective amino acids can be achieved by acidic or alkali treatment or by enzymatic treatment. *e.g.*, Proteases.
2. A disulfide bridge is formed between cysteines and cystine. (Cysteine has

another HS- and -SH that forms the disulfide-SS- bridge). The bridge is destroyed by reduction with β-mercaptoethanol and cysteine is reformed [2].

Non-Covalent Bonds

1. Hydrogen bonds – Biological components like proteins are made up of hydrogen bonds thatplay an important role in stability because these are away from water (which disrupts them). They can be broken down by overheating.
2. Van der Waals forces – These are short dipole-dipole (δ+ & δ-) interactions between closely distances atoms. The bonds can be broken down by denaturing agents like heat, chemicals, *etc.*
3. π-π overlap – These are delocalized in rings with π electron clouds and easily break down by heat.
4. Electrostatic or ionic interactions and salt bridges in biomolecules.

These also get easily disrupted by changes in ionic strength or pH.(*e.g.*, positive residues include Arg, His: while negative residues include Asp, Glu, Cys). They all differ in structure, arrangement, strength, and specificity. Also, all the bonds behave differently in the presence of water [1].

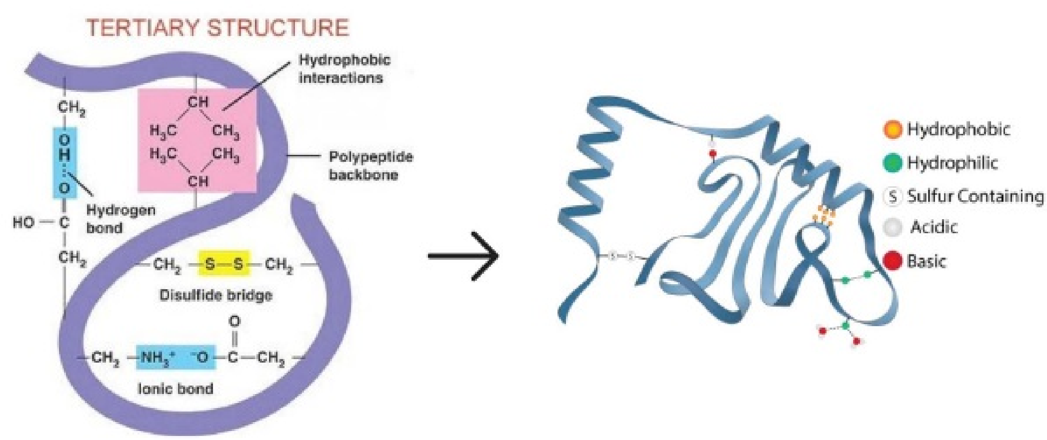

Fig. (2). Different forces in protein stability.

HYDROGEN BONDING

Hydrogen bonding is considered a strong bond that participates in many important chemical processes. This is also responsible for the hydrophobic effect and unique solvent capabilities. This bond formed is between uncharged molecules as well as charged ones. The atom that hydrogen is most strongly bonded to is called H donor, while the other atom is said to be an H acceptor with a partial negative charge that attracts hydrogen. These are the strongest dipole-dipole interactions

CHAPTER 4

Introduction To Physical Techniques for Determination of Structure of Biopolymers

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Abstract: Biopolymers perform important cellular processes, which are isolated, purified and studied with the help of a wide range of biophysical, electrochemical and molecular biology techniques such as NMR, X-ray Crystallography, Electron Microscopy, and Electron Tomography. X-ray Crystallography helps us to establish 3D structures of small and large molecules at atomic resolution *via* the X-ray diffraction method, whereas NMR determines the content and purity of a sample. Electron microscopy obtains high-resolution images of biological and non-biological specimens and electron tomography provides three-dimensional density maps of the pleomorphic organism from macromolecular complexes to cells.

All these techniques, discussed in this unit, provide us a greater insight to unravel the mystery of complex organisms and to understand the structure and functional properties of the biomolecules.

Keywords: Fourier transform, Macromolecules, Mosaicity, Pleomorphism, Synchrotons.

INTRODUCTION

Biopolymers such as DNA, RNA and proteins plays key role in the cellular processes like cell differentiation, cell growth, maintenance, repair, recombination, transcription, translation, *etc.* Unlike synthetic polymers, biopolymers have a well-marked structure. These polymers have a uniformly distributed set of molecular mass and appear as a long chain of worms or a curled up string ball under a microscope. This type of polymer is differentiated based on their chemical structure. Biopolymers plays an essential role in nature [1]. Different types of biopolymers extracted from biomolecules has been shown

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below in Fig. (**1**). They are extremely useful in performing functions like storage of energy, preservation and transmittance of genetic information and cellular construction. Some of the uses of biopolymers has been mentioned below:-

- Sugar based polymers, such as polyactides, naturally degenerate in the human body without producing any harmful side effects. This is the reason why they are used for medical purposes. polyactides are commonly used as surgical implants.
- Starch based biopolymers can be used for creating conventional plastic by extruding and injection molding.
- Biopolymers based on synthetic are used to manufacture substrate mats.
- Cellulose based biopolymers, such as cellophane, are used as a packaging material.
- These chemical compounds can be used to make thin wrapping films, food trays and pellets for sending fragile goods by shipping.

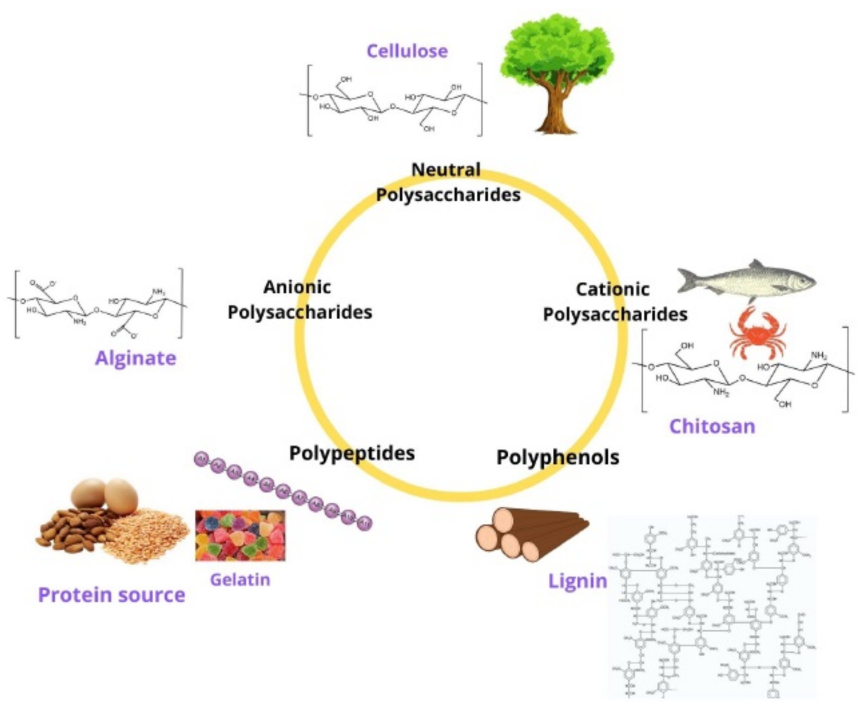

Fig. (1). Biopolymers found in nature.

Immense efforts have been made for their isolation, purification, quantification as well as structural determination and functional characterization. Profound insights into the structural and functional characterization of these biopolymers could help us understand the intricate cellular machinery.A wide range of biochemical, biophysical, electrochemical and molecular biology techniques have really been beneficial in exploring the key and interdependent relationships between the structure and function of these biopolymers. Each instrumentation techniques has its own advantage and disadvantage in terms of their applications, selectivity and sensitivity. In this unit we will discuss some of the physical techniques which provides a greater insight of the structure and functional properties of the biomolecules [2].

