General Genetics

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PREFACE

General Genetics is intended for a one-semester or one-quarter introduction to the principles of genetics. Studies of the undergraduate biology curriculum have identified genetics as one of the most difficult subjects, for two reasons: certain aspects of genetics are abstract and include unfamiliar concepts from probability and statistics, and genetics is quite broad, ranging from molecular biology to population genetics. Furthermore, many instructors have been concerned that available textbooks are too long for all but a full-year course, a perception that is in accord with our own experience. The need for a comprehensive, but not encyclopedic, book has led us to create *General Genetics*. The project has brought together three teachers of complementary expertise—in classical genetics, molecular genetics, and population genetics. Each topic has been written by an author in command of it, and each chapter has been reviewed and criticized by the other two and by teachers throughout the United States, in order to achieve suitable coverage and uniformity of level and style. We have all labored to make this a useful book, one written with a sympathetic concern for the typical undergraduate, who is easily overwhelmed by unnecessary detail. We hope that our efforts have been successful.

The organization of *General Genetics* is the following. First, in Chapters 1–3 we present the most basic phenomena, methods of analysis, and rules of inheritance that make up what is often referred to as classical genetics, the genetics of diploid organisms that began with Mendel's experiments and their interpretations and was extended in the early years of the 20th century by Thomas Hunt Morgan and his *Drosophila* school. This introduction to the formal aspects of the science provides students with the background for subsequent consideration of the molecular basis of the phenomena. The elements of Mendelism and the basis for the chromosome theory of inheritance are introduced in the first two chapters. The third chapter is a discussion of linkage, crossing over and chromosome mapping, and complementation. These first chapters also introduce the basic concepts of probability and statistics that underlie much of classical genetics.

In the next chapters, 4–6, we describe the structure of DNA, chromatin, and chromosomes, the organization of genes in chromosomes, and various mechanisms by which DNA and chromatin are replicated. In these chapters the student will learn about repetitive sequences, Cot analysis, and transposable elements in eukaryotes. These chapters lead logically to a presentation of general cytogenetics in Chapter 6, in which are discussed variations in chromosome number and structure, such as polyploidy, inversions, and translocations. Chapter 6 also includes a discussion of the human chromosome set, important chromosome abnormalities in humans, chromosomal dosage compensation, positions effects, and the molecular basis of the relation between chromosome abnormalities and certain types of cancer.

Chapter 7 departs from the genetics of diploid organisms and presents an analysis of the genetics of bacteria and viruses, with the main emphasis on the systems of genetic exchange in *E. coli* and the genetic properties of selected *E. coli* bacteriophages. Phage biology is presented in terms of five phenomena: examples of the cellular takeover phenomenon, temporal regulation in the phage life cycle, special features of the DNA of some phages, genetic exchange, and lysogeny. The emphasis is primarily on the classical phages T4, T7, and λ.

The next set of chapters (8–12) is concerned with molecular genetics, including gene expression (DNA → RNA → proteins, and many of the subtleties in the flow of genetic information), recombination mechanisms, mutation, and regulation of gene expression in both prokaryotes and eukaryotes. Regulation of gene expression can be a complicated topic to teach because so much detail is known, especially in bacterial systems. In order to be concise and to focus on basic principles, the discussion of regulation centers on the following subjects: general principles of regulation; the λ*lac* and *trp* operons of *E. coli*, as they exemplify basic phenomena that are easily interpreted; a brief description of translational regulation, autoregulation, and antitermination; and those features of regulation in eukaryotes that are fairly well understood. The chapter on recombination mechanisms (Chapter 8) presents the molecular models for transformation, site-specific exchange, transposition, and recombination. Gene conversion and related phenomena are also first presented there. This chapter is discretionary for the instructor, because no information contained in it is required to understand subsequent chapters. The chapter on mutation (Chapter 10) is concerned with three topics: the random nature of mutation, genetic phenomena resulting from mutations, and the molecular basis of mutagenesis. The molecular part of the book is completed by a presentation of genetic engineering (Chapter 12) and some of its more exciting uses, such as gene therapy and the engineering of plants.

Chapter 13 presents somatic cell genetics. It includes discussions of cell fusion as a technique and its importance in gene mapping, the genetics of blood groups, the genetics of the major histocompatibility complex and other antigens implicated in the rejection of transplanted tissue, and the remarkable mechanisms by which antibody diversity is produced.

The final three chapters (14–16) are concerned with the application of genetic principles to entire populations of organisms. These chapters present population genetics and the inheritance of quantitative characters. The use of mathematics has been kept to a minimum, and no mathematical background other than elementary algebra is required. Population genetics and quantitative genetics are active, evolving fields of research, but this is not adequately reflected by the treatment of these subjects in many textbooks. In *General Genetics* these topics are not only up to date but should provide the student with a feeling for the important phenomena and an understanding of how the phenomena can be studied.

