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Frontispiece: Scanning electron micrograph of sea urchin sperm shortly after contact with the surface of the egg.
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PREFACE

Biology— Today and Tomorrow

This book arises out of our conviction that, in its recent cataclysmic evolution, the science of biology has come of age. And, as in all the races and societies of man, "coming of age" brings with it new privileges and new responsibilities. By any reckoning, the responsibilities loom large.

As biology comes of age, so must its teachers and students. Biology, like its sister sciences chemistry and physics, which are themselves rapidly becoming part of the warp and woof of biology, has immense potential for both good and evil. The almost overwhelming advances in biomedicine and biomedical engineering—the development of antibiotics and vaccines and the fashioning of artificial organs; and in agriculture—the emergence of hybrid corn and other crops and livestock to feed the world—will soon be dwarfed by advances we are just beginning to perceive. But with these advances come responsibilities for larger decisions that will inevitably shape the lives of future generations.

As this book is being completed, one of the debates in the Congress and in the Courts centers on determining the vital balance between the need for increased power, to be provided by atomic plants, and the protection of the environment from radioactive and thermal pollution. The question is being asked in all seriousness, "Is a little pollution a good thing?" Which organisms are favored by raising the temperature of the ocean? Given the need for more electricity, where in the political process—and on what

grounds—do we determine which is the lesser of two possible risks, radioactive and thermal pollution or pollution by the products of burning fossil fuels, products including cancer-causing hydrocarbons?

This question is related to another of great moment: The need for a vastly expanded program of cancer research. How does the public and its elected representatives determine whether the field of biomedicine is ready for a billion dollar a year program? How does it assess scientific evidence, especially when, as it so often happens, it is conflicting? Is there a conflict between “basic” and “relevant” research? Should we be preoccupied with “instant relevance?” How does information coalesce into ideas? How does research evolve into technological innovation? We know that for many innovations of great economic and social importance the “lag time” is long, measured not in months or years, but decades. One example, which we trace in Chapter 15, the oral contraceptive pill, required over sixty years of research in anatomy, physiology, systematic botany, and steroid chemistry, all of which would have come to naught but for the powerful stimulus of Margaret Sanger and other pioneers in the field of population control.

The atomic age was thrust upon a world unprepared for it. It is essential, we believe, that the impact of the biological revolution—its sweeping new concepts, its vast potential for technological advance, and its overwhelming social consequences—fall on “the mind prepared.”

Strides are being made in capturing the drama of today's biology, in showing its emergence as an experimental science, and in fostering the inquiring mind. But at the same time the barrier to public judgment and understanding of the subject is increasing as the tide of new facts flows endlessly.

Thus there is a constant need for distillation and synthesis. This book is our distillation of biology. We have tried to provide for the beginning student the essence of the subject. Clifford Grobstein put it well when he wrote, in *The Strategy of Life*, that “Like science in general, biology is rooted in the substantial and the material.” We have thus sought to convey the substantial and material facts about “life as external

reality.” But we have tried to convey more than selected facts and representative examples; we have tried to bring into focus the ideas of biology—their origin, testing and social impact.

We have paid serious attention to the social implications of biology. However our readers should not expect to find a single “catch-all” chapter on “social biology.” We find merit in discussing the social implications of a discovery in the context of other findings to which it is related. Thus aging and “cells out of control”—cancer and congenital defects—are considered together with the mechanisms regulating development; and sterility resulting from “V.D.,” and homosexuality and transvestism, are assessed against the background of the hormones in human reproduction. And so it goes: The origin of race and races is taken up as a question in population genetics, and pesticides and pollution are viewed in the context of environmental biology. Population control appears several times in our story, as seen through the eyes first of the reproductive biologist and then of the student of populations.

We have tried to make the book both timely and timeless. It is timely in the sense that new discoveries and insights are integrated into the text in sufficient depth to permit their full understanding. No subject has been ignored because it is distasteful or sensitive. At the same time, no subject is included just because “it always has been.” The test is always: Is the idea important to an understanding of today's and tomorrow's world? In this sense the book is timeless.