BIOPOLYMER TECHNIQUES

X-ray Crystallography

It is a powerful tool to establish 3D structures of molecules at the sub-atomic level. The method works on the principle of X-ray diffraction by the crystal. The electron in the crystal scatters X-rays beam and the 3D structure of molecules is established due to the interference pattern of the scattered X-rays. Unfortunately, crystals required for diffraction are difficult to obtain, and considerable amounts of proteins may be needed, as given below in Figs. (**2** and **3**). Usually, proteins are created as recombinant material from microorganisms and mammalian cells. They require high labour work but are considered a good approach for the detection of even tough membrane proteins.Initially used for the identification of salt crystal structure, this technique helped Linus Pauling to develop his theory of attractive force (structural information combined with quantum mechanics calculations). From the data obtained from salt crystals, Linus Pauling proposed the primary and secondary structure of protein molecules [Pauling and Corey, 1951]. Both atomic coordinates and structural helical configurations of polypeptide chains were detected and confirmed by X-ray crystallographic analysis. Crystals of myoglobin and haemoglobin were first analyzed in the 1960s by Kendrew and co-workers. Since several such materials may be obtained in crystal forms, like salts, minerals, semiconductors, organic, inorganic and biomolecules, x-ray crystallography has been a primary technique for scientific researches and discoveries. In its initial decades of operation, the technique helped to determine the atomic size, length, nature of chemical bonding, and variations in material's atomic scale, particularly minerals and alloys. This method also helps in the identification of structural arrangement and functions of biological molecules like vitamins, proteins, nucleic acids like deoxyribonucleic acid, *etc.* X-ray crystallography continues to be the prime methodology for characterizing the atomic structure of new materials that are rather difficult to characterize by alternative techniques [3].

CHAPTER 5

Structure and Function of Biological Biomolecules: Carbohydrates, Amino Acids, Proteins, Nucleic Acids, Lipids and Biomembranes

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Abstract: This chapter deals with the introduction, definition and classification of various biological molecules like carbohydrates, lipids and bio-membranes, amino acids, proteins and nucleic acids. The synthesis of carbohydrates, structure and function of monosaccharides, disaccharides and polysaccharides, absolute and relative configuration of sugar, reducing and non-reducing sugar, Fischer projection formula and Haworth projection formula are also briefly described. A brief knowledge about the type of fatty acids, acid value, soap value, various types of lipids, including phospholipids and sphingolipids, is also included. This unit also discusses the properties of various types of amino acids, proteins and nucleic acids, including structures of nucleoside, nucleotides, DNA and RNA.

Keywords: Carbohydrates, Nucleic acid, Nucleotide, Polypeptides, Proteins, Relative and absolute configuration.

CARBOHYDRATES

Carbohydrates are biomolecules consisting of carbon, hydrogen and oxygen atoms. They perform various important roles in living organisms. For example, some polysaccharides serve as storage of energy; the monosaccharide ribose is the backbone of RNA (genetic material) and is also an important component of coenzymes like ATP, NAD, FAD; the monosaccharide deoxyribose is the backbone of DNA [1]. Carbohydrates also play key roles in fertilization, immune system, blood clotting, *etc.*

In the human diet, the most important carbohydrates are starch and sugars which are found in a variety of foods, both natural and processed, for *e.g.* starch is avail-

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Meera Yadav & Prof. Hardeo Singh Yadav (Eds.)

able in cereals, potatoes and even in bread, pizza, pasta, *etc.* (shown in Fig. **1**).

Initially, it was believed that the term carbohydrates refers to the "hydrates of carbon", having general formula $C_x(H_2O)_y$, for *e.g.* glucose ($C_6H_{12}O_6$), cane-sugar ($C_{12}H_{22}O_{11}$), *etc.* But later, it was found that several carbohydrates do not follow the pattern given in the above formula, *e.g.* deoxyribose ($C_5H_{10}O_4$), rhamnose ($C_6H_{12}O_5$), glucosamine ($C_6H_{13}O_5N$). In recent days, carbohydrates are defined as "*Polyhydroxy aldehydes or polyhydroxy ketones or substances that yield such compounds on hydrolysis*", known as carbohydrates [1], for *e.g.* glucose, fructose, galactose, *etc.*

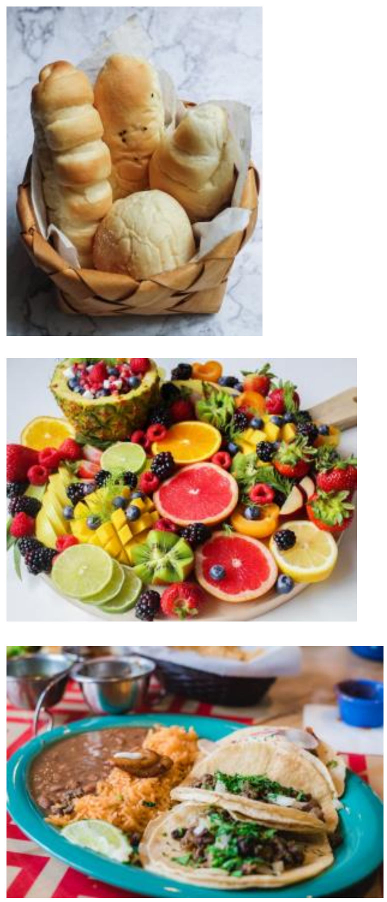

Fig. (1). Food rich in carbohydrates [2 - 4] respectively.

Synthesis of Carbohydrates

Carbohydrates are synthesized in green plants by the process of photosynthesis. Green plants contain chlorophyll, which catalyses the conversion of carbon dioxide into sugar in the presence of water and sunlight [5]. The reaction involved in photosynthesis can be shown as follows:

$$6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Sun light}} C_6H_{12}O_6 + 6O_2 \uparrow$$

Carbohydrates are degraded by animals using O_2, providing energy for their survival and releasing an equivalent amount of carbon dioxide.

Function of Carbohydrates

Carbohydrates participate in a wide range of functions. Some of them are:

- They are the most abundant dietary source of energy for all organisms.
- They are the main precursors for most of the organic compounds, *e.g.* fats, amino acids.
- Carbohydrates, especially glycoproteins and glycolipids, participate in the structure of cell membrane and cellular functions like cell growth, *etc.*
- They provide energy and regulate blood glucose, sparing the use of protein for energy.
- They act as important structural units in plants.

Classification

Carbohydrates are also known as Saccharides (Greek: Sakkharon), which refer to the substances which are sweet in taste [1]. The classification of carbohydrates depends on their behaviour, and is given as follows:

Based on their Behavior Upon Hydrolysis

Monosaccharides

These are the simplest unit of carbohydrates and cannot be further hydrolysed into other smaller fragments [1]. The general formula of monosaccharide is $C_n(H_2O)_n$, where n = 3 to 7, for *e.g.* Glucose ($C_6H_{12}O_6$), Fructose ($C_6H_{12}O_6$), Galactose ($C_6H_{12}O_6$), Ribose ($C_5H_{10}O_5$), *etc.*

Oligosaccharides

The carbohydrates which provide a definite number (2-9) of molecules of monosaccharide on hydrolysis are called oligosaccharides [1]. Based on the number of monosaccharide units obtained after hydrolysis, oligosaccharides can

CHAPTER 6

Structure and Biological Function of Vitamins

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Abstract: This chapter deals with the introduction, classification and biological functions of vitamins. The deficiencies caused by water-insoluble vitamins such as vitamin-A, vitamin-D, vitamin-E and vitamin-K and water-soluble vitamins such as vitamin-C and the vitamin-B complex have been discussed in detail. The structure and properties of various types of vitamins are also part of this subject.

Keywords: Ascorbic acid, Biotin, Niacin, Pyridoxine, Riboflavin, Tocopherols, Vitamin.

