THE SCIENCE OF BIOLOGY

BEAVER

FOURTH EDITION

INSTRUCTOR'S COPY

Compliments

of

THE C. V. MOSBY COMPANY

NEW YORK, N. Y. — SAN FRANCISCO, CAL.
ST. LOUIS, MO.

SENT AT THE REQUEST

OF

MR. FRANK A. VOLK

Your opinion of this book will be appreciated when your review of it has been completed.

THE SCIENCE OF BIOLOGY

THE SCIENCE OF BIOLOGY

By

WILLIAM C. BEAVER, Ph.D.

Head of the Department of Biology, Wittenberg College,
Springfield, Ohio

With 375 Text Illustrations

FOURTH EDITION

ST. LOUIS
THE C. V. MOSBY COMPANY
1952

Third Edition Reprinted

November, 1946
June, 1947
November, 1948
February, 1951

Printed in the
United States of America

Press of
The C. V. Mosby Company
St. Louis

To

MARY MATZ BEAVER

PREFACE TO FOURTH EDITION

Numerous changes have been made throughout this revision. Material has been rearranged for better organization and presentation, and additions and deletions have been made in the light of the needs in various courses as presented. A wide selection of material is given so that a proper balance can be secured in the various courses. Many of the benefits of a course in biology are to be derived from a laboratory or field study of the phenomena of living organisms. Consequently, it seems that a textbook in such a science should make available those pertinent facts which will assist the instructor to help the student to help himself to understand these phenomena better and to develop the many attributes of scientific study, including the scientific method. The instructor must attempt to initiate and maintain in the student a curiosity and fundamental interest in the phenomena of the living world. Through proper techniques and constant practice, the student should develop a method of working and thinking whereby he is able to formulate logical conclusions from scientifically observed and recorded data. He should become familiar with the technique of proving important principles for himself rather than merely reading about them or being told about them. The student should ascertain the facts, and with a minimum of help from the instructor, he should formulate his own conclusions and prove the more important principles based on the scientific interpretation of his collected facts and data.

A textbook is not intended to be a book of entertainment, and illustrations are not included necessarily for beauty or esthetic purposes but to assist the student to gather and evaluate facts scientifically. The joy and entertainment come from scientific discovery of new facts and phenomena with which he may not have been familiar. The joy and satisfaction of learning anything new is an essential basis upon which profitable educational progress is built.

Pronunciations and derivations of terms are more widely considered than in previous editions in order that the student may understand biologic terminology better and increase his command of the English language. Numerous topics have been presented in tables so that facts may be learned easily and compared and contrasted with other facts. A new classification of plants is used since it is based on more natural plant relationships, but a contrast with the older method is given in the Appendix. Several new illustrations are included and several others have been revised. Questions and Topics are added at the ends of the chapters to assist the student in testing himself as well as to guide him in his study. Selected References are included for additional reading in case it is deemed necessary. The glossary is extended to include many of the new materials and principles treated in the text.

To acknowledge all persons who have made contributions toward improving the text would make a prohibitive list. Consequently, the author shall limit his acknowledgments to his immediate colleagues, Professors E. T. Bodenberg, C. A. Brand, and Evelyn Wagner Neal, whose contributions are greatly appreciated. Permission to reproduce numerous illustrations from various sources are acknowledged in connection with each one. The author is indebted to Charles A. Brand and Gerald R. Bradford for certain new illustrations and for corrections in others. The Table of Contents is given in some detail so that the student may derive a certain degree of orientation and the instructor may be guided in placing major emphasis on certain topics. Justification for the somewhat extensive treatment of the various phases of plant and animal biology is based on presumption that one must understand somewhat the various parts of the science of biology in order to comprehend more completely any particular portion of it. The human implications of biology have been presented without attempting to make of this a text in human anatomy, physiology, or psychology.

William C. Beaver

Wittenberg College
Springfield, Ohio

PREFACE TO FIRST EDITION

If an attempt were made to include in a textbook much of the information accumulated in the field of biology, the beginning student would have difficulty in properly selecting the important parts as well as properly visualizing and retaining the fundamentals as he should. This book is written with the hope that it will be of greater service to the instructor and the student by presenting the more important biological facts briefly enough to permit a complete comprehension of the subject as a whole and also to serve as a skeleton to which such additional data may be added as seem desirable. An attempt is made to systematize and condense our biological knowledge so that it can be more easily taught, visualized, and mastered.

Particular attention is called to the following features: (1) Greater emphasis is placed on the economic importance of animals and plants. (2) A generalized discussion of the location and functions of the important ductless (endocrine) glands, especially in man, is included. (3) A comparative study of the ten systems of twenty-eight representative animals, including man, is made in Chapters IX to XVIII. The method of presentation permits the study to be made either on a comparative basis or by studying the various systems of a particular animal by selecting the proper parts of each of these chapters which deal with the animal being studied. This method of presentation better illustrates the general principles of the science as well as the unity and various relationships within the biological world and gives the student the opportunity of basing his conclusions and formulating his principles upon the study of representative animals. (4) A comparative study of the various structures and functions of fifteen representative plants is made in Chapters XXIV to XXIX. These plants may be studied on a comparative basis, or the proper parts of each of these chapters may be used in studying the plants in the usual manner. (5) A detailed reference list of illustrations and drawings in other texts will be of service to the student in his attempt to understand certain points. (6) The general consideration of the phyla of animals and plants includes their general characteristics, a brief but satisfactory classification, and a summary of the number of species in each phylum. (7) A consideration of the more important types of the various orders of insects, including a simple key for the identification of such forms with which the beginning biology student might wish to become familiar, is given. (8) A summary of the metamorphosis and life cycles of various types of animals and plants is given to acquaint the student with this very important phase of the living world. (9) The embryologic development of animals is illustrated by the frog because such demonstration materials are inexpensive and easily secured. (10) The more important theories, laws, and facts of heredity are discussed, with examples from the plant, animal, and human fields. (11) A survey of representative animals of the past and their records is made; a study of geographical distribution of present-day animals in space, a survey of animal and plant ecology, and a summary of the science of paleobotany are included. (12) Living organisms are discussed as to their origins, continuity, development, variations, and descent with change. (13) There are pertinent discussions of the properties of living protoplasm, the structures and functions of various cells and tissues, the process of cell division in animals and plants, the differences between living and nonliving materials, and the fundamental differences between living animals and plants. (14) There is a comprehensive summary of the embryologic origin, distinguishing characteristics, and functions of the epithelial, connective, muscular, and nervous tissues of animals. (15) A history of the development and progress in the field of biology includes many contributions made by earlier workers in the science. (16) A list of pertinent questions and topics is found at the end of the chapters to teach the student to summarize his knowledge, to more completely emphasize the important points, and to stimulate the beginning student to do some original thinking. (17) Sufficient emphasis is placed on the structures and functions of the human body to be of value to students of physical education, preprofessional students, and the general student who may or may not take special courses in human anatomy and physiology. (18) A separate chapter summarizes the more important theories and principles of biology. From this the student may easily review and retain those generalizations which will be of greatest use in his future activities. (19) A special consideration is made of the application of biology in various fields in order to show the contributions which this science has made in the past and to suggest its applications in the future. (20) A separate chapter is devoted to photosynthesis. (21) An appendix includes: (a) important prefixes and suffixes frequently used in biology by means of which the student may readily acquire his necessary biological vocabulary; (b) methods for starting and caring for a balanced aquarium which may be applied in the care of out-of-door pools; (c) directions for collecting, preserving, and mounting insects, which may be profitably continued long after a formal course in biology is completed; (d) a glossary which includes the derivation and definitions of the important terms used in biology.

The essentials of biology are so arranged as to permit an easier and more effective mastery of the fundamentals. In brief, the book is designed to "help the instructor help the student to help himself." Zoological phases of the text may be emphasized more than the botanical, or the latter may be reduced to a minimum to suit the type of course. The author believes that beginning students in biology should become familiar with both plant and animal fields because a majority of them will not take specific courses in both fields. With the proper foundation in both fields, those who desire may take specific courses in either zoology or botany or both. The author is also of the opinion that the principles of biology best can be learned by a rather careful study of well-selected types of animals and plants. This conclusion is the basis for the variety of animal and plant types considered. The variety is sufficiently great as to permit the instructor to select those which best fit the needs of the course as it is being offered.

No attempt can be made in a work of this type to give due credit to the many sources of information which through many years of common use actually have become a part of the science. Cordial thanks are extended to the authors, publishers, colleagues, and students who in various ways have supplied the necessary materials and suggestions for such a work as this. Special acknowledgments are made to Dr. E. T. Bodenberg, Dr. C. G. Shatzer, Dr. C. A. Lawson, Dr. J. W. Barker, Professor R. P. Thomas, and Professor B. B. Young for their many helpful suggestions; and to Miss Adrien Jingozian for preparing Figs. 95, 95A, 96, and 132; to Dr. O. L. Inman, of the C. F. Kettering Foundation for the Study of Chlorophyll and Photosynthesis, for his many helpful suggestions in Chapter XXXVIII; and to many others who directly or indirectly have helped in various ways.

William C. Beaver

Wittenberg College
Springfield, Ohio

CONTENTS

PART I

INTRODUCTORY BIOLOGY

CHAPTER PAGE

1. The Science of Biology and the Scientific Method 17
   - Why Study Biology 17
   - How to Study Biology 19
   - The Scientific Method 20
     - The Clear Recognition and Accurate Statement of the Problem to Be Solved 21
     - The Formulation of Working Hypotheses Which Appear to Explain the Problem and the Suggestion of Methods of Investigation 22
     - The Accurate Collection and Recording of Pertinent Data 23
     - The Formulation of Logical Conclusions by the Scientific Analysis and Correct Interpretation of the Data and Facts 23
   - The Science of Biology and Its Subdivisions 24
2. Microscopes—Early and Present Day 27
3. Cells and the Cell Principle 37
   - The Cell Principle and Its Importance 37
   - Detailed Structure and Functions of Cells 39
4. Cellular Organization of Plants and Animals—Animal and Plant Tissues 46
   - Animal Tissues 46
     - Kinds of Animal Tissues 46
       - Epithelial Tissues 47
       - Connective (Supportive) Tissues 49
       - Muscular (Contractile) Tissues 53
       - Nervous Tissues 54
     - Parts of the Nervous System 54
   - Plant Tissues 55
     - Kinds of Plant Tissues 56
       - Meristematic 56
       - Epidermal 56
       - Parenchyma 56
       - Collenchyma 56
       - Schlerenchyma 59
       - Cork 59
       - Xylem 59
       - Phloem 60
   - Organs 60
   - Systems 60
5. How Cells Divide—Indirect Cell Division or Mitosis (Animal and Plant) 62
   - Mitosis in Animal Cells 62
   - Mitosis in the Cells of Flowering Plants 66
   - Important Facts Regarding Mitosis 70

CHAPTER PAGE

6. PROPERTIES AND ACTIVITIES OF LIVING PROTOPLASM — 73
Physical Properties of Protoplasm — 73
Theories Regarding Physical Structure — 74
Colloidal Systems — 75
Matter, Atoms, Molecules, and Elements — 78
Chemical Composition of Protoplasm — 84
Glucides (Including Carbohydrates) — 86
Lipids (Including Fats) — 87
Proteins — 88
Mineral (Inorganic) Salts — 89
Water — 90
Vitamins — 90
Enzymes — 91
Metabolism, Autosynthesis, Autocatalysis — 92
Growth, Assimilation, and Differentiation — 94
Reproduction — 96
Adaptation and Irritability — 96
Organization and Individuality — 97
Regeneration — 98
Living and Nonliving Things Contrasted — 99

7. LIVING PLANTS AND ANIMALS CONTRASTED — 104

PART 2

PLANT BIOLOGY

8. SURVEY OF THE PLANT KINGDOM — 108
Classification of Plants (Kingdom Plantae) — 109
Number of Species of Plants (Kingdom Plantae) — 110
Summary of Distinguishing Characteristics of Plants (Kingdom Plantae) — 111
Subkingdom Thallophyta — 111
General Characteristics of Thallophytes — 111
General Characteristics of Algae — 112
Phylum Cyanophyta — 113
Phylum Chlorophyta — 114
Phylum Chrysophyta — 116
Phylum Phaeophyta — 116
Phylum Rhodophyta — 118
General Characteristics of Fungi — 119
Phylum Schizomycophyta — 120
Phylum Myxomycophyta — 122
Phylum Eumycophyta — 124
Subkingdom Embryophyta — 129
General Characteristics of Embryophytes — 129
Phylum Bryophyta — 130
Phylum Tracheophyta — 133

9. SIMPLE PLANTS WITH CHLOROPHYLL—ALGAE — 150
General Characteristics of Thallophytes — 150
General Characteristics of Algae — 151
Blue-Green Algae (Phylum Cyanophyta) — 151
Gleocapsa — 152
Oscillatoria — 152
Nostoc — 154
Anabena — 155

CHAPTER		PAGE
	Green Algae (Phylum Chlorophyta)	155
	Chlamydomonas	156
	Protococcus	157
	Spirogyra	157
	Ulothrix	157
	Desmids	159
	Yellow-Green Algae, Golden-Brown Algae, and Diatoms (Phylum Chrysophyta)	159
	Diatoms	159
	Brown Algae (Phylum Phaeophyta)	160
	Laminaria	161
	Fucus	161
	Red Algae (Phylum Rhodophyta)	162
	Nemalion	164
	Polysiphonia	164
10.	SIMPLE PLANTS WITHOUT CHLOROPHYLL—FUNGI	167
	General Characteristics of Fungi	167
	Bacteria (Phylum Schizomycophyta)	168
	Slime Molds (Phylum Myxomycophyta)	172
	True (Higher) Fungi (Phylum Eumycophyta)	173
	Class Phycomycetes	173
	Black Bread Mold	173
	Water Mold	173
	Class Ascomycetes	175
	Penicillium	175
	Aspergillus	175
	Cup Fungus	176
	Yeasts	176
	Mildews	177
	Blights	177
	Class Basidiomycetes	177
	Mushrooms	177
	Bracket Fungi (Pore Fungi)	179
	Smuts	179
	Rusts	181
11.	MOSSES AND THEIR ALLIES—BRYOPHYTES (PHYLUM BRYOPHYTA)	185
	General Characteristics of Bryophytes	185
	True Mosses	186
	Polytrichum	186
	Sphagnum	187
	Liverworts	188
	Marchantia	188
	Porella	189
12.	FERNS AND THEIR ALLIES	191
	General Characteristics of Ferns and Their Allies (Club "Mosses" and Horsetails)	191
	Club "Mosses"	192
	Lycopodium	192
	Selaginella	193
	Horsetails (Scouring Rushes)	194
	Equisetum	194
	Ferns	195
	Pteridium	195
	Polypodium	198

CHAPTER PAGE

13. Gymnospermous Plants—Conifers and Their Allies — 200
    - General Characteristics of Gymnosperms — 200
    - Conifers — 201
        - Pine Tree — 201
    - Cycads (Sago Palms) — 203
        - Zamia — 203

14. Angiospermous Plants—Flowering Plants — 206
    - General Characteristics of Angiosperms — 206
    - Indian Corn (Zea mays) — 209
    - Garden Bean (Phaseolus) — 211
    - Sunflower (Helianthus) — 213

15. Biology of Higher Plants—Anatomy and Physiology — 219
    - The Root — 219
        - General Regions — 219
    - The Stem — 222
        - Study of a Stem of a Dicotyledonous Plant — 222
        - Study of a Stem of a Monocotyledonous Plant — 222
    - The Leaves — 223
    - The Flower — 224
    - Absorption by Plants — 226
        - Water — 226
        - Inorganic Salts — 226
    - Transpiration by Plants — 226
    - Conduction of Liquids — 227
    - Manufacture, Distribution, and Storage of Foods by Plants — 227
        - General Consideration of Photosynthesis — 228
        - Theories and Early Work on Photosynthesis — 231
        - Biochemical Aspects of Photosynthesis — 232
        - Biophysical Aspects of Photosynthesis — 233
        - Influential Factors in Photosynthesis — 234
        - Applied and Commercial Aspects of Photosynthesis — 237
    - Respiration by Plants — 239
    - Correlation and Plant Hormones — 239
    - Growth of Plants, Polarity, Morphogenesis — 241
    - Plant Tropisms (Reactions) — 242
    - Plant Pigments — 243

16. Economic Importance of Plants — 249
    - Economic Importance of Algae — 249
    - Economic Importance of Fungi — 250
    - Economic Importance of Bryophytes — 256
    - Economic Importance of Ferns and Their Allies — 256
    - Economic Importance of Gymnosperms — 257
    - Industrial Plants — 257
        - Fuels — 258
        - Oils — 259
        - Plant Fibers — 260
        - Cork — 261
        - Woods — 261
        - Gums and Resins — 262
        - Coloring Matters (Dyes) — 263
        - Foods — 264
        - Beverages — 264
        - Flavoring Substances — 266
        - Spices — 266
        - Savory Substances — 267
        - Medicines and Poisons — 267

PART 3

ANIMAL BIOLOGY

CHAPTER	PAGE
17. Survey of the Animal Kingdom	272
Phylum 1—Protozoa	274
Phylum 2—Porifera	279
Phylum 3—Coelenterata	286
Phylum 4—Ctenophora	291
Phylum 5—Platyhelminthes	293
Phylum 6—Nemathelminthes	295
Phylum 7—Trochelminthes	297
Phylum 8—Echinodermata	299
Phylum 9—Annelida	304
Phylum 10—Mollusca	309
Phylum 11—Arthropoda	314
Phylum 12—Chordata	325
18. Unicellular, Microscopic Animals (Phylum Protozoa)	344
Amoeba	344
Paramecium	349
Euglena	357
Volvox	360
Plasmodium	363
19. Flatworms and Roundworms (Phylum Platyhelminthes and Phylum Nemathelminthes)	368
Planaria (Dugesia)	368
Liver Fluke	373
Tapeworm	377
Ascaris	379
20. A Segmented Worm—Earthworm (Phylum Annelida)	384
21. Common Insects—Grasshopper and Honeybee (Phylum Arthropoda; Class Insecta)	393
Grasshopper	393
Honeybee	398
22. Identification and Classification (Taxonomy) of Insects	409
No Metamorphosis	410
Incomplete Metamorphosis	411
Orders of the Class Insecta (Insects) of the Phylum Arthropoda	414
Gradual Metamorphosis	419
Complete Metamorphosis	419
23. The Frog—An Amphibious Vertebrate Animal	421
24. Embryologic Development of Animals	442
Ontogeny; Phylogeny; Recapitulation (Biogenetic) Theory; Morphogenesis	442
Embryology of the Frog	444
Embryology of Man (Mammal)	450
25. Biology of Man	458
General Organization of the Human Body	458
Integument (Skin) and Skeleton	459
Motion and Locomotion in Man	467
Foods and Nutrition	472

CHAPTER PAGE

Circulation in Man — 477
Functions of the Blood System — 483
Blood — 484
Clotting (Coagulation) of Human Blood — 486
Structure and Functions of Human Lymph — 487
Human Blood Groups — 489
Respiration in Man — 489
Excretion of Wastes — 492
Coordination in Man and Sensory Equipment — 494
Endocrine (Ductless Gland) System of Man — 506
Human Reproduction and Development — 513
Diseases of Man — 516
Inheritance of Human Traits — 522
Improvement of the Human Race—Eugenics — 526

26. Economic Importance of Animals — 530
Phylum 1—Protozoa (Single-Celled Animals) — 530
Phylum 2—Porifera (Sponges) — 535
Phylum 3—Coelenterata (Hydra, Corals, Sea Anemone, Sea Cucumber) 536
Phylum 4—Ctenophora (Comb Jellies or Sea Walnuts) — 537
Phylum 5—Platyhelminthes (Flatworms) — 537
Phylum 6—Nemathelminthes (Roundworms) — 538
Phylum 7—Rotifera or Trochelminthes (Rotifers) — 539
Phylum 8—Echinodermata (Starfish, Sea Urchin, Sand Dollar, etc.) — 540
Phylum 9—Annelida (Segmented Worms) — 540
Phylum 10—Mollusca (Oysters, Clams, Squids, Snails, Devilfish, Octopus) — 541
Phylum 11—Arthropoda (Crayfish, Lobster, Centipede, Millipede, Insects, Ticks, Mites, Spiders, etc.) — 543
Class Crustacea — 543
Class Diplopoda and Class Chilopoda — 544
Class Arachnoidea — 544
Class Insecta or Hexapoda — 547
General Usefulness of Beneficial Insects — 547
Injurious or Detrimental Insects in General — 549
Economic Importance of Representatives of the Orders of Insects 550
Phylum 12—Chordata (Lampreys, Sharks, Fishes, Frogs, Reptiles, Birds, and Mammals) — 572
Class Cyclostomata (Cyclostomes) — 573
Class Elasmobranchii (Sharks) — 573
Class Pisces (True Fishes) — 573
Class Amphibia (Frogs and Toads) — 573
Class Reptilia (Reptiles) — 573
Class Aves (Birds) — 574
Class Mammalia (Mammals) — 574

27. Homology; Analogy; Autotomy; Regeneration; Morphogenesis 576

28. Early Man and His Records — 585
History of Mankind and Human Society — 585
Early Man and His Records — 586
Java Ape-Man (Pithecanthropus erectus) — 586
Peking Man (Sinanthropus pekingensis) — 588
Piltdown Man or Dawn Man (Eoanthropus dawsoni) — 588
Heidelberg Man (Palaenthropus [Homo] Heidelbergensis) — 588
Neanderthal Man (Homo neanderthalensis) — 589
Cro-Magnon Man or Modern Man (Homo sapiens) — 589

PART 4

GENERAL AND APPLIED BIOLOGY — 591

CHAPTER — PAGE

29. Geographic Distribution of Animals and Plants—Biogeography (Zoogeography and Phytogeography) — 591
    - Why Study Geographic Distribution? — 591
    - Types of Geographic Distribution in Space — 592
    - Principles of Geographic Distribution — 593
    - Geographic Regions of the World — 597
    - Regions of Geographic Distribution of Vegetation of North America — 599
    - General Factors Influencing the Distribution of Organisms — 602
30. Animals and Plants of the Past and Their Records — 605
    - Records of Life — 605
    - Nature and Kinds of Fossils — 605
    - Conditions for Fossil Formation — 611
    - Significance of Fossils — 612
    - Geologic Time Chart — 618
31. An Ecologic Study of Living Organisms—Plants and Animals — 620
    - Ecology of Living Organisms (Plant and Animals) — 620
        - Heredity — 622
            - The Specific Genes of the Organism Being Studied Ecologically — 622
            - The Inherited Abilities and Reactions of the Organism Being Studied — 623
            - Mutations and New Types of Organism — 624
            - The Inheritance of Specific Structures by Organisms Being Studied — 624
            - The Rates of Metabolism of the Organism Being Studied Ecologically — 625
        - Environment — 625
            - Physical Factors — 625
            - Chemical Factors — 630
            - Biologic Factors — 633
            - Human Factors — 637
    - Typical Environments and Their Fauna and Flora — 639
    - Ecology of a Portion of a Lake Shore — 643
    - Ecologic Study of a Portion of Your Campus — 643
32. Unity and Interdependence in the Living World — 646
    - Unity in the Living World — 646
        - Unity Within Each Living Organism — 646
            - Unity Within the Individual Cell — 646
            - Unity Between the Various Cells of Each Tissue — 647
            - Unity Between the Various Tissues of Each Organ — 647
            - Unity Between the Various Organs of Each System — 647
            - Unity Between the Various Systems of a Living Organism — 648
        - Similarity of Structures and Functions Between Closely Related Species of Organisms — 648
        - Unity and Cooperation Between Various Types of Living Organisms — 649
            - Nitrogen Cycle — 649
            - Carbon Cycle — 651
            - Oxygen Cycle — 652
        - Biologic Communities (Associations) and Successions of Plants and Animals — 652
        - Dependence of All Living Animals and Most Plants on Photosynthesis — 654
    - Web of Life and Balance in Nature — 655
    - Plant and Animal Migrations (Dispersal) — 655

CHAPTER	PAGE
33. PARASITISM AND PATHOGENESIS; SYMBIOSIS; COMMENSALISM; GREGARIOUSNESS AND COMMUNAL LIFE; PREDACIOUSNESS; INSECTIVOROUS PLANTS; EPIPHYTISM; SAPROPHYTISM	658
34. HEREDITY—GENETICS	673
Definitions and Methods of Studying Genetics	673
Chromosomes, Polyploidy, and Mitosis	673
Chromosomal Aberrations	679
Genes and Genic Action	680
Mendel's Experiments and Laws	683
Monohybrid, Dihybrid, and Trihybrid Crosses	686
Incomplete Dominance	690
Multiple Genes and Interaction of Genes	692
Lethal Genes	694
Mutations	695
Linkage and Crossing Over	695
Sex Determination and the Sex Ratio	698
Sex-Linked Traits	699
Sex-Influenced Traits	703
Inbreeding and Outbreeding	703
Genetic Improvements of Plants and Animals	705
Production and Maturation of Germ Cells	706
Inheritance or Noninheritance of Acquired Characters	712
Human Inheritance	712
Eugenics and the Future	715
35. VARIATIONS AND ADAPTATIONS IN ANIMALS AND PLANTS	721
Importance of Variations	721
Classifications of Variations	722
Causes of Variations	726
Results of Variations	727
Adaptations	727
36. LIVING ORGANISMS—THEIR ORIGIN, CONTINUITY, DEVELOPMENT, AND DESCENT WITH CHANGE	732
Origin of Life	732
Abiogenesis (Spontaneous Generation)	732
Biogenesis (Life From Life)	733
Origin of Life on the Earth	733
Theories for the Origin of Life on the Earth	734
Continuity of Life	735
Development of Living Organisms	736
Descent of Organisms With Change (Evolution)	736
Evidences of Descent With Change	736
Theories of Descent With Change	746
37. BIOCHEMICAL AND BIOPHYSICAL PHENOMENA	750
Chemical and Physical Properties of Living Protoplasm	750
Atoms and Molecules	750
Electrolytic Dissociation	751
Permeability of Membranes and Osmotic Pressure	752
Diffusion and Conduction	754
Surface Tension	755
Energy	756
Radiant Energy	757
Plant and Animal Colorations	758
Production and Use of Heat	760
Production and Reception of Sound	761

CHAPTER PAGE

Bioluminescence and Light — 762
Bioelectric Phenomena — 764
Enzymes — 766
Plant and Animal Hormones, Including the Ductless (Endocrine) Gland Secretions — 767
Vitamins — 769
Toxins, Split Proteins, Antibodies, and Hypersensitiveness (Allergies) — 772

38. APPLIED BIOLOGY — 775

Biology and Its Relation to Agriculture and Hydroponics — 775
Biology and Its Relation to Foods, Clothing, Furniture, and Fuels — 776
Biology and Its Relation to Human Welfare — 778
Medicine and Health — 778
Biology and Wealth — 779
Water Supplies and Sewage Disposal — 781
Diseases Caused or Transmitted by Animals — 784
Human Diseases — 784
Diseases of Animals Other Than Human — 786
Diseases Produced by Plants — 789
Diseases Caused by Viruses — 789

39. CONSERVATION OF NATURAL RESOURCES — 792

Destruction and Conservation of Forests — 793
Loss and Conservation of Soils — 794
Loss and Conservation of Water — 795
Loss and Conservation of Animal and Plant Wild Life — 796
Loss and Conservation of Minerals and Fuels — 797
Conservation of Human Resources — 797

40. BIOLOGISTS AND THEIR WORK — 800

History and Development of Biology — 800
How Scientists Have Solved Problems — 804

PART 5

APPENDIX — 807

Important Prefixes and Suffixes Used in Biology — 807
Glossary, Biologic Principles, and Theories — 813
New and Old Systems of Classifying Plants Contrasted — 865

THE SCIENCE OF BIOLOGY

Part 1

INTRODUCTORY BIOLOGY

Chapter 1

THE SCIENCE OF BIOLOGY AND THE SCIENTIFIC METHOD

I. WHY STUDY BIOLOGY

When beginning a study of a new subject, it is desirable to know some of the reasons for making such a study and to have in mind some of the valuable and more important results of such an undertaking. One of the reasons for studying biology is to become familiar with the various properties and phenomena of living animals and plants, particularly the structure and functions of living protoplasm in representative animals and plants. With this information one can profitably attempt to explain the various living processes of organisms as a whole.

No matter what his future profession may be, a human being can live a more complete and happy life if he is somewhat familiar with the wonderful phenomena and laws of nature. Biology helps us to appreciate and understand nature and natural laws by making a comprehensive survey of the animal and plant kingdoms.

The present time has aptly been called the age of science. No matter what an individual may choose to do in the future, he should have a certain amount of training in science in order to work and to think more scientifically and accurately. Biology is one of the sciences which will give the individual an opportunity to acquire scientific training and technique and to collect data which may be properly systematized and evaluated, from which proper and logical conclusions may be drawn.

One of the most important and valuable assets to be acquired for successful living is an understanding of human beings, both collectively and as individuals. Much of the lack of success in the family, in society, in government, in business, and in the world at large is due to a misunderstanding of human beings by other human beings. A biologic study of such phases as heredity, endocrine secretions, personal and public health, sanitation, abnormalities and diseases, normal and abnormal human behavior, as well as balanced and perspective viewpoints in the fields of society and government, can help materially in our attempt to live happily and successfully. A consideration of the relative effects of environment and heredity on the various types of human beings can aid us in our understanding of education, social progress, crime, and human diseases and abnormalities. The science of eugenics contributes quite materially to our proper understanding of the problems and progress of human welfare. A biologic study of variations makes us realize that all living things are constantly changing; that the "most invariable thing in nature is variability." This one factor can go far in explaining many of the results of human conduct. In spite of this variation in the living world, biology will reveal also a unity within the animal and plant kingdoms, a method for living happily and harmoniously, if we are able to acquire from nature the rules and regulations. One of the most important contributions of biology is our familiarity with the more important biologic theories and laws which have materially aided in man's progress and thinking. In other words, the cultural values of a natural science, such as biology, are immeasurable.

We have recently come to realize the great importance of our natural resources. Biology will help us understand and will encourage the enactment of such economic regulations as will tend to conserve our natural resources, such as health, forests, wild animals, fish, and wild plants. Such a study also will help us to learn the economic importance of animals and plants, particularly as they relate to medicine, industry, landscaping, agriculture, horticulture, and plant and animal diseases. Such a study also will increase our appreciation and interest in the great out-of-doors. Because of the enormous numbers of insects and their destructive habits, the present time has been called the age of insects. It is only through a study of insects that we will understand their role in nature, their economic importance beneficially and detrimentally, and desirable methods of control. In order to make worthwhile progress in conservation work, we must understand the causes and effects of geographic distribution of living organisms, and we must be familiar with some of the geologic records left by organisms of the past in the various strata of the earth.

Biology can also serve as a foundation for such professions as medicine, dentistry, pharmacy, nursing, agriculture, forestry, education, entomology, horticulture, landscape gardening, and the "profession of living." In our preparation for such professions, we will appreciate the interrelationship of all the sciences, such as chemistry, biology, physics, geology, geography, psychology, sociology, history, paleontology, and many others.

A conscientious and extensive study of the natural sciences will aid us in one of the most worth-while problems of our existence—the formation of such a philosophy of life that we shall live long, happy, and prosperous lives, ready to attack willingly the problems of the day and not to shirk our many responsibilities. It may suggest that each of us has a mission, no matter how great or small, and that there is a certain responsibility for our individual life which is loaned to us at birth, taken away at death, and for which we should feel somewhat accountable during our existence.

II. HOW TO STUDY BIOLOGY

Undoubtedly to some persons such a topic as the above seems somewhat superfluous, but experience shows that students frequently have difficulty in mastering a science in college whether they have had a similar course in high school or not. A great part of this difficulty may be attributed to a lack of knowledge as to how best to study a particular science. Consequently, a few suggestions as to the best procedures to follow may not be amiss. Naturally, there can be no rules which can be applied by all individuals with equal success. Some of the following rules are somewhat general and can be applied profitably in the study of any subject. Others are more specifically related to the mastery of such a science as biology.

Have a particular time and place for study. Permit nothing to interfere with your program of study. Make study a habit which cannot be broken. Start your work promptly; do not waste valuable time in getting started. Before studying a new assignment spend some time reviewing previous work with which you have had particular difficulty. Attempt to associate the various parts of the assignment into a unified whole. Associate the work of the classroom, laboratory, and books in such a way that you have a clear, vivid picture of what has been done. Really to understand a thing you must be able to describe it properly in your own words. Practice this faithfully in your various phases of work.

One of the attributes of science is accuracy. Strive to be as accurate as possible in your descriptions, dissections, drawings, and examinations.

One of the chief difficulties encountered in the study of any new subject, such as biology, is a mastery of the vocabulary or new terms. Make it a rule to look up the derivation of each new word. Pay particular attention to its correct pronunciation. Recall other words with similar derivations. Use all newly acquired words as repeatedly and accurately as possible to ensure familiarity.

Read an assignment through for the purpose of getting a general idea of its contents. Then reread the same assignment more carefully, emphasizing the details and weaving them into a unified whole. When studying, it may be desirable to make notes of the most important points, placing them in such form as to be most serviceable in retaining the valuable ones. Seeing these facts in your own handwriting makes them more lasting and valuable. Certain statements must be copied verbatim, but many should be written in your own words. This latter point is important, because, if you can write it correctly in your own words, you probably will really understand it. When studying an assignment, always refer to diagrams, graphs, and illustrations which pertain to the topic in question. Correlate these as much as possible with your laboratory work.

When attempting to remember something, take the attitude of "intent to remember." We may read a paragraph and at its conclusion be unable to tell its contents. Read with the intent to remember. In this attempt associate your new ideas with those you already know. Utilize your new information as frequently as possible in your thinking, conversation, and writing.

III. THE SCIENTIFIC METHOD

One of the most valuable results of a study of such a science as biology is the development of the so-called *scientific method.* A course in biologic science should give the student a correct idea of the aim and nature of science, the methods employed, and the value and limitations of it. Science attempts to observe and describe facts and relate them to each other. Its conclusions are always subject to revision in the light of newly discovered facts which may not have been available when the original generalizations were made. There are numerous popular, but erroneous, conceptions concerning the limitations and advantages of science and what science tries to do, or can do. Some uninformed persons may think that science can do anything, can solve all problems. While this may not be completely true, the employment of the scientific method in the solution of most problems will give more logical and accurate answers than if an unscientific method is used. However, even when the scientific method is used, if the proper precautions are not followed in the use of its rules, erroneous conclusions or results may be obtained.

The failure to appreciate and understand the true nature of science and its methods has caused much misunderstanding and some unjustified criticism of the value of the methods of science. Some misinformed persons may criticize science because biology cannot explain fully what "life" is. Here, as elsewhere, scientists can use only the tools which are available to them—they can investigate scientifically the chemical reactions and the physical processes inherent in living things and attempt to explain life in terms of such investigations. This may not give the complete explanation of life, possibly because the investigations are as yet incomplete or somewhat inaccurate or because the ultimate problem is not solvable by science. Even if scientists cannot solve the problem completely, they may gradually come closer and closer to the ultimate solution by the correct application of the scientific method.

There may be variations in the steps to be followed in the *use of the scientific method* but the following are representative:

A. The Clear Recognition and Accurate Statement of the Problem to Be Solved

There are enormous numbers of unusual, or previously unobserved, problems or circumstances which are constantly present in the laboratory as well as in daily life. These may be simple and easily solved, or complex, requiring laborious observations and experiments for their solution. Before attempting a solution there must be a *proper awareness and clear recognition of the specific problem or situation.* It should be clearly in mind and accurately stated so that irrelevant, yet closely related, problems do not enter in. In order to have the particular problem clearly in mind, the investigator should organize his present knowledge of the problem and familiarize himself with additional, pertinent information with which he may not now be familiar. The awareness of a specific problem may be stimulated (a) by a mere, general curiosity, (b) by an actual need for the solution of the particular problem, or (c) by thinking or reading about a similar problem or situation. After the problem or situation is clearly stated, the next step follows:

B. The Formulation of Working Hypotheses Which Appear to Explain the Problem and the Suggestion of Methods of Investigation

Working hypotheses may be considered as *unproved assumptions, hypothetical explanations, or reasonable speculations which at present are without proof* but which upon scientific investigation may be helpful in securing the relevant information or data necessary for the eventual solution of the problem. Undoubtedly, as the problem is being stated clearly, one or more working hypotheses suggest themselves. No hypothesis or probable cause, no matter how unimportant it may appear, should be omitted. Each hypothesis is considered in turn, and either it is rejected because evidence proves it to be faulty or it is investigated as far and as scientifically as possible because it is giving reliable, pertinent information with which to work.

After all possible hypotheses have been made, the investigator must determine the *specific methods of investigation* which should be followed in order to secure reliable, pertinent information or data. In general, methods of investigation include (1) accurate observations of facts and phenomena, (2) controlled scientific experiments, (3) or a combination of the two. The correct solution of the problem may be determined in great measure by the use of the proper method of investigation. To devise and use the latter properly may require broad practical training, imagination, special techniques, or possibly elaborate and intricate apparatus and equipment. If possible, the method of investigation should be such that it may be repeated sufficiently to secure truly representative, typical results. In other words, the procedure should be such that it can be checked and rechecked in order to reduce the chance effects of unusual differences, or variations, found in a few instances or individuals. Limited observations, or too few investigations, especially if not checked and rechecked, may give unreliable information.

When using the *experimental method of investigation* it is highly desirable to utilize, when possible, the so-called *control group* in which a separate group of organisms or data is observed under conditions identical with the experimental group except that the one condition (rarely two or three) being examined is not applied to the control group. These so-called *controls* are extremely important in the experimental method and should be used whenever possible. After the working hypotheses have been completed and the proper method of investigation decided upon the next step follows:

C. The Accurate Collection and Recording of Pertinent Data

This may be done by the careful observation of facts or by scientific experimentation in order to prove or disprove the working hypotheses. As pertinent data are accurately collected or as observations are scientifically made, they should be precisely recorded in such ways that significant and meaningful interpretations can be made. All measurements, observations, records, interpretations of data, or "case histories" must be scientifically accurate and sufficiently comprehensive to be reliable. The accurate collection and recording of data and information may make the difference between the problem being solved correctly or incorrectly. The investigator must be honest, open-minded, and faithful, his observations must be correct, his instruments must be accurate and accurately read, and his records must be comprehensive and complete and contain only relevant materials. After the reliable data have been recorded and the correct observations have been made, the next step follows:

D. The Formulation of Logical Conclusions by the Scientific Analysis and Correct Interpretation of the Data and Facts

After the data and facts have been properly recorded, they must be analyzed scientifically and interpreted logically in order to solve the problem correctly. Data and facts must be *rechecked several times to prove their validity and relevance to the specific problem being investigated.* Certain data may be found neither to prove nor disprove the hypotheses; hence they may be discarded as irrelevant or possibly reinvestigated in a different manner so as to give additional data which are relevant. A check should be made repeatedly to keep errors to a minimum. Facts are always present around us, but their proper collection and logical interpretation form the basis upon which scientific knowledge is built.

The conclusions, if drawn logically, (1) may merely substantiate the validity and accuracy of previously known facts or observations or (2) may be entirely new conclusions which could be formulated only in the light of the data collected or from observations made. Be careful not to draw conclusions which are broader than the collected data will actually and logically warrant. It is important to review the entire problem step by step to check whether errors have been made, or if a new procedure has presented itself whereby more accurate data may be acquired.

Possibly, one might say all this is merely a "common sense" method, that it is merely a simple blueprint for mental reasoning. Be that as it may, if the method is properly and carefully used on many types of problems, it cannot help but result in more reliable conclusions and results. If the scientific method is not followed, what better one can be? The fault is not in the scientific method itself but in its improper use, or possibly in not using it at all. The method becomes more useful and usable the more it is used.

IV. THE SCIENCE OF BIOLOGY AND ITS SUBDIVISIONS

Biology, which is the "science of living things," is divided into (1) zoology, which deals with the biology of animals, and (2) botany, which deals with the biology of plants. Botany and zoology have grown so extensively that such subdivisions as the following are really sciences in themselves.

Anatomy* (a -nat′ o mi) (Gr. *anatemno,* cut up)—A study of gross structures, especially by dissection.

Histology (his -tol′ o ji) (Gr. *histos,* tissue; *logos,* study)—A microscopic study of tissues.

Cytology (si -tol′ o ji) (Gr. *kytos,* cell; *logos,* study)—A detailed study of cells and their protoplasm.

Taxonomy (taks -on′ o mi) (Gr. *taxis,* arrangement; *nomos,* law)—The science of systematic classification of organisms.

Embryology (em bri -ol′ o ji) (Gr. *embryon,* embryo; *logos,* study)—A scientific study of the formation and development of an embryo.

Physiology (fiz i -ol′ o ji) (Gr. *phusis,* function; *logos,* study)—A study of the functioning or working of an organism or its parts.

Heredity or **Genetics** (**he -red′ i ti**) (L. *heres,* heir); (je -net′ iks) (Gr. *genesis,* origin)—A scientific study of the inheritance or transmission of characteristics from members of one generation to those of another.

Evolution (ev o -lu′ shun) (L. *e,* out; *volvere,* roll or develop)—A scientific study of developmental changes undergone by organisms whereby they change from time to time.

Ecology (e -kol′ o ji) (Gr. *oikos,* house or home; *logos,* study)—A scientific study of the interrelations of living organisms and their living and nonliving environments.

---

*Pronunciations and derivations are based on *Webster's New International Dictionary; Henderson's Dictionary of Scientific Terms;* or *Dorland's American Illustrated Medical Dictionary.* Only the major emphasis is shown by the symbol ′.

Biogeography (bi o je -og′ ra fi) (Gr. *bios,* life; *geo,* earth; *graphein,* to write)—The science of geographic distribution of organisms in space or throughout a particular region.

Paleontology (pa le on -tol′ o ji) (Gr. *palaios,* ancient; *onta,* beings; *logos,* study)—The scientific study of the distribution of organisms in time as revealed by their records in the strata of the earth's surface.

Pathology (pa -thol′ o ji) (Gr. *pathos,* suffering; *logos,* study)—The scientific study of diseases and abnormal structures and functions, including causes, symptoms, and effects.

Economic Biology—A scientific study of organisms which results in the improvement of desirable types or the destruction or hindrance of undesirable ones, including the value of beneficial organisms and the losses due to detrimental ones.

QUESTIONS AND TOPICS

1. List all the reasons why a study of living organisms (plants and animals, including man) might well be made.
2. List the rules which you will follow in your method of studying biology. Make the rules specific and meaningful and post them on the wall of your study where you may refer to them until you follow them completely. Revise these rules when you have discovered a better procedure to be followed.
3. Define the so-called scientific method. Explain how it may be used in the solution of many problems even in daily life. Make it a practice of using this method whenever and wherever possible.
4. List and describe completely each step to be followed in the scientific method, including enough details to ensure that you know the purpose and correct use of each step.
5. Define biology, zoology, botany.
6. Define and learn the correct derivation and pronunciation of each subdivision of biology as listed in this chapter. Learn the correct pronunciation and derivation of each new term as you encounter it in your study and include a definition to be sure that you understand the meaning of the term. If this is done carefully and conscientiously, some of your difficulties with scientific terms as well as with other words will be materially reduced.

SELECTED REFERENCES

Avery: Survey of Biological Progress, Academic Press, Inc.
Baitsell: Science in Progress, Yale University Press.
Baker: The Scientific Life, The Macmillan Co.
Bawden: Man's Physical Universe, The Macmillan Co.
Cannon: The Way of an Investigator: A Scientist's Experiences in Medical Research, W. W. Norton & Co., Inc.
Cohen and Nagel: An Introduction to Logic and the Scientific Method, Harcourt, Brace and Co., Inc.
Conant: On Understanding Science, Yale University Press.
Driesch: The Science and Philosophy of the Organism, A. & C. Black, Ltd.
Fisher: The Rhesus Factor: A Study in the Scientific Method, Am. Scientist 35: 95-103, 1947.

Haldane: Science and Human Life, Harper & Brothers.
Haldane: Adventures of a Biologist, Harper & Brothers.
Haldane: The Philosophical Basis of Biology, Hodder & Stoughton, Ltd., London.
Jeans: The Universe Around Us, The Macmillan Co.
Jeans: The Mysterious Universe, The Macmillan Co.
Knobloch: Readings in Biological Science, Appleton-Century-Crofts, Inc.
Lewis: The Anatomy of Science, Yale University Press.
Rapoport: Science and the Goals of Man, Harper & Brothers.
Wells et al.: The Science of Life (4 volumes), Doubleday & Co., Inc.
Woodruff: The Development of the Sciences, Yale University Press.

Chapter 2

MICROSCOPES—EARLY AND PRESENT DAY

Because so much scientific progress of the past, present, and future has been and is dependent upon the development and use of the microscope, it seems desirable that an understanding of the history of microscopy, as well as a brief understanding of modern microscopes, should be attempted. No elaborate details can be given, and all contributors to improvements of microscopes cannot be mentioned. The various stages in the development of microscopes illustrate the scientific method. Since problems presented themselves which had to be solved, working hypotheses for their solution were proposed, data were collected and experiments were performed, and finally conclusions were drawn and the particular problems were solved, or if not completely solved the additional information secured may have led other workers to come nearer the true solution.

It is unknown who invented the first *simple microscope* which was really a magnifying glass with a lens thicker at the center than at the edge. Layard excavated a rock crystal at Nineveh which may have been a "lens" of the eighth century B.C. Even though burning glasses were used, probably magnifying glasses were not used extensively until the invention of spectacles at the end of the thirteenth century. The early *simple microscopes* (magnifying glasses) were commonly called *"flea microscopes"* because a flea was a specimen commonly investigated. According to present information, *Anthony van Leeuwenhoek* (1632-1723), a Dutch microscopist, developed a *simple microscope* (about 1673) by mounting a lens between two flat pieces of metal and adding a pivoted point for holding the specimen (Fig. 1). He ground lenses which had magnifications of 40 to 160 diameters. With his lenses he studied bacteria, protozoa, molds, red blood corpuscles, plants, animals, the circulation of blood in the tadpole tail, etc.

A *compound microscope* was invented by *Zaccharias Janssen* and his son *Hans* about 1590 in Middleburg, Holland. These spectacle makers combined lenses when viewing objects and discovered that a second lens would magnify the enlarged image from a magnifying glass. Their microscope was made of three tubes, had a size of 2 by 18 inches, and magnified about nine times.

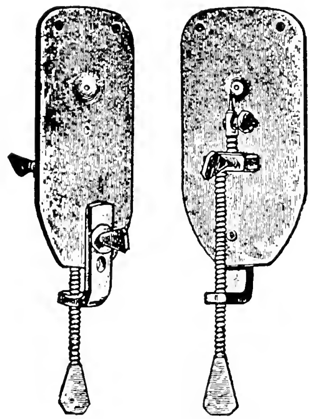


Fig. 1.—Leeuwenhoek's microscope (1673). This simple microscope consisted of a lens mounted between two flat pieces of metal, with an adjustable point for holding the specimen and focusing purposes. (From the Evolution of the Microscope, American Optical Company, Instrument Division.)

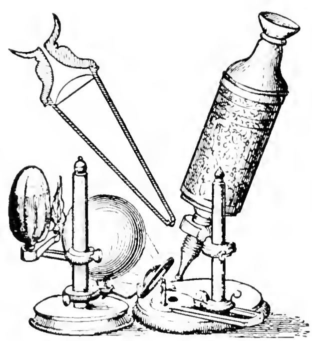


Fig. 2.—Hooke's microscope (1665). The body tube contained a series of lenses which magnified the image in the manner of a compound microscope. Illumination was provided by a lamp and a bull's-eye condenser. The instrument was sixteen inches high and had a maximum magnification of 42 ×. (From the Evolution of the Microscope, American Optical Company, Instrument Division.)

Robert Hooke (1635-1703), an English microscopist, constructed an outstanding microscope in 1665 which consisted of an objective lens, a field lens, and an eye lens. The latter two magnified the image of the former in the manner of a compound microscope. He provided a lamp for illumination and a bull's-eye condenser for intensifying the light. His microscope had magnifications of 14 to 42 diameters (Fig. 2). He studied many types of natural objects, and from his investigations of cork he saw minute, hollow, boxlike structures to which he first applied the word *cell.*

Marcello Malpighi (1628-1694), an Italian scientist and physician, is considered the father of histology because he systematically based his research on the use of magnifying apparatus in his studies of animals and plants. His studies included the detailed structure of lungs, kidneys, spleen, and other organs, the capillary circulation in frogs, and the cellular structure and anatomy of different plants.

Nehemiah Grew (1628-1712), an English physician, microscopically studied plants and carefully described the cells, tissues, organs, and vessels in plants. Malpighi and Grew described the microscopic anatomy of plants so well that it was over a century before any important additions were made to their work.

Jan Swammerdam (1637-1680), a Dutch physician and student of Nature, studied the anatomy of lower animals by dissection and injections, and his results were unequalled for over one hundred years. He showed a remarkable mastery of the most complicated details in the many lower animals which he dissected.

The first *binocular microscope* was designed by *Rheita* in 1645, two microscopes were held together by three links at the eye end and two links at the specimen end. This arrangement accommodated people who differed as to distance between the eyes and permitted the use of both eyes in viewing objects.

Bonannus improved the microscope in 1691 and developed a horizontal type which included a source of light, a condenser to concentrate light, and a rack and pinion mechanism for more efficient focusing (Fig. 3).

Wilson, about 1710, developed a screw-barrel type of microscope (Fig. 4) which was made of ivory and had a handle. The body had threads on the observing end into which lenses of different magnifying powers might be placed. The opposite end contained a condensing lens to concentrate light. The specimen was pushed against a spring for focusing. A Wilson type of microscope was received at Harvard College in 1732 and may have been one of the first compound microscopes used in American colleges, although simple microscopes probably were used earlier.

Cuff, in 1744, made a microscope of brass which was only twelve inches high and had a fine screw adjustment and an eyepiece for measuring the size of objects.

Wollaston developed a *camera lucida* in 1807 for making drawings of microscopic objects.

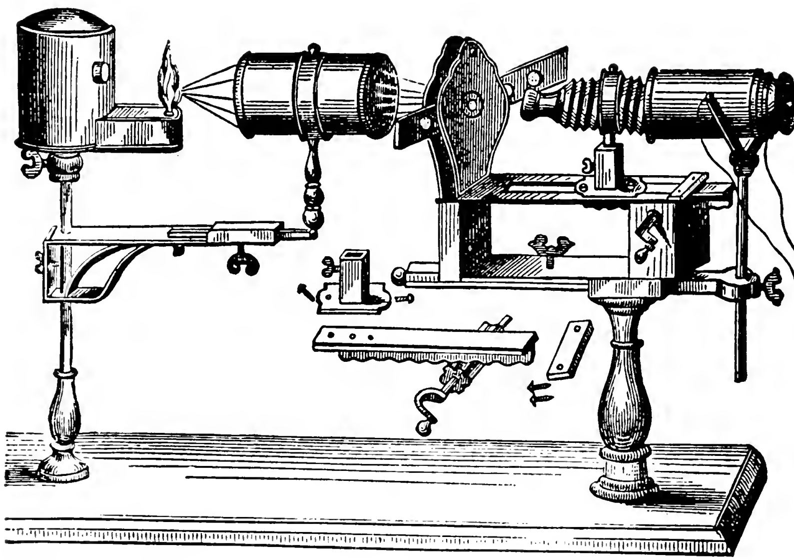


Fig. 3.—Horizontal microscope of Bonannus (1691). This type included a source of light, a condenser to concentrate light on the specimen, and a rack-and-pinion focusing mechanism on a horizontal stand. (From the Evolution of the Microscope, American Optical Company, Instrument Division.)

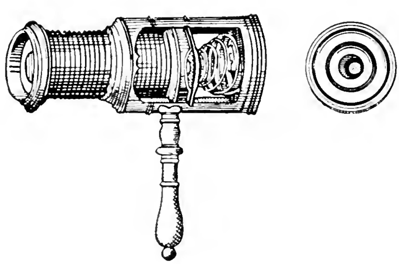


Fig. 4.—Wilson's microscope (about 1710). This model was made of ivory, and the body was cut open and the ends threaded for the attachment of lenses. The specimen was held by a spring for focusing. The handle was unscrewed when carried in the pocket. (From the Evolution of the Microscope, American Optical Company, Instrument Division.)

The need for better lenses led to work on achromatic lenses in an attempt to eliminate the undesirable color fringes (various color bands) seen around objects being observed with high power, single lens objectives. *Vincent* and *Charles Chevalier* made an improved achromatic microscope in 1824 with a magnification of 1800×.

Robert Brown discovered the general occurrence of the *nucleus* in plant cells in 1831.

Dujardin, the French zoologist, in 1835 observed the jellylike, slimy material in animal cells which later was found in living plant cells, and the term *protoplasm* was applied to this material by *von Mohl* in 1846.

Jacob Schleiden and *Theodor Schwann,* through microscopic studies of many plants and animals, promulgated the *cell principle* in 1839.

There were only about a dozen microscopes in the United States in 1831. Instructors were using them by 1850, and students began using them as early as 1875, but they were not in general student use until about 1890.

Charles A. Spencer (1813-1881) built the first American microscope (1847) and built several models for instructor and student. *Robert B. Tolles* (1824-1883) was another early American microscope builder; he started as an apprentice of Spencer but established his own business in 1858. He is famous for his improvements on objectives and for his invention of the homogeneous *immersion objectives.* In the latter, a drop of the proper type of liquid is placed on the cover slip on the slide and the immersion objective is made to contact the liquid, which acts as a type of lens to assist in higher magnifications. We may use oil immersion objectives for high magnifications. *Riddell* invented a binocular microscope in New Orleans in 1851 so that both eyes could be used in viewing an object. *Edward Bausch* (1854-1944) made his first microscope in 1872; he was the son of *J. J. Bausch* (1830-1896), the founder of the Bausch & Lomb Optical Company.

Ernst Abbé (1840-1905) joined the Carl Zeiss Co. in Germany in 1866 and invented the *Abbé condenser* (1872) and a *camera lucida* (1882) for making drawings of microscopic objects.

From our brief and necessarily incomplete consideration it is apparent that many individuals over a long period of time have made their contributions to the improvements of the microscope (Fig. 5). This is characteristic of science—one person merely takes the work a short distance, to be carried forward by others who will profit by the errors and discoveries of their ancestors-in-science.

Until the end of the nineteenth century the making of complete microscopes was largely done by individuals who made one microscope at a time. The metal parts were made by hand and the lenses ground and polished with rather simple equipment. Increasing demands for more microscopes suggested to manufacturers that specialists (scientists, designers, engineers, specialized workers, etc.) must be trained and standards set and that microscopes must be built on an assembly line basis. The

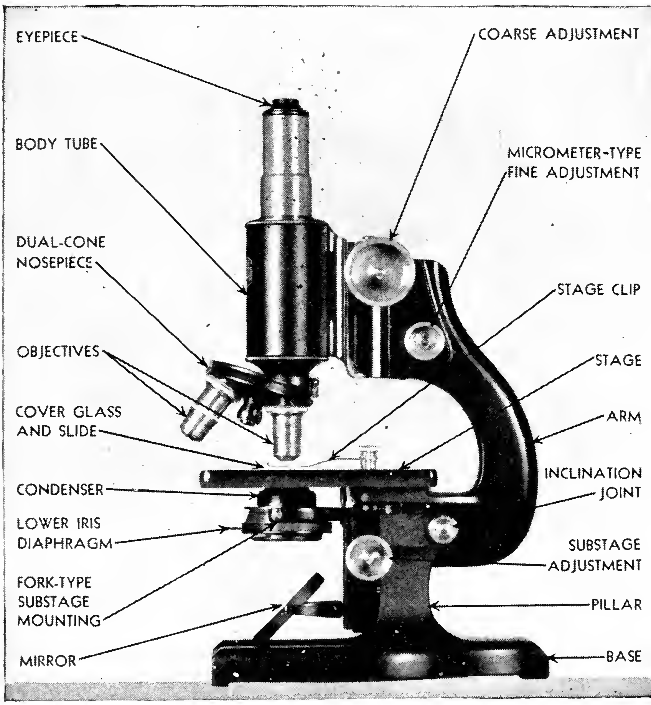


Fig. 5.—Modern microscope with more important parts labeled. (Courtesy of Spencer Lens Co. [Scientific Instrument Division of American Optical Co.])

twentieth century has seen many improvements in the manufacture and usefulness of the various types of microscopes (Figs. 5 and 6). Some of the more recent improvements include ultramicroscopes, ultraviolet microscopy, dark-field microscopy, phase microscopy, and electron microscopy.

When particles too small to be seen with a microscope under ordinary conditions are illuminated by a strong beam of light parallel to the surface of the stage (at right angles to the direction of vision through the microscope), they appear as bright specks due to their reflection of light, but do not show their outline or shape. The apparatus used for such study is called an *ultramicroscope* (L. *ultra,* beyond).

In an *ultraviolet microscope* invisible ultraviolet rays (of shorter wave lengths and beyond the visible violet light waves) are used instead of ordinary light. Because of the invisibility of the ultraviolet rays, photographs must be made since the image cannot be seen. Special quartz lenses must be employed which permit the passage of the ultraviolet rays.

Fig. 6.—Correct position when using a microscope. The microscope should stand upright on the table directly in front of the observer. The left hand should be used on the fine adjustment to maintain the proper focus, thus leaving the right hand for other work while looking through the eyepiece. Both eyes should be kept open in order to minimize eyestrain. This microscope has three objectives on the nosepiece and a mechanical stage to move the slide on the stage. (From Carter: Microbiology and Pathology, The C. V. Mosby Co.)

In *dark-field microscopy* the term dark field refers to a method of illuminating a specimen brightly while the surrounding background (field) remains dark. The most practical dark field is obtained by a special dark-field condenser (dark-field illuminator) whereby direct light rays do not enter the specimen; the oblique light rays are focused on the specimen, which thus appears as a luminous body against a dark field. A very small, bright object is more easily seen in a dark background (field) than is a very small, dark object in a bright field. This is similar to the phenomenon of seeing small dust particles in a beam of light when the region back of the light beam is dark.

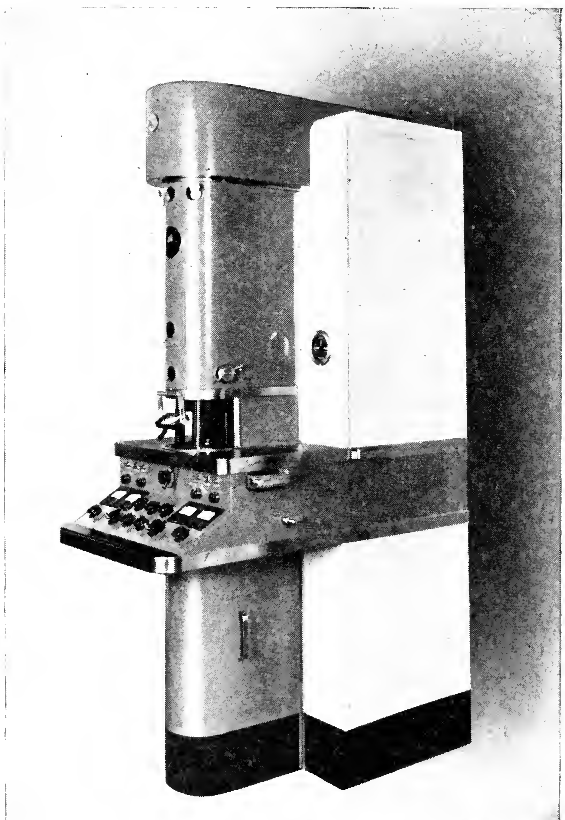


Fig. 7.—An electron microscope capable of magnifying thousands of times. (Courtesy RCA Victor Corporation.)

Phase microscopy was proposed by *Zernike* of Holland in 1932 and has been studied by many, including *Richards* and others in America (1944). Phase contrast is a new factor in image formation that permits the study of living organisms and other transparent materials which inherently have low contrast properties. By the use of special objectives and other equipment a greater contrast between the transparent specimen and its surrounding medium is secured.

Electron microscopy employs the use of electron (magnetic) microscopes. Electrons produced by special apparatus are used instead of light, magnetic fields ("electron lenses") are used instead of glass lenses, and photographic plates are used to record the image since it cannot be seen. The specimens being photographed must be very thin and in a vacuum (Fig. 7). The fact that axially symmetrical magnetic and electric fields could be employed as lenses was discovered by *H. Busch* in 1926. Hence, by the proper use of magnetic fields (acting as lenses), the charged particles (electrons) can be made to do what light waves accomplish in ordinary, optical microscopy. Electron microscopes were made by *Knoll* and *Ruska* (Germany) in 1932, by *Marton* (Belgium) in 1934, and by *Prebus* and *Hillier* (Canada) in 1938. The Radio Corporation of America in 1941 manufactured a commercial electron microscope of the magnetic type. Many kinds and models have been made and used in various parts of the world since that time. Magnifications of thousands of diameters are possible with such apparatus.

QUESTIONS AND TOPICS

1. Define the following types of microscopes: simple, compound, binocular, monocular.
2. List the important stages in the general history of the development of microscopes, including the persons and their specific contributions.
3. Explain how scientific progress may depend on the efficient use of microscopes in such fields as medicine, agriculture, industries, chemistry, water purification, metallurgy, and similar ones.
4. Why can ultraviolet and electron microscopes not be used for viewing objects with the eye?
5. What are chief differences between the following types of microscopes: light, ultraviolet, electron?
6. How does the study of the history of the development of microscopes illustrate the use of the various stages of the so-called scientific method? Be as specific as possible.
7. How can a knowledge of the efficient use of a microscope be of value to us in everyday life, even though we do not plan to follow a scientific career?
8. Can one learn to use a microscope efficiently without some fundamental knowledge of how the various parts of it really function?
9. Is it true that a microscope can be no more efficient than the optical lenses of which it is made?

10. Learn the location and proper functions of all the essential parts of the microscope.
11. Before using such a delicate and expensive instrument as a microscope be certain that you know and observe all the rules for its proper use and care. Carelessness may cause severe damage which may require expensive repairs.

SELECTED REFERENCES*

Burton and Kohl: The Electron Microscope, Reinhold Publishing Corporation.
Carpenter: The Microscope and Its Revelations, J. & A. Churchill, Ltd.
Corrington: Working With the Microscope, McGraw-Hill Book Co., Inc.
Cosslett: The Electron Microscope, Interscience Publishers, Inc.
Gabor: The Electron Microscope, Chemical Publishing Co., Inc.
Gage: The Microscope, Comstock Publishing Co., Inc.
Marton: The Electronic Microscope, J. Bact. **41**: 397, 1941.
Wyckoff: Electron Microscopy; Technique and Applications, Interscience Publishers, Inc.
Zworykin, Morton, Ramber, Hillier, and Vance: Electron Optics and the Electron Microscope, John Wiley & Sons, Inc.