Although we hope that a large audience will find our book useful to read without relation to a formal course of study, it is intended to be a textbook for beginning students. We agree with the sentiment voiced by Loewy and Siekevitz in introducing their *Cell Structure and Function*, that it is the beginner who deserves an initial statement that is fully representative of the contemporary quality and mode of the field. Thus we do not distinguish among beginners. We believe our book will be useful to beginning students no matter what their previous training or academic “track” may be. As we see it, our book can stand alone as a textbook for a one-semester course meeting the requirements of non-majors (but when does one become irrevocably “fixed” as a

"non-biologist?"), or used in conjunction with paperbacks and other readings, as the text for a year's course for biology majors, whatever their preprofessional aims.

Our principal concern has not been the "package" or framework within which our readers will be receiving their training in biology. That responsibility rests with the instructor, who knows the background and experience and the motivations of his students. Rather, we have tried to convey the ideas of our subject, its spirit, and the sense of excitement surrounding it.

We have developed each topic gradually, but with sufficient rigor to make it meaningful no matter whether the instructor elects to follow the sequence we have chosen or whether he follows any one of several other equally valid routes to the same end.

For example, we have tried to offer an incisive treatment of cell regulatory mechanisms, leading up to a consideration of development and its controls, both the cell's inner controls and the environmental forces shaping development. We have worked hard to make topics which students traditionally find difficult, for example the electrochemical changes underlying the nerve impulse, clear and easy to remember. These key concepts are presented within the framework of a modern treatment of the nervous system and the physiological basis of animal behavior, including an analysis of the limbic system, motivation, learning, and the physiological effects of drugs.

Plants have been given major emphasis, with plant structure, function, diversity and development being treated extensively. In fact the sections on diversity of both animals and plants, with which the book is concluded, are, we believe, unique, recapturing the interest of natural history in a framework of modern comparative biochemistry, physiology and behavior.

The ideas of biology constitute an increasingly large part of our social heritage. More and more we are contemplating from whence we came. It was our late President, John F. Kennedy, who said: "All of us have in our veins the exact same percentage of salt in our blood that exists in the ocean, and therefore, we have salt in our blood, in our sweat, in our tears. We are tied to the ocean. And when we go back to the sea—

whether it is to sail or to watch it—we are going back from whence we came."

And the President might have added that in our embryonic lives we spend some time in that "other ocean," the fluid of the amnion.

Thus we ponder our origins and our place in the universe. Our understanding of the living world about us is ever changing, ever expanding. If we are to face the future with confidence, we must understand how our ideas are rooted in the past—and nourished and winnowed in the present. It is toward that end that we offer this book.

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CONTENTS

CHAPTER 1	
The Biological Revolution	1
Living matter uses energy and creates order	2
The brain, the hand, and the industrial revolution	5
The scientific revolution	9
Life turns on itself	10
Knowledge and action	12

PART ONE

The Cell **17**

CHAPTER 2	
The Unit of Life	18
A cell theory	19
The modern concept	22
Seeing is believing . . . and vice versa	23
The electron microscope	24
A "typical" cell	25
The membrane system of the cell	25
The cell interior	36
Cell organelles	39
Nucleus and cell division	42
The cell at work	47

CHAPTER 3	
From Generation to Generation	52
Heredity, the source of likeness and of variability	52
The behavior of chromosomes	53
The discrete nature of the gene	57
Genes come in groups	63
Genes interact with each other	68
Manifold effects of genes	68
Incomplete dominance	68
Multiple alleles	68
Interaction between alleles	69
Interaction between sets of different alleles	70

Modifying genes	70
Quantitative inheritance	70
Chromosomes determine sex	73
Gene groups are arranged in linear order	75
What is a gene?	80
Mutation	81
One gene, one enzyme	82
The chemistry of the gene	83
Haploid organisms and gene recombination	90
Genetics and man	90
Genetics and human society	92

