ESSENTIALS OF BIOLOGY

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To my dear friends, with gratitude for
their support and encouragement.
—J.L.H.

To Catherine, with thanks and love.
—N.K.W.

To Howard Schneiderman, with
thanks from us both and from so
many others for the contributions you
have made to our lives, to science,
and to the future.
—N.K.W. and J.L.H.

Prologue

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, in the courts, on Wall Street, at the World Bank, at the United Nations, and at summit meetings of heads of state, as well as in classrooms, laboratories, hospitals, and agricultural centers. We hear about viral diseases, especially AIDS. About repairing brain damage. About the ozone layer and skin cancer. The greenhouse effect. The disappearance of forests and the rapid loss of animal and plant diversity on our planet. Genetic engineering and frost-resistant strawberry plants. The costs—billions of dollars—of unraveling the genetic code of human beings (the so-called human genome project). 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 the earth. Chemicals produced by plants that protect the plants from their enemies. The fate of whales. The language of wolves. The durability of cockroaches. The origin of humans. The future of our planet.

Essentials of Biology is a brief introduction to the worlds of biology. Its authors are superb guides for the journey. The book is a shorter version of the comprehensive introduction to biology that Norman Wessells and Janet Hopson successfully introduced recently. This new book has retained the clear explanations and exciting writing of the original, but is more selective in the subjects covered and has a vigorously revised and substantially improved art program. It is truly an essential book that will provide the reader with a powerful background for further studies in biology, medicine, agriculture, and the behavioral and social sciences, as well as the knowledge to function as an informed voter, consumer, and denizen of the planet Earth. Beyond that, *Essentials* will contribute to the reader's viewpoint: 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

Biology, the study of life in all its manifestations, no doubt began with the first stirrings of curiosity in our early ancestors, taking root as these early humans applied their intelligence to the problems of tracking game and collecting plant materials. Biology became a more formalized 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.

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 shape of the insect and the shape of 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 applications, as well, in understanding our bodies 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.

For these reasons, the basic Principles of Biology course is a popular one on college campuses. Students who plan to pursue careers in life science, medicine, agriculture, and a broad range of other disciplines (listed in Chapter 1) usually take an introductory biology course, as do many nonmajors (students from unrelated fields) who are simply curious and want to learn the principles that underlie health, fitness, nutrition, genetic engineering, acid rain, the greenhouse effect, and dozens of other current topics.

At most schools, biology majors and nonmajors take introductory biology together, and these "mixed" courses can present the instructor with a real challenge. In particular, which textbook will give the majors the solid foundation of facts and concepts they need while providing the nonmajors with a source that is not overly detailed or presented at too high a level? We designed *Essentials of Biology* to address this need.

This book is a condensation of the well-received *Biology* that we first published in 1988. *Essentials of Biology* maintains the same authoritative selection of topics and the same reader-friendly presentation that has made *Biology* so popular for two-semester courses, but it also incorporates a number of new features that will make it successful for shorter courses or mixed enrollments.

Essentials follows the same levels-of-organization approach we took in *Biology*. The first part, From Atoms to Cells, discusses 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 and how they function; and the central energy pathways of cellular respiration and photosynthesis that sustain all living organisms, directly or indirectly.

The second part, Like Begets Like, covers cellular reproduction, the mechanisms of heredity, and how genes and chromosomes control the daily functions of living cells. In this part, students see how genetics developed as a field, from the earliest studies of cell division to the latest applications of recombinant DNA; how researchers study human genetics, a subject of high student interest; and, in a block of chapters on development, how genes carry out their foremost task—controlling the formation of the embryo and young organism. As in *Biology*, development serves as the conceptual bridge between genetics and the remaining topics in the book, which are all at the level of whole organisms or their systems.

The third part, Order in Diversity, presents a clear picture of the wide spectrum of organisms and their basic characteristics. It starts with the origins of life on this planet and progresses through the kingdoms of organisms that emerged, describing the fascinating diversity of living things, their evolutionary relationships, and how each major group may have arisen.

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 animals, and how they interact with their environments and with each other.

The final part, Population Biology, introduces the sciences of evolution and ecology—from the way populations change over time, to the interactions of the earth's physical forces, to the way groups of organisms relate to those forces and to each other. An important part of this discussion is how environment, ecology, and behavior have shaped our own species' origin and history; how human evolution and activity have affected the earth's ecosystems; and how our future actions will continue to influence them—for better or worse—in the coming centuries.