*Also numerous publications by Bausch & Lomb Optical Co., Spencer Lens Co. (Scientific Instrument Division of American Optical Co.), E. Leitz, Inc., etc.

Chapter 3

CELLS AND THE CELL PRINCIPLE

I. THE CELL PRINCIPLE AND ITS IMPORTANCE

The cell principle states that all living animals and plants (or those which were once alive) are made of cells and that all life phenomena and abilities are fundamentally cellular in nature (Figs. 8 and 9). This principle is important in biology because since its formulation it has stimulated the study of a wide range of living phenomena under a common point of view.

The cell principle was clearly and definitely formulated by the German botanist *Schleiden* and the German zoologist *Schwann* in 1839, although cells had been rather crudely and inaccurately studied previously. An Englishman named *Hooke* had studied cells as early as 1665.

The original formulators of the cell principle did not have accurate and detailed accounts of cells, but much of that information has been contributed by multitudes of scientists since. The principle has been proved repeatedly by these later investigators, but its general purport and content are much the same today as at the time of its adoption.

A study of this principle shows that plants and animals, although apparently different, are really organized and constructed along common lines or units. It shows that the functions of a normal animal or plant, as well as those of an abnormal, diseased organism, are but the expressions of the activities of the individual cells. This principle also influenced the study of physiology by showing that cells and their activities are at the foundation of this phase of science. It also paved the way for much of the unified scientific experimentation of hundreds of biologists, thereby profitably influencing their progress and research. It also laid the foundation for the modern specialized branch of biology known as cytology, which deals with the study of the finer parts of cells.

Early investigators used the term cell because they saw the cell wall or container and practically ignored the extremely important substance within. To them tissues looked like the cells of a honeycomb, or something in which other things might be placed. *Felix Dujardin* (1801-1860) studied and recognized the real importance of the cell contents, especially among the lower animals. *Hugo von Mohl* in 1846 found plant tissues to be made of cells which in turn were composed of that essential material which he named *protoplasm*. *Max Schultze* (1825-1874) stated that all living cells are made of similar protoplasm or, in fact, that this mass of organized protoplasm really is the cell and that bone, chitin, and similar products are manufactured by the active, living protoplasm.

The cell is now considered as the *unit of structure* of animal and plant tissues; that is, units of which they are constructed, as bricks are the units of which brick walls are made. The cells are also *units of function* or *physiology* because the functions and activities of any living organism are the sum of the individual cell activities composing that organism. Each cell works as a unit, performing its particular duty. However, there must be, and is, a proper interdependence, interfunctioning, coordination, and subordination if the organism as a whole is to function normally and efficiently. The cell is also a *unit of development and growth* because even a complex animal or plant with its many cells has grown and developed through the division and increase in size of its individual cells. Thus, the development of an organism is due to the properties and activities of its various cells, each acting as a unit, each contributing its part to the development of the organism as a whole. Cells are also *units of heredity* because the embryo receives from each parent a single sex cell which carries the characteristic determiners. The embryo grows and its future cells are given these determiners through the process of mitosis (indirect cell division). There is in this manner a direct hereditary continuity between the parents of one generation, their germ cells, and the newly formed offspring of the next generation. Cells not only transmit hereditary determiners from one generation to the next, but also through successive cell divisions they retain those hereditary characteristics with which the young embryo is endowed. If it were not for this efficiency of our cells, we might at certain periods in our life fail to retain the characteristics given us by our parents.

Since biology is one of our oldest sciences, one might wonder why the cell principle was not formulated before 1839. Undoubtedly the following will help us to answer such a question: (1) There was a lack of scientific instruments with which to study cells effectively before that time. (2) Experimental science as we know it today was not yet prevalent. (3) Gross or macroscopic anatomy demanded the attention of biologists previous to that time so that a detailed knowledge of cells was not extremely vital. Biology was studied more or less in a general way and a greater emphasis was placed on nature study than on detailed work. (4) A revival of interest in the embryology of organisms in the early part of the last century shifted attention from the gross and superficial aspects to the detailed study of cells and their inherent organization. All of these, and probably many others, paved the way for the formulation of the cell principle at that particular time.

II. DETAILED STRUCTURE AND FUNCTIONS OF CELLS

ANIMAL CELLS	PLANT CELLS
I. *Cytosome* or *Cell Body* (si′ to som) (Gr. *kytos,* cell; *soma,* body) (Fig. 8) 1. *Cytoplasm* (si′ to plazm) (Gr. *kytos,* cell; *plasma,* liquid).—This is that part of the living protoplasm located outside the nucleus. The cytoplasm may be separated, more or less distinctly, into an outer *ectoplasm* (Gr. *ektos,* outer) and an inner *endoplasm* (Gr. *endon,* inner). The *cell sap* or *cytolymph* (si′ to limf) (L. *lympha,* liquid) forms the fluid, ground substance of the cytoplasm. The cytoplasm is usually colorless, somewhat granular, and varies in its viscosity.	I. *Cytosome* or *Cell Body* (Fig. 9) 1. *Cytoplasm.*—This varies in viscosity from a thin syruplike liquid to a gelatinous semisolid. It is usually colorless, elastic, slightly granular, and somewhat mucilaginous. Frequently, the cytoplasm forms a layer next to the cell wall with strands of it extending across the internal vacuole and also surrounding the nucleus. The watery *cell sap* fills the vacuole in the cytoplasm and frequently contains salts, sugars, pigments, organic acids, etc.
2. *Plasma Membrane* (and *Cell Wall*). —In a few animal cells there may be a cell wall, although it is rarely present. Surrounding the cytoplasm there always is a thin, clear, filmlike, rather rigid, *plasma membrane.* The rather dense plasma membrane closely adheres to the cytoplasm and regulates the passage of materials to and from the cell. Plasma membranes are semipermeable because certain liquids and dissolved materials can pass through while others cannot. Diffusion through a semipermeable membrane is called *osmosis* (os -mo′ sis) (Gr. *osmos,* push). Diffusion occurs from the region of higher concentration of a substance to a region of lower concentration of a substance.	2. *Cell Wall* and *Plasma Membrane.*—The cell wall is transparent, pliable, semirigid, and nonliving and gives strength and support to the plant body. The cell wall is secreted by the protoplasm and may be composed of layers, the thickness varying with the tissues. Adjacent cells adhere to each other because of a layer common to them, known as the *middle lamella* (la -mel′ a) (L. *lamella,* small plate). The most abundant constituent of a plant cell wall is *cellulose* (sel′ u los) (L. *cellula,* small cell). Other materials in various cell walls are *lignin* (lig′ nin) (L. *lignum,* wood), a hard organic substance found especially in wood; *cutin* (ku′tin) (L. *cutis,* skin), a waxy substance in epidermal tissues to make then somewhat impermeable to water; *suberin* (su′ ber in) (L. *suber,* cork), a waxy substance in cork tissues to waterproof them. The thin *plasma membrane* lies beneath the cell wall and, being semipermeable, regulates the passage of materials in and out of the cell. *Osmosis* probably occurs much as in animal cells.

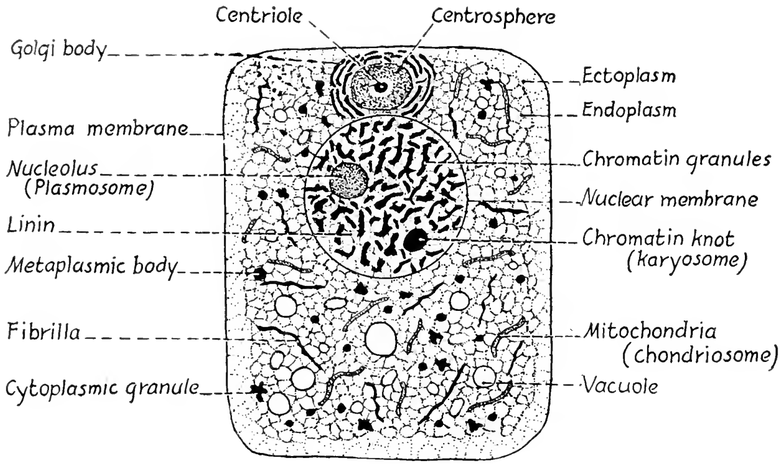


Fig. 8.—An animal cell (diagrammatic and generalized). Not all of the structures shown will be found in any one cell. Special preparation of a variety of cells is necessary to see all of these structures.

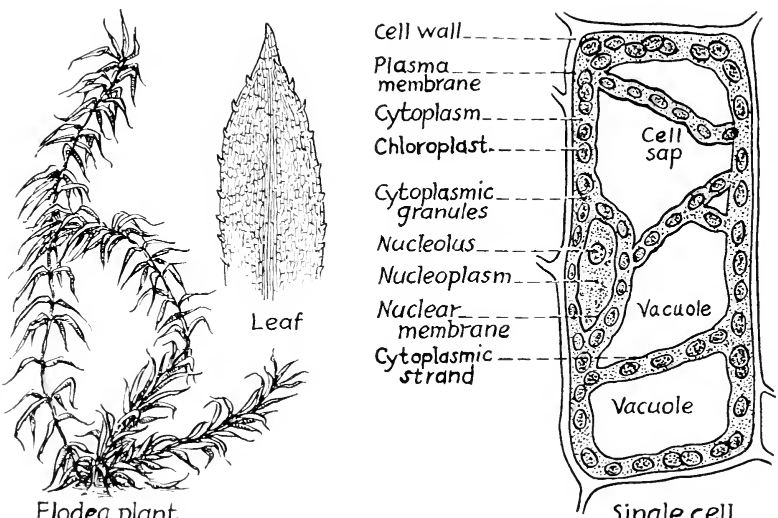


Fig. 9.—A common fresh water plant known as *Elodea (Anacharis)*. Only a thin section of a single cell of a leaf is shown at the right. In the living cell the chloroplasts are green and floating in the cytoplasm. The vacuole contains cell sap.

ANIMAL CELLS	PLANT CELLS
3. *Protoplasmic Strands* ("Bridges").—In both plant and animal cells there may be fine *protoplasmic strands* extending from one cell to another to assist in the continuity between adjacent cells (Figs. 10 and 175).	3. *Protoplasmic Strands* ("Bridges").—The walls of certain plant cells are not uniformly solid but contain minute, thin areas called *pits* which permit the passage of water and dissolved materials between adjacent cells. In other cell walls, numerous small *canals* contain very delicate *protoplasmic strands* called *plasmodesmata* (plaz mo -dez′ ma ta) (Gr. *desma,* bond) for the exchange of foods, the coordination of adjacent cells by the transmission of stimuli, etc. (Fig. 10).
4. *Centrosome* or *Central Body.*—Just outside the nucleus there often is centrosome consisting of a small, granular, deeply stained *centriole* (frequently two) surrounded by a denser area of cytoplasm, the faintly stained *centrosphere.* This body takes part in cell division and is not present in all animal cells and is not present in higher plant cells.	4. *Centrosome* or *Central Body.*—This small body near the nucleus of cells of certain lower plants (algae, fungi, etc.) is *absent in higher plant cells.* When present, it is associated with cell division.
5. *Mitochondria* or *Chondriosomes* (mi to -kon′ dria) (Gr. *mitos,* thread; *chondros,* granular) (kon′ dre o som) (Gr. *chondros,* granular; *soma,* body).—These cytoplasmic bodies occur in most cells and appear as granules, rods, filaments, and sometimes as networks, of variable shapes and sizes. They are common in young cells and are thought to be forerunners of other structures in adults cells. It has been suggested that they may assist in cell respiration.	5. *Mitochondria* or *Chondriosomes.*—These small, granular or rod-shaped structures are commonly present in plant cells, being visible when properly stained. It is thought that they may have the following functions: centers of protein formation and digestion; assist in cell division; form and develop certain plastids.
6. *Golgi Apparatus* or *Golgi Bodies* (gol′ je) (after Golgi, Italian scientist).—This is frequently a netlike structure at one side of the nucleus, although in certain cells it may be diffused. It often surrounds the centrosome. It is thought to have a secretory function, or to assist in the metabolism of certain foods.	6. *Golgi Apparatus* or *Golgi Bodies.*—It is not certain, in the light of present investigations, whether structures comparable to Golgi bodies of animal cells are present in plant cells.

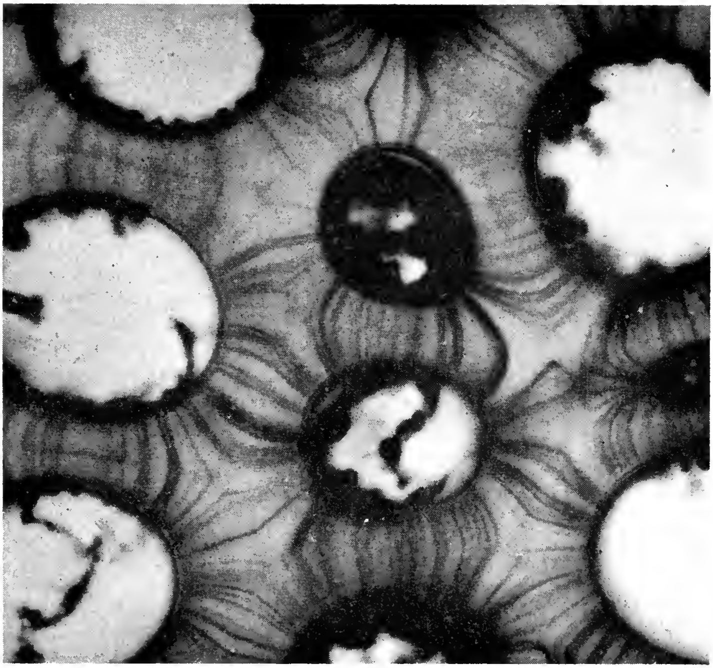


Fig. 10.—A section demonstrating the numerous long protoplasmic strands (plasmodesmata) which pass through the cell walls and connect adjacent cells, as found in the Philippine persimmon. (Copyright by General Biological Supply House, Inc., Chicago.)

ANIMAL CELLS	PLANT CELLS
7. *Vacuoles* (vak′ u ol) (L. *vacuus,* empty).—Spherical *vesicles* (ves′ i-kal) (L. *vesica,* bladder) of liquid, and of various sizes, are known as *vacuoles* and may be present or absent in the cytoplasm of animal cells. A *vacuolar membrane* separates the vacuole contents from the cytoplasm. Vacuoles may contain materials to be digested and absorbed or wastes to be excreted.	7. *Vacuoles.*—The central region of a plant cell usually contains one or more rather clear *vacuoles* containing *cell sap.* The *vacuolar membrane* lines the vacuole. In general, in younger cells the vacuoles are smaller and more numerous, but as the cell grows the smaller vacuoles coalesce and become larger and fewer in number.
8. *Plastids* (Gr. *plastos,* to form).—These are special bodies of various sizes and shapes and are capable of forming certain substances. They are common in plant cells but are occasionally present in some of the lower animals.	8. *Plastids.*—These are specialized, definitely organized bodies, usually oval or spherical in shape, which may be visible in the living conditions. They are of three types: (a) *chromoplasts* (kro′ mo plast) (Gr. *chroma,* color; *plastos,* moulded) are red, yellow, or organe and are common in flowers, fruits, etc.; (b) *leucoplasts* (lu′ ko plast) (Gr. *leukos,* white) are colorless and occur most commonly in storage cells of roots and underground stems; (c) *chloroplasts* (klor′ o plast) (Gr. *chloros,* green) are greenish because of *chlorophyll* and occur in virtually all green cells where they photosynthesize foods.
9. *Metaplasm (Cell Inclusions)* (met′ a-plazm) (Gr. *meta,* between; *plasma,* moulded).—This is a lifeless, passive structure of the cytoplasm and includes fat droplets, reserve foods (proteins, glycogen, yolk, etc.), excretory materials, crystals, etc.	9. *Metaplasm (Cell Inclusions).*—This is a lifeless, passive inclusion and includes stored foods (starch, proteins, fats), waste materials, crystals, etc.
II. *Nucleus* (nu′ kle us) (L. *nucleus,* kernel, or nucleus) 1. *Nuclear Membrane.*—The thin *nuclear membrane* separates the nucleus from the cytoplasm and adheres closely to the nucleus.	II. *Nucleus* 1. *Nuclear Membrane.*—The thin, living membrane separates the nucleus from the cytoplasm. Living plant nuclei are usually rather large, colorless, and viscus and may be spherical, oval, or elongated.

ANIMAL CELLS	PLANT CELLS
2. *Chromatin* (kro′ ma tin) (Gr. *chroma,* color).—When killed and stained, there is a minute, thread-like network of *linin* (lin′ in) (L. *linum,* fiber) to which is attached the granular *chromatin,* so named because it stains deeply with certain dyes. The chromatin plays an important role in the transmission of hereditary characteristics. Modern investigations suggest that the chromatin granules are merely thickened regions of the delicate thread known as the *chromonema* (kro mo-ne′ ma) (Gr. *chroma,* color; *nema,* thread). Eventually the chromatin forms *chromosomes* which are considered in cell division (mitosis).	2. *Chromatin.*—The *chromatin* is usually present in the form of a diffuse, irregular network or *nuclear reticulum* (re -tik′ u lum) (L. *reticulum,* small net) whose principal function is the transmission of most hereditary characteristics. The chromatin will eventually form *chromosomes* which are considered in cell division (mitosis).
3. *Chromatin Nucleoli (Karyosomes)* (nu -kle′ o li) (L. *nucleolus,* little nucleus) (kar′ i o som) (Gr. *karyon,* nucleus; *soma,* body).—One or more rather large, knotlike (or spherical) aggregates of *chromatin* material may be present (especially in resting cells).	3. *Chromatin Nucleoli (Karyosomes).*—These structures have not been described for plant cells.
4. *True Nucleoli (Plasmosomes)* (plaz′-mo som) (Gr. *plasma,* form; *soma,* body).—Frequently, one or more small, spherical, lightly stained *plasmosomes (true nucleoli)* exist and differ from the chromatin nucleoli in staining reactions.	4. *True Nucleoli (Plasmosomes).*—One or more spherical *nucleoli* may be present. It is thought that they may play a role in inheritance, in cell division, and may synthesize and store certain protein foods. They are usually difficult to see in living cells but may be observed if stained properly.
5. *Nucleoplasm* or *Nuclear Sap.*—This makes up the colorless, fluid, ground substance of the nucleus and fills the spaces not occupied by other nuclear structures. It must be remembered that all parts of a cell work together and the life of the cell depends on the balanced interactions between the various parts of the nucleus and cytosome. Sometimes the term *protoplast* is applied to all living parts of a cell, in contrast to the nonliving *metaplast* (inclusions).	5. *Nucleoplasm* or *Nuclear Sap.*—The rather viscous, liquid material within the nucleus is the *nuclear sap.* Sometimes it is called *karyolymph* (Gr. *karyon,* nucleus; L. *lympha,* water). A cell can function normally only when all parts of the nucleus and cytosome interact properly. Sometimes the term *protoplast* is applied to all the living parts of the cell.

QUESTIONS AND TOPICS

1. Why are there various theories regarding the physical structure of protoplasm? In what ways are they similar? Which theory do you prefer? Why?
2. List all the parts of the nucleus and of the cytosome (cell body) with the functions of each.
3. In what general ways do cells of animals and plants differ?
4. Is a certain cell of a living organism always the same chemically, structurally, and functionally? Give proofs for your answer.
5. List all the important results of the formulation of the cell principle.
6. Discuss each of the ways in which the cell is considered a unit.
7. In what ways might a better understanding of cells aid in the prevention and cure of such diseases as tumors and cancers?
8. Explain how the functions of cells are influenced by their structure. Explain how the structure of cells may be modified by the functions which they perform. Give examples.
9. What role does heredity play in determining the size, shape, and functions of the various cells and tissues in a living organism? Do living organisms inherit cells from which such structures as digestive apparatus or excretory systems are developed?
10. List several environmental factors telling how each may influence cells in one way or another.
11. List the names of the men who have made the greatest contributions to the study of cells, including the thing for which each is noted.
12. Define a cell (in your own words if possible). How was a cell originally defined?
13. Why are cells usually cut into thin sections and stained before they are studied? Does a study of such a section reveal the structure of an entire cell? Might certain structures of an entire cell be absent from certain sections? Explain the importance of the latter fact.
14. Are all the structures usually found in diagrams of cells in textbooks to be found in each cell studied on a slide? Explain.

SELECTED REFERENCES

Amberron and Smith: Outline of Physiology, F. S. Crofts & Co.
Baker: Cytological Technique, John Wiley & Sons, Inc.
Caspersson: Cell Growth and Cell Function, W. W. Norton & Co., Inc.
De Robertis, Nowinski, and Saez: General Cytology, W. B. Saunders Co.
Gerard: Unresting Cells, Harper & Brothers.
Guillermond: Cytoplasm of the Plant Cell, Chronica Botanica.
Heilbrunn: An Outline of General Physiology, W. B. Saunders Co.
Hober: Physical Chemistry of Cells and Tissues, The Blakiston Co.
Sharp: An Introduction to Cytology, McGraw-Hill Book Co., Inc.
Sharp: Fundamentals of Cytology, McGraw-Hill Book Co., Inc.
Wilson: The Cell in Development and Inheritance, The Macmillan Co.

Chapter 4

CELLULAR ORGANIZATION OF PLANTS AND ANIMALS—ANIMAL AND PLANT TISSUES

I. ANIMAL TISSUES

A *tissue* is a group of *similar cells differentiated so as to perform certain functions.* According to the cell principle, all living organisms are composed of cells. Consequently, all tissues and organs of an organism are composed of cells. Upon casual and hurried observation all tissues may appear to be made in the same manner, but scientific, microscopic examinations show that the various tissues differ in structure and functions. In order that the functions of an organism, or its parts, may be properly understood, it is necessary to be familiar with the cellular structure of its tissues. In other words, a knowledge of anatomy must precede physiology. The characteristics of the more important animal tissues will be given in table form in order that they may be compared and contrasted more easily.

Kinds of Animal Tissues

A. EPITHELIAL (ep i -the′ li al) (Gr. *epi,* upon; *thele,* nipple) (Fig. 11)	A layer of tissue composed of *flat, cuboidal, or column-shaped cells,* depending on the type of epithelium; there is a *minimum of intercellular space* between cells; they compactly *cover the surface and line the cavities of the body which usually lead to the outside;* they are *not supplied with blood vessels* but must absorb nourishment from the blood and lymph as they pass the cells. Functions: Protective, absorptive, secretive, excretive, sensory.
B. CONNECTIVE (SUPPORTIVE) (ko -nek′ tiv) (L. *cum,* together; *nectere,* to bind) (Figs. 12 and 13)	*Fibers are usually present,* and *much nonliving material* (fibers, plates, masses, etc.) *is produced by the cells;* there is a *maximum of intercellular space;* they are *common in most parts of the body;* they all *arise embryologically from the same source* (mesenchyme cells). Functions: bind body parts together; some kinds form semirigid, or rigid, structures for protection and attachment of other tissues and organs.

Kinds of Animal Tissues (Cont'd)

C. MUSCULAR (CONTRACTILE) (mus′ ku lar) (L. *musculum,* muscle) (Figs. 14 and 15)	*Cells (muscle fibers)* are *usually elongated* and specialized for *contraction* because of their tendency to shorten when stimulated. Special, internal, *contractile fibrillae* produced by the cells are responsible for the contraction. Functions: Move the body as a whole, or its various parts.
D. NERVOUS (ner′ vus) (L. *nervus,* sinew or fiber) (Figs. 16 and 17)	*Highly specialized tissue* whose *cells (neurons)* possess fine *cytoplasmic processes (axons and dendrites)* to conduct nerve impulses; *neurons* vary in size and length of their processes; fine *neurofibrils* in the cytoplasm conduct the impulses in the proper direction; *Golgi bodies* are particularly visible in neurons; *Nissl's granules* in the cytoplasm are probably nutritive as they tend to disappear after prolonged neuron activity. Functions: Receive, interpret, and redirect nerve impulses.

A. Epithelial Tissues (Fig. 11)

1. SQUAMOUS (PAVEMENT)	*Broad, flat cells* arranged like the stones in a pavement. (a) *Simple squamous* is composed of *one layer of cells* which line cavities which do not connect with the outside; examples—the *endothelium* (Gr. *endo,* within) lining the blood vessels and the *peritoneum* (Gr. *peri,* around) lining the body cavity. (b) *Stratified squamous* composed of *more than one layer of cells* and found in the mouth and nose cavities, esophagus, outer layer of the skin of higher (vertebrate) animals, etc.
2. CUBOIDAL	*Cells* are *cube shaped* and line glands, tubules of kidneys, etc.
3. COLUMNAR	*Cells* are tall and *column shaped* but may be somewhat irregular with a *nucleus* in the base of each cell. (a) *Simple columnar* composed of one layer of cells and lining the intestines of most higher animals. (b) *Stratified columnar* composed of more than one layer of cells and found in the trachea (windpipe), etc.
4. CILIATED, FLAGELLATED, and COLLARED	When the free surface of columnar epithelium contains hairlike cilia, whiplike flagella, or "collars," they are named accordingly. Ciliated epithelium is found in the gills of clams, in the roof of the frog's mouth, in the lining of air passages of vertebrates, in which the cilia move materials from the surface. Flagellated epithelium is present on the inner, entodermal layer of *Hydra,* etc. Collared epithelium is found in the canals of sponges, etc.

A. Epithelial Tissues (Cont'd)

5. SENSORY	Forms the *sense organs (receptors)* which are affected by different stimuli; for example, the retina of the eye, the lining membrane of the nose, etc.
6. GLANDULAR (SECRETORY)	Usually modified columnar epithelium for the *secretion* of specific secretions; examples—intestinal tract, etc. Certain glands may be composed of *unicellular, goblet cells;* others may be *complex and multicellular.*
7. GERMINAL (REPRODUCTIVE)	Epithelium which is modified for the *formation of sex cells* in the reproductive organs (testes and ovaries).

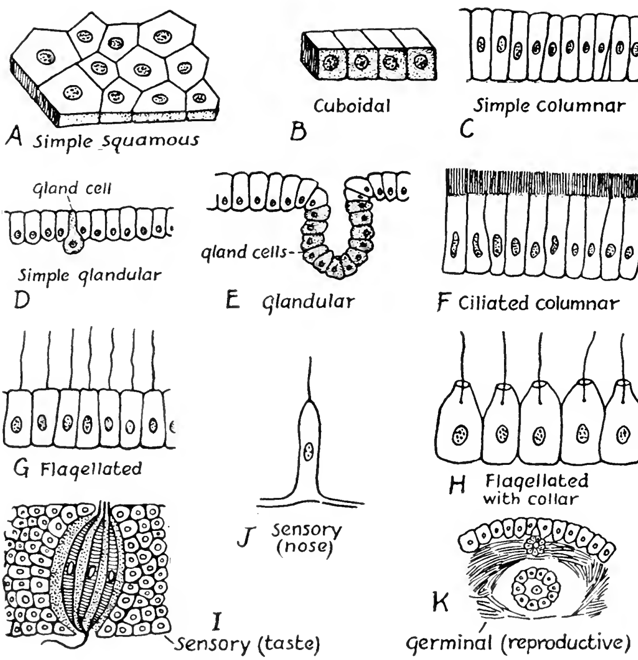


Fig. 11.—Epithelial tissues. The sensory cells (taste) are connected with a nerve below and have sensitive hairs above. In the germinal tissue the origin of the reproductive cell from the epithelial cells can be seen.

B. Connective (Supportive) Tissues (Figs. 12 and 13)

1. RETICULAR	*Fine white fibers* in the form of a *network* for supporting the cells of other tissues in certain organs; examples—spleen, liver, lymph glands, etc.
2. FIBROUS	(a) *Areolar—Minute white fibers frequently in bundles* which form a *network* with a *homogeneous, ground substance* in which are scattered the *connective tissue cells* (rounded, irregular, or spindle shaped); may contain *thicker, single, yellow, elastic fibers;* found surrounding muscles, nerves, etc. (b) *Tendons* and *ligaments—White fibers* which run *parallel* to each other, with cells between them; tendons connect muscles to bones; ligaments connect bones to bones. (c) *Elastic (yellow)*—A preponderance of *single, thick, yellow, elastic fibers* over the less numerous white fibers; found in the blood vessel walls, vocal folds, lungs, etc.
3. ADIPOSE	Certain *rounded cells* are filled with *fat globules* of various sizes; found in various places beneath the skin, around certain organs, etc.
4. CARTILAGE	(a) *Hyaline ("gristle")*—This consists of a *clear, firm, gelatinous, homogeneous matrix* with scattered spaces called *lacunae* (la -ku′ na) (L. *lacuna,* cavity) in which are one or more rounded cartilage cells which secrete the cartilage; examples—ends of long bones and ribs, nose, trachea (windpipe), etc. (b) *Fibrocartilage*—Numerous *fibers* are present in the matrix of this cartilage; examples—external ear, between the vertebrae, etc.
5. BONE	The ground substance, or *matrix, is hardened with calcium carbonate and calcium phosphate; bone cells* are present in the *lacunae* which are connected with *fine canals.* The units of bone construction, known as *Haversian systems,* consist of (a) a *central canal* with an artery, vein, and nerve; (b) *lamellae* made of layers of bony flakes so arranged as to form rough-walled canals which are arranged concentrically in circles or ovals, around the central canal; (c) the *lacunae* or enlarged spaces associated with the lamellae and containing the irregularly shaped *bone cells;* (d) the tiny, wavy, canal-like *canaliculi* which radiate from the lacunae and connect the lacunae with each other and with the central canal; (e) the hard *matrix (bone)* which occupies spaces not previously described and is secreted by the bone cells by the incorporation of lime salts. Bones protect, support, assist in locomotion, serve for attachment of muscles and other tissues, assist in hearing (ear bones), etc.

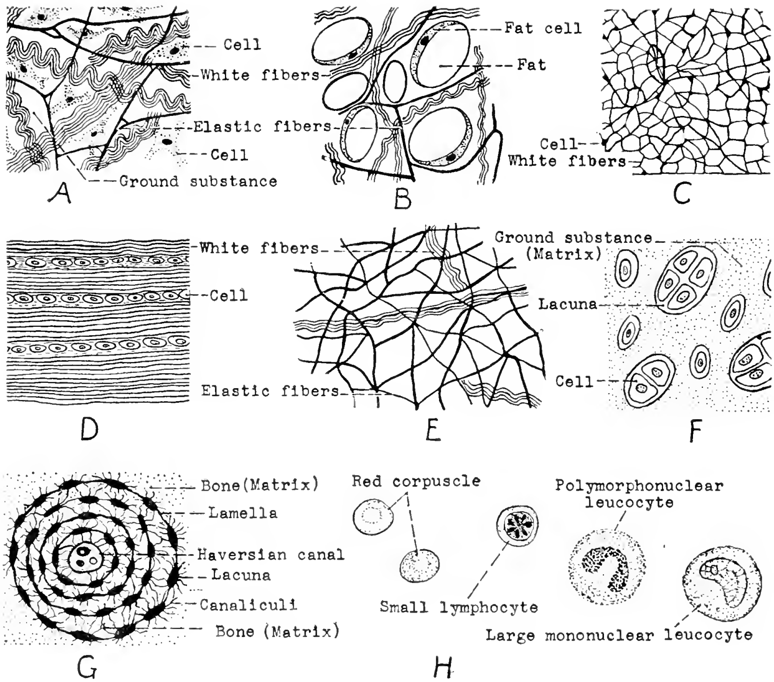


Fig. 12.—Connective tissues. *A,* Areolar (from beneath skin); *B,* adipose (fat); *C,* reticular (from lymph node); *D,* fibrous (from longitudinal section of a tendon); *E,* elastic (yellow); *F,* hyaline cartilage (from end of bone); *G,* osseous (bone) cross section of Haversian system; *H,* blood corpuscles (human). The red blood corpuscle is also known as an erythrocyte; the large mononuclear leucocyte is known as a monocyte.

6. BLOOD AND LYMPH (Fig. 12, H)	The *liquid intercellular matrix* is mobile and is the *blood plasma.* The modified plasma which is outside the blood vessels is the *lymph.* The colorless plasma contains enzymes, hormones, vitamins, foods, wastes, antibodies, and three general types of blood corpuscles: (a) *erythrocytes (red blood corpuscles);* (b) *leucocytes (white blood corpuscles)* of various kinds, which vary as to size, shape and size of the nucleus, kinds of granules in the cytoplasm, etc.; (c) *blood platelets* which are small, irregular, nonnucleated (in mammals) and comparable to the nucleated spindle cells of the frog; the various corpuscles are considered in greater detail in another chapter. Blood carries *foods* to the cells and *wastes* from the cells; carries *oxygen* to the cells and *carbon dioxide* from the cells of the body; carries foods to the endocrine glands which secrete specific *hormones* which are transported to various body parts by the blood; *equalizes temperature* between various body parts; contains *antibodies* which are chemical substances which assist in the body defense in certain diseases; *maintains the acid-alkaline balance* between various body parts; *transports water* and other substances from one part of the body to another; *destroys bacteria* and other foreign particles by *phagocytosis* on the part of certain leucocytes; assists in *blood clotting,* etc.

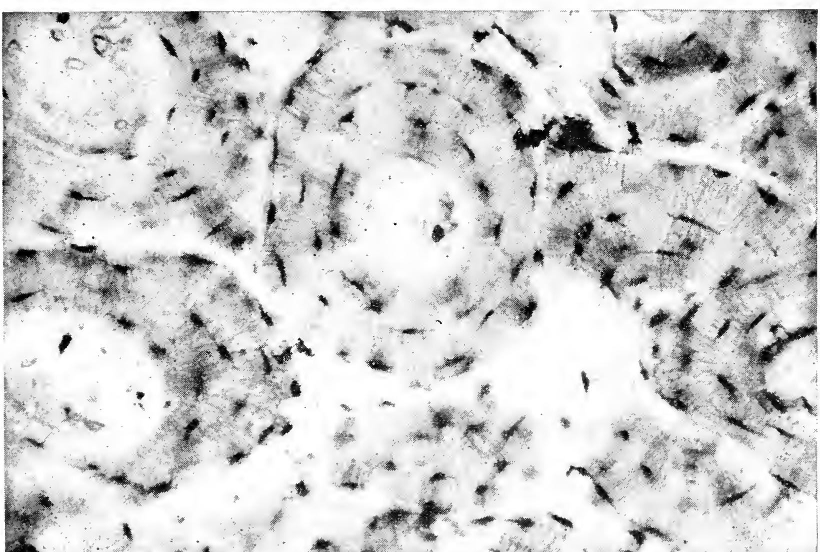


Fig. 13.—Human bone shown in cross section. Note the arrangement of lacunae in concentric lamellae around the Haversian canals. Observe the thread-like canaliculi associated with the lacunae. The bone cells are not clearly visible in the lacunae of such a ground section of bone. (Copyright by General Biological Supply House, Inc., Chicago.)

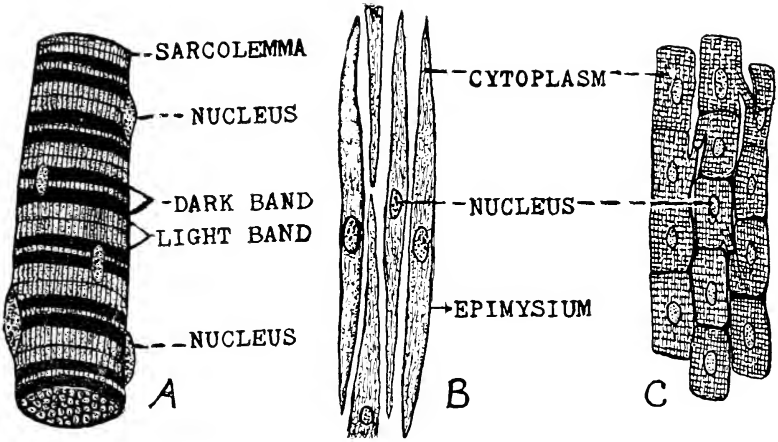


Fig. 14.—Muscle tissues. *A,* Striated (cross-striped); portion of a single cell or fiber; *B,* nonstriated (smooth); several cells; *C,* cardiac (indistinctly striated); several cells. Observe the branchings between the various cardiac cells and the several nuclei in the striated type.

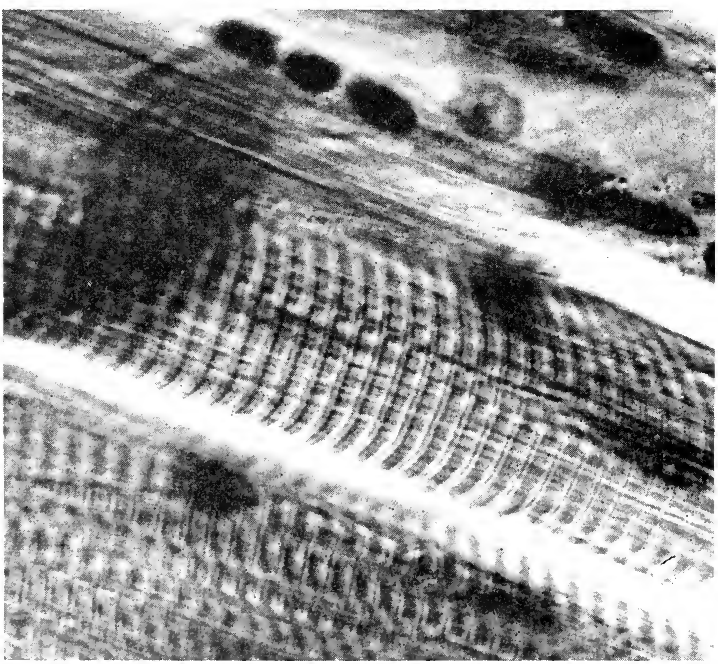


Fig. 15.—Bas relief photomicrograph of striated muscles showing the banded condition at a magnification of 1,000×. (Copyright by General Biological Supply House, Inc., Chicago.)

C. Muscular (Contractile) Tissues (Figs. 14 and 15)

1. SKELETAL	These muscles are *skeletal* (attached to the skeleton) and *voluntary* (subject to the control of the will). Each *cylindroid cell* (muscle fiber) may have rather curved ends and contains *several peripheral nuclei* (multinucleated). *Fine, internal fibrillae (myofibrils)* run parallel to each other and lengthwise of the cell. These cells, at regular intervals, possess alternate *dark and light bands* of different densities which give them their characteristic *striations.* During contraction the light bands increase in width, while the dark bands decrease. Skeletal muscles may *contract more rapidly* than other types of muscles, although they may *fatigue easily.* Each fiber is covered with an elastic membrane, the *sarcolemma* (sar ko -lem′ a) (Gr. *sarx,* flesh; *lemma,* covering), and various fibers are bound together into *muscles* by connective tissues. Muscles are attached to the skeleton by connective tissues known as *tendons* (L. *tendo,* stretch). The more stationary end of a muscle is its *origin* and its more movable part the *insertion.* Skeletal muscles are usually *attached in opposition* so that one may perform a function opposite the other.
2. VISCERAL OR SMOOTH	These muscles are *visceral* (help to form internal, visceral organs) and *involuntary* (not controlled by the will). Each elongated, *spindle-shaped cell* has *one central nucleus* (mononucleated). *Fine, internal, contractile, homogeneous fibrillae* run parallel to the long axis. These muscle *do not have striations* (nonstriated); hence the name *smooth* or *nonstriated.* Visceral muscles *contract slowly* under normal conditions and do not seem to fatigue easily. Each fiber is covered with an *epimysium* (epi -miz′ i um) (Gr. *epi,* upon; *mys,* muscle) which is *not a true sarcolemma.* They are present in the walls of the bladder, blood vessels, etc.
3. CARDIAC	These muscles form the *wall of the heart* (Gr. *kardia,* heart) and are known as *cardiac.* They are *involuntary.* These smaller cells are often *branched* and may be *connected with each other* to form a *syncytium* (sin-sit′ i um) (Gr. *syn,* with; *kytos,* cell), which is a multinucleated association of cells which permit impulses to travel from one cell to another. The *internal, contractile fibrillae* possess *striations* for contraction purposes. The *speed of contraction may be rapid, or rather slow,* depending upon circumstances, with the rate of fatigue being intermediate between the other two types. In this connection it must be remembered that cardiac muscles have alternate periods of contraction, rest, and expansion. There is *no true sarcolemma.* Cardiac muscles are found only in the hearts of vertebrate animals. The striations may not be quite as discernible as in the skeletal muscles.

D. Nervous Tissues (Figs. 16 and 17)

NERVOUS	Nervous tissues are composed of *nerve cells (neurons)*, each with a *single nucleus*. The cells vary greatly in size and shape, as well as in their *cytoplasmic processes* (axon and dendrite). The *axon* (axis cylinder) is long and usually *unbranched* except for occasional side *collaterals*. The *dendrites* (Gr. *dendron*, tree) are usually *much branched*, especially near the neuron, although branches appear to be absent in some instances. The dendrite carries impulses *toward the neuron*, while the axon *carries them away*. The minute gap between consecutive neurons regulates the transmission of impulses between them and is known as the *synapse* (sin′ aps) (Gr. *synapsis*, union). Neurons, depending on the number of cytoplasmic processes, may be classed as *unipolar* (one), *bipolar* (two), *multipolar* (more than two processes). A *nerve* consists of the processes of nerve cells united into a sort of "cable." A *ganglion* is an enlargement composed of the nerve cells and serves as a center of nerve influence outside of the central nervous system. Nerve fibers (processes of neurons) may be classed as (a) *medullated (myelinated)* when they are surrounded by a noncellular, fatty *medullary sheath (myelin sheath)* with constrictions at intervals by the *nodes of Ranvier* and (b) *nonmedullated (unmyelinated)*, in which the nerve fiber *lacks the medullary sheath*. A thin nucleated *neurilemma* (nu ri -lem′ a) (Gr. *neuron*, nerve; *lemma*, cover) may cover certain nerve fibers, such as peripheral nerves going to skin, muscles, viscera. A brain (cerebral ganglion) and spinal cord are composed of various kinds of neurons with processes of various types.

Parts of the Nervous System (Figs. 16 and 17)

- Central nervous system
  - Brain
    - Cerebrum
    - Cerebellum
    - Midbrain
    - Medulla oblongata
    - Pons varolii
  - Spinal cord
- Peripheral nervous system
  - Cranial (brain) nerves and their end organs
  - Spinal nerves and their end organs
  - Sympathetic nervous system with its various subdivisions

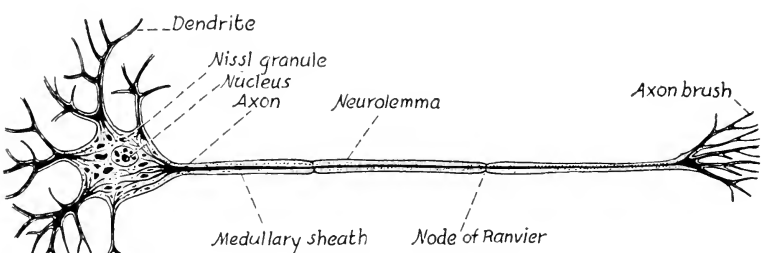


Fig. 16.—Nervous tissue. A nerve cell or neuron is shown much enlarged and somewhat diagrammatically.

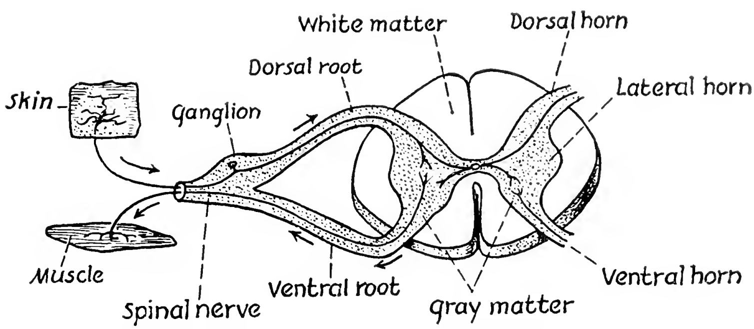


Fig. 17.—Spinal cord in cross section, showing the pathways through the cord and the origin of the spinal nerves. Arrows indicate the pathways over which impulses might travel from the skin through the cord and back to a muscle.

II. PLANT TISSUES

A *plant tissue* is a group of cells commonly of similar structure and performing essentially the same function. An *organ* is composed of various tissues which together perform interrelated functions. For example, a leaf is an organ composed of various types of tissues. Naturally, the simpler, lower types of plants do not have tissues, or, if they do, the tissues are quite simple. The cells of plants show great variations in structure and size, both of which influence the functions of these cells in the physiology of the plant. Plant tissues may be *simple* or *complex* (Fig. 18). The phloem and xylem tissues are considered to be complex because several kinds of cells occur in their construction, while other tissues described below are considered to be simple because they are composed of a single kind of cell. Certain tissues, such as the rapidly growing meristematic tissues, give rise to other tissues and might be considered temporary, while the other tissues remain much the same after being formed and might be considered permanent tissues. When tissues are studied casually and hurriedly, they may appear to be alike, but a scientific, microscopic study shows that because of differences they may be classified into rather different types (Fig. 18).

Types of Plant Tissues (Figs. 18 and 19)

1. MERISTEMATIC (mer is te -mat′ ik) (Gr. *meristes,* divide)
2. EPIDERMAL (ep i -der′ mal) (Gr. *epi,* upon; *derma,* skin)
3. PARENCHYMA (par -eng′ ki ma) (Gr. *para,* beside; *engchyma,* infusion)
4. COLLENCHYMA (kol -eng′ ki ma) (Gr. *kolla,* glue; *engchyma,* infusion)
5. SCLERENCHYMA (skler -eng′ ki ma) (Gr. *skleros,* hard; *engchyma,* infusion)
   A. SCLERENCHYMA FIBERS
   B. STONE CELLS (SCLEREIDS)
6. CORK (kork) (Span. *alcorque,* cork)

7. XYLEM (zi′ lem) (Gr. *xylon,* wood)
   A. TRACHEIDS (trak′ e id) (L. *trachia,* windpipe, or tube)
   B. TRACHEAL VESSELS (TUBES)
   C. XYLEM PARENCHYMA
   D. XYLEM (WOOD) RAY CELLS
   E. XYLEM (WOOD) FIBERS
8. PHLOEM (flo′ em) (Gr. *phloios,* smooth bark)
   A. SIEVE TUBES
   B. COMPANION CELLS
   C. PHLOEM PARENCHYMA
   D. PHLOEM RAY CELLS
   E. PHLOEM FIBERS

Kinds of Plant Tissues (Figs. 18 and 19)

	SHAPE, SIZE, AND ARRANGEMENT OF CELLS	LOCATION AND FUNCTIONS
1. MERISTEMATIC	*Small, thin walled,* frequently *cube shaped,* actively *dividing by cell division* (mitosis) to form and differentiate permanent, mature tissues; cells closely packed and usually with *no intercellular spaces.*	Found near the tips of roots and in buds of stems (terminal, or apical meristems), between bark and wood of trees (cambium), in bark of trees (cork cambium), or where extensive growth occurs; commonly called "growth" tissues.
2. EPIDERMAL	Usually *one cell thick;* outer cell wall often thickened with a waxy, waterproofing substance, *cutin;* cells usually *colorless,* except crescent-shaped *guard cells,* which contain green *chloroplasts* and which control the epidermal pores, or *stomata* (stom′ a ta) (Gr. *stoma,* opening) for exchange of gases; occasionally, red, purple, or bluish pigments in cell sap may give color to leaves, etc. (Figs. 18, 19).	Found on surface of leaves, flower parts, fruits, young roots, and stems; conserve moisture and give mechanical protection against injury, entrance of parasites, and poisonous materials.
3. PARENCHYMA	Usually *spherical or ovoid,* but sometimes cylindroid, with *large central vacuole;* usually *thin cell walls;* numerous *intercellular spaces;* protoplasm may remain alive for long periods of time.	*Very common and abundant,* occurring in practically all parts of higher plants; colorless parenchyma of roots and stems *store water and foods;* green, chloroplast-bearing cells of internal tissues of leaves *photosynthesize foods;* when parenchyma contains chloroplasts, it is called *chlorenchyma* (klor -eng′ ki ma) (Gr. *chloros,* green; *engchyma* infusion).
4. COLLENCHYMA	May be somewhat *elongated,* with pointed, blunt, or oblique ends; *cell walls thickened* with *cellulose* at corners or elsewhere; protoplasm may remain alive for long periods.	Commonly occur beneath the epidermis in younger parts of plants as well as in certain older parts (petiole of leaf); give *support* and *strength.*

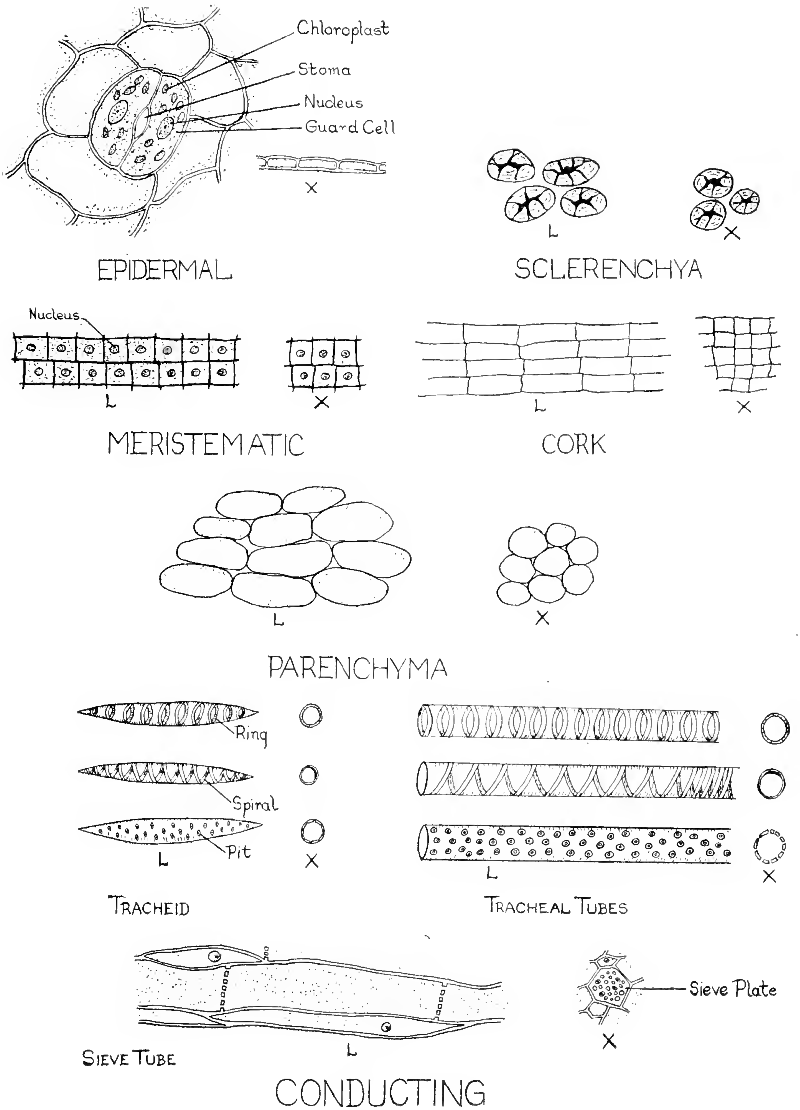


Fig. 18.—Plant tissues shown somewhat diagrammatically. The sclerenchyma tissue shown is a stone cell (sclereid) type of mechanical tissue. The conducting tissues shown include three types of tracheids (found in xylem), three types of tracheal tubes (found in xylem), and sieve tubes with their adjacent, nucleated companion cells (found in phloem). *L*, Longitudinal section; *X*, cross section.

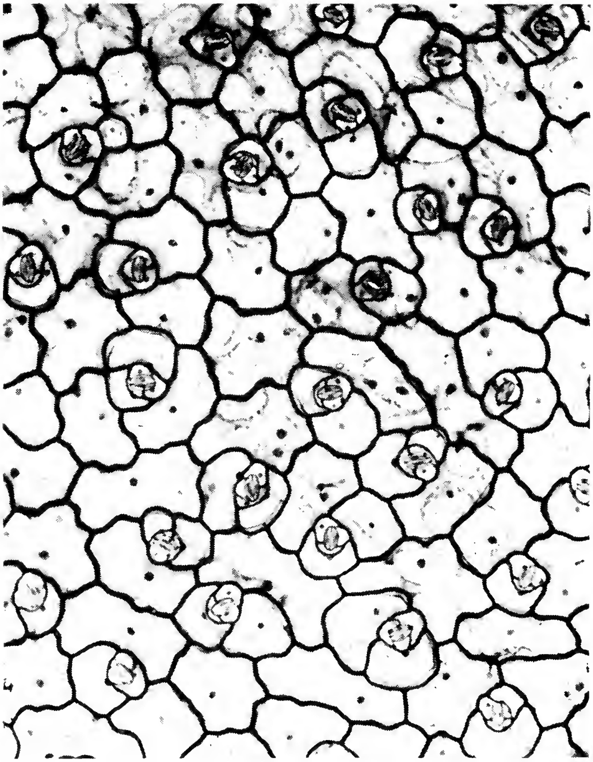


Fig. 19.—Surface view of the epidermis of a plant (*Sedum*), showing the openings called stomata with their surrounding guard cells. (Copyright by General Biological Supply House, Inc., Chicago.)

Kinds of Plant Tissues (Cont'd)

	SHAPE, SIZE, AND ARRANGEMENT OF CELLS	LOCATION AND FUNCTIONS
5. SCLERENCHYMA	*Cell walls* tough and extremely *thickened* by *cellulose* and *lignin;* walls possess thin areas, known as *pits,* whose borders or edges are simple and unthickened *(unbordered pits);* protoplasm dies when cell reaches maturity. Two types of sclerenchyma cells: (a) *Sclerenchyma fibers,* which are *elongated, pliable, elastic cells* with pointed ends and great strength. (b) *Stone cells (sclereids),* which are not elongated but may be irregular in shape, with length and width about equal; minute *pit canals* extend through thickened walls.	Provide *mechanical support* and *strength;* stone cells abundant in shells of nuts, in gritty masses in fruits (pears), in seed coats, and in bark of trees, etc.; because of flexibility, strength, and cohesive ability of fibers, some of them are used in making ropes, twine, mats, and other textiles (fibers of flax, hemp, etc.).
6. CORK	*Cell wall* contains a waxy, waterproofing material called *suberin;* cells frequently rectangular and regularly arranged; arise from cork cambium; protoplasm dies soon after cell is formed.	Forms outer bark of stems and roots of woody plants to give *protection* against mechanical injury and excessive evaporation; may also be present in other plant structures for same purposes.
7. XYLEM	*Complex, woody tissues* composed of *several kinds of cells* which are usually *elongated* and with *thickened walls.* Xylem composed of: (a) *Tracheids,* which are *elongated, tapering, single cells* with a fairly large lumen (cavity); *cell walls* thickened by *spirals* or *rings* of cellulose and lignin and often possess thin areas called *bordered pits* (edge of pit thickened); protoplasm frequently short-lived; common in cone-bearing trees, etc. (b) *Tracheal vessels (tubes),* which are *long, multicellular tubes* composed of chains of long, cylindroid cells whose adjacent ends have dissolved and fused; *cell walls* have *thickenings* and *bordered pits* as do tracheids. (c) *Xylem parenchyma* which is much like ordinary parenchyma with somewhat thicker walls. (d) *Xylem (wood) ray cells* which are chiefly parenchymatous tissue to conduct materials radially in stems, etc. (e) *Xylem (wood) fibers* which are elongated, *fiberlike cells* characterized by *bordered pits.*	*Xylem* (wood) functions as *conducting tissue,* transporting water, mineral salts, etc., *upward;* thickened areas of tracheids, vessels, etc., give *strength and support;* tracheids common in cone-bearing evergreens; tracheal vessels most abundant in higher plants; xylem parenchyma *stores foods;* ray cells *store foods* and *conduct materials radially* across stems, etc.; xylem fibers give *strength* and *support.*

Kinds of Plant Tissues (Cont'd)

	SHAPE, SIZE, AND ARRANGEMENT OF CELLS	LOCATION AND FUNCTIONS
8. PHLOEM	*Complex tissues* composed of *several kinds of cells; phloem* always contains *sieve tubes* and *parenchyma,* and other three kinds of cells described may, or may not, be present, depending on specific tissue. Phloem may be composed of: (a) *Sieve tubes,* which are elongated *rows of thin-walled, cylindroid* living *cells* whose end walls *(sieve plates)* contain sievelike *pores;* protoplasm continuous from cell to cell through sieve pores; in mature sieve tube cells living protoplasm lacks nuclei. (b) *Companion cells,* which are *adjacent to sieve tubes,* are somewhat *shorter* and *smaller* than latter, and possess *prominent nuclei.* (c) *Phloem parenchyma* much like ordinary parenchyma and always present in phloem. (d) *Phloem ray cells* which are parenchymatous to conduct materials radially. (e) *Phloem fibers* which are elongated cells whose structure gives strength.	*Phloem* conducts *foods* manufactured in leaves *downward* through stems and roots; companion cells common in flowering plants and because of pores between them and sieve tubes, former may assist in *conducting* and *storing foods;* phloem parenchyma *stores foods;* phloem ray cells *store foods* and *conduct materials radially* in stems, etc.; phloem fibers give *support* and *strength.*

III. ORGANS

An organ is an association of different tissues which act together to perform some specific function. For instance, the human arm is an organ of motion consisting of such tissues as bone, cartilage, muscle, blood and lymph, connective, vascular (blood vessels), nervous, epithelial, and adipose. Many organs are usually required for performing a particular function, each organ contributing some part, large or small, to the functioning of the whole. All organs tend to function together in a more or less harmonious manner if the living organism is normal and healthy. If ill or defective, there is a maladjustment of the interaction and interdependence of the various organs of that individual.

The leaf of a plant is an organ, composed of such tissues as epidermal, chlorenchyma, collenchyma, xylem, phloem, etc.

IV. SYSTEMS

A system is an association of different organs which perform a specific function. For instance, the digestive system consists of such organs as the tongue, teeth, salivary glands, pharynx, esophagus, stomach, large and small intestines, liver, pancreas, and the gall bladder.

QUESTIONS AND TOPICS

1. Define (1) tissue, (2) organ, and (3) system.
2. What role does heredity play in the process of tissue formation?
3. Give the distinguishing characteristics and location of the following tissues: (1) epithelial, (2) nervous, (3) connective, and (4) muscular.
4. In nervous tissue describe the structure and functions of (1) neuron, (2) dendrite, (3) axon, (4) synapse, (5) nerve, (6) nerve pathway, (7) ganglion, and (8) brain.
5. Why is blood considered a tissue? How does it differ from other tissues? Should it be classed with the connective tissues or separately? Why? Why might blood be called a compound rather than a simple tissue?
6. Contrast and give examples of involuntary and voluntary muscle tissues. Do involuntary muscles react without a stimulus? Why should the muscles of the heart be involuntary? Which of the three groups of muscles are striated?
7. Do you consciously send impulses to your skeletal muscles when you walk?
8. What types of muscles are used in each of the following: (1) breathing, (2) pumping blood, (3) swimming, and (4) digesting foods?
9. Explain what happens in muscles when a so-called habit has been formed.
10. Contrast animal tissues with plant tissues. Which plant tissues perform functions which resemble those performed by animal tissues? Give specific examples.
11. What role does mitosis play in the development of tissues?
12. Give the distinguishing characteristics and functions of each kind of plant tissue.

SELECTED REFERENCES

Cameron: Tissue Culture Technique, Academic Press, Inc.
Child: Individuality in Organisms, University of Chicago Press.
Cowdry: General Cytology, University of Chicago Press.
Dawson: Lambert's Histology, The Blakiston Co.
Elwyn and Strong: Bailey's Textbook of Histology, Williams and Wilkins Co.
Haden: Principles of Hematology, Lea & Febiger.
Maximow and Bloom: Histology, W. B. Saunders Co.
Nonidez and Windle: Histology, McGraw-Hill Book Co., Inc.
Sharp: An Introduction to Cytology, McGraw-Hill Book Co., Inc.
Sharp: Fundamentals of Cytology, McGraw-Hill Book Co., Inc.
Stiles: Handbook of Microscopic Characteristics of Tissues and Organs, The Blakiston Co.
Weiner: Blood Groups and Transfusions, Charles C Thomas, Publisher.

Chapter 5

HOW CELLS DIVIDE— INDIRECT CELL DIVISION OR MITOSIS (ANIMAL AND PLANT)

One of the most interesting and important phenomena in living cells is the process of mitosis in which the cells undergo a series of very complicated stages of division. The so-called *resting stage* occurs between two successive periods of mitosis. The cell during this stage is resting only as far as actual cell division is concerned, but metabolism and other cellular activities are progressing normally. It is during this stage that young cells grow to their normal, mature size. Mitosis in animal and plant cells occurs in much the same general way, although, as might be expected, there are certain fundamental differences. Both of these methods of mitosis will be described and contrasted.

A *resting cell* in animals may be characterized by the following: (1) the nucleus is more or less spherical (Fig. 8); (2) irregular granules of chromatin of various sizes and shapes are suspended in netlike fashion within the nucleus; (3) a pair of granular centrioles is usually found within the centrosome (central body); (4) the nuclear membrane and the nucleolus are present; (5) the cytoplasm appears to be normal.

I. MITOSIS IN ANIMAL CELLS (Figs. 20 and 21)

The entire process of mitosis in animal cells is a continuous one but for convenience is divided into four phases (Fig. 20): (1) prophase, (2) metaphase, (3) anaphase, and (4) telophase.