CHAPTER 4

The Molecules of Life 95

Atoms, ions, and molecules	97
Water and life	103
The carbohydrates—Ready energy and protection	109
The lipids—High energy content and surface activity	116
Nucleic acids—Biological information storage, retrieval and transfer	119
Proteins—Specificity of structure and control	125

CHAPTER 5

The Flow of Molecules and of Energy 132

What is metabolism?	133
Enzymes—Catalysis and control	135
On entering the cell	137
From radiant energy to living matter	141
From food to fuel	145
How is metabolism studied?	153
The cell is not a bag of enzymes	154

CHAPTER 6

The Flow of Information 158

Enzyme specificity—The key to metabolic regulation	159
How the information is duplicated	160
How the message is transcribed	163
How the transcribed message is translated	164
The linear language folds itself into a three-dimensional structure	170
How large structures are formed from smaller ones	171
How the cell switches the production of enzymes on and off	173
How enzyme activity is regulated	175
How cellular structures might regulate metabolic activities	176

PART TWO

The Emergence of Form 179

CHAPTER 7

The Shape of Things to Come 181

The component processes of development	182
The embryo grows	182
Its cells specialize	183
The organism takes shape	184
How animals develop	186
Origin and maturation of germ cells	186
The sperm—Small and mobile	188
The indispensable egg	191
Egg and sperm unite	191
Cleavage—Partitioning the zygote	192
An egg in action	193
The cells are rearranged during gastrulation	194
Origins of the nervous system	195
Embryonic induction	196
An eye is formed	198
"Space capsules" for development	200
An inner "space capsule"	200
The course of human development	202
How a flowering plant develops	204
Origin of gametes and fertilization	204
A common pattern of embryo development	205
Summary	208

CHAPTER 8

Developmental Processes and Their Controls 210

The cell's inner controls	210
The nuclear control center	210
Genes in action	216
The cytoplasmic environment	221
Cellular interactions	225
The life history of muscle	226
Cells that recognize their neighbors	233
Environmental controls	235
Embryonic polarity	235
Meristems and the control of post-embryonic plant development	236
Photoperiodic effects	239
Senescence	240
Cell death in morphogenesis and senescence	241
Cells out of control	242
Congenital defects	243
Cancer	246
Summary	248

PART THREE

Why Organisms Behave As They Do

251

CHAPTER 9

The Versatile World of Microbes

253

Eucaryotes, procaryotes and viruses	253
The roles of bacteria in nature	254
Isolation of pure cultures	255
The procaryotic cell	255
Genetic material	256
The cytoplasm and ribosomes	258
The cell membrane	258
The cell wall	259
Flagella and fimbriae	260
Resting stages	261
Diversity of procaryotes	261
The major groups of procaryotes	262
Metabolism of bacteria	262
Phototrophs	263
Chemotrophs	264
The growth of bacteria	265
Replication and distribution of DNA	268
Metabolic control in bacteria	270
Viruses	272
Life history of a phage	273
Temperate phage and lysogeny	275
Plant and animal viruses	276
Sexuality of bacteria	276
Methodology of bacterial genetics	277
Conjugation	277
Transduction	280
Microbiology and medicine	281
Poliomyelitis—Conquest of a viral disease by mass immunization	282
Microbiology and industrial technology	282

CHAPTER 10

Plants—The Food Providers

284

Structure of a green land plant	285
Plant cells and cell walls	285
Plant tissues and organs	287
Structure of xylem and phloem	289
Plant organ systems	292

