

Chapter 1

Chemical Composition of Living Cells

Overview

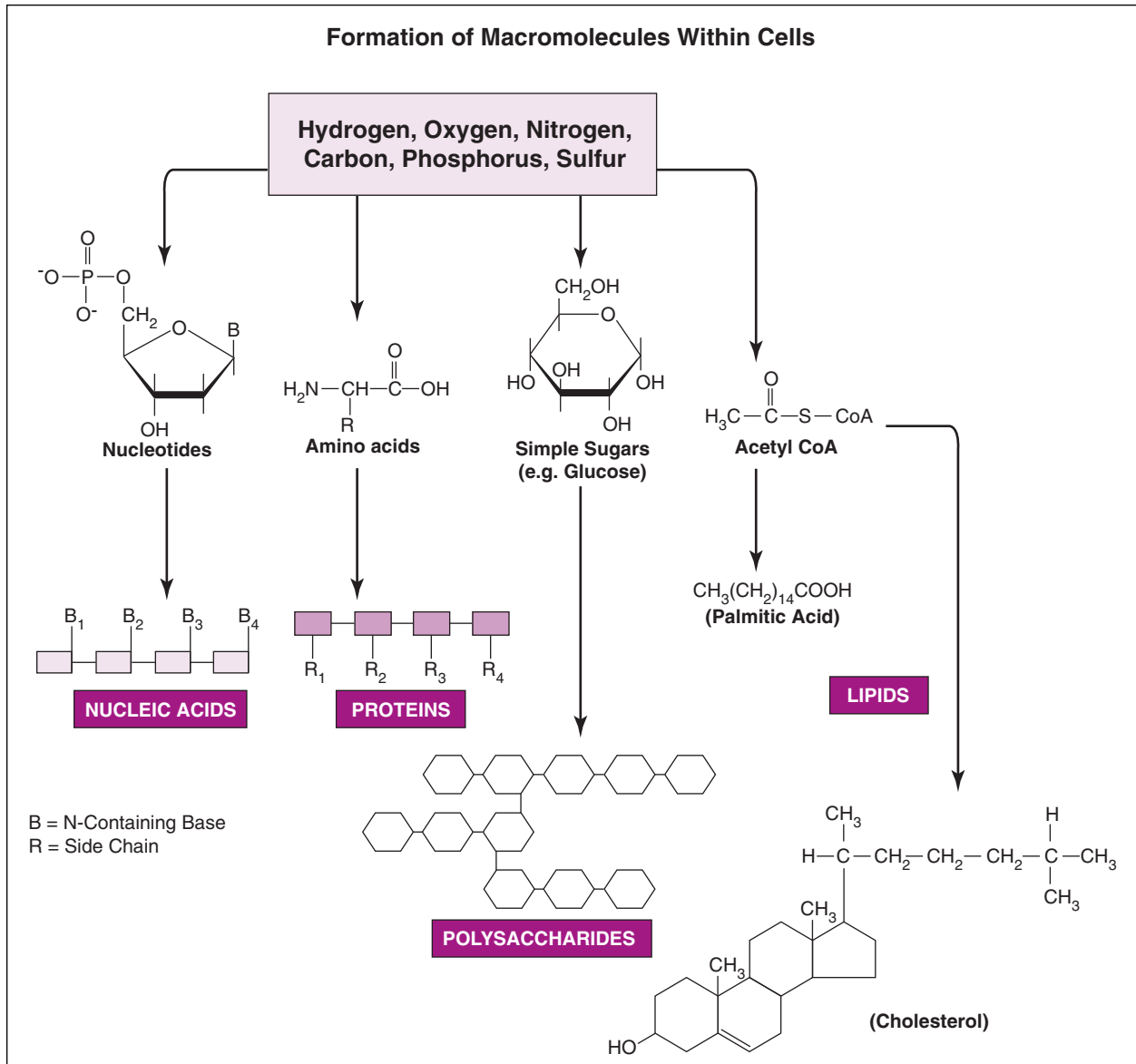
- Hydrogen, oxygen, nitrogen, carbon, sulfur, and phosphorus normally make up more than 99% of the mass of living cells.
- Ninety-nine percent of the molecules inside living cells are water molecules.
- Cells normally contain more protein than DNA.
- Homogenous polymers are noninformational.
- All non-essential lipids can be generated from acetyl-CoA.
- Like certain amino acids and unsaturated fatty acids, various inorganic elements are dietarily "essential".
- Most all diseases in animals are manifestations of abnormalities in biomolecules, chemical reactions, or biochemical pathways.