INTRODUCTION

Along with some biologically important compounds like proteins, carbohydrates and lipids, some organic chemical compounds are known as vitamins which are also required in small quantities for normal health and growth of animal life (including man). These organic compounds or vitamins cannot be synthesized by the body and hence must be obtained through diet or some other synthetic sources (shown in Fig. **1**). Due to this reason, vitamins are called essential nutrients. However, the word vitamin excludes dietary minerals, essential fatty acids and essential amino acids [1].

Vitamins are normally required in very small quantities by the body to complete its functions. These perform many biochemical functions as antioxidants, for *e.g.* vitamin E & C; as enzyme cofactors or their precursors, *e.g.* B-complex vitamins; hormone-like, *e.g.* vitamin D; regulators of mineral metabolism, regulators of cell and tissue growth and differentiation, *e.g.* some forms of vitamin A also facilitate or control vital chemical reactions in the body cells. The enzyme cofactors (as a catalyst) help enzymes in their metabolism. Here vitamins either may be tightly bound to enzymes as part of a prosthetic group like biotin, which is a part of

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enzymes that are involved in making fatty acids, or maybe less tightly bound to enzyme catalysts such as coenzymes that carry chemical groups or electrons between molecules, *e.g.* folic acid carries methyl, formyl and methylene groups in the cell [3]. These roles of vitamins in enzyme-substrate reactions are the best-known, although other functions are equally important. Lack of any vitamin in our body may develop a specific deficiency.

Fig. (1). Some vitamins-rich foods [2].

Till now, many vitamins have been isolated. Initially, they are designated by some selected letters of the alphabet (as shown in Fig. **2**), but as soon as their structure has been established, the vitamins are renamed. Each vitamin name (word vitamin followed by an alphabet) refers to a number of vitamers that show the same biological activity due to similarity in their structure [4]. For example, retinal, retinol and four known carotenoids qualify as "vitamin A", each with slightly different properties. Here vitamin A is the "generic descriptor" of the vitamin. Vitamers can be converted to the active form of the vitamin in the body and sometimes these are even inter-convertible to one another.

Fig. (2). Vitamins [5].

HISTORY

Long before the vitamins were identified, it was recognized that certain foods are necessary to maintain health. In ancient Egypt, night blindness (a disease caused by the deficiency of vitamin A) was cured by feeding animal (goat, pig, *etc.*) liver to a person [6]. In 1747, James Lind, the Scottish surgeon discovered that scurvy (a deadly disease in which collagen is not properly formed, causing poor wound healing, bleeding gums, severe pain and death) can be prevented by using citrus foods [6]. In 1753, Lind published his *Treatise on the Scurvy,* where the use of lemons and limes was recommended to avoid scurvy; however, it was not widely accepted [6].

During the late 18th and early 19th centuries, a number of vitamins were isolated and identified by scientists. Rickets in rats was cured by using lipid from fish oil and was called “antirachitic A”. Thus, the first vitamin ever isolated that cured rickets was initially named “vitamin A”; however, now it is known as “vitamin D” [7]. In 1881, at the University of Tartu (now Estonia), Nikolai Lunin, a Russian surgeon, studied the effects of scurvy. He made an artificial mixture of all the constituents of milk (proteins, fats, carbohydrates and salts known at that time) and fed mice with this mixture while other mice were fed with milk. The mice fed with the mixture died, and the mice fed with milk developed normally. Therefore, he concluded that “milk must contain small quantities of unknown substances which are essential for life along with the known ingredients”. However, his advisor Gustav von Bunge did not accept his conclusions. In 1905, a similar result was published in a Dutch medical journal by Cornelius Pekelharing but not widely reported [8]. In 1890, Christiaan Eijkman found that a nerve disease (polyneuritis) broke out among his laboratory chickens. The disease was similar to the polyneuritis associated with the nutritional disorder beriberi. In 1897, he discovered that when the chickens were fed with unpolished rice instead of polished rice, it helped to prevent beriberi in chickens [9]. In 1906-07, Frederick Gowland Hopkins, a British biochemist, observed that certain amino acids cannot be synthesized by the animals and concluded that in addition to proteins, carbohydrates, fats, *etc*., some foods contain ‘accessory factors’ that are necessary to support growth and proper functioning of the body [6]. In 1912, he published the same. In the same year, Casimir Funk, a polish scientist, observed that polyneuritis in pigeons could be cured by increasing their diet with a concentrate made from rice bran, present in the outer husk of the rice, which was removed during polishing. Thus he proposed that polyneuritis occurred due to lack of a vital factor found in rice bran in the bird’s diet. Similarly, he believed that some human diseases like beriberi, scurvy and pellagra were also caused by deficiencies of some vital factors and could be cured if the same is supplied to them in their diet. Funk called these vital factors as “vital amines”, later shortened to “vitamines”, as each of the factors contained an amine [10]. Later it was found that all the vitamins do not contain nitrogen, hence all are not amines; therefore, the final ‘e’ was dropped from ‘vitamine’ to de-emphasize the amine reference [11].

CHAPTER 7

Enzymes (Biocatalyst)

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Abstract: In this chapter, brief accounts for the classification, nomenclature, and physiochemical nature of enzymes have been discussed. This chapter also deals with the action mechanism of an enzyme, enzyme kinetics, and factor affecting enzyme activity. A brief discussion about coenzymes, cofactors, and their role in biological systems has been addressed in this chapter.

Keywords: And enzyme kinetics, Biological catalyst, Coenzymes, Cofactor, Denaturation, Reaction specificity.

INTRODUCTION

The term enzyme was coined by Kuhne in 1878 for the biologically derived catalysts. These are protein molecules which work as a catalyst. They increase the rate of chemical reactions in the body. Enzymes work on the substrate and convert them into products [1]. Some important features of enzymes are as follows-

1. All enzymes are proteinous in nature, but all proteins are not enzymes.

2. They act as a catalyst to accelerate a chemical reaction.

3. They are very specific in their action.

4. Their names end in –ase, *e.g.*, sucrase, lactase, maltase, *etc*.

5. Enzymes work by weakening chemical bonds, which lower the activation energy.

6. Enzymes are key to life, *i.e.*, no enzyme, no life.

7. Enzymes contain active sites.

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Meera Yadav & Prof. Hardeo Singh Yadav (Eds.)

ENZYME STRUCTURE

Enzymes are made up of long chains of amino acids that arefolded into a very precise three-dimensional shape and contained an active site. An active site may be defined as a region on the surface of an enzyme to which substrate will bind and catalyse a biochemical reaction. There are various enzymes, and their names predict their activity. Enzymes not only break large chemicals into smaller ones but also build large chemicals from smaller ones along with many other chemical tasks. For example, an enzyme found in saliva (shown in Fig. **1**), amylase, breaks down starch molecules into glucose and maltose. Lipase breaks down fats into smaller molecules [1].

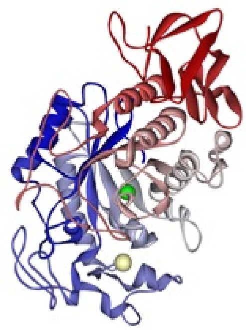

Fig. (1). Salivary amylase, chloride ion green: calcium beige [2].

Some chemicals are called activators, which help to enhance enzyme activity. Some chemicals can slow down the activity of an enzyme or even stop any further activity of the enzyme, and such chemicals are called inhibitors. Most drugs are such types of chemicals that either enhance or slow down the activity of some enzymes in the human body [1].

NOMENCLATURE AND CLASSIFICATION

Each enzyme is allocated two names. The first one is a trivial name or also called recommended name, which is very suitable for everyday use. The second one is a systematic name as projected by the International Union of Biochemistry (IUB).

Recommended Name

Most commonly used enzyme names end with the suffix '-ase' attached to the substrate, type of chemical reaction, *etc*. [3].

A. Based on the type of substrate as given in Table **1** [3]:

Table 1. Enzyme with their substrate.