Structure and growth of a root— Making it underground	292
Structure and growth of a stem— Connecting roots and leaves	295
Cellulose and lignin—Paper and pollution	297
Photosynthesis—How leaves work	298
Importance of leaves	298
Carbon dioxide and the rate of photosynthesis	301
Polluted air	302
Light and photosynthesis— Shade plants versus sun plants	302
Moving chloroplasts around	303
Obtaining water and minerals— How roots work	303
Importance of soil—The good earth	303
Hydroponics	304
Essential elements— The salt of the earth	304
The root system and water absorption	306
Water absorption— Root hairs and "fungus roots"	307
Diffusion and osmosis	309
Turgor pressure	310
Transport of water and food— How stems work	312
Root pressure and transpiration— Up the stem with water	312
Transport of food— Down and up the stem with sugar	313
Using aphids to measure phloem transport	313
Mechanism of phloem transport	314
Integrating plant activities by regulating growth—Plant hormones	314
Auxins and phototropism	315
How auxins stimulate cell enlargement	317
Inhibitory effects of auxins	317
Auxin effects on fruit growth and abscission	318
Auxin effects on organ formation	319
Auxins in weed control	319
Gibberellins	320
Cytokinins	321
Ethylene	322
Abscisic acid	323
Hormonal interactions	323
Plant growth regulators and human affairs	323

CHAPTER 11

The Mobile Animals 325

An approach to the study of animal function	326
An emphasis on man and the vertebrates	327
Basic body plans	327
Skin	330
Human skin	330
Other skins	332
The skeleton	334
The human skeleton	336
The insect skeleton	340
Muscle	341
Movement without muscles	341
Structure of muscle cells—	
Fibrous cells and fibrous molecules	342
How muscles move things	344
Activation of muscle cells	345
Regulation of degree of contraction	347
Cardiac muscle and some other special muscles	349

CHAPTER 12

Food and Energy for the Animal Way of Life 351

Nutrition	352
A complete diet—Wool, wood, milk or fish	352
Nutritional requirements of man	352
Feeding mechanisms	355
Digestion	357
Human digestive system	357
Digestion in other vertebrates—	
Some specializations	362
Digestion in insects	363
The breath of life	364
Human respiratory system	365
Transport of oxygen and carbon dioxide	366
Control of respiration	367
Some problems in human respiration	367
Air pollution	368
Respiration in vertebrates other than man	370
Respiration in insects	373
Moving the blood	374
The human circulatory system	375
Diseases of the human circulatory system	384
A second circulatory system—	
The lymphatic system	385
Some other circulatory systems	386
Regulating the water supply	387
Human excretory system	387
Kidney diseases	390
Osmoregulation and excretion in some other vertebrates	390
Osmoregulation and excretion in insects	392
Osmoregulation in vertebrates—	
A second look	393

Temperature regulation	393
Temperature regulation in homeotherms	394
Temperature regulation in poikilotherms	396

CHAPTER 13

Controlling the Animal Way of Life—The Nervous System 400

Nervous control systems	401
Structure of nerve cells	401
True nerve cells	401
The supporting cast—Glial cells	404
How nerve cells function	405
Conduction of nerve impulses	405
Rate of impulse conduction	407
The neural language	408
Synapses	408
The human nervous system	410
How nerve cells are arranged	410
The central nervous system—Spinal cord	411
The emerging importance of the brain	413
Autonomic nerves	414
Receptors and sense organs	416
Decoding the sensory message	418
Sensations	419
How receptors work	420
Adaptation	420
Major sense organs of man	420
The central nervous system—The brain	421
Hindbrain—The medulla	424
Hindbrain—The cerebellum	425
Midbrain	426
Forebrain	427
Drugs and the brain—A two-edged sword	430
Evolution of nervous systems	432
Nerve nets	432
Flatworm nervous systems	433
Insect nervous systems	434

CHAPTER 14

Animal Behavior 438

The survival value of behavior	438
Built-in behavior—Reflexes and instincts	439
The role of environment in the development of behavior	441
Biological clocks	442
Motivation	444
Learning	445
Memory	448
Some patterns of animal behavior	449
Social behavior	449
Migration, homing and orientation	451
Human behavior—Some prospects	453

