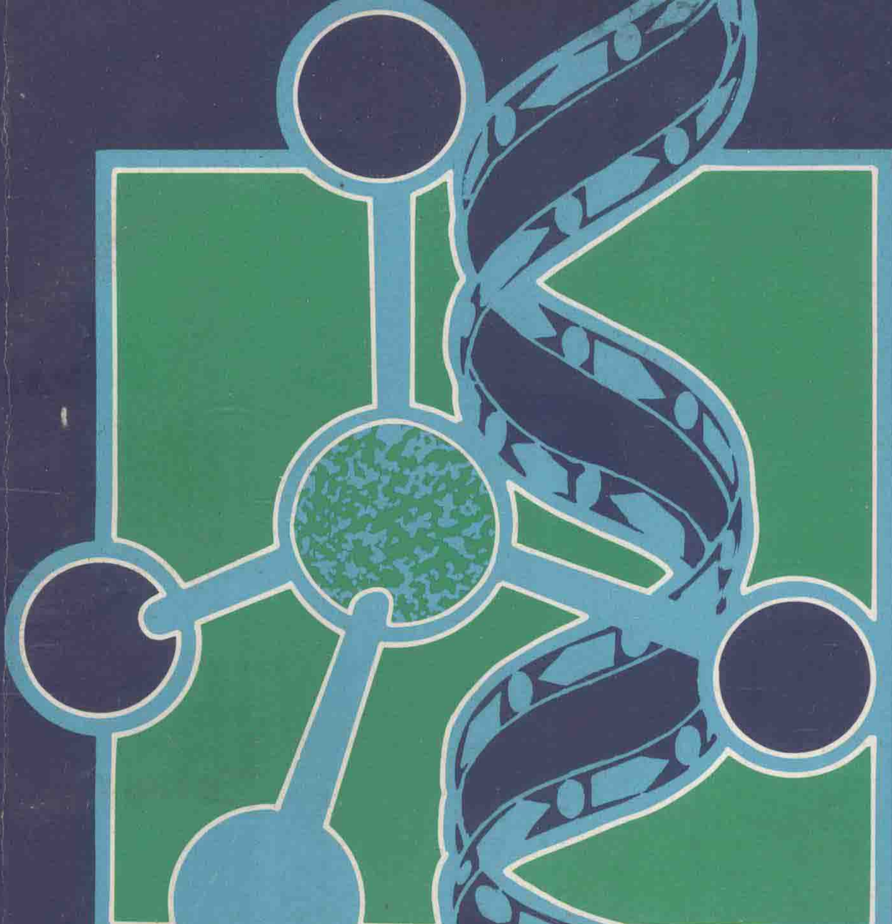

SECOND EDITION

# HANDBOOK OF CELLULAR CHEMISTRY

Annabelle Cohen

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**SECOND EDITION**

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# HANDBOOK OF CELLULAR CHEMISTRY

To Roslyn, who made it possible

# PREFACE to second edition

It is a fact recognized by students, teachers, and authors alike that data relating to the cell seem to have an almost limitless capacity to proliferate. In the comparatively short time that has elapsed between the first and the present editions of this text, numerous new developments have appeared on the horizon. Nowadays, scientific research is front-page news, and students are usually introduced to advances in cellular chemistry by the mass media while their textbooks trail forlornly behind. Preparation of a second edition of this text was a welcome opportunity to update its contents and to reorganize and improve the presentation. New aspects of enzyme function, cell membranes, genes, and viruses, *inter alia,* have been incorporated into the text. In addition, I have extensively revised sections dealing with chemistry, physiologically active molecules, acid-base balance, and metabolism. A list of selected references has been included for those readers who would like to explore various topics in greater detail.

Enlarging the scope of the text and modernizing it will, I hope, enhance its general usefulness. My aims are still the same: to relay accurate, clear, and updated information to students and, above all, to help them perceive the intrinsic coherence and harmony that underlie the processes of life.

I am deeply indebted to students and colleagues for their constructive suggestions, interest, and encouragement; and to my sons, David and Benjamin, whose scientific know-how and enthusiasm are a constant source of inspiration to a very proud parent.

Thanks are due the following individuals, whose comments, recommendations, and criticisms have helped me make this new edition more responsive to the needs of students and faculty: J. Langdon, University of South Alabama; F. Thompson, St. Elizabeth's School of Nursing; H. Halstead, Wichita State University; L. Pegau, Miss Porter's School; W. Lang, Jefferson

Medical College; G. Neufeld, Emporia Kansas State College; S. Gillis, Mercy Central School of Nursing; G. Price, Temple University; C. Hall, Northeastern Hospital; and L. Poplin, Del Mar College.