Chapter 14 focuses on polymorphisms and their detection, on the influence of mating systems and population structure on genotype frequencies, and on the measurement and phenotypic effects of inbreeding. Chapter 15 presents the processes of mutation, migration, natural selection, and random genetic drift as they affect allele frequencies, with an emphasis on observational and experimental examples of the phenomena. Chapter 16 concerns multifactorial inheritance and its analysis by means of correlations between relatives, different types of heritability and their uses in animal and plant breeding, and the applications (and misapplications) of the principles of quantitative genetics to the analysis of human behavior.

Each chapter in *General Genetics* is supplied with numerous problems that range in difficulty. Most of the problems are straightforward, but some are challenging. Answers to all problems are given in the back of the book, though without explanation in order to conserve space. Ken Jones (California State University, Northridge) checked all answers to problems of the text. Many colleagues and friends have graciously provided problems that they found to be instructive through their own teaching experience.

An extensive glossary is also provided at the end of the text, as well as a short reference list, as well as a list of additional readings and references. We have emphasized general articles, such as those in *Scientific American,* that provide additional information without being so specialized and advanced as to overwhelm the beginner.

A *Student Guide and Solutions Manual* is also available as a separate volume. This manual contains detailed solutions to each problem in *General Genetics*, a summary of each chapter for purpose of emphasis and review, a listing of all key terms that appear in boldface in the text, simpler and more extensive explanations of certain phenomena presented in the text, a set of drill questions (simple questions that only test whether the student has read and understood the very basic material), additional questions of the same level as those in the text, and a few more challenging questions. Complete answers are given to all questions in the manual. Ed Simon (Purdue University) provided many of the problems in the *Student Guide* from his extensive collection of excellent problems collected over more than a decade of teaching genetics at the undergraduate level.

We are indebted to many reviewers, who read and criticized portions of the book ranging from single chapters to nearly the entire book. These reviewers represent research scientists who are knowledgeable in the minutiae of individual chapters, teachers of large and small classes in genetics, and undergraduate and graduate students. The reviewers were the following: Adelaide Carpenter (Univ. of California, San Diego), Rowland Davis (Univ. of California, Irvine), Frank Enfield (Univ. of Minnesota), Seymour Fogel (Univ. of California, Berkeley), David Fox (Univ. of Tennessee), Rachel Freifelder and Jon Greene (both students at Univ. of California, San Diego), Jeff Hall (Brandeis Univ.), Phil Hedrick (Univ. of Kansas), James Higgins (Michigan State Univ.), Ben Hochman (Univ. of Tennessee), Karen Hughes

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January 1985

Leon Snyder
David Freifelder
Daniel Hartl

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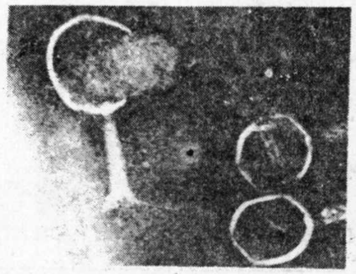

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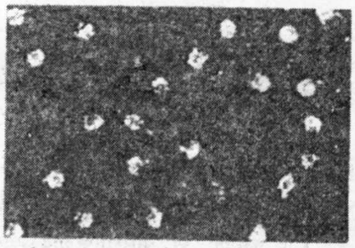

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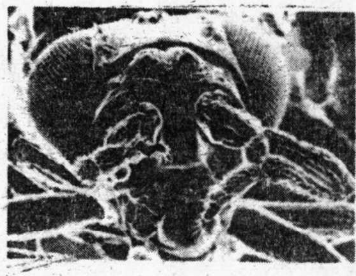

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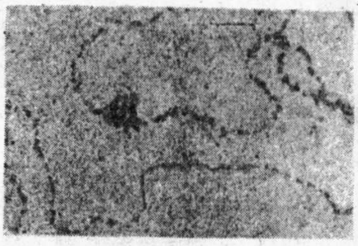

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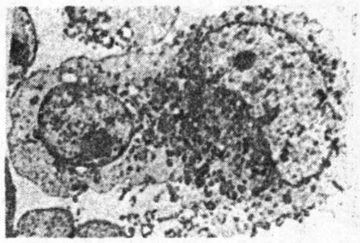