Substrate	Enzyme (Substrate + Suffix 'ase')
Carbohydrates	Carbohydrases
Proteins	Proteinases
Lipids	Lipases
Nucleic acids	Nucleases
Maltose	Maltase
Sucrose	Sucrase
Urea	Urease
Aspartic acid	Aspartase
Fumaric acid	Fumarase

B. Based on the type of reaction which they catalyzed are given in Table **2** [3]:

Table 2. Type of chemical reaction catalyzed by an enzyme.

Reaction	Enzyme
Hydrolysis	Hydrolases
Isomerization	Isomerases
Oxidation	Oxidases
Reduction	Reductase
Dehydrogenation	Dehydrogenases
Decarboxylation	Decarboxylases

C. Based on the type of reaction catalyzed along with the type of substrate are given in Table **3** [3]:

Table 3. Type of substrate and type of reaction catalyzed by an enzyme.

Substrate	Reaction	Enzyme
Alcohol	Dehydrogenation	Alcohol dehydrogenase (removal of hydrogen from alcohol)
Succinic acid	Dehydrogenation	Succinic dehydrogenase
Glucose	Oxidation	Glucose oxidase
Glycogen	Synthesis	Glycogen synthetase
Phosphoglycerate	Isomerization	Phosphoglyceromutase

CHAPTER 8

Hormones

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Abstract: This chapter includes an introduction, classification, and type of hormones, as well as their biological functions. This chapter also gives a brief discussion about the structure, properties, and regulatory action of hormones. Various plant hormones and their functions have been discussed in this chapter.

Keywords: Cortisol, Osteoporosis, Oxytocin, Plant hormones, Progesterone, Sex hormones, Testosterone, Vasopressin.

INTRODUCTION

The term 'hormone' is derived from the Greek word 'hormaein', which means "to set in motion". Hormones are specific molecules that act as chemical messengers. These are secreted directly into the blood by the endocrine glands. These are carried by the circulatory system to organs and tissues of the body to exert their functions [1]. The major body functions include monitoring of basic needs, hunger, to a complex mechanism like reproduction [2]. The hormones secreted into the blood come in contact with a number of cells, but only certain target cells are influenced by these. For each specific hormone, there are specific receptors in the target cells, which may be present on the surface of the cell membrane or inside the cell. As the hormone binds to the receptor, some changes occur, influencing the cellular function. Since the hormones influence the target cells over a distance hence this type of signaling is known as endocrine signaling [3]. Hormones also influence the neighboring cells when secreted into the interstitial fluid surrounding cells, which then diffuse to nearby target cells. This type of signaling is known as paracrine signaling. Sometimes the hormones cause changes to the same cell that releases them and do not enter the other cells, known as autocrine signaling [3].

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The glands, part of the endocrine system shown in Fig. (**1**), that produce hormones are ductless; hence they are released directly into the blood. The glands are:

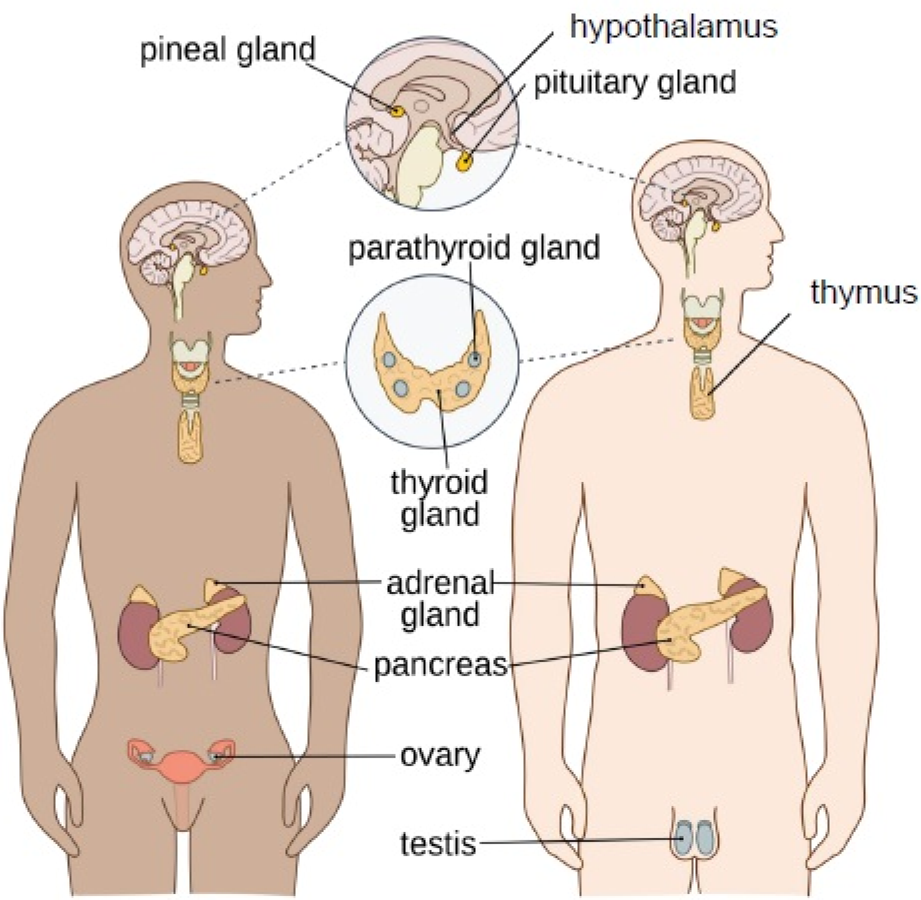

Fig. (1). A diagram of the endocrine system [4]. (image courtesy: scioly.org).

- **Hypothalamus**: It combines the endocrine and nervous systems. It initiates endocrine responses when it receives input from body and brain areas. The hormones produced by it play a role in hunger, moods, body temperature, and release of hormones from other glands and can also control thirst, sleep, and sex drive [5]. Hypothalamus includes the following hormones [6]-
  - Corticotropin-releasing hormone: It stimulates the anterior pituitary to release adrenocorticotropic hormone (ACTH).
  - Gonadotropin-releasing hormone: It stimulates the anterior pituitary to release luteinizing hormone and follicle-stimulating hormone.

  - Thyrotropin-releasing hormone: It stimulates the anterior pituitary to release thyroid-stimulating hormone (TSH).
  - Growth hormone-releasing hormone: It stimulates the anterior pituitary to release growth hormone (GH).
  - Oxytocin: It is stored in the posterior pituitary. It induces labour during childbirth and controls bleeding after childbirth. It also induces the release of milk from mammary glands.
  - Antidiuretic hormone (vasopressin): It is also stored in the posterior pituitary. It helps the kidneys to reabsorb water.
- **Parathyroid**: Releases hormones that balance the amount of calcium in the body [7].
- **Thymus**: Releases hormones that produce T-cells and help in the function of the adaptive immune system [8].
- **Pancreas**: It is located between the stomach and proximal portion of the small intestine. It helps to control blood sugar levels by producing hormones like insulin and glucagon. Insulin promotes the uptake of glucose by liver and muscle cells and converts it to glycogen, thus decreasing blood sugar levels. But glucagon promotes the breakdown of glycogen, stored in liver and muscle cells, and releases glucose, thus increasing blood sugar levels [9].
- **Thyroid**: It is located in the neck and is regulated by the hypothalamus-pituitary axis. Hormones produced by this gland are associated with regulating metabolism and growth, calorie-burning, and heart rate. Hormones produced by this gland are thyroxine (T_4) and triiodothyronine (T_3) [10].
- **Adrenal**: It consists of two glands located in each kidney. It consists of two parts adrenal cortex and adrenal medulla, each producing different sets of hormones.
  - Adrenal cortex: It releases mineralocorticoids, *e.g.* aldosterone, and glucocorticoids, *e.g.* cortisol. Aldosterone helps to increase reabsorption by kidneys and regulates water balance. Cortisol is released when blood sugar levels decrease due to long-term stress. It increases the blood glucose levels through glycogenesis by liver cells. It also aids in the metabolism of proteins, carbohydrates, and fats [11].
  - Adrenal medulla: It releases epinephrine, *e.g.* adrenaline, and norepinephrine, *e.g.* noradrenaline. These are released as a result of short-term stress and cause an increase in heart rate, breathing rate, contraction of cardiac muscle, blood glucose level and blood pressure [11].
- **Pituitary**: It is also known as the "master control gland" because it controls other glands and releases hormones that trigger growth. It is present at the base of the brain and is attached through the pituitary stalk to the hypothalamus. It consists of two distinct regions: the anterior pituitary gland and the posterior pituitary gland [12].

