Organic Molecules In Action

MURRAY GOODMAN
FRANK MOREHOUSE

Gordon and Breach,
Science Publishers, Inc.

Organic Molecules in Action

MURRAY GOODMAN
University of California, San Diego

and

FRANK MOREHOUSE

GORDON AND BREACH SCIENCE PUBLISHERS
New York London Paris

Gordon and Breach, Science Publishers, Inc.
One Park Avenue
New York, N.Y. 10016

Editorial office for the United Kingdom

Gordon and Breach, Science Publishers Ltd.
42 William IV Street
London W.C.2.

Editorial office for France

Gordon & Breach
7–9 rue Emile Dubois
75014 Paris

First Printing—1973
Second Printing with corrections—1974

Library of Congress catalog card number 72-85025. ISBN 0 677 01810 X (*hardback*). Printed in the United States of America.

PREFACE

THIS BOOK grew out of our belief that all educated people should have an understanding of science. Much of our modern world is based on scientific discovery and the resulting technological applications. Scientists, social scientists and humanists must communicate with and understand each other since the survival of mankind requires the development of scientific programs whose social implications and human consequences have been taken into account.

Within the domain of science, chemistry plays a central role because it deals with the elements and molecules composing the universe. Organic molecules derive from compounds of carbon and other elements such as hydrogen, oxygen, nitrogen, sulfur, etc. Millions of combinations exist in nature, or have been synthesized, including those upon which life itself is based.

The book commences with a consideration of how life began and evolved. We present an overview of the code of life, emphasizing that studies of molecular size and shape have revolutionized our understanding of biological phenomena. These studies have relied heavily on the use of x-rays to show the details of the three-dimensional structure of organic molecules.

In our text we demonstrate the relationship of organic chemistry to the world about us. To accomplish this task, we discuss polymers in order to explain how so many of the synthetic materials used today are prepared. We place some scientific discoveries such as those of quinine, aspirin, hormones, vitamins and hallucinogens in an historical context. We point out that modes of biological action for most drugs are unknown. We give examples of accidental observations which lead to significant technological breakthroughs (e.g., the discovery of penicillin, the initial syntheses of guncotton and nylon). We stress that discovery in chemistry is a continuing process and that more scientific understanding is essential in the building of a better world.

On numerous occasions we have encountered undergraduates who recall absolutely nothing from their organic chemistry studies shortly after completing their courses. We found that in most cases the course content represented a watered-down exposure to a curriculum used to train chemists. We therefore undertook a completely different approach by choosing representative areas of chemistry that we believe are important to educated people. By definition, such a book can never be complete. However, each subject is presented in substantial detail, and therefore this book should be appropriate as a general introductory chemistry text and also as an informative reference for more advanced students.

Many people helped in the creation of this book. The text was perused at various stages by colleagues, Professors Martin Kamen, Paul Saltman, Stanley Miller and F. Thomas Bond. Through their constructive criticism, we were able to improve the organization and presentation of the material. Helpful comments were received on specific chapters by Drs. Michael Verlander and Ugo Lepore. We want to call particular attention to the discussions and suggestions of Dr. Jerrold Meinwald, who helped us formulate the chapter on Molecules of the Senses, and to Drs. F. R. Salemme and Jens Birktoft who helped us with the chapter on Molecular Structure by X-ray Vision. The guidance we received from Dr. Stephen Freer was indispensable in helping us make aspects of x-ray diffraction not only intelligible but readable. Dr. Eugene Cordes of the University of Indiana and Dr. Harold Moore of the University of California, Irvine, examined the entire text and made most useful suggestions for revisions and modifications. The chemical figures and many of the illustrations are the work of Mr. Theodore Velasquez to whom we are indeed grateful.

M. G. and F. M.

FIGURE 1.1 The Crab Nebula represents the remains of a supernova explosion that was visible and recorded in the year 1054 in China and Japan. It went completely unnoticed in the western world until the eighteenth century. [Photograph courtesy of the Hale Observatories.]

For a detailed discussion of the Crab Nebula see page 2.

The photograph on the following page shows several specimens of *Amanita muscaria*. For the story of the "divine mushroom" see page 153.

FIGURE 8.1 *Amanita muscaria*—"The Divine Mushroom". This species of mushroom, long known throughout Europe and Asia as a fly agaric is believed by some to be the source of Soma, the hallucinogen of Vedic culture.