While the general organization of topics in *Essentials* is the same as in *Biology*, we made some dramatic changes to create a shorter book useful for mixed audiences of student readers. We combined several chapters, reducing the total number from 51 to 46. We removed 25 to 40 percent of the material in each chapter by streamlining the prose; shortening the chapter introductions and endings by substituting point-by-point lists; removing some examples where fewer strong examples could make the same points; cutting some concepts and some detail, but leaving all those topics that our panel of academic reviewers felt were essential for students in a one-semester course; and designing hundreds of new and vastly improved figures that are closely coordinated to the text and can help students visualize and understand biological structures and processes more easily than through lengthier prose discussions. The result is a greater emphasis on essential concepts, a clearer presentation through words and illustrations, a greater proportion of space devoted to unifying themes and take-home messages, and a de-emphasis on detail.

In addition, we updated every chapter with relevant new research and applications of interest to students. We replaced many of the original boxed essays from *Biology* with new student-oriented subjects. And we added some new pedagogical features, including an advance organizer in the chapter introduction, underlined take-home messages for easy study and review, a very complete index to improve the book's utility as a reference, and the use of visual icons in many figures to help the student grasp the physical context for a structure or process (for example, see Guided Tour, page xxviii).

In all, *Essentials* maintains the same well-chosen and clearly explained subjects as *Biology*—thanks to our team of authors, consultants, contributors, and reviewers. But through vigorous revision and condensation, we have created an entirely new, up-to-date textbook with all the topics a biology major needs to know, presented in a way that will interest and give equal access to nonmajors.

We hope our strategy will be a winning one for the users of this book. And we hope our work will provide a foundation of knowledge from which the reader—whether future scientist or informed citizen in a nonscientific field—can understand the stream of discoveries sure to come in biology in the decades ahead, as well as to participate in the democratic process of regulating and utilizing the fruits of those discoveries.

Acknowledgments. We are indebted to hundreds of people for their help in undertaking and completing this project. None have done more than our consultants, Dr. John Postlethwait of the University of Oregon and Dr. 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 contributed heavily to the chapters on genetics, provided invaluable advice on matters large and small throughout the project's development, and designed virtually all of the new figures for the book.

Once again, we extend our warmest appreciation to those who contributed to *Biology*, as well as the reviewers from various colleges, universities, and institutions who provided critical feedback and recommendations for cutting and revising (see page xi). Their input was very important to our goals of authoritativeness and effective presentation, and it was much appreciated.

Many scientists, photographers, and artists contributed to the book's art program by allowing us 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.

A long and complex science book such as this, couched in readable prose and illustrated with hundreds of photos, drawings, charts, graphs, tables, boxes, and appendices, demands the tender loving care of a talented team of professionals at all stages of development. We are indebted to Hal Lockwood, Janet Greenblatt, Stuart Kenter, Carol Dondrea, Blake Edgar, Pattie Myers, Karen Judd, Bev Fraknoi, Lesley Walsh, Sandy Woods, Richard Lynch, Judith Levinson, and Renee Deprey.

Our 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. 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 each other. 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 fact 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 instructors who use this book will find it a stimulating introduction to the intricate, fascinating, and beautiful world of life on earth.

Janet L. Hopson and Norman K. Wessells

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A Guided Tour to *Essentials of Biology*

Chapter Introduction

LITERARY QUOTE AND PHOTO

Appropriate literary quote and stunning photo to capture student interest and set the tone for the chapter.

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How Plants Reproduce, Develop, and Grow

I took an earthenware pot, placed in it 200 lb of earth dried in an oven, soaked this with water, and planted in it a willow shoot weighing 5 lb. After 5 years had passed, the tree grown therefrom weighed 169 lb and about 3 oz. . . . Finally, I again dried the earth of the pot and it was found to be the same 200 lb minus about 2 oz. Therefore, 164 lb of wood, bark, and root had arisen from water alone.

Jean-Baptiste van Helmont, *Ortus Medicinae* (1648)

A living castaway: After months at sea, a coconut palm sprouts and takes root just above the tide line on a Virgin Islands beach.

Flowering plants have flourished largely because of their innovations in sexual reproduction, the flowers, fruits, and seeds. Yet many plants within this group also exploit asexual *vegetative reproduction,* a kind of cloning that can involve stems, roots, or leaves and result in offspring that are genetically identical to the parent. The study of both modes of reproduction in flowering plants and of subsequent growth and development of new individuals helps reveal how plants differ from animals.