A. Prophase (Gr. *pro,* before or first; *phasis,* appearance) (Fig. 20, *A-D*)

In animal cells the divided *centrosomes* migrate away from each other around the nuclear wall until finally they are at opposite sides of the original nucleus. Each centrosome is surrounded by a halo of radiating,

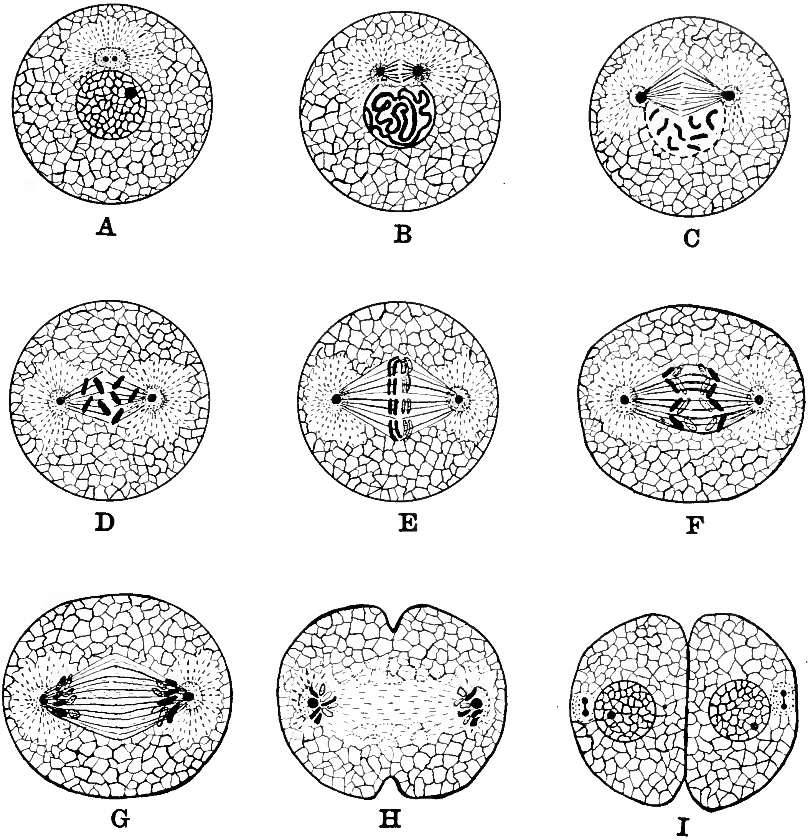


Fig. 20.—Animal cell mitosis in which the chromosome number is assumed to be 8. *A,* Prophase (beginning), with chromatin granules in netlike arrangement; centrosome dividing and surrounded by the astral rays (asters); *B,* prophase (early), with the chromatin consolidating and beginning to form a definite number of threadlike bodies; centrosomes moving farther from each other; spindle figure (spindle) arising between them; *C,* prophase (late) with nuclear membrane disappearing; each chromosome, under highest magnification, appearing as a double structure because of its two parallel strands (chromatin elements) in contact with each other; *D,* prophase (later), with nuclear membrane absent, centrosomes at opposite ends of the cell, chromosomes distributed on the spindle; *E,* metaphase, in which the chromosomes are arranged in equatorial plate, and each chromosome splits lengthwise into two similar parts; *F,* anaphase (early), in which half of each original chromosome moves over the spindle toward opposite centrosomes; *G,* anaphase (later), in which the two sets of chromosomes continue to travel over the spindle toward each centrosome and aster; *H,* telophase (early), in which the chromosomes reach their respective centrosomes and there gradually lose their distinctive chromosome characteristics; spindle and asters disappearing; cytoplasm starts to divide; *I,* telophase (later), in which the cytoplasm is completely divided by the newly formed cell membrane; nuclear wall and entire nuclear contents reappear; centrosomes are already dividing in preparation for the next cycle of cell division. Each of the newly formed cells will now grow to normal size and, sooner or later, will undergo the process of mitosis.

semibroken lines of force, known as the *aster,* which emanate out into the cytoplasm. The centrosomes also form a small, lightly staining set of fibers, known as the *spindle,* between them as they migrate. This spindle becomes more clearly defined in later stages. The asters and spindle both stain lightly and may be called the *achromatic* (ak ro-mat′ ik) *figure* or *amphiaster* (Gr. *a,* without; *chromatin,* staining well). The spindle eventually occupies the position where the original nucleus has been.

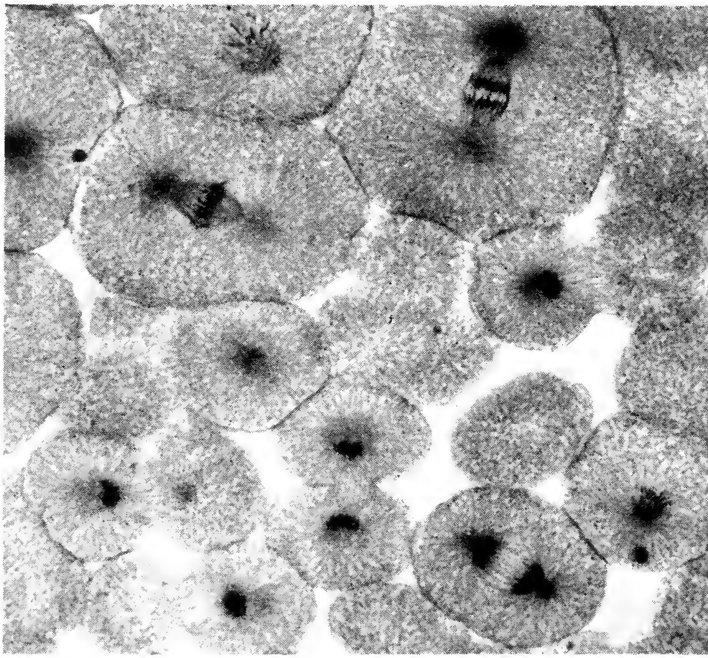


Fig. 21.—Photograph of a section of the embryo of a whitefish showing many figures of the various stages of mitosis. Note particularly the chromosomes, spindle, asters, etc. (Copyright by General Biological Supply House, Inc., Chicago.)

The nuclear membrane disappears about this time. The chromatin granules within the original nucleus lose their netlike appearance and form a specific number of bodies known as *chromosomes.* Each cell of a specific species of animal or plant has a definite number of characteristic chromosomes, provided the cell is normal. The chromosomes carry the genes or determiners of heredity.

Finally, the chromosomes migrate in an orderly manner toward the middle of the original nucleus and arrange themselves on the center of the spindle, known as the *equatorial plate.* The latter lies approximately equidistant between the two centrosomes.

B. Metaphase (Gr. *meta,* between or after; *phasis,* appearance) (Fig. 20, *E*)

This stage is known as the equilibrium phase with the chromosomes lined up across the middle of the equatorial region and balanced between the two opposing forces of the opposite centrosomes. Each chromosome now *splits lengthwise into two equal parts.* This is very necessary if the linear arrangements of the hereditary genes contained within the chromosomes are to be equally divided between the two future cells. The chromosomes which have each divided lengthwise now separate into two exactly similar groups.

C. Anaphase (Gr. *ana,* up; *phasis,* appearance) (Fig. 20, *F-G*)

In this stage the two equal halves of each chromosome migrate from the equatorial region along the spindle toward the opposite centrosomes. Some of the newly formed chromosomes move slowly, while others go rapidly. The part of the spindle to which the chromosomes are attached is known as the *attachment fibers of the spindle.* The part of the spindle over which the chromosomes have already traveled is known as the *used spindle* or *interzonal connecting fibers* which are visible between the two groups of migrating chromosomes. In later anaphase stages the cell membrane constricts, still later to divide the cell proper into two parts. In certain cells, at least, a plate of small granules appears at the position of the former equatorial plate. This plate becomes more pronounced and may play a part in dividing the cell at that point (Fig. 20).

D. Telophase (Gr. *telos,* end; *phasis,* appearance or aspect) (Fig. 20 *H-I*)

This stage is a reconstruction stage. The entire cell now is divided at the equatorial plate of the spindle. Each half cell (daughter cell) eventually becomes entire and normal with the characteristics of the original parent cell. The nucleus again becomes spherical. The nuclear membrane reappears. The asters disappear completely. The chromosomes change into an irregular network of chromatin granules again as found in the original nucleus. The spindles disappear by the end of this stage. Each daughter cell now grows to approximately the same size as the original parent cell. Later, the process of mitosis will repeat itself in each of the two previously formed daughter cells.

II. MITOSIS IN THE CELLS OF FLOWERING PLANTS (Figs. 22 and 23)

Mitosis in the cells of the higher or flowering plants resembles the process described for animals, except for minor differences in certain stages (contrast Figs. 20 to 23).

A. Prophase (Fig. 22, *2-5*)

In the so-called resting stage (nondividing), the nucleus is separated from the surrounding cytoplasm by the *nuclear membrane;* the deeply stained nuclear granules are in the form of *chromatic strands.* When a

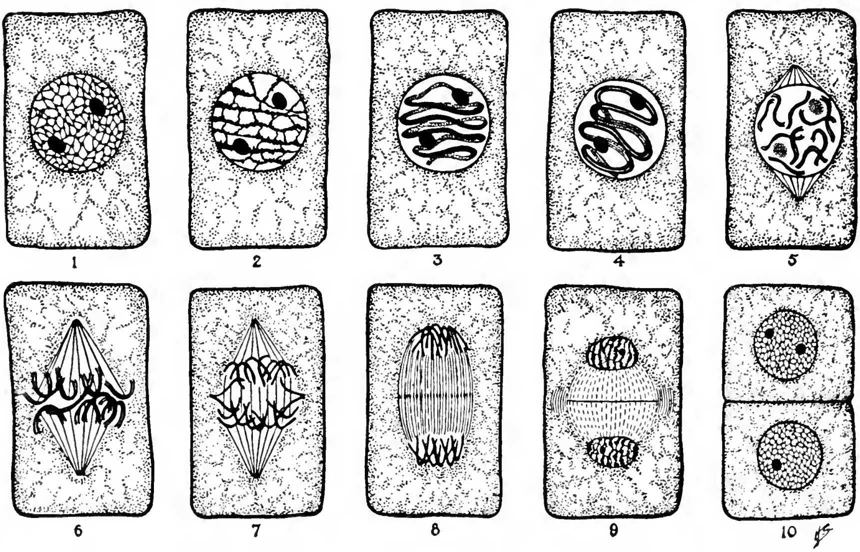


Fig. 22.—Mitosis in plants. *1,* Before mitosis begins, strands of chromatin appear as a granular network within the nucleus. *Prophase stages: 2-5,* Network tends to disappear and the chromatic strands thicken and shorten, eventually forming a specific number of chromosomes; each chromosome consists of two darkly stained chromatids more or less in contact with one another and which will separate when each chromosome divides lengthwise later; in stage *5* the spindle is forming and the nucleolus disappearing. *Metaphase stage: 6,* Chromosomes line up on equatorial plate in the middle of the spindle which has just been completed. *Anaphase stages: 7,* Each chromosome divides lengthwise into two equal parts. Each new or daughter chromosome moves along the spindle toward opposite ends of the cell. *8,* Chromosomes at ends of the cell; cell wall begins to form as minute swellings appear on each spindle fiber at the equatorial plate. *Telophase stages: 9,* Chromosomes disintegrate again into a network of chromatin granules; nuclear membrane appears; cell wall continues to develop; spindle disappears. *10,* Mitosis complete; cells similar to the original cell but smaller; nuclei and cell wall complete. The two daughter cells will now grow to normal size. (Copyright by General Biological Supply House, Inc., Chicago.)

nucleus is to divide, the chromatic strands thicken and shorten, finally forming a definite number of strands, known as *chromosomes.* Each *chromosome* contains two parallel *chromatids* which are more or less in contact with each other. At times the chromatids are surrounded by a lighter matrix; at other times the matrix is not visible.

The first visible signs of mitosis in a plant cell is the shortening and thickening of the granular *chromatic strands* to form a specific number of *chromosomes* (Fig. 22, *5, 6*). The number of chromosomes in the normal cells of any one species of plant is the same. In the onion, for instance, there are sixteen chromosomes in each cell. In other plants the number may be different but again specific for that particular plant. The chromosomes gradually become thicker and shorter (Fig. 22, *6, 7*). During this stage the nuclear membrane completely disappears, thus permitting the chromosomes to move somewhat freely within the cell. In the nuclear region appears a spindle-shaped group of fibers, the *spindle,* extending from one end of the cell (cell pole) to the opposite pole. No asters and no centrosomes are present in higher plants as they are in animals.

B. Metaphase (Fig. 22, *6*)

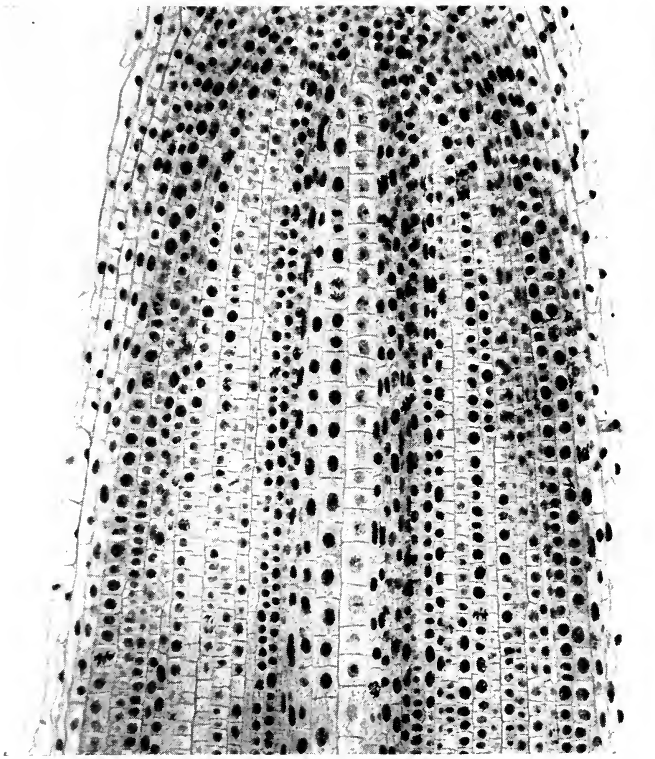
In this stage the chromosomes localize themselves on the middle or equatorial plane of the spindle. The halves of each chromosome, formed by *longitudinal division,* now move along the spindle toward opposite poles of the cell. One-half of each original chromosome with its contents goes to each pole.

C. Anaphase (Fig. 22, *7, 8*)

In this phase the newly formed chromosomes continue their migration toward the poles where they will eventually be localized.

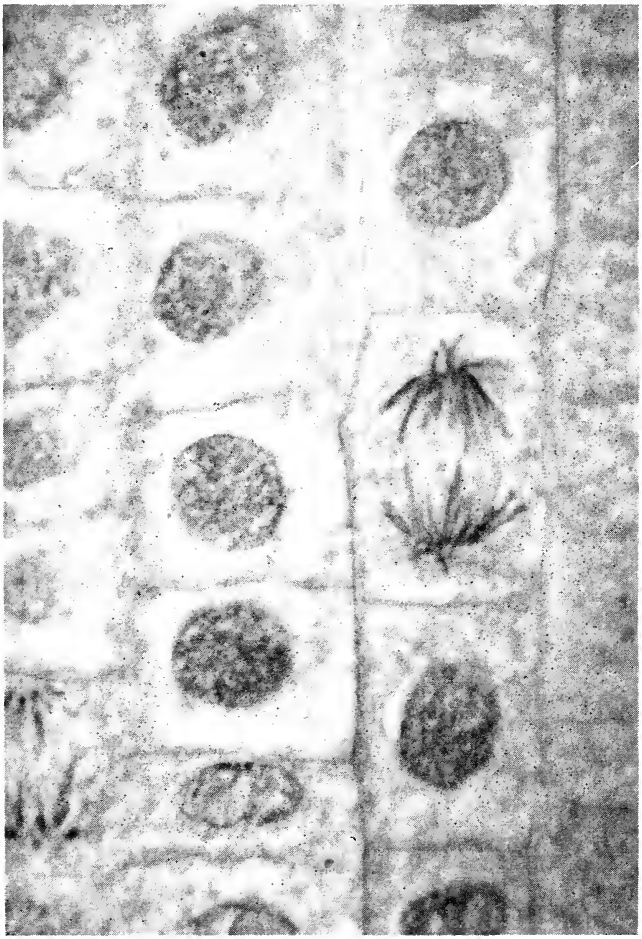
D. Telophase (Fig. 22, *9*)

In this final stage the chromosomes are crowded together at their respective poles. Each chromosome changes into a fine network of chromatin material which somewhat resembles that of the original parent cell. A new *nuclear membrane* is formed in each new cell. The remaining nuclear contents are also formed. A partition called the *cell plate* forms across the middle of the original cell. The cell plate splits into two parallel plates between which is formed the new *cell wall.* The latter divides the original cell into two daughter cells. There is no indenta-



A.

Fig. 23.—Various stages of mitosis as shown by photographs of sections of the root tip of the onion (*Allium*). *A,* Low power; *B,* high power. (Copyright by General Biological Supply House, Inc., Chicago.)



B.

Fig. 23 (Cont'd).—For legend, see opposite page.

tion of the cell wall as in the mitosis of animal cells (contrast with Fig. 20). The two daughter cells continue to reform their missing parts and increase in size (Fig. 22, *10*).

IMPORTANT FACTS REGARDING MITOSIS

In the process of mitosis new cells always arise from "parent" cells. The mechanical aspects of mitosis are remarkable, complicated, and at present not understood completely. The nucleus undergoes the more visible changes during mitosis. These changes are in all probability both chemical and physical. Undoubtedly the surrounding cytoplasm also plays an important role in mitosis, although the exact nature of it is at present unknown. At certain stages the nucleoplasm and cytoplasm are not separated by the usual nuclear membrane.

During the entire process of mitosis, there is a continuity of chromatin in some form or other from the original parent cell to the two daughter cells. The chromatin is divided accurately and equally between the newly formed cells. Chromatin transmits hereditary genes from one cell to others, and also from the parents of one generation to the offspring of the next or following generations. In this way chromatin materials are responsible for the inheritance of certain characteristics which are passed from one cell to the next and at the proper time will determine that particular characteristic in the living organism.

The first signs of mitosis (a) in animal cells are the division and migration of the centrosomes and (b) in plant cells, the formation of chromosomes from the strands of chromatin granules. Later, in the telophase stages, the cell membrane of animal cells indents to form the cell membrane between the daughter cells; the cell wall between daughter cells of plants is formed by an accumulation of granules along the equatorial plate without an indentation of the original cell wall (Figs. 20 and 22).

Each species of plant or animal has a definite number of chromosomes which appear when the cells of that particular organism divide. Most animals and plants have an even number of chromosomes (occur in pairs), although a few species have an odd number in their cells. (For a more complete table showing the numbers of chromosomes in cells, see the chapter on Heredity.)

Mitosis plays an important role in growth. Living organisms grow either by an increase in the number of cells (by mitosis) or by an increase in the size of cells already present. In many cases a combination of these two methods results in the growth of the organism. The formation of the various tissues and organs in an embryo is associated with properly regulated and controlled mitosis. The rate of cell division is affected by the age of the organism, usually being more rapid in the younger and slower in the older.

Mitosis assists in the repair of tissues and restoration of lost parts of living organisms. Certain tissues are repaired rather easily, while others are repaired with difficulty or not at all. It is unknown what stimulates the cells to repair or what stops them at the proper time so that there is no overproduction of cells.

Certain abnormalities and diseases of animals and plants are due to abnormal cell divisions. The causes of these abnormal mitoses are probably internal or external influences which are not well understood at this time. This type of mitosis is the cause of such conditions as extra toes and fingers and certain kinds of cancerous growths. One way to attack the diseases of the latter type is to find out what causes the cells to behave abnormally and divide uncontrollably rather than attempt to treat such diseases after they have started.

Mitosis, at least in certain organisms, shows a marked tendency to occur at certain hours of the day or night. In the onion root tip the maximum number of cell divisions occurs around 1 and 11 P.M.; the minimum number of cell divisions, around 7 A.M. and 3 P.M. In the root tips of the pea (Pisum) there are three cell division maxima, 1 P.M., 5 P.M., and 5 A.M., and three cell division minima, 11 A.M., 3 P.M., and 9 P.M. These were described by Friesner in 1919 and 1920.

The duration of the various phases of mitosis has been determined for a few species. The accompanying table summarizes the results for various temperatures. These data are based on the work of Laughlin in 1919.

DURATION OF VARIOUS PHASES OF MITOSIS IN ALLIUM

CELL STUDIED	TEMPERATURE	MINUTES REQUIRED				
		PROPHASE	METAPHASE	ANAPHASE	TELOPHASE	TOTAL TIME
Root tip of onion (Allium)	10° C.	88.0	1.4	3.0	4.6	97.0
	20° C.	74.0	1.0	2.5	4.0	81.0
	30° C.	55.0	0.3	1.0	1.5	57.8

QUESTIONS AND TOPICS

1. Define mitosis in your own words. What happens in each stage?
2. Is the process of mitosis continuous or does it stop at certain intervals?
3. How long does it take an average cell to go through each of its stages of mitosis? What factors might influence this rate of cell division?

4. Why is it so essential that the individual chromosomes divide lengthwise during the metaphase stage?
5. When each chromosome divides lengthwise, what causes each resulting half to migrate toward opposite ends of the cell?
6. What are the controlling forces which start and stop the process of mitosis?
7. When injured tissues repair themselves by mitosis, what starts and stops the process? What is happening when injuries fail to repair?
8. What is the probable relationship between mitosis and cancer? Suggest a method of preventing this disease.
9. Why do we study young tissues in mitosis? What, in general, is the rate of mitosis in older tissues?
10. What is the relationship between mitosis and heredity?
11. List the chief differences between the process of mitosis in animals and plants.

SELECTED REFERENCES

Schrader: Mitosis: The Movements of Chromosomes in Cell Division, Columbia University Press.

White: The Chromosomes, Chemical Publishing Co., Inc.

Chapter 6

PROPERTIES AND ACTIVITIES OF LIVING PROTOPLASM

I. PHYSICAL PROPERTIES OF PROTOPLASM

The "living" substance of plants and animals is known as *protoplasm* (pro′ to plazm) (Gr. *protos,* first; *plasma,* moulded). We consider an organism to be alive when certain activities within the protoplasm result in certain specific, discernible properties and reactions or behaviors which we have decided are characteristic of living beings. Likewise, when these activities within the protoplasm cease, with the cessation of certain reactions and properties, we consider the organism to be dead. Life then might be considered in terms of relative activities of the protoplasm of which living organisms are composed. It has even been theorized that life and death may possibly be relative phenomena. Regardless of this, we know that all things, both nonliving and living, are composed of matter. Matter might be defined as any solid, liquid, or gas which occupies space. From this viewpoint the matter which composes a living organism is the same matter which that dead organism contains except that it is probably rearranged and thus has taken on different properties and activities.

Possibly a beginning student in biology may believe that he will be able to see "life" if he merely views living protoplasm highly magnified with a microscope. So far, scientists with the best of equipment have been unable to do so. What have they seen? They have merely observed certain characteristics displayed by that living protoplasm, as a consequence of which they conclude that such protoplasm is alive. Just because scientists cannot see "life" or cannot secure the ultimate answer as to what life is is no justifiable reason for not studying living protoplasm to get as much reliable information as possible concerning it. A scientist takes things as they are and as he finds them, and by careful observations and experiments, he secures additional data which may take him only a small step in advance. Progress is a series of such consecutive, progressive advances. What one scientist discovers may be the stepping-stone for the discoveries of other scientists.

What are some of the physical properties of protoplasm when viewed with high magnifications of the microscope? Protoplasm usually appears to be a *colorless, odorless, jellylike material, with granules and globules of various shapes and sizes, which is constantly varying in appearance and consistency.* Many colorless structures are rendered more visible by the application of various dyes which stain certain parts and not others. Protoplasm is *slightly heavier than water* because of the additional substances of which it is composed. It is a *somewhat viscous semifluid* which under certain conditions may display internal, *flowing ("streaming") movement.* Protoplasm differs in consistency at different times and also in appearance. The same protoplasm may appear quite different when studied by different methods. When the inherent variabilities of protoplasm and the different methods of studying it are taken into consideration, we may have at least partial explanations for the differences of opinion among the various investigators as to the physical structure of protoplasm.

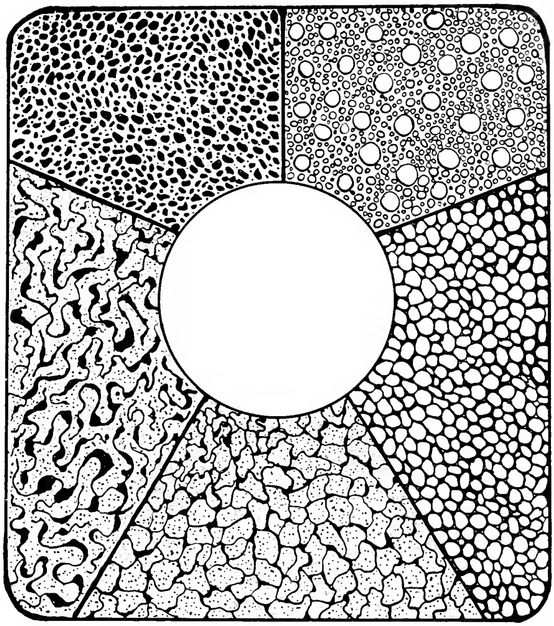
Theories Regarding Physical Structure

Some of the *theories* which have been proposed from time to time regarding the *physical structure of protoplasm* are (1) *granular* (gran′ u-lar) (L. *granum,* grain), in which aggregates of minute *granules* are distributed in a liquid medium (Fig. 24, *A*); (2) *fibrillar* (fi -bril′ ar) (L. *fibrilla,* small fiber), in which small *fibers* are present in a liquid medium (Fig. 24, *B*); (3) *reticular* (re -tik′ u lar) (L. *reticulum,* little net), in which the fibers appear as a *network* embedded in a liquid material (Fig. 24, *C*); (4) *alveolar* (al′ ve o lar) (L. *alveolus,* small pit, or hollow), in which a foamlike mass of *minute, spherical bubbles* are embedded in a more viscid medium (Fig. 24, *D*); (5) *colloidal* (kol-oid′ al) (Gr. *kolla,* glue; *eidos,* form), in which the many complex substances of protoplasm are present in a *finely divided,* or *colloidal condition* (Fig. 24, *E*).

Which of these theories is correct? Or, are they all correct in part, depending upon the method of investigation used and the particular characteristic displayed by the specific protoplasm being studied at a certain time? The chemical and physical changes which are constantly going on in protoplasm probably explain the different appearances of the different protoplasms and even the variations in appearance in the same protoplasm from time to time.

A

E



B

D

C

Fig. 24.—Diagram to illustrate different theories of the physical structure of protoplasm. *A,* Granular theory; *B,* fibrillar or filar theory; *C,* reticular theory; *D,* alveolar theory; *E,* colloidal theory.

Colloidal Systems

The results of recent scientific investigations suggest that the *chemical constituents of protoplasm are in a finely divided, colloidal state, thus forming a complex colloidal system.* A *colloid* (Gr. *kolla,* glue) is a mixture of invisible, submicroscopic particles of comparatively large size (usually larger than molecules) which are suspended in a liquid medium. Colloids often have a sticky, gluelike property; hence the name. The sizes of colloidal particles may vary from one-millionth (0.000,001) to one-ten-thousandth (0.0001) of a millimeter (mm.) in diameter. Colloids do not diffuse through a parchment or similar membrane, while crystalloid solutions, like those of sugar or salt, do. When a colloid is evaporated, it leaves a formless mass, while a crystalloid solution leaves crystals of definite form. Possibly a better understanding of a colloid can be gained by stating that such familiar materials as milk, ink, egg white, gelatin in water, etc., are colloids. In the language of the chemist, the *particles* (solid, liquid, or gas) of a colloid and the *medium* (solid, liquid, or gas) in which the particles exist in a colloidal condition are known as *phases.* The colloidal particles are called the *dispersed phase,* and the medium in which they are dispersed is called the *dispersion medium.* Hence we have a variety of colloidal systems; some of the more common are given in the accompanying table.

DISPERSED PHASE	DISPERSION MEDIUM	EXAMPLES
Gas	Liquid	Foams or froths
Liquid	Gas	Fog or mist (water droplets in air)
Liquid	Liquid	Emulsions (oil in water; butterfat and milk which have been "homogenized")
Solid	Gas	Smoke (carbon particles in air)
Solid	Liquid	Ferric oxide in water; colloidal gold in water

Some of the properties and many important reactions of matter which is in a colloidal state depend upon the great surface displayed by the enormous numbers of minute colloidal particles which constitute that particular matter. Possibly the great amount of surface exposed by small particles may be illustrated as follows: A cube of matter having edges one centimeter long has an exposed surface of 6 sq. cm. (six surfaces, each 1 sq. cm. in area). If this cube of matter were divided into similar, smaller cubes, each having edges only 0.01 cm. long, the total number of small cubes would be 1,000,000. Each small cube has a surface area of 0.0006 sq. cm., and the total surface area of all the small cubes will be 600 sq. cm., or an area one hundred times greater than the original large cube. However, if the original large cube were divided into extremely minute cubes, each with a size of an average colloidal particle (0.000,001 cm. diameter), there would result one million billion cubes (each having edges 0.000,001 cm. long), and the total surface areas of all the colloidal-sized cubes would be 6,000,000 sq. cm., or one million times as great as the original cube. These 6,000,000 sq. cm. are the equivalent of over 6,500 square feet, or a city lot 65 by 100 feet. It should be recalled that the original cube was only 1 cm. square; however, there is an enormous surface exposure when even a small block of matter is properly divided into particles of colloidal size.

Protoplasm may exist as a liquid *sol* (L. *solvo,* melt) which flows or as a more solid *gel* (L. *gelu,* solid). Under certain conditions it may change from the sol to the gel state, or from the gel to the sol, or back again, depending on the relative distribution of the contained colloidal particles. If particles are more or less uniformly distributed in a liquid medium, the liquid flows easily (sol state), but if the particles are arranged in a network which contains the liquid, it would not flow (semisolid, gel state). Certain materials which are considered to be nonliving, such as gelatin, etc., form colloidal suspensions in water and exhibit the fluid, sol state when warm and the semisolid gel state when cooler. These states are reversible, as they may be in living protoplasm.

When a strong beam of light is passed through a colloid, the small colloidal particles suspended in the liquid reflect the light, and the path of the light appears as a visible cone known as *Tyndall's cone,* named for John Tyndall, the British physicist (1820-1893) who discovered it. In this manner the same effect is observed when light passes through fog or smoke. However, if the same strong beam of light is passed through a true solution of a substance, no such cone is visible.

If the proper colloidal particles suspended in a liquid are viewed through a microscope, the motion of the light reflected from the colloidal particles reveals that the latter are moving. This unordered movement (in all directions, back and forth) is called *Brownian movement* because it was first observed in 1827 by the Scotch botanist Robert Brown.

Molecules in the interior of a colloidal particle are attracted equally in all directions by other surrounding molecules, while those on the surface of a colloidal particle are subject to unequal forces of attraction (similar to the unequal attraction of molecules on the surface of a liquid). Because colloidal particles are so small and numerous, they possess a great total surface area, so that there are great numbers of molecules on the surface of each particle. As a result, these surface molecules are able to attract and hold other molecules, atoms, or ions through a process called *adsorption* (L. *ad,* to; *sorbere,* to draw in). This property plays an important role in many phenomena in the nonliving and living worlds.

When a colloid is placed between two electrodes of a cell with a relatively high voltage, the colloidal particles migrate either toward the positive or negative electrodes, depending on the specific colloid. Colloidal metals (and metal sulfides) tend to migrate toward the positive electrode; hence they must bear a *negative electrical charge.* Most colloidal hydroxides of metals (containing the hydroxyl OH) move toward the negative electrode; hence they bear a *positive charge.* The electrical charge borne by colloidal particles is due to the somewhat selective adsorption of positive or negative *ions* from the surrounding medium, the specific type of ion adsorbed depending on the particular colloid. *Ions* (Gr. *ion,* going) are atoms, or groups of atoms, with either positive or negative electrical charges. Colloidal particles bearing electrical charges may explain some of the electrical phenomena of nonliving as well as living substances.

Certain colloids, known as emulsoids (L. *emulgere,* to drain), are less selective regarding their adsorption of ions and tend to adsorb molecules of the medium in which they are dispersed (dispersion medium). As these colloidal particles adsorb these molecules of the dispersion medium, they may swell until the entire colloidal system becomes more and more viscous, or even semisolid, as in jellies, gelatin desserts, etc. The swelling of dried fruit in water is another example.

In general, colloids are of great importance because all vital processes of animals and plants are associated with colloidal materials. The living protoplasm of plants and animals is colloidal in character. Many foods of animals are colloids. The growth of plants, the germinating of seeds, and many similar phenomena are associated with colloids and their properties.

Matter, Atoms, Molecules, and Elements

Matter, of which all materials are composed, is made of extremely small, microscopically invisible *molecules* (L. *molecula,* little mass) with *intermolecular spaces* between them. A *molecule* is composed of the union of two or more atoms and is the smallest unit of matter capable of a separate, distinct physical existence. A molecule of free oxygen consists of two atoms (Figs. 25 and 26). A molecule of water consists of two atoms of hydrogen and one atom of oxygen; hence the *molecular formula* for water is H_2O (Fig. 27). An *atom* (Gr. *atomos,* indivisible) is the smallest particle of an element capable of taking part in a *chemical reaction.* There are as many different kinds of atoms as there are *elements (elementary substances),* and vice versa. An *element* is composed of atoms having the same *atomic number,* and, by ordinary means, cannot be built up from simpler or decomposed into simpler substances. There are over ninety definitely known basic elements, with claims for the discovery of a few more. The chemical elements are known by symbols which usually are the first or first few letters of the name of the element. For example, the symbol for hydrogen is H; for oxygen, O; for carbon, C; for magnesium, Mg.; etc. In some cases the symbol is derived from the Latin name of the element. For example, the Latin name for iron is *ferrum,* and the symbol is Fe; the Latin name for potassium is *kalium,* and the symbol is K; the name for sodium is *natrium,* and the symbol is Na.; etc. All the known elements are grouped in a table (periodic arrangement of the elements based on their atomic structure) and each element is given a specific number. Hydrogen has the atomic number 1; helium, 2; carbon, 6; nitrogen, 7; oxygen, 8; magnesium, 12; mercury, 80; uranium, 92; etc.

Molecules are too small to be visible with the highest magnification of an ordinary microscope which uses light rays, because the smallest particle visible with such a light (optical) microscope must have a diameter of 150 millimicrons (1 millimicron is one-millionth of a millimeter and is abbreviated mμ). The largest molecules probably have a diameter of approximately only 1 millimicron. The term millimicron is used here instead of millimeter or centimeter because the latter are too large for measuring and recording such minute objects. However, an electron microscope which uses beams of electrons instead of beams of light can be used to photograph the larger molecules even though they do not produce an image which can be seen with the eye.

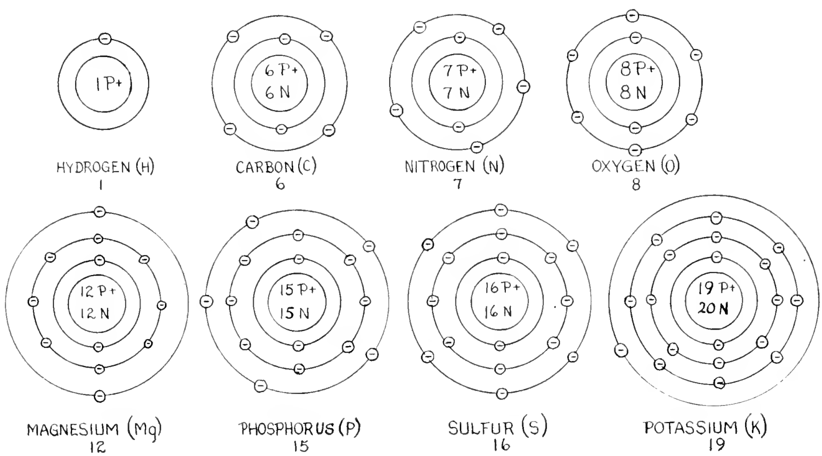


Fig. 25.—Diagrams representing the structure of the atoms of certain of the elements which may be present in protoplasm. The atomic number, which is the same as the number of nuclear protons, is given below each name. The symbols in parentheses follow each name. *P,* proton (+ electrical charge); *N,* neutron (electrically neutral); small circle with a dash, an electron (− electrical charge). The inner circle represents the nucleus of the atom; the outer rings represent one or more orbits ("shells") of the electrons.

Molecules are constantly in rapid motion, moving about in their *intermolecular spaces.* Their speed depends upon certain conditions and varies over wide ranges, but an average speed is thought to be approximately 2 million million times their own diameter per second (about twenty miles per minute) in such a substance as a gas. No matter how sparsely distributed, molecules cannot travel so fast and so far without colliding with other molecules also in motion. This energy of molecular movement is an example of *kinetic energy* (Gr. *kinein,* to move). The intermolecular space between molecules in a gas is greater than the space between molecules in a liquid or solid. In the atmosphere the several kinds of molecules must move about one thousand times their own diameters before colliding with other molecules. The motion of molecules in a gas is greater than in a solid because in the latter they merely vibrate back and forth because of the mutual attraction between adjacent molecules and probably the closer association of molecules.

If a single molecule could possibly be completely isolated and remain so, its kinetic energy would remain constant. However, the kinetic energy of molecules is influenced by the kinetic energy of surrounding molecules. When molecules increase their speed, they exert greater pressure on other molecules, so that the average distances between them is increased. Consequently, when heat is applied to certain substances, the molecules increase their speeds and the substance expands. We measure the amount of kinetic energy in terms of temperature. Likewise, contraction usually is the consequence of reduced molecular speed. If molecules of two kinds are placed together, the two kinds tend to mix with each other through the process called *diffusion* (L. *diffundere,* to pour). If a drop of perfume volatilizes (becomes a gas) in a room, its molecules will move and mix with the various molecules of the atmosphere and the odor will diffuse so as to be detectable some distance away. Our nose is affected by the molecules of the perfume so we detect the odor. The odor is not detected immediately because it takes some time for the perfume molecules to move toward us and the various molecules of the atmosphere offer resistance (because of collisions). The continual bombardment of an enclosing wall or membrane by molecules exerts a *pressure* which varies with the number of molecules, their movements, temperature, etc. Likewise, a chemical substance will diffuse through water in which it is placed. These phenomena of diffusion through gases, liquids, and solids are common in the nonliving and living worlds.

An *atom* is the smallest unit particle of an element capable of taking part in a chemical reaction. There are as many different kinds of atoms as there are elements (elementary substances), and vice versa. These submicroscopic atoms are invisible. As a result of recent scientific studies it is thought that atoms consist of smaller units which are arranged somewhat like a miniature solar system, with much of the atom supposedly "empty" space. The units which compose atoms are:

1. A large central *atomic nucleus* consisting of particles smaller but heavier than the electrons. These nuclear particles are called (a) *protons,* which are charged with positive electricity, and (b) *neutrons,* which are uncharged electrically (neutral). Each nuclear proton has the power

to hold one of the whirling electrons in its orbit. Thus, the number of electrons is determined by the number of positive protons in the nucleus. The atom as a whole is electrically neutral (neither positive nor negative). The nucleus of the oxygen atom contains eight positively charged protons which hold the eight negatively charged electrons in the two orbits. The nuclear protons and neutrons are held together by *intra-atomic forces* (Figs. 25 to 27).

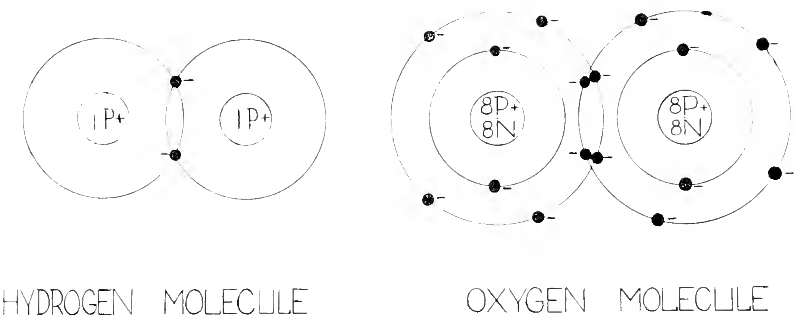


Fig. 26.—Diagram representing the structures of the molecules of the gases hydrogen and oxygen. In the case of hydrogen, the mutual utilization of one electron from each atom (total, two electrons) is involved in the combination. In oxygen, two electrons from each atom (total, four electrons) are involved in the combination. *P*, proton (+ electrical charge); *N*, neutron (electrically neutral); black circle with dash, an electron (− electrical charge). The inner circle represents the nucleus of the atom; the outer rings represent one or more orbits ("shells") of the electrons.

2. A series of negatively charged *electrons* ("planetary" electrons) which revolve in one or more concentric orbits ("shells") about the nucleus and whirling at inconceivable speed. Modern suggestions state that electrons may be "whirlpools of energy." Depending on the kind of atom, there may be from one to seven concentrically arranged orbits, and each orbit has a maximum of electrons which it can accommodate (although sometimes an orbit may not have its maximum number). In general, the inner orbit must be filled to capacity before a second appears. The maximum numbers of electrons in the various orbits are suggested below:

ORBIT	NUMBER OF ELECTRONS (MAXIMUM)
First	2
Second	8
Third	18
Fourth	32
Fifth	18
Sixth	12
Seventh	2

The chemical and physical behaviors of the atom are determined largely by the number and arrangements of the orbital electrons. It is common knowledge that proper bombardment of certain atoms (with neutral neutrons, protons, etc.) results in the release of tremendous amounts of *atomic energy* by the process of *nuclear fission*. For example, the energy released by the fission of one pound of U^{235} (a fissionable isotope of uranium) is roughly equivalent to that secured from burning 10,000 tons of coal. It is unknown how, or if, comparable energy releases occur in phenomena outside of the artificially conducted experiments of recent years.

Each kind of element has an atomic number which is specific for that kind of element, but some of these same elements have been discovered to have different atomic weights and consequently are known as *isotopes* (i′ so tope) (Gr. *isos,* equal; *topos,* place). Isotopes having the same atomic number are identical as far as their chemical properties and their extranuclear structures are concerned, but they differ in their atomic weights and with regard to the structure of the atomic nucleus (number of neutrons).

Artificially produced *radioactive isotopes* are extremely valuable in the study of certain biologic problems. The use of such radioactive isotopes as "tracers" is valuable because they emit certain radiations whose presence can be detected in various parts of an organism by sensitive Geiger counters. Hence, the rate of absorption of iodine by the thyroid gland has been determined by the use of radioactive iodine, and this has assisted in the treatment of goiter. Radioactive phosphorus has been traced to the stems and certain parts of the leaves of tomato plants, while radioactive zinc concentrates in tomato seeds. The many uses of radioactive isotopes will be of great value in the study of animal and plant metabolism, diagnosis and treatment of certain diseases, etc.

Atoms with less than one-half of the maximum number of electrons in the outer orbit may under certain conditions even lose those which they have, while atoms with more than one-half the maximum number of electrons in the outer orbit may add electrons until the outer orbit is filled to its maximum. The additions or losses of electrons (negatively charged) in the orbits does not affect the structure of the atomic nucleus, but the latter can no longer be electrically neutral after such changes. Normally, the positively charged protons and the negatively charged electrons are balanced. Hence, the loss of electrons makes the atom positively charged and the addition of electrons makes the atom negatively charged. Such a charged atom is called an *ion.* Atoms which have gained electrons have a negative electrical charge and are called *anions;* atoms which have lost electrons have a positive electrical charge and are called *cations.* Since like charges repel and unlike charges attract each other, we find that anions and cations combine. The amount of combining which atoms can undergo is determined by the number of electrons in the outer orbit at the beginning and the number that can be gained or lost. Hence, hydrogen, having only one electron, tends to lose it, becoming a (positive) cation. Oxygen, with six electrons in its outer orbit, tends to gain two, becoming a (negative) anion. Thus two atoms of hydrogen and one atom of oxygen combine to form a molecule of water, since hydrogen loses only one electron and oxygen gains two electrons (Fig. 27).

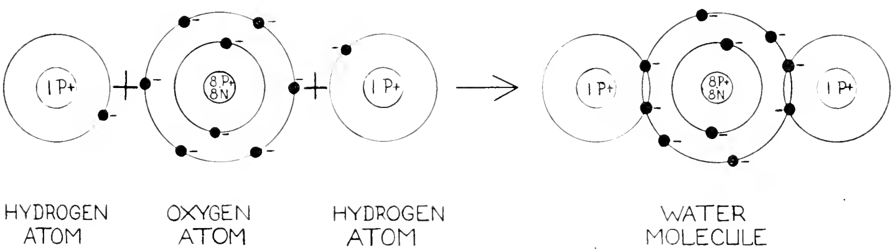


Fig. 27.—Diagrams representing the formation of a molecule of water from two atoms of hydrogen and one atom of oxygen. The union is represented by the sharing of electrons in the outer orbits of the atoms concerned. *P,* proton (+ electrical charge; *N,* neutron (electrically neutral); black circle with dash, an electron (− electrical charge). The inner circle represents the nucleus of the atom; the outer rings represent one or more orbits ("shells") of the electrons.

Molecules may vary in complexity from the simple water molecule to the extremely complex long carbon "chains" and "rings" present in many living, organic materials. Molecules may contain only one kind of atom (such as O_2) or they may contain atoms of two or more different kinds (such as CO_2); in the latter case they form a compound. Atoms are held together either by the attraction of opposite ions or by the sharing of an electron by two different atoms.

Many substances in living organisms are soluble in the large quantity of water present in the protoplasm, and in solution many of them dissociate to form *ions.* Hence, a molecule of common salt, sodium chloride (NaCl), dissociates into (1) a positive sodium ion (Na^+) while losing its single outer electron and (2) a negative chlorine ion (Cl^-), gaining one extra outer electron. A substance which dissociates to form ions is called an *electrolyte* (e -lek′ tro lite) (Gr. *elektron,* amber; *lysis,* loosing) because of its ability to conduct electric currents. Acids, bases (alkalis), and salts dissociate in solution. The acids produce the characteristic hydrogen ions (H^+), alkalis produce the characteristic hydroxyl ions (OH^-). The production of ions from salts is of great importance, as is the nearly equal production of both hydrogen and hydroxyl ions (near neutrality) necessary in living protoplasm. The production of ions is of importance in the conduction of electric currents associated with certain living phenomena as well as in forming and maintaining the proper acid-base relationship for the various metabolic activities of living protoplasm.

Other physical and chemical phenomena of living organisms are considered in a later chapter.

II. CHEMICAL COMPOSITION OF PROTOPLASM

Attempts to analyze living protoplasm chemically probably cause important changes in it. Consequently, the results of the chemical analysis may or may not be the same as for living protoplasm. The constituents are known, but we do not know how the complex combinations of them actually form the basis for life. Protoplasm contains only common, inexpensive elements. The total value of all the chemicals present in the protoplasm of the human body is approximately one dollar. There are no known chemical elements which are present only in protoplasm; all of the elements which comprise it are common in the earth, water, or atmosphere. Of the four most abundant elements in protoplasm, free oxygen is common in the atmosphere, most of the carbon occurs in the bodies of living or dead organisms or their products, hydrogen is usually combined with oxygen to form water, and most of the free nitrogen occurs in the atmosphere, although proteins contain nitrogen in their makeup. Even though living protoplasm consists of a few common, inexpensive elements, they are combined in certain proportions into compounds which are associated in some unique way so as to help form the chemical basis of life.

A *compound* is a chemical union of two or more different elements which are in definite proportions, and the properties of the compound are different from those of its constituent elements. In other words, in a compound all its molecules are composed of the same proportion of atoms which are combined in a definite way. For example, carbon dioxide (CO_2) and carbon monoxide (CO) are both compounds, but the proportion of the atoms differs. The physiologic effects are different also—carbon dioxide stimulates breathing, while carbon monoxide stops it. *Compounds* may be divided into *organic* and *inorganic*. *Organic compounds* are commonly referred to as those which contain carbon (with the exception of the carbonates, containing $-CO_3$), while *inorganic compounds* are those which have their origin in, or are associated with, the mineral world, such as rocks, ores, soils, the constituents of the natural atmosphere, etc. There are approximately 300,000 carbon-containing compounds known. Examples of organic compounds are marsh gas or methane (CH_4), ethyl alcohol (C_2H_5OH), and a sugar ($C_{12}H_{22}O_{11}$), while examples of inorganic compounds are water (H_2O), table salt (NaCl), sulfuric acid (H_2SO_4), and lime or calcium carbonate ($CaCO_3$). A *mixture* is composed of two or more substances which are not combined firmly (each of which retains its own properties) and need not be in any definite proportion. The composition of a mixture may vary, and the constituents usually may be present in different proportions in different mixtures. For example, the atmosphere is a mixture of such gases as hydrogen, nitrogen, oxygen, etc., which may vary in their proportions in different atmospheres.

The following elements (with their symbols) are found in average protoplasm (those essential to life being indicated by *):

Oxygen	(O)	(76.0%)*	99% of the weight
Carbon	(C)	(10.5%)*	
Hydrogen	(H)	(10.0%)*	
Nitrogen	(N)	(2.5%)*	
Phosphorus	(P)	(0.3%)*	About 1% of the weight
Potassium	(K)	(0.3%)*	
Sulfur	(S)	(0.2%)*	
Magnesium	(Mg)	(0.02%)*	
Iron	(Fe)	(0.01%)*	
Chlorine	(Cl)	(0.10%)	
Sodium	(Na)	(0.05%)	
Calcium	(Ca)	(0.02%)	

Chlorine and sodium do not seem to be essential for most plants, while calcium is unessential for certain lower animals. In addition to those listed, certain types of protoplasm at times are found to contain other elements in small amounts.

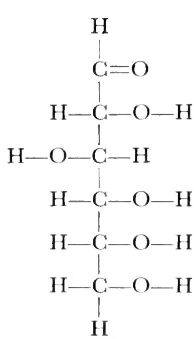
In general, the elements listed above are not free in the protoplasm but are combined as compounds such as the following: glucides (including carbohydrates), lipids (including fats), proteins, inorganic salts, water, vitamins, and enzymes.

A. Glucides (Including Carbohydrates)

The so-called glucides (glu′ sid) (Gr. *glykys*, sweet) are a large group of organic compounds which include the commonly known *carbohydrates* (kar bo -hy′ drate) (L. *carbo*, carbon, coal; Gr. *hydor*, water). The term carbohydrates as used here implies "hydrates of carbon," in which the ratio of hydrogen to oxygen is 2:1. The simplest carbohydrates in protoplasm are the *simple sugars* with the formula $C_6H_{12}O_6$. Carbohydrates are usually simpler in chemical structure than proteins but they nevertheless have a wide range of complexity among themselves. Like proteins, the more complex carbohydrates may be split into simpler materials by the action of enzymes. This happens when they are acted upon by the enzymes of certain digestive juices. Through the proper chemical action certain carbohydrates may be converted into fats, which explains the proper selection of foods during prescribed cases of dieting. Carbohydrates furnish elements which may assist in the building of protoplasm, but their chief role is a readily available supply of heat and energy. When glucose is oxidized (oxygen united with it), it yields water, carbon dioxide, and energy; the latter, which originally held the sugar together, now is available for use:

GLUCOSE		OXYGEN		WATER		CARBON DIOXIDE		
$C_6H_{12}O_6$	+	$6O_2$	$\rightarrow$	$6H_2O$	+	$6CO_2$	+	ENERGY

Of the simple sugars, glucose (dextrose) is the only one present in any quantity in the body for fuel purposes. Carbohydrates are stored in animals as *glycogen* (animal starch) because the large molecules cannot dialyze through the semipermeable cell membranes. Glycogen is stored in the liver and muscles where it is converted as needed into usable glucose, which has the following formula:



Glucose (A Simple Sugar)

Glucides may be classified according to their complexity. The following examples with their formulas will illustrate:

1. *Monosaccharides* (mono -sak′ a rid) (Gr. *monos,* one; *sakchar,* sugar), which contain one sugar group: glucose (dextrose or grape sugar), $C_6H_{12}O_6$.

2. *Disaccharides* (Gr. *di,* two), which contain two simple monosaccharide sugar molecules: maltose (malt sugar), $C_{12}H_{22}O_{11}$, and sucrose (cane sugar or beet sugar), $C_{12}H_{22}O_{11}$.

3. *Polysaccharides* (Gr. *poly,* many), which contain several monosaccharides united: starch $(C_6H_{10}O_5)_n$ (in this case n is a rather large number), cellulose, found in many plants $(C_6H_{10}O_5)_x$, glycogen, or animal starch $(C_6H_{10}O_5)_x$ (in these cases x is a larger number than the n of starch).

B. Lipids (Including Fats)

The group of organic compounds known as lipids (lip′ id) (Gr. *lipos,* fat) includes the true fats and a number of related fatlike substances which have properties similar to fats but contain things in addition to the fatty acids. Fats contain the same chemical elements as found in carbohydrates but possess much less oxygen in proportion to the carbon and hydrogen. Each molecule of a true fat is composed of one molecule of glycerol (glycerine) and three molecules of some fatty acid, such as stearic acid, palmitic acid, or oleic acid, etc. All fats contain glycerol but differ in the kind of fatty acid combined with the glycerol. One molecule of glycerol ($C_3H_5[OH]_3$) plus three molecules of stearic acid ($C_{18}H_{36}O_2$) produces a common fat (in beef tallow) known as tristearin ($C_{57}H_{110}O_6$). In the process, $3(H_2O)$ is given off.

Fats contain twice as much heat energy as carbohydrates or proteins. This accounts for their common use as foods in cold weather. One gram of protein produces about 4 calories of heat and 1 gram of carbohydrate, about 4 calories, while 1 gram of fat yields about 9 calories. A calorie is a unit of heat measurement and is the equivalent of the amount of heat required to raise the temperature of 1 gram of water (1 c.c.) 1° C.

Fats are used in the body in the construction of the plasma membrane around the cells and the medullary (myelin) sheath around certain nerve fibers. Fats are stored in various places as reserve supplies of energy. Fats are stored under the skin to reduce body heat loss and to round out the cavities between the tissues. Fats placed around such organs as the kidneys help to hold them in place. Fats are not utilized as a source of body energy as readily as are the carbohydrates. Fats can be formed from carbohydrates by the body, and, to a limited extent, fats can be converted into usable glucose. Fats of the animal body are derived from the carbohydrates and fats consumed as foods. Fats occur in butter, cream, oils, meats, seeds, and nuts.

C. Proteins

Proteins (pro′ te in) (Gr. *protos,* first) are complex organic compounds which contain carbon, hydrogen, oxygen, and nitrogen, and usually sulfur and phosphorus. Proteins are present in all protoplasm and are characterized by the element nitrogen. It is thought that there are specific proteins for each species of living organism and that each living organism probably has several specific and unique types. The *theory of species specificity* states that due to the constituent proteins, the protoplasm of each species of living organism is specific for that species and differs less slightly from that of related species and markedly from that of more distantly, or unrelated, species. Studies along these lines have substantiated the evidence of evolutionary relationships between certain organisms which has been derived from other facts.

Proteins are the most varied and complex of all the constituents of protoplasm, each molecule being made of hundreds of atoms. Proteins contain such elements as:

Carbon	(C)	Approximately	50%
Oxygen	(O)	Approximately	25%
Nitrogen	(N)	Approximately	16%
Hydrogen	(H)	Approximately	7%
*Sulfur	(S)	Approximately	0.3-2%
*Phosphorus	(P)	Approximately	0.0-0.8%

The units of which proteins are made are *amino acids,* which contain an *amino group* (NH_2) and an *acid (carboxyl) group* (COOH). There are over thirty different amino acids known. The great variety of proteins is made possible by the various combinations and proportions of the amino acids used in their construction. The various proteins are formed by joining the acid group of one with the amino group of another amino acid. The protein can act as an acid, and thus combine with alkalis, because of its acid group (COOH) and can act as an alkali, and thus combine with acids, because of its amino group

*Present only in certain types of proteins.

(NH_2). Hence they are *amphoteric* (am′ fo ter ik) (Gr. *amphotere*, in both ways), which is probably important in regulating the proper acid-base relationship in living protoplasm.

The large size of their molecules causes proteins to assume colloidal characteristics in water, which explains the colloidal nature of protoplasm. Proteins contribute the structural components of protoplasm, as well as important constituents of enzymes and certain hormones, in addition to supplying energy and heat. They assist greatly in growth and repair. Animal protoplasms, in general, seem to be able to manufacture only a few types of amino acids from raw materials, while plants can synthesize many of them from simpler substances. In general, animals are dependent, directly or indirectly, on plants for most of them. When proteins are digested, they are broken up into amino acids before they can be absorbed by the blood, which carries them to various parts of the body where they are made into new proteins. The digestion of proteins releases energy which was required to hold their components together. Examples of proteins with their chemical formulas are (1) albumin of the white of egg ($C_{239}H_{389}O_{78}N_{58}S_2$) and (2) zein of corn ($C_{736}H_{1161}O_{208}N_{184}S_3$).

D. Mineral (Inorganic) Salts

In spite of the fact that mineral salts are not present in great quantities, they are nevertheless of great importance in maintaining the normal activities and physiologic equilibrium of living protoplasm. Chemical analysis of body fluids reveals that the quantity and kinds of salts in them greatly resemble the concentrations of the mineral salts of sea water from which the first protoplasm is thought to have originated. The different salts in ocean water are sodium and magnesium chlorides, magnesium, calcium, and potassium sulfates, and calcium carbonate, in addition to minute quantities of other salts. When these salts dissociate in water (ionize), the sodium, magnesium, calcium, and potassium contribute positively charged ions, and the chlorine, sulfates, and carbonates contribute most of the negatively charged ions. These positive and negative ions are probably associated with certain electrical phenomena of protoplasm.

Normally, the concentration of the various salts in body fluids is quite constant, because any appreciable deviation will be followed by impaired functions, or possibly death in extreme cases. Calcium salts are important in the building of bones and the coagulation of blood. A sufficient decrease in the calcium ions in the blood may result in convulsions, or even death. Normal contractions of heart muscles can occur only if there is a proper balance of sodium, potassium, and calcium ions. Mineral salts maintain the normal osmotic balance between the living protoplasm and the various environmental factors. All in all, it may be that deficiencies in mineral salts are more important than temporary deprivations of the organic foods. About fifteen elements are known to be essential in mineral salts in human diet, although some are needed only in traces. About 30 grams of these mineral salts are lost from the human body daily through feces, urine, and sweat, and they must be replaced. Rich food sources for minerals include vegetables, milk, cheese, meat, eggs, etc. Iron is necessary to build hemoglobin, and iodine is necessary to produce thyroxin, the hormone of the thyroid gland.

E. Water

A rather large part of all protoplasm is water, the percentage varying with the type of protoplasm, the conditions under which it has lived previous to the analysis, etc. More water is present in aquatic organisms than in those living in dry environments. Water itself is not alive, but it forms an arena in which the various nonliving substances which make up the living protoplasm may perform (Fig. 27). Many of the movements associated with living protoplasm are influenced in part, at least, by the water content. Water acts as the dispersing medium of the colloidal systems of living protoplasm. Water is essential in passing foods into a living organism and in eliminating wastes from it. Water also assists in equalizing temperatures throughout an organism as well as in diluting certain detrimental substances which may have entered. Water also tends to reduce friction and prevent structures from abnormally adhering to each other. A certain amount of water seems to be necessary for the reception of certain stimuli, especially those of the senses of taste and smell.

F. Vitamins

Vitamins (L. *vita,* life; *amine,* formed from ammonia) are rather simple organic compounds which even in small quantities are essential to life. The various vitamins are quite different chemically and originally were thought to be amines formed from ammonia; hence the name is now incorrect from a chemical composition standpoint. In general, they cannot be manufactured by the animal body (but are produced by plants) so must be secured in sufficient amounts in the diet in order to ensure that the various metabolic processes are performed normally. Each vitamin which has been successfully analyzed so far has a different chemical formula, and each has somewhat specific functions. Today we know the chemical structure of most of the vitamins so far discovered, and many of them have been prepared synthetically. Vitamins were discovered about 1912, and much scientific progress has been made since that time through chemical analyses, animal experimentation, etc.

From recent experiments dealing with the exact functions of a vitamin it has been observed to act as a catalyst for some fundamental reaction common to all protoplasm. When there is a vitamin deficiency below a certain level, certain behaviors and metabolic functions are impaired, the particular effects being determined by the type of vitamin involved. Plants probably have their specific vitamin requirements just as animals, although this has not been studied so extensively as in the animals. Plants synthesize most of the vitamins so they must play important roles in their metabolisms. Some of the vitamins are components of *enzymes* which control many physiologic processes in cells or contribute to the actual formation of certain enzymes. It is probable that many vitamins in plants act as the components of enzymes or as the progenitors of enzymes. In green plants, vitamin B is essential for normal root development. Vitamin K regulates the oxidation-reduction processes in living cells. The various roles of vitamins in the numerous processes of living organisms are considered in greater detail in a later chapter.

G. Enzymes

An *enzyme* (Gr. *en,* in; *zyme,* yeast, or leaven) is a *nonliving, complex organic (protein) catalyst* (kat′ a list) (Gr. *katalysis,* dissolving) *produced only by living protoplasm, and controls the speed of a chemical reaction without taking part in the reaction itself or without being consumed as the result of it.* Because one of the first enzymes was isolated (by the German scientist Büchner) from crushed yeast cells, the unknown substance was called an enzyme. Every animal and plant cell contains many different enzymes, each with a *specific function.* A pure enzyme is *specific* because it controls one type of chemical action and acts on a specific kind of substance known as the *substrate.* Many enzymes perform their function where they are formed, but some operate outside the cell which produces them. Digestive enzymes illustrate the latter. Most enzymes are *soluble in water* and can be evaporated to a dry state and retain their catalytic abilities for a long time. Most enzymes possess an *optimum temperature* at which they function best, and most are destroyed by boiling. They are also influenced by *acids, alkalis,* and *pressure.*

As stated previously, some of the vitamins are components of enzymes. Experimental evidence indicates that the complex chemical reactions associated with respiration are controlled, at least in part by special oxidizing enzymes called *respiratory enzymes.* It is suggested that the protein *genes* (hereditary determiners) must have some close relation to enzymes. Probably specific genes (discussed in a later chapter) determine the presence of specific enzymes which are essential for the numerous chemical processes in metabolism.

Enzymes are usually classed after the type of chemical action produced in a particular substance. For example, *hydrolytic enzymes* (Gr. *hydor,* water; *lysis,* loosing) break down substances by causing them to combine with water or build up substances by removing a molecule of water from two simpler molecules of a substance when they combine.

2 molecules of glucose sugar ($C_6H_{12}O_6$) + hydrolytic enzyme →
1 molecule of sucrose sugar ($C_{12}H_{22}O_{11}$) + H_2O

Proteolytic enzymes (Gr. *protos,* first; *lysis,* loosing) break down, or possibly build up, proteins. Enzymes are frequently named by adding *-ase* to the substance acted on: *lipases* (Gr. *lipos,* fat) change fats to glycerine and fatty acids; *amylase* (diastase) (L. *amylum,* starch) changes starch and dextrins to maltose (sugar); *maltase* (A.S. *mealt,* malt) changes maltose to glucose (sugar); *proteinases* convert various types of proteins into amino acids or intermediate products.

Enzymes are of great economic importance in industries as a few examples will illustrate: the making of breads, cheeses, syrups, glycerine, alcoholic beverages, soy sauce, etc.; the retting (removal) of fibers from the stems of hemp, flax, and other plants; the ripening of tobacco; the preparation of sizing for paper and textiles; the preparation of skins for tanning; the preparation of certain medicinal products, etc.

