Organic Chemistry in Medicine

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CONTENTS

PREFACE

Chemistry, physics, and mathematics are extensively used in medicine. Today medical chemistry is a basic science for examining the physiological and pathological processes in the human body.

The history of organic medical chemistry dates back to 1530 when Theophrastus Paracelsus criticized ancient medicine. He believed that human life was due to chemical processes, that diseases were disorders of the chemical processes in human body, and that treatment of diseases should be carried out with chemical compounds. It took centuries to establish this insight.

During the 18th century, Carl Scheele obtained many inorganic and organic compounds, in 1828 Friedrich Wöhler synthesized urea, and in 1868 Friedrich Miescher discovered DNA. At the end of the 19th century, Emil Fischer established the structure of carbohydrates and proteins, in 1897, Eduard Buchner proved that alcoholic fermentation takes place extracellularly, and in 1926, James Sumner found that enzymes are proteins. Between 1920 and 1940, vitamins and hormones were studied. Glycolysis and fermentation were clarified in the 1930s and 1940s. Hans Krebs discovered urea and citrate cycles. In the 1950s, Pouling proposed the helix model of proteins, and in 1953, James Watson and Francis Crick discovered that DNA was a double helix. In the following decades, a leap was made in the study of nucleic acids, genetic code, and protein biosynthesis.

The scope of the proposed book is the organic chemistry in medicine. It is intended for students of medicine and dentistry, for doctors and dentists, as well as for laboratory doctors, biochemists, pharmacists, and scientists who want to get acquainted with the basics of medicine.

The texts about compounds and chemical processes that have direct significance for medicine are typed in color.

January 2025

Prof. Budin Michov, MD, PhD, ScD

ABBREVIATIONS

A	Adenosine
AAC	**A**ntigen-**a**ntibody **c**omplex(es)
ACTH	**A**drenoco**r**ticoto**t**ropic **h**ormone
A_r	Relative atomic mass, dimensionless
Asn	Asparagine
Asp	Aspartate
ATP^{4-}	Adenosine triphosphate
C	Cytosine
Cis	Cysteine
CoA (CoASH)	Coenzyme A
CT	Corticotropin – s. ACTH
dATP	Deoxyadenosine triphosphate
dCTP	Deoxycytidine triphosphate
dGTP	Deoxyguanosine triphosphate
DNA	Deoxyribonucleic acid(s)
DNase	**D**eoxyribo**n**ucle**ase**
dTTP	Deoxythymidine triphosphate
EC	**E**nzyme **C**ommission. These initials and their subsequent numbers denote the enzymes in the international enzyme classification.
EDTA	Ethylenediaminetetraacetate
Eq.	Equation
G	Guanosine
GABA	**G**amma **a**mino**b**utyric **a**cid (4-aminobutyric acid)
Gal	Galactose
Gln	Glutamine
Glu	Glutamate
Gly	Glycine

$[H^+]$	Equilibrium proton concentration, in mol/dm³ (mol/L)
$[\mathbf{H}^+]$	Equilibrium proton concentration, dimensionless. $[\mathbf{H}^+] = [H^+]/[H^+]_0$, where $[H^+]_0$ is the proton concentration equal to 1 mol/dm³ (mol/L).
HINA	**H**ydrazine of **i**so**n**icotinic **a**cid
His	Histidine
I	Ionic strength, in mol/kg or mol/dm³ (mol/L)
$\boldsymbol{I}$	Dimensionless ionic strength. $\boldsymbol{I} = I/I_0$, where I_0 is the ionic strength equal to 1 mol/dm³ (mol/L).
I_c or (I)	Concentration ionic strength, in mol/dm³ (mol/L)
I_m	Mass ionic strength, in mol/kg
Ig	**I**mmuno**g**lobulin(s)
Ile	Isoleucine
K	Thermodynamic equilibrium constant, different dimensions
$\boldsymbol{K}$	Thermodynamic equilibrium constant, dimensionless. $\boldsymbol{K} = K/K_0$, where K_0 is equal to 1 mol/dm³ (mol/L).
K_c	Concentration equilibrium constant, different dimensions
$\boldsymbol{K_c}$	Concentration equilibrium constant, dimensionless. $\boldsymbol{K_c} = K_c/K_0$, where K_0 is equal to 1 mol/dm³ (mol/L).
K_w	Ionic product of water, in $(\text{mol/dm}^3)^2$ or $(\text{mol/L})^2$
Leu	Leucine
LPS	**L**ipo**p**oly**s**accharide(s)
Lys	Lysine
M_r	Relative molecular mass, dimensionless
Met	Methionine
mRNA	**M**essenger **RNA**
NAD^+/NADH	Oxidized/reduced **n**icotinamide **a**denine **d**inucleotide
$NADP^+$/NADPH	Oxidized/reduced **n**icotinamide **a**denine **d**inucleotide **p**hosphate
$[OH^-]$	Equilibrium concentration of hydroxide ion, in mol/dm³ (mol/L)