One aspect of plant development is particularly distinctive: Plants have perpetual embryonic centers that produce new organs throughout the life of the individual, whereas most animals form organs only as embryos. The plant's unique capacity for renewed growth and development throughout adult life is utilized during flowering and sexual reproduction as well as in modified form during vegetative reproduction.

Our goal in this chapter is to survey the entire range of plant parts, reproductive processes, and growth—from the drab to the glorious, from the asexual to the sexual, from pollen and eggs to the woody tissues of mature trees and bushes. The details of reproduction and growth help to characterize the flowering plants (and, in some respects, the conifers) and explain why they are such highly successful groups.

Our discussions will cover:

- Vegetative reproduction, or multiplication through cloning in nature and agriculture
- Sexual reproduction, and the roles of flower, pollen, sperm, egg, pollination, and fertilization
- The development of plant embryos
- Seeds and the dispersal of the new generation
- Germination of the seed and development of the new seedling
- Primary growth—increasing size and the addition of new tissues in the young plant
- Secondary growth—the development of wood and bark in older plants
- Plant life spans and life-styles

VEGETATIVE REPRODUCTION: MULTIPLICATION THROUGH CLONING

High in the Appalachian Mountains of West Virginia, there is a low, dense thicket of blueberry bushes nearly

UNIFYING THEME

Unifying themes to help tie together chapter facts and concepts.

ADVANCE ORGANIZER

A list of the chapter's major topics in their order of presentation.

Key to use of color appears on page xxxii.

Aids to Learning

176 CHAPTER 10/FOUNDATIONS OF GENETICS

THOROUGHBREDS AND THOROUGH BREEDING

Horse racing is big business: Owners in 40 countries race more than half a million thoroughbreds, and fans wager billions annually. Ironically, while human Olympic sprinters continue to improve their speeds each year, horses are no faster now than they were 50 years ago. Have horses reached their inherent speed limit? Or is there another explanation for their lack of improvement, despite advances in nutrition and veterinary medicine?

Irish geneticists B. Gaffney and E. P. Cunningham recently developed a complicated method for analyzing change in 31,263 thoroughbreds over the past 25 years. Like other researchers, they found strong evidence of inbreeding, or unusually close genetic similarity based on matings between related horses. They expected this, because 80 percent of all thoroughbreds are descendants of just 31 horses brought to England from the Middle East and North Africa at the turn of the eighteenth century. Just as Mendel artificially selected and bred peas of a certain color, height, and shape, race horse breeders have selected and interbred these descendants to preserve competitive disposition, strong slender legs, and, above all, swift running speed. But did this practice of "breeding the best to the best" backfire and produce, instead, a "regression to the norm"—an averaging of traits and a loss from the population of alleles for both extreme slowness *and* extreme swiftness?

Figure A HAVE THOROUGHBREDS REACHED AN UPPER SPEED LIMIT?

Gaffney and Cunningham think not and report that thoroughbred populations still have considerable genetic variation. Based on their analyses, thoroughbreds should now be running about 2.5 percent faster than they did a quarter century ago and have definitely not approached their natural upper speed limit. Many observers think more practical factors are at fault: lax training methods (underexercising the valuable race horses); unsound breeding practices (pairing horses by their "papers" and family histories rather than their actual sizes, shapes, and speeds); and poor race track running surfaces. If the recent study is correct, we could be seeing faster horse races in the future. If it's wrong, the record-setting horses of the past, like Man O'War and Secretariat, could be legends forever.

green seeds in the F_2 generation. He knew that if you toss a coin in the air, it has an equal chance, or probability, of landing heads or tails. If you toss two coins, there are four possibilities: two heads; two tails; one head and one tail; or one tail and one head. Thus, the probability of two heads (or two tails) is 1 in 4, while the probability of one head and one tail is 2 in 4.

Figure 10-5b, step 3, shows a simple means (devised after Mendel's time) of displaying the probability of different allele combinations. This method, called a **Punnett square,** can be used for three, four, or more coin tosses or genetic traits. The various boxes in the Punnett square indicate the probabilities of seeing each of the possible head-tail combinations or, in the case of genetic factors, allele combinations. Thus, you can draw Punnett squares with the alleles from one parent along one side (representing the classes of possible gametes) and those from the other parent along the other side. By crossing each pair of alleles and filling in all the boxes of the Punnett square, you can see all the possible combinations and calculate the ratio of results.