CHAPTER 15**The Hormones In Human Reproduction 454**

Reproduction—The general scheme	454
Why sex?	456
The reproductive system in the human female	457
The ovary as timepiece	458
A description of menstruation	461
The reproductive system in the human male	462
Sex hormones and human behavior	462
Mechanism of sex hormone action	464
Hormones, receptors and second messengers	464
Prostaglandins	466
Conception and contraception—Population control	467
Coitus	467
The “safe period”	469
Birth control methods	469
How the “Pill” was developed	470
Sterility and venereal disease	471
Homosexuality and transvestism	474

CHAPTER 16**The Web of Life 476**

Time and succession	477
Nature's machinery	479
The cycle of nutrients	480
Limiting factors	483
The flow of energy	483
The importance of primary producers	485
Ecosystems of the world	486
The seas	487
Seashores and estuaries	488
Rivers and streams	489
Lakes and ponds	490
Freshwater marshes	490
Deserts	490
Tundra	491
Grasslands	492
Forests	492
Order in diversity	493

CHAPTER 17**Ecology and Man 494**

Human population growth	495
Doubling time	496
The demographic transition	498
The quality of human life	498
Hunters, food gatherers, and agriculturalists	500
Ecosystem diversity and stability	500
Control by chemicals	501
Toward a balance	503

PART FOUR**Populations 505****CHAPTER 18****Evolution In Action 507**

Industrial melanism	507
Sources of variation	510
No selection, no evolution	510
Sequential evolution	511
The modern view	513

CHAPTER 19**Races and Species 514**

The Galapagos archipelago	514
Darwin's finches	516
Geographic isolation	518
Isolating mechanisms	519
Character divergence	521

CHAPTER 20**The Origin of Life 524**

Origin of the solar system	525
Evolution of the earth's atmosphere	525
Primitive earth—Its temperature and energy sources	525
The earliest fossils	526
Laboratory studies	528
Polymer synthesis	529
Biological organization	529
Origin of eucaryotes—Symbiosis and evolution	531
Spontaneous generation	532
The search for extraterrestrial life	532

CHAPTER 21**Cataloging Nature 534**

Understanding diversity	535
Who is related to whom—Homology provides the key	535
The problem of convergence	537
Clues from reproduction and early development	538
Clues from the electron microscope, chromosomes and behavior	538
Clues from biochemistry—Molecular taxonomy	539
Clues from newly discovered organisms	541
Fragile family trees—Phylogenies	541
How to catalog organisms	544
A vocabulary for classification	545

Some problems of systematics	547
Systematics in the service of man	549
The kingdoms of organisms	550

CHAPTER 22

Unfolding Diversity 553

The fossil record	554
Timespans of the earth's history	555
Early life	557
The Paleozoic era	557
The appearance of marine invertebrates	558
The first land plants	558
Primitive landscapes	559
Animal life on land	559
The age of fishes	560
Early amphibians	561
The rise of reptiles	562
The Mesozoic era	562
The flowering plants	562
The age of reptiles	563
The first birds	563
Early mammals	565
The Cenozoic era	565
The age of mammals	565
Modern mammals	566

PART FIVE

The Diversity of Life 569

CHAPTER 23

Plants 571

The "double life" of a plant—	
Alternation of generations	572
Algae—The grass of many waters	575
Green algae—Division Chlorophyta	576
Love thy neighbor—Algal symbioses	580
Plentiful food—Divisions Chrysophyta	
and Pyrrophyta	580
Seaweeds—Divisions Phaeophyta and	
Rhodophyta	584
Fungi—The filamentous way of life	588
Water molds and bread molds—	
Classes Oomycetes and Zygomycetes	589
Sac fungi—Class Ascomycetes	590
Lichens—Collective security	591
Club fungi—Class Basidiomycetes	592
Sexless fungi—Class Fungi Imperfecti	595
Slime molds—Division Gymnomycota	595
Invading the land	596
Mosses and Liverworts—	
Division Bryophyta	597
Vascular plants—Division Tracheophyta	600