CHAPTER 9

Fundamentals of Thermodynamics: Principle Applicable To Biological Processes

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Abstract: All living organisms require energy from the surrounding and utilized by biomolecules that mediates the flow of energy from exergonic reactions to the energy requiring processes of life. This unit deals with the energy behind life in the form of three laws of thermodynamics. Derived the mathematical equations for the laws. Comparison of thermodynamic parameters like ΔH or ΔS and ΔG have been done to provide meaning ful insights about a process and its use in calculating the relative contributions of molecular phenomena to an overall process.

Keywords: Biomolecules, Calorimeter, Denaturation, Glycolysis, Phototrophs, Pyruvate.

INTRODUCTION

Living organisms need energy for various life processes like movement, biomolecular synthesis, transportation of ions and molecules across membranes, *etc.* All species gain energy from their environment and use it to carry out their life process. Studying certain energy transformation phenomena requires awareness of thermodynamics processes. Thermodynamics gives us an analysis of energy transformations occurring in the cell. Biological processes also obey the law of thermodynamics. The principles of thermodynamics help us to understand the relationship between heat, energy, and matter in the biological system. This chapter presents several basic thermodynamics principles that give us a broader understanding of various biological processes [1]. Sun is the ultimate source of all forms of energy. Living organisms rely directly on sunlight like plants (Fig. **1**). Some bacteria live in extreme conditions, such as Antarctica, also some blue-green algae grow in the lakes under dense layers of ice, and these also require energy in those remote areas. All living organisms require energy to synthesize

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food, to reproduce and store and carry out metabolic activities for survival. The energy of sunlight and its wavelength λ or frequency ν is interdependent, which is shown by the relation, $E = h\,c/\,\lambda = h\,\nu$, where

h = Planck's constant (6. 634 x 10^{-34} Js)

c =speed of light in vacuum (2.99 x 10^{8} m/s)

Fig. (1). The sun is the source of energy of all virtue of life. We can harvest its energy in the form of electricity by using windmills driven by air heated by the sun.

What is the Basic Concept of Thermodynamics?

In every thermodynamic analysis, a distinction between system and surrounding is necessary. A system is the part of the universe we're concerned with. It may be a combination of Chemicals in a test tube, or a single cell, or a whole organism. The surrounding environment includes everything else other than the system. These systems are categorized into isolated, closed, and open types (as shown in Fig. **2**).

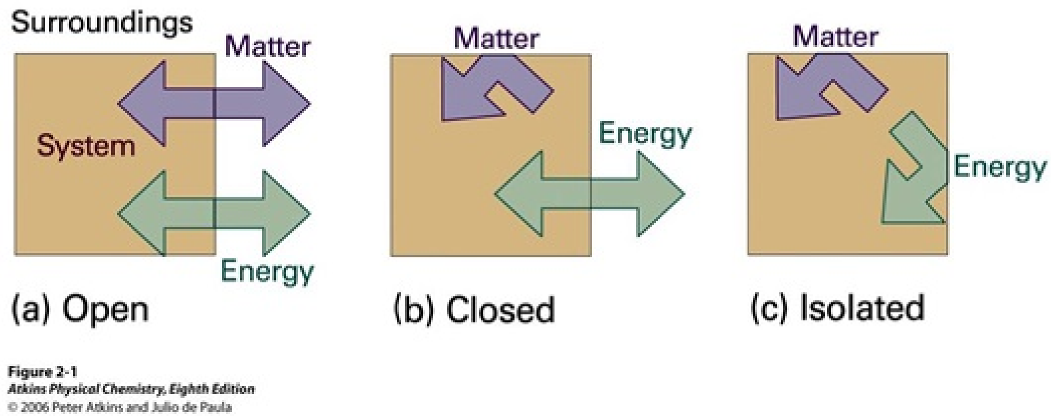

Fig. (2). The characteristics of isolated, closed, and open systems. Isolated systems exchange neither matter nor energy with their surroundings. Closed systems may exchange energy, but not matter, with their surroundings. Open system may exchangeeither energy or matter with surrounding.

An isolated system doesn't share matter or energy with the external environment.

A closed system doesn't share any matter with the surroundings.

An open system has external interaction with both system and surroundings.

All living beings are usually open systems that can exchange matter and energy with the surrounding [1].

Even when the system is closed, it can still interact with its surroundings. One such kind of interaction is called work. If the surroundings exert a force, F, on the system and this force is exerted along a path of length l; the surrounding does work on the system:

$W = Fl$

If W = +ve, then it indicates work is done on the system.

If W = -ve, it indicates work is done by the system.

STATE VARIABLES

State variables that characterize the condition of a complex system are known as state functions.

Every State variable corresponds to one of the underlying state space coordinates. Such variables include macroscopic properties, including pressure, volume, temperature, density, composition, surface area, *etc.* For example, an ideal gas

CHAPTER 10

Bioenergetics, Metabolism of Biomolecules, Photosynthesis and Respiration, Transcription and Translation, Recombinant DNA Technology

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Abstract: This unit describes how living organisms are procuring their life with energy transform in order to perform biological work. This chapter explores the in-depth metabolism of carbohydrates, lipids and fats, proteins, nucleic acids and nucleotides. The relationship between photosynthesis and cellular respiration, the structure of DNA and the technology of recombinant DNA have been described in detail.

Keywords: Catabolism, Citric acid cycle, Glycolysis, Oxidative phosphorylation, Photorespiration, Photosynthesis, Recombinant DNA.

INTRODUCTION

Bioenergetics is a branch of biochemistry. A study about the transformation of energy in the living systems is bioenergetics. This type of energy is created by living organisms. All living organisms use energy, but they use it in different ways. Consider plants and animals, the plants use energy in such a manner that causes them to release oxygen as a byproduct, while animals require oxygen for living. All living organism converts foods, sunlight, minerals, water, oxygen, *etc*. into beneficial energy. The application of bioenergetics helps us to understand how living cells transform energy often through the production, retention or consumption of adenosine triphosphate (ATP). Progressions of the bioenergetics, cellular respiration or photosynthesis, are essential to most aspects of cellular breakdown; therefore to life itself [1, 2].

Metabolism is a chemical transformation occurring within the living organisms for the sustenance of life. Some enzymes are produced during the metabolism of

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cells. These enzyme-catalyzed reactions are responsible for the growth and replication of living organisms as well as their response to various stimuli in their surroundings. The explanation of digestion is about all chemical reactions that occur in maintaining the living cells and the organisms. This type of chemical reaction keeps our body alive and functioning [3]. Metabolism can be suitably assigned into two kinds:

a. Catabolism –the energy is obtained by the breaking of molecules called catabolism.

b. Anabolism – It is a constructive part of metabolism. The synthesis of more complex substances from smaller units in living cells is called anabolism.

Anabolism uses energy kept within the system of adenosine triphosphate (ATP) to form larger molecules from smaller molecules. Catabolic reactions are destroying larger molecules into smaller molecules by producing ATP and raw materials for anabolic reactions. The production of ATP is necessary for the proper routine of energetic functions like living cell reactions and procedures of the body that entail energy is delivered from the exchange of ATP to ADP. This energy is used in the transmission of nerve impulses, muscle contraction, active transport through plasma membranes, protein synthesis and cell division. Since all digestible forms of carbohydrates are finally converted into glucose, it is significant to consider how glucose is competent to energy supply in the form of Adenosine triphosphate (ATP) to numerous cells and tissues.