III. METABOLISM, AUTOSYNTHESIS, AUTOCATALYSIS

Metabolism (me -tab′ o lizm) (Gr. *metabole,* to change) includes those chemical activities of living protoplasm which are associated with growth, maintenance, repair, and the constant building of new, living, protoplasm from nonliving chemicals. Living protoplasm has the unique and characteristic ability to change the potential energy of the large molecules of carbohydrates, fats, and proteins into kinetic energy and heat as the larger molecules are changed to simpler forms. Metabolism may be divided into (1) *anabolism* (a -nab′ o lizm) (Gr. *ana,* up; *bole,* build), in which the chemical processes unite simpler substances to form more complex substances, with the production of new protoplasm, growth, and the storage of energy, and (2) *catabolism* (ka -tab′ o lizm (Gr. *kata,* down; *bole,* throw), in which complex substances are broken down, protoplasm may be used up, and energy released. Both anabolism and catabolism occur constantly and simultaneously. In young organisms or in younger parts of older organisms, anabolism predominates over catabolism; during maturity the two are more or less balanced; in old age catabolism predominates over anabolism. Certain protoplasms naturally metabolize at a high rate, while others have a lower rate. The metabolic rate of a particular individual may vary from time to time, being influenced by age, height and weight, sex, activity, certain endocrine secretions, general health, etc.

The *basal metabolic rate* is the measurement of the amount of energy expended (heat given off) just for mere living purposes, with no work being done and no food being digested. The determination of the *basal metabolism* of a human being is of great value in determining certain factors from a health standpoint. The characteristic ability of living protoplasm of organisms to duplicate itself or certain of its parts by synthesizing complex molecules out of simpler ones, under the influence of specific enzymes, is referred to as *autosynthesis* (aw to -sin′ the sis) (Gr. *autos,* self; *synthesis,* put together). The duplication of chromosomes, genes, and possibly filterable viruses, and reproduction itself illustrate this phenomenon.

Certain forces in the molecules which compose *genes* enable them to rearrange the chemical substances in the protoplasm into the same structural (chemico-physical) pattern which the genes possess. This is essential if the constancy and stability in the inheritance of an organism are to be continued through successive generations. However, occasionally there seem to be changes in the normal structural pattern of genes which result in certain effects and charges known as *mutations* (mu -ta′ shun) (L. *mutare,* to change). These mutations are one source of variations and form one basis for the statement "the most invariable thing in life is variability." These and other variations are the causes and effects of the *gradual developmental changes (evolution)* constantly undergone by living organisms (ev o -lu′ shun) (L. *evolvere,* to unroll or change).

There are certain nonliving, nonprotoplasmic chemical substances such as giant molecules of proteins which also possess autosynthesis. However, these molecules of protein are much simpler than those in living protoplasm. There seem to be autosynthetic phenomena in both living and nonliving substances, but in each case the product formed is specific and unique for that substance.

The ability of a catalyst to synthesize more of its own substance (create more molecules of its own kind), thus gradually increasing the speed of the chemical action, may be considered as *autocatalysis* (aw to ka -tal′ i sis) (Gr. *autos,* self; *kata,* down; *lysis,* loosing). Sometimes this term seems to be used as a synonym of autosynthesis. The disintegration of cells or tissues by the action of *autogenous enzymes* (aw -toj′ e nus) (Gr. *autos,* self; *genesis,* origin) which they produce may be considered as autolysis. Life seems to be the result of the interactions and counteractions of these and many other factors, some of which are not yet known.

IV. GROWTH, ASSIMILATION, AND DIFFERENTIATION

True growth is characteristic of all living organisms and consists of anabolism, in which the protoplasmic substances synthesize more of their kind from materials which are unlike the protoplasm, thus increasing their bulk. True growth in living organisms may be the result of the increase in the size of cells, an increase in the number of cells, or a combination of these two. All living organisms have limits beyond which they cannot, or do not, grow. Certain organisms do not seem to grow much after the adult stage, while others continue growth for a longer period of time. The particular size of each organism is probably due to its inherent hereditary materials and the influence of environmental factors both outside and inside the organism. The process of building smaller particles of chemicals into larger particles of protoplasm which differ from the original particles (food) is known as *assimilation* (a sim i -la′ shun) (L. *ad,* to; *similis,* alike).

In the nonliving world there are phenomena which approximate growth somewhat. A crystal of table salt (NaCl) placed in a supersaturated solution of table salt (maximum amount of salt which will normally dissolve in hot water and which will release some of the salt when the solution cools) will add to its surface some of the dissolved salt, thereby forming a larger and larger crystal which maintains a fairly constant form characteristic for that kind of crystal. In this case the raw material used in building is essentially the same as the final product, and the increase in size has been by *accretion* (ak -re′ shun) (L. *ad,* to; *crescere,* to add or grow). This is to be distinguished from true growth by *intussusception* (in tus sus -sep′ shun) (L. *intus,* within; *suscipere,* to make up), in which chemical rearrangements result in *growth from within.* In nonliving things the method of size increase and the chemical composition are determined by the specific nature of the beginning, raw material, while in true growth the nature of the final product formed is determined by the protoplasm of the organism involved. A cat and dog may be fed the same kind of food, but each animal assimilates and grows in a manner unique for it. There are still many unsolved problems in connection with how growth is initiated, how it continues, and also how it ceases. It is not only important to have a tissue or organ grow to be normal, but it is equally essential to have it cease growth when normality has been reached. Such abnormal growth as tumors, cancers, etc., still constitute major problems in this field.

From what has been said it would seem that a cell dividing by mitosis would always produce two identical cells which eventually would be similar to the original. Frequently, this does happen, as in the formation of similar cells in the different tissues. However, if this always happened, a multicellular man, who develops from an original cell by repeated mitoses, would be composed of cells which would all be alike, because the chromosomes, genes, etc., are supposedly alike. From our studies of tissues it was observed that there are many differences in structures and functions in various tissues, which originally all arose from the first cell. How can different cells arise from a common origin?

If chromosomes and their genes alone determine the structure and functions of cells, then should not all cells in a multicellular organism be alike? It is thought that *genes* produce enzymes, or act as enzymes, which influence the behavior of cells under certain conditions. Because of variations in external and internal environmental factors (such as foods, enzymes, etc) which can influence groups of cells, or even the opposite ends of a single cell, differently, even the same genes in the various cells will not express their inherent potentialities in the same way in all cells. In other words, differences in physical and chemical factors are thought to influence even identical genes in such different ways that variations in structures and functions are developed. This is the basis for *cellular differentiation* (changes in the organization of protoplasm) which results in different types of cells, tissues, etc. After their differentiation, the cells and tissues are subjected to still further variations, in this case possibly by even the same environmental influences, because now the tissues are even different. It has been experimentally observed that the embryologic development of a cell or tissue is influenced by its inherent abilities (genes, etc.) and by the particular environment (chemical and physical) to which it is subjected. Both of the phenomena are considered in greater detail in other chapters.

V. REPRODUCTION

Reproduction, or the ability to reproduce themselves, is a characteristic of living organisms. Most offspring are remarkably like their parents, which suggests there are similar forces which operate generation after generation in order to ensure this phenomenon of continuity. Naturally, certain offspring differ somewhat from their parents, and the explanations are to be found in differences in the heredity mechanism or differences in environmental factors, or a combination of both. The various methods of reproduction of plants and animals, their embryologic developments, the effects of environmental factors, and the operations of heredity (genetics) are considered in other chapters. Reproduction is essential if individuals are to propagate their kind and if the race is to continue existence. The specific methods of reproduction in plants and animals are numerous and varied as a study of living organisms will reveal.

VI. ADAPTATION AND IRRITABILITY

Adaptability is the ability of living organisms to undergo changes appropriate to their life needs and to fit efficiently into their environments so that their life processes may proceed as normally and effectively as possible. Adaptiveness of living organisms depends upon their irritability (their capacity to respond to stimuli). Nonliving things may be more or less affected by external influences, although their reactions are always more or less the same, while living things do not always react to the same stimuli in the same way. These differences in reactions are dependent on the adaptability of the living protoplasm. Naturally, the specific or definite response to a particular type of stimulus cannot always be predicted in a living organism as it can in nonliving materials. Adaptations of living organisms may be of three kinds: (1) changes in structure (structural); (2) changes in functions (functional); (3) changes in both structure and function (structural-functional).

When certain parts of a living organism have been impaired or destroyed, frequently other parts, through the inherent process of self-regulation, take on compensatory reactions or activities in order to regain a complete, well-balanced normality. Examples of such activities are as follows: If one human kidney is diseased or destroyed, the other adjusts or compensates to attempt to do the work of both. If tissues or organs require more oxygen, the circulatory system attempts to circulate the extra amounts necessary. The quantity and quality of the digestive juices are regulated within certain limits by the variations in the diet of the organism. When emergencies arise, increased energy is required. Consequently, larger quantities of foods in various parts of the organism are liberated and changed to meet the extra demands.

Through some internal recording or regulation, the efforts and reactions of living organisms frequently serve as a kind of experience by which they are led to avoid similar, undesirable kinds of actions in the future and attempt to repeat the desirable and successful ones. This makes for the preservation of the individual, as well as the race, in the struggle for existence.

VII. ORGANIZATION AND INDIVIDUALITY

All parts of living organisms are so integrated that the whole thing is a unit or an individual. Individuality is due to the fact that some one part of the organism which is most active presides or predominates over the less active parts and thus keeps them all in organized subordination. In each living organism there are (1) interdependence and systematic correlation of parts, (2) a variable susceptibility to environmental influences, (3) inherent self-regulatory tendencies, and (4) a centralized control. All of these working harmoniously together make the living organism a unified individual rather than a mere inchoate mass of separate and unrelated parts.

Many, if not all, living organisms are organized on one or more axes along which the various tissues, organs, and physiologic units are arranged in a somewhat graded series, the more active being at the controlling apical region, and the less active at the opposite end. Between these two regions is a graded series of decreasing activities extending from one end to the other on this imaginary line or axis. This arrangement of structures and physiologic units is known as the *axial gradient* which to a great extent determines the organization of the organism as well as its individuality. Organisms which possess such an organization are said to possess *axiate organization.* This phenomenon is studied in various organisms in other chapters.

VIII. REGENERATION

The protoplasms of all living organisms have the ability to regenerate to a greater or lesser degree (Fig. 28). If certain parts of an organism are destroyed or impaired, there is an attempt on the part of the individual to regain its completeness and normality.

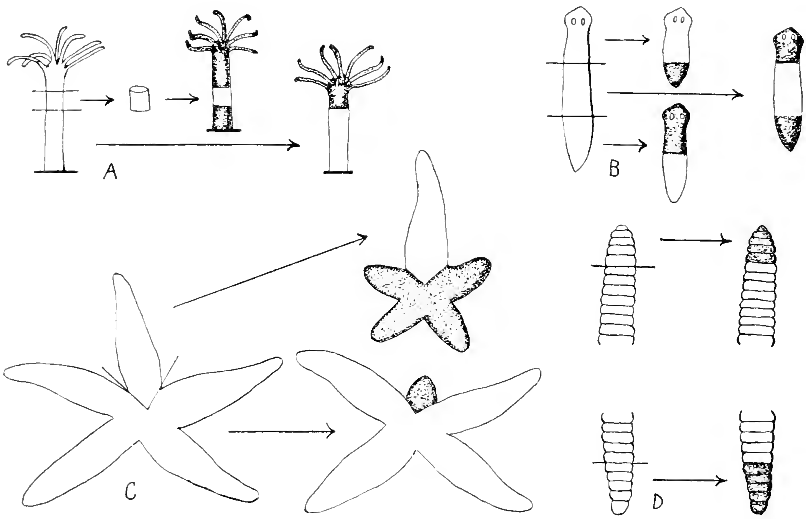


Fig. 28.—Regeneration of animals as shown by *A*, Hydra; *B*, Planaria; *C*, starfish; *D*, earthworm. The lines show the position where the parts were removed and the darker (stippled) areas are those which have been regenerated. Note that in the starfish the missing ray is regenerated and the missing ray also regenerates the four missing rays. The kind of regeneration which develops depends to a great extent upon where the cut is made.

In general, regeneration in the higher or more complex organisms is more or less limited to certain structures and regions. If the skin on the tip of a human finger is lost, it will be replaced, but if the tip of the entire finger is removed, there is no appreciable restoration of the lost part. Regeneration thus is relative and is determined or influenced by the part affected. Other illustrations of regeneration of higher organisms are: the healing of wounds of plants and animals, repair of broken bones, production of new blood corpuscles, replacement of sap lost from injured plants, and renewal of bark removed from trees.

In lower types of organisms a part of an organism may have the ability of restoring all the missing parts for an entirely new individual. For instance, one ray or arm of a starfish may be removed (Fig. 28). The missing ray will be replaced, and the removed ray has the ability to add the four rays to itself in order to make two complete individuals, each with the normal number of five rays. The flatworm (Planaria) may be cut into several transverse pieces. Each resulting piece has the inherent ability to regenerate some form of Planaria (Fig. 28). The earthworm may regenerate a missing "head" or "tail" region. The Hydra may replace missing tentacles, layers of cells, or even the mouth region (Fig. 28).

IX. LIVING AND NONLIVING THINGS CONTRASTED

A survey of various living organisms as a group contrasted with different kinds of nonliving substances reveals certain differences. Many of these differences are quite apparent upon casual observation, and additional ones will be observed when more detailed studies are made. Most biologists agree that the phenomena of living organisms are more complex than comparable phenomena in nonliving substances but that both are more or less associated with chemical and physical processes. The *mechanistic theory* suggests that all vital phenomena are to be explained by a complete understanding of all the chemical and physical forces which operate in living protoplasm—that life is merely the result of the proper interactions and counteractions of these forces. The *vitalistic theory* suggests that some unique, supernatural force or power which is not reducible to the terms of physics and chemistry is responsible for the initiation, continuity, and control of vital activities—that this "extra something" differentiates living from nonliving and that science shall never be able to create life or be able to understand it completely. The more significant characteristics of living organisms and nonliving substances are contrasted briefly in the accompanying table.

LIVING (ANIMATE) ORGANISMS	NONLIVING (INANIMATE) SUBSTANCES
COMPOSITION	
All living organisms, both plant and animal, have been found to be composed of a highly organized, chemically complex *protoplasm* with its unique characteristic chemical and physical properties.	Even though certain nonliving substances may have a definite chemical composition and specific physical properties, none of them have ever been observed to be composed of protoplasm.

LIVING (ANIMATE) ORGANISMS	NONLIVING (INANIMATE) SUBSTANCES
STRUCTURE AND ORGANIZATION	
All living protoplasm is a complex and specific organization of structures and parts which are coordinated so as to *function together as a unit, or an organism.* All living things are composed of units, called *cells,* which have nuclear materials, cytoplasm, etc., each possessing distinct characteristics and properties. The latter are constantly changing because the chemical and physical constituents are *highly organized* in a *dynamic system.*	Certain nonliving substances, such as crystals, may have a definite molecular structure and organization typical for each kind of crystal, but this organization is *inert, static, and not dynamic.* The various structures which characterize each inanimate substance are rather simple in comparison with complex protoplasm, and all nonliving substances are *without cells.*
RESPIRATION AND WASTE ELIMINATION	
All living organisms *respire,* or exchange oxygen and carbon dioxide at rather definite measurable rates. These gases (oxygen for animals; carbon dioxide for plants) are usually taken from the atmosphere. During metabolism, there is respiration and the production and elimination of wastes. In many living organisms the latter have rather specific qualities which characterize the different kinds of living things.	The exchange of gases is present in certain inanimate substances, but it is not quite the same kind of phenomenon found in living organisms. A nail may rust or oxidize (oxygen added), or a motor may take in oxygen and give off carbon dioxide, or carbon monoxide, but these and similar phenomena are different from true respiration.
MOVEMENT	
Dynamic movements usually result from rather complex interactions of physical and chemical forces within the protoplasm. These independent, *autonomous movements* seem to be responses to stimuli with an expenditure of energy rather than imposed by external forces. They may be rapid or slow, depending upon the organism and the quantity and quality of stimuli.	Certain inanimate things seem to display certain movements which may seem to approximate those of living organisms, although they are usually of a simpler nature. Camphor particles in water may move and modify their movements in response to certain external factors. Crystals of certain types (salts, etc.) dissolve and diffuse (move) in an aqueous environment. A drop of mercury in water to which nitric acid is added seems to display a type of movement which somewhat resembles the "flowing" movements of living protoplasm. Brownian movements are displayed by such things as particles of dyes suspended in water etc.

LIVING (ANIMATE) ORGANISMS	NONLIVING (INANIMATE) SUBSTANCES
IRRITABILITY AND ADAPTATION	
All living protoplasm is typically sensitive to certain environmental factors (*irritability*) and tends to react or respond (*adaptation*) because of the labile, dynamic nature of protoplasm and the extremely complex interactions of physical and chemical forces. Responsiveness to stimuli is characteristic of living protoplasm but does not seem to be limited to it. By *adaptation,* living organisms attempt to adjust themselves to their environments so as to live as successfully as possible. Because of irritability, protozoa, bacteria, the various parts of animals and plants, etc., tend to display *variable responses* which vary from time to time and are influenced by the inherent nature of the specific protoplasm and the quantity and quality of the stimuli.	Certain nonliving materials which display movements also seem to display something which approximates irritability and responsiveness under certain conditions. However, the type of response is usually simpler and more predictable than in living organisms. When light rays which fall on a photoelectric cell are interrupted, they may open doors, set off alarms, or count cans in a commercial cannery. Pressing a starter button may result in the movement in an electric generator. The drop of mercury in acidified water may "respond" to contacts with certain other chemicals. The movements displayed by certain inanimate objects may truly resemble some of the simpler movements of certain living organisms, but on the whole they are less complicated and rather more predictable and standardized.
GROWTH AND DEVELOPMENT	
All living plants and animals *require foods* and they *grow,* each true to its type, and *from within,* through *intussusception.* Living organisms also possess the property of *assimilation* (producing living protoplasm from nonliving foods). The energy-bearing molecules are taken in, rearranged, and delicately adjusted into other more complex molecules of living protoplasm under the influences of *enzymes* and *catalysts. Metabolism,* which characterizes protoplasm, consists of *anabolism* (constructive chemical changes, with the storage of energy) and *catabolism* (destructive chemical changes with a release of energy). Usually true growth is accompanied by changes in structure, form, and functions which constitute true *development.* Growth may be the result of an increase in the number of cells, an increase of the size of cells without an increase in numbers, or a combination of the two. Certain structures of living organisms may also be duplicated by *autosynthesis.*	Certain inanimate materials may increase in size *externally* by adding materials which are essentially similar to the original materials by the process of *accretion.* A crystal of table salt in a supersaturated solution of table salt will increase in size by externally adding more salt. Living organisms grow by producing certain other materials true to type, while increases in size of inanimate crystals are influenced by the beginning, raw materials. In other words, the final product is the same as the beginning. Certain chemicals combined to produce the so-called "chemical gardens" (crystals of chemicals in water glass) may increase in size and form beautifully patterned structures which may resemble plantlike structures. However, are these true growth in the accepted sense?

LIVING (ANIMATE) ORGANISMS	NONLIVING (INANIMATE) SUBSTANCES
REPRODUCTION AND HEREDITY (GENETICS)	
All living organisms *reproduce* to form new units of their own kinds. The newly formed units or offspring tend to resemble their parents because of a *continuity pattern* carried from generation to generation through the numerous phenomena of *heredity (genetics)*. "All living organisms arise only from living organisms." So far, nothing comparable to *genes*, etc., has been discovered in the nonliving world. The phenomena of reproduction and heredity are inherent abilities of living protoplasm, even though they may at times be influenced by environmental factors to a certain extent. They seem to be initiated internally and for the most part controlled internally. Living organisms possess the qualities listed above, but a nonliving object never has more than a few of them, and then in a somewhat modified way.	Certain nonliving substances may at times break into smaller pieces, but are these phenomena truly comparable to the complicated processes frequently involved in giving origin to offspring in the animate world? Are these small bits capable of developing into a new individual as in the the living world? Is there inheritance, in the accepted sense, in these inanimate materials?

QUESTIONS AND TOPICS

1. What is meant by a physical property of protoplasm? List all the physical properties of protoplasm; attempt to understand the causes for each physical property and the effects of such a property on the living protoplasm.
2. Learn the correct pronunciation, derivation, and meaning of each new term used in this chapter.
3. Explain how the chemical composition of a living protoplasm depends on, and varies with, the chemical substances taken in.
4. What difficulties are encountered in attempting to analyze living protoplasm chemically? Be sure that the results secured are accurate for the protoplasm when it was still living (before the analyses were started). Might the chemical composition of protoplasm differ when dead from what it might be if the same protoplasm could be analyzed and still be kept alive?
5. Why is nitrogen an essential element for living matter? What general types of food contain nitrogen?
6. Which are more important, the organic or inorganic foods? Why? Give the chief sources of mineral salts.
7. Define (1) catalyst, (2) enzyme, (3) vitamin, (4) metabolism, (5) anabolism, (6) catabolism, (7) colloidal system, (8) sol and gel, (9) Brownian movement, (10) adsorption, (11) emulsoid, and (12) diffusion.
8. Describe the structure of an atom, including the characteristics of each of its parts.

9. Is the rusting of a nail or the rotting of wood to be considered as catabolism? Why? Is the making of concrete from sand, cement, and water to be considered as anabolism? Why?
10. When is an organism considered young? When mature? When old? What factors influence and determine the age of an organism? Would it have been desirable if Nature had not placed death in the scheme of things? Why? Attempt to explain what is meant by death in biologic terms.
11. Do all living organisms possess the same degree of irritability? Is the irritability of the same organism constant? What factors are responsible for this? What role does heredity play in this connection?
12. Define individuality. Of what does individuality consist? Explain the relationships between irritability, adaptability, and individuality.
13. What is meant when we state that an organism is "organized"?
14. Contrast living and nonliving things in as many ways as you can. Is the distinction between them always clear? Give examples.
15. Explain each of the traits which we consider to be characteristic of living organisms.
16. Discuss radioactive isotopes and their roles in the studies of diseases of living organisms.
17. Discuss the roles which radioactive isotopes may play in tracing certain chemicals throughout plants.
18. Discuss the electrical properties displayed by protoplasm and how these phenomena may explain certain functions and abilities in a living organism.

SELECTED REFERENCES

Alexander: Life: Its Nature and Origin, Reinhold Publishing Corp.
Davson and Danielli: The Premeability of Natural Membranes, The Macmillan Co.
Lotka: Elements of Physical Biology, Williams & Wilkins Co.
Moulton: The Cell and Protoplasm, Science Press Printing Co.
Osterhout: The Nature of Life, Henry Holt & Co., Inc.
Rice and Teller: The Structure of Matter, John Wiley & Sons, Inc.
Schrodinger: What Is Life? The Macmillan Co.
Seifriz: Protoplasm, McGraw-Hill Book Co., Inc.

Chapter 7

LIVING PLANTS AND ANIMALS CONTRASTED

Living plants and animals possess many characteristics which are common to both groups, but in many ways they are dissimilar or opposite. While the distinctive features between higher plants and higher animals are obvious, discrimination between them becomes quite difficult in some of the lower forms. In fact, there are certain organisms which are claimed by the botanists as being plants and by the zoologists as being animals because of the presence of both plantlike and animal-like traits in the same individual. Such individuals might be considered as plant-animals and may be illustrated by such forms as *Euglena, Volvox* (Figs. 173, 174), etc. One might consider the Tree of Life as consisting of two main trunks (one plant, the other animal) with numerous branches and subdivisions to represent the various types in each kingdom. In this case the roots are hidden from our view (origin in the past), and new branches are being constantly formed while others are dying. The two main trunks arise from a common ancestral trunk, which suggests the close relationships which exist between the two groups, in spite of the fact that certain individuals on either side may at times be quite dissimilar. Since it is theorized that plants and animals may have had a common ancestry, there is no single difference which absolutely separates all plants from all animals.

In spite of the fact that no absolute criteria can be established, what bases, even though they may be somewhat unsatisfactory, can be used to separate the two groups or to identify individuals in each group? The following are stated briefly so that contrasts and comparisons can be made more easily.

CELLULAR STRUCTURE

Outside the *plasma membrane* of plant cells there usually is a semirigid *cell wall* composed of *cellulose* which gives some rigidity and support but at the same time prevents excessive movement. Animal cells also possess a *plasma membrane* but usually *without a semirigid cell wall;* thus support is lacking but certain movements are permitted. Cellulose, a carbohydrate, is also present in certain unicellular animals (protozoa) and even in certain members (such as tunicates) of the highest phylum of animals. Certain animal cells may secrete hard, rigid intercellular materials. A few animal cells may even possess a cell wall. When water is removed from cells by *plasmolysis* (plaz -mol′ i sis) (Gr. *plasma,* form; *lysis,* loosing), the entire animal cell shrinks, while the plasma membrane usually shrinks away from the cell wall in plants.

CHLOROPHYLL AND PHOTOSYNTHESIS

Plants usually possess green *chlorophyll* by means of which carbon dioxide and water, in the presence of energy-supplying light, are combined into carbohydrate foods by the process of *photosynthesis.* Certain plants such as the fungi (molds, bacteria, yeasts, mushrooms, etc.) lack chlorophyll and must depend upon outside sources for their nutrition. Chlorophyll-bearing plants have the ability to convert kinetic energy derived from the sunlight into potential energy which is stored in the plant. True animals do not possess chlorophyll, although a few borderline organisms (*Euglena, Volvox* [Figs. 173, 174], etc.) may. Hence, in general, animals are dependent upon plants either directly (herbivorous animals) or indirectly (carnivorous animals) for their nutrition. Animals have the ability to change the potential (stored) energy of foods into other types of energy, including kinetic, which can be used for movement and other purposes. The various methods of securing nutrition in plants and animals will be considered in more detail in later chapters.

GROWTH

In plants and animals, growth consists of an increase in the number of cells, an increase in size without an increase in the number of cells, or a combination of the two. Plants might be considered as possessing unlimited growth in which the ratio of nonliving tissues to living tissues gradually increases until the greater part of the plant body may be composed of dead tissues. The older, dead tissues usually remain in plants for support and are constantly increasing over a period of time, while young growing tissues are constantly forming. In most plants, active, embryonic tissues continue growing over long periods of time, as in tips of stems and roots. In plants, the maximum size for a certain species is quite variable and depends greatly upon external environmental conditions.

Animals might be considered as having rather limited growth, in which the mature individual reaches a certain size and characteristic form which do not change to any great extent after maturity is reached. In limited growth in animals the ratio of nonliving to living tissues is rather constant, there never being a constant increase of nonliving as in many plants. By the time animals are mature, most of the embryonic tissues have disappeared. In general, the plant kingdom shows less variation in structure than the animal kingdom does, and even higher plants are less highly organized than comparable higher animals. From a metabolic standpoint, green plants synthesize their organic foods and animals must depend upon outside sources for them. There are some nonchlorophyll plants (fungi) which also depend on outside sources for their nourishment.

LOCOMOTION AND ACTIVITIES

Most plants are sessile (attached), or floating, and not capable of locomotion, while most animals are able to locomote; even the few which are attached (such as sponges, corals, oysters, barnacles, etc.) have relatively rapid movements of certain body parts. There are certain lower plants (bacteria, certain algae, etc.) which are motile. In lower animals the locomotor equipment may be simple cilia, flagella, or pseudopodia, as may be the case in certain lower motile plants. In higher animals locomotion is the result of highly developed nervous, muscular, and skeletal systems.

In general, because of their mode of life, plants store up energy in organic food materials, while animals generally use up energy which they have secured ultimately, and directly or indirectly, from plants. Both plants and animals react to a great variety of stimuli (external and internal), but the former react relatively more slowly than do animals. Plants do not possess nerve tissues, but this is also true for many of the simpler animals. The common sensitive plant *(Mimosa pudica)* exhibits a rather high degree of sensitivity and responsiveness, as does Venus's-flytrap.

EXCRETION OF WASTES

Plants and animals produce wastes as a result of their metabolic activities which are frequently eliminated through the general body surface. However, many of the simple animals have distinct excretory equipments which are not encountered even in the higher plants. The rather complex methods of waste elimination are common in higher animals.

It is evident that there is no single difference which distinguishes all plants from all animals, but studies of large numbers of both groups reveal that they have much in common. In order that comparisons and contrasts may be made between simple and complex plants on the one hand and simple and complex animals on the other, it is suggested that representatives of both groups be studied with these viewpoints in mind. The higher plants and higher animals may be rather readily available, but the lower, simpler plants and animals may not be. It would be a worth-while exercise to study the simple plants and animals that inhabit a fresh-water pool. These may be supplemented with selected specimens which illustrate points of difference mentioned above.

QUESTIONS AND TOPICS

1. Define a plant and an animal in the light of the knowledge gained in this chapter.
2. List and explain each of the principal differences between the group of plants as a whole and the group of animals as a whole.
3. Give reasons why you think animals and plants are closely related and may have had a common ancestry.
4. Discuss the significance of such organisms which we call plant-animals.
5. Need there be clear-cut differences between plants and animals? Why?
6. List some of the more common characteristics possessed by both plants and animals.
7. If you make a field or laboratory study of the various plants and animals encountered in a fresh-water pool, what conclusions can you draw?

SELECTED REFERENCES*

Bates: The Nature of Natural History, Charles Scribner's Sons.
Calkins: The Smallest Living Things, The University Society.
Chapman: Animal Ecology, With Especial Reference to Insects, McGraw-Hill Book Co., Inc.
Comstock: Handbook of Nature Study, Comstock Publishing Co., Inc.
Fasset: Manual of Aquatic Plants, McGraw-Hill Book Co., Inc.
Gates: Field Manual of Plant Ecology, McGraw-Hill Book Co., Inc.
Hausman: Beginner's Guide to Seashore Life, G. P. Putnam's Sons.
Jacques: Living Things—How to Know Them, William C. Brown Co.
Miner: Seashore Life, G. P. Putnam's Sons.
Morgan: Field Book of Ponds and Streams, G. P. Putnam's Sons.
Muenscher: Aquatic Plants, Comstock Publishing Co., Inc.
Needham and Needham: Guide to the Study of Fresh-Water Biology, Comstock Publishing Co., Inc.
Pratt: Manual of Common Invertebrate Animals, A. C. McClurg & Co.
Ward and Whipple: Fresh Water Biology, John Wiley & Sons, Inc.
Welch: Limnology, McGraw-Hill Book Co., Inc.

*This list of references deals primarily with animals and plants in water. References for other plants and animals are found in various other chapters.

Part 2
PLANT BIOLOGY

Chapter 8
SURVEY OF THE PLANT KINGDOM

A detailed study of the entire plant kingdom cannot be made in such a short chapter because there are over 300,000 species (different kinds) of more or less well-known plants. Only a few plants which are representative of the various subdivisions of the plant kingdom will be considered. A more detailed consideration of the structures and functions of certain representative plants will be found in other chapters.

In order to study properly and scientifically the representative members of the plant kingdom, a system of classification must be utilized by means of which investigators in all parts of the world may study the same species of plants and call them by the same scientific name. Without scientific names and classifications, a certain plant might have a large number of different names given to it by students in various parts of the world. In the selection of languages for use in classification and scientific names, Greek and Latin are used because they are more universally understood and because they are not so susceptible to changes in each local community. In other words, these languages are more or less standardized and consequently are very desirable for purposes of classification and naming. Complete, accurate, scientific descriptions and classifications of plants also make it possible to identify and correctly name unknown species of plants. If we did not have specific scientific terms and classifications, each investigator would more or less have to make his own classification and follow his own methods of naming and then would be unable to know if he were studying a form previously described or if he really had a new species.

For these reasons, the entire plant kingdom is divided into several main divisions or phyla (singular, phylum). All of the plants included in a particular phylum have one or more characteristics in common. These characteristics are considered below for each of the phyla of plants and are described under the heading of General Characteristics.

Naturally, if our classification went no farther than phyla, there would be too many differences among the various members so that the system would be practically useless. Consequently, all the members of a phylum, having one or more arbitrarily chosen characters in common, are placed in a subdivision, called a class. Sometimes a phylum is divided into subphyla. In a similar way classes may be divided into orders, orders into families, families into genera (singular, genus), and genera into species. The scientific name of any plant is composed of its genus and its species; i.e., ordinary corn has the scientific name of *Zea mays,* the former being the genus and the latter the species.

Kingdom Plantae

Subkingdom *Thallophyta* (tha -lof′ i ta) (Gr. *thallos,* "leaflike," or young shoot; *phyta,* plants) (plants not forming an embryo) (Figs. 29 to 42)

1. Phylum *Cyanophyta* (si an -of′ i ta) (Gr. *kyanos,* blue; *phyta,* plants) (blue-green algae) (Fig. 29)
2. Phylum *Chlorophyta* (klor -of′ i ta) (Gr. *chloros,* green; *phyta,* plants) (green algae) (Fig. 30)
3. Phylum *Chrysophyta* (kris -of′ i ta) (Gr. *chrysos,* gold; *phyta,* plants) (yellow-green, golden-brown algae and diatoms) (Fig. 31)
4. Phylum *Phaeophyta* (fe -of′ i ta) (Gr. *phaios,* brown or dusky; *phyta,* plants) (brown algae) (Fig. 32)
5. Phylum *Rhodophyta* (rod -of′ i ta) (Gr. *rhodon,* red; *phyta,* plants) (red algae) (Fig. 33)
6. Phylum *Schizomycophyta* (skiz o mai -kof′ i ta) (Gr. *schizo,* split or fission; *mykes,* fungus; *phyta,* plants) (bacteria) (Fig. 34)
7. Phylum *Myxomycophyta* (mik so mai -kof′ i ta) (Gr. *myxos,* slime; *mykes,* fungus; *phyta,* plants) (slime molds or slime fungi) (Fig. 35)
8. Phylum *Eumycophyta* (yu mai -kof′ i ta) (Gr. *eu,* good or true; *mykes,* fungus; *phyta,* plants) (true fungi)
   (1) Class *Phycomycetes* (fi ko mai -se′ tez) (Gr. *phykos,* algalike; *mycetes,* fungi) (algalike fungi) (Figs. 36 and 64)
   (2) Class *Ascomycetes* (as ko mai -se′ tez) (Gr. *ascus,* sac; *mycetes,* fungi) (Ascus or sac fungi) (Figs. 37 to 40)
   (3) Class *Basidiomycetes* (ba sid i o mai -se′ tez) (Gr. *basidium,* base or club; *mycetes,* fungi) (Basidium or club fungi) (Figs. 41, 42 and 65)

Subkingdom *Embryophyta* (em bri -of′ i ta) (Gr. *embryon,* embryo; *phyta,* plants) (plants forming an embryo) (Figs. 43 to 60)

9. Phylum *Bryophyta (Atracheata)* (bri -of′ i ta) (L. *bryon,* moss; *phyta,* plants) (a tre ke -a′ ta) (Gr. *a,* without; *tracheia,* duct or vessel) (moss plants) (plants without vascular [conducting] tissues)
   (1) Class *Musci* (mu′ si) (L. *muscus,* moss) (true mosses) (Figs. 45 and 46)
   (2) Class *Hepaticae* (he -pat′ i se) (L. *hepaticus,* liver) (Liverworts) (Figs. 43 and 44)

10. Phylum *Tracheophyta (Tracheata)* (tre ke -of′ i ta) (Gr. *tracheia,* duct or vessel; *phyta,* plants) (plants with vascular tissues)
   A. Subphylum *Lycopsida* (laik -op′ si da) (Gr. *lykos,* wolf; *opsis,* appearance) (simple vascular system; small, green leaves)
      Class *Lycopodineae* (lai ko po -din′ e e) (Gr. *lykos,* wolf; *pous,* foot) (club "mosses") (Figs. 47 and 48)
   B. Subphylum *Sphenopsida* (sfen -op′ si da) (Gr. *sphen,* wedge; *opsis,* appearance) (simple vascular system; small, scalelike leaves; jointed stems)
      Class *Equisetineae* (ek wi se -tin′ e e (L. *equus,* horse; *seta,* tail or hair) (horsetails or scouring rushes) (Fig. 49)
   C. Subphylum *Pteropsida* (ter -op′ si da) (Gr. *pteris,* wing or fern; *opsis,* appearance) (complex vascular system; large, conspicuous leaves)
      (1) Class *Filicineae* (fil i -sin′ e e) (L. *filix,* fern) (true ferns) (Figs. 50, 51, and 68)
      (2) Class *Gymnospermae* (jim no -spur′ me) (Gr. *gymno,* exposed or naked; *sperma,* seed) (exposed, naked seeds) (conifers and allies) (Figs. 52-54)
      (3) Class *Angiospermae* (an ji o-spur′me) (Gr. *angio,* enclosed; *sperma,* seed) (true flowering plants with seeds enclosed by carpels) (Figs. 55 to 60)
         (a) Subclass *Dicotyledoneae* (di kot i le -do′ ne e) (Gr. *di,* two; *kotyledon,* embryonic, seed leaf) (two cotyledons [embryonic leaves]) (beans, sunflowers, dandelions, etc.) (Figs. 55 to 57)
         (b) Subclass *Monocotyledoneae* (mon o kot i le -do′ ne e) (Gr. *mono,* one; *kotyledon,* embryonic, seed leaf) (one cotyledon [embryonic leaf]) (corn, grasses, etc.) (Figs. 58 to 60)

Number of Species of Plants (Kingdom Plantae)

		Approximate number of species
Subkingdom Thallophyta		
1. Phylum Cyanophyta (blue-green algae)	1,400	
2. Phylum Chlorophyta (green algae)	5,700	
3. Phylum Chrysophyta (yellow-green, golden-brown algae and diatoms)	5,700	
4. Phylum Phaeophyta (brown algae)	900	
5. Phylum Rhodophyta (red algae)	2,500	
Total (Algae)		16,200*
6. Phylum Schizomycophyta (bacteria)	2,500?	
7. Phylum Myxomycophyta (slime molds)	300	
8. Phylum Eumycophyta (true, higher fungi)	75,000	
(1) Class Phycomycetes (algalike fungi)		
(2) Class Ascomycetes (ascus fungi)		
(3) Class Basidiomycetes (basidium fungi)		
Total (Fungi)		77,800*
Subkingdom Embryophyta		
9. Phylum Bryophyta		
(1) Class Musci (true mosses)	13,900	
(2) Class Hepaticae (liverworts)	8,500	
Total		22,400*
10. Phylum Tracheophyta		
A. Subphylum Lycopsida		
(1) Class Lycopodineae (club "mosses")	900	
B. Subphylum Sphenopsida		
(1) Class Equisetineae (horsetails)	25	

*Does not include certain groups not being studied.

C. Subphylum Pteropsida

(1) Class Filicinae (ferns)	8,000		
(2) Class Gymnospermae (conifers and allies)	640		
(3) Class Angiospermae (flowering plants)	195,000		
Total		204,565	
Grand Total			320,965*

SUMMARY OF DISTINGUISHING CHARACTERISTICS OF PLANTS (KINGDOM PLANTAE)

		CHLOROPHYLL	TRUE LEAVES, STEMS, AND ROOTS	MULTICELLULAR EMBRYOS	VASCULAR TISSUES (PHLOEM AND XYLEM)	FLOWERS	SEEDS EXPOSED (NAKED)	SEEDS ENCLOSED
Subkingdom Thallophyta	Fungi	–	–	–	–	–	–	–
	Algae	+	–	–	–	–	–	–
Subkingdom Embryophyta	Mosses and Liverworts	+	–	+	–	–	–	–
	Club "Mosses," Horsetails, and Ferns	+	+	+	+	–	–	–
	Gymnosperms	+	+	+	+	–	+	–
	Angiosperms	+	+	+	+	+	–	+

The plant kingdom (Kingdom Plantae) may be divided into two subkingdoms: *Thallophyta* (tha -lof′ i ta) (Gr. *thallo,* sheetlike or "leaf-like"; *phyta,* plants) and *Embryophyta* (em bri -of′ i ta) (Gr. *embryon,* embryo; *phyta,* plants). The former consists of eight phyla whose representatives are all rather *simply constructed* (without true leaves, stems, or roots), and *none produce multicellular embryos.* The *Embryophyta* are primarily land plants which produce *multicellular embryos* in a female sex organ. The *Embryophyta* will be considered later in this chapter.

SUBKINGDOM THALLOPHYTA

General Characteristics of Thallophytes

The thallophytes are *simply constructed* and are *among the oldest of plants.* They usually live in water or moist places. They are *without true leaves, stems, or roots,* although in certain species there may be structures which resemble them in a general way. Some species are

*Does not include certain groups not being studied.

unicellular, some consist of long filaments composed of a linear series of cells, and others consist of sheetlike masses of cells. Some of the higher forms are even multicellular. In general, they do not possess rigid tissues by means of which they can grow upward to any great extent. Thallophytes *do not possess true vascular (conducting) tissues* (phloem and xylem) which are present in higher plants. *Spores* are produced in *sporangia* (spor -an′ ji a) (Gr. *sporos,* spore; *angios,* vessel) which are *usually unicellular structures.* When *sex cells (gametes)* are formed, they are produced in *gametangia* (gam e -tan′ ji a) (Gr. *gametes,* gametes or sex cells; *angios,* vessel) which are *usually unicellular structures.* When the egg is fertilized to form a *zygote,* the latter does *not produce a multicellular embryo* while still in the female sex structure. Many species of thallophytes are of *great economic importance,* both detrimentally and beneficially. Thallophytes include the *algae* (al′ ge) (L. *alga,* seaweed) and the *fungi* (fun′ji) (L. *fungus,* fungus, or mushroom). The algae contain *chlorophyll* which, in the presence of energy-supplying *light,* is able to combine *carbon dioxide* and *water* to produce *carbohydrates* through the process of *photosynthesis* (fo to -sin′ the sis) (Gr. *phos,* light; *synthesis,* put together). The *fungi lack chlorophyll* and are unable to manufacture their foods; they must depend upon outside sources for their nourishment. The fungi will be considered later in this chapter and in greater detail in a later chapter.

As will be noted in the classification of plants, the first five phyla of the subkingdom *Thallophyta* constitute the so-called "algae," while the next three phyla constitute the so-called "fungi." Certain species of algae will be considered more in detail in the next chapter.

General Characteristics of Algae

The term algae is applied to that group of thallophytes which possesses *chlorophyll* by means of which *photosynthesis* may take place (Figs. 29 to 33). The algae vary greatly among themselves, and many of them even resemble certain fungi in some respects. There are several characteristics which are common to both algae and fungi, except that the former possess chlorophyll while the latter do not. Algae are common in *fresh water* (aquatic) and in *salt water* of oceans (marine). They may be *free living* in fresh or salt water, where, together with the animals, they make up the so-called *plankton* (plangk′ ton) (Gr. *plangktos,* wandering). Others may live on the bottom, where, together with the animals, they constitute the so-called *benthon* (ben′ thon) (Gr. *benthos,* depths of the sea). Certain species may grow in moist soils, on moist trees and rocks, in ice and snow, or in hot springs. Certain species may live *symbiotically* with other organisms for mutual benefits. Algae may live symbiotically with certain fungi in an association known as *lichens* (li′ ken) (Gr. *leichen,* liverwort), in which case the algae supply foods and the fungi supply water and give protection (Fig. 327). Some species of algae may be *parasites,* others *saprophytes,* while a few may be found on other plants as *epiphytes* (ep′ i fite) (Gr. *epi,* upon, *phyton,* plant). Certain species of algae will be considered in greater detail in the next chapter.

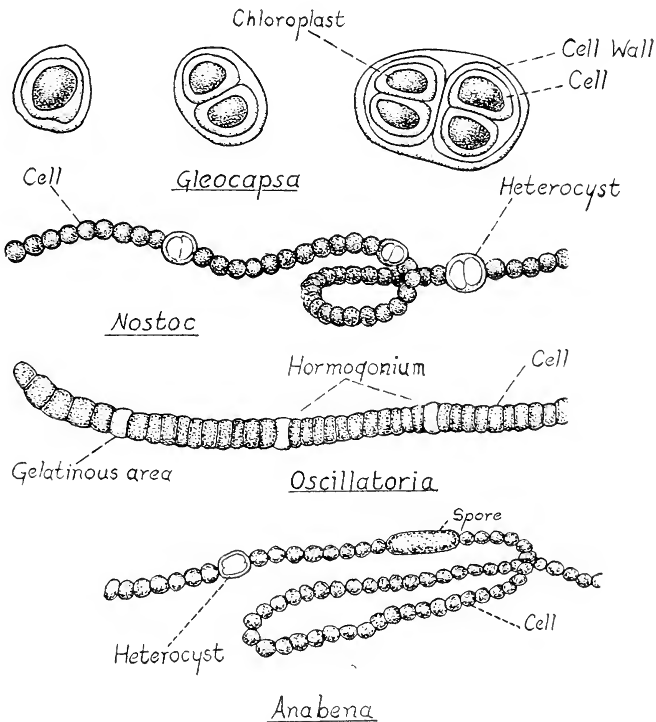


Fig. 29.—Blue-green algae of the phylum *Cyanophyta.*

In the following pages each phylum of plants will be considered as to the general characteristics of the phylum as a whole, and a rather brief classification of certain phyla into subphyla, classes, subclasses, with outstanding characteristics, examples, and illustrations, will be given.

1. **Phylum Cyanophyta** (si an -of′ i ta) (Gr. *kyanos,* blue; *phyta,* plants).—The blue-green algae are *simple, unicellular plants,* although certain species may form *colonies* of similar cells with little differentia-

tion between them. In addition to the green *chlorophyll,* there is a blue pigment called *phycocyanin* (fi ko -si′ anin) (Gr. *phykos,* alga or seaweed; *kyanos,* blue). Sometimes a red pigment may also be present in certain species. The *chlorophyll is distributed throughout the cell* and is not localized in definite bodies known as plastids, as found in other *algae* (Fig. 29). There is *no definite organized nucleus;* the nuclear, chromatin materials are scattered throughout the center of the cell. The cells are often surrounded by a *slimy, gelatinous sheath.* Because of this, the term *Myxophyta* (myx -of′ i ta) (Gr. *myxo,* slime; *phyta,* plants) has been used as the name of the phylum. Foods are stored as *glycogen* (gli′ ko jen) (Gr. *glykys,* sweet), a starchlike carbohydrate.

Reproduction occurs *asexually* by *fission (cell division). No sexual reproduction* is thought to occur in blue-green algae as it does in certain species of other algae. *None of the vegetative (body) cells, or reproductive cells, possess threadlike flagella* which are present in certain types of algae of other phyla.

Most species of blue-green algae grow in fresh water, although a few species grow in salt water. They may cause the water in ponds and lakes to have a yellowish-green color and may be so abundant that they are known as "water blooms," thereby giving the water a "soupy" appearance, a "fishy" taste, and a foul odor. Many species occur in soils, on moist rocks, in greenhouses, on flower pots, and in other moist places. Several species grow in hot springs where the temperature may be over 75° C. and where they may precipitate the magnesium and calcium salts to form *travertine* (trav′ er tin), a whitish, chalklike deposit which may have bright colors because of the contained algae. Blue-green algae may precipitate calcium carbonate in lake waters to form deposits of *marl* (L. *marga,* marl), an earthy mixture of clay and calcium carbonate which is used as a fertilizer on lime-deficient soils.

Certain species may be associated with certain species of chlorophyll-less fungi to form plants known as *lichens* (li′ ken) (Fig. 327). A few species may be parasites in the digestive tracts of animals, including man. Blue-green algae, together with other algae and animals, are great sources of foods for aquatic animals. Some species may even be present on other plants as *epiphytes* (ep′ i fite) (Gr. *epi,* upon; *phyta,* plants). There are approximately 1,400 species.

Examples: *Gleocapsa* (Fig. 29), *Oscillatoria* (Fig. 29), *Nostoc* (Fig. 29), and *Anabena* (Fig. 29).

2. **Phylum Chlorophyta** (klor -of′ i ta) (Gr. *chloros,* green; *phyta,* plants).—In certain species of green algae the *chlorophyll* may be asso-

ciated with additional pigments known as *carotinoids* (carotene and xanthophyll). The chlorophyll is localized in definite bodies called *plastids,* or more specifically known as *chloroplasts* (klo′ ro plast) (Gr. *chloros,* green; *plastos,* moulded or body) (Fig. 30). The cell wall consists of *cellulose* (sel′ u losz) (L. *cellula,* little cell), and the stored food is *starch.* The latter is formed by special structures known as *pyrenoids* (pi′ re noid) (Gr. *pyren,* fruit-stone; *eidos,* resemblance) located on the chloroplasts. The *nucleus is well organized,* as is true of all algae except the blue-green. Green algae vary in structure; the plant body may be *unicellular, colonial,* or *multicellular,* depending upon the species. When the vegetative (body) cells or the reproductive cells are motile, each bears *two to four anterior flagella, usually of equal length.*

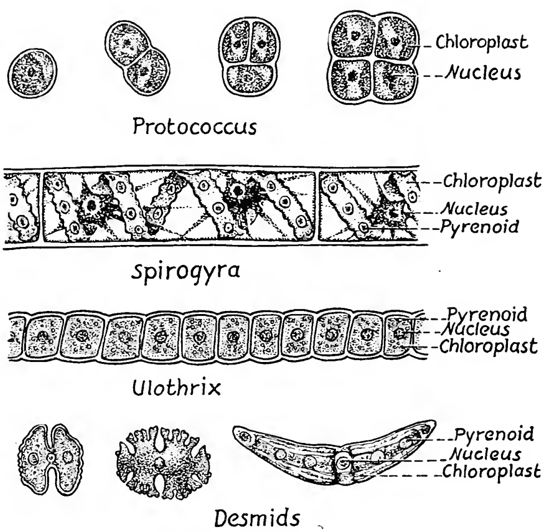


Fig. 30.—Green algae of the phylum *Chlorophyta.*

Reproduction occurs (a) *asexually* by *cell division,* by *fragmentation,* by *motile zoospores,* or by *nonmotile spores* or (b) *sexually* by *isogamy* (i -sog′ a my) (Gr. *isos,* equal; *gamos,* marriage) with the fusion of gametes (sex cells) of equal size, by *heterogamy* (het er -og′ a my) (Gr. *heteros,* different) with the fusion of gametes of unequal size, or by *oogamy* (o -og′ a my) (Gr. *oon,* egg) which is a special type of heterogamy in which the female gamete (egg) is nonmotile. The particular method or methods of reproduction depend upon the species. The structures which produce the sex cells in green algae are *unicellular;* hence they cannot be called sex "organs" in the true sense.

Most green algae live in fresh water, although a few live in the water of the ocean (marine). Other species live in soils, on rocks or trees, in ice or snow. Some species live in salt lake waters whose concentration of salt is much greater than that of ocean water. A few species live on other plants or animals. A few live symbiotically with such animals as protozoa, sponges, and *Hydra.* Sometimes certain types may live symbiotically with certain species of chlorophyll-less fungi to form plants called *lichens* (Fig. 327). Green algae, together with other algae and animals, may supply foods for fresh-water and marine animals. Certain marine forms in conjunction with red algae may secrete lime salts which assist in the formation of reefs in the ocean. There are approximately 5,700 species.

Examples: *Chlamydomonas* (Fig. 61), *Ulothrix* (Fig. 30), *Protococcus* (Fig. 30), *Spirogyra* (Figs. 30 and 62), and desmids (Fig. 30).

3. **Phylum Chrysophyta** (kris -of′ i ta) (Gr. *chrysos,* gold; *phyta,* plants).—In the yellow-green algae, or golden-brown algae, or diatoms, the yellowish-brown pigments known as *carotinoid pigments* are more abundant than the *chlorophyll* so that they may have yellowish-green or golden-brown colors. The pigments are contained in special bodies called *plastids.* A *well-organized nucleus* is characteristic. The cell walls may be composed of a *pair of overlapping halves (valves)* which are frequently impregnated with glasslike *silica* (Fig. 31). Depending upon the species, these algae may be *unicellular, colonial,* or, in a few instances, *multicellular* individuals. The stored foods are *oils* and an insoluble carbohydrate called *leucosin* (lu′ ko sin) (Gr. *leukos,* white).

Asexual reproduction occurs by *cell division,* by *motile zoospores,* or by *nonmotile spores.* When present, *sexual reproduction* occurs by *isogamy* (fusion of similar gametes). The method or methods of reproduction depend upon the species. There are approximately 5,700 species.

Example: Diatoms (Fig. 31).

4. **Phylum Phaeophyta** (fe -of′ i ta) (Gr. *phaios,* brown or dusky; *phyta,* plants).—The brown algae are *multicellular,* some species being quite large. They are *nonmotile (sessile),* being attached by rootlike *holdfasts.* Depending upon the species, the plant body may be composed of a few cells or it may be over a hundred feet long, as in some of the kelps. Brown algae are *marine,* usually present in colder waters. The *chlorophyll* is masked by a golden-brownish pigment called *fucoxanthin*

(fu ko -zan′ thin) (L. *fucus,* alga or seaweed; *xanthos,* yellow). Usually there are several *plastids* per cell, but *no pyrenoids* are present. Each cell has a single, *organized nucleus* and may contain *vacuoles.* Some of the cells have an organization similar to that of higher plant cells, some even having a centrosome similar to that of animal cells. Stored foods are *fats* and *soluble sugars.*

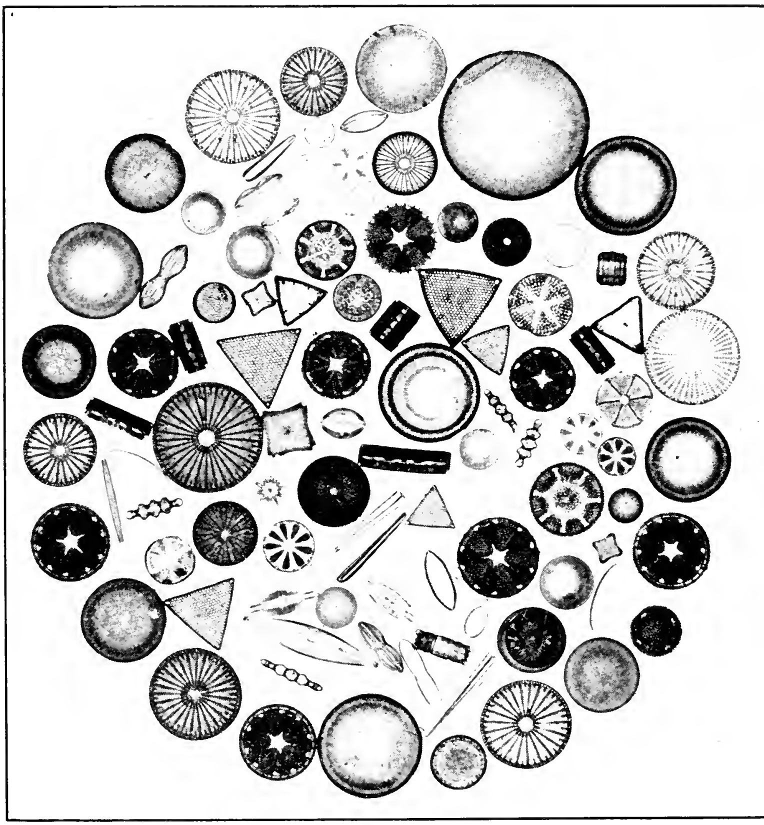


Fig. 31.—Photograph of several species of diatoms of the phylum *Chrysophyta.* (Copyright by General Biological Supply House, Inc., Chicago.)

Brown algae possess *alternation of generations* or *metagenesis* (met a-jen′ e sis) (Gr. *meta,* over; *genesis,* origin) in which a free-living, multicellular, gamete-producing *gametophyte* (gam -me′ to fite) (Gr. *gamos,* marriage; *phyta,* plants) alternates with a free-living, multicellular, spore-producing *sporophyte* (spor′ o fite) (Gr. *spora,* spore or "seed"; *phyta,* plants). Depending upon the species, *asexual reproduction* may occur by *fragmentation*, by *motile zoospores*, or by *nonmotile spores*. Depending upon the species, *sexual reproduction* may occur by *isogamy*, by *heterogamy*, or by *oogamy*. When present, the motile, pear-shaped reproductive cells bear *two lateral flagella of unequal length*.

Certain brown algae are of value as sources of iodine, potassium, fertilizers, and foods for animals and man. There are approximately 900 species.

Examples: The Kelp *(Laminaria)* (Fig. 32) and Rockeed *(Fucus)* (Fig. 32).

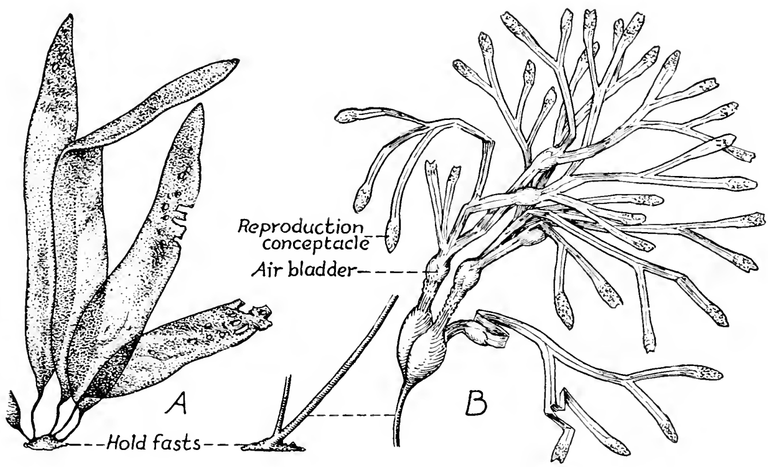


Fig. 32.—Brown algae of the phylum *Phaeophyta*. *A*, The kelp (*Laminaria sp.*); *B*, the rockweed (*Fucus sp.*).

5. **Phylum Rhodophyta** (ro -dof′ i ta) (Gr. *rhodon*, red; *phyta*, plants). —The red algae are frequently referred to as "sea mosses" because of the fancied resemblance of certain forms to true mosses. They contain *plastids* with *chlorophyll* associated with a red pigment called *phycoerythrin* (fai ko e -rith′ rin) (Gr. *phykos*, alga or seaweed; *erythros*, red) and sometimes with a blue pigment called *phycocyanin*. In most species the plants are *multicellular* and may be branched or rather simple, in the form of a ribbon cylinder, or sheet. Different species vary in size from a few inches to several feet in length. Each cell contains a *nucleus*, *central vacuoles*, and *one or several plastids*, some of which possess *pyrenoids*. Broad, *cytoplasmic strands* which connect adjacent cells are features of red algae. Stored foods are insoluble *"starches."*

Reproduction may occur *asexually* by *nonmotile carpospores* produced in a special structure known as a *carpogonium* (kar po -go′ ni um) (Gr. *karpos,* fruit; *gonos,* birth). The latter is characteristic of red algae. The *nonmotile sperm* (from the *antheridia*) is carried by water to the female *carpogonium* where fertilization results in a *zygote.* The latter forms many *filaments,* the tips of which form the many *carpospores.* In *Polysiphonia,* the *carpospore* forms a new plant which produces *sporangia* (spor -an′ ji a) (Gr. *spores,* spore; *angos,* vessel), each with *four asexual tetraspores* (tet′ ra spor) (Gr. *tetra,* four; *sporos,* spore). The nonmotile tetraspores produce Polysiphonia plants either with male *antheridia* or with female *carpogonia.* Because the sex cells are unlike and the egg is nonmotile, the process is called *oogamy. None of the sex cells, or asexual reproductive cells, bear flagella* which is characteristic of red algae.

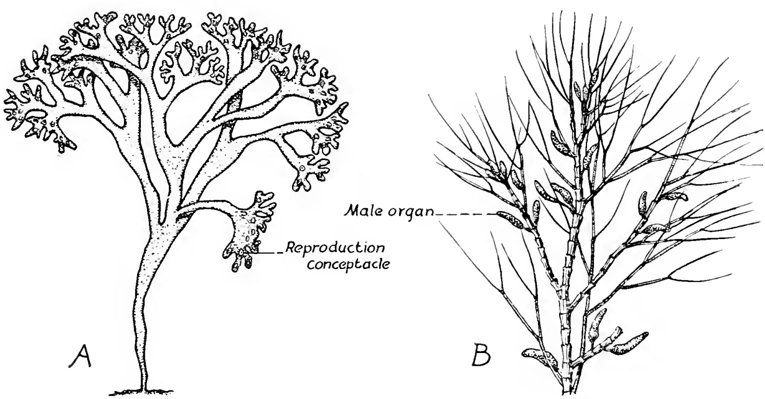


Fig. 33.—Red algae of the phylum *Rhodophyta. A,* "Irish moss" (*Chondrus sp.*); *B,* feathery thallus of *Polysiphonia sp.*

Most red algae are usually attached in warmer sea waters (marine), although a few species are inhabitants of fresh water. There are approximately 2,500 species.

Examples: *Nemalion* (Fig. 63), *Polysiphonia* (Fig. 33), and *Chondrus* (Fig. 33).

General Characteristics of Fungi

The "fungi," which include the last three phyla (*Schizomycophyta, Myxomycophyta,* and *Eumycophyta*) of the Thallophytes, may be characterized as follows: Fungi *lack chlorophyll* and consequently must depend upon a *heterotrophic mode of nutrition* (het ero -trof′ ik) (Gr.

heteros, other; *trophe,* food or nourishment). Because they must secure foods from outside sources, fungi must live in an environment in which there is a certain amount of *moisture.* Heterotrophic fungi may be (1) *saprophytes* (sap′ ro fite) (Gr. *sapros,* dead; *phyton,* plant) living on dead organic materials or (2) *parasites* (pa′ ra site) (Gr. *para,* beside; *sitos,* food) living in, or on, the body of another living plant or animal. A few species of fungi are *autotrophic,* and they will be considered later. Fungi *lack true leaves, stems, and roots;* they *do not form multicellular embryos;* they *lack true vascular (conducting) tissues* (phloem and xylem) which are present in higher plants. Included in the "fungi" are bacteria, slime molds, yeasts, bread molds, water molds, mushrooms, bracket fungi, *Penicillium,* smuts, rusts, etc. The bacteria differ from the slime molds and other fungi in that the former are unicellular, with smaller cells, and without an organized nucleus.

