

# Biological Chemistry

Підручник з біологічної хімії складається з 30 розділів і містить текстові матеріали та велику кількість ілюстрацій, у тому числі хімічні формули, реакції та їх рівняння, малюнки складених внутрішньоклітинних перетворень біомолекул та метаболічні "схеми". Підручник призначений для студентів медичних та фармацевтичних факультетів вищих навчальних закладів України.

Yu. Gubsky

# BIOLOGICAL CHEMISTRY



Vinnytsia  
Nova Knyha  
2020

УДК 577.1(075)

Г93

*Recommended by the High Scientific Board of I. Horbachevsky Ternopil State Medical University as a textbook for students of medical and pharmaceutical faculties of higher educational establishments of Ukraine (Report № 17 of 20.05.2016)*

*Recommended by the Central Commission of Experts in Biological and Medical Chemistry of Health Ministry and National Academy of Medical Sciences of Ukraine as a textbook for students of medical and pharmaceutical faculties of higher educational establishments of Ukraine (Letter № 23 of 14.04.2016)*

**Author:**

**Gubsky Yuriy I.** – DSci, Professor, Corresponding Member of National Academy of Medical Sciences of Ukraine, Head of Research and Organizational Department, Presidium, NAMS of Ukraine

**Reviewers:**

**Komisarenko Serhiy V.** – DSci, Professor, Full Member (Academician) of National Academy of Sciences and National Academy of Medical Sciences of Ukraine, Director of O. Palladin Institute of Biochemistry, NAS of Ukraine.

**Nizhenkovska Iryna V.** – DSci, Professor, Head of Pharmaceutical, Biological and Toxicological Chemistry Department, O. O. Bogomolets National Medical University.

**Erstenyuk Hanna M.** – DSci, Professor, Head of Medical and Biological Chemistry Department, Vice-Rector of Ivano-Frankivsk National Medical University.

**Gubsky Yu.**

Г93 Biological chemistry = Біологічна хімія : textbook / edited by Yu. Gubsky. – 3rd edition. – Vinnytsia : Nova Knyha, 2020. – 488 p. ISBN 978-966-382-835-0

The textbook in Biological Chemistry consists of 30 chapters made up of text material and plentiful illustrations, including chemical formulas, reaction equations, drawings depicting complicated intracellular transformations of biomolecules, and metabolic “charts”.

The textbook is intended for students of medical and pharmaceutical faculties of higher educational establishments of Ukraine.

**УДК 577.1(075)**

Підручник з біологічної хімії складається з 30 розділів і містить текстові матеріали та велику кількість ілюстрацій, у тому числі хімічні формули, реакції та їх рівняння, рисунки складних внутрішньоклітинних перетворень біомолекул і метаболічні “схеми”.

Підручник призначений для студентів медичних та фармацевтичних факультетів вищих навчальних закладів України.

ISBN 978-966-382-835-0

© Gubsky Yu., 2020

© Nova Knyha, 2020

# Yuriy Ivanovich Gubsky (Yu. I. Gubsky)

Ukrainian biomedical scientist, educator. Achievements include research in biochemical toxicology and pharmacology, elucidation of biochemical mechanisms of biomembranes and DeoxyriboNucleic Acid damage under biocide xenobiotics (organophosphates, chloroalkanes) intoxication, apoptosis as the route of cellular progression switched on under conditions of hepatocytes and neurons chemical lesion.

## Education

Doctor of Medicine, Medical University, Kiev, Ukraine, 1969; Master of Science in Biochemistry and Biological Chemistry, Medical University, Kiev, Ukraine, 1972; Doctor Medical Scis. in Biochemistry, Supreme Attestation Commission, Moscow, 1984.

## Career

Junior lecturer Department Biochemistry Kiev Medical University, 1972–1976, senior lecturer, 1976–1985, professor, 1985–1987; head department biochemical pharmaceutical Institute Pharmaceutical and Toxicology, Kiev, since 1987; head chair bioorganic, biological and pharmaceutical chemistry National Medical University, since 1997; Vice director Institute Pharmaceutical and Toxicology, Kiev, 1987–1992; director department biomedical science Supreme Attestation Commission Ukraine, Kiev, 1992–2000.

