

THE MOLECULAR BASIS
OF
EVOLUTION



The MOLECULAR BASIS OF EVOLUTION

NEW YORK • JOHN WILEY & SONS, INC.

London • Chapman & Hall, Limited

CHRISTIAN B. ANFINSEN

National Heart Institute
National Institutes of Health
Bethesda, Maryland

TO MY MOTHER
AND
TO THE MEMORY OF
MY FATHER

Copyright © 1959 by John Wiley & Sons, Inc.

All rights reserved. This book or any part thereof must not be reproduced in any form without the written permission of the publisher.

Library of Congress Catalog Card Number: 59-11794

Printed in the United States of America

PREFACE

The writing of this book has been stimulated by the excitement and promise of contemporary protein chemistry and genetics and by the possibilities of integration of these fields toward a greater understanding of the fundamental forces underlying the evolutionary process. It has become, inevitably, a highly personal volume expressing the experimental and philosophical outlook which has resulted from a process of self-education in an unfamiliar area of science. As with many biochemists, pure biology, including genetics, has not been a major exposure in my education, and the process of learning something about these subjects has been both a revelation and a struggle. Various kind, and frequently amused, friends, versed in the complexities of modern genetics, have sifted through these pages, and I hope that most of the misinterpretations and frank mistakes have been eliminated.

It has been highly interesting of late to observe how many scientists, working either in protein chemistry or in genetics, or for that matter in relatively unrelated fields, have arrived at long-range research plans that are similar to my own, down to almost the last detail of experimental planning. This book, therefore, will undoubtedly represent the point of view of numerous other biologically oriented individuals. On the other hand, some of the ideas to be discussed are so new and controversial that for every well-informed reader of this book who,

in general, approves them there may be another who considers them nonsense.

The recent advances in the development of techniques for the study of protein structure have made it possible to elucidate the complete amino acid sequences of a number of rather large polypeptides possessing hormonal activity, and nearly complete sequences should soon be available for several with enzymatic activity as well. Concomitantly, there have been developed methods for the analysis of the finer, more subtle, structural aspects of proteins, concerned with folding, intramolecular bonds of various types, and intermolecular interactions. These advances now begin to enable us to discern the vague outlines of macromolecules, in the three-dimensional sense, and to ascribe their physical behavior and biological activity to specific covalent and noncovalent structural features.

We like to believe that Nature has been extremely wise and efficient in the design of the chemical compounds, however large and complicated, which make up the structure and machinery of living things. Thus, although chemical differences are found among the representatives of a given protein as isolated from a variety of species, we tend to suppose that such variations, rather than being fortuitous and unimportant irrelevancies, are part of a complicated and highly integrated set of variations in all the functionally and structurally important elements of the cell, the summation of which accounts for the unique morphology and phenotypic character of the individual organism.

In the last few years, a number of studies have shown that various biologically active molecules may be subjected to considerable degradation without loss of functional competency. It becomes necessary, therefore, to consider that the "macromolecularness" of proteins and other large molecules may, in many cases, be concerned not only with a specific biological property but with other, more subtle, phenomena of cellular activity and engineering not yet apparent, such as adsorption to surfaces or substrates. We must, perhaps, expect a multiplicity of variables in the "natural selection" of variants in molecules, all of which may, together, determine the biological suitability of a particular molecular species.

An understanding of the underlying principles governing the species specific variations in molecular structure and of the effect of such variations on species characteristics must involve a clarification of the process of translating information present in the genetic material of the cell into the chemical language of enzymes, regulators, and the like. Such considerations are only now becoming possible as

the result of the dramatic strides taken in the last few years in genetic theory and methodology, and a portion of the discussion in the following pages will have to do with the experimental background of the analysis of genetic fine structure and with the possible significance of such analysis to the question of protein biosynthesis.

It is abundantly clear that the metabolic organization of all living cells, whether plant or animal, shows a remarkable uniformity. Even a cursory examination of the literature of comparative biochemistry and physiology indicates that such biochemical functions as glycolysis, proteolysis, and fatty acid degradation, as well as more integrated processes such as electromotor activity and active transport through membranes, are ubiquitous in nature. Discounting the likelihood of completely parallel evolution in the plant and animal kingdoms, and in their major branches, we are led to conclude that, long before significant specialization, there existed in the waters of the earth various primeval forms of life which were endowed with representatives of most of, if not all, the important biological processes characterizing living things as we know them today. Although it is unlikely that we shall ever have more than opinions regarding the origin of life, it does seem possible to approach, experimentally, the nature of the *speciation* which began when such primeval cells had become established. This approach must involve a backward extrapolation of the information we can obtain on the chemical and genetic factors in organisms chosen from our modern environment.