The Law of Segregation

Since Mendel reasoned that each pea plant receives two alleles of each gene—one allele coming from each parent's gamete—he also reasoned that the number of alleles must be reduced as the parent produces gametes so that the offspring receives two alleles of each gene, not four. As Chapter 9 explained, just this kind of reduction occurs during meiosis and gamete formation and ensures that eggs, pollen, or sperm are haploid and carry just one allele of each gene.

By considering this separation and reduction of alleles during gamete production, one can understand the results of self-pollination within a heterozygote (Yy). In effect, this is equivalent to a cross between two Yy plants, each producing some gametes that carry the dominant Y allele for yellow seeds and some that carry the recessive y allele for green seeds. If the plants produce pollen (or sperm) and eggs with Y and y occurring in equal ratios, and if the gametes combine randomly at fertilization, one-quarter of the F_2 progeny will receive a Y from both

BOXED ESSAYS

Boxed essays that present interesting experiments, new research findings, and newsworthy topics to help students understand biology's real-world applications and implications.

JAWED FISHES: AN EVOLUTIONARY MILESTONE 435

(a) (b) (c)

Figure 24-32 TELEOSTS, THE MOST DIVERSE FISHES.
The earth's oceans, rivers, and lakes teem with seemingly endless varieties of teleosts. (a) The sailfish *(Istiophorus platypterus)*, with its long, bladelike upper jaw and huge dorsal fin that can be raised or lowered out of the way. (b) The masked butterfly fish *(Chaetodon semilarvatus)* of the Red Sea. (c) The rainbow wrasse *(Laproides phthirophagus)*, a common reef fish in both hemispheres.

dramatically, and fins can be used as paddles, brakes, or even true gliding wings, as in the flying fish. We will discuss various aspects of fish physiology in later chapters.

The second subclass of bony fishes, the sarcopterygians, is older than the actinopterygians. It includes a few modern species with fascinating adaptations for breathing air and walking, plus extinct species that were the first vertebrates to crawl onto land more than 360 million years ago. In contrast to the thin, bony fins of teleosts, sarcopterygians have thick *lobed* fins with large bones and muscles. Certain sarcopterygians also have external and internal nostrils, or *nares,* and a good sense of smell.

Sarcopterygians include the living lungfish and coelacanths and the extinct rhipidistian fishes. *Lungfish* are rare freshwater fish that live in shallow rivers and lakes in Australia, South America, and Africa. They have both gills and lungs, relying on the former when their environment is wet and the latter when it is dry, and they are locked in a protective mud and mucus "cocoon."

Coelacanths are large (up to 1 m or so) primeval-looking fishes once thought to be extinct, but rediscovered off Madagascar in 1938 (Figure 24-33). They possess a fat-filled swim bladder for buoyancy, analogous to the shark's fat-storing liver, and pectoral and pelvic fins that move in a coordinated way during slow swimming, much as the forelegs and hind legs of land vertebrates move during walking.

The final group of fleshy-finned fish, the extinct *rhipidistians,* were probably the ancestors of the land vertebrates. The muscular lobed fins of these fishes probably allowed them to "walk" along the bottom of shallow ocean bays and tidal flats. Rhipidistians lived during the Devonian period, about 350 to 400 million years ago, and may have pursued insects and other invertebrate food sources up onto land. The oldest fossilized animal tracks of vertebrates yet found were left by rhipidistians in 360- to 370-million-year-old sandstone formations on the Orkney Islands, off the northeastern coast of Scotland.

The evolution of the fishes was far from linear. During the Devonian period, the age of fishes, the waters literally teemed with a bewildering array of ostracoderms, cyclostomes, acanthodians, early actinopterygians, lungfish, and rhipidistians. The first amphibians also arose from ancestral fish and lived among this Devonian variety.

Figure 24-33 A COELACANTH *(Latimaria chalumnae):* A FLESHY-FINNED LIVING FOSSIL.
This rare fish closely resembles its ancient predecessors. The fish is about a meter in length and can move slowly forward using its thick-based fins, such as the posterior-dorsal one seen here.

UNDERLINING

Underlined take-home messages that present or emphasize key concepts.

Unique Art Program

ICONS

Extensive use of icons or small diagrams that help students fit the structure or process into its actual physical context in a living organism.