Author: The Correction of Chemical Hepatic Injury, 1989, Chemical Accidents and Ecology, 1993, Biological Chemistry: Manual for High Medical School, 2000; 2007; 2011, 2017, author, editor: Pharmaceutical Drugs in Psychopharmacology, 1997, Bioorganic Chemistry: Manual for High Medical School, 2007; 2009; Biological Chemistry: Manual for High Medical School, 2011, 2017. Inventor and patentee in field.

P. L. Shupik National Medical Academy of Postgraduate Education, Faculty Member, Palliative and Hospice Medicine Chair, Head (since 2010).

## Membership

Fellow Academy Medical Sci. Ukraine (elected 1994; secretary-general 1994-9).



# CONTENTS

<b>PREFACE</b> .....	10
----------------------	----

## **Part 1. BIOMOLECULES. CELLS. METABOLISM**

<b>Chapter 1. BIOCHEMISTRY: BIOMOLECULES, METABOLISM</b> .....	13
1.1. Biochemistry as fundamental biomedical science. ....	13
1.2. Biomolecules – major classes, representatives .....	14
<b>Chapter 2. PROTEINS. AMINO ACIDS. PEPTIDES</b> .....	19
2.1. Amino acids: structure, properties. ....	19
2.2. Peptide bonds, polypeptides .....	24
2.3. Proteins. Levels of protein structure .....	28
<b>Chapter 3. NUCLEIC ACIDS. NUCLEOTIDES. DNA. RNA</b> .....	36
3.1. Nucleic acids and the flow of genetic information .....	36
3.2. Nucleotides: structure, biological functions .....	37
3.3. Nucleic acids as polynucleotides: DNA, RNA .....	42
<b>Chapter 4. CARBOHYDRATES. SUGARS AND THEIR DERIVATIVES</b> .....	46
4.1. Monosaccharides. Hexoses. Pentoses. Amino sugars .....	47
4.2. Oligosaccharides. Homopolysaccharides .....	49
4.3. Heteropolysaccharides. Glycoproteins .....	53
<b>Chapter 5. LIPIDS. FATTY ACIDS. BIOMEMBRANES</b> .....	57
5.1. General characteristics of lipids. Biological functions .....	57
5.2. Fatty acids: structure and properties .....	58
5.3. Structure and properties of special classes of lipids .....	61
5.4. Steroids: cholesterol, bile acids, steroid hormones .....	67
<b>Chapter 6. CELLS. METABOLISM: GENERAL ASPECTS</b> .....	71
6.1. Metabolism: overall conception, metabolic pathways .....	71
6.2. Cells. Compartmentalization of metabolic pathways .....	72