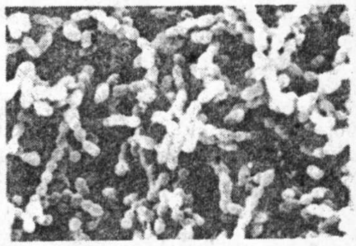

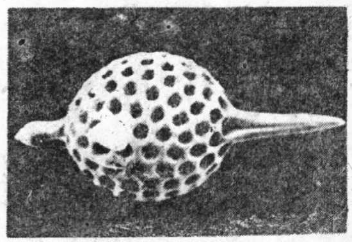

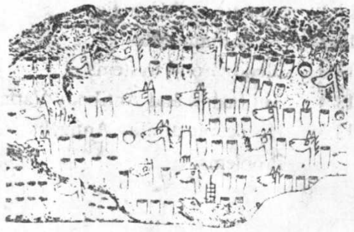

Publishers Note: A separate *Student Study Guide* (ISBN 0-87620-054-5) is available to accompany *General Genetics* (ISBN 0-86720-050-2). The *Student Study Guide* contains the following: • Complete worked out solutions to each problem in the text • Complete chapter summaries • Drill questions with answers.

Two important concepts unify modern biology. The first is the idea that all living things are highly ordered systems with properties determined to a large extent by this organization. The second is the persistence of ordered living systems over long periods of time through heredity and evolution—the continuity of life, or descent with modification. **Heredity** is the process by which all living things produce offspring unquestionably like themselves. This capacity of complex biological systems for self-reproduction involves the transmission from parent to offspring of information that specifies a particular pattern of growth and organization. **Genetics** is the science of heredity; it is concerned with the physical and chemical properties of the hereditary material, how this material is transmitted from one generation to the next, and how the information it contains is expressed in the development of an individual.

Organisms resemble one another because they have received hereditary information from some common ancestor. Since species continue to exist through many generations, the hereditary material must be inherently stable. However, within most species, immense hereditary diversity is present. A familiar example is the variation that exists among humans, even those as closely related as sisters or brothers. Hereditary variability is an essential factor in evolution, a term that means cumulative change in the genetic characteristics of populations of organisms through time. Evolution is the most important generalization in biology; it is the process that enables us to understand the origin of the enormous number of species of living things and the relation between them. Evolution provides the logical basis for understanding how the complex organisms existing today were derived through continuous lines of descent, with modification, from the first primitive organisms.

The development of modern ideas concerning the processes involved in evolution began in 1858, with the proposal by Charles Darwin that new

Facing page: The ancient practice of artificial pollination. An Assyrian relief, dating from the ninth century B.C., showing masked priests pollinating date palms. (Courtesy of Hans Stubbe.)

species are formed through the action of environmental forces on hereditary variation present in populations. This mechanism of evolutionary change, which Darwin called **natural selection,** is an idea based on three observations:

1. Almost all species produce more offspring than can possibly survive and reproduce.
2. A great deal of variability affecting survival and reproduction is present in most populations.
3. At least some of this variability is inherited.

From these observations Darwin reasoned that individuals differing even slightly in any way that makes them better adapted to their environment will have a higher rate of survival and reproduction. Furthermore, to the extent that the advantageous variations are hereditary, they will tend to increase in frequency in succeeding generations. The role of natural selection in evolutionary change was clear to Darwin, but he was unable to explain either the source of the inherited variations or the process of hereditary transmission.

In 1866 Gregor Mendel published the results of experiments in which he had investigated inheritance in garden peas. From these findings he deduced both the existence of discrete hereditary elements and the rules determining their behavior in reproduction. The principles of inheritance that Mendel recognized were to become the foundation for genetics and a key to development of modern biology, but their significance was not appreciated until 1900. The results of independent experiments published during that year by three botanists clearly confirmed Mendel's results and led to the recognition of their importance. In the early decades of this century, the processes involved in the transmission of inherited traits became the first well-understood aspect of the new science of genetics. The interactions of genetics with other scientific disciplines have resulted in a constant flow of new ideas and approaches to understanding heredity and evolutionary change. Applications during the late 1940s of the concepts and techniques of physics and chemistry to the investigation of genetic materials and genetic mechanisms initiated rapid and exciting advances in our understanding of the molecular basis of genetic phenomena. We now know in detail the chemical and physical properties of deoxyribonucleic acid (DNA), the molecule that carries hereditary information, and understand many aspects of the conversion of that information into the biological properties of cells and organisms. This knowledge of the physical nature of heredity has led to another important biological generalization:

> All living things, from those as simple as viruses to those as complex as humans, are based on a common system of information storage and expression.

Our consideration of genetics will begin with the development of the fundamental concept of the science—namely, that the hereditary determinant deduced by Mendel and now called a **gene** is a unit of inheritance transmitted from parent to progeny during reproduction. The ideas and methods of