6. **Phylum Schizomycophyta** (skiz o my -kof′ i ta) (Gr. *schizo,* split or fission; *mykes,* fungus; *phyta,* plants).—The *bacteria* (bak -ter′ i a) (Gr. *bakterion,* small rod) are *simple, unicellular (microscopic) plants without chlorophyll* so that a great majority of them must secure foods from outside sources, although a few are able to manufacture foods by *chemosynthesis* or by *photosynthesis* (Fig. 34). The method of nutrition for a majority of bacteria is *heterotrophic* (het ero -trof′ ik) (Gr. *heteros,* other; *trophe,* food or nourishment), securing their foods from outside sources. Consequently, they may be (1) *saprophytes* (sap′ ro fites) (Gr. *sapros,* dead; *phyton,* plant) which obtain foods from dead, nonliving organic materials or (2) *parasites* (pa′ ra site) (Gr. *para,* beside; *sitos,* food) which live in, or on, the living bodies of plants or animals. In the latter instance, if a diseased condition is produced, they are known as *pathogenic bacteria* (path o -jen′ ik) (Gr. *pathos,* suffering; *genos,* produce). A rather small group of bacteria can synthesize organic foods from carbon dioxide and other simple inorganic substances. Consequently, they are *autotrophic* (o to -trof′ ik) (Gr. *autos,* self; *trophe,* nourish). The autotrophic types may be grouped as (1) *chemosynthetic* (kem o sin -thet′ ik) (Gr. *chymos,* juice; *syn,* with; *tithenai,* to place), in which the energy required for the synthesis of foods is derived from the oxidation of certain chemicals, and (2) *photosynthetic,* in which light supplies the food-forming energy and the pigments are purplish-red, or greenish, but are not chlorophyll. The chemosynthetic and photosynthetic bacteria are considered in a later chapter.

Bacteria are considered to be plants rather than animals (1) because of their methods of reproduction which resemble those of certain algae and true fungi, (2) because their cell walls often contain cellulose, a substance which is quite common in higher plants, (3) because they synthesize vitamins like those of certain plants, (4) because some species are able to utilize simple, inorganic materials from which more complex organic compounds may be synthesized.

The forms which bacterial cells may assume include (1) the *coccus* (spherical), (2) *rod shaped* (cylindrical), (3) *spiral shaped,* (4) *filamentous* (which may be branched) (Fig. 34). A bacterial cell has a *cell wall* which in some species contains cellulose. The *protoplasm* of the cell is somewhat *homogeneous*, contains *vacuoles* and *granules,* including *chromatin. No organized nucleus* and *no plastids* are present.

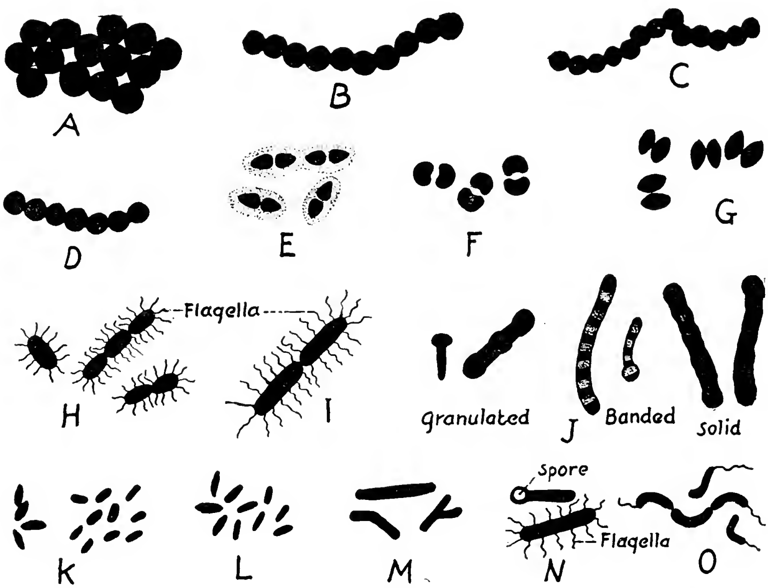


Fig. 34.—Various types of bacteria (coccus or spherical, rod-shaped, spirals) of the phylum *Schizomycophyta. A, Staphylococcus aureus* (0.8-1.0μ), boils, abscesses, pus, etc.; *B, Streptococcus pyogenes* (0.6-1.0μ), infections, etc.; *C, Streptococcus erysipelatis* (0.6-0.8μ), erysipelas; *D, Streptococcus scarlatinae* (0.6-1.0μ), scarlet fever; *E, Diplococcus pneumoniae* (0.5-1.0μ), pneumonia; *F, Neisseria gonorrheae* (gonococcus) (0.6-1.0μ), gonorrhea; *G, Neisseria intracellularis* (meningococcus) (0.6-0.9μ), meningitis; *H, Escherichia coli* (colon organism) (0.5 × 1.0μ), intestinal organisms; *I, Eberthella typhosa* (0.6 × 2.5μ), typhoid fever; *J, Corynebacterium diphtheriae* (0.3-0.8 × 1.0-6.0μ), diphtheria; *K, hemophilus influenzae* (0.2 × 0.7μ), influenza (?); *L, Hemophilus pertussis* (0.3 × 0.7μ), whooping cough; *M, Mycobacterium tuberculosis* (0.15-0.35 × 0.5-5.0μ), tuberculosis; *N, Clostridium tetani* (0.4-0.6 × 2.0-4.0μ), tetanus or lockjaw; *O, Vibrio comma* (0.4-0.6 × 1.0-3.0μ), Asiatic cholera. Organisms drawn somewhat on proportionate scale. Actual dimensions are given in microns (μ), which are each equal to 1/25,000 inch.

Not all species are able to locomote in a liquid, but when they do, this is accomplished by the rhythmic, vibratile actions of whiplike protoplasmic structures known as *flagella* (fla -jel′ a) (L. *flagellum,* whip).

Certain types of bacteria, like higher plants, require free atmospheric oxygen for their normal activities and are known as *aerobes* (a′ er obe) (Gr. *aer,* air; *bios,* life). Other species do not require free oxygen but secure it by breaking down certain types of oxygen-bearing foods through the action of *enzymes.* These are known as *anaerobes* (ana′ er obe) (Gr. *an,* without; *aer,* air; *bios,* life).

The various types of bacteria grow at different temperatures. Those growing best at temperatures of 14° C. or below are known as *psychrophiles* (si′ kro fil) (Gr. *psychros,* cold; *philein,* to love) and those having an optimum temperature between 20° and 40° C. are *mesophiles* (mes′ o-fil) (Gr. *mesos,* middle), while those that grow best above 45° C. are called *thermophiles* (ther′ mo fil) (Gr. *thermo,* heat).

Bacteria produce *enzymes* (en′ zim) (Gr. *en,* in; *zyme,* leaven) with which they perform various functions. Those which are active within the cells (intracellular) are called *endoenzymes,* while those which are secreted to the outside are called (extracellular) *exoenzymes.*

Not all bacteria produce diseases; in fact, a great majority of them do no harm, and a few species are actually beneficial. *Pathogenic bacteria* may produce diseases in other plants, in animals, and in man. Bacteria reproduce *asexually* by *fission* in which the cell divides into two parts. Frequently, after fission, the cells may remain together to form a *colony.* Under favorable conditions fission may occur every twenty to thirty minutes. Certain species produce resistant *endospores* by a condensation of the cell contents into a spherical or oval mass and the loss of a certain amount of water (dehydration). A resistant spore wall surrounds the spore (Fig. 34). A few species of bacteria may produce within their cells a number of small bodies called *gonidia* (go -nid′ i a) (Gr. *gone,* "seed"; *idion,* small), each of which develops into a typical bacterial cell. Certain species, especially the filamentous types, may produce tiny *conidia* (ko -nid′ i a) (Gr. *konis,* dust; *idion,* small) at the tips of the filaments, similar to the formation of such structures by certain true fungi.

Examples: Bacteria (various types of cocci, rods, spirals, and filaments) (Fig. 34).

7. **Phylum Myxomycophyta** (mik so mai -kof′ i ta) (Gr. *myxos,* slime; *mykes,* fungus; *phyta,* plants).—The slime molds (slime fungi) are

primarily *saprophytes* on damp, decaying vegetable materials. They resemble certain fungi in their *methods of spore formation* and resemble certain lower animals because of their *slimy, amoeba-like bodies,* their amoeboid methods of locomotion by the formation of *pseudopodia,* and their *ingestion of solid foods.* The vegetative plant body is a thin mass of naked, slimy protoplasm known as the *plasmodium* (plaz -mo′ di um) (Gr. *plasma,* liquid; *eidos,* form) which contains numerous *nuclei* (multinucleated) and creeps by a flowing of the protoplasm with the formation of *pseudopodia* (su do -po′ di a) (Gr. *pseudes,* false; *pous,* foot). It ingests solid foods in ways which resemble those of certain lower animals.

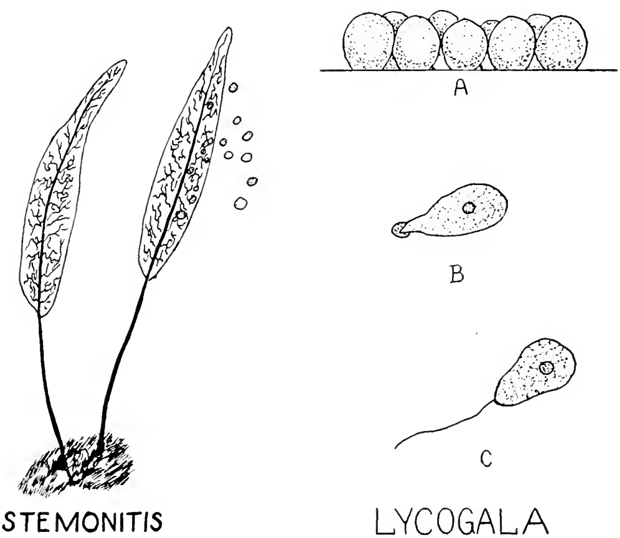


Fig. 35.—Slime molds of the phylum *Myxomycophyta. Stemonitis* shows a stalked sporangium (spore case) with its branched capillitium and spores. *Lycogala* shows, *A,* fruiting bodies (sporangia) which produce spores internally; *B,* germinating spore to form a mononucleated protoplast; *C,* a mononucleated, pear-shaped swarm spore with a flagellum at the pointed end; some of the swarm spores function as gametes to form a zygote which eventually grows to form a multinucleated, amoeboid plasmodium; from the latter are produced the fruiting bodies again.

The plasmodium produces a number of spore cases called *sporangia* (spor -anj′ i a) (Gr. *sporos,* spore or "seed"; *anggeion,* vessel). The color of the sporangium varies with the species (colorless, purple, orange, brown, etc.). Numerous *unicellular, nonmotile spores* are formed in each sporangium. Each germinating spore forms one to four *swarm* *cells or myxamoebae* (mik sa -me′ be) (Gr. *myxa,* slime; *amoibe,* change), each having one to two *flagella.* Locomotion is by flagella or by the formation of pseudopodia. Two myxamoebae fuse to form a *zygote* (zi′ gote) (Gr. *zygotos,* joined) by a process somewhat like sexual reproduction. Several zygotes may join to form a new *plasmodium* in which the nuclei are not fused. There are approximately 300 species. Slime molds are considered more in detail in a later chapter.

Examples: *Stemonitis* (Fig. 35) and *Lycogala* (Fig. 35).

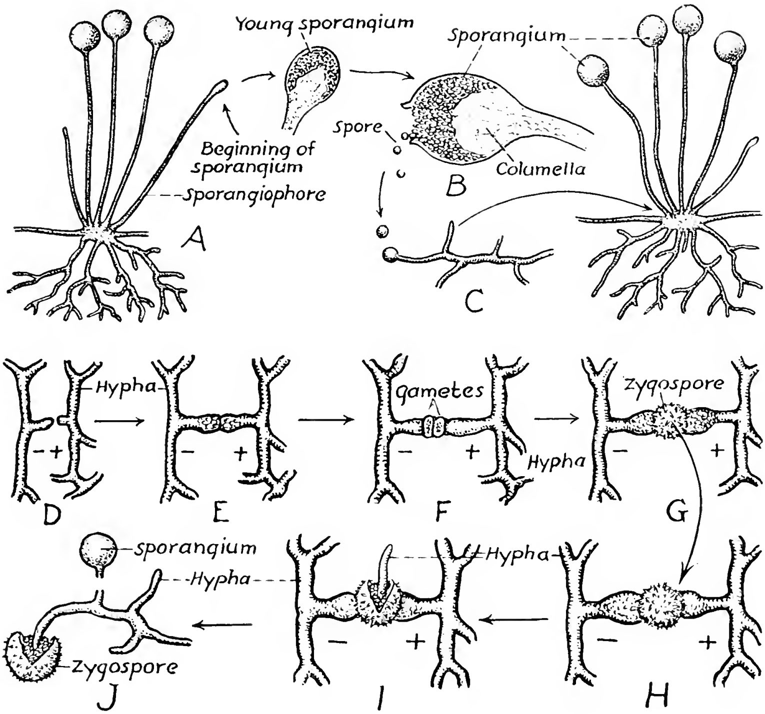


Fig. 36.—Black bread mold *(Rhizopus nigricans)* of the phylum *Eumycophyta,* class *Phycomycetes. A,* Portion of mycelium; *B,* sporangium (enlarged and with escaping spores); *C,* germination of spore into mycelium; *D-F,* conjugation of hyphae (+ and −) to form a zygote; *G-J,* formation and germination of zygospore. Stages *A-C* show asexual spore formation; stages *D-J* show sexual spore (zygospore) formation.

8. **Phylum Eumycophyta** (yu mai -kof′ i ta) (Gr. *eu,* true or good; *mykes,* fungus; *phyta,* plants).—These true, higher fungi include the algalike fungi of the class *Phycomycetes,* the sac (ascus) fungi of the class *Ascomycetes,* and the basidium (club) fungi of the class *Basidiomycetes.*

(1) **Class Phycomycetes.**—The algalike fungi of the class *Phycomycetes* (fi ko mai -se′ tez) (Gr. *phykos,* algalike; *mycetes,* fungi) consist of *filamentous hyphae,* with *organized nuclei* but usually *without septae* (cross walls). The threadlike *hyphae* (hi′ fe) (Gr. *hyphe,* web) frequently form a web known as the *mycelium* (mi -se′ li um) (Gr. *mykes,* fungus). Members of this class are common *saprophytes,* some living in water. Young hyphae may be branched, nonseptate, and contain numerous nuclei. Older hyphae, especially during sexual reproduction, may show septae. Rootlike *rhizoids* (ri′ zoid) (Gr. *rhiza,* root; *eidos,* form) may absorb materials from the substratum and anchor the plant. *Sporangiophores* (spor -an′ ji for) (Gr. *sporos,* spore; *anggion,* vessel; *pherein* (to bear), bear *spore cases* called *sporangia* in the species which

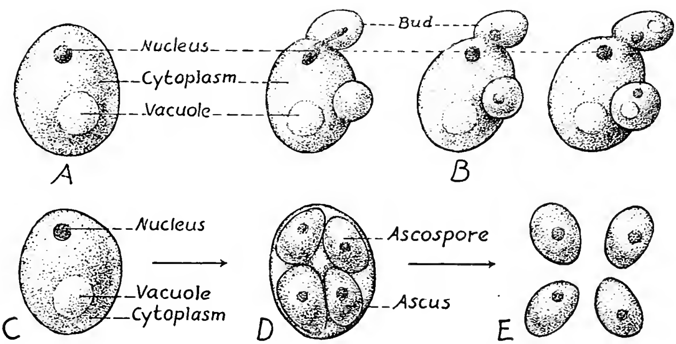


Fig. 37.—Bread yeast *(Saccharomyces cerevisiae)* of the phylum *Eumycophyta,* class *Ascomycetes.* *A,* Yeast cell; *B,* three stages showing reproduction by budding (asexual); *C,* yeast cell which under certain conditions will develop an ascus (*D*) with its ascospores (*E*). A new yeast cell will develop asexually from each ascospore.

are not aquatic. The air-borne, nonmotile, asexual spores germinate to form new hyphae. In aquatic species, such as *Saprolegnia, motile zoospores* are formed in *zoosporangia.* *Sexual reproduction* may occur by *isogamy* or *heterogamy,* depending upon the species. The sexual method is known as *conjugation* and takes place between two different filaments (as in *Rhizopus*) or between two different parts of the same filament (as in *Saprolegnia*). In each instance the fertilized egg forms a *zygote* (zygospore) which develops a new hypha.

Examples: *Rhizopus* (black bread mold) (Fig. 36) and *Saprolegnia* (water mold) (Fig. 64).

(2) **Class Ascomycetes.**—The ascus (sac) fungi belong to the class *Ascomycetes* (as ko mai -se′ tez) (Gr. *ascus,* sac; *mycetes,* fungi) because at some stage in their life cycle all of them may reproduce by

the formation of a saclike *ascus* in which are formed *ascospores.* They all possess *organized nuclei* and all are *filamentous,* with such exceptions as certain types of yeasts. When *hyphae* are present, they are septate (cross walls). Many species are of great economic importance in the

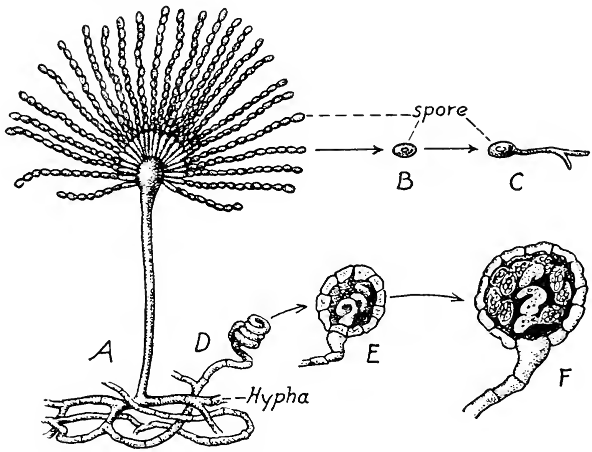


Fig. 38.—Blue-green mold (*Aspergillus sp.*) of the phylum *Eumycophyta,* class *Ascomycetes.* *A,* Portion of mycelium, showing spore formation; *B-C,* spore and its germination; *D-F,* formation of ascospores; *D,* hypha twisted into a coil; *E,* coiled hypha surrounded by an ascus (sac); *F,* coiled hypha forming ascospores within the ascus.

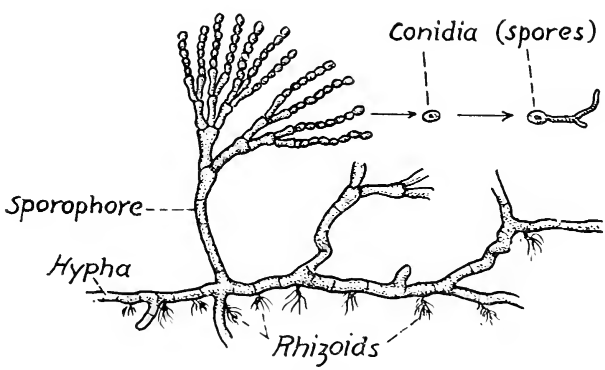


Fig. 39.—Bluish-green mold (*Penicillium sp.*) of the phylum *Eumycophyta,* class *Ascomycetes.* Such molds do not frequently form ascospores, although a few species do so occasionally.

manufacture of foods, as cheeses by such types as *Penicillium camemberti* or *P. requeforti,* in the production of antibiotics by such types as *Penicillium notatum,* etc., in the fermentation of sugars by yeasts, by parasitizing higher plants with the production of such diseases as powdery mildews, and by the production of such plant diseases as blights, etc.

Certain species reproduce *asexually* by the formation of *conidiospores* (ko -nid′ i o spor) (Gr. *konis,* dust; *sporos,* spore) in which the tips of

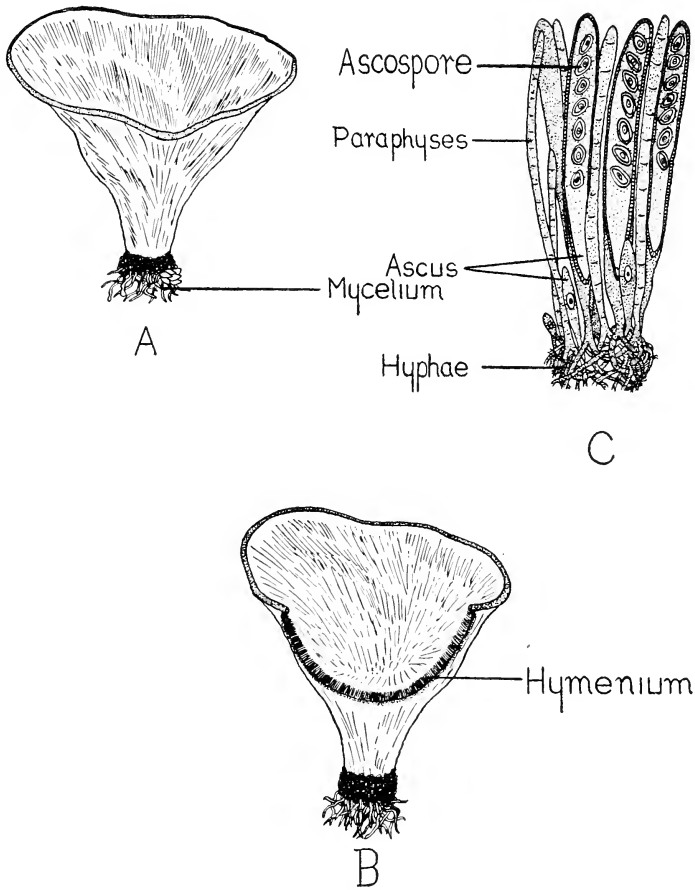


Fig. 40.—Cup fungus (*Peziza*) of the phylum *Eumycophyta,* class *Ascomycetes.* *A,* cup with mycelium for attachment; *B,* section through the cup showing the hymenium; *C,* enlarged section of the hymenium showing immature and mature asci with ascospores, paraphyses, and hyphae.

certain hyphae form chains of colored spores *(conidia),* as in *Penicillium, Aspergillus,* etc. Yeasts commonly reproduce by asexual *budding* in which a small protuberance is pushed from the cell. The ascomycetes are considered in more detail in a later chapter.

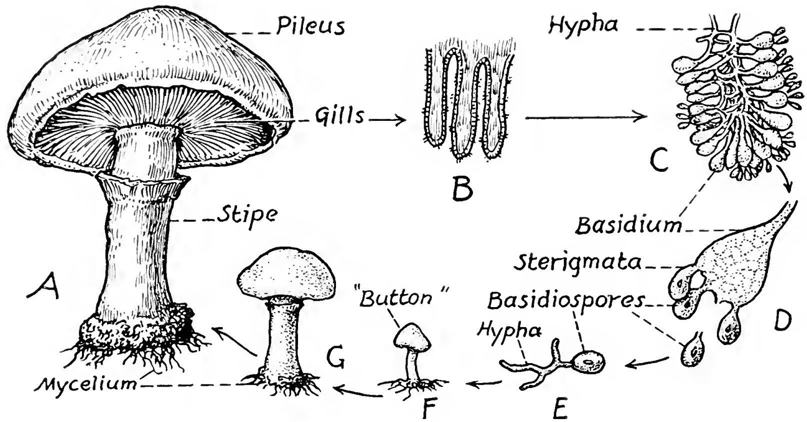


Fig. 41.—Common edible or field mushroom *(Psalliota* [*Agaricus*] *campestris)* of the phylum *Eumycophyta,* class *Basidiomycetes. A,* The so-called mushroom (sporophyte); *B,* three gills of the mushroom in cross section; *C,* one gill much enlarged to show its hyphae and basidia; *D,* a basidium with basidiospores; *E;* germinating spore; *F,* immature "button" mushroom; *G,* later stage in development of the immature into the mature mushroom.

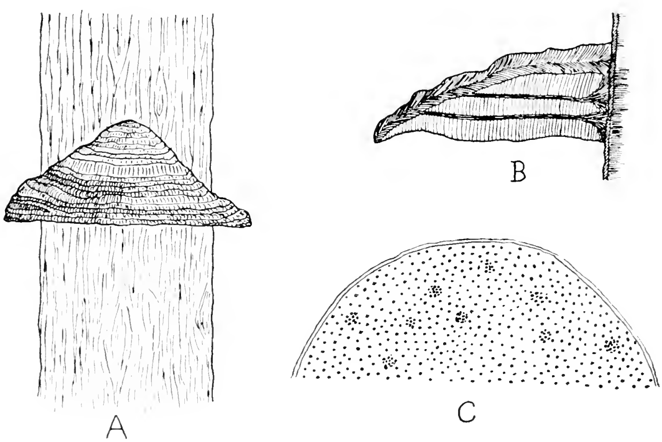


Fig. 42.—Shelf (bracket) fungus of the phylum *Eumycophyta,* class *Basidiomycetes. A,* Attached to a tree; *B,* section of a sporophore showing three annual layers of the porous hymenium, with the newest below; *C,* undersurface showing openings to pores, beneath which are borne the basidiospores.

Examples: *Penicillium* (Fig. 39), *Aspergillus* (Fig. 38), cup fungi such as *Peziza* (Fig. 40), *yeasts* (Fig. 37), powdery mildews, and blights, etc.

(3) **Class Basidiomycetes.**—The basidium (club) fungi belong to the class *Basidiomycetes* (ba sid i o mai -se′ tez) (Gr. *basidium,* club or base; *mycetes,* fungi) because they produce *basidiospores* on club-shaped *basidia* (ba -sid′ i a) (Gr. *basis,* base). They all possess *organized nuclei;* they all are constructed of *filamentous hyphae* which are *septate* (cross walls). In some instances the hyphae may be rather closely compacted and the interhyphal spaces may even be filled in with rather solid substances, as in the case of the bracket (shelf) fungi (Fig. 42).

In certain species other types of *asexual spores* are produced. For example, certain types of smuts produce *conidiospores* somewhat like those produced by certain ascomycetes. In the corn smut (Fig. 66), the fungi produce heavy-walled, dark-colored *smut spores* called *chlamydospores* (klam′ i do spor) (Gr. *chlamys,* cloak; *sporos,* spore). In the black stem rust of wheat *(Puccinia graminis)* several varieties of spores (Fig. 67) are formed: reddish-orange, summer spores known as *uredospores* (u -re′ do spor) (Gr. *uredo,* blight; *sporos,* spore), brownish-black winter spores known as *teliospores* (te′ li o spor) (Gr. *telios,* end; *sporos,* spore), small *pycniospores* (pik′ ni o spor) (Gr. *pyknos,* crowded), and spring spores called *aeciospores* (e′ si o spor) (Gr. *aecium,* injury). These various types of spores are considered in greater detail in a later chapter.

Examples: Mushrooms (Fig. 41), bracket fungi (Fig. 42), smuts (Fig. 66), and rusts (Fig. 67).

SUBKINGDOM EMBRYOPHYTA

General Characteristics of Embryophytes

The Embryophytes constitute the remainder of the plant kingdom, and their representatives, in general, are more complex than the Thallophytes. *Embryophyta* (em bri -of′ i ta) (Gr. *embryon,* embryo; *phyta,* plants) produce a *multicellular embryo* from the *fertilized egg (zygote)* which is *parasitic* for some time in the female sex organ (in the gametophyte in higher plants). They all produce *multicellular sex organs* which are surrounded by a sterile, *protective jacket layer.* The male sex organ is the multicellular *antheridium* (an ther -id′ i um) (Gr. *anthos,* flower; *idion,* diminutive), while the female sex organ is the multicellular *archegonium* (ar -ke go′ ni um) (Gr. *arche,* beginning; *gonos,* offspring). The multicellular spore-forming spore cases, called *sporangia* (spor -anj′ i a) (Gr. *sporos*, spore or "seed"; *anggeion*, vessel) are also protected by a sterile *jacket layer*. These protective jacket layers are necessary in land plants where they are subjected to a variety of environmental influences. All embryophytes reproduce by *oogamy* (o -og′ a my) (Gr. *oon*, egg; *gamos*, marriage) in which *unlike sex cells (gametes)* fuse and the *egg cell is nonmotile*. All have a definite *alternation of generations* in which a multicellular *sporophyte* (spor′ o fite) (Gr. *sporos*, spore; *phyton*, plant) alternates with a multicellular *gametophyte* (gam e′ to fite) (Gr. *gametes*, spouse; *phyta*, plants).

Embryophytes are essentially *terrestrial* (land plants), although a few species may live in water. They all contain *chlorophyll* in green *plastids*. The aerial parts of the plants may be protected by a layer of waxlike *cutin*. *Embryophyta* include the two phyla *Bryophyta* and *Tracheophyta*, both of which are considered in greater detail in later chapters.

9. **Phylum Bryophyta** (bri -of′ i ta) (L. *bryon*, moss; *phyta*, plants).—The Bryophytes include the *liverworts*, which belong to the class *Hepaticae* (he -pat′ i se) (L. *hepaticus*, liver), and the *true mosses*, which belong to the class *Musci* (mu′ si) (L. *muscus*, moss). They are *terrestrial* plants which require a certain amount of moisture for their living activities, and water is required for the transmission of the male sperm to the female egg. They possess *chlorophyll* in *chloroplasts* for the process of *photosynthesis*. Liverworts and true mosses possess *similar methods of reproduction and life cycles* and are *much alike structurally and functionally* in spite of differences which may appear upon casual observation. In general, the plant body of Bryophytes is never filamentous but is composed of blocks, or sheets, of cells forming a *parenchymatous tissue* (par eng -kim′ a tus) (Gr. *para*, beside; *engchyma*, infusion) composed of cells with rather thin walls. Consequently, none of the Bryophytes grow to any great height. They *lack true roots, true stems*, and *true leaves*, because they *lack the vascular tissues*, xylem and phloem, which are present in higher plants. Rootlike *rhizoids* anchor the plants and absorb materials from the substratum.

Bryophytes possess *alternation of generations* in which a multicellular *gametophyte* alternates with a multicellular *sporophyte*. The latter is more or less dependent upon the gametophyte. The multicellular, gamete-producing *gametangia* (gam e -tan′ ji a) (Gr. *gametes*, gametes, or spouse; *anggeion*, vessel) possess a *protective layer of sterile cells*. Bryophytes develop a *multicellular embryo* from the *fertilized egg (zygote)*, from which the sporophyte develops. *No asexual spores* are produced. *Asexual* reproduction may occur by *fragmentation* of the plant or by special bodies known as *gemmae* (jem′ i) (L. *gemma,* bud), depending upon the species.

(1) **Class Hepaticae (Liverworts).**—Many of the liverworts *grow flat on the substratum* and have *dorsoventral bodies,* with the dorsal (upper) surface of their gametophyte different from the ventral (lower) surface. Certain liverworts have *flat, lobed, thallose bodies* which have a fancied resemblance to the lobes of a liver of higher animals; for example, *Marchantia* (Fig. 43). Other species, called the *leafy liverworts,* have bodies with *"leaflike" structures* (not true leaves), thus

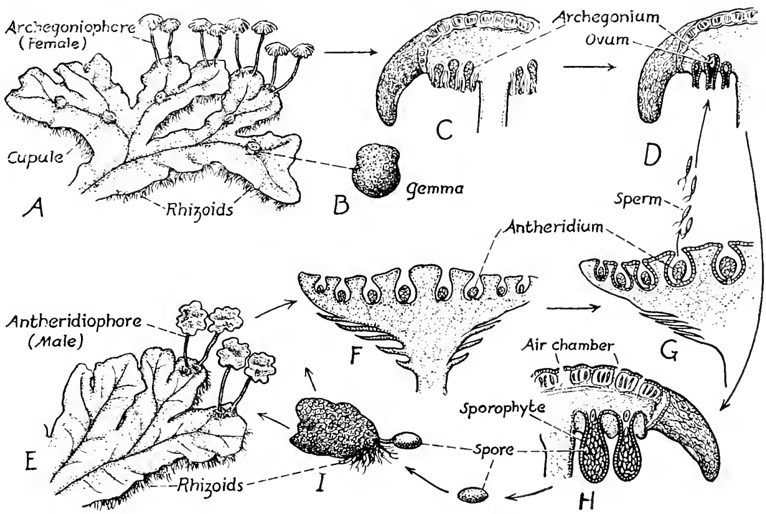


Fig. 43.—Common liverwort (*Marchantia sp.*) of the phylum *Bryophyta,* class *Hepaticae.* *A,* Female plant or thallus; *B,* gemma produced in a cupule; the gemma will develop into a thallus similar to the one on which it was formed; *C,* longitudinal section of an archegonial receptacle (female); *D,* archegonial receptacle in a longitudinal section much enlarged; *E,* male plant or thallus; *F,* longitudinal section of an antheridial receptacle (male); *G,* antheridial receptacle in logitudinal section much enlarged; *H,* archegonial receptacle in longitudinal section still further enlarged and with a sporophyte (spore-forming plant) attached to the base of the archegonium; the sporangium is filled with spores; *I,* spore germinating into a new thallus with its rhizoids. The thalli will develop into adult liverwort plants.

resembling certain true mosses, except that these leafy liverworts are prostrate on the substratum; for example, *Porella* (Fig. 44). There are approximately 8,500 species. Liverworts are considered in greater detail in a later chapter.

Examples: Thalloid liverworts *(Marchantia)* (Fig. 43) and leafy liverworts *(Porella)* (Fig. 44).

(2) **Class Musci** (True Mosses).—These are *small, green plants* which are *usually upright* and may grow so densely in some moist places as to form a mat of vegetation. Such masses of vegetation may consist of hundreds of individual moss plants. Even though mosses contain

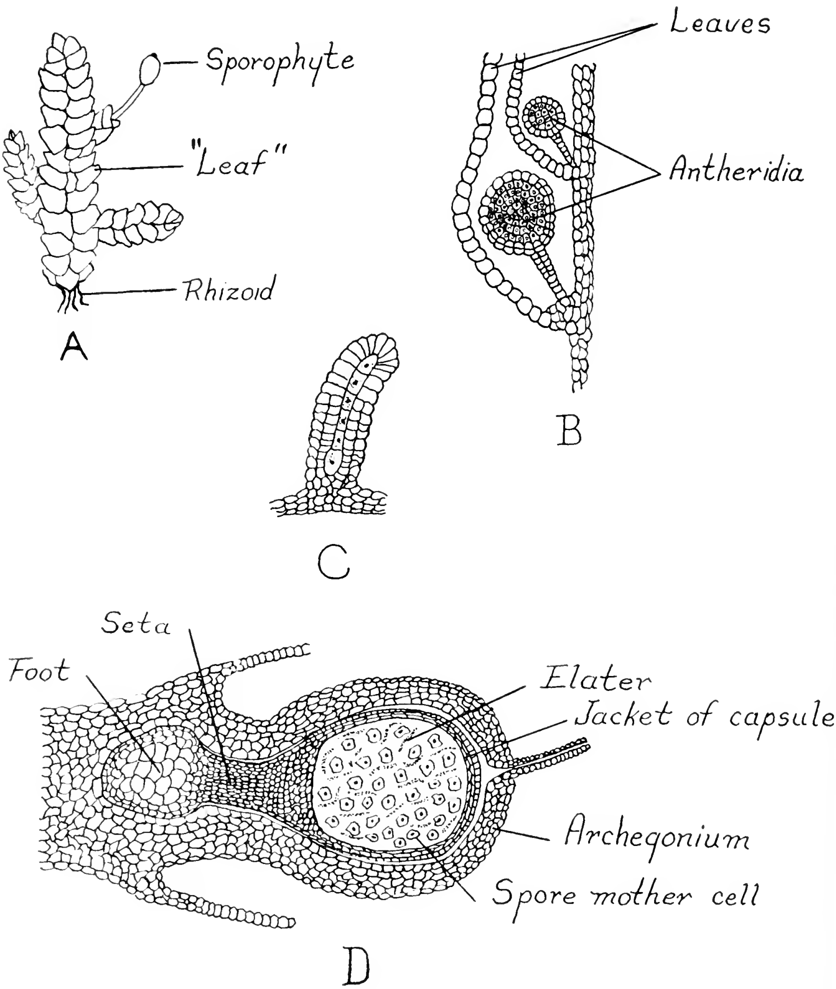


Fig. 44.—Leafy liverwort (*Porella*) of the phylum *Bryophyta,* class *Hepaticae.* *A,* female plant with an attached sporophyte; *B,* portion of a branch of a male plant bearing antheridia which produce antherozoids (male); *C,* young archegonium from an archegonial branch of a female plant showing an egg and elongated neck; *D,* developing sporophyte (in longitudinal section) attached to the parent gametophyte.

rootlike *rhizoids* and structures which superficially resemble stems and leaves, they are *not true roots, stems, and leaves,* because they *lack the vascular tissues* (phloem and xylem). Each individual consists of a *stemlike axis* with its small, attached *leaflike structures.* The *sporophyte* of most mosses is usually larger than those of liverworts, even though the sporophytes are parasitic in both. There are approximately 13,900 species. True mosses are considered in greater detail in a later chapter.

Examples: *Polytrichum* (hairy-cap moss) (Fig. 45) and *Sphagnum* (peat or bog moss) (Fig. 46).

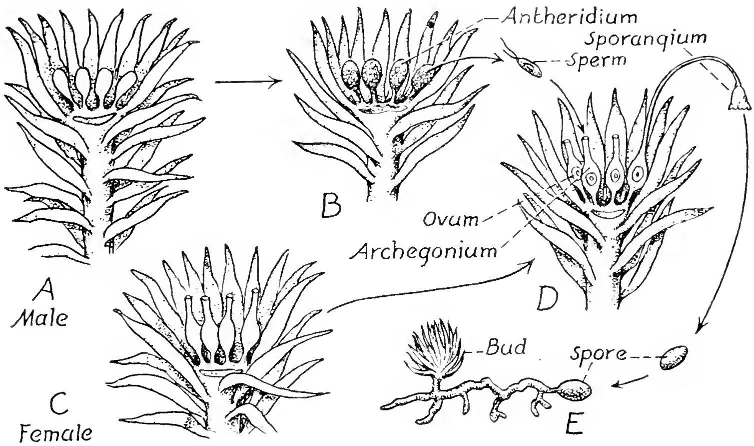


Fig. 45.—Common moss (*Polytrichum sp.*) of the phylum *Bryophyta,* class *Musci.* *A,* Male gametophyte plant with cluster of antheridia at tip; *B,* tip of male gametophyte enlarged to show antheridia which produce sperm; *C,* female gametophyte plant with cluster of archegonia at tip; *D,* tip of female gametophyte enlarged to show archegonia which produce eggs (ova); an ovum fertilized by a sperm is shown developing (at the right) into a sporangium (spore-bearing organ) which produces numerous spores; *E,* spore germinating to form a bud which develops into a gametophyte plant (either male or female).

10. **Phylum Tracheophyta** (tre ke -of′ i ta) (Gr. *tracheia,* duct or vessel; *phyta,* plants).—The plants of this phylum all possess a *vascular system* composed of *phloem* and *xylem tissues* whose complexity varies with the various groups. This phylum includes the club "mosses" of the subphylum *Lycopsida,* the horsetails of the subphylum *Sphenopsida,* and the ferns, gymnosperms, and angiosperms (flowering plants) of the subphylum *Pteropsida.*

Tracheophytes possess *true leaves, stems, and roots, skeletal materials* for more or less upright growth, *stomata* (small openings) for the exchange of gases, and a protective layer of waxlike *cutin,* in certain parts. The *sporophyte* is larger than the rather inconspicuous *gametophyte,* and the former is independent when mature. Hence, there is an *alternation of generations.* Tracheophytes are primarily *terrestrial,* although some live in water. The development of plants with vascular systems is one of the great steps in the evolution of plants. A recent theory suggests that the vascular plants may have evolved from some algal ancestor, probably from the *Chlorophyta.* All possess *multicellular sex organs,* and *multicellular embryos* are developed from the *fertilized egg (zygote).*

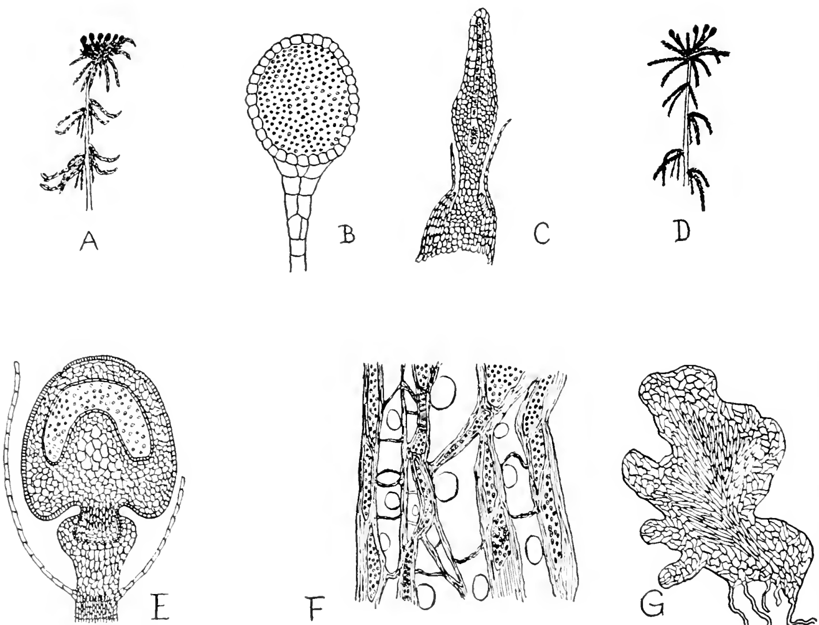


Fig. 46.—Bog or peat moss *(Sphagnum)* of the phylum *Bryophyta,* class *Musci. A,* plant showing terminal antheridial (male) branches (at tip); *B,* antheridium (in section) producing sperm; *C,* archegonium (in section) showing egg and elongated neck; *D,* plant showing terminal sporophytes (at tip); *E,* sporophyte (in section) showing basal foot for attachment to gametophyte, the seta, and the production of spores; *F,* leaflike organ (surface view) showing cells containing chloroplasts and other clear, dead cells for water storage; the latter connect with the outside by means of pores; *G,* protonema (young thalloid gametophyte) from which the erect, adult gametophyte will arise; rootlike rhizoids are shown.

A. **Subphylum Lycopsida** (laik -op′ si da) (Gr. *lykos,* wolf; *opsis,* appearance).—The club "mosses" belong to the class *Lycopodineae* (lai ko po -din′ e e) (Gr. *lykos,* wolf; *pous,* foot). The *sporophyte* consists of true *root, stem,* and *leaves.* The *small, microphyllous leaves* (mi kro -fil′ us) (Gr. *mikros,* small; *phyllon,* leaf) are usually *spirally arranged.* The *roots* and *stems* are *usually branched dichotomously* (di -kot′ o mus ly) (Gr. *dicha,* in two; *temnein,* to cut). Spore-producing *sporangia* occur *singly on the upper surface* of specialized leaves known as *sporophylls* (spor′ o fil) (Gr. *sporos,* spore; *phyllon,* leaf). Usually the sporophylls with their sporangia are grouped at the tips of the stems to form *cones* or *strobili* (strob′ il i) (Gr. *strobilos,* cone). The spore-bearing organs are often foot or club shaped. Club "mosses" are principally *perennial, creeping evergreens,* which explains their common name of "ground pines."

Examples: Club "moss" *(Lycopodium)* (Fig. 47) and smaller club "moss" *(Selaginella)* (Fig. 48).

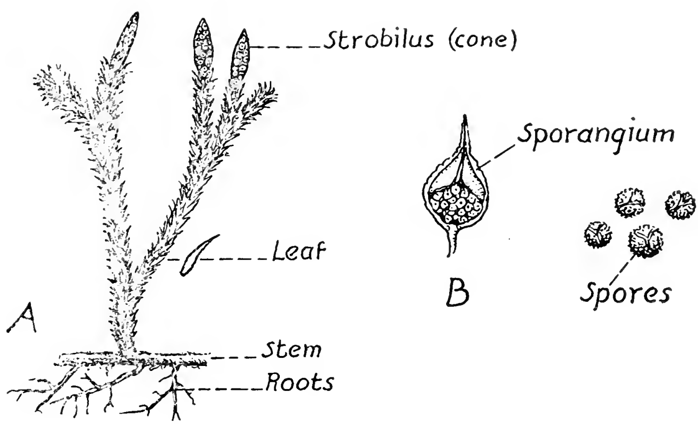


Fig. 47.—Club "moss" or "ground pine" (*Lycopodium sp.*) of the subphylum *Lycopsida,* class *Lycopodineae.* *A,* Branches bearing reproductive strobili, each with sporophylls; *B,* sporophyll enlarged, showing sporangium and spores.

B. **Subphylum Sphenopsida** (sfen -op′ si da) (Gr. *sphen.* wedge; *opsis,* appearance).—The horsetails belong to the class Equisetineae (ek wi se -tin′ e e) (Gr. *equus,* horse; *seta,* tail or hair). The *sporophyte* has *true roots, stems,* and *leaves; the small leaves are scalelike* (sometimes wedgelike) and in *whorls* at the *nodes* of the *hollow, jointed stems* (distinct nodes); stems are *usually ribbed* and *impregnated with silica* which explains the common name of scouring rushes. A *horizontal, branched, underground stem,* or *rhizome* (ri′ zom) (Gr. *rhizoma,* root) in most species, bears two types of *aerial stems:* (1) the *sterile, green branched* *vegetative stem* and (2) the *colorless, unbranched, fertile, reproductive stem* with its single, terminal *cone.*

Sporangia (five to ten in number) are borne on a *sporangiophore* which is shield shaped or umbrella shaped. Numerous sporangiophores are grouped to form the *cones* (strobili). The *spores are alike (homosporous),* and each has four ribbonlike, hygroscopic *elaters* (el′ at er) (Gr. *elater,* driver) which are affected by moisture changes to assist in the movement of the spores. A germinating spore forms a small, green, ribbonlike young *gametophyte,* with *rhizoids,* and usually with both male *antheridia* and female *archegonia.* The *spiral, multiflagellated sperms* swim to the archegonium where the *egg* is fertilized to form a *zygote.*

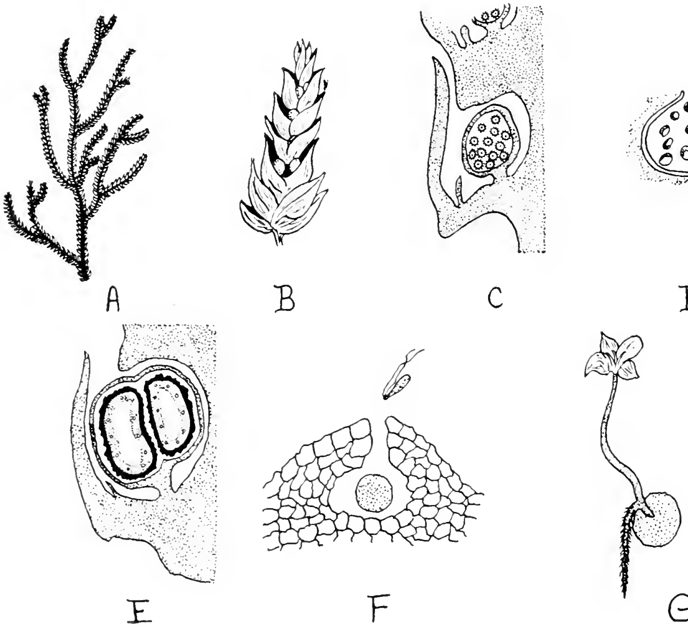


Fig. 48.—Smaller club "moss' (*Selaginella*) of the phylum *Tracheophyta,* class *Lycopodineae.* *A,* Part of a mature sporophyte; *B,* strobilus (from tip of branch) consisting of numerous sporophylls, each with a basal sporangium; *C,* microsporangium (in section) producing small microspores; *D,* microsporangium (in section) in which biflagellated sperms (antherozoids) are produced from megagametophytes, the latter having developed from microspores; *E,* megasporangium (in section) producing large megaspores; *F,* archegonium (in section) with its egg, in a megagametophyte, and a sperm about to enter; a megaspore (within the megasporangium) germinates to form a megagametophyte which contains archegonia (with egg, etc.); a fertilized egg forms a zygote from which develops the parasitic, embryonic sporophyte; *G,* older sporophyte (still attached to the megagametophyte) bearing embryonic, primary stem, leaves, and roots.

The latter forms a *multicellular embryo* which develops into a new *sporophyte.* Hence, there is *alternation of generations.* There are approximately 25 species.

Examples: Horsetail *(Equisetum)* (Fig. 49).

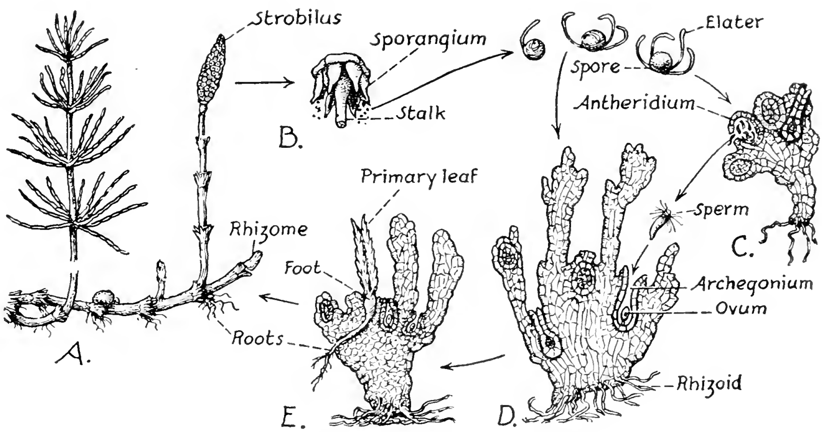


Fig. 49.—Common horsetail or scouring rush (*Equisetum*) of the subphylum *Sphenopsida,* class *Equisetineae.* *A,* Sterile, vegetative branch (left) and fertile, reproductive branch (right); *B,* one unit of a strobilus much enlarged to show several sporangia; *C,* prothallus with antheridia for sperm production and an archegonium for egg (ovum) production; *D,* gametophyte with archegonia for ovum (egg) production and antheridia for sperm production; *E,* embryo of horsetail plant developing from a fertilized egg in the gametophyte. The embryo consists of two primary leaves, a stalklike foot, and a primary root. The prothallus eventually disappears and the embryo develops into a mature plant with both kinds of aerial branches, as shown in *A.*

C. **Subphylum Pteropsida** (ter -op′ si da) (Gr. *pteris,* wing or fern; *opsis,* appearance).—

FERNS.—The true ferns belong to the class *Filicineae* (fil i -sin′ e e) (L. *filix,* fern). The sporophyte consists of *true roots, stem* and *leaves;* the *leaves are generally large,* or *megaphyllous* (Gr. *megas,* large), and in ferns are commonly called fronds. The *vascular system is rather well developed* (Figs. 50, 51, 68, and 69).

Multicellular *sporangia* are borne in clusters, called *sori* (so′ ri) (Gr. *soros,* heap), on the *lower surface of the leaves* or on the margins in certain species. In the ferns, the *sporophyte* is *large and independent* when mature, while the *gametophyte* is *small, free living, and also independent.* This is in contrast to the higher plants in which the gametophyte is dependent upon the sporophyte. There is an *alternation of generations.*

A motile, *multiflagellated sperm* swims through water to fertilize the *egg* (ovum) in the female *archegonium,* thus forming a *zygote.* The latter produces a *multicellular embryo* which develops a *sporophyte.* A germinating spore forms a small, thin, green, heart-shaped *prothallus* (prothallium) with male *antheridia* and female *archegonia.*

Examples: *Pteridium* (Fig. 50) and *Polypodium* (Fig. 51).

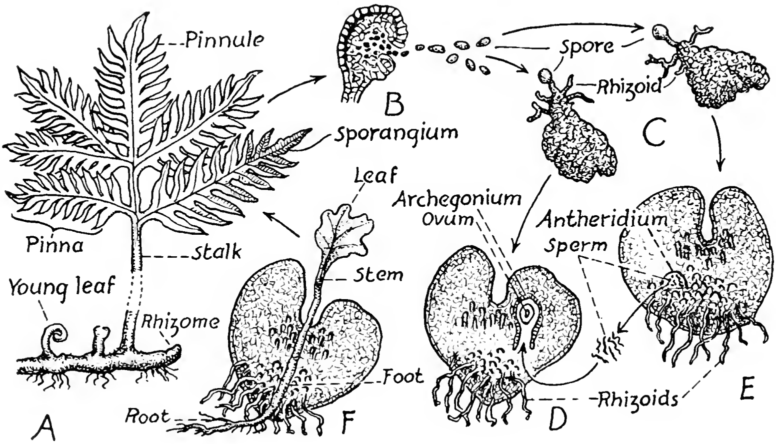


Fig. 50.—Common fern *(Pteridium)* of the subphylum *Pteropsida,* class *Filicineae. A,* Fern plant or sporophyte; *B,* sporangium enlarged and emitting spores; *C,* two spores developing into prothalli; *D,* prothallus with archegonia (female) near the notch with one archegonium enlarged to show the ovum; antheridia (male) near the rhizoids; *E,* similar prothallus with archegonia and antheridia, with an enlarged antheridium to show the sperm; self-fertilization does not occur; *F,* prothallus with a young fern plant growing out of the archegonium from the fertilized ovum. The prothallus to which this sporophyte is attached eventually will disappear.

Gymnosperms.—The gymnosperms, or those plants which produce *seeds exposed* (naked) on *female sporophylls,* known as *megasporophylls,* belong to the class *Gymnospermae* (jim no -spur′ me) (Gr. *gymnos,* naked or exposed; *sperma,* seed). The gymnosperms include the cone-bearing evergreens (conifers) and their allies.

Gymnosperms are *rather large, woody, perennial plants* which are mainly *evergreen* (retain leaves more than one growing season). Certain types may be short and shrubby. They possess *true roots, stems, and leaves:* in the cone-bearing evergreens the leaves may be *needlelike* or *scalelike.* The *sporophyte* generation is large, complex, and independent, while the *gametophyte* is small (microscopic) and *dependent* (parasitic) upon the sporophyte. *Two kinds of cones* composed of *sporophylls* are

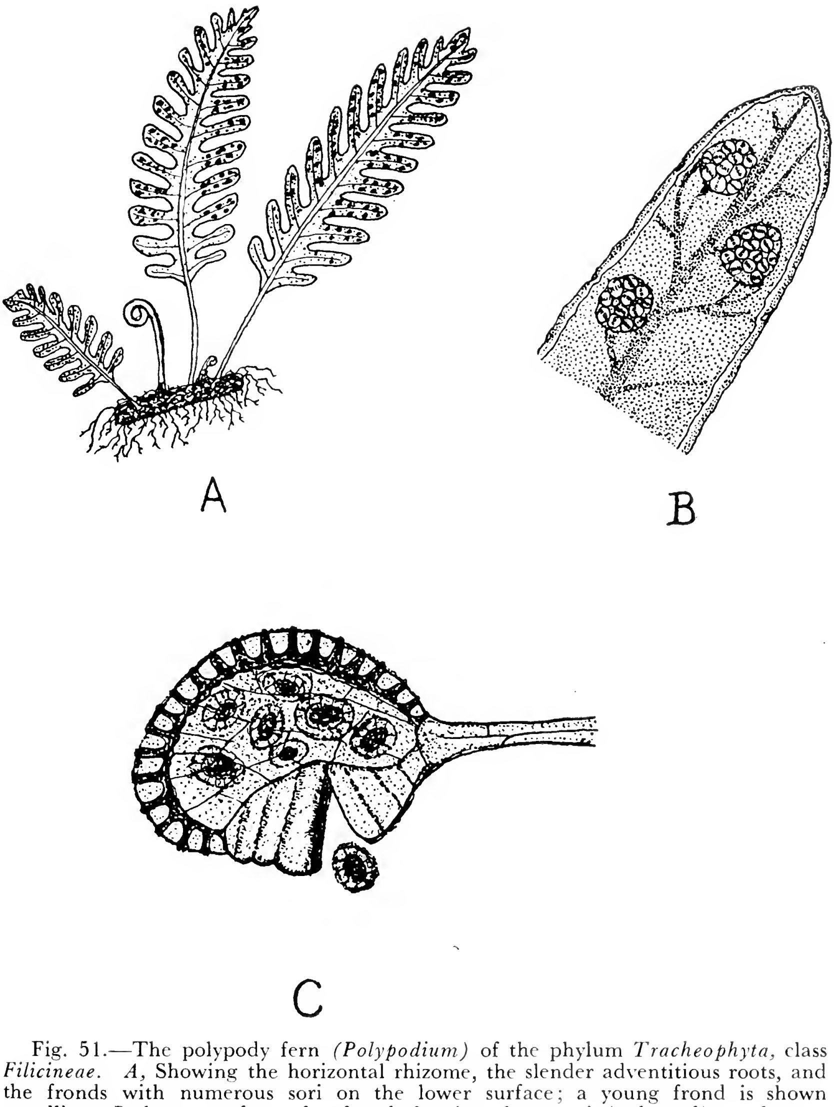


Fig. 51.—The polypody fern *(Polypodium)* of the phylum *Tracheophyta,* class *Filicineae.* *A,* Showing the horizontal rhizome, the slender adventitious roots, and the fronds with numerous sori on the lower surface; a young frond is shown unrolling; *B,* lower surface of a frond showing three sori (enlarged), each consisting of numerous sporangia which produce spores; *C,* a sporangium much enlarged, showing the stalk, the internal spores, the capsule with thin walls, and the water-sensitive annulus (band of cells, each of which has three thick walls and an outer thin wall); the annulus responds to changes in moisture and bends back, thus throwing the spores to the outside.

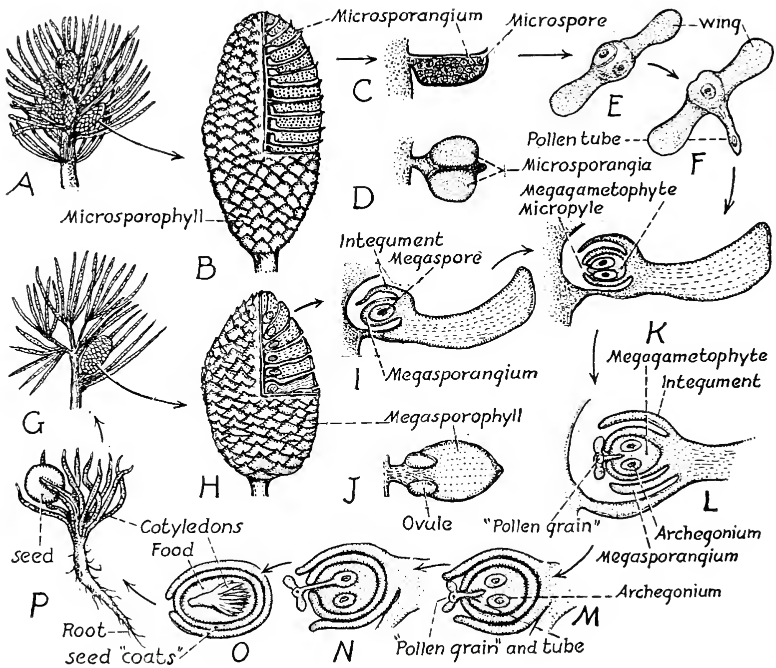


Fig. 52.—Pine tree life cycle *(Pinus sp.)*. *A,* Branch with (male) staminate cones; *B,* staminate cone enlarged with upper right section showing microsporophylls, microsporangia, and microspores; *C,* microsporophyll enlarged (side view) showing microsporangium and microspores; *D,* microsporophyll enlarged and viewed from below; *E,* microgametophyte (pollen grain) developed from a microspore; *F,* developing microgametophyte with its pollen tube and nuclei; *G,* branch with (female) carpellate cone; *H,* carpellate cone enlarged with upper right section showing megasporophylls, megasporangia, and megaspores; *I,* megasporophyll enlarged (side view) showing megasporangium and megaspore; *J,* megasporophyll enlarged and viewed from above; *K,* megasporophyll still more enlarged (side view), showing megasporangium, integument, megagametophyte, and micropyle; *L,* entrance of microgametophyte (pollen grain) into the megasporangium through the micropyle. Note the megagametophyte with its archegonia, each containing a megagamete (egg); *M,* as *L* above, with pollen tube growing toward archegonium; *N,* fusion of the contents of the microgametophyte (pollen grain) and the megagamete (egg) of the archegonium; *O,* mature pine seed (longitudinal section) with two seed coats and food; *P,* germination of seed (split) showing cotyledons and root. This young plant is an immature sporophyte which eventually will develop into a pine tree.

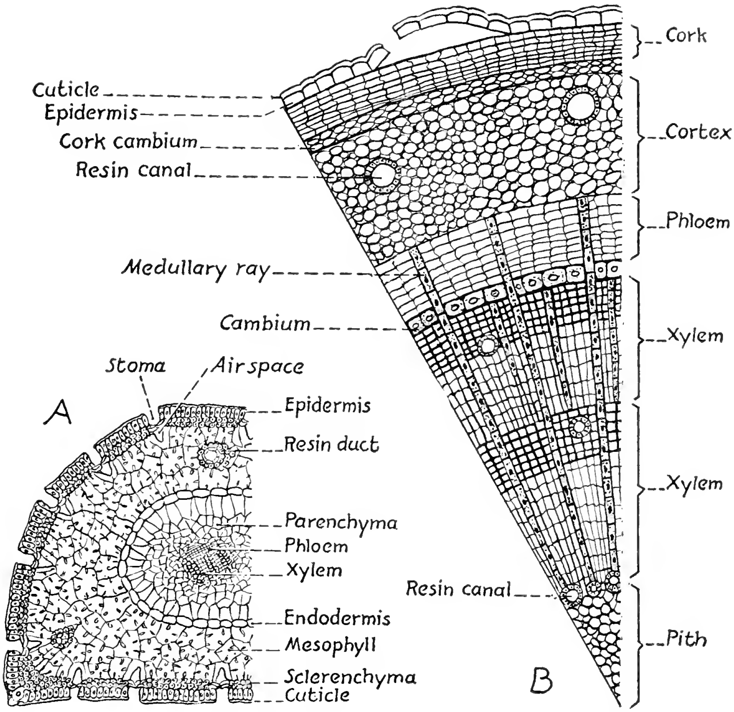


Fig. 53.—Pine tree *(Pinus sp.)*. *A,* One-half of a needle (leaf); *B,* a stem, both in cross section and somewhat diagrammatically. Note there are two layers of xylem (one for each year of stem growth) and that the outer cells of each xylem represent fall wood, while the inner layers of each xylem represent spring wood. The spring and fall growths of each xylem constitute an annual ring. The sclerenchyma of the leaf is also known as mechanical tissue; the mesophyll contains chlorophyll and is called photosynthetic tissue.

usually present. The male cones are composed of *microsporophylls,* while the female cones are composed of *megasporophylls.* The *ovules* (immature, undeveloped seeds), and later the *true seeds,* are borne *exposed* on the female *megasporophylls.*

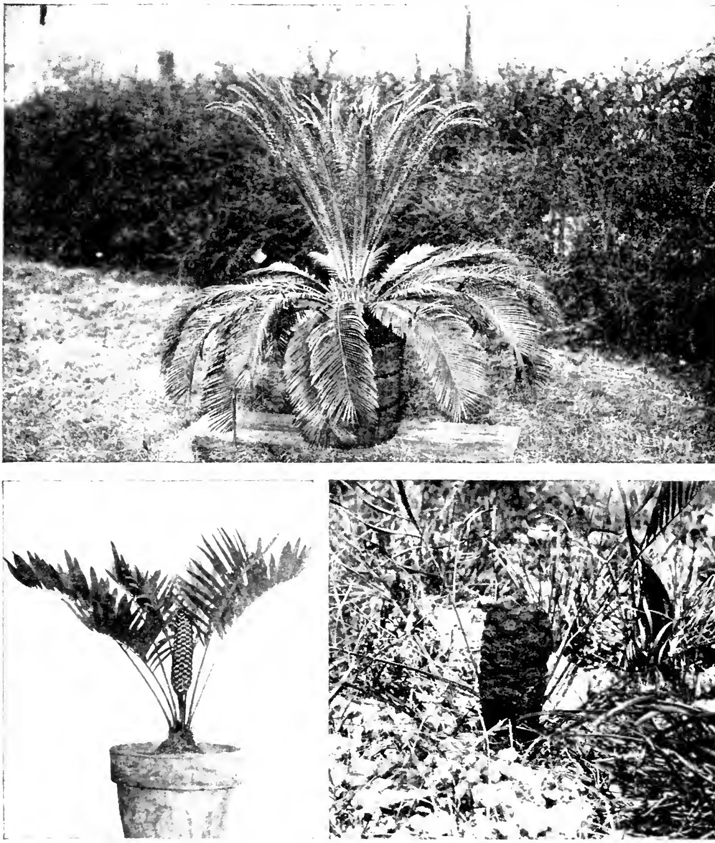


Fig. 54.—Cycads. *Cycas* (above) with a crown of young leaves unfolding; male plant of *Zamia* (lower left) at the time of "flowering"; mature fruiting plant of *Zamia* (lower right). (From Weatherwax: Plant Biology, W. B. Saunders Co.)