## **Part 2. ENZYMES. GENERAL METABOLIC PATHWAYS**

<b>Chapter 7. METABOLISM. ENZYMATIC REACTIONS</b> .....	77
---	----

7.1. Metabolism: general conceptions, metabolic pathways . . . . .	77
7.2. Enzymes as the principal molecular devices of metabolism . . . . .	80
7.3. Enzyme nomenclature and classification . . . . .	84
7.4. Molecular mechanisms of enzyme catalysis . . . . .	91
<b>Chapter 8. COENZYMES. CONTROL OF ENZYMATIC REACTIONS . . . . .</b>	<b>94</b>
8.1. Coenzymes: classification, structure. Vitamins as coenzyme precursors . . . . .	94
8.2. Kinetics of enzyme catalysis. Michaelis – Menten theory . . . . .	99
8.3. Inhibition of enzymes. Kinds of inhibitors . . . . .	103
8.4. Enzymic catalysis regulatory mechanisms . . . . .	107
<b>Chapter 9. BIOENERGETICS-1. CATABOLIC PATHWAYS. TRICARBOXYLIC ACID CYCLE . . . . .</b>	<b>114</b>
9.1. Bioenergetics. ATP and other high-energy compounds . . . . .	114
9.2. Overview of catabolic pathway steps . . . . .	116
9.3. Tricarboxylic acid cycle: overview . . . . .	117
9.4. Tricarboxylic acid cycle: reactions and enzymes . . . . .	118
<b>Chapter 10. BIOENERGETICS-2. MITOCHONDRIAL ELECTRON TRANSPORT. OXIDATIVE PHOSPHORYLATION . . . . .</b>	<b>124</b>
10.1. General notions of free energy transfer in biochemical systems . . . . .	124
10.2. Electron transport chain in mitochondria . . . . .	126
10.3. Oxidative phosphorylation. ATP synthase . . . . .	131
<b>Part 3. METABOLISM OF MAJOR CLASSES OF BIOMOLECULES</b>	
<b>Chapter 11. CARBOHYDRATE METABOLISM-1. PATHWAYS OF GLUCOSE OXIDATION . . . . .</b>	<b>137</b>
11.1. Major routes of carbohydrate metabolism. . . . .	137
11.2. Aerobic and anaerobic oxidation of glucose. Glycolysis . . . . .	139
11.3. Enzymatic reactions of glycolysis. Regulation of glycolysis . . . . .	140
11.4. Aerobic oxidation of glucose. Oxidative decarboxylation of pyruvate. . . . .	149
11.5. Pentose phosphate pathway . . . . .	150
<b>Chapter 12. CARBOHYDRATE METABOLISM-2. GLYCOGEN METABOLISM. GLUCONEOGENESIS. . . . .</b>	<b>156</b>
12.1. Glycogen metabolism. Glycogen-storage diseases . . . . .	156
12.2. Gluconeogenesis: reactions, regulation. . . . .	167

12.3. Regulation of carbohydrate metabolism . . . . .	172
12.4. Control of blood plasma glucose. Diabetes mellitus. . . . .	174
<b>Chapter 13. LIPID METABOLISM-1. TRIACYLGLYCEROL CATABOLISM.</b>	
OXIDATION OF FATTY ACIDS. KETOGENESIS . . . . .	177
13.1. Lipids: general characteristics, biological functions . . . . .	177
13.2. Fat metabolism: overview, lipolysis . . . . .	179
13.3. Degradation of fatty acids ( $\beta$ -oxidation) . . . . .	182
13.4. Ketone bodies. Ketogenesis in diabetes mellitus . . . . .	188
<b>Chapter 14. LIPID METABOLISM-2. LIPOGENESIS. CHOLESTEROL</b>	
<b>METABOLISM. LIPID METABOLISM PATHOLOGY . . . . .</b>	<b>193</b>
14.1. Biosynthesis of fatty acids: reactions, enzymes . . . . .	193
14.2. Biosynthesis of acylglycerols: triglycerides, phosphoglycerides. . . . .	197
14.3. Sphingolipids: representatives, metabolism . . . . .	201
14.4. Cholesterol synthesis and biotransformation. Atherosclerosis . . . . .	207
<b>Chapter 15. AMINO ACID METABOLISM-1. AMINO ACID DEGRADATION:</b>	
<b>DEAMINATION, TRANSAMINATION, DECARBOXYLATION. UREA CYCLE . . . . .</b>	<b>213</b>
15.1. Protein turnover. Principal pathways of amino acid metabolism . . . . .	213
15.2. Transamination of amino acids: reactions, enzymes. . . . .	216
15.3. Deamination of amino acids: reactions, enzymes. . . . .	220
15.4. Decarboxylation of amino acids: reactions, biological significance. . . . .	221
15.5. Amino nitrogen metabolism. Urea cycle: reactions, enzymes. . . . .	223
<b>Chapter 16. AMINO ACID METABOLISM-2. AMINO ACID SPECIALIZED</b>	
<b>METABOLIC PATHWAYS. PORPHYRIN METABOLISM . . . . .</b>	<b>228</b>
16.1. General pathways of amino acids carbon skeleton degradation . . . . .	228
16.2. Specialized pathways of individual amino acid metabolism . . . . .	231
16.3. Amino acids as precursors of biologically important compounds . . . . .	242
16.4. Diseases associated with abnormal amino acid metabolism . . . . .	244
16.5. Biosynthesis and catabolism of porphyrins. Gout . . . . .	245
<b>Chapter 17. METABOLISM OF PURINE AND PYRIMIDINE</b>	
<b>NUCLEOTIDES. PURINE DEGRADATION. GOUT . . . . .</b>	<b>255</b>
17.1. Nucleotides: structure, biochemical functions . . . . .	255
17.2. Biosynthesis of purine nucleotides . . . . .	257