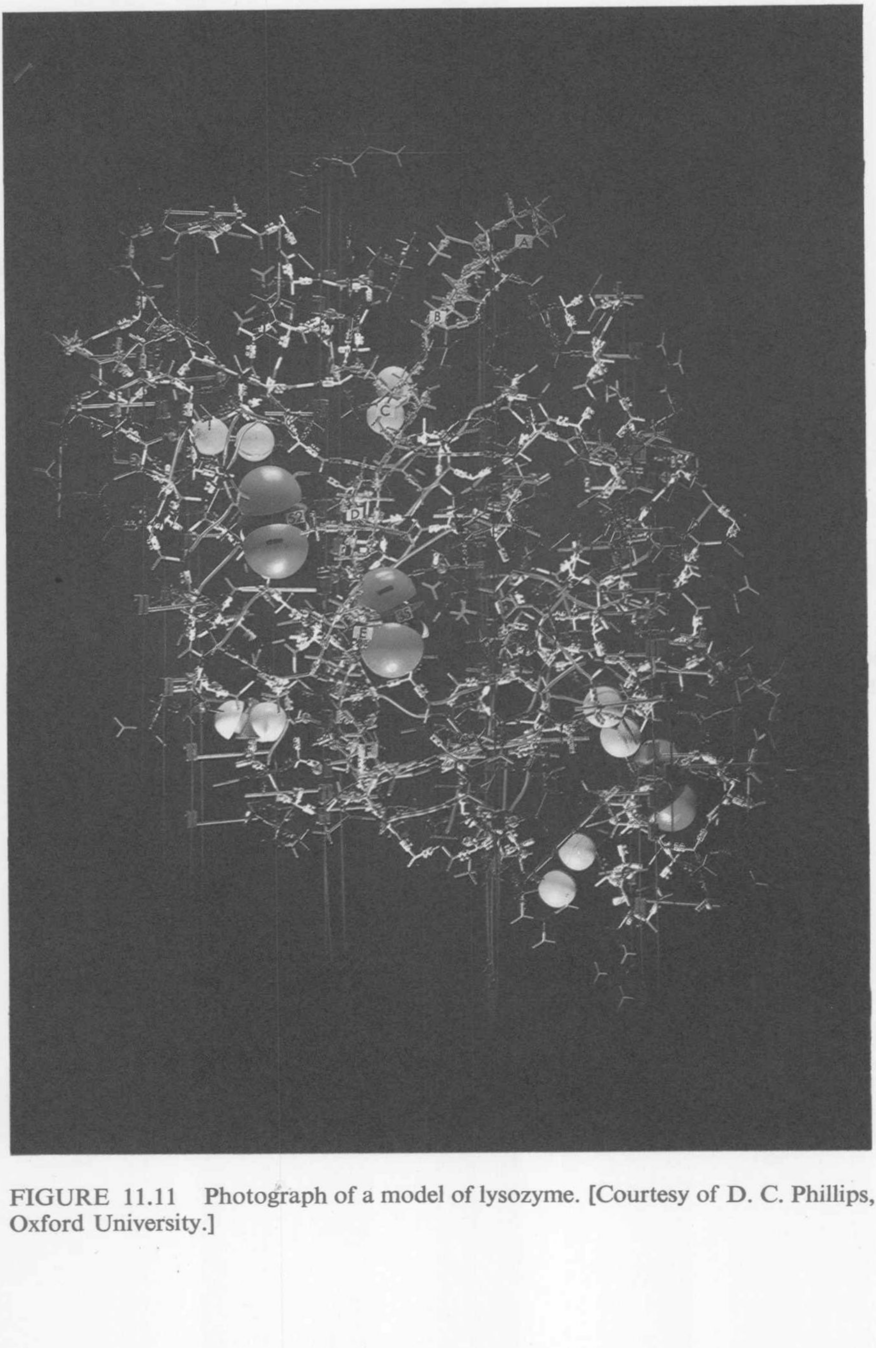


FIGURE 11.11 Photograph of a model of lysozyme. [Courtesy of D. C. Phillips, Oxford University.]

The structure of lysozyme shown in the preceding photograph is discussed in detail on page 256.

A full explanation of the α-helix model shown on the following page can be found on pages 261-263.

