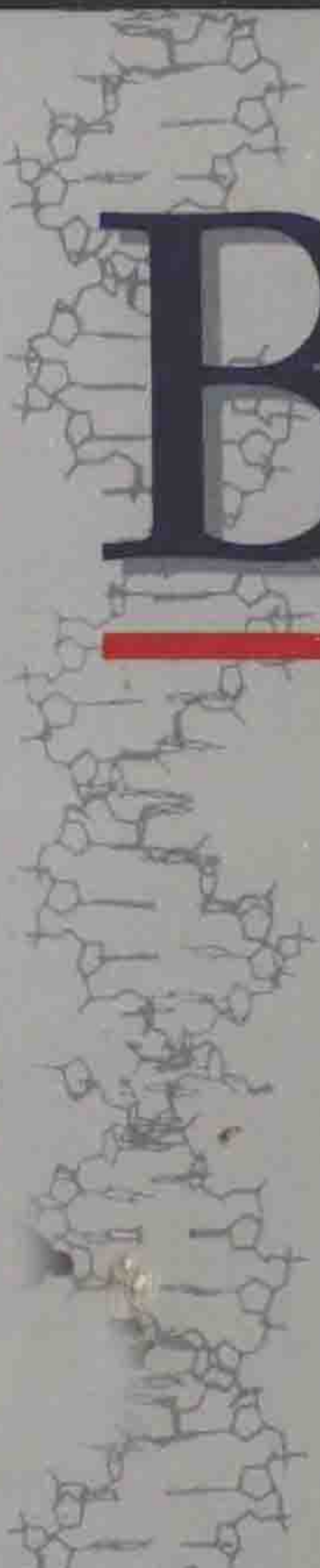




BIOLOGY

Wessells

Hopson



BIOLOGY

Norman K. Wessells

Stanford University

Janet L. Hopson



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To our parents and spouses, whose love and support at different times in our lives made this book possible: Norman W. Wessells, Grace M. Wessells, Catherine P. B. Wessells, David W. Hopson, Ruth L. Hopson, and Michael A. Rogers.

First Edition

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Prologue

Biology! At no time in history has the science of life been so visible and so important to human life and the future of our planet. Newspapers, magazines, and television feature biology prominently every day. Biological issues are discussed in Congress, the courts, on Wall Street, at the World Bank, at the United Nations, at summit meetings of heads of state as well as in classrooms, laboratories, hospitals, agricultural centers. We hear about viral diseases. About repairing brain damage. About the ozone layer and skin cancer. Desertification. Genetic engineering and frost-resistant strawberry plants. How memory works. Organ transplants. Drugs that will prevent heart attacks. In vitro fertilization. The destruction of rain forests. Acid rain. Crops that require no insecticides. The extinction of dinosaurs after an asteroid crashed into Earth. Chemicals produced by plants that protect them from their enemies. The fate of whales. The language of wolves. The durability of cockroaches. The origin of man. The future of our planet.

This book is an introduction to the worlds of biology. Its authors are superb guides for the journey.

Norman Wessells has taught and written about biology since he joined Stanford University in 1962. He has made important research discoveries in developmental and cell biology, vertebrate biology, and neurobiology. He is best known for his insightful studies of the mechanisms by which developing tissues and organs interact during mammalian development. His biological subjects have included chick and mouse embryos, hormones, cell locomotion, growth of nerve cells, lung development, the ultrastructure of algae, and the impact of advances in biology on society.

But, preeminently, *Norman Wessells* is a master teacher, treasured by students for his wonderful teaching. Three special talents have secured his effectiveness as a teacher and writer. First, he is able to explain complex ideas in plain language that can be understood and remembered. Second, he has a terrific sense for selecting durable and important subjects and examples to write about. And, finally, he has a clear view of how new-found knowledge can be put to use by the reader and by the larger society.

Janet Hopson is a marvelously talented science writer whose articles have appeared in the *New York Times Magazine*, *Smithsonian*, *Reader's Digest*, *Psychology Today*, *Rolling Stone*, *Cosmopolitan*, and numerous other major publications. Her work has also appeared in

a dozen books, including six textbooks, and she has taught and lectured about writing for several years at the University of California, Berkeley, U.C., Santa Cruz, Mills College, and other schools.