17.3. Biosynthesis of pyrimidine nucleotides . . . . .	263
17.4. Catabolism of purine and pyrimidine nucleotides. Gout . . . . .	265

**Part 4. FUNDAMENTALS OF MOLECULAR BIOLOGY AND GENETICS**

<b>Chapter 18. GENE, GENOME. DNA REPLICATION . . . . .</b>	<b>270</b>
18.1. Gene, genome. DNA, RNA: structure, properties. . . . .	270
18.2. Telomeres. Telomerase . . . . .	281
18.3. DNA technologies. . . . .	284
<b>Chapter 19. mRNA TRANSCRIPTION. RIBOSOMAL TRANSLATION. . . . .</b>	<b>288</b>
19.1. mRNA. Transcription: enzymes, mechanisms . . . . .	288
19.2. Genetic code. Translation in ribosomes. . . . .	291
19.3. Ribosomal molecular machinery . . . . .	293

**Part 5. METABOLIC CONTROL. HORMONES AND VITAMINS**

<b>Chapter 20. HORMONES-1. BIOCHEMICAL AND CELLULAR MECHANISMS OF HORMONAL REGULATION . . . . .</b>	<b>301</b>
20.1. Hormones: general definitions. . . . .	301
20.2. Basic principles of hormone effects . . . . .	303
<b>Chapter 21. HORMONES-2. HORMONES OF PEPTIDE AND PROTEIN NATURE. . . . .</b>	<b>308</b>
21.1. Peptide and protein hormones of hypothalamus and hypophysis. . . . .	308
21.2. Protein hormones of pancreatic gland. . . . .	321
<b>Chapter 22. HORMONES-3. AMINO ACID DERIVED HORMONES: CATECHOLAMINES, THYREOIDS. LIPOPHILIC HORMONES . . . . .</b>	<b>327</b>
22.1. Catecholamines and other biogenic amines . . . . .	327
22.2. Thyroid hormones: representatives, pathology . . . . .	331
22.3. Steroid hormones: representatives, effects, pathology . . . . .	335
22.4. Hormonal regulation of calcium homeostasis. . . . .	342
22.5. Eicosanoids. Biomedical and pharmacological aspects . . . . .	346
<b>Chapter 23. BIOCHEMISTRY OF NUTRITION-1. VITAMINS AS ESSENTIAL COMPONENTS OF HUMAN DIET. WATER-SOLUBLE VITAMINS. . . . .</b>	<b>350</b>
23.1. Biochemistry of nutrition. Components of human diet . . . . .	350
23.2. Vitamins: basic definitions, classes of vitamins . . . . .	352

23.3. Water-soluble vitamins. Vitamins as coenzymes: structure, biochemical properties. . . . .	353
---	-----

**Chapter 24. BIOCHEMISTRY OF NUTRITION-2. VITAMIN C.**

LIPID-SOLUBLE VITAMINS AS BIOREGULATORS AND ANTIOXYDANTS . . . . .	367
24.1. Vitamin C (ascorbic acid) . . . . .	367
24.2. Vitamin A (retinol): structure, biochemical functions. . . . .	370
24.3. Vitamin D (calciferol) as calcium and phosphorous homeostasis regulator . . .	373
24.4. Vitamin E (tocopherol) as principal antioxidant in human body . . . . .	375
24.5. Vitamin K: structure of vitamers. Role in blood clotting. . . . .	377

**Part 6. BIOCHEMISTRY OF SPECIALIZED TISSUES  
AND PHYSIOLOGICAL FUNCTIONS**

**Chapter 25. BIOCHEMISTRY OF BLOOD. HEMOSTASIS. COAGULATION**

CASCADE SYSTEM . . . . .	380
25.1. Blood: composition, biochemical functions. . . . .	380
25.2. Hemoglobin: transport of oxygen. Hemoglobinopathies . . . . .	382
25.3. Hemostasis: blood clotting, fibrinolysis. . . . .	389