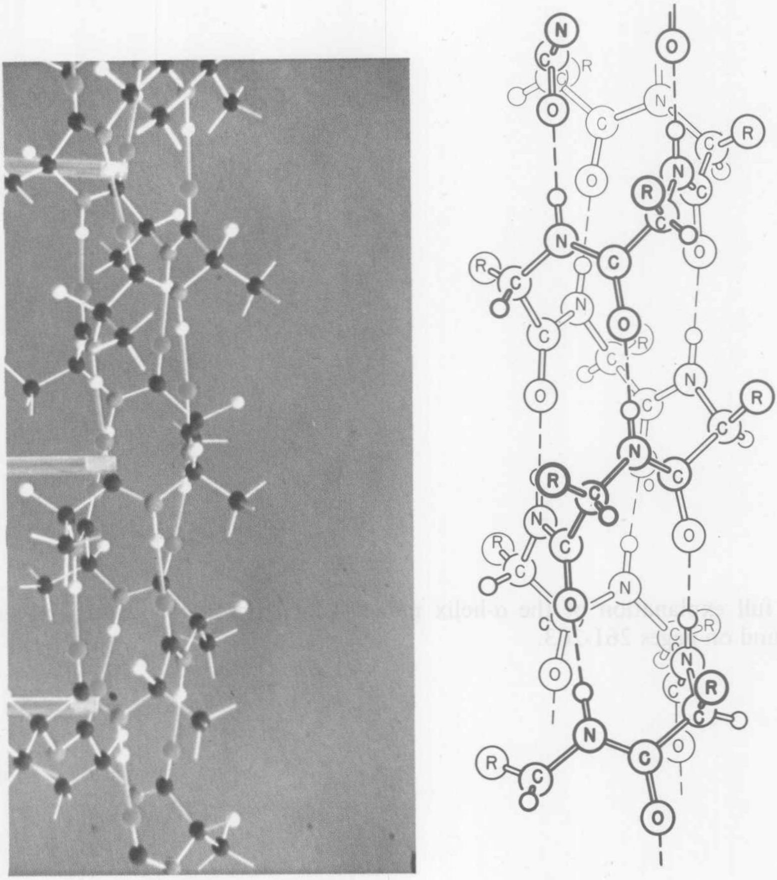


FIGURE 11.18 The α-helix model.

CONTENTS

CHAPTER I

PREBIOTIC SYNTHESIS
Origins of Biological Molecules

THE STORY of organic molecules begins more than five billion years ago, before the sun and the earth and the other planets in our solar system formed. At that time, somewhere in the star-packed core of our galaxy, an ancient star was dying. The death of this old star—a blinding supernova explosion—signalled the coming of the solar system. It produced and threw out the atoms which now constitute the solar system, including the earth and all its inhabitants.

But between the supernova and the peopling of earth lies a fascinating story—the story of the formation and evolution of the organic molecules responsible for the appearance of life on earth. How did it all happen? What is the connection between the death of a star and the birth of man? The two events are separated by 5 billion years, but the atoms synthesized by the supernova are the very atoms that now make up our modern world. We can follow the paths of the atoms from the simplest organic molecule—methane—to the ultimate earth creature known today—man—through the molecular transformations we know as organic reactions.

If the whole story were written chronologically in ten volumes of 500 pages each, each page would represent 1 million years. Man would not appear until the last page of the last volume.

Let us look first at the beginning of the story, how the molecules of life came to exist on earth before the first living organism appeared in the maternal waters.

The Supernova

Our galaxy, the Milky Way, is between 10 and 15 billion years old. It is saucer-shaped and the central region is crowded with billions of large stars. When one of these stars dies, it goes out with a bang and not a whimper—to paraphrase the poet, T. S. Eliot. It explodes with an unearthly violence, releasing particles with enough energy to escape to the spiral fringes of the galaxy. These particles are also sufficiently energetic to undergo all the nuclear reactions needed to populate the entire periodic table.

But why should a star explode on its death bed? A star is mostly a cloud of hydrogen gas. As it ages, internal gravitational forces cause it to contract. As it contracts, its density increases. The increasing density accelerates the contraction until the core of the star approaches the density of nuclear matter. At this critical stage, tremendous repulsive forces build rapidly, and the core explodes as a consequence of the contraction.