**Annabelle Cohen**

# PREFACE to first edition

Biology is a composite science in the sense that living systems are primarily complex physicochemical systems. It it therefore customary to introduce beginning students to courses in biology and human physiology with a series of lectures on chemistry as it pertains to living structures and function. This handbook is based on such lecture material.

The study of biology on a chemical or molecular level is generally called *biochemistry*. The term *cellular chemistry* is used here in a broad sense to refer to the chemical organization and related activities of living cells. The student should realize, however, that the contents of this handbook are only a representative sample of a complicated and rapidly expanding body of knowledge. My aim in this text has been to select and explain important concepts in terms of the most recent advances in the field without at the same time overwhelming the beginner with a mass of technical detail.

For students of the life sciences, physical and chemical concepts acquire special significance when they are correlated with the function of cells, particularly the cells of human beings. I have therefore included a variety of relevant topics, ranging from cell membrane dynamics to digestive enzymes. In view of the current importance of nucleic acids in the biomedical sciences, a section on genetic defects and viruses has also been added. It is my hope that students will obtain sufficient information and be stimulated to question and to delve further into the chemical realities of life by these up-to-date, comprehensive, brief discussions.

It is a pleasure to acknowledge the helpful suggestions and continuing encouragement of my son David, a student at the Massachusetts Institute of Technology.

**Annabelle Cohen**

# CONTENTS

# 1

# INTRODUCTORY CHEMISTRY FOR BIOLOGISTS

If a cell or a tissue is removed from the body and analyzed in a test tube, it will be found to consist of a mixture of substances, including water, salts, proteins, sugars, and fats. Most of these substances, the nonliving chemical raw materials from which living protoplasm is made, exist in the form of *molecules*. Molecules can be broken down by conventional chemical methods into smaller units called *atoms*. In our universe, all matter (anything that occupies space and has mass or weight) is composed of atoms. Protoplasm may thus be considered a rather complex form of matter derived from chemical units that happen to be present on this particular planet. The study of the composition and properties (characteristics) of substances and the changes they undergo is the science of *chemistry*. Some knowledge of this science is essential for understanding the nature of the structure and function of living systems.

molecules

atoms

chemistry

## ELEMENTS

The enormous numbers of substances found on earth, in both living and nonliving forms, are all made up of elements or combinations of elements. The term *element* is given to elementary chemical substances that cannot be further decomposed (broken down) into simpler substances by ordinary chemical means.

element

Some elements, such as gold, silver, copper, and sulfur, were known to the ancient world. As man's knowledge of chemistry advanced, more of the earth's elements were identified until what appeared to be a reasonably complete list of 92 naturally occurring elementary substances was assembled. These ranged from the lightest known element, hydrogen, to the heaviest, uranium. At present, there are 106 elements; the additional 14 elements have been made by man in various accelerator devices (such as cyclotrons).

Human tissues contain only about 20 of these elements. In

**Table 1-1.** Chemical symbols based on Latin names of elements

| Element | Chemical symbol | Latin name |
|---|---|---|
| Antimony | Sb | Stibium |
| Copper | Cu | Cuprum |
| Gold | Au | Aurum |
| Iron | Fe | Ferrum |
| Lead | Pb | Plumbum |
| Mercury | Hg | Hydrargyrum* |
| Potassium | K | Kalium |
| Silver | Ag | Argentum |
| Sodium | Na | Natrium |
| Tin | Sn | Stannum |
| Tungsten | W | Wolfram† |

*Literally meaning "liquid silver"; mercury is a liquid metallic element.
†Wolfram is the German name for tungsten.