Janet Hopson has three special techniques. One is the declarative sentence, which she uses with skill and grace to convey ideas clearly and memorably. The second is the ability to capture and hold the attention of the reader with marvelous examples drawn from an encyclopedic knowledge of biology. The third is the ability to relate the biology she writes about to the world's work, to commerce, archeology, medicine, agriculture, conservation, behavior, and other subjects.

She has contributed both exciting ideas and graceful writing to *Biology*.

The contributing authors, all leaders in their fields, lend a special authority and currency to many of the chapters. All of them have paid attention to biology's pervasive impact on much that transpires in our world today. This view appears throughout the book in insightful comments on how rapidly advancing discoveries in biology impact other fields of knowledge such as sociology, psychology, economics and business, law, ethics, and the humanities, as well as biology's more obvious relatives such as physics, chemistry, mathematics, computer and information science, medicine, agriculture, engineering, and natural resource management.

This book will provide the reader with a powerful background for further studies in biology, medicine, agriculture, and the behavioral and social sciences. Beyond that it imparts the generic skills of problem solving and scientific reasoning. We believe the book will give its readers a distinct advantage as they continue their careers. And beyond that, it will contribute to the way the reader views the world: the world will look different, it will have more texture, more connectedness, a certain inner logic.

As consulting editors, we have contributed to the lively ferment that went into the book. It has been both challenging and exciting and we are delighted with the finished product. We hope you will enjoy it.

Howard A. Schneiderman
St. Louis, Missouri

John H. Postlethwait
Eugene, Oregon

Preface

Each person's daily world is filled with living things—roommates, trees and shrubs of various kinds, butterflies, stray dogs, flowers, mosquitoes. Much of our physical culture, moreover, is based on biological materials: wooden buildings and furniture; wool, cotton, and linen clothes, carpets, curtains, and upholstery; food, beverages, spices, and pharmaceuticals are but a few examples. Absent its living things, the world would be nothing but a ball of rock, water, and gases, and we humans would never have evolved with our sensibilities, our curiosities, and our dependencies upon other organisms.

Biology, the study of living things, no doubt began as soon as consciousness and curiosity first stirred in our ancient ancestors, and as they applied their intelligence to the problems of collecting animals and plants for food. Biology became more formalized as an intellectual endeavor soon after people could record their knowledge in pictures or words, and it continues today as a fundamental part of a good education. Understanding what defines a living thing, how and why it functions as it does, and how each of the millions of kinds of organisms arose on Earth intensifies our perspectives on and pleasures in the surrounding world. Anyone can watch with interest and even inspiration as a bee lands on a fragrant flower. But the experience is far richer for the observer who understands that the shapes of the insect and the blossom have evolved as complements to each other; that the flower is the plant's showy, tasty, fragrant advertisement, attracting animals that will inadvertently assist in the plant's reproduction; and that the bee has elaborate mechanisms for finding the flower and communicating its location to other members of the hive. The study of biology has vast practical application as well, in understanding one's body and personal health, in grappling with the ethical questions that face us as citizens, and in sensing both our place in the web of interdependent living things and our need to help protect the delicate ecological balance that sustains us all.

The Strategy

By chance and good fortune, students today live amid a revolution in the biological sciences. Significant, sometimes startling discoveries come almost weekly as scientists and their students around the world exploit new techniques, theories, and approaches. To find his or her way in the fast-moving field of modern biology, the novice requires a positive strategy. Our strategy to meet this challenge is fourfold. We feel that a beginning student needs a book that has:

Authority—accuracy and selectivity, with a consistency of scientific taste expressed in the facts, concepts, and explanations selected for inclusion

Breadth of coverage—a complete survey of the disciplines that make up modern biology, including biochemistry, genetics, development, physiology, ecology, evolution, behavior, and an overview of the full range of living organisms

Depth—explanations detailed enough to teach the reader not simply what happens in living things, but what the mechanisms are, and why they function as they do

High-quality presentation—writing that the reader can enjoy and appreciate while exploring the science of life

The Organization

Any successful approach to the teaching of biology rests on the ordering of subjects. The organization of *Biology* is based on the levels of organization within a living thing and its environment.