Two types of spores (heterospory) are formed; namely, *microspores,* which develop into male *microgametophytes,* and *megaspores,* which develop into female *megagametophytes.*

Pollination occurs by wind, the pollen being carried near the *micropyle* (mi′ kro pile) (Gr. *mikros,* small; *pyle,* gate) or little opening of the ovule. A *pollen tube* is formed through which the male pollen grain (sperm) may travel to reach the egg. In gymnosperms *single fertilization* occurs in which *one sperm* is involved in fertilizing the *egg*. Gymnosperms are considered in greater detail in a later chapter.

Examples: Pine tree *(Pinus)* (Figs. 52 and 53) and cycad or sago palm *(Zamia)* (Fig. 54).

ANGIOSPERMS.—The angiosperms, or *flowering plants,* which produce their *seeds enclosed in an ovary (carpels),* belong to the class *Angiospermae* (an ji o -spur′ me) (Gr. *angios,* enclosed; *sperma,* seed).

The *sporophyte is large and independent* (when mature), while the *gametophyte is small and dependent* (upon the sporophyte). Angiosperms possess *true roots, stems, and leaves.* A well-developed *vascular system* is present. *Two kinds of spores (heterospory)* are produced; namely, *microspores,* which form male *microgametophytes,* and *megaspores,* which form *female megagametophytes. Flowers* of some kind are characteristic. True *seeds* are enclosed in an *ovary* (carpels).

Pollination occurs by wind, insects, or birds, rarely by water. A *pollen tube* is formed, extending from the *stigma* of the pistil down through the style to the *ovary,* where the *male sperm* unites with the *egg* (ovum) (Fig. 71). In angiosperms *double fertilization* occurs in which one sperm (male nucleus) fuses with the egg (true fertilization) to form a *zygote,* which will form the multicellular *embryo.* The *other sperm* (male nucleus) fuses with *two polar nuclei* in the female gametophyte to form the *nutritive, endosperm tissue* to be used by the developing embryo. Angiospermous plants are considered in greater detail in a later chapter.

CHARACTERISTICS OF DICOTYLEDONOUS AND MONOCOTYLEDONOUS ANGIOSPERMS

DICOTYLEDONOUS ANGIOSPERMS	MONOCOTYLEDONOUS ANGIOSPERMS
Two embryonic seed leaves	One embryonic seed leaf
Flower parts usually in 4's or 5's or multiples of these	Flower parts in 3's or multiples of 3
Leaves net-veined	Leaves parallel-veined, and usually long and narrow
Some have woody stems, others have herbaceous stems	Most have herbaceous stems (few exceptions)
Vascular bundles of stems usually arranged in a circle (cylinder)	Vascular bundles scattered throughout stem
Cambium (meristematic tissue) between the phloem and xylem of vascular bundle	No cambium between the phloem and xylem usually
Examples: Beans (Figs. 55 and 56), sunflowers (Fig. 57), roses, violets, clovers, snapdragons, potatoes, elms, oaks, apples, maples, hickories, poplars, lilacs, etc.	Examples: Corn (Figs. 58 to 60), wheat, bluegrass, lilies, irises, daffodils, cattails, etc.

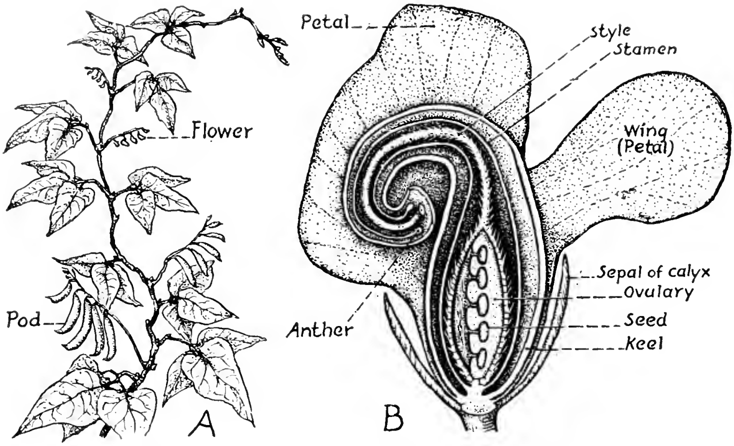


Fig. 55.—Common garden bean or kidney bean *(Phaseolus sp.)*. *A*, Plant showing the twining vine, leaves, flowers, and pods (legumes); *B*, one flower very much enlarged in longitudinal section (somewhat diagrammatic). The ovulary is also called the ovary.

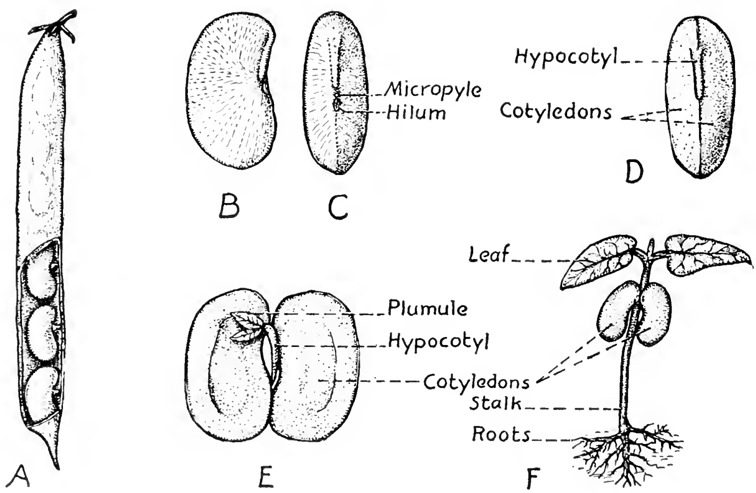


Fig. 56.—Common garden bean or kidney bean *(Phaseolus sp.)*. *A*, Pod (legume) with part of wall removed to show bean seeds; *B*, bean seed with seed coat in side view; *C*, same as *B* in face view; *D*, face view of bean with seed coat removed; *E*, cotyledons spread to show structures between them; *F*, seedling of bean showing the true leaves and the cotyledons (embryo seed leaves), the latter being pushed out of the ground during germination.

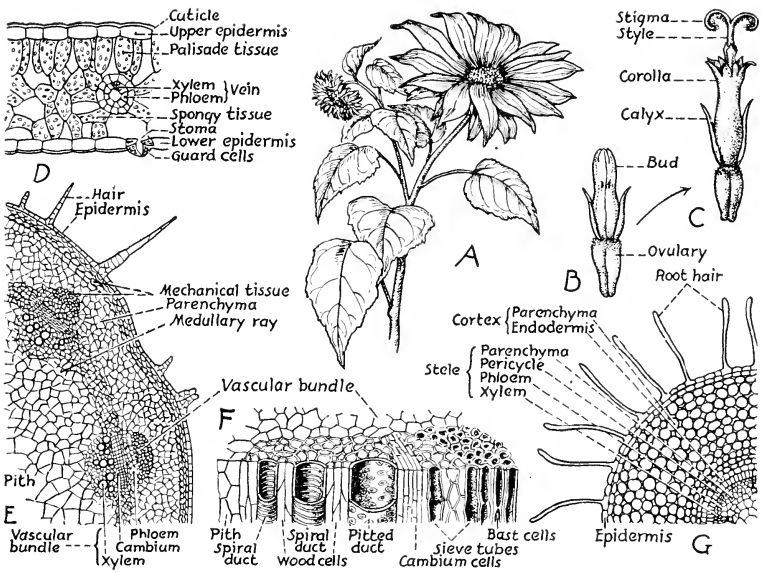


Fig. 57.—Sunflower *(Helianthus sp.)*. *A,* Part of plant showing flowers and leaves; *B,* disk floret in bud; *C,* disk floret further developed with elongated style and opened stigmas; *D,* leaf in cross section (somewhat diagrammatic); *E,* stem in cross section; the mechanical tissue and the parenchyma constitute the cortex; *F,* enlarged vascular bundle (such as shown in *E*), showing cross and longitudinal views; the spiral and pitted ducts are present in the xylem or woody part of the bundle; the sieve tubes and bast cells constitute the phloem of the bundle; the embryonic, thin-walled cambium lies between the xylem and phloem; *G,* root in diagrammatic cross section in the region of maturation. The ovulary is also known as the ovary.

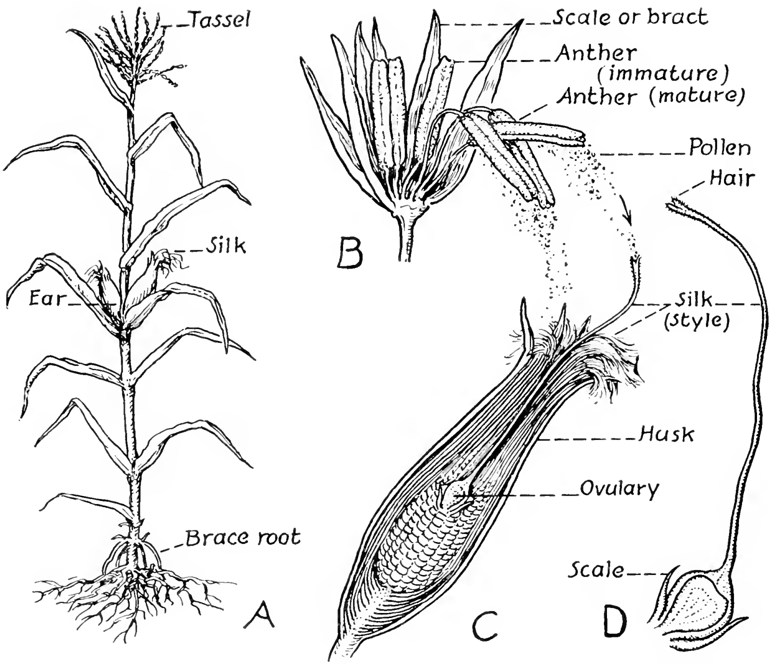


Fig. 58.—Indian corn *(Zea mays)*. *A, Plant* with parts; *B,* part of tassel (male) showing an immature flower at the left and a mature flower with three anthers at the right (very much enlarged); *C,* ear of corn (female) in longitudinal section with one ovary (ovulary) and silk much enlarged; *D,* female flower (pistil), much enlarged, showing the hair to receive pollen and the silk (style) to conduct it to the ovary (ovulary). The corn seed (grain) is shown in Fig. 59.

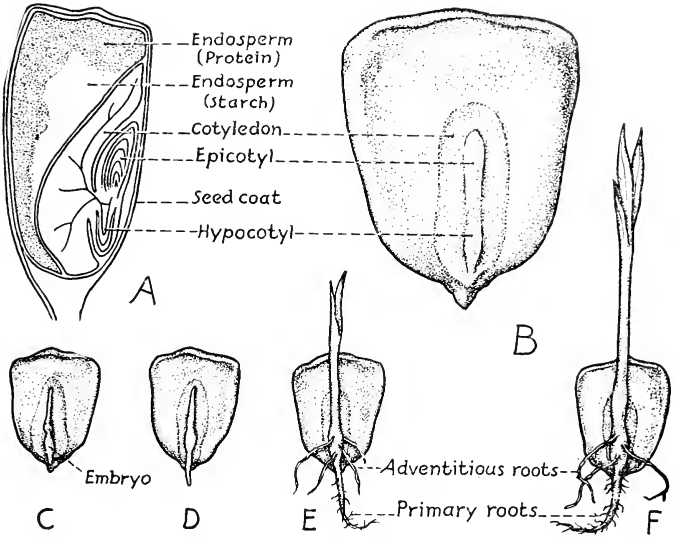


Fig. 59.—Indian corn showing its grain and its germination. *A,* Longitudinal section perpendicular to the broad face of the grain (much enlarged); *B,* surface or face view; *C,* surface view with seed coat removed; *D, E, F,* stages of germination and embryo development.

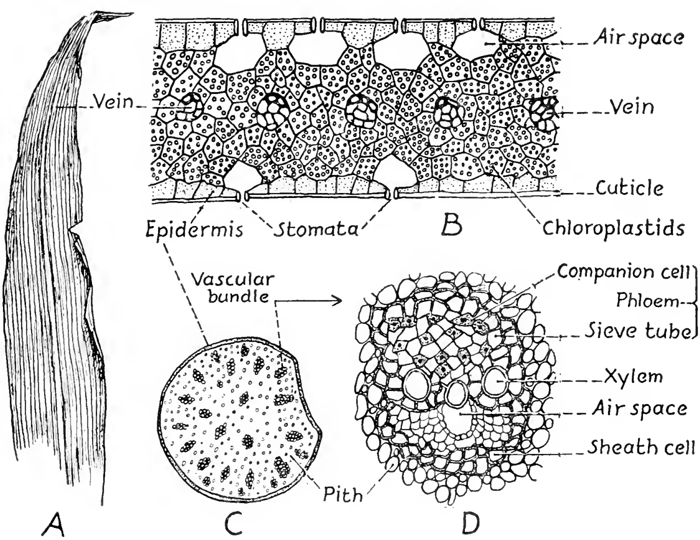


Fig. 60.—Indian corn *(Zea mays).* *A,* Leaf (external view); *B,* leaf in cross section (somewhat diagrammatic); *C,* stalk or stem (cross section); *D,* one vascular bundle very much enlarged (cross section). Chloroplastids are also called chloroplasts.

The class *Angiospermae* may be divided into the subclasses (1) *Dicotyledoneae* (di kot i le -do′ ne e) (Gr. *di*, two; *kotyledon*, embryonic, seed leaf) and (2) *Monocotyledoneae* (mon o kot i le -do′ ne e) (Gr. *mono*, one; *kotyledon*, embryonic, seed leaf). A cotyledon (seed leaf) is a food-storing and food-digesting part of the embryo which supplies it with food during its early development.

QUESTIONS AND TOPICS

1. Learn the meaning, correct pronunciation, and derivation of each term used in this chapter.
2. Define (1) plant kingdom, (2) subkingdom, (3) phylum, (4) subphylum, (5) class, (6) subclass, (7) genus, and (8) species.
3. Why are Greek and Latin used in composing a system of classification and in forming a scientific name? Of what does a scientific name consist? Give several examples.
4. Discuss the needs for a scientific classification of plants. List some serious objections to the use of common names in scientific work.
5. Tell how so many common names may originate for one and the same plant.
6. Explain what is meant by the binomial system of nomenclature.
7. Give the general characteristics of each plant phylum. What do certain phyla have in common? Do certain phyla seem to be more closely related to each other than others? Give specific reasons why.
8. List the total number of species for the plant kingdom. List the number of species in each phylum. How does the total for the plant kingdom compare with the animal kingdom?
9. Give specific evidence that the representatives of the various phyla increase in complexity of structure and function, as we observe them, from the lower to the higher phyla. What conclusions do you draw from this?
10. Define a life cycle (life history). Do all plants have a life cycle?
11. In general, are plants sessile (attached) or motile? List the affects of attachment on such phenomena as securing foods, development of the organism, protection, reproduction, etc.
12. Which plant phylum do you consider to be most important? Give specific reasons why you say so. What makes a plant economically important?
13. Are all economically important plants necessarily of value? List several plants to prove your point.
14. Discuss alternation of generations in plants, including how this phenomenon differs from ordinary life cycles. What proportion of plants studied possess alternation of generations? List advantages and disadvantages of this phenomenon.
15. How do plants illustrate the principle of "struggle for existence"?
16. List a number of ways in which man is influenced (beneficially and detrimentally) by plants.
17. Explain the role of plants in a so-called "balanced environment," or "balanced community." Can any living organism live entirely by itself in a state of complete isolation?

18. Contrast and give specific examples of asexual and sexual reproduction in plants.
19. Contrast and give an example of each: monocotyledon and dicotyledon, ovule and seed, rhizoid and root, gymnosperm and angiosperm, antheridium and archegonium, parasite and saprophyte, chemosynthesis and photosynthesis, pollination and fertilization, homospory and heterospory, isogamy and heterogamy, algae and fungi, sporophyte and gametophyte.
20. List the conclusions you can logically draw from your scientific study of the plant kingdom in this chapter.

SELECTED REFERENCES

Armstrong: Western Wild Flowers, G. P. Putnam's Sons.
Asch: The Story of Plants, G. P. Putnam's Sons.
Bailey: How Plants Get Their Names, The Macmillan Co.
Clute: The Common Names of Plants and Their Meanings, W. N. Clute & Co.
Comstock: Handbook of Nature Study, Comstock Publishing Co., Inc.
Coulter: The Story of the Plant Kingdom, University of Chicago Press.
Cuthbert: How to Know the Spring Flowers, William C. Brown Co.
Cuthbert. How to Know the Fall Flowers, William C. Brown Co.
Fuller: The Plant World, Henry Holt & Co., Inc.
Fuller and Tippo: College Botany, Henry Holt & Co., Inc.
Gager: General Botany, The Blakiston Co.
Gibbs: Botany, The Blakiston Co.
Gray: Manual of Botany, American Book Co.
Hausman: Beginner's Guide to Wild Flowers, G. P. Putnam's Sons.
Hill, Overholts, and Popp: Botany, McGraw-Hill Book Co., Inc.
Hylander and Stanley: College Botany, The Macmillan Co.
Hylander: The World of Plant Life, The Macmillan Co.
Jacques: Plant Families—How to Know Them, William C. Brown Co.
Jacques: Plants We Eat and Wear, William C. Brown Co.
Johnson: Taxonomy of Flowering Plants, Century Co.
Kern: Essentials of Plant Biology, Harper & Brothers.
Mathews: Handbook of American Wild Flowers, G. P. Putnam's Sons.
Pool: Basic Course in Botany, Ginn and Co.
Pool: Flowers and Flowering Plants, McGraw-Hill Book Co., Inc.
Robbins and Weier: Botany, John Wiley & Sons, Inc.
Seymour et al.: Favorite Flowers in Color, Wm. H. Wise & Co., Inc.
Sinnott: Botany: Principles and Problems, McGraw-Hill Book Co., Inc.
Smith et al.: Textbook of General Botany, The Macmillan Co.
Swingle: Textbook of Systematic Botany, McGraw-Hill Book Co., Inc.
Transeau, Sampson, and Tiffany: Textbook of Botany, Harper & Brothers.
Trelease: Winter Botany (published by the author).
Weatherwax: Plant Biology, W. B. Saunders Co.
Wilson and Haber: Plant Life, Henry Holt & Co., Inc.

Chapter 9

SIMPLE PLANTS WITH CHLOROPHYLL—ALGAE

PLANTS WITHOUT TRUE LEAVES, STEMS, OR ROOTS; NOT FORMING MULTICELLULAR EMBRYOS; AND WITHOUT TRUE VASCULAR (CONDUCTING) TISSUES (SUBKINGDOM THALLOPHYTA)

GENERAL CHARACTERISTICS OF THALLOPHYTES

1. Thallophytes include the algae and fungi. The former contain *chlorophyll* which, in the presence of energy-supplying light, is able to combine *carbon dioxide* and *water* to produce *carbohydrates* through the process of *photosynthesis* (fo to -sin′ the sis) (Gr. *phos,* light; *synthesis,* put together). The *fungi lack chlorophyll* and are unable to manufacture their foods but must depend upon outside sources for their nourishment.

2. Thallophytes are simple plants which *lack true leaves, true stems, and true roots.* However, certain species may have structures which somewhat resemble them, but they *do not possess the two vascular tissues* (phloem and xylem) of the true organs.

3. This group of plants is vast and varied, ranging from the *unicellular, microscopic* types to the *large, multicellular* forms, some of which are over 200 feet long. Certain species consist of a linear series of cells, while others consist of sheetlike masses of cells; hence the name *thallophyta* (tha -lof′ i ta) (Gr. *thallo,* sheetlike or "leaf-shaped"; *phyta,* plants).

4. The *sporangia* (spor -an′ ji a) (Gr. *sporos,* spore or seed; *angios,* vessel), which are structures which produce spores, and the *gametangia* (gam e -tan′ ji a) (Gr. *gametes,* gametes or sex cells; *angios,* vessel), which produce sex cells (gametes), are both *usually unicellular.*

5. The *zygote* (fertilized egg cell) *does not produce a multicellular embryo* while still within the female sex structure.

6. *Thallophytes do not possess the two vascular tissues* called *phloem* (flo′ em) (Gr. *phloios,* smooth bark) and *xylem* (zi′ lem) (Gr. *xylon,* wood). These two tissues are present in higher plants.

7. Thallophytes usually *live in water, or moist places,* and *do not possess rigid tissues* for extensive upright growth.

8. Many species of thallophytes, both algae and fungi, are of great economic importance, both beneficially and detrimentally.

GENERAL CHARACTERISTICS OF ALGAE

The term algae does not apply to a natural group of plants, but it is a desirable name applied to those thallophytes which carry on *photosynthesis* because of the presence of *chlorophyll.* The algae vary greatly among themselves, and many of them resemble certain fungi in many respects. There are several characteristics which are common to both algae and fungi, except that the former possess chlorophyll, while the latter do not. These facts will be discussed in this chapter and the next.

Algae are common in *fresh water* and in the *salt waters* of the oceans (marine). They may be *free living* in fresh or salt water, where, together with the animals, they make up the so-called *plankton* (plangk′ ton) (Gr. *plangktos,* wandering). Others may live on the bottom, where together with the animals, they constitute the so-called *benthon* (ben′ thon) (Gr. *benthos,* depths of the sea). Certain species may grow in moist soils, on moist rocks and trees, in snow and ice, or in hot springs. Certain species may live *symbiotically* with other organisms for mutual benefits. Algae may live symbiotically with certain fungi in an association known as *lichens* (li′ ken) (Gr. *leichen,* liverwort), in which case the algae supply foods and the fungi supply water and give protection. Some species may grow on other plants as *epiphytes* and on animals and may be *saprophytes* or *parasites.*

BLUE-GREEN ALGAE (PHYLUM CYANOPHYTA)

These are *simple, unicellular plants* although certain species may form *colonies* of similar cells among which there is little differentiation. In addition to the green *chlorophyll,* there is a blue pigment called *phycocyanin* (fi ko -si′ anin) (Gr. *phykos,* alga or seaweed; *kyanos,* blue). Sometimes a red pigment may also be present in certain species. The *chlorophyll is distributed throughout the cell* and not localized in definite bodies known as plastids (Fig. 29). There is *no definite, organized nucleus;* the nuclear, chromatin materials are scattered throughout the center of the cell. The cells are often surrounded by a slimy, gelatinous *sheath.* Because of this, *myxophyta* (myx -of′ ita) (Gr. *myxo,* slime;

phyta, plants) has been used as the name of the phylum. Foods are stored as *glycogen* (starchlike carbohydrate).

Reproduction occurs asexually by transverse *fission* (simple cell division). *None of the reproductive, or vegetative (body), cells possess threadlike flagella* which are present in many other types of algae.

Most species of blue-green algae occur in fresh water, although a few species are marine. They may cause the water in ponds and lakes to have a greenish-yellow color and may be so abundant that they are known as "water blooms," thereby giving the water a "soupy" appearance, a foul odor, and a "fishy" taste. Many species also occur in soils, on moist rocks, in greenhouses, on flower pots, and other moist places. Several species grow in hot springs with temperatures over 75° C., where they precipitate the magnesium and calcium salts to form *travertine,* which may have bright colors due to the contained algae. Blue-green algae may precipitate calcium carbonate in lake waters to form deposits of *marl* on the bottom.

Other species may grow on other plants as *epiphytes* (ep′ if ites) (Gr. *epi,* upon; *phyta,* plants), while still other species are associated with certain species of chlorophyll-less fungi to form plants known as *lichens* (li′ ken) (Fig. 327). A few species may even be parasitic in the digestive tracts of animals, including man. Blue-green algae, together with other algae, are great sources of food for aquatic animals. About 1,400 species are classified in 150 genera. The following typical examples will be considered: *Gleocapsa, Oscillatoria, Nostoc,* and *Anabena* (Fig. 29).

Gleocapsa (gle o -kap′ sa) (Gr. *gloia,* glue; *kapsa,* box).—Simple, primitive, *unicellular* plants with each cell composed of (1) an outer, bluish-green region due to the diffused *chlorophyll* and *phycocyanin* (blue pigment) and (2) a central region containing scattered *chromatin granules* (Fig. 29). There is *no organized nucleus* and *no plastids.* Numerous unicellular plants may be grouped together and surrounded by a jellylike material. *Gleocapsa* reproduces by *fission* (simple cell division) and is common on wet rocks and other damp places.

Oscillatoria (os i la -to′ ri a) (L. *oscillare,* to swing).—A linear series of *Oscillatoria* plants are associated to form a *colony* which is *filamentous* (Fig. 29). Each individual cell is self-sufficient and hence is considered as a separate plant. The *chlorophyll* and *phycocyanin* (blue pigment) are distributed in the outer region of the cell and not in an organized plastid. The *chromatin granules* occupy the central region and *do not form an organized nucleus.* Frequently the living filaments may glide back and forth or may oscillate, hence the name *Oscillatoria.* Reproduc-

Summary of Distinguishing Characteristics of Algae

	MOTILE CELLS (REPRODUCTIVE)	STORED FOODS	PIGMENTS IN ADDITION TO CHLOROPHYLL	PLASTIDS	NUCLEUS	CYTOPLASMIC STRANDS BETWEEN BODY CELLS
BLUE-GREEN ALGAE (*Cyanophyta*)	None	Glycogen (starchlike carbohydrate)	Phycocyanin (and sometimes a red pigment)	None	None	None
GREEN ALGAE (*Chlorophyta*)	When present, there are 2 to 4 anterior flagella usually of equal length	Starch (pyrenoids present)	Carotinoids (carotene and xanthophyll)	Chloroplast	Well organized	None
YELLOW-GREEN ALGAE, GOLDEN-BROWN ALGAE, AND DIATOMS (*Chrysophyta*)	Present or absent, depending on species	Oils and leucosin	Carotinoids	Present	Well organized	None
BROWN ALGAE (*Phaeophyta*)	When present, 2 lateral, unequal flagella	Fats and soluble sugars	Fucoxanthin	Present	Well organized	None
RED ALGAE (*Rhodophyta*)	None	"Starch" (insoluble) (pyrenoids in some species)	Phycoerythrin (sometimes phycocyanin)	Present	Well organized	Present

tion is by *cell division* (fission). Sometimes, soft *gelatinous areas* develop between cells, thereby breaking the filament into pieces known as *hormogonia* (hor mo -go′ nia) (Gr. *hormos,* chain; *gonos,* offspring). A hormogonium may form a new colony. *Oscillatoria* is common on damp earth, stones, flower pots, and other damp places.

Nostoc (nos′ tok) (F. *nostos,* return).—This blue-green alga is *unicellular,* with the individual, globose cells arranged as a chainlike *colony,* resembling a necklace of beads (Fig. 29). The strands of cells are enclosed in a *ball of jelly.* Each cell contains *chlorophyll, phycocyanin,* and *chromatin granules* as in *Gleocapsa* and *Oscillatoria.* At certain intervals in the chain are thick-walled, transparent cells known as *heterocysts* (het′ er o sists) (Gr. *heteros,* different; *kystis,* sac or pouch) which serve to break the filaments into *hormogonia,* as in *Oscillatoria.*

	REPRODUCTION	
	ASEXUAL	SEXUAL
BLUE-GREEN ALGAE	1. Fission (cell division)—*Gleocapsa, Oscillatoria, Nostoc, Anabena* 2. Hormogonia—*Oscillatoria, Nostoc* 3. Heterocysts—*Nostoc, Anabena* 4. Spores—*Anabena*	None
GREEN ALGAE	1. Fission (cell division)—*Protococcus, Desmids* 2. Fragmentation—*Spirogyra, Ulothrix* 3. Motile zoospores produced by zoosporangia—*Chlamydomonas, Ulothrix* 4. Nonmotile spores produced by Sporangia	1. Isogamy—*Chlamydomonas Spirogyra, Ulothrix,* Desmids 2. Heterogamy 3. Oogamy
YELLOW-GREEN ALGAE, GOLDEN-BROWN ALGAE, AND DIATOMS	1. Fission (cell division)—Diatoms 2. Motile zoospores 3. Nonmotile spores Auxospores—Diatoms	1. Isogamy—Diatoms
BROWN ALGAE	1. Fragmentation—*Fucus* 2. Motile zoospores—*Laminaria* 3. Nonmotile spores (Alternation of generations, metagenesis, with gametophyte and sporophyte generations)	1. Isogamy 2. Heterogamy—*Fucus* 3. Oogamy—*Laminaria*
RED ALGAE	1. Nonmotile carpospores—*Nemalion, Polysiphonia* 2. Nonmotile tetraspores—*Polysiphonia* (Certain species have alternation of generations, metagenesis, with gametophyte and sporophyte generations)	1. Oogamy—male antheridia produce nonmotile sperm; female carpogonia produce nonmotile egg—*Nemalion; Polysiphonia*

Occasionally a heterocyst may germinate to form a new filament, thus functioning as a *spore*. *Nostoc* is common in ponds and pools of fresh water.

Anabena (an a -be′ na) (Gr. *anabainein,* to go up).—This blue-green alga resembles *Nostoc* in its beadlike *strands, pigments, heterocysts,* and *jelly* covering (Fig. 29). It differs in that certain enlarged, thick-walled cells, known as *spores,* contain much food and may separate from the filament and form a new *colony*.

GREEN ALGAE (PHYLUM CHLOROPHYTA)

In certain species of green algae the *chlorophyll* may be associated with additional pigments known as *carotinoids* (carotene and xanthophyll). The chlorophyll is localized in definite bodies known as *chloroplasts* (klo′ ro plast) (Gr. *kloros,* green; *plastos,* moulded or body). The *nucleus is well organized* (Fig. 30). The cell wall consists of *cellulose* (sel′ u losz) (L. *cellula,* little cell), and the stored food is *starch*. The latter is formed by structures on the chloroplasts known as *pyrenoids* (pi′ re noid) (Gr. *pyren,* fruit-stone; *eidos,* resemblance). Green algae vary in structure, and the plant body may be *unicellular, colonial,* or *multicellular,* depending upon the species. When the reproductive or vegetative (body) cells are motile, each bears *two to four anterior flagella, usually of equal length*.

Reproduction occurs (1) asexually by *cell division,* by *fragmentation,* by *motile zoospores,* or by *nonmotile spores* or (2) sexually by *isogamy* (i -sog′ a my) (Gr. *isos,* equal; *gamos,* marriage) with the fusion of gametes (sex cells) of equal size, by *heterogamy* (het er -og′ a my) (Gr. *heteros,* different) with the fusion of gametes of unequal size, or by *oogamy* (o -og′ a my) (Gr. *oon,* egg) which is a special type of heterogamy in which the egg (female gamete) is nonmotile. The structures which produce the sex cells in green algae are always *unicellular*.

Most green algae live in fresh water, but some are marine, while others grow in soil, on rocks, or on trees. Several species live in snow or ice. Some live in salt lake waters whose concentration of salt is much greater than that of the ocean. A few species may grow on other plants or animals. A few live symbiotically with such animals as protozoa, sponges, and *Hydra*. Certain types may live together with chlorophyll-less fungi to form plants called *lichens* (Fig. 327). Green algae, as well as other algae, supply foods for fresh-water and marine animals. Marine green algae in conjunction with red algae secrete lime salts which assist in the formation of reefs in the ocean. About 5,700 species are classified in 360 genera. The following typical examples will be considered: *Chlamydomonas, Ulothrix, Protococcus, Spirogyra,* and desmids.

Chlamydomonas (klam id o -mo′ nas) (Gr. *chlamydos,* cloak; *monas,* one).—This simple, unicellular green alga is common in fresh water and soils. Each cell is *spherical* or *ovoid* and contains a central *nucleus,* a single, large, cup-shaped *chloroplast* with a *pyrenoid,* an *eyespot, two anteriorly located flagella of equal length,* a *cell wall of cellulose,* and two excretory *contractile vacuoles* near the anterior end (Fig. 61). Some investigators classify this organism as a single-celled protozoan (animal).

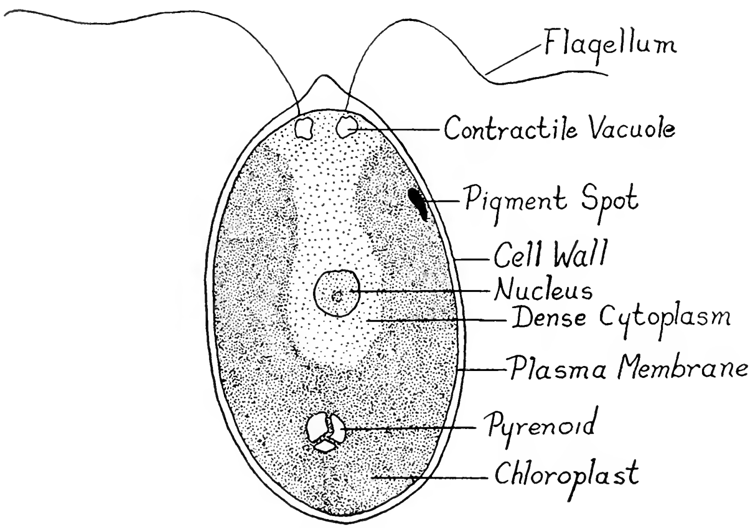


Fig. 61.—A green alga *(Chlamydomonas)* of the phylum *Chlorophyta.* The chloroplast is cup shaped; the pigment spot is also known as the eye spot. Because of certain characteristics, this unicellular organism is considered by some to be a protozoan (single-celled animal).

At certain times there may be formed within the cell two, four, or eight *motile swarm spores (zoospores)* which resemble the parent cell except in size and which swim out to form new *Chlamydomonas.* In some instances the contents of the parent cell may divide into eight, sixteen, or thirty-two small *gametes (sex cells)* which resemble miniature Chlamydomonas plants. When released into water, two gametes of equal size, but coming from different parent cells, fuse by the process of fertilization known as *isogamy* (i -sog′ a my) (Gr. *isos,* equal; *gamos,* marriage). In the fusion of isogamous (alike) gametes, there is no differentiation into male and female sex cells. The fertilized cell is called a *zygote* and surrounds itself with a *thick, resistant wall* to withstand adverse conditions. Eventually, the single nucleus of the zygote produces four nuclei which are incorporated into four *zoospores,* each of which forms a Chlamydomonas plant. The zoospores and the gametes look alike except that the former are larger.

Protococcus (pro to -kok′ us) (Gr. *protos,* first; *kokkus,* berry or round).—This *unicellular, thick-walled, round* green alga is common on trees and in moist places. Each cell has a *nucleus* and a lobed *chloroplast.* Reproduction occurs by *cell division,* and occasionally several individual cells may remain together to form a *colony* (Fig. 30).

Spirogyra (spi ro -ji′ ra) (Gr. *speira,* coil or spiral; *gyros,* curved).—This green alga is common in fresh water where it may be called "pond scum" or "water silk." Each unbranched filament is composed of a linear series of cells and is covered with a slippery, mucilaginous *sheath.* Each cell contains a single, *organized nucleus* located in the center of the cell and surrounded by *cytoplasm* (Fig. 30). *Strands of cytoplasm* also extend to the *pyrenoids* located on the *chloroplasts.* One or more spiral-shaped *chloroplasts* may be present in a cell.

Reproduction is by *fragmentation* (asexual) and by *conjugation* (sexual). In the latter, the cells in two adjacent filaments form a *conjugation tube* between them, and the contents of one cell passes through the tube to the cell of the other filament. This fusion, or fertilization, produces a *zygote* which eventually will produce a new filament. Even though the *gametes* are all the same size (*isogamous*), the one which migrates might be considered as male and the other as the female. In most cases, nearly all the cells of a certain filament produce gametes at the same time. However, the cells of a single filament may unite at times (Fig. 62).

Ulothrix (u′ lo thriks) (Gr. *oulos,* wooly; *thrix,* hair).—This is a *filamentous, unbranched, fresh-water, multicellular* green alga with a basal *holdfast cell* for attachment to the substratum. The vegetative (body) cells of the filament are differentiated and interdependent. Each vegetative cell contains an *organized nucleus* and a *chloroplast* which resembles an open band or ring and which contains numerous *pyrenoids* (Fig. 30).

Reproduction occurs by *fragmentation,* by *zoospores,* and by *isogamy.* Certain reproductive structures are known as *zoosporangia* and each contains two, four, eight, sixteen, or thirty-two large, motile *zoospores.* Each *zoospore* bears *four flagella* and forms a new filament by cell division.

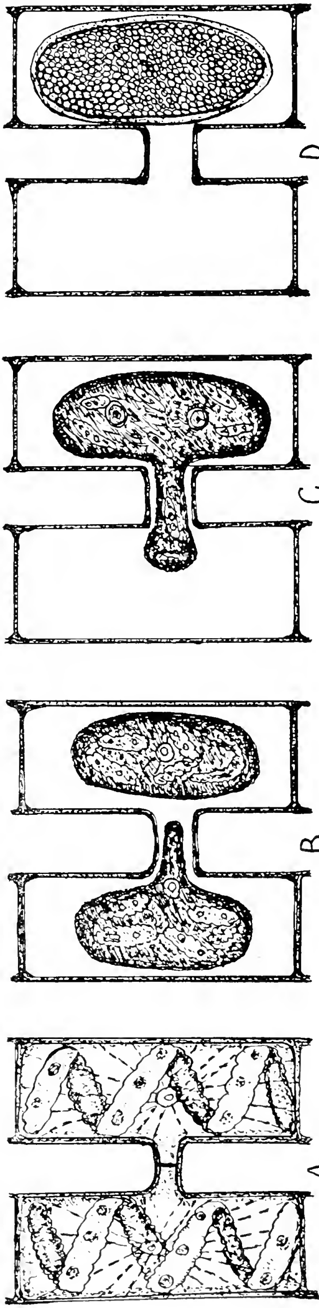


Fig. 62.—*Spirogyra* (green alga) cells in the process of conjugation (modified sexual reproduction). *A*, Two adjacent cells building a conjugation tube between them; *B*, cell contents somewhat rounded and that of the male gamete flowing toward the female; *C*, practically all of the contents of the male and female cells fused; *D*, the formation of a resistant zygospore (zygote) from which will develop a new filament of *Spirogyra* cells.

Other reproductive cells are formed in *gametangia* (gam e -tan′ ji a) (Gr. *gametes,* spouse; *angos,* vessel) and each contains eight, sixteen, thirty-two, or sixty-four *gametes* (sex cells). Each gamete is smaller than the zoospore and bears only *two flagella.* The fusion of these gametes of equal size (*isogamy*) produces a *zygote,* the gametes arising from different filaments. Each zygote eventually will produce *four zoospores,* each of which will attach and form a new filament by cell division.

Desmids (des′ mid) (Gr. *desmos,* chain).—These *green algae* are frequently found floating in fresh water and may be *solitary* or in *filamentous* or *irregular colonies.* In most species each cell is divided into two *halves* which are joined by a connecting *isthmus* (Fig. 30). Each half cell contains a *chloroplast.* An organized *nucleus* is located in the isthmus. Reproduction is by *cell division* and by *conjugation,* which resembles the similar phenomenon in *Spirogyra.*

YELLOW-GREEN ALGAE, GOLDEN-BROWN ALGAE, AND DIATOMS (PHYLUM CHRYSOPHYTA)

The yellow, or brown, *carotinoid pigments* are more abundant than the *chlorophyll* so these algae have a golden-brown, or yellowish-green, color. All pigments are contained in organized *plastids.* The cell walls are usually composed of a *pair of overlapping halves* (valves) which are frequently impregnated with *silica* (glasslike). Depending on the species, these algae may be *unicellular, colonial,* or, in a few instances, *multicellular individuals.* Stored foods are oils and an insoluble carbohydrate called *leucosin* (lu′ ko sin) (Gr. *leukos,* white). The *nucleus is well organized.*

Reproduction occurs asexually by *cell division,* by *motile zoospores,* or by *nonmotile spores.* Sexual reproduction, when present, is *isogamous* (gametes which are alike). The phylum contains the yellow-green algae, the golden-brown algae, and the diatoms. About 5,700 species are classified in 300 genera. Various species of diatoms will be considered as typical forms.

Diatoms (di′ a toms) (Gr. *dia,* across or two; *tome,* to cut).—These *unicellular,* delicate algae are common in fresh and salt water and may form *filaments* or other types of *colonies.* Different species vary in shape, including rods, disks, triangles, etc. (Fig. 31). Each cell is composed of *two overlapping halves* (valves) like a pill box. The *cell walls* are *transparent and glasslike* (siliceous) and do not disintegrate even when the cell dies. The cell walls are ornamented with *patterns of fine dots, or perforations*, which create *beautiful designs* unique for the various species. Each *protoplast* of the cell contains one or many yellowish-brown *plastids* which impart the brownish color to most diatoms, although some species have green or blue plastids. Each cell contains an *organized nucleus*. Reserve foods include *fats* and an insoluble food known as *volutin* (vo -lu′ tin).

Reproduction may occur asexually by *cell division* with each new cell forming a new valve inside the old one. Eventually certain of these cells will become smaller and smaller. In the latter case certain rejuvenescent cells called *auxospores* (ok′ so spor) (Gr. *auxe*, grow; *spora*, spore) are produced. The latter usually result from the fusion of two diatoms (gametes), and eventually a cell of normal size will be produced again. The gametes are usually of equal size (*isogamous*).

Diatoms are common in fresh and salt waters, although some species are found in soils, on other plants, and even in hot springs. Diatoms are important components of the diets of aquatic animals. When diatoms die, their siliceous shells accumulate on the bottom to form diatomaceous earth. The latter is used in preparing polishes, tooth powders, filters, insulating materials, etc. It is believed that diatoms may have aided in the formation of oil because they are often found to be associated with oil deposits in the earth.

BROWN ALGAE (PHYLUM PHAEOPHYTA)

The brown algae are *multicellular* and *nonmotile*, being attached by rootlike *holdfasts*. Depending on the species, the plant body may be composed of only a few cells or it may be over a hundred feet in length, as in some of the kelps. They are *marine* and usually found in colder waters. The *chlorophyll* is masked by the golden-brown pigment, *fucoxanthin* (fu ko -zan′ thin) (L. *fucus*, alga or seaweed; *xanthos*, yellow). Usually there are several *plastids* per cell, but *no pyrenoids* are present. Each cell has a single *nucleus* and *vacuoles*. The cells have an organization similar to that of higher plants, some even having a centrosome similar to the centrosome of animal cells. Stored foods are *fats* and *soluble sugars*.

All brown algae possess *alternation of generations* or *metagenesis* (met-a -jen′ e sis) (Gr. *meta*, over; *genesis*, origin), in which a free-living, multicellular, gamete-producing *gametophyte* (gam -me′ to fite) (Gr.

gamos, marriage; *phyta,* plants) alternates with a free-living, multicellular, spore-producing *sporophyte* (spor′ o fite) (Gr. *spora,* spore; *phyta,* plants). Reproduction may occur asexually by *fragmentation,* by *motile zoospores,* by *nonmotile spores;* or sexually by *isogamy* (i -sog′ a my) (Gr. *isos,* equal; *gamos,* marriage or gametes) in which gametes of equal size fuse, by *heterogamy* (het er -og′ a my) (Gr. *heteros,* different) in which gametes of unequal size fuse, or by *oogamy* (o -og′ a my) (Gr. *oon,* egg) which is a special type of heterogamy with a nonmotile egg. The motile, pear-shaped reproductive cells bear *two lateral flagella of unequal length.*

Certain brown algae are important sources of iodine, potassium, fertilizers, and foods for animals and man. About 900 species are classified in 190 genera. The following typical examples will be considered: *Laminaria* and *Fucus.*

Laminaria (lam i -na′ ri a) (L. *lamina,* flat blade).—These brown algae or *kelps,* known as "devil's-aprons," are common on our seacoasts and may be over six feet long. The *sporophyte* plants consist of long, flat *blades,* stalklike *stipes,* and branched, rootlike *holdfasts.* Patches of *zoosporangia* (zoo spo -ran′ ji a) (Gr. *zoon,* animal; *spora,* spore or seed; *angos,* vessel) on the blades produce numerous *zoospores.* The latter produce two types of microscopic *gametophytes:* (1) the simple, branched, filamentous *male gametophyte* which bears terminal *antheridia* (an ther -id′ i a) (Gr. *anthos,* "flower"; *idion,* small) and (2) the *female gametophyte* which is a short filament with one-celled *oogonia* (o o -gon′ i a) (Gr. *oon,* egg; *gonos,* offspring). Each *antheridium* produces a *sperm* with *two flagella of unequal length.* Each *oogonium* produces an *egg.* Oogamous fertilization produces a *zygote,* which germinates to form the sporophyte plant. Hence, there is alternation between the large, conspicuous *sporophyte* and the microscopic *gametophytes* (Fig. 32).

Fucus (fiu′ kus) (Gr. *phykos,* seaweed).—This *marine brown alga* or rockweed is commonly *attached* to rocks along seacoasts. The plant is *leathery* and *dichotomously forked* and is attached by a disklike *holdfast.* The green *chlorophyll* is usually masked by a *brown pigment* called *fucoxanthin* (fu ko -zan′ thin) (L. *fucus,* alga or sea weed; *xanthos,* yellow) and carried in special bodies known as *chromoplasts* (Gr. *chroma,* color). Bladderlike *floats* filled with *gas* buoy up the *multicellular* plant (Fig. 32). Every body cell has an organized *nucleus.* Stored foods consist of *fats* and *soluble sugars.* Enlarged tips called *receptacles* (re -sep′-ta kl) (L. *recipere,* to receive) contain numerous *openings* which lead into cavities known as *conceptacles* (kon -sep′ ta kl) (L. *concipere,* to receive). The latter bear the *sex organs.* In some species, male and female sex organs are located within the same conceptacle, while in others the *(male) antheridia* (an the -rid′ i a) (Gr. *anthos,* flower; *idion,* diminutive) are borne on one plant and the *(female) oogonia* (o o -go′ ni a) (Gr. *oon,* egg; *gonos,* begetting) are formed on another plant.

Each *oogonium* is borne on a short stalk and when mature contains *eight eggs. Numerous, multicellular, branched, hairlike paraphyses* (paraf′ i ses) (Gr. *para,* beside; *physis,* growth) surround the oogonia. The paraphyses bear enlarged *antheridia,* each of which produces *numerous pear-shaped sperms,* each with *two lateral, unequal flagella.* The sperm and egg unite in the water to form a *zygote* which forms a new *Fucus* plant by cell division. Since the sperm is much smaller than the egg, this process of fertilization is known as *heterogomy* (het er -og′ a my) (Gr. *heteros,* different; *gamos,* marriage or gamete). *Fucus* may reproduce asexually by *fragmentation.* The cells of the plant body contain a double (diploid) number of chromosomes, while the sex cells contain a single (haploid) number. The gametophyte generation is reduced to merely the male sperm or the female egg. Apparently the sperms are attracted by a chemical substance secreted by the eggs. The sperms swim by the action of the two unequal flagella. Unfertilized eggs may be induced to develop by treatment with solutions of acetic or butyric acid, the phenomenon being known as *artificial parthenogenesis* (par then o -jen′ e sis) (Gr. *parthenos,* virgin; *genesis,* descent or birth).

RED ALGAE (PHYLUM RHODOPHYTA)

These plants commonly are called sea "mosses" and contain *plastids* with *chlorophyll* associated with a red pigment called *phycoerythrin* (fai ko e -rith′ rin) (Gr. *phykos,* alga or seaweed; *erythros,* red) and sometimes with a blue pigment called *phycocyanin.* In most species the plant is *multicellular* and may be branched or relatively simple, in the form of a cylinder, ribbon, or sheet. Different species vary in size from a few inches to several feet in length (Fig. 33). Each cell contains a *nucleus, central vacuoles,* and one or several *plastids,* some of which possess *pyrenoids.* Broad, conspicuous *cytoplasmic strands* which connect adjacent cells are features of red algae. Stored food is an *insoluble "starch."* Red algae are usually attached in warmer sea waters, with a few species in fresh water.

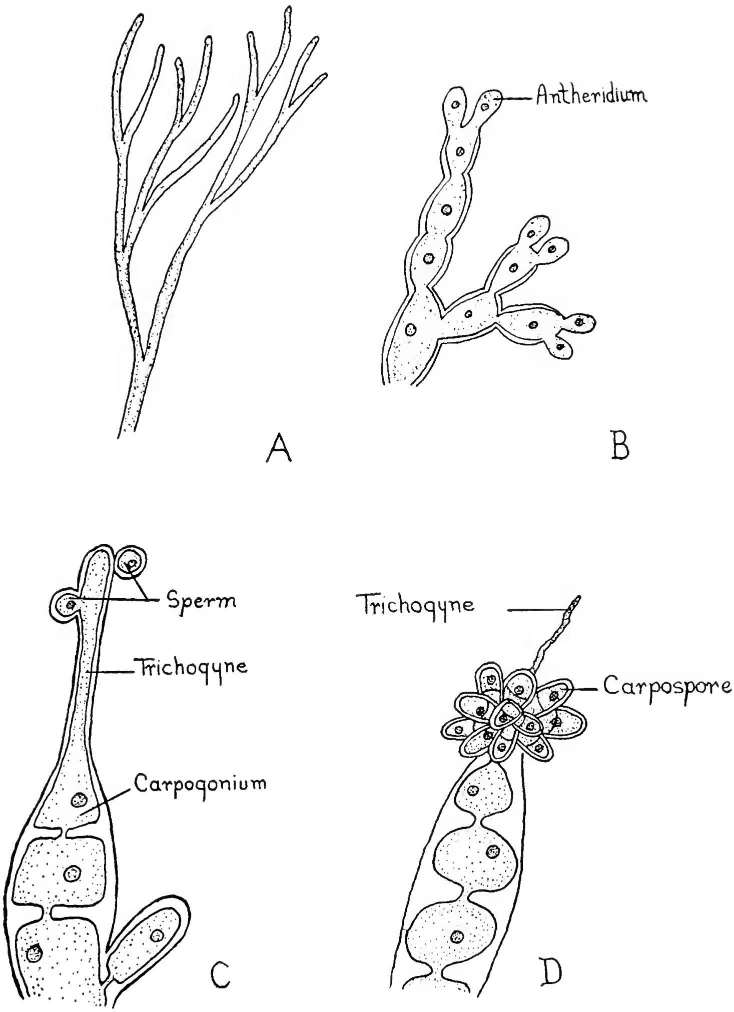


Fig. 63.—Red alga *(Nemalion)* of the phylum *Rhodophyta.* *A,* Portion of a forked, cylindrical body (thallus) which grows attached to rocks along the seacoast; B, portion of a branch bearing brushlike filaments whose tips divide into antheridia, each of which contains a nonmotile sperm (spermatium); *C,* portion of a branch bearing a basal carpogonium (with an egg) and an elongated trichogyne; a nonmotile sperm, carried by water, descends the trichogyne to unite with the egg to form a zygote; *D,* portion of a carpogonium showing asexual, nonmotile carpospores being produced by the zygote; the released carpospores germinate into new *Nemalion* plants.

None of the sexual or asexual reproductive cells bear flagella which is characteristic of red algae. In sexual reproduction the *nonmotile male gamete* is carried by the water to the female *carpogonium* (kar po-go′ ni um) (Gr. *karpos,* fruit; *gonos,* offspring). The latter is characteristic of red algae. Fertilization results in the production of a *zygote.* Many red algae *alternate between a free-living sporophyte and a free-living gametophyte.* About 2,500 species are classified in 400 genera. The following typical species will be considered: *Nemalion* and *Polysiphonia.*

Nemalion (nem -al′ i on) (Gr. *nema,* thread).—This *cylindrical, forked, marine,* red alga is attached to rocks on the seacoast. The body is composed of interwoven, branched threads surrounded by a gelatinous material (Fig. 63). Some branches bear brushlike *filaments* whose tips are divided into short *antheridia,* each containing one *sperm.* The tips of other branches bear female structures consisting of an enlarged, basal *carpogonium* (kar po -go′ ni um) (Gr. *karpos,* fruit; *gonos,* offspring) with an *egg* and an elongated, hairlike, tubular *trichogyne* (trik′ o jin) (Gr. *thrix,* hair; *gyne,* female) to receive the *nonmotile sperm.* The nucleus of the sperm descends the trichogyne to the carpogonium where it fuses with the egg nucleus to produce a *zygote.* Short projections are developed from the carpogonium which grow into short filaments at whose tips are produced the *asexual, nonmotile carpospores* (kar′ po spor) (Gr. *karpos,* fruit; *spora,* spore). The latter germinate to form a new *Nemalion* plant.

Polysiphonia (poli si -fo′ ni a) (Gr. *polys,* many; *siphon,* tube).—This *marine, red alga* grows on rocks and is profusely *branched.* The *main axis* and the *larger branches* consist of a central core made of a single row of elongated *core cells* surrounded by a layer of *jacket cells* (Fig. 33). The elongated cells are connected with each other by *cytoplasmic connectives* which form tubelike structures or *"siphons";* hence the name *Polysiphonia.* Each cell has a *nucleus* and numerous *red plastids* containing *phycoerythrin* (fi ko e -rith′ rin) (Gr. *phykos,* alga or seaweed; *erythros,* red) which masks the *chlorophyll.* Stored foods are insoluble "starch."

Polysiphonia is *diecious* (di -e′ sius) (Gr. *dis,* two; *oikos,* house), the *male gametes* being produced by one plant and the *female gametes* by another plant. The lateral branches of the male plants bear clusters of *antheridia* which produce numerous, *nonmotile sperm* (gametes). On the side branches of other plants are borne female structures known as *carpogonia* (kar po -go′ ni a) (Gr. *karpos,* fruit; *gonos,* birth). Each carpogonium has an elongated *trichogyne* (trik′ o jin) (Gr. *thrix,* hair; *gyne,* female) to receive the nonmotile sperm brought by the water. The nucleus of the sperm travels down the trichogyne to the carpogonium, where nuclear fusions and cell divisions occur. Eventually this results in the formation of many *filaments,* the tips of which produce many *carpospores.* Other filaments form an *urn-shaped covering* which encloses the carpospores. When the latter are released through an opening in the covering, they produce new plants which form *sporangia* (spor-an′ ji a) (Gr. *sporos,* spore; *angos,* vessel), each with *four tetraspores* (tet′ ra spor) (Gr. *tetras,* four; *sporos,* spore). The *sporangia* are borne on the central core cells just beneath the jacket cells. When liberated, the tetraspores produce *Polysiphonia* plants, either with male *antheridia* or with female *carpogonia.* This complex life cycle consists of (1) male or female plants, (2) the zygote and its carpospores, and (3) plants producing tetraspores. *None of the reproductive cells are motile* which is characteristic of red algae.

QUESTIONS AND TOPICS

1. List the general characteristics of the thallophytes (Subkingdom Thallophyta).
2. List the distinguishing characteristics by means of which the following phyla may be differentiated: *Cyanophyta, Chlorophyta, Chrysophyta, Phaeophyta,* and *Rhodophyta.*
3. In what ways do algae differ from the fungi?
4. List all the asexual methods of reproduction found in the algae, describing each.
5. List all the sexual methods of reproduction found in the algae, describing each.
6. Explain what is meant by metagenesis (alternation of generations). Describe what is meant by a gametophyte. Explain what is meant by a sporophyte.
7. What evidence from your studies of algae can you give for an explanation for the origin of sex?
8. Describe the increase in complexity of structures and methods of reproduction as you progress from the simpler to the higher types of algae.
9. What progressive developments take place in the vegetative body of the algae as we go from the simpler to the higher types?
10. List the evolutionary changes which take place in individual cells of algae as we go from the simpler to the higher types.
11. List the economic importance of the algae of each phylum, including beneficial as well as harmful items.
12. Make a list of the habitats for each phylum to which the algae belong.
13. Explain the importance of algae in the lives of fish and other types of aquatic organisms.

14. Diagram a typical life cycle of an alga in each of the phyla.
15. Define all the terms used in the discussion of algae, including the correct pronunciation and derivation of each term.

SELECTED REFERENCES

Fritsch: The Structures and Reproduction of Algae, Cambridge University Press.

Smith: Cryptogamic Botany; vol. 1, Algae and Fungi, McGraw-Hill Book Co., Inc.

Smith: The Fresh Water Algae of the United States, McGraw-Hill Book Co., Inc.

Tiffany: Algae, The Grass of Many Waters, Charles C Thomas, Publisher.

Tilden: The Algae and Their Life Relations, University of Minnesota Press.

Chapter 10

SIMPLE PLANTS WITHOUT CHLOROPHYLL—FUNGI

PLANTS WITHOUT TRUE LEAVES, STEMS, OR ROOTS; NOT FORMING MULTICELLULAR EMBRYOS; WITHOUT TRUE VASCULAR (CONDUCTING) TISSUES (SUBKINGDOM THALLOPHYTA)

GENERAL CHARACTERISTICS OF FUNGI

The term fungi is no longer used in the scientific classification but commonly refers to that group of thallophytes which *lack chlorophyll,* which, in most species, must depend upon a *heterotrophic mode of nutrition*

SUMMARY OF DISTINGUISHING CHARACTERISTICS OF FUNGI

			TRUE FUNGI (EUMYCOPHYTA)		
	BACTERIA (SCHIZOMYCOPHYTA)	SLIME MOLDS (MYXOMYCOPHYTA)	ALGA-LIKE FUNGI (PHYCOMYCETES)	ASCUS FUNGI (ASCOMYCETES)	BASIDIUM FUNGI (BASIDIOMYCETES)
Multicellular embryos	–	–	–	–	–
Plastids and chlorophyll	–	–	–	–	–
Organized nucleus	–	+	+	+	+
Filamentous hyphae	–*	–	+	+*	+
Septate hyphae	–	–	–†	+	+
Amoeboid plasmodium	–	+	–	–	–
Reproduction: Asexual	Fission Endospores* Gonidia* Conidia*	Sporangiospores Motile swarm-cells (myxamoeba)	Sporangiospores Motile zoospores (aquatic species)	Ascospores Conidiospores* Budding*	Conidiospores* Chlamydospores* Uredospores* Teliospores* Pycniospores* Aeciospores*
Reproduction: Sexual	None?	Isogamy	Isogamy* Heterogamy*	Ascospores* (by fusion)	Basidiospores (by fusion)

*Certain species.
†Except certain older hyphae.

(het-ero -trof′ ik) (Gr. *heteros,* other; *trophe,* nourishment or food). Heterotrophic fungi may be (1) *saprophytes* (sap′ ro fite) (Gr. *sapros,* dead; *phyton,* plant), living on dead organic materials, or (2) *parasites* (pa′ ra site) (Gr. *para,* beside; *sitos,* food), living in or on the body of another living plant or animal. A few species are *autotrophic* and will be considered later.

Fungi *lack true leaves, stems, and roots;* they *do not form multicellular embryos;* they *lack the two vascular tissues (phloem and xylem)* which are present in the higher plants. The fungi group includes the *bacteria* (Phylum *Schizomycophyta*), the *slime molds* (Phylum *Myxomycophyta*), and the *true (higher) fungi* (Phylum *Eumycophyta*), representatives of which will be considered in this chapter. The true fungi and slime molds differ from the bacteria in that the bacteria are unicellular, do not have an organized nucleus, and usually have smaller cells and their methods of reproduction differ from those of the slime molds and true fungi.

BACTERIA (PHYLUM SCHIZOMYCOPHYTA)

Bacteria (bak -te′ ria) (Gr. *bakterion,* small rod) are placed in the phylum *Schizomycophyta* (skiz o my -kof′ i ta) (Gr. *Schizo,* fission; *myco,* fungus; *phyta,* plants) (Fig. 34). Bacteria are *simple, unicellular plants without chlorophyll;* thus a majority of them are unable to photosynthesize their foods but must secure them in other ways. The method of nutrition for a majority of them is *heterotrophic* (het ero -trof′ ik) (Gr. *heteros,* other; *trophe,* food or nourish), securing their foods from outside sources. Consequently, they may be (1) *saprophytes* (sap′ ro fite) (Gr. *sapros,* dead; *phyton,* plant), which obtain foods from nonliving, organic materials or (2) *parasites* (pa′ ra site) (Gr. *para,* beside; *sitos,* food), which live in or on the bodies of living plants or animals. In the latter case, if a diseased condition is produced, they are known as *pathogenic bacteria* (path o -jen′ ik) (Gr. *pathos,* suffering; *genos,* produce).

A small minority of bacteria are *autotrophic* (ot o -trof′ ik) (Gr. *autos,* self; *trophe,* nourish), being able to synthesize organic foods from carbon dioxide and other simple inorganic substances. These autotrophic species may be grouped into (1) *chemosynthetic,* in which the energy required for the synthesis of foods is derived from the oxidation of certain chemicals, and (2) *photosynthetic,* in which light supplies the food-producing energy and the photosynthetic pigments are reddish-purple or greenish (not chlorophyll).