[**OH**$^-$]	Equilibrium concentration of hydroxide ion, dimensionless. [**OH**$^-$] = [OH$^-$]/[OH$^-$]$_0$ where [OH$^-$]$_0$ is the concentration of hydroxide ion equal to 1 mol/dm³ (mol/L).
PAS	**P**ara **a**mino**s**alicylic acid
Pg	**P**rosta**g**landin(s)
pH	Hydrogen exponent (Latin, *pondus*, *potentia hydrogenii*) – negative decimal logarithm of [**H**$^+$], dimensionless
Phe	Phenylalanine
pI, pH(I)	Isoelectric point (Latin, *pondus isoelectricus*), dimensionless
pK	Negative decimal logarithm of K, dimensionless
pK_c	Negative decimal logarithm of $\boldsymbol{K_c}$, dimensionless
RNA	**R**ibo**n**ucleic **a**cid(s)
RNase	**R**ibo**n**ucle**ase**
rRNA	**R**ibosomal **RNA**
S	Svedberg unit (10^{-13} s)
SDS	**S**odium **d**odecyl **s**ulfate
Ser	Serine
T	Thymidine
THF	**T**etra**h**ydro**f**olate
Thr	Threonine
tRNA	**T**ransport **RNA**
Try	Tryptophan
Tyr	Tyrosine
z_i	Number of elementary charges (electrovalence) of ion i, dimensionless
ζ	Electric potential of an ion or polyion, in V

NB! To derive logarithmic values of [H], I, and K, dimensionless quantities should be used. They represent the ratios between these quantities and an imagined value equal to 1 mol/dm³ (1 mol/L).

CHAPTER 1

ORGANIC CHEMISTRY IN MEDICINE

Organic chemistry is dealing with the structure, properties, and reactions of natural products, polymers, and drugs. The term *organic chemistry* has survived until now, but today this term means more precisely *chemistry of carbon compounds*. Only carbon, its oxides and carbonic acid, incl. its salts refer to inorganic chemistry. Due to the special properties of carbon and above all the ability of its atoms to form sufficiently long chains, the number of organic compounds exceeds millions. Another feature of organic compounds is that most of them have covalent bonds and, therefore, either do not dissociate or dissociate poorly in aqueous solution.

History

Until the 18th century, chemists believed that compounds in living organisms were endowed with a vital force that distinguished them from inorganic compounds. Jöns Berzelius, in accordance with his time, assumed that the construction of living matter required a mystical life force (*vis vitalis*). However, in 1828 Friedrich Wöhler produced the *organic* compound urea (carbamide, $CO(NH_2)_2$) from the *inorganic* compound ammonium cyanate (NH_4OCN). He wrote to Berzelius: "I must inform you that I can synthesize urea without the need for a kidney, in general, an animal, be it a human or a dog." In 1856, William Perkin produced the organic dye known as Perkin's mauve.

A crucial breakthrough for organic chemistry was the concept of chemical structure, developed in 1858 independently by both Friedrich Kekule and Archibald Couper. They suggested that tetravalent carbon atoms could link to each other to form a carbon lattice.

The pharmaceutical industry began in the last decade of the 19th century when the German company Bayer manufactured acetylsalicylic acid (Aspirin). By 1910, Paul Ehrlich developed the arsenic-based Salvarsan – the first effective drug against syphilis. Thus, he grounded the chemotherapy. In the 20th century, polymers and enzymes were shown to be large organic molecules, and petroleum was shown to be of biological origin.

Organic compounds are hydrocarbons that contain only carbon and hydrogen, as well as compounds based on carbon, but also containing other elements, especially oxygen, nitrogen, sulfur, phosphorus, halogens, and other. Organometallic compounds contain carbon and metals.

1.1. Characteristics of Carbon

Why carbon, among the already known more than 100 elements, is used by nature for the construction of organic matter? Carbon is an element in the 14 group in the periodic table of elements, located in the middle of its second period. Due to its location, carbon does not form ionic bonds, but stable covalent bonds with both other carbon atoms and atoms of other elements, especially hydrogen. One carbon atom can form covalent bonds with up to 4 carbon atoms, which in turn can bind to other carbon atoms.

While ionic bonds do not have a spatial orientation, covalent bonds have a strong spatial orientation. For example, the carbon atom can have different geometry: either tetrahedral sp^3-hybridization, as in diamond, or triangular sp^2-hybridization, as in graphite, or linear sp-hybridization, as in CO_2. Due to these properties, it forms or participates in the formation of unbranched and branched countless chain or ring compounds.

There are other elements that form chains and rings, too, such as boron, silicon, and sulfur. However, their bonds are weaker and unstable than those of carbon are. In addition, other atoms or atomic groups can be attached to a carbon atom without causing a significant weakening of the C–C bonds.

1.2. Structural Theory

Mainly Alexander Butlerov developed the theory of organic compound structure (structural theory). It is based on four postulates:

1. *The atoms of organic compounds are connected to each other in a strictly defined order according to their valence.*
   The bonding of atoms in a molecule is represented by a structural formula, which differs from the general formula. For example, vinyl alcohol and acetaldehyde have different structural formulas, but the same general formula C_2H_4O.
2. *The structure of organic molecules determines their properties.*
   In connection with this postulate, the concept of functional groups was introduced. Examples are the alcohol group –OH and the carboxyl group –COOH.