Lipids are macromolecules which dissolve in a non-polar solvent and it is an essential part of living organisms. Sometimes scientists define lipids as hydrophobic or amphipathic small molecules. Triglycerides (TGs) and cholesterol store excess energy from the diet. These are often considered a contributing factor in heart diseases and obesity in humans, while lipids are also required for physiological activity. The main functions of TGs are storing energy in adipocytes and muscle cells, dietary fat is a collective constituent of the cell membranes, steroids, bile acids, and building blocks of the molecule. Vertebrates and humans use their excessive fats as sources of vitality for body parts such as the heart to function. Lipid metabolism in plants takes place in different ways as compared to that taking place in animals. Hydrolysis is the ingestion of unsaturated fats into the epithelial cells of the intestinal divider. In the epithelial cells, unsaturated fats are packaged and shipped to the rest of the body [4].

Proteins are made by amino acids and include many essential biological compounds such as enzymes, hormones or antibodies. Each protein contains 2,000 amino acids which are associated with peptide bonds. Protein is a very important material for the growth of the human body. Proteins are excessively enormous to be consumed into the circulatory system, so they are separated into amino acids and little pieces with a few amino acids before absorption. The split of the proteins into amino acids is involved by several enzymes (As shown in Fig. **1**).

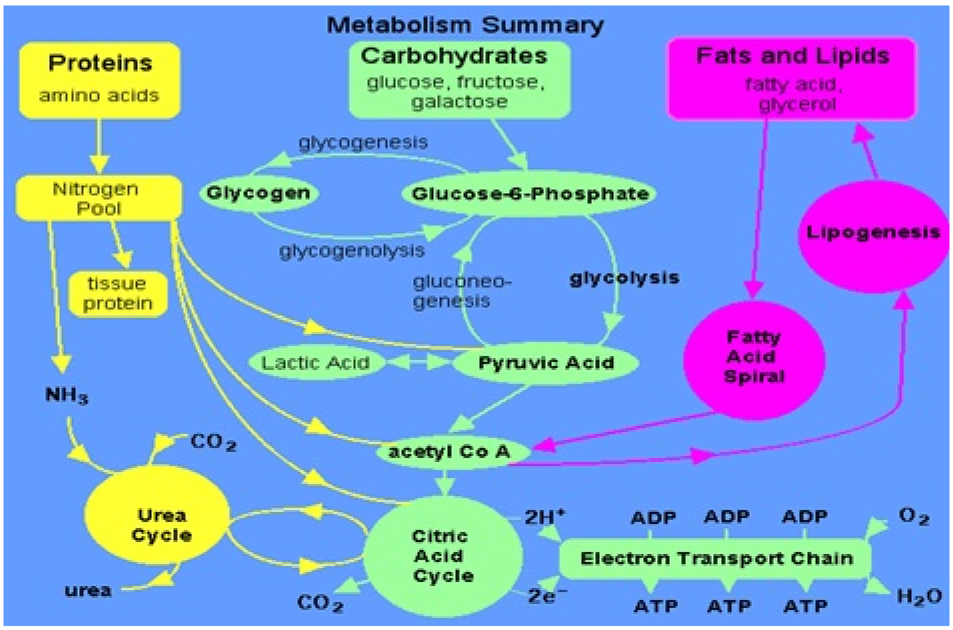

Fig. (1). Living Organisms Metabolism. (Chemistry.elmhurst.edu).

Photosynthesis and cellular respiration which enables us to live on earth, are interconnected through an imperative relationship.

Oxidative phosphorylation is the last metabolic process of cellular respiration that takes place following the breaking of glucose and the citric acid cycle. During cellular respiration, twenty-six out of thirty ATP units are produced by one glucose unit from oxidative phosphorylation. Within metabolism, the replications of DNA is a biological activity that gives two new DNA strains from one original DNA. This process occurs in all living organisms and is the basis for biological inheritance. Transcription is the process of making an RNA duplicate and directs the synthesis of the protein. The translation is the process of making a sequence of amino acids or a protein as per the information carried in the molecule of mRNA.

The genetic code describes the link between the sequence of base pairs in a gene and the corresponding amino acid sequence. The ribosome reads the sequence of the mRNA in groups of three bases to assemble the protein in the cell cytoplasm [5].

SUBJECT INDEX

A

Acid(s) 3, 10, 20, 38, 43, 48, 49, 50, 64, 65, 73, 94, 97, 137, 138, 148, 157, 159, 160, 162, 170, 174, 188, 189, 190, 191, 192, 193, 196, 197, 198, 200, 219, 223, 238, 239, 217, 241, 242, 246, 247, 248, 253, 265, 275, 291, 302, 306, 341, 342, 343, 346, 364, 373, 374, 377, 381, 387, 389, 390, 393, 402, 404,
abscisic 302, 306
arachidonic 291
aspartic 64, 65, 157, 160, 265
bile 200, 364
carbonic 43, 73
carboxylic 73, 148, 189, 190, 373
citric 50, 404
deoxyribonucleic 94, 97, 174
diethenoid 191
folic 217, 246, 247, 248, 253
fumaric 265, 275
gluconic 137
glutamic 64, 157, 159, 160
glycolic 138
hydrochloric 38, 50
hydrocyanic 49
hydroxylic 48
keto 162
lactic 50, 170
linoleic 191, 192, 193
monoethenoid 191
nicotinic 238, 239
okadaic 20
oleic 191, 193, 196, 381
oxalic 50
palmitic 188, 190, 196
palmitoleic 192
polynucleic 174
ribonucleic 174
pantothenic 241, 242, 253
phosphatidic 196, 197, 198
phosphoric 173, 188, 196
pyruvic 346, 374
retinoic 219, 223
saccharic 137
steric 381
succinic 275
uric 3, 10, 389, 390
Activation 225, 227, 263, 269, 272, 341, 371, 375, 406
thermal 227
energy 263, 269, 272, 341, 371, 406
Active 2, 342
transportation 342
transport ion pumps 2
Activity 2, 8, 201, 217, 222, 229, 243, 247, 264, 269, 266, 274, 292, 298, 326, 330, 341, 342, 343, 346, 365,
anti-inflammatory 229
biological 217, 343, 365
catalytic 269, 274
cellular power 341
efficient free radical scavenging 247
enzymatic 2
hormonal 298
metabolic 8, 292, 326, 342, 346
significant growth-promoting 201
Addison's disease 293, 312
Adenosine 279, 280, 338, 340, 341, 363, 364, 372, 386, 402
monophosphate 280, 341, 386
triphosphate 279, 280, 338, 340, 363, 364, 372, 402
Adrenocorticotropic hormones (ACTH) 288, 290, 291, 292, 293, 312, 313
Aldosterone 289, 296, 297, 313
function of 297, 313
Aldotetrose 126
Algae 325, 347, 366
blue-green 325
Alzheimer's disease 229
AMP rephosphorylation 340
Amylases 2, 145, 264, 266, 279
Amylopectin 145, 146

Meera Yadav & Hardeo Singh Yadav (Eds.)