**Chapter 26. BIOCHEMISTRY OF SPECIALIZED CELLS AND PHYSIOLOGICAL**

**FUNCTIONS. BIOCHEMISTRY OF LIVER. METABOLISM OF XENOBIOTICS. . . . .**

26.1. Liver: survey of major biochemical functions . . . . .	398
26.2. Liver: metabolism of heme and bile pigments. Bilirubin transformation. Icterus. . . . .	403
26.3. Liver detoxification function. Biotransformation of xenobiotics and endogenous waste products . . . . .	408

**Chapter 27. BIOCHEMISTRY OF TOOTH AND SALIVA . . . . .**

27.1. Anatomy and physiology of human teeth . . . . .	415
27.2. Biochemical composition and molecular organization of dental tissues. . .	417
27.3. Tooth enamel: properties, biochemical composition . . . . .	417
27.4. Dentin: structure, biochemistry. Periodontum. Cementum . . . . .	420
27.5. Tooth pulp: physiology, metabolism . . . . .	426

27.6. Tooth pathology. Caries: biochemical aspects . . . . .	427
27.7. Biochemical components and functions of saliva. . . . .	428
<b>Chapter 28. BIOCHEMISTRY OF MUSCLES. MOLECULAR PHYSIOLOGY OF MUSCLE CONTRACTION. . . . .</b>	<b>430</b>
28.1. Muscle tissue: general characteristics of functions, structure and biochemistry . . . . .	430
28.2. Sliding filament model of muscle contraction. Role of calcium in muscle contraction control . . . . .	440
28.3. Regulation of muscle contraction. Role of calcium in muscle contraction control. . . . .	444
<b>Chapter 29. BIOCHEMISTRY AND MOLECULAR PATHOLOGY OF CONNECTIVE TISSUE . . . . .</b>	<b>446</b>
29.1. Connective tissue: cells and biomolecules . . . . .	446
29.2. Structural and adhesive proteins of connective tissue. Structural proteins of extracellular matrix . . . . .	450
29.3. Biochemistry of extracellular matrix. Glycosaminoglycans and proteoglycans of connective tissue . . . . .	457
29.4. Molecular pathology of connective tissue . . . . .	462
<b>Chapter 30. BIOCHEMISTRY OF SPECIALIZED CELLS AND PHYSIOLOGICAL FUNCTIONS. BIOCHEMISTRY OF NERVE TISSUE AND NEUROTRANSMITTERS. . .</b>	<b>466</b>
30.1. Nerve tissue: general characteristics of structure and functions . . . . .	466
30.2. Peculiarities of brain biochemical composition and metabolism. . . . .	469
30.3. Neurotransmitters: classification, receptors, representatives . . . . .	470
30.4. Drugs, neurotransmitters and synapses . . . . .	483
<b>LIST OF REFERENCES . . . . .</b>	<b>487</b>

*Навчальне видання*

**Губський Юрій Іванович**

## **Біологічна хімія**

Підручник (англійською мовою)

Редактор *В. О. Луценко*

Технічний редактор *Ж. С. Швець*

Коректор *Ю. П. Тертун*

Комп'ютерна верстка: *О. С. Парфенюк*

Підписано до друку 12.05.20. Формат 60×90/16. Папір офсетний.  
Гарнітура Arsenal. Друк офсетний. Ум. друк. арк. 30,5. Зам. № 1993.

ПП “Нова Книга”

21029, м. Вінниця, вул. М. Ващука, 20

Свідоцтво про внесення суб'єкта видавничої справи  
до Державного реєстру видавців, виготівників  
і розповсюджувачів видавничої продукції

ДК № 2646 від 11.10.2006 р.

(067) 6562650, (063) 5270178

E-mail: [info@novaknyha.com.ua](mailto:info@novaknyha.com.ua)

[www.nk.in.ua](http://www.nk.in.ua)

**ridmi**  
ТВІЙ УЛЮБЛЕНИЙ КНИЖКОВИЙ

**КУПИТИ**