Primitive vascular plants—	
Subdivision Psilopsida	602
Club mosses—Subdivision Lycopsidea	602
Horsetails—Subdivision Sphenopsida	602
Ferns—Subdivision Pteropsida	604
Seed plants—Subdivision Spermopsida	607
Importance of seeds	607
Conifers and their relatives—	
The gymnosperms	608
Flowering plants—Class Angiospermae	613
Secrets of success	613
What is a flower?	613
Teaming up with insects—	
Improved pollination	615
Fruit peddling—Improved	
distribution of seeds	619
Plant parenthood—Double fertilization	619
Nonwoody plants	620
The fast life of a flowering plant	620
The development of resistance to	
drought and cold	620
Genetic flexibility	621
Two subclasses—Dicots and monocots	621
The importance of flowering plants to man	622

CHAPTER 24

Animals 625

Major trends in animal evolution	627
Phylum Protozoa	627
Simplest protozoans—Class Flagellata	629
Amoebas and their relatives—	
Class Sarcodina	630
Malarial organisms and their kin—	
Class Sporozoa	632
The ciliates—Class Ciliata	634
Sponges, filters of the ocean—	
Phylum Porifera	636
Hydras, jellyfish, corals—	
Phylum Coelenterata	639
Classes of coelenterates	641
Ancestors and descendants of the coelenterates	645
Flatworms—Phylum Platyhelminthes	646
Planarians—Class Turbellaria	647
The road to parasitism	647
Flukes—Class Trematoda	649
Tapeworms—Class Cestoda	650
Ribbon worms—Phylum Nemertinea	650
Two routes to one-way traffic	651
Roundworms and others—	
Phylum Aschelminthes	653
Earthworms, leeches, and marine worms—	
Phylum Annelida	655
The significance of segmentation	658
Snails, clams, and squids—	
Phylum Mollusca	659

Chitons—Class Amphineura	661
Snails—Class Gastropoda	661
Bivalves—Class Pelecypoda	663
Squids and octopods—Class Cephalopoda	663
Evolutionary origins of mollusks	666
A link to the arthropods—	
Phylum Onychophora	666
A brief lesson in animal geography	667
Insects, spiders and crustaceans—	
Phylum Arthropoda	668
Some evolutionary trends in the arthropods	670
Crabs, lobsters, and shrimps—	
Class Crustacea	670
Spiders and their kin—Class Arachnida	675
Insects—Class Insecta	679
Kinships among the arthropods	688
A possible crossroad—Lophophorate phyla	689
Starfishes, sea urchins and sea lilies—	
Phylum Echinodermata	690
Chordate characteristics	693
Sea squirts and amphioxus—	
Invertebrate chordates	694
The origin of chordates and vertebrates	696
Animals with backbones—	
Subphylum Vertebrata	698
Fishes—Superclass Pisces	699
Newts and frogs—Class Amphibia	703
Turtles, snakes, lizards, and crocodiles—	
Class Reptilia	705
Birds—Class Aves	707

Porpoises, pangolins, and people—	
Class Mammalia	712
Some afterthoughts on kinships and success	717

CHAPTER 25

Mankind Evolving	719
Man as an animal	720
Prosimians—The first primates	722
“Improved” primates—The monkeys	722
Anthropoid apes	723
The first toolmaker	725
Early wanderers	726
The man who became extinct	727
The races of modern man	730
The origin of the races	732
Is man still evolving?	732

Glossary	735
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Appendices	763
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Credits and acknowledgments	773
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Index	778
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CHAPTER 1

- 2 Living matter uses energy and creates order
- 5 The brain, the hand, and the industrial revolution
- 9 The scientific revolution
- 10 Life turns on itself
- 12 Knowledge and action

The Biological Revolution

Three billion years ago life began on this planet. Whether it arose spontaneously from nonliving matter or was seeded by spores from a distant corner of the universe we do not as yet know. What followed, however, is becoming a well-chronicled drama, a sweep of accelerating events which has transformed our planet from a lifeless rock reflecting the rays of the sun to an intricate, teeming, minutely balanced living world in which the sun's energy and the materials of the earth are continually converted into the multitude of structures and processes of life.