Amylose 145
Anabolic process 5
Anabolism 5, 364
Anaerobic glycolysis 374
Anemia 231, 238, 242, 244, 247, 252
megaloblastic 247, 252, 253
Anti-diuretic hormones 308
Arthritis 10, 12, 240
inflammatory 10
ATP 180, 279, 338, 340, 341, 342, 343, 344, 345, 347, 348, 364, 366, 371, 372, 373, 376, 377, 387, 392, 394, 405, 402, 406
break-down 402
chemotrophs extract 342
creation of 387, 393
framing 377
hydrolysis assay 343
production of 341, 364, 366, 392, 394
regenerate 342
synthesis 366, 392
ATP hydrolysis 341, 342, 343, 344, 345, 371, 372
free energy of 343
ATP synthase 392, 393, 394
and electron transport 393
encapsulates 393

B

Biological functions of coenzyme 279
Biopolymer techniques 94
Bioremediation process 15
Biuret reaction 161
Blood 289, 296, 297
glucose levels 289, 297
pressure 289, 296
Bragg's 96, 107
formula 96
law of diffraction 107
Brain hormones 307, 313
Brassinosteroids 201
Breathlessness 250
Broccoli 222
florets 222
leaf 222
Bronsted-Lowry 39, 49
acid-base model 49
acid-base reaction 39
Brønsted-Lowry's theory 38
Butyrylcholinesterase 17

C

Cancers and gene editing 24
Carbohydrates 120, 121, 140, 391, 402, 405
dietary 140
energetic 402
synthesis of 120, 121, 391
synthesize 405
Carbohydrates metabolism 245, 374, 402
Carboxylase 267
Cardiac arrest 297
Cardiomyocyte cells 20
Cardiovascular disease 234, 248
Carotenodermia 224
Catabolism 5, 155, 363, 364, 383,389, 390, 402, 405, 407
of pyrimidine 389
purine 390, 407
Catalase 266, 277
Catalyses 2, 60, 121, 264, 272, 273, 274, 275, 371, 376, 394
enzyme succinic acid dehydrogenase 275
non-biological 272
Catalytic 75, 277, 388
enzyme ribonucleotidereductase 388
nature of enzyme 277
power, enzyme's 75
Cellulase 277
Chymotrypsin 266
Chymotrypsinogen 280, 335
Corneas, infected 222
Coronavirus disease 105

D

Deficiency 144, 217, 222, 223, 226, 229, 231, 233, 234, 240, 241, 242, 243, 247, 249, 250, 253, 294
folate 247
lactose 144
of vitamin 222, 223, 231, 233, 234
Diseases 4, 7, 9, 10, 12, 14, 16, 21, 22, 25, 26, 100, 106, 217, 218, 231, 234, 244, 251, 252, 253
blood vessel 244
cellular 100, 106
eye 234
genetic 21

infectious 22
inflammatory bowel 231
thyroid 4
Disorder 4, 14, 21, 229, 235, 250, 251, 252, 312, 331, 333, 367
bleeding 229
endocrine 312
fatmalabsorption 229
genetic 21
intestinal 250
metabolic 4, 252
neurological 252
polygenic 14
psychiatric 14
Dizziness 240
DNA 2, 14, 24, 57, 60, 61, 64, 169, 176, 177, 183, 184, 365, 383, 388, 389, 394, 395, 396, 400, 401, 403, 404
annealing process 64
chimeric 404
human 14
polymerases 169, 395, 403
tumour 24

E

Effects, cardiovascular 236
Electrolysis 48
Electron 92, 100, 101, 105, 106, 107, 276
Microscopy 92, 100, 101, 106, 107
tomography 92, 105
transport system 276
Electrostatic field 65
Embryogenesis 299
EMP pathway 404
Endergonic and exergonic reactions 369
Endocytosis 205, 206, 385
Energy 68, 75, 77, 93, 103, 120, 122, 187, 234, 281, 325, 326, 327, 328, 333, 346, 347, 363, 364, 366, 367, 369, 371, 380, 391, 404, 406,
free binding 75
mechanical 366
source of 281, 326, 404, 406
storage of 93, 120, 380
storing 364
supply 364
transactions 366
Energy change 8, 334, 337, 338, 367, 368
free 334, 337, 338, 367, 368
Enthalpy changes 71, 330, 331, 334
Environmental pollutions 14
Enzyme(s) 15, 141, 244, 272, 277, 282, 377, 385
aldose-ketoseisomerase 376
carboxylase 244
catalytic 15
catalysis 272, 282
cellular 385
glyceraldehyde 3-phosphate dehydrogenase 377
maltase 141
monomeric 277
ESI complexes 275
Essential nutrients 216
Estrogens 200, 290, 291, 298, 299
Excessive consumption of vitamin 224
Exergonic 325, 346, 369, 371, 372
catabolic reactions 372
reactions 325, 346, 369, 371
Eye(s) 219, 222, 229, 237, 238, 244, 245, 251, 252
disorders 238
dry 245
health 237, 238, 244
itchy 238

F

Fatty acid synthesis 244, 381
Fehling's solution 124, 136, 137
Fisher's template theory 273
Flu, preventing 227
Follicle-stimulating hormone (FSH) 288, 290, 291, 300, 301
Food(s) 155, 156, 217, 235, 238, 342
oxidation 342
protein-rich 155, 156
staple 235, 238
vitamins-rich 217
Free energy transition 341

G

Gene 5, 7, 13, 14, 21, 22, 23, 26, 402
silencing 5
therapy 7, 13, 14, 21, 22, 23, 26, 402
therapy in theory 21
Genetic proteins 172

Glands 289, 292, 293, 301, 307, 309, 312
mammary 289
prothoracic 307, 309
thymus 312,
thyroid 292, 293, 301
Glucogenesis 312
Glucokinase 376
Gluconeogenesis 244, 383, 404
Glucose galactose 123
Glycogenesis 289
Glycogen synthetase 265
Glycolysis 338, 346, 375, 379, 404, 406
pathway 379, 404, 406
process 338, 346, 375, 406
Glycoproteins 122, 173, 204, 291, 312
hormone 291
Growth 172, 289, 290, 294, 302
hormone (GH) 172, 289, 290, 294
inhibitors 302

H

Headaches 224, 227, 238, 240, 247, 250, 251, 294
migraine 238
Health Benefits 229, 232, 234, 243
of Vitamin 229, 232, 234
of Vitamin B6 243
Heart 229, 232, 236, 242, 244, 243, 250, 364,
attack 232, 242, 243, 250
diseases 244, 364
failure 229, 236
Hormonal 4, 172
imbalances 4
proteins 172
Hormone(s) 189, 244, 290, 291, 292, 295, 296, 301, 302, 312, 313,
cortisol 313
erythropoietin 302
glucagon 302
glycoprotein polypeptide 301
happy 244
lipid-soluble 290
love 295
steroid 189, 290, 296, 312
stress-related 241
thyroid 291, 292, 301, 302
Horse raddish peroxidase 4
Hydrolase 18, 265, 266, 267
Hydrolysis 121, 122, 123, 170, 171, 172, 189, 194, 195,266, 267, 345, 380, 385, 387, 389
of nucleic acids 389
of protein 266
reactions 267
Hyperkeratosis 233

I

Immune 11, 24, 120, 204, 219, 227, 242, 301
function 242
system 11, 24, 120, 204, 219, 227, 301
Immunomodulators 24
Immunosensors 17
Immunotherapy 24
Infertility therapy 300
Insulin 11, 17, 290
synthesis 11, 290
therapy 17
International union of biochemistry (IUB) 264, 266
Isomerases 265, 266, 267
Isomerization 136, 265, 376

J

Juvenile hormones 307, 308, 311, 312, 313

K

Ketotetrose 125, 126
Kidney diseases 243
Korsakoff’s 235, 251
psychosis 235
syndrome 235, 251

L

Lactase 144, 263
intestinal enzyme 144
Lewis acid-base 4, 41, 42, 43, 49
reactions 49
theory 41
Lipases 4, 265, 267
Lipids metabolism 380
Lipogenesis 380, 381
Lipoproteins 172, 173, 189, 199, 381, 406
Liver 231, 240

damage 231
disease 240
Living 57, 363, 365
cells transform energy 363
organisms metabolism 365
system functions 57
Loss 11, 162, 170, 187,224, 227, 233, 236, 244, 245, 247, 250, 252
hair 224, 245
memory 236
Luteinizing hormone (LH) 288, 290, 291, 300, 313