In the first part, *From Atoms to Cells*, we discuss atoms and molecules, the building blocks of all matter; biological molecules, the stuff of cells and organisms; the flow of energy in living things; the parts of cells, their basic functions, and how energy propels them; and, in the final two chapters, cellular respiration and photosynthesis, the central energy pathways that sustain all living organisms, directly or indirectly. We describe respiration first because it evolved before photosynthesis and because it is universal: all cells break down chemical compounds in a similar way to acquire usable energy for their survival. Photosynthesis is described next because, while it is crucial to virtually all life on Earth, it is carried out by only a subset of living things—the plants, algae, and certain microbes.

The second part, *Like Begets Like*, covers cellular reproduction, the mechanisms of heredity, and the way genes and chromosomes control the daily functions of living cells. While some books begin their coverage of genetics with the structure and function of the genetic information molecules called DNA, we feel that before students can fully appreciate the shape and role of DNA molecules they need to understand how cells divide, what chromosomes are and do, and, in general, how or-

ganisms inherit their parents' traits. We trace the chronological story of how genetics developed as a field because it shows with unparalleled drama how scientific experiments bring about revised views of nature and how new facts and ideas are built upon a foundation of old. Human genetics, a subject of generally high interest, is our last topic in genetics. We place it here so that we can apply all the concepts presented earlier—from cell division to recombinant DNA—to its understanding. Immediately following the coverage of genetics is a block of chapters on development. With this arrangement, the student can see how genes carry out their foremost task—controlling the formation and unfolding of the embryo and young organism. And development is the conceptual bridge between genetics and the remaining book topics, which are all at the level of whole organisms, their systems, or their populations.

The third part, *Order in Diversity*, starts with the origins of life on this planet and progresses through the five kingdoms of organisms that emerged, describing the fascinating diversity of living things, their evolutionary relationships, and how each major group may have arisen. We think that students need a clear picture of the wide spectrum of organisms and their basic properties before they can learn, in later chapters, how those organisms survive the daily struggle for existence and how they interact with their environments and with each other.

The fourth and fifth parts, *Plant Biology* and *Animal Biology*, describe the physiology or day-to-day functioning of the most complex groups, the plants and the animals. We place plants first because they are excellent examples of the inseparability of structure and function in living things; because plants and their ecological roles are so fundamental to all life on Earth; and because the placement provides important perspectives as we study the analogous and more familiar systems in animals in the subsequent part.

The eleven chapters of the final part, *Population Biology*, provide an in-depth treatment of the sciences of evolution and ecology—from the way populations change over time, to Earth's physical environment, to the way organisms relate to their surroundings and to each other. This part includes a discussion of how animals behave. Some books consider animal behavior as a final subject in their physiological sections. We feel, however, that an animal's full behavioral repertoire is best viewed in an ecological context, since that is where behavior contributes to survival and, indirectly, to evolutionary success. Chapter 50, on human origins and evolution, is also positioned to build on the part's foundation of environment, ecology, and behavior—the powerful influences that shaped our own species' origin and history. Finally, Chapter 51 is an extended essay that explores how human evolution and activity have affected Earth's ecosystems, and how our future actions

will continue to influence them—for better or worse—in the coming centuries.

The Approach

To achieve our goals of authoritative coverage, breadth, depth, and high-quality presentation within the organizational framework we have just described, we began by analyzing contemporary biological knowledge, relying, in part, on input from faculty consultants across the country. Next, experts in various subdisciplines (including Wessells) wrote first drafts of the 51 chapters. Then, based on careful reviews by a large panel of biologists at a range of institutions, the authors rewrote all of the chapters. In so doing, we tried to ensure high readability, a uniform style, a consistent level of presentation, and an emphasis on the interrelations between biological topics. Themes that recur in many chapters include evolution, the key place of development and cellular biology, and the importance of adaptation and ecology in every organism's life and every species' history. The explosion of biological knowledge in the late twentieth century—particularly in our ability to manipulate genes and engineer new genetic combinations—comes amid similar explosions in computer science, material science, particle physics, and other areas. So rapid is the present rate of discovery that it is difficult for scientist and student alike to avoid becoming overwhelmed with new information. With the help of our original contributors and many faculty reviewers, our task has been to present the fundamentals of biology—some dating several centuries, but most developed since the mid-1800s—as well as to distinguish from among the very recent findings those we believe to be lasting and significant, not simply new and glamorous. We hope our strategy will be a successful one for the users of this book. And we hope our work will provide a foundation of biological knowledge from which the reader—whether future scientific professional or informed citizen in a nonscientific field—can understand the stream of discoveries sure to come in biology in the decades ahead and participate in the democratic process of regulating and utilizing the fruits of those discoveries.