All living organisms, from microbes to mammals, are composed of chemical substances from both the inorganic and organic world, that appear in roughly the same proportions, and perform the same general tasks. **Hydrogen, oxygen, nitrogen, carbon, phosphorus, and sulfur** normally make up more than 99% of the mass of living cells, and when combined in various ways, form virtually all known organic biomolecules. They are initially utilized in the synthesis of a small number of building blocks that are, in turn, used in the construction of a vast array of vital macromolecules (**Fig 1-1**).

There are four general classes of macromolecules within living cells: **nucleic acids, proteins, polysaccharides, and lipids**. These compounds, which have molecular weights ranging from 1×10^3 to 1×10^6 , are created through polymerization of building blocks that have molecular weights in the range of 50 to 150. Although subtle differences do exist

between cells (e.g., erythrocyte, liver, muscle or fat cell), they all generally contain a greater variety of proteins than any other type of macromolecule, with about 50% of the solid matter of the cell being protein (15% on a wet-weight basis). Cells generally contain many more protein molecules than DNA molecules, yet **DNA** is typically the largest biomolecule in the cell. About **99%** of cellular molecules are **water** molecules, with water normally accounting for approximately 70% of the total wet-weight of the cell. Although water is obviously important to the vitality of all living cells, the bulk of our attention is usually focused on the other 1% of biomolecules.

Data in **Table 1-1** regarding the chemical composition of the unicellular Escherichia coli (E. coli), are not greatly different for multicellular organisms, including mammals. Each E. coli, and similar bacterium, contains a single chromosome, therefore, it has only one unique

**Figure 1-1**

DNA molecule. Mammals, however, contain more chromosomes, and thus have different DNA molecules in the nucleus.

Nucleic Acids

Nucleic acids are nucleotide polymers (from the Greek word **poly**, meaning "several", and **mer**, meaning "unit"), that store and transmit genetic information. Only 4 different nucleotides are used in nucleic acid biosynthesis. Genetic information contained in nucleic acids is stored and replicated in **chromosomes**, which

contain **genes** (from the Greek word **gennan**, meaning "to produce"). A chromosome is a deoxyribonucleic acid (DNA) molecule, and genes are segments of intact DNA. The total number of genes in any given mammalian cell may total several thousand. When a cell replicates itself, identical copies of DNA molecules are produced, therefore the hereditary line of descent is conserved, and the genetic information carried on DNA is available to direct the occurrence of virtually all chemical reactions within the cell. The bulk of genetic information carried on DNA provides instructions for the

Table 1-1		
Approximate Chemical Composition of a Rapidly Dividing Cell (<i>E. coli</i>)		
Material	% Total Wet Wt.	Different Kinds of Molecules/Cell
Water	70	1
Nucleic acids		
DNA	1	1
RNA	6	
Ribosomal		3
Transfer		40
Messenger		1000
Nucleotides and metabolites	0.8	200
Proteins	15	2000-3000
Amino acids and metabolites	0.8	100
Polysaccharides	3	200
(Carbohydrates and metabolites)		
Lipids and metabolites	2	50
Inorganic ions	1	20
(Major minerals and trace elements)		
Others	0.4	200
	100	

Data from Watson JD: Molecular Biology of the Gene, 2nd ed., Philadelphia, PA: Saunders, 1972.

assembly of virtually every protein molecule within the cell. The flow of information from nucleic acids to protein is commonly represented as **DNA** → **messenger ribonucleic acid (mRNA)** → **transfer RNA (tRNA)** → **ribosomal RNA (rRNA)** → **protein**, which indicates that the nucleotide sequence in a gene of DNA specifies the assembly of a nucleotide sequence in an mRNA molecule, which in turn directs the assembly of the amino acid sequence in protein through a tRNA and rRNA molecules.

Proteins

Proteins are amino acid polymers responsible for implementing instructions contained within the genetic code. **Twenty different amino acids** are used to synthesize proteins,

about half are formed as metabolic intermediates, while the remainder must be provided through the diet. The latter group is referred to as "**essential**" amino acids (see Chapter 3). Each protein formed in the body, unique in its own structure and function, participates in processes that characterize the individuality of cells, tissues, organs, and organ systems. A typical cell contains thousands of different proteins, each with a different function, and many serve as enzymes that catalyze (or speed) reactions. Virtually every reaction in a living cell requires an enzyme. Other proteins transport different compounds either outside or inside cells (e.g., lipoproteins and transferrin (an iron-binding protein) in plasma, or bilirubin-binding proteins in liver cells); some act as storage proteins (e.g., myoglobin binds and

stores O₂ in muscle cells); others as defense proteins in blood or on the surface of cells (e.g., clotting proteins and immunoglobulins); others as contractile proteins (e.g., the actin, myosin and troponin of skeletal muscle fibers); and others are merely structural in nature (e.g., collagen and elastin). Proteins, unlike glycogen and triglyceride, are usually not synthesized and stored as nonfunctional entities.