M

Macronutrient 253
Membrane transport 338
Memory disorder 251
Menopausal hormone therapy 299
Menopause 4, 299
Menstrual 232, 290, 299
cramps 232
cycles 290, 299
Metabolic hormones 291
Methionine synthase 248
Method 3, 9, 65, 105
biochemical 9
colorimetric 3
electrophoresis 65
glucose oxidase 3
imaging 105
Michaelis-Menten equation 271
Micronutrients 10, 253
essential 10
Microorganisms 6, 8, 25, 94, 101, 376, 380, 381, 389, 390
anaerobic 380
soil 389
Millon's 171
Reaction 171
reagent 171
Mineralocorticoids 289
Monophosphate 179
Monosaccharides 120, 122, 123, 124, 125, 126, 127, 130, 134, 135, 144
Morphogenetic hormones 291
Multiple sclerosis 251
Myelinogenesis 248
Myocardial infarction 12, 26

N

Nausea 224, 227, 234, 236, 240, 244, 246, 248, 251
Nerve functions 235, 243
Neurotransmitters 75, 232, 241, 298
NMR 9, 98
spectroscopy 98
spectroscopy method 9
technique 98
Non-covalent intermolecular interactions 57
Non-essential amino acid 151, 152, 154, 155, 157
Nuclear 98, 99
magnetic resonance 98
overhauser effect 99
Nucleic acid(s) 386, 389, 402
degradation 389
metabolism 386, 402
Nucleoproteins 172, 173
Nucleosidase 390
Nutrient(s) 9, 26, 172
deficient 9, 26
proteins 172

O

Oils 7, 34, 35, 187, 188, 190, 191, 193, 194, 195, 196, 231, 228
almond 228
corn 228
palm 228
peanut 228
safflower 228
soybean 228
sunflower 191, 196, 228
Optimization of crystalline protein 107
Osteoporosis 4, 287, 294, 300, 312
Oxidoreductases 266, 267

P

Pancreatic juice 290
Pancreatitis 12
Pathways 8, 280, 281, 341, 370, 374, 375, 376, 379, 385, 392, 405, 406
aerobic 341
biochemical 406
energy-production 406

glycolytic 375
metabolic 8, 280, 281, 374, 405
proteasome 385
respiratory 370
Peripheral 203, 204, 206, 251, 229
nerve disorder 251
neuropathy 229
protein 203, 204, 206
Peroxidase 4
Pheromone biosynthesis 307
Phosphoglycerate isomerization 265
Pituitary 283, 294, 301
gland 301
hormones 293, 294
tumor 294
Polycystic ovary syndrome 4
Post-translational modification (PTM) 280
Principle(s) 100, 325
basic thermodynamics 325
of electron microscopy 100
Production 8, 312
fertilizer 8
of glucose 312
Properties 2, 5, 33, 35, 36, 65, 66, 97, 103, 223, 216, 217, 327, 334, 371
antioxidants 223
electrostatic 66
macroscopic 327
thermodynamic 334
Proteases 2, 58, 385
Proteinases 265
Protein(s) 66, 101, 170, 172, 229, 291, 369, 376, 402
catalytic 172
denatured 170
hexokinase 376
hormones 291
kinase 229
metabolism 402
phosphoglucomutase 369
thermophilic 66
Proteolysis 385
Proton motive force (PMF) 392

R

Rapid ureate test (RUT) 3
Reaction 37, 38, 42, 43, 49, 76, 160, 161, 171, 246, 265, 266, 268, 269, 270, 272, 279, 330, 338, 339, 344, 347, 364, 369, 371, 372
allergic 246
catabolic 364
catalytic 279
cellular 347
electrostatic 76
enzyme-based 372
Recombinant DNA 363, 400, 401, 402, 403, 405
technology 401
Recombination 92, 403, 405
genetic 405
hereditary 403
Respiratory tract infections 227
Restriction endonuclease 4
Retinal receptors 219
Retinopathy 229, 251
Riboflavin deficiency 238
Ribonucleoti dereductase 389
RNA 64, 120, 173, 174, 176, 177, 183, 184, 185, 186, 206, 383, 388, 395, 396, 397, 400, 403
and protein folding 64
polymerase 383, 395, 397, 403
pre-messenger 383, 396
small cytoplasmic 185
splicing 396

S

Salivary amylase 264
Serine proteases 276
Sex hormones 200, 287, 290, 299
female 290
male 290
Sexual infantilism 11
Signal 2, 101, 279
transduction 279
transmission 2
particle analysis (SPA) 101
Skeletal myopathy 229, 251
Skin 219, 223, 224, 225, 233, 234, 237, 238, 240, 242, 244, 246, 251, 252
dry 238
healthy 219
rashes 244
Skin wrinkling 234

Sources of 41, 49, 102, 140, 157, 222, 226, 228, 232, 235, 237, 239, 241, 243, 244, 245, 247, 249, 281
vitamin A 222
vitamin B2 237
vitamin B3 239
vitamin B5 241
vitamin B6 243
vitamin B7 244, 245
vitamin B9 247
vitamin B12 249
vitamin D 226
Sphingomyelins 189, 196, 198, 199
Sphingophospholipids 189, 196, 198
Starch 120, 123, 124, 142, 144, 145, 146, 147, 148, 380, 381
animal 146
dietary 381
hydrolysis 142
resistant 145
STEM techniques 107
Stereoisomers 127, 128
Steroids 189, 199, 200, 206, 241, 364, 380, 381
Streptomycetes 389
Stress 292, 298, 306
Structure of 147, 175, 244, 292, 295, 300, 304
biotin 244
cortisol 292
cytokinin 304
glycogen 147
oxytocin 295
progesterone 300
purine 175
Succinic 265, 275
acid dehydrogenase 275
dehydrogenase 265
Synthesis 2, 8, 162, 196, 199, 233, 290, 364, 325, 346, 365, 386, 387, 391, 394, 402, 406
bacterial fermentation 249
biomolecular 325, 346
impaired collagen 233
lipid 406
of glucose 8
of nucleic acids 386
parathyroid hormone 290
purine 386
pyrimidine 386
urea 162
Synthetase 267, 384, 399
catalyst aminoacyl-tRNA 384
enzyme aminoacyl-tRNA 399
System 71, 331, 333
enthalpy 71
entropy 331, 333

T

Techniques 26, 92, 94, 97, 98, 100, 101, 102, 105, 106, 107, 380, 384, 385, 396, 400
biological 105
genetic engineering 26
instrumentation 94, 105
molecular biology 92, 94
natural synthesis 384
Testosterone 200, 287, 290, 291, 300, 301
levels 300
production of 300, 301
Thermal shift assay 336
Thermodynamic 325, 330, 336, 345, 346, 348
efficiency 345
parameters 325, 330, 336, 346
hydrolysis 348
processes 325, 348
Thiamine deficiency 235, 236
Thymidylate synthase 389
Thymine pyrophosphate (TPP) 280
Thyroid-stimulating hormone (TSH) 289, 290, 291, 292, 293, 294, 301, 302, 313
Thyrotropin-releasing hormone (TRH) 289, 291, 301
Tissues 199, 230, 300
fatty 230
nervous 199
reproductive 300
Tollen's reagent 124, 136, 137
Transcription process 396, 403
Transferases 266, 267
Transmission 101, 102, 105
electron micrographs 101
electron microscopes 105
microscopy 102
Triosephosphate isomerase 376

V

Vander Waal 57, 66, 68, 77
forces 66

interaction 57, 66, 68, 77
Vision 219, 223, 230, 253
blurred 230
Vitamin B-complex 234

W

Waals 67, 68, 69
contact distance 68
forces of attraction 67
interaction 69
Waals's dispersion powers 70
Water-soluble hormones 290

X

Xanthine 390
oxidase 390
Xanthoproteic 161, 171
reaction 161
test 171
X-ray 94, 97
crystallographic analysis 94
diffraction 94, 97
diffractometry method 97
X-ray crystallography 9, 92, 94, 95, 96, 97, 107, 129
diffraction in 95, 107
method 95

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