Before examining for the reader the aspects of the mechanism of evolution that have been particularly illuminated by recent advances in biology and chemistry, it has been necessary to outline, in a broad sort of way, some of the basic fundamentals of evolution and the specific sciences, particularly genetics, that have contributed so essentially to its understanding. In the opening chapter, therefore, I have collected and rephrased some gleanings from the massive literature of morphological evolution to serve as a background for what follows. In several subsequent chapters is presented further preparatory material dealing with classical and contemporary genetics and with the basic facts of protein structure. Finally, after some discussion of the rapidly expanding body of knowledge relating structure to function in biological systems, I have considered a few aspects of natural selection in evolution which suggest themselves as a result of contemporary research, as well as some experimental approaches at the molecular level.

This book was written for pleasure, with the desire for self-enlightenment as the major stimulus. Since I cannot help but feel that

everyone in science must be interested in the evolutionary process as the central theme of biology, I have listed a number of the original articles and books which contributed to the subject matter of this book.

I am greatly indebted to many of my friends and colleagues, including Dr. W. F. Harrington, Dr. Daniel Steinberg, Dr. W. R. Carroll, Dr. E. D. Korn, and Dr. W. D. Dreyer, who have read and helped improve various chapters of this book. I should also like to express my gratefulness to Dr. Bruce Ames for his patient help in connection with some of the discussions of genetic subjects. My special thanks are due Professor John T. Edsall of Harvard University and Dr. Michael Sela of the Weizmann Institute of Science, Rehovoth, Israel, who have read the entire manuscript and whose suggestions have been invaluable in the avoidance of error and in the improvement of style and organization. Finally, I should like to thank my wife, Florence Anfin- sen, for the cheerful and understanding support she gave to a frequently rather morose husband.

Bethesda, Maryland
May 1959

CHRISTIAN B. ANFINSEN

GROUND RULES FOR THE READER

A prospectus of this book was circulated to a number of experts by the publisher before the actual job of writing was begun. The opinions received have been very helpful in establishing what I hope is the proper slant. One opinion, in particular, expressed a point of view so similar to my own that I have asked its author, Dr. William Stein, of the Rockefeller Institute for Medical Research, for permission to reproduce it here.

It has always seemed to me, and I may be wrong in this, that when an expert communicates with the relatively non-expert, he has a responsibility to stay pretty close to the facts. An expert can speculate to other experts without scruple. They have the equipment to meet him on his own grounds, evaluate the evidence and accept or reject the speculation as they choose. The non-expert has no such basis for evaluation. He has to accept relatively uncritically what the expert tells him, and hypothesis and fact soon become confused in his mind. A plausible speculation—and the speculations of the true expert are always plausible—can soon masquerade successfully as gospel. In the present state of our ignorance, I would regard this as unfortunate. It would seem to me that a book such as this one should aim to stimulate thought and experiment among practicing scientists, and should not lull the uninitiated into thinking that we understand more than we do.

We shall deal, in this book, with many contemporary hypotheses, some of which are far from general acceptance. Consequently, I would like to emphasize two points of caution to the reader. First, simple examples have purposely been chosen to illustrate the presentation of subjects which in fact are sometimes complicated by exceptions and inconsistencies. Second, it will be apparent that the author, like anyone else, has occasionally taken sides.

CONTENTS

1	The Time Scale and Some Evolutionary Principles	1
2	Genes as Determinants of Heredity	15
3	The Chemical Nature of Genetic Material	39
4	The Substructure of Genes	67
5	Protein Structure	98
6	The Biological Activity of Proteins in Relation to Structure	126
7	Species Variation in Protein Structure	142
8	Genes as Determinants of Protein Structure	164
9	On the Accuracy of Protein Synthesis	185
10	The Biosynthesis of Proteins	195
11	Genes, Proteins, and Evolution	211