Some of the *chemosynthetic bacteria* include: (1) the *sulfur bacteria* which live in waters, soils, and sewage, and which oxidize hydrogen sulfide to free sulfur and then to sulfuric acid, thereby releasing energy for the synthesis of organic compounds from carbon dioxide and other inorganic substances. The sulfuric acid undergoes chemical changes in the soil to form sulfates which are the principal sources of sulfur for green plants; (2) the *iron bacteria* which live in iron-containing waters and oxidize the iron compounds, thereby releasing energy for the synthesis of organic compounds; (3) the *hydrogen bacteria* which live in soils and oxidize molecular hydrogen to form water, thereby releasing energy; (4) the *nitrifying bacteria* which live in soils—one group oxidizes ammonia to nitrites and the other group oxidizes the nitrites to nitrates, thus releasing energy. Other bacteria, the *symbiotic nitrogen-fixing bacteria,* live symbiotically in the nodules of the roots of leguminous plants where they fix the free nitrogen to form nitrates. Still other soil bacteria, the *nonsymbiotic nitrogen-fixing bacteria,* fix the free nitrogen to form nitrates (not in roots). Hence, the essential nitrate supply of the soil is affected by the actions of these various bacteria (Fig. 325).

Some typical *photosynthetic bacteria* include: (1) the *purple sulfur bacteria* which, because of their purple pigment, are able to synthesize organic compounds in a manner similar to that used by chlorophyll-bearing plants; (2) the *purple nonsulfur bacteria* which synthesize organic compounds by the utilization of molecular hydrogen in the presence of light; (3) the *green bacteria* which synthesize organic compounds by oxidizing hydrogen sulfide and reducing carbon dioxide.

Bacteria are considered to be plants, rather than animals, because (1) their methods of reproduction resemble those of certain algae and true fungi, (2) their cell walls often contain cellulose, (3) they synthesize vitamins like those of certain plants, (4) some species are able to utilize simple inorganic compounds from which more complex organic compounds may be synthesized.

Bacteria are *unicellular* and the *simplest* and *smallest* of living organisms, being visible only under high magnifications (Fig. 34). When growing under certain conditions many individuals may associate themselves to form a *colony* whose color and other characteristics are more or less specific for each species. Typically, bacteria are not over 4 to 5 microns long (a micron is one-thousandth part of a millimeter).

The forms of bacteria (Fig. 34) include: (1) the *coccus* (spherical or ovoid), (2) the *rod-shaped* (cylindrical), (3) the *spiral-shaped,* (4) the *filamentous* (which may be branched). There are various types of each of the four described above. For example, there are *Staphylococci* (masses of cocci forms), *Streptococci* (chains of cocci), *Diplococci* (pairs of cocci), *Sarcina* (box-shaped mass of cocci), etc.

Certain types of bacteria, like higher plants, require free, atmospheric oxygen for their normal activities and are known as *aerobes* (a′ er obe) (Gr. *aer,* air; *bios,* life). Other species do not require free oxygen but secure oxygen by breaking down certain types of oxygen-bearing foods through the action of enzymes. These are called *anaerobes* (ana′ er obe) (Gr. *an,* without; *aer,* air; *bios,* life). Certain species are at times aerobic and at other times anaerobic.

A bacterial cell has a *cell wall* which in some species contains *cellulose.* In some species an external, slimy layer or *capsule* is present. A few species form a slimy, gelatinous mass called a *zooglea* (zo o -gle′ a) (Gr. *zoon,* animal; *gloia,* glue) in which great numbers of bacteria are embedded in a mucilaginous matrix which is frequently iridescent. The *protoplasm* of the cell is fairly *homogeneous* and contains *vacuoles* as well as *granules,* including *chromatin.* An *organized nucleus and plastids are absent,* although certain investigators maintain that certain species possess a structure which resembles a nucleus.

Each species of bacteria has a temperature at which it grows best and is known as its *optimum temperature.* As this temperature is decreased or increased, growth is retarded until it eventually ceases. On the basis of optimum growth temperatures, bacteria are grouped into (1) *psychrophiles* (si′ kro fil) (Gr. *psychros,* cold; *philein,* to love), or those growing best at temperatures below 14° C.; (2) *mesophiles* (mes′ o fil) (Gr. *mesos,* middle; *philein,* to love), or those having an optimum temperature between 20° and 40° C., and (3) *thermophiles* (ther′ mo fil) (Gr. *therme,* heat; *philein,* to love), or those that grow best at temperatures above 45° C. Psychrophilic organisms are common in cold, deep waters, where they exist as saprophytes. Psychrophiles may decompose foods in cold storage plants. A majority of bacteria are mesophilic. The saprophytic types common in soils, water, etc., grow best at room temperature (20° to 25° C.). Those growing in animals grow best at temperatures which approximate their animal host. Bacteria which produce human diseases grow best at body temperature (approximately 37° C.). Thermophilic bacteria may be found in many places but particularly in hot springs, decaying vegetation, etc. Thermophils are not known to produce diseases, although they can be bothersome in food canning, milk pasteurization, etc.

Not all bacteria are able to locomote in liquids, but when they do, this is accomplished by the rhythmic, vibratile action of whiplike protoplasmic structures known as *flagella* (fla -jel′ a) (L. *flagellum,* whip). The number and location of flagella vary with the species (Fig. 34), some having a single flagellum, others having a tuft of flagella at one end, others having tufts at each end, and still others having flagella over the entire surface.

Like other plants, bacteria produce *enzymes* with which they perform various functions. Those which are active within cells are called (intracellular) *endoenzymes,* while those which are secreted to the outside are called (extracellular) *exoenzymes.* Bacterial enzymes digest foods by converting complex, water-insoluble foods into simpler, water-soluble types. Bacteria also synthesize enzymes which affect processes of oxidation and reduction and hence are influential in respiration.

Probably when most persons think of bacteria they think of diseases. However, of the total number of bacterial species, only a comparatively small group produces diseases in animals and other plants. In fact, a few species are actually beneficial, while a great majority are neither harmful nor beneficial according to our present knowledge. Some of the diseases produced by bacteria, yeasts, and fungi, as well as some of the benefits, are discussed in the chapter on Economic Importance of Plants.

Bacteria cause diseases in plants as illustrated by the following typical examples: (1) soft rot of cabbage, carrot, cucumber, celery, etc., (2) the wilt diseases of corn, tomatoes, potatoes, squash, melons, cucumbers, etc., (3) the root rot of cotton, (4) fire blight of pears and apples, (5) crown galls of apples, grapes, raspberries, alfalfa, etc., (5) bacterial blight of beans, (6) bacterial blight of walnut, and many others.

Bacteria may cause such diseases in animals as tuberculosis in cattle and hogs, chicken cholera, pneumonia, septicemia in cattle, anthrax in sheep, glanders in horses, goats, and sheep, botulism in chickens and other animals, rat plague, Bang's disease (brucellosis or undulant fever) in cattle, tularemia in rabbits, etc.

Bacteria reproduce asexually by *fission* in which the cell divides into two parts at right angles to the long axis (Fig. 34). Mitosis is apparently not utilized in the process, since no mitotic figures have been observed. Frequently, after fission, the cells may remain together to form a *colony.* Each species forms a colony which has more or less constant characteristics for that species and thus may be used for identifying them. Under favorable conditions (proper food, moisture, temperature, etc.) fission may occur every twenty to thirty minutes. At this rate of fission a single bacterial cell in twenty-four hours would have nearly 5 million trillion offspring whose total weight would be many hundred tons. However, this rapid reproduction does not occur in nature because of limited food supplies, the production of poisonous wastes, etc.

Another asexual method of reproduction possessed by certain species, primarily rods, is by the production of resistant *endospores.* When a spore is formed, the cell condenses its protoplasm into a spherical or oval mass which is quite resistant to external conditions. This mass forms the spore with its protective spore wall and its relatively low water content. When proper environmental conditions are encountered, the spore germinates to form a new bacterial cell, which will divide by fission.

A few species of bacteria produce within their cells a number of tiny bodies called *gonidia* (go -nid′ i a) (Gr. *gone,* "seed"; *idion,* small), each of which develops into a typical bacterial cell. Certain species, especially the filamentous types, may produce tiny *conidia* (ko -nid′ i a) (Gr. *konis,* dust; *idion,* small) at the tips of the filaments, similar to the formation of such structures by certain true fungi.

SLIME MOLDS (PHYLUM MYXOMYCOPHYTA)

There are about 300 species of slime molds (slime fungi), most of which are *saprophytes* on damp, decaying vegetable matter. They resemble certain fungi in their methods of spore formation and resemble certain lower animals by their slimy, amoeba-like bodies, their amoeboid methods of locomotion, and their ingestion of solid foods. Although the methods of reproduction and the physiologic activities vary with the species, the following general description is rather common and typical.

The *vegetative body* is a thin mass of slimy, naked, viscous protoplasm known as the *plasmodium* (plaz -mo′ di um) (Gr. *plasma,* liquid; *eidos,* form). The plasmodium contains *many nuclei* and creeps by a flowing amoeboid motion through the formation of *pseudopodia* (su do -po′ di a) (Gr. *pseudes,* false; *pous,* foot). It may ingest solid foods in a manner similar to that employed by certain lower animals (Fig. 35).

After a period of amoeboid locomotion the plasmodium produces a number of *spore cases* known as *sporangia* (spor -anj′ i a) (Gr. *sporos,* seed; *anggeion,* vessel). The sporangia vary in size and form, depending on the species, and are used in classifying slime molds. Sporangia may be colorless, purple, orange, brown, etc. As a sporangium matures, the internal protoplasm forms a network of delicate fibers known as the *capillitium* (kap i -lit′ i um) (L. *capillus,* hair), in the meshes of which are formed numerous *unicellular, nonmotile spores* (Fig. 35).

The liberated spores germinate, each producing one to four *swarm cells* or *myxamoebae* (mik sa -me′ ba) (Gr. *myxa,* slime; *amoibe,* change) and each having one to two *flagella.* The myxamoeba locomotes by flagellar action or by amoeboid pseudopodia. Two myxamoebae fuse in a form of sexual reproduction to form a *zygote* (zi′ gote) (Gr. *zygotos,* joined). Several zygotes may fuse to form a new plasmodium in which the nuclei have not fused. Some common slime molds include *Stemonitis* (Fig. 35), *Lycogala* (Fig. 35), *Badhamia, Physarum,* etc.

TRUE (HIGHER) FUNGI (PHYLUM EUMYCOPHYTA)

A. Class Phycomycetes (fi ko my -ce′ tez) (Gr. *phykos,* seaweed; *mykes,* fungus)

1. **Black Bread Mold** (*Rhizopus nigricans*) (ri′ zo pus; ni′ gri kans) (Gr. *rhiza,* root; *pous,* foot) (L. *nigricans,* black).—This mold is typical of the black molds which are common *saprophytes* on moist, organic materials such as bread, fruits, potatoes, animal dung, etc. A few species may parasitize man and other animals. Certain species parasitize squash, cowpeas, cotton, and other plants. Other species are used commercially in the production of alcohol, acids, enzymes, etc. They are called black molds because of their dark-colored spores.

The irregular, whitish or grayish, mass of threadlike *hyphae* (hi′ fe) (Gr. *hyphe,* web) comprise the weblike *mycelium* (mi -se′ li um) (Gr. *myxos,* fungus) (Fig. 36). The young hyphae are *branched* and *without cross walls (nonseptate)* and contain *numerous nuclei,* while cross walls (septa) may be present in older hyphae, especially when reproducing sexually. Rootlike hyphae known as *rhizoids* (ri′ zoid) (Gr. *rhiza,* root; *eidos,* form) absorb nourishment from the substratum and serve as anchors. Other hyphae grow over the surface and are called *stolons* (sto′ lons) (L. *stolo,* shoot), from which arise the spore-forming hyphae known as *sporangiophores* (spor -an′ jio for) (Gr. *sporos,* spore; *anggeion,* vessel; *pherein,* to bear). Each sporangiophore bears a globular *spore case (sporangium)* at its tip which becomes darker as it matures. The *air-borne, asexual, nonmotile spores* germinate to form hyphae.

Sexual reproduction occurs by the formation of small projections between two adjacent hyphae. The projections fuse and each forms a *sex cell (gamete).* The two gametes fuse in the fertilization process known as *conjugation,* thus producing a *zygote (zygospore).* The latter develops a new hypha. The two types of hyphae necessary for the sexual process are called "plus" and "minus" hyphae or strains.

2. **Water Mold** (*Saprolegnia*) (sap ro -leg′ ni a) (Gr. *sapros,* rotten; *legnon,* edge).—The fungi of this group are primarily *saprophytes* in

water, securing foods from dead plants or animals. A few species cause serious damage by parasitizing fish, amphibia, turtles, etc. Goldfish in aquaria are frequently affected by the white mycelia of water molds.

In *Saprolegnia* (Fig. 64) the hyphae are *branched* and the tips bear enlarged *zoosporangia* (zo o spor -an′ jia) (Gr. *zoon,* animal; *sporos,*

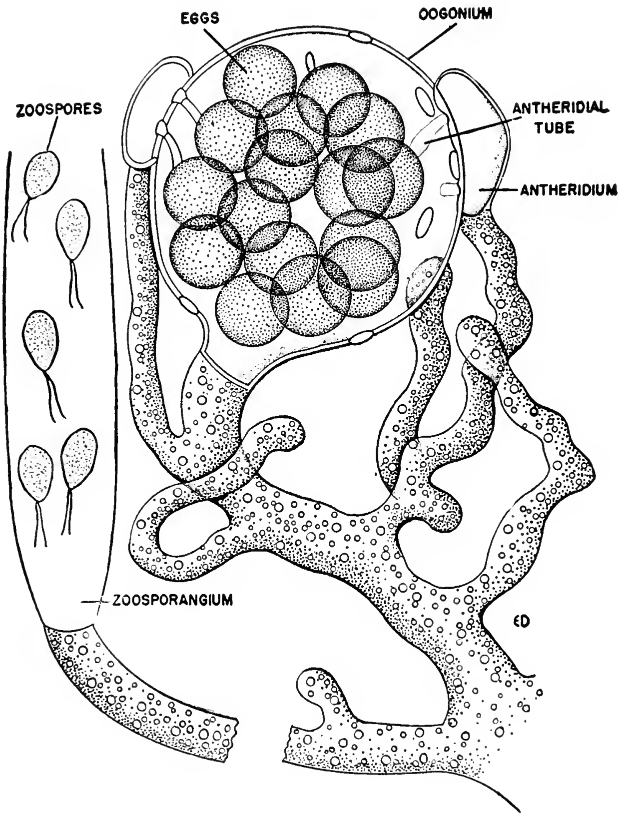


Fig. 64.—A common water mold *(Saprolegnia)* of the class *Phycomycetes. Left,* reproduction by asexual, motile zoospores; *right,* sexual reproduction by gametes produced in antheridia and oogonia. The antheridia form antheridial tubes through which the male gametes pass. (From Fuller and Tippo; College Botany, Henry Holt and Company.)

spore; *anggeion,* vessel). The *biciliated zoospores* (swarm spores) liberated by the zoosporangia swim ("swarm") in the water, then lose the cilia, and surround themselves with a wall. Each of these gives rise to many more zoospores, each of which germinates to form a new hypha.

Sexual reproduction in *Saprolegnia* occurs by developing enlarged *oogonia* (o -ogo′ ni a) (Gr. *oon,* egg; *gonos,* beget) and clublike, male *antheridia* (an ther -id′ ia) (Gr. *anthos,* flower; *idion,* diminutive). Each *oogonium* contains *eggs.* The *antheridia* penetrate the oogonia and discharge *male nuclei* through antheridial tubes. An egg fertilized by a male nucleus forms a *zygote* which develops a new hypha. In *Saprolegnia* the same plant produces the *antheridia* and *oogonia (monecious).*

B. Class Ascomycetes (ask o my -ce′ tez) (Gr. *askos,* sac; *mykes,* fungus)

1. **Penicillium** (pen i -sil′ i um) (L. *penicillus,* painter's brush).—This blue-green mold has a loose mass of hyphae which grows on, or in, such materials as damp leather, foods, citrus fruits, etc. The spore-bearing hyphae are called *conidiophores* (ko -nid′ io for) (Gr. *konis,* dust; *idion,* diminutive; *pherein,* to bear), the tips of which resemble *tiny brushes,* bearing chains of colored *spores (conidia)* at the tips (Figs. 39 and 73). The spores are very small, light in weight, and usually present in the air.

Penicillium is classed as an *Ascomycete* because certain hyphae may produce *ascospores* (ask′ o spor) (Gr. *askos,* sac; *sporos,* spore or seed) within saclike *asci.*

Species of *Penicillium* are responsible for food spoilage and destruction of paper, leather, lumber, etc. *Penicillium camemberti* and *P. roqueforti* impart the flavors and odors to these common types of cheeses. The bluish-green areas in the cheese are masses of conidia. *P. notatum* is widely used as a source for the bactericidal antibiotic penicillin (pen i-sil′ in). *Antibiotics* (an ti bi -ot′ ik) (Gr. *anti,* against; *bios,* life) are organic substances which are synthesized by one type of organism and which inhibit, or destroy, another type of organism. This common antagonistic inhibition between two species of organisms (especially fungi) is called *antibiosis* (an ti -bio′ sis). In 1940, the possible medical use of *penicillin* and other antibiotics in the destruction of pathogenic bacteria was suggested. Since then, numerous antibiotics, such as *streptomycin, tyrothricin, Chloromycetin, aureomycin,* and many others, have been isolated. These and others are considered elsewhere in the text.

2. **Aspergillus** (as per -jil′ us) (L. *aspergere,* brush).—This blue-green mold is composed of a loose mass of hyphae growing on or in damp foods, leathers, fabrics, fruits, etc. The spore-bearing hyphae are called *conidiophores* which produce chains of colored *spores (conidia)* on the enlarged,

globose tips of these hyphae (Fig. 38). In many ways the Aspergillus molds resemble the Penicillium molds, but the tips of the conidiophores differ in their specific methods of producing the *conidia* (Figs. 38 and 73).

Aspergillus is classified as an Ascomycete because certain hyphae may produce *ascospores* within saclike *asci.* Species of *Aspergillus* cause the spoilage of bread and other foods, the deterioration of leathers and fabrics, the decay of tobacco, and the rotting of fruits. Certain species may cause lung and ear infections in animals, including man. Certain species of *Aspergillus* may be used commercially in the production of alcohols and organic acids.

3. **Cup Fungus** (*Peziza*) (pe -zi′ za) (L. *pezica,* sessile fungus) (Fig. 40).—The so-called cup fungi possess a fleshy, cuplike body (*ascocarp*) specifically called an *apothecium* (ap o -the′ si um) (Gr. *apo,* away; *thece,* cup) which is composed of tightly compacted hyphae and which is often borne on a *stalk.* Inside the cup is a layer of cylindroid or sac-shaped *asci* and sterile hyphae called *paraphyses* (pa -raf′ i sez) (Gr. *para,* beside; *physis,* growth). The asci and paraphyses constitute a layer called the *hymenium* (hi -me′ ni um) (Gr. *hymen,* skin). The *asci* usually contain eight *ascospores.*

There are over 5,000 species of cup fungi, many of which are *saprophytes* on decaying vegetable matter, on dead wood, or on the ground. Some species may be brilliantly colored, and in some the saucer-shaped fruiting body may be four inches in diameter.

4. **Yeasts** (ye′ st) (A.S. *gist,* ferment).—Yeasts are typically *unicellular, saprophytic fungi* usually *without hyphae,* although a few species may develop a short hypha (Fig. 37). Each cell is usually *ovoid in shape* and contains an *organized nucleus. Asexual reproduction* is commonly accomplished by *budding* in which a small protuberance (*bud*) is projected from the cell. The bud may free itself from the mother cell or remain attached and produce more buds, eventually forming a many-celled chain of cells.

Under certain conditions a yeast cell may become a simple, single *ascus* in which are formed *ascospores* (usually four). In other instances two yeast cells may fuse before the ascospores are produced.

Yeasts are of economic importance in the production of alcohol from sugars, in the rising of bread by the production of carbon dioxide, in manufacturing certain vitamins, and by being parasites on higher plants, animals, and man. A yeastlike organism causes "leaf curl" on peach trees, in which the leaves curl and become yellow. Single asci are formed on the surface of the diseased leaves. The disease may be prevented by a thorough application of a "dormant spray" (Bordeaux mixture and lime sulfur sprays) two weeks before the buds unfold. The economic importance of yeasts is considered in the chapter on Economic Importance of Plants.

5. **Mildews** (mil′ du) (A.S. *mildeaw,* honeydew).—Powdery mildews are fungi which are chiefly *parasites* on the leaves and stems of flowering plants. The masses of hyphae appear as whitish, or grayish, *powdery areas* on the surfaces of the affected plant. Certain hyphae, the *haustoria* (hos -to′ ri a) (L. *haurire,* to drink) penetrate and absorb food from the cells of the plant host. *Asexual reproduction* occurs by forming chains of *spores (conidia)* at the tips of the surface hyphae.

Ascospores are formed within the *asci.* The asci develop within small, *closed ascocarps,* known specifically as *cleistothecia* or *perithecia* (kli sto-the′ si a) (Gr. *kleistos,* closed; *theke,* box) (peri -the′ si a) (Gr. *peri,* around; *theke,* box). The latter are produced by the hyphae on the surface of the host plant. Sometimes the hyphae of the asocarp may be elongated and delicately branched.

Powdery mildews appear as whitish, dusty patches upon such plants as lilacs, roses, apples, clovers, dandelions, grapes, maples, berries, and other flowering plants. Dusting infected plants with flowers of sulfur may be beneficial in combating these diseases.

6. **Blights** (blite) (A.S. *blaecan,* grow pale).—Blights are diseases of plants in which the blossoms, young leaves, or branches die suddenly. Examples are the fire blight of pears and the blight of chestnut trees. The latter is produced by the ascomycetous fungus *(Endothia parasitica)* which was introduced from China about 1900 and which has killed most of the chestnut trees in the United Statès. In these the *asci* are present in *dark, ovoid ascocarps* known specifically as *perithecia. Conidia (spores)* may be produced in flask-shaped fruiting bodies called *pycnidia* (pik -nid′ i a) (Gr. *pyknos,* dense; *idium,* diminutive). The mycelium of the fungus parasitizes the cambium and the living cortex cells of the chestnut tree.

C. Class Basidiomycetes (ba sid io my -se′ tez) (Gr. *basis,* base or club; *mykes,* fungus)

1. **Mushrooms.**—Mushrooms are *saprophytic fungi* which derive their foods from decomposing organic materials in the soil, dead leaves, bark,

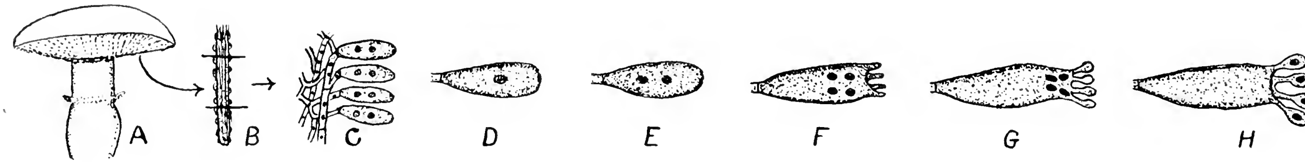


Fig. 65.—Mushroom, showing the fusion of two nuclei (modified fertilization) preparatory to forming the basidium which in turn will form basidiospores on the necklike sterigmata. *A,* Adult mushroom, showing numerous gills; *B,* gill composed of mycelium and cut in section; C, enlarged area of part of a gill showing immature basidia, each with two nuclei (binucleate); D, immature basidium with two nuclei fused into one (this fusion corresponds to fertilization in which the nuclei of male and female gametes unite); *E,* two nuclei formed by division of the fused nucleus; *F,* four nuclei formed by division of previous two (note the four immature sterigmata); *G,* nuclei moving toward the future basidiospores; *H,* four basidiospores each with a nucleus, and borne on a sterigma. These basidiospores will be shed and develop a hypha, and eventually a new mushroom (See Fig. 41). (From various sources.)

wood, etc. The vegetative body consists of masses of *septate hyphae* which penetrate the substratum. Fleshy, fruiting bodies called *sporophores* are produced for reproduction purposes (Fig. 41). Each sporophore typically consists of a broad, caplike or umbrella-shaped *pileus* (pil′ eus) (L. *pileus,* cap) and a stalklike stipe (L. *stipes,* stalk). On the undersurface of the pileus are *gills* which are thin plates of compact hyphal tissues and which bear club-shaped basidia (ba -sid′ i a) (Gr. *basis,* base). The latter bear numerous *basidiospores* (Fig. 65), each attached by a slender *sterigma* (ster -ig′ ma) (Gr. *sterigma,* support). In the case of the common, edible, field mushroom *(Psalliota [Agaricus] campestris),* a single sporophore may produce nearly two billion basidiospores, each of which may germinate to form a new hypha. At certain times there may be fusion between two cells of adjacent hyphae (by a process equivalent to a sexual process), producing a binucleated cell which is the *basidium.* This nucleus will divide to form four nuclei, one for each of the four basidiospores. Each of the latter is pinched off from the sterigma and scattered by the wind. There are several hundred species of mushrooms and toadstools but only a comparatively few of them are poisonous. Most of the latter belong to the genus *Amanita.* Unless the collector of wild mushrooms is familiar with the specimens he collects, he should take no chances with the deadly species. It is better to forego the use of mushrooms rather than be sorry later.

2. **Bracket Fungi (Pore Fungi).**—The bracket fungi or shelf fungi are members of the family known as *pore fungi* because the underside of the *caps (shelves)* contain hundreds of *tiny tubes* which appear as *pores on the lower surface.* The internal tissues around these tubes produce club-shaped *basidia* which bear *basidiospores* (Fig. 42). The latter escape through the pores.

The hyphae of tree-inhabiting shelf fungi secrete enzymes which digest the tissues of the wood and bark and absorb organic compounds from these tissues. The shelflike *sporophores* described above are often tough and woody. In certain species they may be perennial, forming new spore-producing hyphae in annual layers, year after year. Shelf fungi are common causes of wood decomposition, and parasitic species often kill living trees. Among the important wood-rotting pore fungi is *Merulius lacrymans* which causes the common "dry rot" of wood.

3. **Smuts.**—Smuts are produced by a group of smut fungi *parasitic on flowering plants,* in which the irregular masses of *septate hyphae* penetrate the tissues of the host plant. They are called smuts because the

fungi produce heavy-walled, dark-colored, smut spores known as *chlamydospores* (klam′ i do spor) (Gr. *chlamys,* cloak; *sporos,* spore or seed). The latter are especially prevalent in the ovary tissues of the host plant but may appear in other tissues. The resistant smut spores may be dormant until the next spring when each germinates to form a cylindric tube of one to four cells known as a *basidium.* The latter produces *basidiospores (sporidia).* The basidiospores attack host plants, producing hyphae which eventually form smut spores.

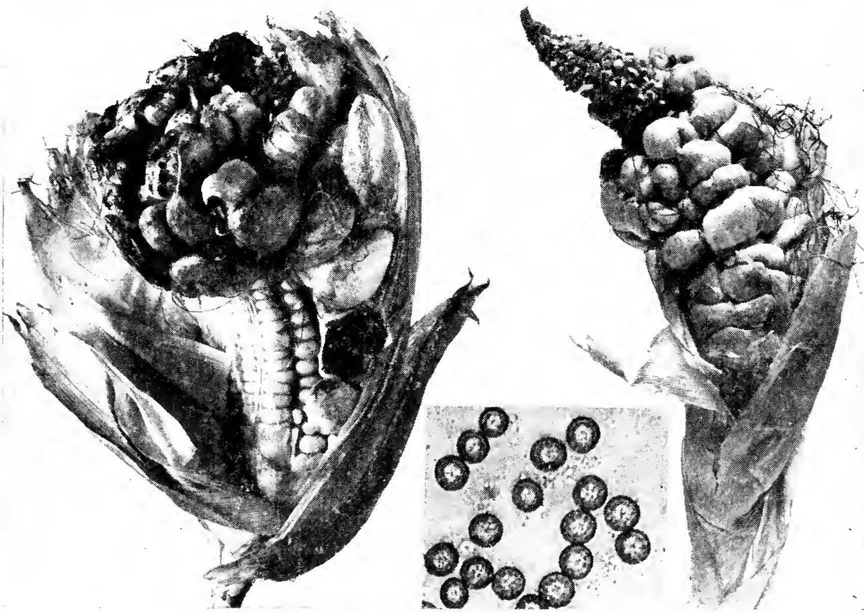


Fig. 66.—Corn smut *(Ustilago zeae)* showing unbroken tumors at the right but broken and disseminating spores at the left; insert shows chlamydospores of corn smut. (By permission from Botany by Hill, Overholts, and Popp. Copyright, 1950, McGraw-Hill Book Company, Inc.)

In some species of smuts, *conidia* are also found on the parasitized plant. Thus as many as three types of spores may be formed in certain life cycles. In certain species the basidiospores conjugate in pairs before germination.

Smuts constitute a common group of about 400 species and are primarily parasitic on members of the grass family such as corn (Fig. 66), oats, wheat, rice, rye, barley, etc., where they are responsible for tremendous crop losses. In the *smut of corn, Ustilago Zaea* (us ti -la′ go; ze′ a) (L. *ustilago,* thistlelike plant; *zea,* kind of grain), the tumorlike masses of smut may appear on any part of the plant (Fig. 66). When these *tumors* mature in the summer or fall, they are masses of black *chlamydospores.* The latter usually germinate the next spring or summer to infect new corn plants. The *basidiospores,* formed on the *basidia,* produce *germ tubes* capable of infecting any part of the corn plant. The resulting mycelia mass together at definite points and break out as the smut tumors. The latter are white at first but become black as the *chlamydospores* mature. Annual losses in the United States due to corn smut are estimated at $100,000,000.

4. **Rusts.**—Rust fungi are *parasitic* on various *flowering plants and ferns.* They are called rusts (A.S. *rust,* red) because of their *reddish-brown spores* on the surface of the leaves and stems. Hyphae penetrate the tissues of the host plant. A rust may parasitize two unrelated species of plants, alternating between the two hosts.

A very destructive rust is the *black stem rust of wheat* (Fig. 67) known as *Puccinia graminis* (puk -sin′ i a; gram′ in is) (Puccini, an Italian anatomist; L. *graminis,* grass). The life cycle of this wheat rust may be briefly described as follows:

In the summer the hyphae live in the stems and leaves of wheat where the blisterlike *uredosori (uredinia)* (u -re′ do so ri) (Gr. *uredo,* blight; *soros,* heap) contain many unicellular, rough, reddish-orange, wind-disseminated, *summer spores* called *uredospores* (Fig. 67). These spores may infect other wheat plants and are known as the "red rust" of wheat.

In late summer the hyphae form black pustules known as *teliosori (telia)* which produce thick-walled, resistant, brownish-black, *winter spores* called *teliospores (teleutospores)* (te′ li o spor) (Gr. *telios,* end; *sporos,* spore) (Fig. 67). This is the "black rust" stage. The teliospores remain dormant on wheat straw and germinate next April or May. Each germinating teliospore produces a clublike *basidium* with its four *basidiospores* (ba -sid′ i o spor) (Gr. *basis,* base or club; *sporos,* spore) which are wind borne to the common, wild, European barberry (not the cultivated Japanese barberry).

The basidiospores (Fig. 67) germinate and send hyphae into the barberry leaves, while the *yellowish-red spots on the upper surface* form small, flask-shaped *pycnia (spermogonia)* (pik′ ni a) (Gr. *pyknos,* crowded); (sper mo -go′ ni a) (Gr. *sperma,* "seed"; *gonos,* offspring). The pycnia produce small, unicellular *pycniospores (spermatia)* at the tips of the hyphae which line them. The pycniospores may be carried by insects and are of two types, known as plus and minus. A plus spore fuses with a minus spore to form a mycelium which produces chains of yellowish-red, spring spores called *aeciospores* (e′ si o spor) (Gr. *aecium,* injury) in small cuplike *aecia* on the *lower surface of the barberry leaves.* The *aeciospores* are windblown to young wheat plants in the spring, where their hyphae again form *uredospores* to complete the life cycle (Fig. 67).

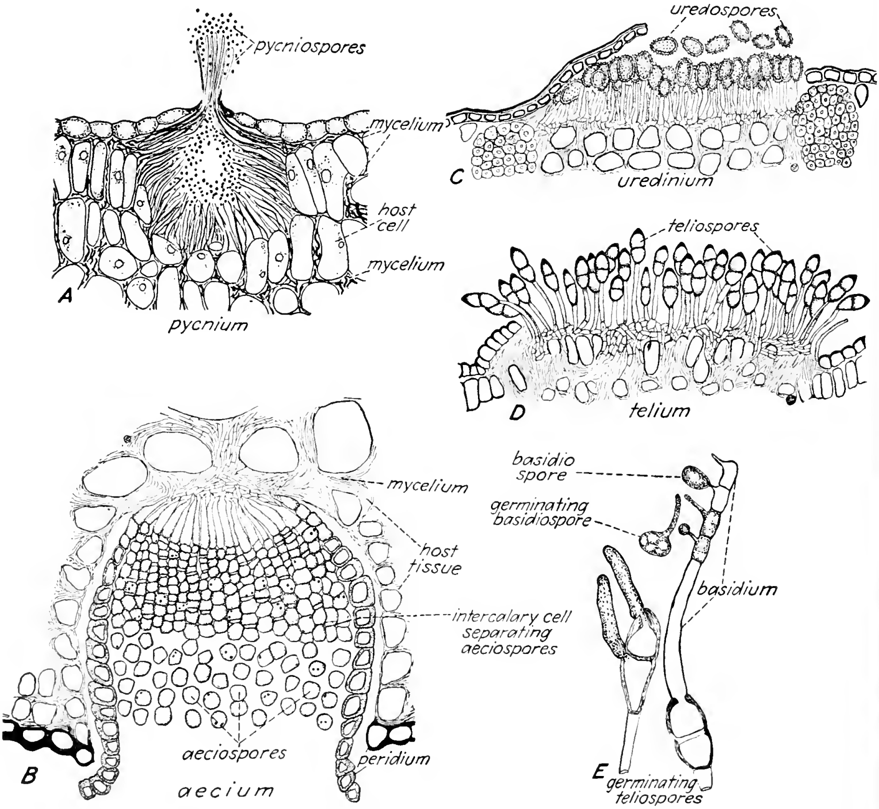


Fig. 67.—Wheat rust *(Puccinia graminis). A,* Section of leaf through a pycnium; *B,* section through an aecium in a barberry leaf; *C,* section through a uredinial sorus, showing unicellular, rough uredospores on slender stalks; *D,* section through a telial sorus, showing two-celled teliospores on long pedicels; *E,* germinating teliospores—*left,* both cells of the spore germinating; *right,* only the apical cell germinating; the germ tube has been transformed into a basidium, from each cell of which a basidiospore has been or is being formed. A germinating basidiospore is also shown. (By permission from Botany, by Hill, Overholts, and Popp. Copyright, 1950. McGraw-Hill Book Company, Inc.)

Common rusts include the cedar-apple rust which parasitizes cedars and spends the rest of the year on apple trees or hawthorns; the white pine blister rust in which the fungus alternates between the white pine tree and wild gooseberries and currants. Other rusts cause diseases of corn, oats, rye, pears, cherries, plums, peaches, various cone-bearing trees, many types of garden vegetables, cultivated flowers, and many other types of economically important plants.

QUESTIONS AND TOPICS

1. Review the general characteristics of the thallophytes (Subkingdom Thallophyta).
2. List the distinguishing characteristics by means of which the following phyla may be differentiated: *Schizomycophyta, Myxomycophyta,* and *Eumycophyta.*
3. Why are slime molds considered as plants? What animal characteristics do they possess?
4. Describe the life cycle of a typical slime mold.
5. List all the ways you can in which fungi affect man in one way or another.
6. Give reasons why you consider fungi to be higher or lower types of plants than algae.
7. List and describe each of the asexual methods of reproduction found in fungi.
8. Describe the process of conjugation found in certain fungi. In what ways does this process resemble sexual reproduction? In which fungi do you find conjugation?
9. Define and give the derivation of each new term encountered in this chapter.
10. Describe the ways in which sunlight and dry air may be detrimental to fungi.
11. Explain how fungi secure their nourishment and oxygen.
12. Diagram the life cycle of *Rhizopus nigricans.* Why are the gametes of this algalike fungus not considered to be true eggs and sperms?
13. Explain how bread molds on the inside of the loaf. What is the source of the mold?
14. Why are bacteria considered to be plants? Why are they classed as fungi?
15. List all the ways in which bacteria may be (1) beneficial and (2) harmful.
16. Contrast and give examples of heterotrophic and autotrophic nutrition.
17. List the distinguishing characteristics of the following classes of the true fungi: *Phycomycetes, Ascomycetes,* and *Basidiomycetes,* including examples of each class.
18. Diagram a typical life cycle of each class of true fungi *(Eumycophyta).*
19. Why are yeasts classed as Ascomycetes? In what ways do yeasts differ from other Ascomycetes?
20. Why are *Penicillium* and *Aspergillus* classed as Ascomycetes? Of what economic importance are these two fungi?
21. Contrast the structure of asci and basidia.
22. Describe the life cycle of the black stem rust of wheat, including the various hosts, stages, types of spores, damages, etc.
23. Why are the sporophores of many fungi borne upright?

24. Do any of the fungi produce multicellular embryos? Do any of them possess plastids and chlorophyll?
25. Do all cells of fungi possess nuclear materials? Do they all possess an organized nucleus?
26. Describe the increase in complexity of structures and methods of reproduction as we proceed from the simpler to the higher types of fungi.
27. List all conclusions you can logically draw from your study of fungi.

SELECTED REFERENCES

Allen, Holtman, and McBee: Microbes Which Help or Destroy Us, The C. V. Mosby Co.
Bessey: Textbook of Mycology, The Blakiston Co.
Birkeland: Microbiology and Man, Appleton-Century-Crofts, Inc.
Christensen: Common Edible Mushrooms, University of Minnesota Press.
Clifton: Introduction to Bacteria, McGraw-Hill Book Co., Inc.
Conant et al.: Manual of Clinical Mycology, W. B. Saunders Co.
Dodge: Medical Mycology, The C. V. Mosby Co.
Fitzpatrick: The Lower Fungi (Phycomycetes), McGraw-Hill Book Co., Inc.
Frobisher: Fundamentals of Bacteriology, W. B. Saunders Co.
Greaves and Greaves: Elementary Bacteriology, W. B. Saunders Co.
Jordan and Burrows: Textbook of Bacteriology, W. B. Saunders Co.
Krieger: Mushroom Handbook, The Macmillan Co.
Henrici and Ordal: The Biology of Bacteria, D. C. Heath & Co.
Henrici et al.: Molds, Yeasts, and Actinomycetes, Henry Holt & Co., Inc.
Large: The Advance of Fungi, Henry Holt & Co., Inc.
Lewis and Hopper: Introduction to Medical Mycology, Year Book Publishers, Inc.
Lindegren: The Yeast Cell, Educational Publishers, Inc.
Nickerson et al.: Biology of Pathogenic Fungi, Chronica Botanica Co.
Rahn: Microbes of Merit, Jacques Cattell Press.
Rice: Textbook of Bacteriology, W. B. Saunders Co.
Sallee: Fundamental Principles of Bacteriology, McGraw-Hill Book Co., Inc.
Singer: The Agaricales (Mushrooms), Chronica Botanica Co.
Smith et al.: Manual of Phycology, Chronica Botanica Co.
Stitt, Clough, and Branham: Practical Bacteriology, Hematology and Parasitology, The Blakiston Co.
Thomas: Fieldbook of Common Mushrooms, G. P. Putnam's Sons.
Waksman: Microbial Antagonisms and Antibiotic Substances, Commonwealth Fund.
Waksman: Principles of Soil Microbiology, Williams & Wilkins Co.
Wolf and Wolf: The Fungi, 2 vols., John Wiley & Sons, Inc.

Chapter 11

MOSSES AND THEIR ALLIES—BRYOPHYTES (PHYLUM BRYOPHYTA)

INTERMEDIATE PLANTS WITH CHLOROPHYLL; WITHOUT TRUE LEAVES, STEMS, OR ROOTS; WITHOUT VASCULAR (CONDUCTING) TISSUES; FORMING MULTICELLULAR EMBRYOS (SUBKINGDOM EMBRYOPHYTA)

GENERAL CHARACTERISTICS OF BRYOPHYTES

1. The members of the phylum *Bryophyta* (bri -of′ i ta) (Gr. *bryon,* moss; *phyta,* plants) are *terrestrial plants,* although they *require considerable moisture for growth* and *fertilization.*

2. In general, the adult plant body of Bryophytes is composed of blocks, or sheets, of cells forming a *parenchymatous tissue,* in contrast to the simple construction of the Thallophytes. The adult plant body of Bryophytes is never filamentous, but the developmental, protonema stage of mosses may be filamentous.

3. The gamete-producing sex organs, the *gametangia* (gam e -tan′ ji a) (Gr. *gametes,* spouse or gametes; *anggeion,* vessel), are *multicellular* and possess a protective *layer of sterile cells,* while the gametangia of Thallophytes are unicellular (few exceptions).

4. *Water is required for fertilization* in Bryophytes, as in most algae.

5. All Bryophytes possess an *alternation of generations* between the gamete-producing *gametophyte generation* and the spore-forming *sporophyte generation.* The latter is more or less dependent on the gametophyte.

6. Bryophytes develop a *multicellular embryo* from the *zygote* (fertilized egg), from which the sporophyte develops.

7. *No asexual spores* are produced by Bryophytes.

8. *Asexual reproduction* may occur by *fragmentation* of the plant, or by special bodies known as *gemmae* (jem′ i) (L. *gemma,* bud).

9. Bryophytes are *without true vascular (conducting) tissues* such as phloem and xylem.

10. Bryophytes, including mosses and liverworts, possess *chlorophyll* in *chloroplasts* for the purpose of *photosynthesis.*

11. Mosses and liverworts *possess similar methods of reproduction and life cycles* and are *much alike structurally and functionally* in spite of differences which may be apparent upon casual observation.

12. True mosses belong to the subkingdom *Embryophyta,* the phylum *Bryophyta,* and the class *Musci* (mūs′ si) (L. *muscus,* moss).

13. Liverworts belong to the subkingdom *Embryophyta,* the phylum *Bryophyta,* and the class *Hepaticae* (he -pat′ i se) (L. *hepaticus,* liver).

TRUE MOSSES

1. **Polytrichum** (po -lit′ ri kum) (Gr. *polys,* many; *thrix,* hair) is a common, true moss known as the *hairy cap moss.* Mosses are *small terrestrial plants* which require a certain amount of *moisture for growth and fertilization processes.* They usually grow so densely as to form a *mass of vegetation.* Each individual plant consists of a *stemlike axis* to which are attached *small, leaflike appendages* (not true stems or leaves because of the absence of the vascular tissues, phloem and xylem) (Fig. 45). Rootlike *rhizoids* absorb materials and anchor the plants.

Several male *antheridia* (an the -rid′ i a) (Gr. *anthos,* flower; *idion,* diminutive) are borne in a cluster at the tips of certain stemlike axes, while several female *archegonia* (ar ke -go′ ni a) (Gr. *arche,* beginning; *gonos,* offspring) are borne at the tips of other stemlike axes. *Polytrichum* has its sexes in separate plants, being *diecious* (di -e′ si us) (Gr. *dis,* two; *oikos,* house). In other species of mosses the antheridia and archegonia are borne on the same plant, being *monecious* (bisexual).

In *Polytrichum* the *antheridia* are separated by multicellular, sterile hairs called *paraphyses* (pa -raf′ i sez) (Gr. *para,* beside; *physis,* growth), and both are surrounded by a rosette of leaflike appendages which may be colored and resemble a "flower." Each antheridium consists of a short *stalk* and an enlargement which produces *unicellular male sperms.* The sperms are *coiled,* bear *two long, terminal flagella,* and escape from the apex of the antheridium.

The female *archegonia* are separated by *paraphyses,* and each archegonium has a *stalk* supporting an enlarged *venter* which surrounds the *egg.* When mature, a *canal* leads through the long *neck* to the venter. During fertilization the motile sperm swims through water from the antheridium to the female plant. It travels down the canal to the venter where a sperm and egg fuse by the fertilization process known as *oogamy* (o -og′ a mi) (Gr. *oon,* egg; *gamos,* marriage). In oogamy the two gametes are unlike and the egg is stationary. The fertilized egg, known as a *zygote,* is retained in the venter where it forms an *embryo* by numerous cell divisions. The embryo is parasitic on the female gametophyte plant, being given water, food, and protection. The embryo then grows to form a new plant known as the *sporophyte* (spor′ o fite) (Gr. *sporos,* spore; *phyta,* plants). A sporophyte consists of a *foot,* which is attached to the female plant, and a stalklike *seta,* at whose tip is a spore case or *sporangium* (spor -an′ ji um) (Gr. *sporos,* spore; *ang-geion,* vessel). The *sporangium* or *capsule* is covered with a hairy cap or *calyptra* (ka -lip′ tra) (Gr. *kalyptra,* covering); hence the common name of hairy cap. When the calyptra is removed, a lidlike *operculum* (o -per′ ku lum) (L. *operculum,* lid) is observed to cover the capsule. Beneath the operculum is a ring of hygroscopic *teeth* known as the *peri-stome* (per′ i stom) (Gr. *peri,* around; *stoma,* opening). The teeth are affected by moisture, and their movements expel the *spores* from the capsule. When immature, the *capsule* contains *spore mother cells,* each of which undergoes reduction division (meiosis) and produces four spores. The four spores of each tetrad are of two kinds. One kind contains a small, *Y chromosome* (sex chromosome) and produces a male plant; the other kind contains a large, *X chromosome* and produces a female plant. This method of sex determination is similar to that in man in which there are also X and Y chromosomes.

Each spore germinates to form a threadlike, branched *protonema* (pro to -ne′ ma) (Gr. *protos,* first; *nema,* thread). The cells of the protenema bear *chloroplasts* with which to photosynthesize food. *Rhizoids* anchor the young plant and absorb materials from the soil. *Buds* appear on the protonema, and these, by cell divisions, produce a new male or female moss plant. There is an *alternation of generations* between the gametophyte plant and the sporophyte plant. Under certain conditions some mosses may reproduce asexually by a *fragmentation* of the plant or by the formation of special bodies known as *gemmae* (jem′ i) (L. *gemma,* bud).

2. **Sphagnum** (sfag′ num) (Gr. *sphagnos,* moss) is the name of a genus to which belong the peat or bog mosses which are common inhabitants of bogs, ponds, and other wet places. Their life cycles are similar to that of *Polytrichum.* The upright, branched *axis* may be one foot long and bears *leaflike appendages* ("leaves") (Fig. 46). The latter contain two types of cells—one for *water storage* and the other containing *chloroplasts*

for *photosynthesis* purposes. The water storage cells are large and empty and have openings to the outside. *Sphagnum* can absorb water up to twenty times its weight.

Depending on the species, male *antheridia* and female *archegonia* may be present on the same plant (but different branches) or on different plants. The *fertilized egg (zygote)* develops into a *sporophyte* which has a *base* embedded in the gametophyte, a short stalklike *seta,* and an enlarged capsule. Because of the short seta, the gametophyte develops a structure known as the *pseudopodium* (su do -po′ di um) (Gr. *pseudes,* false; *pous,* foot) at the base of the foot in order to elevate the spore-producing capsule above the gametophyte. *Alternation of generations* similar to that described above takes place. Unlike *Polytrichum,* when a spore germinates, it forms a thin, lobed, platelike *prothallus ("protonema"). Sphagnum* may frequently reproduce by *fragmentation.*

Sphagnum and other mosses grow on the edges of ponds and lakes where they may gradually fill in the entire body of water. During this process of filling in there may be masses of floating mosses. The water of such bogs is apparently antiseptic because many things have been preserved for years in such bog water. This antiseptic property is utilized when *Sphagnum* is used for surgical dressings. In addition, the water absorption properties are useful in this connection.

Sphagnum is also utilized in gardening to keep the soil porous and to increase the water-retaining capacity. Because of the water-holding abilities, it is used by florists in packing cut flowers, in the development of seedlings, etc. *Sphagnum* and other mosses have accumulated in bogs and swamps in the past where they have slowly decomposed and become compacted and carbonized. This process has produced peat which is a valuable fuel. Vast deposits of peat in the United States could be used in place of coal.

LIVERWORTS

1. **Marchantia** (mar -kan′ shi a) (after the French botanist, Marchant, who died in 1678) is the genus to which belong the *flat, lobed, thalloid liverworts* commonly found prostrate on moist rocks and soil along streams. These plants are called liverworts because of their fancied resemblance to the lobed liver of higher animals.

The surface of the branched thallus body possesses *rhomboidal areas,* each of which has a *pore* in its center for the exchange of gases. Internally, the thallus has *air chambers* and *columns of cells* containing *chloro-*

plasts for *photosynthesis.* Rootlike *rhizoids* anchor the thallus and absorb materials from the substratum (Fig. 43).

Marchantia is *diecious,* one thallus bearing male *antheridia* and another thallus bearing female *archegonia.* On the male thallus (male gametophyte) arise the stalklike *antheridiophores* with *lobed disks* at the tip. The male *antheridia* are borne in *cavities* which open on the *upper surface of these disks.* Each antheridium is an enlarged, oval structure which produces *coiled, biflagellated sperms (gametes)* (Fig. 43).

On the female thallus (female gametophyte) arise the stalklike *archegoniophores* with *small, terminal disks* bearing *fingerlike rays* (Fig. 43). The female *archegonia* are borne on the *undersurface of these disks.* Each archegonium has a hollow, tubular *neck* and an enlarged *venter* with a single *egg (ovum)* at the base of the latter.

The sperm swims through the water from the antheridium to the venter of the archegonium where the sperm and egg fuse *(fertilize)* to form a *zygote.* The latter through numerous cell divisions forms a *multicellular embryo* from which develops the spore-producing *sporophyte.* The latter consists of a foot embedded in the disk of the female gametophyte, a *seta,* and a *capsule (sporangium).* The latter produces numerous *spores.* Elongated, spiral-shaped, hygroscopic *elaters* (el′ a ter) (Gr. *elater,* driver) are affected by moisture and expel the spores from the capsule. The spores germinate to form new male or female gametophytes (thalli).

There is an *alternation of generations* between the gamete-producing *gametophyte* and the spore-forming *sporophyte* which is quite similar to that in true mosses. Unlike the moss sporophyte, the Marchantia sporophyte does not possess stomata (stom′ a ta) (Gr. *stoma,* opening) and is usually smaller than in most mosses. *Marchantia* may also reproduce *asexually* by the formation of special bodies known as *gemmae* (jem′ i) (L. *gemma,* bud) in little *gemma cups* or by the process of *fragmentation.*

2. **Porella** (por -el′ a) is a common *leafy liverwort* (Fig. 44) which may form a green mass on moist soil, rocks, or rotten wood. Some species of leafy liverworts may grow on tree trunks in damp forests. Some species may resemble true mosses, but the liverworts are prostrate on their substratum.

Porella has *three rows of leaflike structures* attached to a *stemlike axis.* The latter may be branched and is attached by *rhizoids.* The leaflike structures are much simpler than the gametophyte of *Marchantia,* consisting of *one layer of cells* and without a midvein. The sporophyte of

Porella is similar to that of *Marchantia,* consisting of a *foot, stalk,* and *sporangium (capsule).* The latter bears *spores* and *elaters* as in the thalloid liverworts.

QUESTIONS AND TOPICS

1. List the characteristics of (1) *Embryophyta,* (2) *Bryophyta,* (3) *Hepaticae,* and (4) *Musci.*
2. Learn the pronunciation, derivation, and a definition of each new term used in this chapter.
3. Discuss the economic importance of bryophytes.
4. Contrast gametophytes and sporophytes in as many ways as possible as illustrated by the bryophytes.
5. Make a diagram of a true moss life cycle showing the stages in correct sequence and the chromosome numbers in the gametophyte and sporophyte generations.
6. Make a diagram of a liverwort life cycle showing the stages in correct sequence and the chromosome numbers in the gametophyte and sporophyte generations.
7. Why are the axes, "leaves," and rhizoids not considered to be true stems, leaves, and roots?
8. Why are the mosses and their allies classed as Embryophytes?
9. Why are the bryophytes considered not to have true vascular (conducting) tissues?
10. In what ways do the leafy liverworts resemble certain mosses?
11. In what ways do the leafy liverworts differ from the thalloid liverworts?
12. How do the gametangia of *Bryophyta* differ from the gametangia of *Thallophyta?*
13. Why do the bryophytes require a considerable amount of moisture?
14. List some of the more important values of *Sphagnum* mosses.
15. Explain why most bryophytes are rather short plants, giving specific reasons because of structures, growing conditions, etc.
16. Describe the structure and functions of elaters.
17. Describe differences in structures of the zygote developments in the mosses and in the liverworts. (Contrast protonema and prothallus.)
18. Describe the method of determination of sex in bryophytes. In what ways are these methods similar to the sex determination methods in man?

SELECTED REFERENCES

Conard: How to Know the Mosses, William C. Brown Co.
Evans: Classification of the Hepaticae, Botanical Review 5: 49-96, 1939.
Grout: Mosses With a Hand Lens, A. J. Grout, Newfane, Vt.
Grout: Mosses With a Hand Lens and Microscope, A. J. Grout, Newfane, Vt.
Smith: Cryptogamic Botany (vol. 2): Bryophytes and Pteridophytes, McGraw-Hill Book Co., Inc.
Verdoorn et al.: Manual of Bryology, Chronica Botanica Co.

Chapter 12

FERNS AND THEIR ALLIES

HIGHER PLANTS WITH CHLOROPHYLL; WITH TRUE LEAVES, STEMS, AND ROOTS; WITH VASCULAR TISSUES (PHLOEM AND XYLEM); WITHOUT SEEDS; FORMING MULTICELLULAR EMBRYOS (SUBKINGDOM EMBRYOPHYTA)

GENERAL CHARACTERISTICS OF FERNS AND THEIR ALLIES (CLUB "MOSSES" AND HORSETAILS)

1. Ferns and their allies belong to the subkingdom *Embryophyta* because they form *multicellular embryos* and to the phylum *Tracheophyta* because they possess *true vascular tissues* of varying degrees of complexity.

2. The phylum *Tracheophyta* includes such subphyla as (1) *Lycopsida* (club "mosses") having simple vascular tissues, small, green leaves, usually spirally arranged, and branched stems and roots, (2) *Sphenopsida* (horsetails), having a simple vascular system, small leaves in whorls (sometimes scalelike), jointed, and hollow stems which are usually roughened by ribs and silica, and (3) *Pteropsida* (ferns), having a rather complex vascular system and usually large, conspicuous leaves.

3. Tracheophytes possess *true leaves, stems, and roots, skeletal materials* for upright growth, *stomata* for the exchange of gases, and a protective layer of *cutin*.

4. Club "mosses," horsetails, and ferns have somewhat similar methods of reproduction and life cycles.

5. The *gametangia* (sex organs) are *multicellular,* as in the Bryophytes, but in contrast to the unicellular sex structures of the Thallophytes.

6. Tracheophytes possess an *alternation of generations* in which a gamete-producing *gametophyte generation* alternates with a spore-forming *sporophyte generation.*

7. The *gametophyte* bears characteristic multicellular sex organs known as the male *antheridia* and the female *archegonia.*

8. The *sporophyte* is *relatively large and independent* (with true leaves, stems, and roots), while the *gametophyte* is usually *rather small and inconspicuous* (contrast with bryophytes).

9. In ferns and their allies the *multicellular sporangia* (spore cases) are usually borne on leaves so that such *sporophylls* are an important characteristic.

10. In certain species the *sporophylls* bear *sporangia* in which the *spores are all alike (homosporous);* in others there are *two kinds of sporophylls, two kinds of sporangia,* and *two kinds of spores (heterosporous).*

11. *Sporangia* may (1) be borne in *clusters (sori),* as in ferns, (2) occur in groups of 5 to 10 upon shield-shaped sporangiophores to form conelike *strobili,* as in horsetails, or (3) occur singly on the upper surface of the sporophylls to form a clublike *strobilus,* as in club "mosses."

12. *Spores* germinate to form different types of young gametophytes: (1) colorless, rather bulky *prothalli* with male antheridia and female archegonia in club "mosses," (2) thin, green, *irregular gametophytes,* with antheridia and archegonia in horsetails, (3) small, thin, green, heart-shaped *prothalli* with antheridia and archegonia in ferns.

CLUB "MOSSES"

1. **Lycopodium** (laik o -po′ di um) (Gr. *lykos,* wolf; *pous,* foot).—The club "mosses" belong to the subkingdom *Embryophyta* because they produce *multicellular embryos,* to the phylum *Tracheophyta* because they possess *true vascular tissues,* and to the subphylum *Lycopsida* (laik -op′ si da) (Gr. *lykos,* wolf; *opsis,* appearance).

Plants belonging to the genus *Lycopodium* (Fig. 47) are small and are commonly called *club "mosses"* because of the *mosslike leaves* and the *club-shaped cones (strobili)* borne on stalks. They are also referred to as *"ground pines"* because of their *prostrate, creeping habits* and their resemblance to *evergreen, miniature pine trees.* The *main stem (rhizome)* is prostrate on the ground and is branched. It possesses *roots* and sends up numerous upright *stems,* usually about eight inches tall. The upright stems bear *small, green leaves,* usually spirally arranged. *Lycopodium* possesses a *simple vascular system* consisting of alternate strands of *phloem* (sieve tubes and companion cells) and *xylem* (tracheids). *Stomata* occur on the leaves and stems for the exchange of gases.

Sporangia-bearing leaves are known as *sporophylls.* In some species the single *sporangia* are borne on leaves which may be located on any part of the stem. In other species the sporophylls are concentrated at the tips of the branches to form conelike *strobili.* The *spores* are *all* *alike (homosporous)* and are wind disseminated. A spore germinates to form a colorless, rather lumpy *prothallus* (young gametophyte) which is usually in the soil. In some cases a small part of the inconspicuous gametophyte is above the ground and is green.

Male *antheridia* and female *archegonia* similar to those of the Bryophytes are embedded on the upper surface of the gametophyte. *Rhizoids* anchor the gametophyte. The *antheridia* produce *biflagellated sperms* (like those of true mosses) that swim to the *egg* which is fertilized to form a *zygote.*

By cell division the zygote forms two cells, one of which forms a *suspensor* which pushes the embryo into the food tissues of the gametophyte. The other cell forms the *multicellular embryo* which develops into a young, leafy *sporophyte.* The latter remains as a temporary parasite on the gametophyte. The embryo forms a special organ called the *foot* which acts as an absorbing organ. A *root* forms and the gametophyte tissues eventually decay, thus leaving the herbaceous sporophyte independent.

The various species of *Lycopodium* are common plants of forests and mountains. They are widely used in the preparation of decorations, wreaths, and other articles where the evergreen stems can be used.

2. **Selaginella** (sel i ji -nel′ a) (L. *selago,* shrubby plant).—The delicate, perennial, smaller club "mosses" belong to the genus *Selaginella* (Fig. 48) and are widely distributed but are most abundant in the tropics. One species of *Selaginella,* known as the "resurrection plant," can withstand dry conditions in southwestern United States by rolling up into a ball. Other specimens are grown as ornamental plants in greenhouses.

Most species of *Selaginella* are usually creepers, although a few are erect. The *stems* are branched, with tiny, green, triangular, stomata-bearing *leaves,* usually in four rows. *Roots* anchor the plant and absorb materials. The *vascular system* is rather simple and varies with the species. At the base of each leaf is a membranous *ligule* (lig′ ul) (L. *ligula,* little tongue) of unknown function but of value in differentiating *Selaginella* from *Lycopodium* which lacks this structure.

Cones at the tips of the branches are composed of spore-producing *sporophylls.* In a cone the upper surface of each *microsporophyll* has in its axil (upper angle) a small *microsporangium* which produces many small *microspores.* The larger *megasporophylls* produce *four large megaspores* in each *megasporangium* located in the axil. Frequently, the microsporophylls are located toward the tip of the cone, while the megasporophylls are located below, but on the same cone. Since *Selaginella* produces two kinds of spores (microspores and megaspores), it is *heterosporous.*

A *megaspore* germinates to form a *megagametophyte* (female gametophyte) within the megaspore while still in the megasporangium. As the megagametophyte develops, it forms several female *archegonia, rhizoids, stored foods,* and *chlorophyll.*

A *microspore* develops within the microsporangia to form a small, parasitic *microgametophyte* (male gametophyte). The latter is surrounded by the microspore wall and consists of *one prothalial cell* and one male *antheridium.* No chlorophyll is formed. The antheridium produces *biciliated sperms.*

When the microsporangial walls rupture, the *microspores* are carried to the *megasporangia.* The sperm swims to the *archegonium* where the *egg* is *fertilized* to form a *zygote.* By cell division, the latter forms two cells, the upper one becoming a *suspensor* to push the embryo into contact with the stored foods of the megagametophyte. The other cell of the zygote develops into the *embryo.* The latter develops a mass of cells known as the *foot* by which foods are absorbed from the megagametophyte. Eventually, the embryo produces a *stem, root,* and *two cotyledons* (embryonic "seed" leaves). Later this young *sporophyte* becomes independent by photosynthesizing its own food. The production of a suspensor by the zygote is somewhat similar to a phenomenon in the higher seed-producing plants.

HORSETAILS (SCOURING RUSHES)

Equisetum (ek wi -se′ tum) (Gr. *equus,* horse; *seta,* tail).—The horsetails belong to the subkingdom *Embryophyta:* phylum *Tracheophyta;* subphylum *Sphenopsida* (sfen -op′ si da) (Gr. *sphen,* wedge; *opsis,* appearance) because of the wedge-shaped leaves of certain species. All horsetails belong to the genus *Equisetum* (Fig. 49) which has the following characteristics: *hollow, jointed stems,* usually ribbed and containing silica, *branches and small leaves* (sometimes scalelike) *in whorls,* and *strobili (cones)* composed of whorls of shield-shaped *sporangiophores,* each of which bears five to ten *sporangia* (spore cases).

The *sporophyte* of *Equisetum* consists of a branched horizontal *rhizome* with *nodes.* The latter bear whorls of scalelike leaves. In most species, the rhizomes bear (1) upright, colorless, unbranched *fertile stems* with a *strobilus* at each tip and (2) upright, green, bushy *vegetative (sterile) stems* with many whorled branches at the nodes. Because of the rough, silica-bearing stems, they may be used for scouring purposes and are commonly known as scouring rushes. The *vascular system* consists of vascular bundles composed of phloem and xylem.

The terminal *homosporous strobili (cones)* consist of whorls of shield-shaped (umbrella-like) *sporangiophores,* each of which bears five to ten elongated, saclike *sporangia* (spore cases). The *spores* possess *four elators* which are ribbon shaped and hygroscopic. The elators respond to differences in moisture and may assist in spore dispersal (Fig. 49).