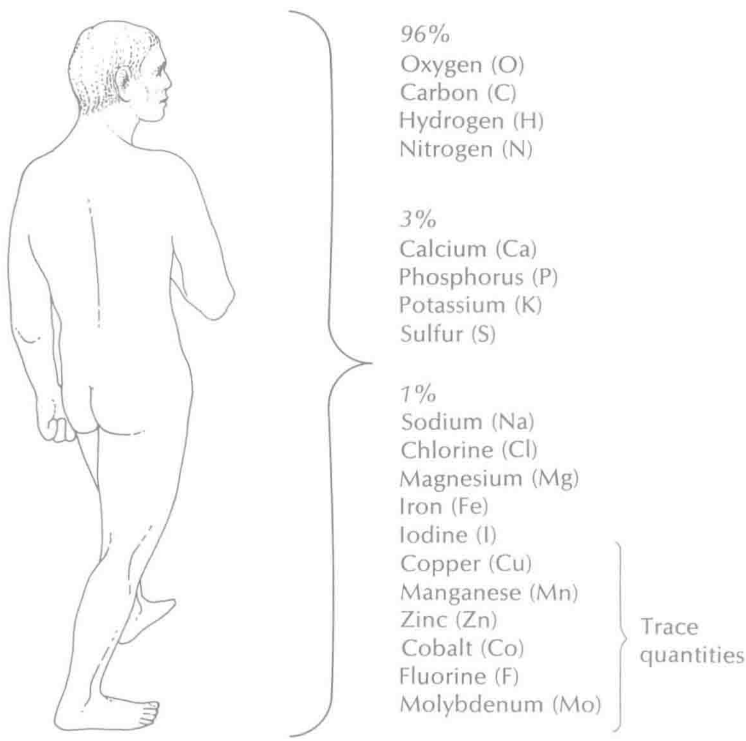


**Fig. 1-1.** The elements present in human tissues (approximate percentage by weight).

fact, four of them, namely *carbon, hydrogen, oxygen,* and *nitrogen,* compose approximately 95% of the substance of the body (Fig. 1-1).

In chemical shorthand, each element is represented by a symbol. The symbol is usually the *capital* initial letter of the English or Latin name of the element and sometimes, to avoid confusion, one more *small* letter from the name. Some symbols derived from Latin names of elements are listed in Table 1-1.

## Atomic structure of elements

Elements are composed of extremely small, discrete particles called atoms (the mass of an atom is in the range of $10^{-24}$ to $10^{-23}$ g; see appendix to this chapter for an explanation of the magnitude of these numbers). The *atom* is the smallest unit of an element that exhibits all the characteristic properties and undergoes the characteristic chemical changes of that element. Atoms of the same element are more or less alike and differ in their properties from atoms of other elements. Each element thus has its own characteristic atoms. It is important to remember that the symbol for an element not only represents the *name* of the element, but is also the chemist's way of representing *one atom* of that element. atom

For many years it was considered that atoms were indivisible units that could not be broken down into anything smaller. However, it is now known that atoms are clusters of varying numbers of even smaller (subatomic) particles called *protons, electrons,* and *neutrons.** The arrangement of these particles in an atom resembles in some respects a solar system of planets orbiting around a sun. The mass of an atom is concentrated in a positively charged *nucleus* made up of all the protons and neutrons of that particular atom, whereas the electrons orbit the nucleus at relatively great distances and in various energy levels, or shells. nucleus

The subatomic particles are classified as follows:

1. *Protons* are positively charged particles (having a +1 charge) with an assigned mass of 1 atomic mass unit. They are found in the nucleus of every atom. protons
2. *Electrons* are negatively charged particles (having a −1 charge) with a mass of about 1/1,840 of an atomic mass unit (protons are about 1,840 times heavier than electrons). They are found moving around outside the nucleus at various distances from it. electrons
3. *Neutrons* are uncharged (neutral) particles with a mass approximately equal to the mass of a proton, that is, 1 atomic mass unit. They are found in the nucleus of every atom except the common hydrogen atom. neutrons

---

*There are other subatomic particles, but they are not relevant to this discussion.

**Table 1-2.** Fundamental atomic particles

| Name | Symbol | Location in atom | Assigned mass (d or amu) | Charge |
|---|---|---|---|---|
| Electron | e or e− | Outside of nucleus | 0 | −1 |
| Proton | p | Nucleus | 1 | +1 |
| Neutron | n | Nucleus | 1 | 0 |

atomic mass unit

dalton

Note that the mass of either a proton or a neutron is considered to equal approximately *one atomic mass unit* (amu). Chemists also frequently express atomic mass in terms of the *dalton* unit (*d*); that is, 1 d equals 1 amu. The dalton (or atomic mass unit) is an arbitrary unit defined as 1/12 the mass of the most common naturally occurring form of carbon, namely carbon 12 ($^{12}C$). This carbon atom has 6 protons (and 6 electrons) and 6 neutrons and has been assigned the standard atomic mass of exactly 12.0000 d. Because the mass of an electron is negligible when compared with that of either a proton or a neutron, it is generally considered to have no mass. The characteristics of these subatomic particles are summarized in Table 1-2.