Polysaccharides

Polysaccharides are polymers of simple sugars (i.e., monosaccharides). (The term saccharide is derived from the Greek word **sakchar**, meaning "sugar or sweetness".) Some polysaccharides are **homogeneous polymers** that contain only one kind of sugar (e.g., glycogen), while others are complex **heterogeneous polymers** that contain 8-10 types of sugars. In contrast to heterogeneous polymers (e.g., proteins, nucleic acids, and some polysaccharides), homogeneous polymers are considered to be "**noninformational**". Polysaccharides, therefore, can occur as functional and structural components of cells (e.g., glycoproteins and glycolipids), or merely as noninformational storage forms of energy (e.g., glycogen). The 8-10 monosaccharides that become the building blocks for heterogeneous polysaccharides can be synthesized from glucose, or formed from other metabolic intermediates (see Chapter 20).

Lipids

Lipids (from the Greek word **lipos**, meaning "fat") are naturally occurring, nonpolar substances that are mostly insoluble in water (with the exceptions being the short-chain volatile fatty acids and ketone bodies), yet soluble in nonpolar solvents (like chloroform and ether). They serve as membrane components (cholesterol, glycolipids and phospholipids), storage forms of energy (triglycerides),

precursors to other important biomolecules (fatty acids), insulation barriers (neutral fat stores), protective coatings to prevent infection and excessive gain or loss of water, and some vitamins (A, D, E, and K) and hormones (steroid hormones). Major classes of lipids are the saturated and unsaturated fatty acids (short, medium, and long-chain), triglycerides, lipoproteins {i.e., chylomicrons (CMs), very low density (VLDL), low density (LDL), intermediate density (IDL), and high density lipoproteins (HDL)}, phospholipids and glycolipids, steroids (cholesterol, progesterone, etc.), and eicosanoids (prostaglandins, thromboxanes, and leukotrienes). All lipids can be synthesized from **acetyl-CoA**, which in turn can be generated from numerous different sources, including carbohydrates, amino acids, short-chain volatile fatty acids (e.g., acetate), ketone bodies, and fatty acids. **Simple lipids** include only those that are esters of fatty acids and an alcohol (e.g., mono-, di- and triglycerides). **Compound lipids** include various materials that contain other substances in addition to an alcohol and fatty acid (e.g., phosphoacylglycerols, sphingomyelins, and cerebrosides), and **derived lipids** include those that cannot be neatly classified into either of the above (e.g., steroids, eicosanoids, and the fat-soluble vitamins).

Although the study of physiological chemistry emphasizes organic molecules, the **inorganic elements** (sometimes subdivided into macro-minerals, trace elements, and ultra trace elements), are also important (see Chapter 48). Several are "**essential**" nutrients, and therefore like certain **amino acids** and **unsaturated fatty acids**, must be supplied in the diet. Inorganic elements are typically present in cells as ionic forms, existing as either free ions or complexed with organic molecules. Many "**trace elements**" are known to be essential for life, health, and reproduction, and have well-established actions (e.g., cofactors for enzymes, sites for binding of oxygen (in transport), and structural

components of nonenzymatic macromolecules; see Chapters 48-52). Some investigators have speculated that perhaps all of the elements on the periodic chart will someday be shown to exhibit physiologic roles in mammalian life.

Because life depends upon chemical reactions, and because most all diseases in animals are manifestations of abnormalities in biomolecules, chemical reactions, or biochemical pathways, physiological chemistry has become the language of all basic medical sciences. A fundamental understanding of this science is therefore needed not only to help illuminate the origin of disease, but also to help formulate appropriate therapies. The chapters which follow were designed, therefore, to assist the reader in developing a basic rational approach to the practice of veterinary medicine.

Questions

1. The most prevalent compound in a living cell is normally:

- Protein
- Nucleic acid
- Water
- Lipid
- Polysaccharide

2. The basic building block for all lipids is:

- Water
- Acetyl-CoA
- Phosphorus
- Nucleic acid
- Arginine

3. The largest biomolecule in a living cell is usually:

- Glycogen
- Protein
- Cholesterol
- Deoxyribonucleic acid
- Triglyceride

4. Which one of the following is a largely homogenous polymer, and therefore "noninformational"?

- mRNA
- Phospholipid
- Protein
- Hydrogen
- Glycogen

5. Select the FALSE statement below:

- Some inorganic elements are considered to be "essential" nutrients.
- Triglycerides are considered to be "simple" lipids.
- Some polysaccharides are complex polymers in that they contain several different types of sugars.
- Virtually every reaction in a living cell requires an enzyme.
- Only 10 "essential" amino acids are used in the synthesis of proteins.

6. About 50% of the solid matter in a cell is normally composed of:

- Nucleic acids
- Protein
- Carbohydrate
- Lipid
- Inorganic ions

6. b
5. e
4. e
3. d
2. b
1. c