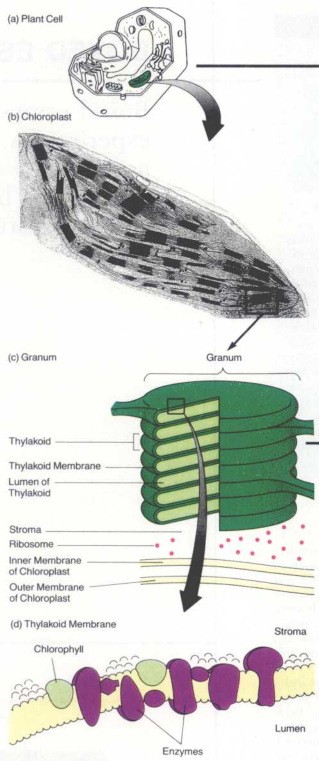
COLORS

The consistent use of assigned colors and shapes throughout the book to designate specific atoms, molecules, cellular structures, and processes.

DIAGRAMS

Extensive use of process diagrams that depict sequential biological events. Individual steps are numbered and keyed to step-by-step discussions in the text or figure legend.

Figure 8-4 THE STRUCTURE OF CHLOROPLASTS: SITES OF PHOTOSYNTHESIS.
Plant cells (a) contain chloroplasts, such as the one pictured in (b). This electron micrograph of a chloroplast (magnification 15,000×) reveals the internal stacks of membranes, the grana. Each granum (c) consists of flattened sacs called thylakoids; adjacent grana are interconnected by the thylakoid membrane (d). Most of the enzymes and pigments for the light reactions of photosynthesis are embedded in the thylakoid membranes. The stroma, a gel-like matrix, surrounds the grana. The enzymes for the light-independent reactions of photosynthesis as well as chloroplast DNA and ribosomes and other substances are located in the stroma.



Chloroplasts: Sites of Photosynthesis

In eukaryotic cells, both phases of photosynthesis take place in chloroplasts, and the reactions depend on the unique structure of these organelles just as cellular respiration depends on the architecture of the mitochondrion (see Chapter 5). Chloroplasts have a variety of shapes, but most are elongated like minute bananas (Figure 8-4a and b). Chloroplasts are somewhat larger than mitochondria, and a typical plant cell contains from 20 to 80 of them (usually about 40). Two lipid bilayer membranes surround the chloroplast (Figure 8-4c); internally, a gel-like matrix called the *stroma* contains ribosomes, the machinery for protein synthesis, and DNA, which, in at least one species, forms genes that turn on and off in response to light. Some essential chloroplast proteins are encoded in the cell's nuclear DNA, synthesized in the cytoplasm, then moved into chloroplasts. The most prominent internal structures in chloroplasts are the stacks of flattened sacs called *grana* (meaning "grains"; see Figure 8-4c). Each flattened sac in a granum is called a **thylakoid** (from the Greek word for "sack"), and a *thylakoid membrane* surrounds the internal space, or *lumen*, of each sac (Figure 8-4d).

The chlorophyll, enzymes, and cofactors that participate in the light-dependent reactions of photosynthesis are embedded in the thylakoid membrane (see Figure 8-4d). Most of the enzymes that catalyze the light-independent reactions are found in the stroma, or matrix, surrounding the stacks of thylakoids.

HOW LIGHT ENERGY REACHES PHOTOSYNTHETIC CELLS

A browsing animal that eats a fresh green leaf from a bush is consuming light energy that may have left the sun just 8 minutes earlier. But what exactly is light energy, and how does it interact with the molecules of a living leaf?