Acknowledgments

We are indebted to literally hundreds of people for help in undertaking and completing this project. None has done more than our consultants, John Postlethwait of the University of Oregon, and Howard Schneiderman of the University of California, Irvine, and Monsanto Company, who were the primary formulators of the book's outline and organization. In addition, Dr. Postlethwait wrote the chapter on genetic engineering, and contributed heavily to the other chapters in the genetics section, and both he and Dr. Schneiderman provided invaluable advice on matters large and small throughout the project's development. Special thanks go to former Stan-

ford colleague Peter Raven, of Washington University in St. Louis and director of the Missouri Botanical Garden. Dr. Raven provided advice, perspectives, and constructive criticism for the book's final chapter.

We also extend our warmest appreciation to the original contributors of chapters; their names are listed on the title page. Other scientific contributors who helped us update and reshape the material include David Graber, National Park Service, Sequoia National Park; Lewis J. Feldman, University of California, Berkeley; Russ Fernald, University of Oregon; Kent Holsinger, University of Connecticut; Rhoda Love, University of Oregon; Douglas Miller, Stanford University; Joyce Owen, University of Oregon; William B. Siström, University of Oregon.

More than one hundred reviewers from various colleges, universities, and institutions provided critical feedback and recommendations for revision. Their input was very important to implementing our goals of authoritativeness and effective presentation, and is much appreciated. A list of those scientific reviewers follows this preface.

Many scientists, photographers, and artists contributed to the book's art program by giving permission to use or modify drawings, and to print or reprint photographs. Their names and the figure references for their work appear in the Credits and Acknowledgments section at the end of the book. In particular, the late Geoffrey V. Goldin made numerous imaginative contributions to the art program, and we are deeply grateful for his work.

A long and complex science book such as this, couched in readable prose and illustrated with some 1,200 photos, drawings, charts, graphs, tables, boxes, and appendixes, demands the tender loving care of a talented team of professionals at all stages of development. Pre-eminent have been Mary M. Shuford, whose extraordinary organizational skills and saintly patience and concern for detail have had numerous impacts on every page, and Judith Kromm, who devoted great care and skill to the developmental editing of the book. We are also indebted for the editorial, design, and production efforts of Marjorie Anderson, Sally Beckham, Kathy Bendo, Leon Bolognese, Jacqueline Bryan, Mary Louise Byrd, Jane Edsell, Jackie Estrada, Beverly Fraknoi, Cele Gardner, Andrea Lévy, Michael C. Kennedy, Laura Lamorte, John Lennard, Della Mancuso, Roberta Meyer, Irene Pavitt, Elaine Romano, Jennifer Soyke, Phyl Stevens, Suzanne Thibodeau, Peter Veres, Ruth Veres, Lesley Walsh, and Betty White.

Our joint and deepest gratitude goes to Eirik Børve, our collaborating publisher, who has, at every step of the way, placed his intelligence, energy, and exceptional management skills behind our goal of teaching biology in the most effective manner possible. Mr. Børve's encour-

agement and good spirits kept us stimulated throughout the seven-year-long project, and his support for both a high degree of scientific rigor and a student-oriented presentation was unstinting. So much teaching and learning at the college level depends on carefully published textbooks, and we feel that Mr. Børve represents the very best in his field.

Finally, we express warmest appreciation to one another. A collaboration between a professional biologist and a widely published writer is truly a beneficial education for both parties.

Even with the careful contributions of our aforementioned friends and colleagues, errors of facts or interpretation may have found their way into the book. For these, we alone assume responsibility, and stand ready to correct them.

We sincerely hope that the students and professors who use this book will find it a stimulating introduction to the intricate, fascinating, and beautiful world of life on Earth.