This wonderful and complex planet of ours may not appear so very unusual to a spaceship approaching it from afar—to an astronaut 100,000 miles away the earth is but a small body spinning through space at 66,600 miles an hour, one of a group of nine planets circling in their orbits about the sun. In physical terms the earth is not especially remarkable; it is surrounded by a gaseous envelope, the atmosphere. It has a diameter of approximately 7900 miles and a circumference of about 25,000 miles. Its surface area of nearly 200 million square miles is about one-third land and the rest water. It has an inner solid core and a molten outer core, enclosed in a rocky mantle that extends to the earth's surface. However, what makes the earth unique in our solar system is that everywhere on its surface, on land, in its rivers, in its lakes and oceans, and for large distances

into the atmosphere, there is *life*. And within this envelope of life that we call the **biosphere**, man is only one of a remarkable variety of organisms that have adapted to almost the entire range of physical conditions found on earth.

The highest human settlement in the world is in Chile at an altitude of 5700 meters (18,700 feet). Most humans would be starved for oxygen at this altitude and would be dizzy, weak, and unable to work. However, a few people and many species of animals have adapted to these high altitudes. Beetles live in the highest meadows of the Himalayas, earthworms are found at the extremes of cold and altitude at the snow line of the Andes, and eagles and vultures soar as high as 7000 meters.

At another extreme, marine animals have been collected from 10,500 meters below the ocean's surface at pressures of one ton per square centimeter; we will undoubtedly find living organisms at even greater depths when we have devised suitable apparatus for collecting them.

The lowest air temperature (-88°C) was recorded in Antarctica in 1960. Temperatures almost this low have also been recorded in the Yukon Territory of Canada on several occasions, and the plants and animals of the Arctic are obviously capable of surviving at temperatures this low and probably lower. More remarkably, the green alga *Chlorella*, a single-celled plant, has been frozen to -182°C and survived, and dry seeds of plants have germinated after three weeks in liquid air at -190°C . At the other extreme of temperature blue-green algae and certain bacteria live in hot springs (such as those in Yellowstone Park) at temperatures only 12 degrees centigrade below the boiling point of water.

Life is remarkable for reasons other than adaptability. The sweep of evolution has given rise to living systems which are increasingly able to control the conditions under which they live and thus escape the constraints and the capriciousness of their physical surroundings. Thus, for instance, while some organisms developed spores, eggs, or seeds which are able to survive drought or extreme cold, others evolved **warm-bloodedness** and thereby extended their range of life activities beyond that of their ancestors.

Man is a new arrival on this earth (Fig. 1-1);

yet through the coupled evolution of his hand and his brain, the stage is now set for ever-increasing control of the arbitrary constraints of our environment to a degree which is still almost unimaginable. But before attempting to evaluate the magnitude and consequences of this *biological revolution*, we must ask ourselves how evolution—the upward sweep of the history of life on our earth—could have occurred, how living matter (more than other physical matter) is endowed supremely well with this ability to evolve.

LIVING MATTER USES ENERGY AND CREATES ORDER

There is a law of physics, the *second law of thermodynamics*, which asserts that **systems** in isolation “run down.” Let us explain what we mean by “isolation” and by “running down,” for the second law is an elusive concept unless one understands the meaning of each of its components in very concrete terms.

The most important concept of thermodynamics is energy, which is defined as the ability to do work. The word work has a familiar, everyday ring to it: we all have a feeling for what it is to do work and we all know that one needs energy to perform it. The work with which we are most familiar is mechanical work in which a force moves a mass through a given distance. But there are other forms of work along with their respective forms of energy. Electrical work can be performed by the expenditure of electrical energy, chemical work by chemical energy and so on. Furthermore, these various forms of energy are interconvertible so that chemical energy, for instance, can be transduced into mechanical energy and even vice versa. Living matter is particularly effective in performing energy transductions: our muscles convert chemical energy to mechanical energy that results in movement; when a firefly flashes its signal, it converts chemical energy to light energy; an electric eel converts the chemical energy stored in its “batteries” to electrical energy; the human eye converts light energy to chemical energy and then to electrical energy. Cells, the basic units of which all living organisms are composed, are specialists in converting one form of energy to another.