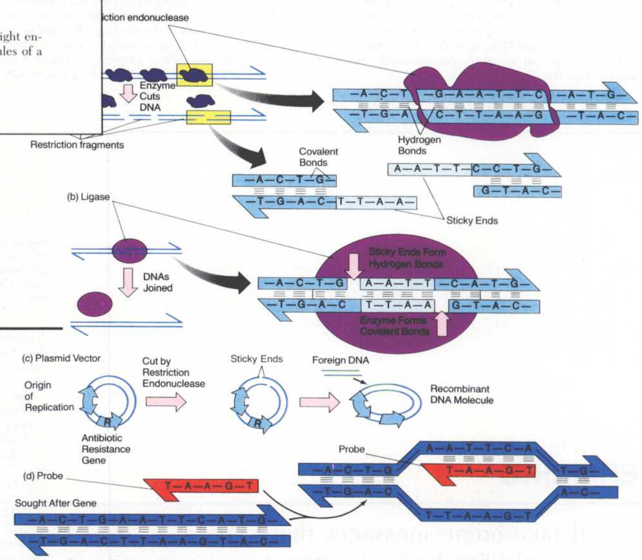


Figure 14-13 TOOLS OF THE GENETIC ENGINEER.
(a) Restriction endonucleases can cut DNA at specific sequences and leave overlapping "sticky" ends. (b) DNA ligase enzymes rejoin the sticky ends at complementary sequences. (c) New genes can be spliced into vectors, which are usually plasmids, to form recombinant DNA molecules. Vectors can carry such novel gene sequences into different host organisms. (d) Molecular probes are stretches of RNA with base sequences complementary to a desired gene, often part of a recombinant DNA molecule.

Molecular Probes

The final tool of the genetic engineer is a probe for locating recombinant DNA molecules, genes, or other desired pieces of genetic information. A **probe** can be a specially prepared stretch of RNA or DNA with a sequence complementary to the specific series of nucleotides in the sought-after gene (Figure 14-13d).

Let's see, now, how a researcher would use these tools to clone and transfer a gene.

Engineering a Bigger Mouse

Genetic engineers used the tools just described plus a few specialized techniques to isolate the gene for rat growth hormone, clone it, and transfer it into the giant mouse shown on page 229. Here's what they did, step by step.

A researcher took the DNA from rat cells and cut it with a restriction endonuclease into hundreds or thou-

Tools for Review

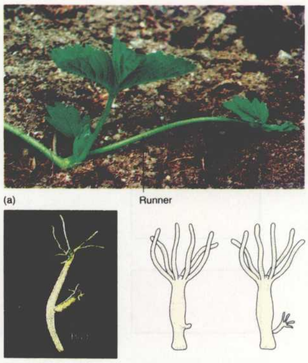


Figure 9-11 ASEXUAL REPRODUCTION IN PLANTS AND ANIMALS.
(a) Strawberry runners demonstrate a form of asexual reproduction used by plants. The plants grow new runners, or horizontal stems, which send their own roots down into the ground to form a new plant. (b) The hydra (here, magnified about 9×) is an aquatic animal that can reproduce asexually. Hydras can produce buds through simple mitotic division, and each bud pinches off and grows into a new full-sized hydra by further mitotic division.

based on novel combinations of traits from both parents. Spontaneous mutations can provide further variability, as well. The sexually reproducing organism in a sense gambles on giving its offspring a better hand; its genetic "cards" are "reshuffled" and "redealt" instead of being passed along in original form. Thus, new combinations of traits can arise much more rapidly in sexually than in asexually reproducing organisms and increase the chances of the species surviving sudden significant environmental changes.

Despite these great advantages, sexual reproduction does have drawbacks. An organism that cannot reproduce asexually—a mammal, for example—can never bequeath its own exact set of genetic material, no matter how successful, to its progeny, the way a prizewinning strawberry plant can pass along its hereditary complement to a clone. The very mixing process that created the successful gene combination in the adult works to dismantle it partially in the offspring. Researchers are currently trying to perfect techniques for cloning mammals so that the desirable traits of a prizewinning bull, let's say, could be reproduced in thousands of offspring, and not subject to the variability of sexual reproduction.

LOOKING AHEAD

The spectacular dance of the chromosomes during mitosis and meiosis, as well as the cycling of cells through periods of growth, synthesis, and division, allows for both fidelity and variability in the passage of genetic information from one cell generation to the next. Our next chapter explains how biologists unraveled those mysteries of inheritance.

SUMMARY

1. The nucleus is the repository of hereditary information, which is contained in DNA and organized in structures called *chromosomes*.

2. Chromosomes are made up of a substance called *chromatin*, which is a combination of DNA, *histones*, and nonhistone proteins. *Nucleosomes* are sites where DNA is wrapped about sets of histone molecules.

3. In most eukaryotic organisms, there are two copies of each chromosome; the two form a *homologous* pair. *Sex chromosomes* are the exception. Diploid cells and organisms contain homologous pairs of chromosomes. Haploid cells and organisms contain only one set of chromosomes.

4. The mitotic *cell cycle* consists of four phases: G_1, a period of normal metabolism; S, the phase of DNA replication plus metabolism; G_2, a brief period of further cell growth; and *M*, mitosis. The nonmitotic stages (G_1, S, G_2) are referred to collectively as *interphase*.