Norman K. Wessells
Janet L. Hopson

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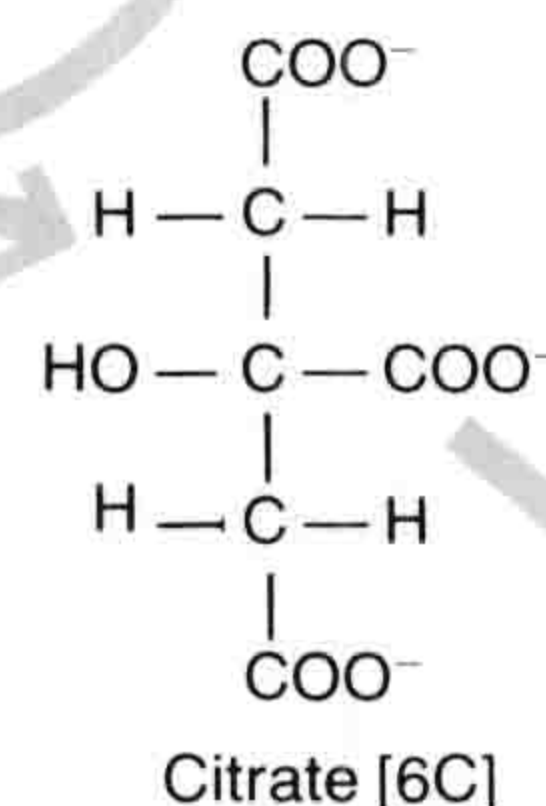
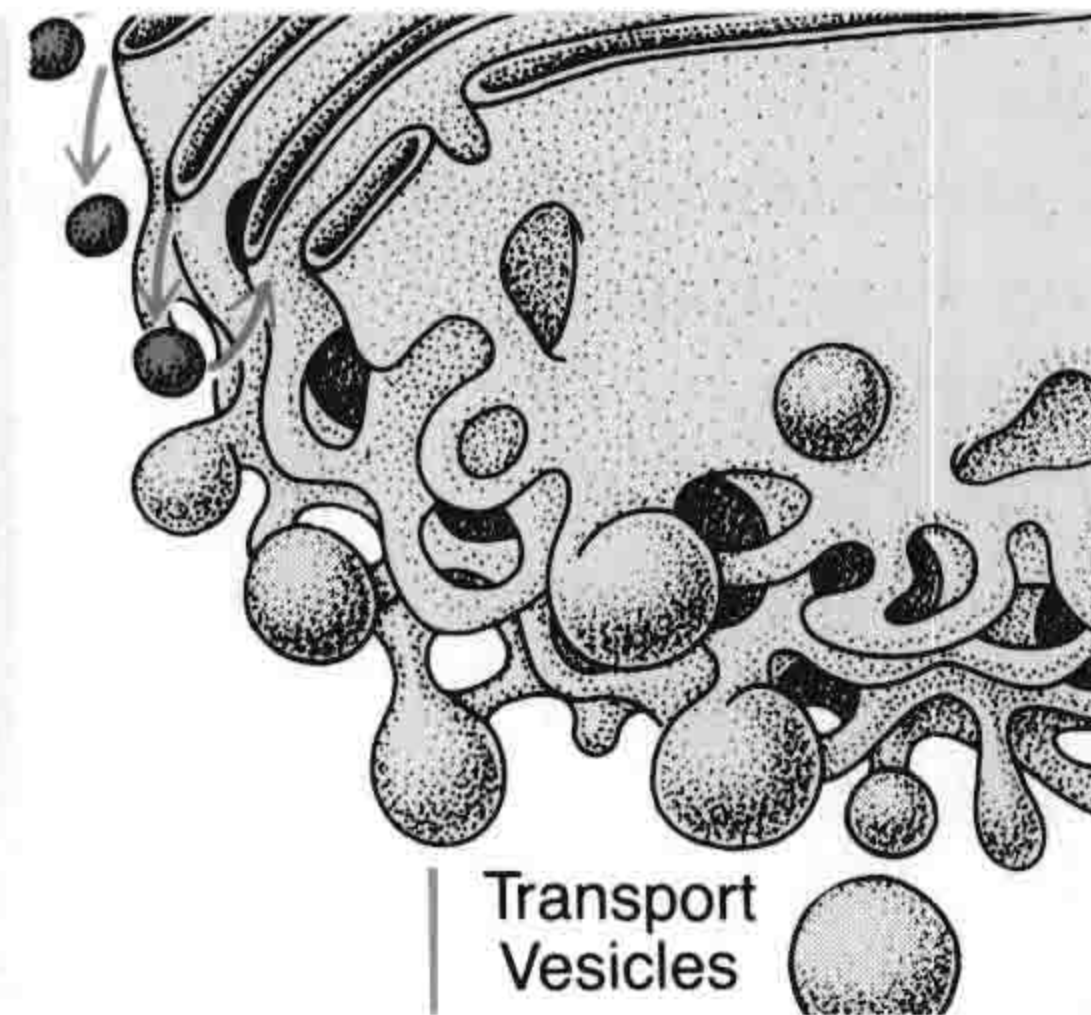