The debris consists of cosmic gas and dust, probably containing all the elements of the periodic table, but still mostly hydrogen (about 90%). The non-hydrogen portion is mainly helium, the other inert gases, and methane. The other elements constitute the dust particles and amount to only a few thousandths of a percent of the total mass of gas and dust. But the quantity of material expelled by a supernova is so great that even this tiny portion contains enough material to furnish a sun with its planets.

The supernova which provided the material for our solar system occurred more than 5 billion years ago, but only 900 years ago, man had the privilege of actually observing a supernova. It was so bright at first that it could be seen with the naked eye in broad daylight. Most of the debris has since drifted away into space, but the remnants are still visible at night through a telescope. This luminous cloud of gas and dust is called the Crab Nebula (Figure 1.1). The event was viewable in the year 1054 and was duly reported by Japanese and Chinese astronomers but went unnoticed in Europe. It is now known that the Crab Nebula is 6000 light years from earth and therefore the explosion occurred 6000 years before the oriental scientists' eyes gazed upon it and noted that it was brighter than Venus. This supernova could be seen with the naked eye for well over a year. It then faded into heavenly obscurity.

In 1731 John Brevis rediscovered the event with the aid of a telescope and correctly deduced that it was the remnant of the 1054 supernova. Supernovae can be as bright as 100 million of our suns. The Crab Nebula which is not very bright today is important because it emits not only visible light but also x-rays and radiowaves. The source of the radiowaves lies in a pulsar which is a rapidly rotating, highly condensed star. The Crab Nebula contains the only pulsar so far clearly seen by optical telescope.

Some of the cosmic gas and dust from the ancient supernova drifted to the present location of our solar system on the periphery of the galaxy about 5 billion years ago and gathered itself together into a diffuse cloud. Again, internal gravitational forces caused the inner denser portion of the cloud to compact itself and form a new smaller star—our sun.

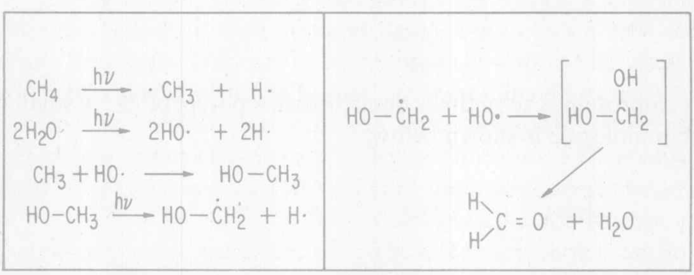
The remainder of the cosmic material was held by the gravitational pull of the sun and gradually coalesced to form the earth and the other planets. The material of the earth did not have sufficient mass to hold its cosmic gas and most was lost to space. At first, then, the earth was just an accumulation of cosmic dust, relatively cool, and without much of an atmosphere. This was about 4.8 billion years ago.

The ball of cosmic dust—the new earth—was made up of metals and their oxides, water as ice and as hydrates, ammonium compounds, silicon and sulfur compounds, and carbides. The ball became more and more compact because of its own gravity and the tremendous pressure of compaction, particularly at the center, raised the temperature of the mass. Chemical reactions, set off by the temperature increase, contributed to the heating effect, and the earth gradually differentiated into a dense molten core, a mantle, and a crust. The heat drove volatile materials and gases to the surface. These molecules formed the primitive atmosphere of the earth. This atmosphere was not a nitrogen and oxygen atmosphere such as we have today. It was a methane and ammonia atmosphere, and very steamy until the crust of the earth cooled enough to allow the primitive oceans to form.

The new earth was barren rock and water, basking in the brilliance of the new sun. Unfiltered as yet by our present layer of ozone, the sun provided the high-energy ultraviolet light needed to convert the simple molecules of the primitive atmosphere into new molecules capable of reacting further to build the complex molecules of life. Two of the most important of these new molecules which formed photolytically are formaldehyde and hydrogen cyanide. Formaldehyde forms from methane and water irradiated by ultraviolet light.

$$CH_4 + H_2O \xrightarrow{h\nu} H_2C{=}O + 4H\cdot$$

Stepwise sequence:



Hydrogen cyanide forms when methane and ammonia are irradiated, by the same kind of sequence.

$$CH_4 + NH_3 \xrightarrow{h\nu} H{-}C{\equiv}N + 6H\cdot$$