5. The events of mitosis can be divided into four phases: *prophase*, *metaphase*, *anaphase*, and *telophase*.

6. At the beginning of mitosis, two identical chromatids become associated with the *spindle* and align in the middle of the cell along the *metaphase plate*. In anaphase, the centromeres divide, and the two chromatids are drawn toward opposite poles.

7. The polar microtubules extend from the spindle poles and overlap at the equator. As the region of overlap decreases, the poles are moved farther apart. Spindle microtubules extend from the *kinetochores* in the centromere of the chromatids toward the spindle poles. These fibers shorten, pulling the chromatids toward the poles.

8. In animals, spindle formation is associated with centrioles; in most plants and fungi, it is associated with microtubule-organizing centers.

9. In animal cells, *cytokinesis*, or division of the cytoplasm, results from the

LOOKING AHEAD

Many chapters end with *Looking Ahead*, a short section that ties the main thread of the chapter to the discussions in the following chapter.

SUMMARY

A point-by-point recap of the chapter's main concepts and facts.

le ring of actin fila- … equator. In plants, … he building of a *cell* … s equator.

… ial type of cell divi- … chromosome num- … tic prophase I, the … each homologous … gether in a process called *synapsis*. In anaphase I, the homologous chromosomes separate to opposite poles. During meiosis II, each sister chromatid of the pair moves to one of the poles. The result is four haploid cells.

11. Meiosis allows for the random distribution of homologous parental chromosomes in offspring, as well as the genetic variability that results from *crossing over*.

12. Asexual reproduction, in which new organisms arise from mitotic processes, preserves an organism's "winning genetic formula" in a particular environment. Sexual reproduction, which involves meiosis and gamete production, ensures greater variability in offspring and ensures hereditary enrichment as new genes and gene families arise.

KEY TERMS

anaphase
autosome
cell cycle
cell plate
centromere
chalone
chromatid
chromatin
chromosome
clone
crossing over
cytokinesis
diploid
G_1 phase
G_2 phase
haploid
histone
homologous
interphase
karyotype
kinetochore
meiosis
metaphase
metaphase plate
mitosis
M phase
nucleosome
prophase
sex chromosome
S phase
spindle
synapsis
synaptinemal complex
telophase

QUESTIONS

1. What part of the cell contains the hereditary information? Which structures contain this information? Which molecules make up these structures?

2. The cell cycle consists of four phases: G_1, S, G_2, and M. What occurs during each phase? Which has the most variable length?

3. What is the outcome of mitosis? Does each daughter cell receive identical chromosomes?

4. What is the outcome of meiosis? Does each haploid cell receive identical chromosomes?

5. Which of the following statements apply to mitosis, which to meiosis, and which to both?
   a. DNA replication occurs before this process starts.
   b. When the chromosomes first become visible, they are already doubled.
   c. Homologous chromosomes pair.
   d. Each daughter cell receives an identical complement of chromosomes.
   e. The centromere is the last part of the chromosome to divide.

6. Two kinds of microtubules separate the chromosomes during cell division. What are they, and how do they operate?

7. Describe the function of the centriole or microtubule-organizing center during cell division.

8. Describe the process of cytokinesis first in a dividing animal cell, then in a plant cell.

ESSAY QUESTIONS

1. Did you inherit equal numbers of chromosomes from your two parents? From your four grandparents? Explain.

2. Is a species more likely to survive in a changing environment if all its members are identical or if they are diverse? What is accomplished by sexual reproduction? What are the advantages of asexual reproduction?

For additional readings related to topics in this chapter, see Appendix C.

KEY TERMS

Key terms are listed to help students identify the chapter's most important vocabulary.

QUESTIONS

Study questions, both short answer and essay questions, help students review and retain the most important information.

SUGGESTED READINGS

A list of classic and up-to-date references for additional reading beyond the text material occurs in a special appendix and is cited at the end of each chapter.

Key to Use of Color

Atoms

Oxygen

Hydrogen

Carbon or

Nitrogen

Phosphorus

Sulfur

Electrons

Atomic nucleus

Biological molecules

Carbohydrates

Lipids

Proteins or

DNA or

RNA

ATP

Cell parts

Nucleus

Cytoplasm

Mitochondria

Chloroplast

ER, Golgi complex

Energy pathways

Glycolysis

Fermentation

Krebs cycle

Electron transport chain

Light-dependent reactions

Light-independent reactions

Contents in Brief

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