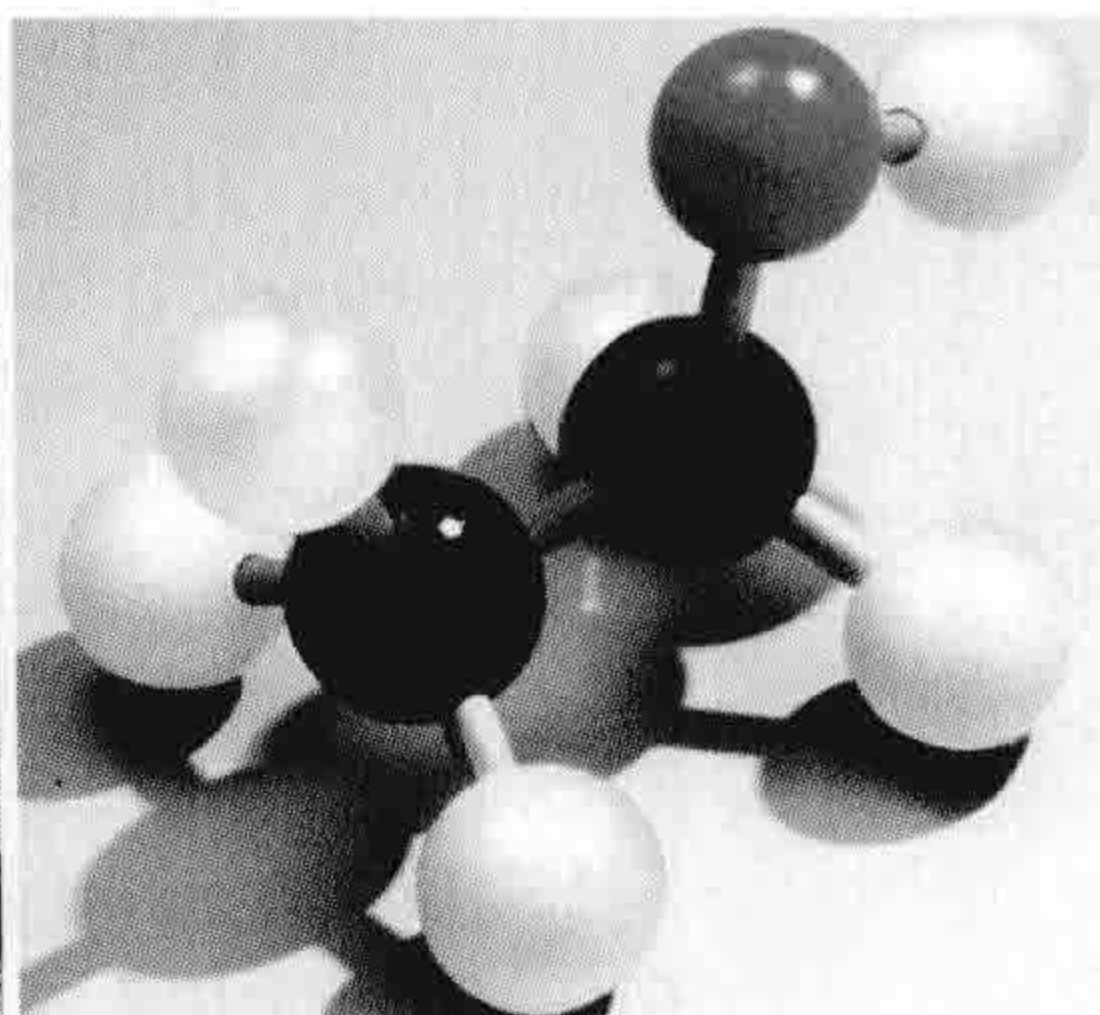
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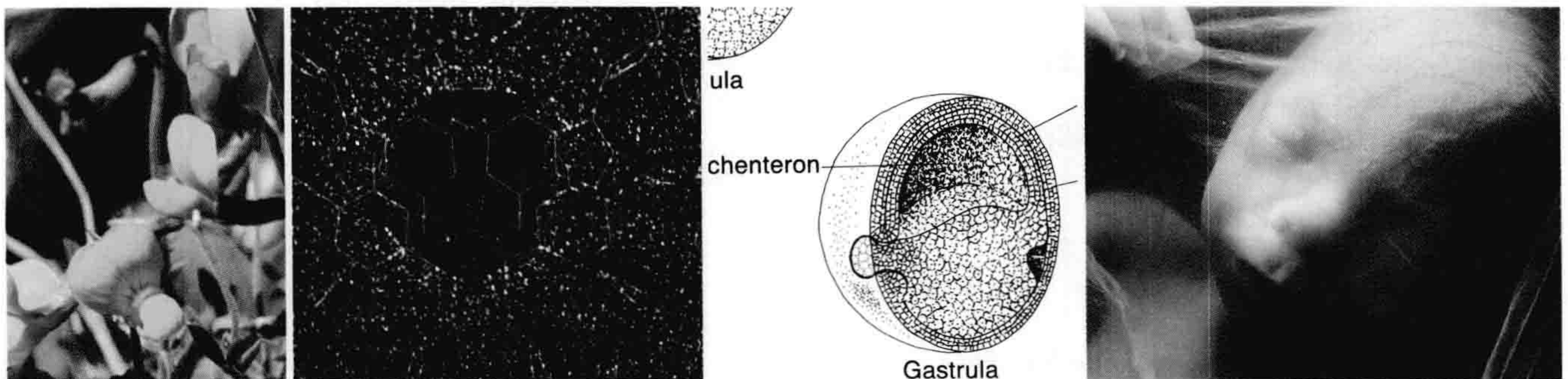