## Electron shells

electron shells

energy levels

The atom, as described by the Danish physicist Niels Bohr in the early years of the twentieth century, was visualized as consisting of a very small, dense, positively charged nucleus, with electrons moving in circular or elliptical orbits at fixed distances around the nucleus. According to this model, an atom can have as many as 7 *electron shells*. A shell is defined as a discrete volume around a nucleus in which a given electron or set of electrons moves. Each shell can hold only a given maximum number of electrons. The first shell (nearest the nucleus) can hold a maximum of 2 electrons; the second, a maximum of 8; the third, up to 18; the fourth and fifth, a maximum of 32; and so on. Shells are often referred to as *energy levels* and are identified by the letters K (the first shell) through Q for the successive shells up to the seventh.

Regardless of the total number of electron shells, the outermost shell never contains more than 8 electrons; if the atom has just 1 shell (as is found only in the two lightest elements, hydrogen and helium), then it can be completely filled by only 2 electrons.

Diagrams of several representative atoms are shown in Fig. 1-2. The number of neutrons (n) and protons (p) making up the nucleus of each atom are indicated in the central circle. The electrons (e) are shown as numbers of e at the appropriate energy levels outside the nucleus. The shells, or energy levels, are numbered at the right side of the atoms from the nucleus outward.

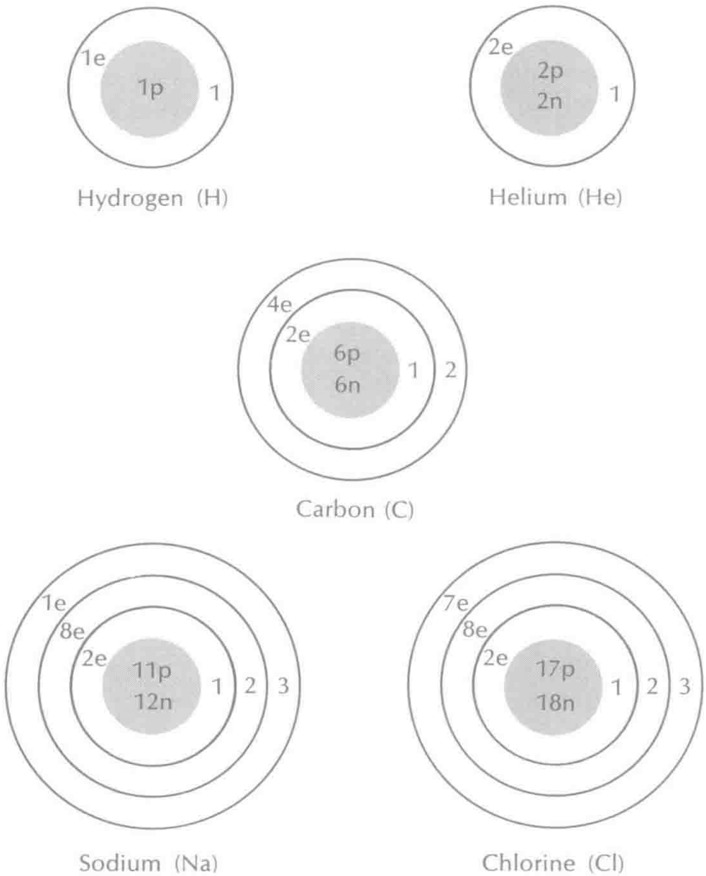


**Fig. 1-2.** Atomic structures of selected elements, indicating numbers and locations of protons (p), electrons (e), and neutrons (n). These drawings represent cross sections through the nuclei and three-dimensional, spherical electron shells. The sizes of the nuclei are greatly exaggerated; on this scale, each nucleus would actually be much smaller than a pencil point.

Note that hydrogen has only 1 electron in only 1 shell; thus its outermost shell is incompletely filled. Helium has 2 electrons in its only shell, which is therefore completely filled with the maximum number of electrons (2) for that shell. Carbon has 2 shells, the first of which is filled with the maximum 2 electrons; the second, the outermost, is incompletely filled with 4 electrons. The sodium atom has 11 electrons in 3 shells. The first is filled with 2 electrons; the second, with 8; and the third shell, the outermost, is incomplete with only 1 electron. Chlorine has 17 electrons, likewise distributed in its 3 shells, with 2 electrons in the first, 8 in the second, and 7 in the incomplete outer third shell. The electrons in an incompletely filled, or unsatisfied, outermost shell are ex-