The important thing to recognize about these various forms of energy is that when they interconvert, they do so quantitatively, that is, without any energy being created or destroyed in the process. This is what the *first law of thermodynamics* states and numerous experiments have demonstrated that this law is obeyed just as scrupulously by living matter as it is by the heat engines investigated by the early students of thermodynamics.

To establish the first law, the systems under investigation had to be isolated from their environment so that no energy flowed between them and their environment. It was soon discovered that such isolated systems "ran down," that is, their ability to perform work decreased as work was being performed by them. The second law of thermodynamics was able to explain this important observation by distinguishing between **free energy** (G) and **enthalpy** (H) and showing how these two properties of matter are related to each other.

Free energy is that portion of the energy of a

system which is able to perform work. When an isolated system performs work, the free energy of the system decreases. The enthalpy is the energy given off or absorbed and can be measured directly in an isolated system by the change in temperature which the system experiences. By studying heat engines it was soon discovered that free energy and enthalpy are not necessarily directly related to each other. That is, the loss of free energy during the performance of work by an isolated system is not necessarily equal to the increase in enthalpy associated with the process. It turned out that another term is involved in the equation. This term consists of two other properties of matter, one of which is the **absolute temperature** which is measured in Kelvin units. The other property is the **entropy**, which is related to the state of orderliness or organization of the system. The higher the state of organization, the lower is the entropy. The second law states that when a system performs work it runs down not only because the free energy decreases but because the entropy, its state of disorganization,

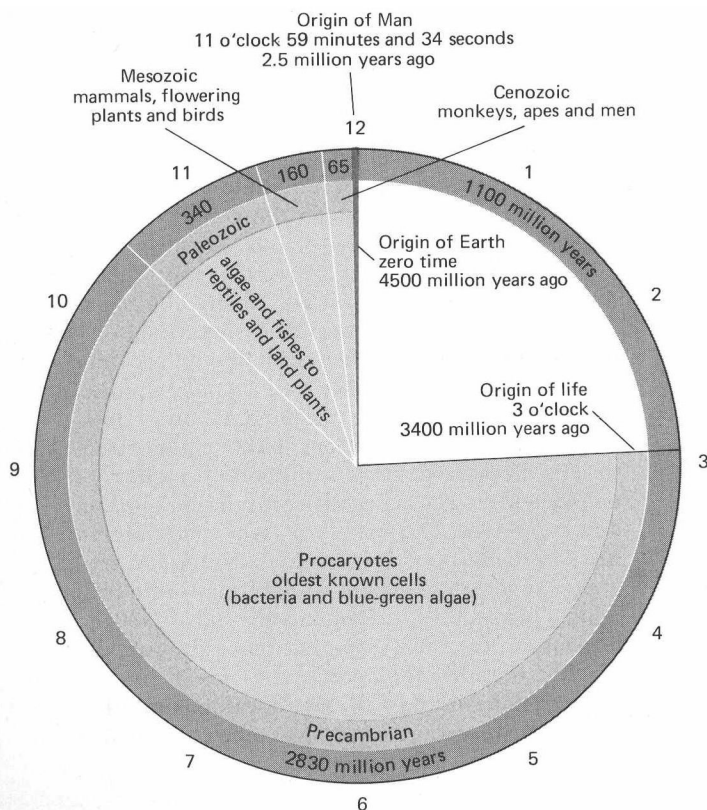


Figure 1-1 Man is a new arrival on the earth. If the age of the earth were 12 hours, then man has been on the scene for only 26 seconds. Notice how the pace of evolution accelerates, how the evolutionary periods become shorter and shorter.