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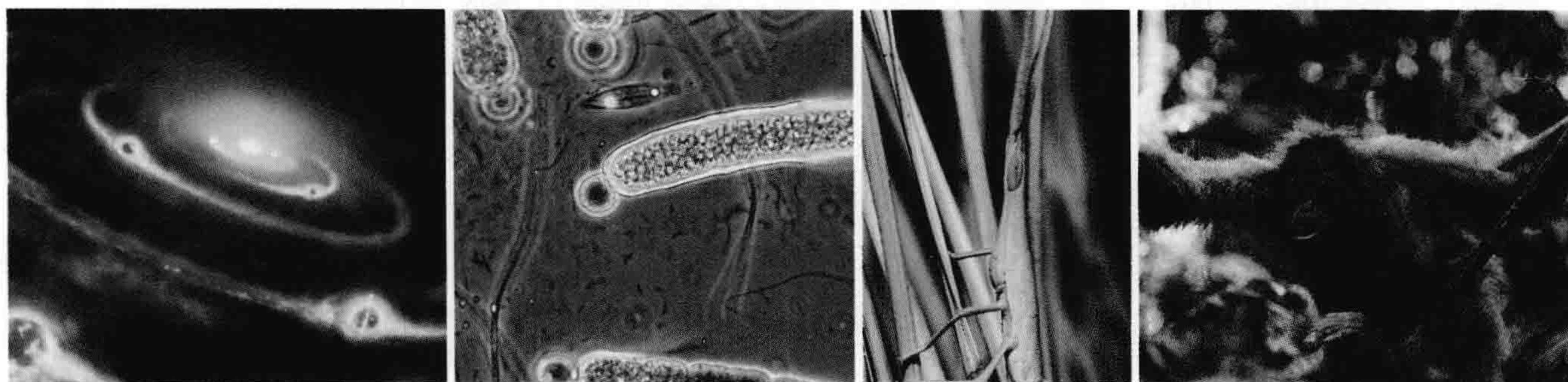
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