Germinating spores form small, green, irregularly lobed, thalloid *gametophytes.* These bear *rhizoids* and usually both male *antheridia* and female *archegonia.* The antheridium produces *coiled, multiflagellated sperms* which swim to the *egg* in the *archegonium* where *fertilization* produces *a zygote.* The latter develops into an *embryo* from which a new *sporophyte* with its leaves, stems, and roots is formed. Hence, there is an *alternation of generations* (Fig. 49).

FERNS

1. **Pteridium** (te -rid′ i um) (Gr. *ptero,* wing or feather).—The ferns belong to the subkingdom *Embryophyta;* phylum *Tracheophyta;* subphylum *Pteropsida* (ter -op′ si da) (Gr. *pteris,* wing, or feather; *opsis,* appearance) because of the winglike or featherlike appearance of certain species.

The *brake ferns (brackens) (bracken,* fern*)* are common species in temperate regions and many belong to the genus *Pteridium* (Fig. 50). The slender, *underground stem (rhizome)* continues to grow at its anterior end, while it dies at the opposite end. It may even separate into pieces, thus producing independent plants. The underground stem is quite well developed, consisting of internal parenchyma cells, mechanical tissues, vascular bundles (with phloem and xylem), and epidermis (Fig. 69). Long, slender *roots* arise from the underground stem. A young *leaf* arises from the stem as a tightly coiled structure which pushes through the soil. When in the air it uncoils and continues to grow to form a slender, central *petiole* and a much-divided *blade.* The entire leaf of a fern is referred to as a *frond* (L. *frons,* leaf), and the small leaflets are called *pinnae* (L. *pinnae,* feather) (Fig. 68). In general, the internal structure of the leaf is similar to that of higher plants, being composed of epidermis, stomata, guard cells with chlorophyll, veins, spongy tissue, and a palisade layer.

Certain of the green leaves of a bracken bear numerous *sporangia* (spore cases) on the edge of the undersurface of each leaflet. Such spore-producing, green leaves are called *sporophylls* (Fig. 68). All the common ferns produce one type of *spore* and are therefore ***homosporous.*** When sporangia are grouped in clusters, they are known as *sori* (Gr. *soros,* heap). Each sporangium consists of a *capsule* borne on a *stalk.*

Fig. 68.—Fruiting fronds of various ferns showing the ways in which spores are produced. *1,* Sensitive fern; *2,* cinnamon fern; *3,* climbing fern; *4,* common grape fern; *5,* common polypody fern *(Polypodium)*; *6,* bracken fern *(Pteridium)*; *7,* maiden hair fern; *8,* common chain fern; *9,* Christmas fern; *10,* spinulose shield fern; *11,* common bladder fern; *12,* obtuse woodsia fern; *13,* boulder fern; *14,* walking fern; *15,* ebony spleenwort fern. (Copyright by General Biological Supply House, Inc., Chicago.)

The capsule wall contains a row of special, moisture-sensitive cells known as the *annulus* (an′ u lus) (L. *annulus,* ring). The walls of the annulus cells are thicker on one side and, when affected by moisture, tend to straighten the annulus, thus throwing the spores from the ruptured capsule.

Within the capsule are formed *spore mother cells,* each of which forms *four spores,* as in the true mosses. At this time the chromosome number is reduced from 2N to N. When the spores are shed in late summer, they germinate to form a flat, green, heart-shaped *prothallus* (prothallium) with a *notch* at its anterior end. *Rhizoids* anchor the prothallus and absorb water and nutrients. The prothallus matures to form a *gametophyte* which may not be over one-fourth inch in diameter. The same gametophyte may produce male *antheridia* and female *archegonia* on its lower surface.

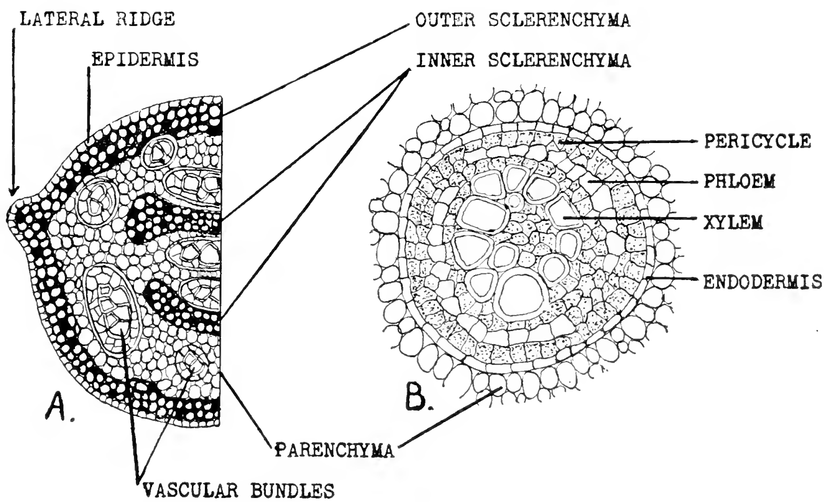


Fig. 69.—Rhizone (underground stem) of bracken fern. *A,* one-half of rhizone shown in cross section; *B,* a vascular bundle highly magnified.

The *antheridia* may form on nearly any part of the undersurface, but usually they are more numerous on the older, posterior part where the rhizoids are most abundant. *Archegonia* are usually limited to the area just back of the notch. Each antheridium is small and dome shaped. Internally there are formed numerous, *spiral, multiflagellated sperms* (antherozoids). Each archegonium is small and simpler than it is in liverworts and true mosses. It consists of an enlarged *venter,* a *neck* with a *canal,* and an *egg* within the venter.

During *fertilization* one sperm unites with the egg to form a *zygote* which develops into a parasitic *embryo* within the venter. The embryo becomes four lobed and forms the young sporophyte. The lobes develop into four structures: a temporary *foot* (absorb food), *primary root, stem,* and *primary leaf.* Although male antheridia and female archegonia are present on the same gametophyte, most of the antheridia develop and discharge their sperms before the eggs are mature in the archegonia of the same plant. Hence, cross-fertilization between different plants usually occurs. The life cycle of the bracken shows *alternation of generations* between the independent sporophyte generation (with 2N chromosomes) and the independent gametophyte generation (with N chromosomes). A contrast between ferns and mosses may be observed below:

	SPOROPHYTE	GAMETOPHYTE
Moss	Relatively small Short lived	Relatively large and conspicuous May live for years
Fern	Large and conspicuous May live for years	Relatively small Short lived

2. **Polypodium** (pol i -po′ di um) (Gr. *polys,* many; *podion,* small foot).—The common *polypody ferns* of the genus *Polypodium* (Figs. 51 and 68) have rather simple but *lobed, leaf blades.* The thick *rhizome* is horizontal and possesses numerous slender, fibrous, adventitious (unusual) *roots.* Several *leaves (fronds)* arise from the rhizome. Dotlike aggregates of sporangia known as *sori* (Gr. *soros,* heap) are present on the undersurface of the leaves. The particular arrangement of the sori varies with the species. In many ferns each sorus is covered by a protective, membranous *indusium* (in -du′ zi um) (L. *induere,* to put on). Each sporangium consists of a thin-walled *capsule* borne on a *stalk.* A hygroscopic *annulus* is composed of a band of moisture-sensitive cells. Some of the walls of the annulus cells are thick, while the other walls are thin. Their response to moisture changes causes the annulus to bend, thus hurling the spores from the capsule.

QUESTIONS AND TOPICS

1. List the characteristics of (1) the phylum *Tracheophyta,* (2) subphylum *Pteropsida,* and (3) class *Filicineae.*
2. Learn the pronunciation, derivation, and meaning of each new term used in this chapter.
3. Discuss the economic importance of ferns, horsetails, and club "mosses."
4. Explain how the sporophytes and gametophytes differ in ferns, horsetails, and club "mosses."
5. Make a diagram of a typical fern life cycle showing the stages in correct sequence and the chromosome numbers in the sporophyte and gametophyte generations.

6. Why are the leaves of ferns and their allies considered to be true leaves?
7. Why are ferns and their allies classed as Embryophytes?
8. Why are the ferns and their allies considered to have true vascular tissues?
9. Contrast the sporophytes and gametophytes of ferns with those of true mosses.
10. In what ways are the gametangia (sex organs) of Tracheophytes similar to those of the Bryophytes but different from those of the Thallophytes?
11. Describe the structure and function of stomata.
12. Describe the type of young gametophyte formed from a germinating spore in club "mosses," horsetails, and ferns.
13. Describe how the multicellular sporangia are borne in ferns, horsetails, and club "mosses."
14. Why is water necessary for fertilization in ferns?
15. Describe the structure and function of the annulus.
16. Compare the alternation of generations in ferns with a similar phenomenon in horsetails and club "mosses."
17. Describe the structure and function of the suspensor.
18. In what ways do *Lycopodium* and *Selaginella* differ?
19. In what ways do *Pteridium* and *Polypodium* differ?
20. Why must there be a reduction in the number of chromosomes previous to fertilization?
21. Describe the structure and function of the "foot."
22. Discuss the functions of spore mother cells.

SELECTED REFERENCES*

Bower: The Ferns (3 vols.), Cambridge University Press.
Durand: Field Book of Common Ferns, G. P. Putnam's Sons.
Small: Ferns of the Southeastern States, Science Press Printing Co.
Smith: Cryptogamic Botany (vol. 2): Bryophytes and Pteridophytes, McGraw-Hill Book Co., Inc.
Verdoorn: Manual of Pteridology, Chronica Botanica Co.
Wherry: Guide to Eastern Ferns, Science Press Printing Co.

*Also refer to textbooks in list of references on p. 149.

Chapter 13

GYMNOSPERMOUS PLANTS—CONIFERS AND THEIR ALLIES

HIGHER PLANTS WITH CHLOROPHYLL; WITH TRUE LEAVES, STEMS, AND ROOTS; WITH VASCULAR TISSUES; WITH EXPOSED (NAKED) SEEDS; FORMING MULTICELLULAR EMBRYOS (SUBKINGDOM EMBRYOPHYTA)

GENERAL CHARACTERISTICS OF GYMNOSPERMS

1. The gymnosperms belong to the subkingdom *Embryophyta;* the phylum *Tracheophyta;* subphylum *Pteropsida;* class *Gymnospermae* (jim-no-spur′ me) (Gr. *gymnos*, naked or exposed; *sperma*, seed) because the *seeds are produced on the exposed* (naked) *surface of the megasporophylls* and are not protected by an ovary wall, as in angiosperms.

2. Gymnosperms are usually *rather large, woody, perennial plants* which are mainly *evergreen* (retain leaves more than one growing season). Certain types may be short and shrubby.

3. Gymnosperms possess *true roots, stems, and leaves.* In the cone-bearing evergreens the leaves may be needlelike or scalelike.

4. The sporophyte generation is large, complex, and independent, while the gametophyte generation is much smaller (microscopic) and parasitic upon the sporophyte.

5. *Cones* composed of *sporophylls* are usually present; in the conifers, the male and female cones may be present on the same plant (*monecious*) or on different plants (*diecious*), depending upon the species.

6. *Ovules* (immature, undeveloped seeds) and *true seeds* are borne exposed (naked) on female *megasporophylls* (a single megaspore is retained within the megasporangium where the female megagametophyte develops). The sporophylls often form cones.

7. Two kinds of *spores* are formed (*heterosporous*); namely, *microspores,* which produce male microgametophytes, and *megaspores,* which produce female *megagametophytes.* (The two spores may be the same size or the microspores may even be larger than the megaspores, yet they produce different types of gametophytes.)

8. *Pollination* occurs by wind, the pollen grains landing near, or in, the micropyle (little opening) of the ovule and forming a pollen tube leading to the egg.

9. In gymnosperms, single fertilization occurs in which one sperm is involved in fertilizing the egg, in contrast to double fertilization as it occurs in the angiosperms (flowering plants).

10. In pine trees, the lapse of time between pollination and subsequent fertilization (actual union of the sex gametes) is a marked feature. For example, if pollination occurs in June, fertilization may not ordinarily occur until July of the next year. This time lapse varies with the species, locality, etc., but usually a year elapses between pollination and fertilization. After fertilization the seed develops rather rapidly, reaching maturity by the end of the year in which fertilization occurs.

11. Gymnosperms are considered to be higher plants than ferns, horsetails, and club "mosses" because (1) of the two kinds of cones which bear, respectively, male microsporophylls and female megasporophylls; (2) of a temporary retention of the developing microgametophytes (pollen grains) in the microsporangium; (3) of a retention of the megaspore and the megagametophyte in the megasporangium (nucellus); (4) of the direct parasitism of both male microgametophyte and female megagametophyte upon the large, conspicuous sporophyte; (5) of the development of a pollen tube and the establishment of the seed habit.

CONIFERS

Pine Tree (*Pinus*) (L. *pinus,* cone bearing) (Figs. 52 and 53).—The conifers belong to subphylum *Pteropsida,* class *Gymnospermae* (jim no-spur′ me) (Gr. *Gymnos,* naked; *sperma,* seed); order *Coniferales* (ko ni-fer-a′ lez) (L. *conus,* cone; *fero,* to bear) because most of them bear *cones composed of sporophylls* (sporangium-bearing leaves). There are over 500 species of conifers, including the various species of pine, spruce, fir, juniper, cedar, hemlock, larch, yew, cypress, redwoods, etc. The *leaves* are *simple* and are either *needlelike* or *scalelike.* Conifers are often referred to as "evergreens" because most of the leaves on many species remain throughout the year. A few, such as the bald cypress and larch (tamarack), are deciduous. All are *woody* and usually are trees, although some are shrubs. Some of the oldest and largest plants are conifers; for example, the giant sequoia trees of California may be over 30 feet in diameter, 300 feet tall, and 4,000 years old; the redwoods may be 15 feet in diameter, 300 feet tall, and 1,000 years old.

Pine trees have large, *branched stems,* and the *needlelike leaves* are borne in *clusters* on short, spurlike branches. The number of leaves per cluster (2 to 5) and the length of the leaves vary with the species.

In the pines, the male and female cones are borne on the same tree (monecious) (Fig. 52). In other conifers, the male and female cones may be borne on separate plants (diecious). The simple, *staminate (male) cones* are smaller than the female and are *borne in a group.* Each *male cone* is composed of *microsporophylls* which are spirally arranged and attached to a central axis. Each microsporophyll bears two *microsporangia* on the undersurface, in which are produced numerous *microspore mother cells,* each of which produces four *microspores (pollen grains).* Each pollen grain develops into a *microgametophyte* by producing two *prothallial cells* and an *antheridial cell.* The latter divides to form a *generative cell* and a *tube cell.* During this process a pair of *"wings"* forms on the four-celled pollen grain to assist in its dissemination by the wind, in some cases for hundreds of miles.

The *ovulate (female) cones* are larger than the male and usually are borne *singly.* Each *female cone* (Fig. 52) is composed of scalelike *megasporophylls* attached to a central axis. Each megasporophyll bears two *ovules* on its upper surface. An *ovule* consists of (1) an external, protective *integument* which has a *micropyle* (small opening) for the entrance of a pollen grain and (2) a central *megasporangium (nucellus).* When young, the *megasporangium* has one *megaspore mother cell* which produces four *megaspores,* three of which abort. The one megaspore develops into the female *megagametophyte* which contains two or three *archegonia.* Each archegonium contains an egg within a *venter.*

During *pollination* the wind carries the *pollen grains (microspores)* to the female cones, where pollen enters through the *micropyle* and contacts the *megasporangium (nucellus)* by means of a sticky liquid. The pollen grains form *pollen tubes* through the *nucellus* toward the *archegonia.* The *generative cell* and the *tube cell* pass through the pollen tube, and the former produces two, nonmotile *sperms (male nuclei).*

About one year after pollination the *fertilization process* occurs and consists of the fusion of one *sperm* with the *egg* within the *archegonium.* The resulting *zygote,* by cell division, eventually produces an *embryo* and *suspensor cells.* The latter force the embryo in contact with the food *endosperm* (transformed female megagametophyte). Later the embryo develops an *epicotyl* (ep i -kot′ il) (Gr. *epi,* upon: *kotyle,* vase or cup) and a *hypocotyl* (hi po -kot′ il) (Gr. *hypo,* under), which bears a number of primary, embryonic seed leaves known as *cotyledons* (kot i -le′ don)

(Gr. *kotyle,* cup or vase). The embryo is surrounded by the *endosperm* (food) which is covered by the *seed coat* (hardened integument). The seed thus formed was originally the ovule and contains a *wing* for wind dispersal. When a seed germinates, the embryo produces a young *seedling* which eventually develops into a pine tree (sporophyte generation). Since gymnosperms produce two different kinds of spores (microspores and megaspores), they are *heterosporous.*

Conifers are of great economic value, serving as sources of lumber for furniture, buildings, boxes, poles, railroad ties, etc., wood pulp for the manufacture of paper, and numerous other uses. Cedars and their allies are used in making shingles, pencils, cedar chests, etc. The balsam fir produces a resin from which Canada balsam is manufactured. The latter is used to affix coverglasses on slides permanently. Certain types of pines yield turpentine, rosin, pitch, and similar products.

CYCADS (SAGO PALMS)

Zamia (za′ mi a) (L. *zamia,* fir cone).—The cycads (sago palms) belong to the class *Gymnospermae* and the order *Cycadales* (sik a -da′ lez) (Gr. *kykas,* coco palm). They are palmlike trees or low shrubs with unbranched *stems,* terminating in a tuft of thick, pinnate (fernlike) leaves which are often spiny edged. In *Zamia* (Fig. 54), which occurs in Florida, the short, tuberous stem is not over four feet tall and bears a crown of leathery, *pinnate leaves.* Sometimes much of the stem is underground. In general, the cycads are inhabitants of the tropics or semitropics.

Zamia is *diecious* since male and female cones are borne on separate plants. The female *carpellate cones* are composed of *peltate* (shield-shaped) *megasporophylls,* each of which bears two *ovules,* with a *micropyle* (small opening) in the enclosing *integument.* In the center of the ovule is the *megasporangium (nucellus).* The latter contains one *megaspore mother cell* which produces four *megaspores,* three of which disintegrate. The nucleus of the remaining megaspore divides to form two nuclei, and further division results in numerous nuclei. Walls separate the nuclei, so this multicellular tissue becomes the *female megagametophyte* which produces two to six *archegonia.* Each archegonium consists of one large *egg* and a *neck.*

The male *staminate cones* are smaller than the female and consist of numerous *microsporophylls.* Each of the latter bears numerous (thirty to forty) *microsporangia* on the lower surface. Each microsporangium contains many *microspore mother cells* which produce many *microspores (pollen grains).* When still within the microsporangia, the nuclei of the pollen grains divide to form two, one of which produces a *prothallial cell* and one of which divides later to form (1) a *generative cell* and (2) a *tube cell.* These three-celled pollen grains (immature microgametophytes) are carried by the wind to the female cones where, because of a sticky liquid, they pass through the micropyle of the ovule to contact the nucellus. The *tube cell* forms a branched *pollen tube* through the nucellus by digesting the latter. The *generative cell* divides to form (1) a *body cell* and (2) a *stalk cell.* The body cell divides to form two large *multiflagellated (ciliated), motile sperms* (antherozoids). This unique characteristic of wind-pollinated plants is probaby an ancestral trait no longer needed.

About six months after pollination a sperm fuses (*fertilizes*) with an egg in the archegonium, forming a *zygote.* The latter develops (1) a multicellular *embryo,* (2) two *cotyledons* (primary, embryonic leaves), (3) *hypocotyl,* (4) *epicotyl,* and (5) a long, coiled *suspensor* to push the embryo in contact with the *endosperm* (food) of the megagametophyte. Thus the original *ovule* is changed into a *seed* with its *seed coat.* Upon germination the seeds develop either a staminate or a carpellate sporophyte. Certain portions of the stem contain starch and may be used as food.

QUESTIONS AND TOPICS

1. List the distinguishing characteristics of the subkingdom *Embryophyta,* the phylum *Tracheophyta,* the subphylum *Pteropsida,* and the class *Gymnospermae.*
2. Learn the meaning, pronunciation, and derivation of each new term used in this chapter.
3. Discuss the similarities between the conifers and the cycads. Discuss the ways in which they differ.
4. In what ways are gymnosperms considered to be higher plants than the ferns?
5. List the ways in which gymnosperms are of economic value.
6. Make a detailed diagram of the life cycle of the pine tree, including the various stages in correct sequence, with each labeled properly.
7. Do you consider the conifers to be higher or lower plants than the cycads? Why?
8. Considering the method of sexual reproduction in *Zamia,* do the sperm need to be motile (flagellated)? What explanation can you give for their motility?
9. In the conifers, the sperm lacks flagella. Of what significance is this?
10. Explain the phenomenon of alternation of generations in gymnosperms.
11. Explain the formation and function of the pollen tube.

12. Why would it not be desirable to have the pollen tube preformed rather than form it just as needed? Explain.
13. What are the chromosome numbers in the sporophyte and the gametophyte?
14. Why must there be a numerical reduction in the number of chromosomes previous to the union of the sperm and egg?
15. Explain what is meant by "evergreen."
16. Contrast and give an example of monecious and diecious.
17. Contrast between ovules and true seeds.
18. Contrast between pollination and fertilization, giving examples of each.
19. Explain why ovules and true seeds are said to be borne exposed (naked) and hence are gymnospermous.
20. Explain the significance of the phenomenon of heterospory.
21. Describe the structure and function of the micropyle.

SELECTED REFERENCES*

Bowers: Cone-bearing Trees of the Pacific Coast, McGraw-Hill Book Co., Inc.
Chamberlain: The Living Cycads, University of Chicago Press.
Chamberlain: Gymnosperms, Structure and Evolution, University of Chicago Press.
Eliot: Forest Trees of the Pacific Coast, G. P. Putnam's Sons.
Harlow: Trees of Eastern United States and Canada, McGraw-Hill Book Co., Inc.
Harrar and Harrar: Guide to Southern Trees, McGraw-Hill Book Co., Inc.
Jacques: How to Know the Trees, John S. Swift Co., Inc.
Longyear: Trees and Shrubs of the Rocky Mountain Regions, G. P. Putnam's Sons.
Mathews: American Trees and Shrubs, G. P. Putnam's Sons.

*Also refer to textbooks in list of references on p. 149.

Chapter 14

ANGIOSPERMOUS PLANTS—FLOWERING PLANTS

HIGHER PLANTS WITH CHLOROPHYLL; WITH TRUE LEAVES, STEMS, AND ROOTS; WITH VASCULAR TISSUES; WITH ENCLOSED SEEDS; FORMING MULTICELLULAR EMBRYOS (SUBKINGDOM EMBRYOPHYTA)

GENERAL CHARACTERISTICS OF ANGIOSPERMS

1. Angiosperms, or flowering plants, belong to the phylum *Tracheophyta;* subphylum *Pteropsida,* class *Angiospermae* (an jio -spur′ me) (Gr. *angios,* vessel or enclosed; *sperma,* seed) because the *ovules and seeds are enclosed by megasporophylls (carpels)* (Fig. 71). At maturity, the latter constitute the fruit.

2. Angiosperms constitute the dominant, economically most important, and the largest class in the plant kingdom, comprising nearly 200,000 species in approximately 10,000 genera.

3. The angiosperms are *widely distributed on the earth,* where they are primarily *terrestrial,* although a few are aquatic (hydrophytes).

4. Angiosperms possess *true leaves, stems, and roots.*

5. Angiosperm possess *flowers and true seeds* (Fig. 71).

6. The angiosperm plant, whether it be corn, bean, sunflower, or a deciduous tree, is the *sporophyte* with its roots, stem, leaves, and flowers. The cells of the sporophyte contain the double number (diploid) of chromosomes (2N).

7. The *sporophyte* produces *two types of spores (heterospory),* although, as in the gymnosperms, the *microspores* may actually be larger than the *megaspores.*

8. The *gametophyte generation* is represented by the (female) *megagametophyte* and the (male) *microgametophyte.* The microgametophyte is represented by the *pollen grain* and the *pollen tube* with its three cells (two sperms and one tube nucleus). The megagametophyte is the *embryo sac* consisting of seven cells (one egg, two nonfunctional synergid cells, three nonfunctional antipodal cells, and two polar nuclei). The two polar nuclei fuse with one sperm nucleus to form the *endosperm* (food) whose cells contain the unique, triple number of chromosomes (3N). The two synergid cells are thought to be remnants of the arche-

gonium. The three antipodal cells are regarded as remnants of the prothallus tissue. A sex cell contains the N number of chromosomes.

9. The adult *sporophyte* is large and independent, while the *gametophyte* is very small and dependent (without chlorophyll).

10. *Pollination* occurs by pollen landing on the stigma and a *pollen tube* being formed through the stigma, style, and part of the ovary.

11. Water is not required for the *fertilization* of the egg by the sperm.

12. *Pollination* may be by wind, insects, birds (rarely by water), depending upon the species.

13. A so-called *double fertilization* occurs, in which one sperm (1N) fuses with the egg (1N) (true fertilization) to form a *zygote,* with its diploid (2N) number of chromosomes, which will develop into the *embryo.* The other sperm (male gamete) fuses with the two polar nuclei in the center of the female gametophyte (megagametophyte), thus forming a nucleus with the unique, triploid (3N) number of chromosomes. This triploid nucleus is called the primary endosperm nucleus because its gives rise to the *nutritive, endosperm tissue.* The tube nucleus usually disintegrates.

14. The *vascular (conducting) system of angiosperms typically consists of long, tubular vessels* composed of segments derived originally from single cells which have been fused at maturity into long, continuous tubes. In contrast, the conducting tissues of the xylem of gymnosperms are composed of single-celled tracheids.

15. In the evolution of plants, from the simplest algae to the angiosperms, there has been an increase in the size and independence of the sporophyte, while there has been a reduction in size and independence in the gametophyte.

16. The *Angiospermae* are divided into the subclasses (1) *Dicotyledoneae* (di kot i le -do′ ne e) (Gr. *di,* two; *kotyledon,* embryonic seed leaf) and (2) *Monocotyledoneae* (mon o kot i le -do′ ne e) (Gr. *mono,* one; *kotyledon,* embryonic seed leaf), which may be differentiated as follows:

DICOTYLEDONEAE	MONOCOTYLEDONEAE
2 cotyledons (embryonic seed leaves)	1 cotyledon
Net-veined leaves	Parallel-veined leaves
Vascular bundles of the stems usually arranged in a circle (cylinder)	Vascular bundles scattered throughout the stem
Cambium (meristematic tissue) between the phloem and xylem of the vascular bundle	Usually no cambium
Some have woody stems; others have herbaceous stems	Mostly herbaceous stems (few exceptions)
Flower parts usually in fours or fives, or multiples of these	Flower parts typically in three's or multiples of three.

17. The *flowers,* which are distinguishing characters of the entire group of angiosperms, show great diversity of structure. Flowers are concerned with the sexual reproductive process and lead to the formation of fruits (matured ovary) and seeds (embryo, food endosperm, and seed coat). Flowers may be composed of four sets of parts attached to the apex of the stem and known as the *receptacle* (Fig. 71). Going from the outside of the flower toward the center, the four parts are (1) *sepals,* (2) *petals,* (3) *stamens* for the production of pollen, and (4) *pistils* for the reception of pollen and the production of ovules, the latter forming the mature seeds. The sepals collectively constitute the *calyx* (Gr. *kalyx,* cup), while the petals collectively constitute the *corolla* (L. *corolla,* crown). A *complete flower* has all four sets of parts, while an *incomplete flower* has any one of the four sets of parts lacking. Sepals and petals together constitute the *perianth* (Gr. *peri,* around; *anthos,* flower).

The *odors of flowers* are produced by the formation of chemical substances in special secreting cells, usually on the petals. The petals of certain flowers have glands known as *nectaries* for the secretion of the sweetish *nectar,* collected by insects. *Flower colors* usually result from the presence of pigments known as *anthocyanins* (an tho -si′ an in) (Gr. *anthos,* flower; *kyanos,* dark blue) or *carotenoids* (kar′ o ten oidz) (L. *carota,* carrot or yellowish; Gr. *eidos,* form). The anthocyanins are blue, red, and purple water-soluble pigments, while the carotenoids are yellow, orange, and sometimes reddish pigments.

A *stamen* consists usually of a stalklike *filament* and an enlarged *anther* for the production of pollen. A *pistil* consists usually of an enlarged, basal *ovary* within which seeds are formed, a slender *style* arising from the ovary, and an enlarged, pollen-receiving *stigma* at the tip of the style. The enlarged, *ovary portion of the pistil* is composed of one or more *carpels* (Gr. *karpos,* fruit) within which are *ovules* from which *seeds* are formed by fertilization.

The angiosperms are widely distributed and numerous (approximately 200,000 species), so that it is impossible to study all of the many groups. However, a detailed study of a few, well-selected representatives may suffice for an orientation in the class as a whole. Consequently, Indian corn (*Zea mays*) is selected because it is a large, common monocotyledonous type, the garden bean (*Phaseolus*) is chosen because it is a common dicotyledonous form, and the sunflower (*Helianthus*) because it is a typical dicotyledonous type with a composite flower.

INDIAN CORN

Zea mays (ze′ a) (Gr. *zea,* corn).—Indian corn has an erect *stem* from which *adventitious roots* are formed at the *nodes* (L. *nodus,* knob or joint) to assist the true *roots* in the absorption of water and dissolved materials from the soil as well as to assist in anchoring the plant (Figs. 58 to 60). Consequently, such unusual adventitious roots are called "brace roots" or "prop roots." Roots which develop directly from stems or leaves are called adventitious.

Corn has a typical *monocotyledonous stem* with numerous *vascular bundles* (Fig. 60) *scattered throughout the stem* which is composed of *parenchyma cells* (par -eng′ kima) (Gr. *para,* beside; *engchyma,* infusion) of various sizes and shapes. These can be observed in a cross section. The external cover of the stem consists of a layer of *epidermis* whose cells are relatively small and thick walled. Beneath the epidermis is a narrow layer of (mechanical) *sclerenchyma tissue* (skler -eng′ kima) (Gr. *skleros,* hard; *engchyma,* infusion) whose cells are small and thick walled with *lignin* (lig′ nin) (L. *lignum,* wood). Each *vascular bundle is surrounded by a sheath or layer of thick-walled (mechanical) sclerenchyma tissues.* Internally, each bundle consists of (1) *phloem* (toward the periphery of the stem) and (2) *xylem* (toward the center of the stem). There is no meristematic cambium separating the phloem and xylem, as in dicotyledonous stems, so there can be no indefinite increase in size after the primary tissues are mature. Bundles lacking cambium are called "closed" bundles because of their inability to grow indefinitely (Fig. 60).

The *phloem* of a mature bundle conducts liquids downward and consists of regularly arranged, nonnucleated, *sieve tubes* and *companion cells* (Fig. 18). The sieve tubes have their adjacent end walls supplied with a perforated *sieve plate.* Often a narrow, thin-walled, elongated, nucleated, *companioin cell* lies parallel to the sieve tube.

The *xylem* conducts liquids upward and consists of *two large vessels,* with pitted walls, located next to the phloem. Between these two vessels are a few, hollow, one-celled *tracheids* (Fig. 18). The innermost part of the xylem contains one or two *vessels* whose walls have ring-shaped or spiral thickenings. Between the latter vessels and the sheath of mechanical tissue is a large, hollow *intercellular space.*

The *leaves* of corn are characterized by numerous, main *veins running parallel to the long axis,* and all connected by a network of fine, inconspicuous, branches (Fig. 60). The veins are actually *vascular bundles* which are connected with the vascular bundles of the stem. The broad portion of a leaf is called the *blade*. The tissues of the corn leaf are as follows: (1) An *epidermis* on the upper and lower surfaces composed of *one layer of cells*. Openings on the surfaces are known as *stomata* (stom′ ata) (Gr. *stoma,* opening) and are for the exchange of gases. Each stoma is bordered by *guard cells* to regulate the size of the opening. Just beneath each stoma is an irregularly shaped, *intercellular (substomal) space* for the storage of gases. (2) A mass of *compactly arranged cells* which contain *chloroplasts* for *photosynthesis*. (3) *Veins* which are vascular bundles composed of phloem and xylem. The true *root system* of corn is fibrous and quite extensive in order to anchor the plant and to absorb water and nutrients from the soil. Small *root hairs* are extensions of the epidermal cells of certain regions of the roots and serve to increase the absorption area of the root system. A *nucleus* is usually present near the tip of the hair, and there is a large *vacuole*.

The *flowers* of the corn plant are incomplete and on different parts of the same plant. The *tassel* at the tip of the stem consists of pollen-bearing *stamens* (male flowers). Each stamen consists of a stalklike *filament* at the tip of which is the enlarged, pollen-producing *anther* (Fig. 58).

The *female flowers (pistils)* consist of a series of enlarged *ovaries* ("kernels") arranged on the corn cob to form the corn "ear." A long *style* (the "silk" of corn) is attached to each ovary, and the tip of the style, called the *stigma,* is sticky to receive the wind-desseminated *pollen*. A *pollen tube,* for the conduction of pollen, grows through the style to the ovary. Fertilization takes place within the ovary (Fig. 58).

A grain of corn is really a fruit because it consists of a ripened ovary (Fig. 59). A mature grain of corn consists of an outer *pericarp* (per′ i-karp) (Gr. *peri,* around; *karpos,* fruit) firmly fused to the *seed coat* beneath. On the concave side of the grain, beneath the pericarp, is the *embryo* embedded in the extensive *endosperm* (food). The endosperm is composed of three parts: (1) a single layer of cells next to the nucellus is called the *aleurone layer;* these cells are filled with grains of protein known as *aleurone* (alu′ ron) (Gr. *aleuron,* flour); (2) an inner, *starchy endosperm;* (3) an outer, *horny endosperm* containing proteins.

The *embryo* (Fig. 59) consists of (1) *one broad cotyledon* for absorption of food from the endosperm, (2) a well-developed *plumule* consisting of a stem and one or more foliage leaves, (3) a very short *hypocotyl* (hi po-kot′ il) (Gr. *hypo,* under or below; *kotyle,* cup), (4) a *radicle* (rad′ i kel) (L. *radix,* root) which is the lower part of the hypocotyl and forms the primary root of the seedling, (5) a sheathlike *coleoptile* (kol′ e-op til) (Gr. *koleos,* sheath; *ptilon,* feather) which completely encloses the plumule, (6) a sheathlike *coleorhiza* (kol e o -ri′ za) (Gr. *koleos,* sheath; *rhiza,* root) which encloses the radicle.

Upon germination the radicle breaks through the coleorhiza and forms a temporary *primary root.* Adventitious, fibrous roots are soon formed. The plumule breaks through the protective coleoptile to form true *leaves* which develop *chlorophyll* for *photosynthesis.*

GARDEN BEAN

Phaseolus (fa -se′ o lus) (L. *fabaceous,* bean) (Figs. 55 and 56).—The common garden bean belongs to the phylum *Tracheophyta;* subphylum *Pteropsida,* class *Angiospermae,* the subclass *Dicotyledoneae;* family *Leguminosae* (le gum i -no′ se) (L. *legumen,* to gather) because the legumes (fruits) are frequently gathered for various purposes. The family is commonly called the pea or pulse family (L. *puls,* pottage or porridge) and includes such foods as peas, beans, peanuts, lentils, etc., such forage crops as clovers, alfalfa, vetches, etc., and such ornamental plants as sweet peas, lupine, lotus, wistaria, Judas tree, etc. Locust trees are used as timber. The family includes such drug plants as senna, licorice, etc. Leguminous plants add nitrogenous materials to the soils through the fixation of free nitrogen by the actions of special types of bacteria which inhabit the enlarged nodules on the roots.

The bean plant may be short, bushlike, or a vinelike annual, depending upon the variety. The *stalks (stems)* may be long and slender and, due to unequal rates of growth on opposite sides, have a tendency to twine spirally around objects with which they come in contact. The external epidermis is rather thin and affords limited protection. In certain parts of the stems and leaves there may be *hairs* (outgrowths of epidermal cells).

The *leaves* of the bean plant are usually *trifoliate* (three leaves arising from one point) and *net veined* (frequently branched). The thin *epidermal* layer contains *stomata* for the exchange of gases. *Guard cells* control the size of the opening of the stoma. Below the stomata are *air spaces* surrounded by cells which contain *chlorophyll* in green *chloroplasts.* The chlorophyll, through energy supplied by light, combines the carbon dioxide and water to form carbohydrates by the process of *photosynthesis.* Part of the manufactured foods may be used by the plant and the remainder stored, particularly in the developing seeds. The stored carbohydrates and proteins in bean seeds make them valuable as foods. The *veins* (vascular bundles) of leaves conduct materials throughout the leaf and are continuations of the vascular bundles of the leaf petiole, stem, etc.

The rather conspicuous *flowers* (Fig. 55) of the common bean are *irregular* (bilaterally symmetrical, with petals of various sizes and unequally spaced), *perfect* (both stamens and pistils), and *complete* (all four sets of flower parts). They are usually small, *whitish-purple,* and *racemose* (flowers along an elongated axis). The *calyx* is composed of four to five green *sepals,* more or less united. The *corolla* is *papilionaceous* (butterfly-like) and consists of four to five *petals,* some of which may be coalesced. In those species with definitely irregular flowers, the large, recurved, somewhat contorted, upper petal is called the *standard,* the two lateral petals are called *wings,* and the two lower (anterior) petals are fused to form the *keel* which may be spirally coiled. There are usually ten *stamens* (nine of which may be united into a thin sheath around the pistil while one is free). Each stamen bears a pollen-producing *anther* at its tip.

The female *pistil* is composed of a single, elongated *ovary* (one carpel) which contains several *ovules,* a filamentous *style,* and a pollen-receiving *stigma.* When the ovary matures, it becomes a bivalved, multiseeded *pod (legume). Pollen tubes* are formed through the style and extend from the stigma to the ovary. Fertilization occurs in the ovary, and the fertilized *ovules* develop into the *true seeds* (Fig. 56).

The *pod (legume)* is linear, usually slightly curved, with *two halves (valves),* several internal seeds, and usually with remains of the style. The *seeds* (Fig. 56) are composed of two similar halves known as *cotyledons* in which foods have been stored for use in germination of the seed. There is *no endosperm* (food), as in the case of corn, but its place is taken by the *two cotyledons.* Each seed is attached to the pod by a stalk-like *funiculus* (fu -nik′ u lus) (L. *funiculus,* small cord).

The *bean seed* is a *dicotyledon* which *lacks endosperm.* The seeds, like those of other *legumes* (leg′ um) (L. *legumen,* pulse or "pod"), are developed in a *legume (pod),* which is the mature, ripened *ovary* (Fig. 56). Since a ripened ovary is known as a *fruit,* the legume (pod) is a rather special type of fruit.

Each individual *seed* consists of (1) a small, prominent scar, the *hilum* (hi′ lum) (L. *hilum,* small), where it was attached to the pod; (2) a prominent ridge above the hilum, the *raphe* (ra′ fe) (Gr. *raphe,* seam), which is formed by the ovule beneath; (3) the *micropyle* below the hilum (mi′ kro pile) (Gr. *mikros,* small; *pyle,* gate) which is a small opening in the seed coat for the entrance of pollen; (4) *seed coats* which form the protective covering; (5) *two cotyledons* (kot i -le′ don) (Gr. *kotyle,* cup) which are the two fleshy halves of the bean for the storage of food; (6) the *plumule* (or *epicotyl*) with its true leaves folded over the growing tip; (7) the *hypocotyl;* and (8) the *radicle* (rad′ i kel) (L. *radix,* root) which is continuous with the hypocotyl and forms the *embryonic root.* The tip of the radicle points toward the micropyle. All of these structures may best be seen in seeds which have been soaked to initiate germination.

During germination, the food of the cotyledons is digested and transferred to the plumule, hypocotyl, and radicle. The embryonic, *primary root* is formed from the radicle which bends downward under the influence of gravity. The hypocotyl elongates and carries with it the plumule and the two cotyledons out of the soil. The two cotyledons spread to allow the developing foliage leaves of the plumule to develop. The cotyledons may develop chlorophyll for carrying on photosynthesis for a time, but eventually they shrivel. The *roots* absorb water and nutrients from the soil and conduct them to the stalk (stem).

SUNFLOWER

Helianthus (he li -an′ thus) (Gr. *helios,* sun; *anthos,* flower).—The sunflower belongs to the phylum *Tracheophyta;* subphylum *Pteropsida;* class *Angiospermae;* subclass *Dicotyledoneae;* family *Compositae* (kompoz′ i te) (L. *cum,* together; *ponere,* to place) because of the many closely compacted individual flowers (florets) which form a *head,* commonly mistaken for the flower (Fig. 57). Common plants with *composite flowers* include sunflowers, dandelions, ragweeds, cockleburs, goldenrods, daisies, asters, zinnias, dahlias, marigolds, lettuce, artichoke, etc. The enormous production of seeds and the efficient devices for their dispersal have distributed them widely. The pollen of many of them, including goldenrods, ragweeds, etc., are causes of pollen (hay) fever.

A sunflower plant consists of a *stem* with *nodes* (joints), at which *leaves* are borne, and *internodes,* between successive nodes, by which growth occurs by an elongation process.

Internally, a mature *stem* of a dicotyledonous plant such as a sunflower (Fig. 57) consists of (1) a central, *pith region* composed of thin-walled *parenchyma cells;* (2) *vascular bundles* which are arranged in a circle toward the periphery of the stem and composed of (a) *xylem* (toward the pith), composed of thick-walled cells (single-celled *tracheids* and *vessels*), (b) *phloem* (toward the periphery of the stem), composed of nonnucleated, *sieve tubes* (with perforated *sieve-plates*) and elongated, nucleated *companion cells,* and (c) a thin layer of meristematic tissue called *cambium* which separates the xylem and phloem; (3) the *pericycle* which is a cylinder of mechanical tissue, external to the vascular bundles, composed of thick-walled cells, with some thin-walled cells; individual bundles are separated by radial strands or *rays,* composed of *parenchyma cells* to conduct materials across the stem; the entire central core of the stem described so far constitutes what is called the *stele;* (4) a layer of *cortex* just external to the stele composed of large, thin-walled cells; (5) a layer of *mechanical tissue* beyond the cortex composed of thick-walled cells; (6) the *epidermis* external to the *mechanical tissue* composed of elongated, flat cells whose outer walls are impregnated with a waxy *cutin* to make them impermeable to water. Certain epidermal cells may produce extensions known as *hairs.* A connection between a vascular bundle and a leaf is called a *leaf trace.*

Dicotyledonous stems (as well as gymnospermous stems) usually produce so-called *secondary tissues* in contrast to the monocotyledons which do not produce secondary tissues. The secondary tissues arise from the *cambium* and consist of *secondary xylem* and *secondary phloem.* In the stems of annual plants the secondary xylem and secondary phloem are formed for only one season, but in perennial plants (especially shrubs and trees) the cambium forms secondary xylem and phloem year after year. In stems of woody trees and shrubs, where secondary xylem and phloem are formed year after year, the xylem formed in the spring is composed of large, relatively thin-walled elements (spring wood), while the xylem formed during the summer is composed of small, thick-walled elements (summer wood). The *annual rings* are concentric lines of demarcation between the large-celled, thin-walled spring wood of the current year and the small-celled, thick-walled summer wood of the previous year. The number of rings is not always an accurate criterion of age, because under unusual conditions two rings may be formed in one year. The thickness of an annual ring is often greatly influenced by environmental conditions, such as water supply, weather conditions, etc. The *secondary phloem* of most woody dicotyledons may contain thick-walled, elongated cells with pointed ends and are called *bast fibers.* The *secondary xylem* may contain rigid, thick-walled, elongated cells with pointed ends and are called *wood fibers.*

A mature sunflower *leaf* (Fig. 57) consists of a broad *blade* attached to the *stem* by a slender *petiole.* *Net veins* conduct materials throughout the leaf. *Photosynthesis* is carried on by the *chlorophyll* which absorbs *light energy* and combines *carbon dioxide* and *water* to manufacture *organic compounds,* with *oxygen* as a by-product. Some of the stored energy is used by the plant for its various metabolic activities, while some of the energy absorbed is used in the manufacture of the organic foods. Capture and storage of light energy by chlorophyll-bearing plants is a unique phenomenon. The leaf blade (Fig. 57) includes (1) an external *epidermis* whose cells are often irregular when viewed from the surface but rectangular in cross section; the outer walls of the epidermal cells contain a waxy *cutin;* (2) a region of column-shaped *palisade cells* beneath the upper epidermis which are compactly arranged and contain many *chloroplasts;* (3) a layer of *spongy tissue* beneath the palisade layer composed of irregularly shaped, loosely packed cells with numerous *intercellular spaces* between them (*chloroplasts* are also present in the cells of the spongy tissue); (4) a lower *epidermis* similar to the upper epidermis except that it contains openings known as *stomata* for the exchange of gases. Each stoma is bordered by two bean-shaped *guard cells* which contain *chloroplasts* and regulate the size of the stoma. The stomata open into *intercellular cavities* (substomal cavities) in which gases may be exchanged with the leaf cells. Both epidermal tissues may bear *hairs;* (5) *veins* which are *vascular bundles* composed of xylem and phloem as in the petiole and stem; a *sheath* of variable thickness surrounds the vein.

An older sunflower plant has a *primary root* with lateral *branch roots* which may have an extensive branching root system for anchorage and absorption.

The *regions of a mature root,* beginning at the tip, include (1) the cup-shaped *root cap* which protects the root as it is pushed through the soil; (2) the *meristematic region* (growing region) which is covered by the root cap and is composed of small, similar, closely packed, rapidly dividing cells; (3) the *elongation region,* just back of the growing region, which is composed of cells which are increasing in length; (4) next the *maturation region* in which the cells are differentiated and are taking on mature characteristics; and (5) following this the *mature region* in which most cells have completed their development. All these regions can be observed in a longitudinal section.

Internally the *mature region of a root* (Fig. 57) consists of (1) a central *stele* (Gr. *stele*, pillar), (2) a surrounding cylinder of tissues called the *cortex*, and (3) the external *epidermis*. These can be observed in a cross section.

The *stele* in the center is composed of (1) *xylem,* (2) *phloem,* (3) *parenchyma,* and (4) *pericycle.* The *xylem* is in the form of a + and is composed of thick-walled cells (tracheids and vessels) of various sizes; the *phloem* is located in the angles between the strands of xylem and consists of *sieve tubes* with their *companion cells;* the *parenchyma tissues* lie between the xylem and phloem and are composed of rather large, thin-walled cells; the *pericycle* (Gr. *peri,* round; *kyklos,* circle) surrounds all of the above tissues and is in the form of a cylindrical sheath (ringlike in cross section), being composed of one or several layers of thin-walled cells.

The *cortex* is composed of *endodermis* and *parenchyma tissues.* The *endodermis* (en do -der′ mis) (Gr. *endo,* within; *derma,* "skin") is the innermost, single layer of cortex cells. The *parenchyma tissues* are just external to the endodermis and are composed of rounded cells of various sizes.

The *epidermis* (ep i -der′ mis) (Gr. *epi,* upon; *derma,* "skin") covers the root and is one cell thick. Certain epidermal cells may possess projections known as *root hairs* to increase the absorption of the root. Growth of the root occurs toward the tip rather than in the region with root hairs, so that the latter are not injured as the root is pushed through the soil.

The *composite flower* of the sunflower (Fig. 57) is composed of numerous individual flowers grouped together so as to form a *head* which resembles a single flower in a general way. The small flowers are borne on a disklike *peduncle* (pe -dung′ el) (L. *pedunculus,* small foot).

At the edge of the flower-bearing disk are two or more spirals of overlapping, flat, green *bracts* (L. *bractea,* thin plate). On the face of the disk is an outer circle of closely packed *flowers,* each in the axil of a small bract (modified leaf). The two types of flowers on the head are (1) *ray flowers,* forming one or two rows at the edge, and (2) *disk flowers,* forming the remainder of the head. The marginal, *ray flower* consists of a strap-shaped *corolla,* one side of which is modified into a broad, flat structure. The stamens and style of the ray flower may be abortive. These marginal ray flowers may be sterile or they may contain only pistils. Each inner, *disk flower* consists of a wedge-shaped, hollow *receptacle* partly enclosing the *ovary* which contains one functional *ovule.*

Fused petals (*corolla*) surround the style, and their tips are recognizable as five blunt teeth. The pollen-producing *anthers* are united at their edges to form an *anther tube* around the style. The *style* extends beyond the *corolla tube* and the surrounding *anther tube* and terminates in two protruding *stigmas* (Gr. *stigma,* mark). The *calyx* is represented by two scales (pappus) at the top of the ovary.

After fertilization (union of male and female gametes) the ovary enlarges and contains one *seed.*

QUESTIONS AND TOPICS

1. List the distinguishing characteristics of the class *Angiospermae,* subclass *Dicotyledoneae,* subclass *Monocotyledoneae,* and the family *Compositae.*
2. Learn the meaning, pronunciation, and derivation of each new term used in this chapter.
3. Discuss the economic importance of angiosperms.
4. Discuss the distribution and habitats of angiosperms.
5. Make a detailed diagram of a typical angiospermous plant life cycle, including the various stages in correct sequence, with each labeled correctly.
6. Describe the sporophyte generation and the gametophyte generation in angiosperms, including their relative sizes and independence.
7. Compare the pollination process in angiosperms with the pollination as it occurs in a gymnosperm such as a pine tree.
8. Describe the structures and functions of the various parts of a complete flower.
9. Describe the seed production process of angiosperms.
10. List the chromosome number in the gametes, sporophyte, and endosperm.
11. Contrast monocotyledonous angiosperms with dicotyledonous angiosperms in as many ways as possible.
12. Describe the formation of the pollen tube and its function.
13. Review all of the plant tissues described in this chapter, including their distinguishing structural characteristics and functions.
14. Describe the structure and functions of the ovary. Why are angiosperms said to form enclosed seeds?
15. Contrast what is meant by pollination and fertilization.
16. Discuss the so-called double fertilization process and its significance.
17. Define heterospory and give examples from the angiospermous plants.
18. In the botanical sense, contrast a fruit and seed, giving examples of each.
19. Describe the structure and functions of cambium.
20. Describe the construction and functions of cotyledons.

SELECTED REFERENCES

Bailey and Bailey: Hortus, The Macmillan Co.
Britton and Brown: An Illustrated Flora of Northern United States, Canada, and British Possessions, New York Botanical Gardens.
Clements and Clements: Flower Families and Their Ancestors, The H. W. Wilson Co.
Coulter and Chamberlain: Morphology of Angiosperms, D. Appleton & Co.

Cuthbert: How to Know the Spring Flowers, H. E. Jacques, Mt. Pleasant, Iowa.
Douglass: Climatic Cycles and Tree Growth, Carnegie Institution of Washington.
Hausman: Beginner's Guide to Wild Flowers, G. P. Putnam's Sons.
Hausman: Illustrated Encyclopedia of American Wild Flowers, Garden City Publishing Co., Inc.
Hutchinson: Families of Flowering Plants, The Macmillan Co.
Hylander: The World of Plant Life, The Macmillan Co.
Johnson: Taxonomy of Flowering Plants, Century Co.
Mathews: American Wild Flowers, G. P. Putnam's Sons.
Mathews: American Trees and Shrubs, G. P. Putnam's Sons.
Moldenke: American Wild Flowers (illustrated), D. Van Nostrand Co., Inc.
Pool: Flowers and Flowering Plants, McGraw-Hill Book Co., Inc.
Seymour et al.: Favorite Flowers in Color (illustrated), Wm. H. Wise & Co., Inc.
Small: Manual of Southeastern Flora, Science Press Printing Co.
Skene: The Biology of Flowering Plants, The Macmillan Co.
Wherry: Wild Flower Guide, Doubleday & Co., Inc.

Chapter 15

BIOLOGY OF HIGHER PLANTS—ANATOMY AND PHYSIOLOGY

I. THE ROOT

General Regions.—Very important parts of the roots are the tips of the finest branches. The surface of these branches is covered for a considerable distance, from a point slightly behind the tip, with fine, transparent, hairlike root hairs. Each root hair is really a continuous extension from one of the outer flattened, epidermal cells of the root. Each root hair contains a nucleus and a vacuole within the cytoplasm. The extreme tip of the root is protected by a root cap, the outer cells of which are constantly destroyed as the root is pushed through the soil. Some of the growth of the root occurs in the formative region just above the root cap and is known as the embryonic region. The cells of this region are small, closely packed, angular, filled with protoplasm, and frequently dividing by mitosis. Just above this region is the elongation region in which the cells grow in length by taking water into the vacuoles distributed in their cytoplasm. The next region is the maturation region (cell differentiation region) in which different cells begin to undergo specialization and differentiation. In this region the cells of the epidermis form root hairs, and the cells of the central axial part of the root form conduction tissues for the transportation of plant materials. The fourth region includes the remainder of the root and is known as the mature region. The cells here are differentiated into various tissues of the mature root (Figs. 57 and 70).

The mature root consists of primary and secondary tissues. The former develop from differentiated cells which arise directly by cell division from the embryonic region of the root tip. The secondary tissues are produced from the cambium, which develops from undifferentiated cells that retain their embryonic character.

The mature region of a root consists of the following **primary tissues:** (1) epidermis, (2) cortex, (3) stele. The *epidermis* is an outer protective layer of one cell thickness. Just beneath the epidermis is the *cortex* or differentiated region which surrounds the central stele. The cortex consists of (1) parenchyma (Fig. 18), composed of thin-walled cells which usually measure about the same in each direction and which possess stored food and water in the large vacuoles of their cytoplasm; (2) endodermis, or the inner boundary of the cortex, formed by a layer of cells resembling those of the epidermis; (3) mechanical tissues which are present in certain plant roots and absent in others. The *stele,* or solid, central cylindrical portion of the root, consists of (1) pericycle, (2) primary xylem (woody tissue), (3) primary phloem, and (4) parenchyma. The pericycle surrounds the stele and consists of one or more layers of cubical cells just inside the endodermis. The primary xylem extends lengthwise of the stele. The first cells to be differentiated in the primary xylem are the tracheids (Fig. 18) which are elongated cells with pointed ends and walls thickened in certain places. The three most common types of tracheids are the spiral tracheids, in which the cell wall is thickened along a spiral, the remainder of the wall being thin; the annular tracheids, in which the cell wall has a series of thickened rings; pitted tracheids, in which the cell wall is generally thickened with only pits of thin walls. The protoplasm of the tracheids dies and leaves them hollow in order to transport water through the root. As the root develops, the primary xylem also develops spiral vessels, annular vessels, and pitted vessels. These vessels are formed by joining a number of elongated cells end to end. The end walls where the cells join are dissolved, thus forming a long tubular structure. The side walls of the vessels have thickenings similar to the tracheids. The protoplasm of the vessels dies and thus a long hollow tube is formed for conducting plant liquids (Fig. 18). The primary phloem of the mature root is composed of numerous strands of cells located between the numerous primary xylem strands and alternating with them. The primary phloem consists of (1) sieve tubes (Fig. 18) and (2) companion cells. A sieve tube is formed by uniting a number of elongated cells end to end in a way similar to that in which a xylem vessel is formed, except that the side walls are not especially thickened and the end walls are not dissolved. These end walls develop sievelike pores through which the cytoplasm of adjacent cells is continuous. Closely associated with the sieve tubes of most plants are companion cells (Fig. 18), the length of which is equal to or shorter than the portion of the sieve tube which arises from one cell. The cytoplasm and nucleus are present in companion cells, while the nuclei of cells which form sieve tubes disappear. The tracheids and vessels of the primary xylem conduct water and other materials from the roots to the leaves. The sieve tubes and companion cells of the primary phloem conduct to the roots organic materials which they have received from the stems and leaves. The parenchyma of the root is composed of numerous thin-walled cells which lie between the primary xylem and primary phloem.

All the tissues just described are primary tissues and arise directly by cell division from the embryonic region. In the mature region of roots of dicotyledonous plants (seeds having two cotyledons or seed leaves), certain cells remain undifferentiated, retain their embryonic character, and form *cambium.* The cambium is bounded by the phloem on the outside and xylem on the inside. Somewhat back of the mature region, the cambium forms a continuous cylinder between the xylem and phloem. The cambium consists of small cubical cells which divide rapidly by mitosis during the growing season. Growth of the cambium causes the root to increase in diameter. Tissues formed by the cambium are known as **secondary tissues,** which include (1) secondary xylem, (2) secondary phloem, (3) medullary rays, and (4) annual rings. The *secondary xylem* is formed on the inner side of the cambium, while the *secondary phloem* is formed on the outer side. As the root becomes older, the secondary xylem and phloem occupy most of the stele and form two concentric regions separated by cambium. In certain places the cambium produces parenchymatous strands which extend radially between the xylem cells toward the center and between the phloem cells toward the periphery of the stele. These radially arranged strands are the *medullary rays.* The secondary xylem produced by a single year's growth is represented by a so-called *annular ring.* In the roots of plants which live several years, the formation of new secondary xylem and phloem continues year after year, forming concentrically arranged annular rings. The xylem vessels produced during the early spring are generally large and thin walled, while the xylem vessels formed near the end of the growing season are smaller and thick walled. Hence, each annular ring is composed of two types of xylem vessels described above.

The functions of roots ordinarily include anchorage of the plant, support of the stem, absorption of water and dissolved materials, and storage of manufactured foods. In some instances special types of roots perform other more specialized functions.

II. THE STEM

The development and differentiation of the tissues of a stem occur in the buds at the ends of the stem and its branches. The growing end of a stem does not have a root cap as does a root, but it does have an embryonic region, an elongation region, a maturation region, and a mature region. The many similar cells of the embryonic region of the bud divide rapidly by mitosis. Growth and cell differentiation occur in the bud so that the youngest part of the stem or branch is nearest the bud. The elongation region develops after the bud opens. The differentiation of the cells of the stem to form xylem, phloem, parenchyma, etc., is generally similar to the corresponding cells of the root.

Study of a Stem of a Dicotyledonous Plant.—If a thin section of such a plant as the sunflower is studied, the following structures are visible (Fig. 57): (1) epidermis, (2) cortex, and (3) stele. The *epidermis* is composed of a single layer of flattened cells for protection. The walls are infiltrated with a waxy substance (cutin) to prevent loss of water. The *cortex* consists of parenchyma cells and mechanical tissues. The parenchyma cells of the cortex are continuous with the large parenchyma cells of the pith. These two groups of parenchyma cells separate adjacent vascular bundles. The mechanical tissue is formed of elongated, thick-walled cells to give rigidity to the stem. The tissues of the *stele* of the stem are quite different from the stele of the root. The conducting tissues of the stem stele consist of a series of *vascular bundles* arranged in the form of a ring, leaving a large central area of pith. Each *vascular bundle* is composed of *xylem and phloem separated by cambium.* In young stems the large parenchyma cells of the pith and cortex are continuous between the vascular bundles. The parenchyma forms radiating *medullary rays* (pith rays) between the vascular bundles. In each vascular bundle the phloem lies external to the cambium and the xylem internal to it. The xylem cells have thick walls as in the root xylem and conduct liquids from the roots to the leaves, etc. The *annular rings* are even more noticeable in stems than they are in roots, although they are formed in much the same manner in each. The phloem conducts materials downward toward the roots.

Study of a Stem of a Monocotyledonous Plant.—If a thin section of such a plant as corn is studied, certain differences will be noted (Fig. 60). In the monocotyledonous stems the *vascular bundles* are scattered throughout the *parenchyma.* Each vascular bundle contains only primary xylem and phloem but no cambium separating them. It is impossible to distinguish pith and cortex. The vascular bundles and the stem as a whole do not increase in diameter beyond a certain point. Each vascular bundle is enclosed by *mechanical tissue* composed of long, thick-walled cells. These mechanical tissues, together with those just beneath the epidermis, give rigidity to the stem.

The functions of a stem include the support of flowers and leaves, the manufacture of foods (in certain instances), the storage of materials, and the conduction of materials.

III. THE LEAVES

Leaves vary in size and shape in different plants (Figs. 53, 55, 57, 60, and 70). They vary from the needlelike leaves of the pine, to the large leaves of certain palms. A typical leaf consists of (1) a flat, expanded *blade* (lamina); (2) the *stalk* (petiole); (3) the *base* for attachment.

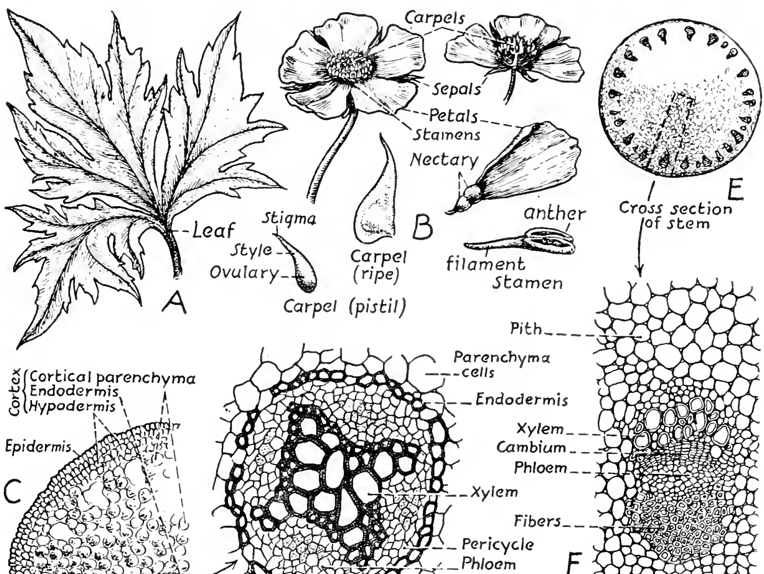


Fig. 70.—Buttercup *(Ranunculus sp.)*. *A,* Leaf; *B,* flower and its parts (carpels are also known as pistils); *C,* root in cross section with its central stele (composed of xylem, phloem, and pericycle) shown enlarged in *D; E,* stem in cross section with a portion enlarged in *F,* showing the detailed structures, particularly the vascular bundle. Note the difference in the locations of xylem and phloem in the root and stem. Observe the nectar-producing nectary at the base of the petal.

The blade may be simple, as in the case of the sunflower, or compound (divided into leaflets), as in the horse chestnut. The margin of the blade may be smooth or irregular. Within the blade are veins which consist of vascular bundles. Each vascular bundle contains extensions of xylem and phloem cells of the stele of the stem.

The internal structure of a leaf may be studied from a thin cross section. The upper surface is protected by the upper *epidermis,* the cells of which contain cutin to prevent rapid loss of water. The lower surface is protected by the lower epidermis. In the lower epidermis, and less frequently in the upper, are slitlike *stomata* (Fig. 18) (singular, stoma) which lead into intercellular air spaces within the leaf. Each stoma is surrounded by a pair of semicircular *guard cells* which control the size of the stoma. The guard cells contain green *chlorophyll,* while the epidermal cells do not. The interior of the leaf is composed of *mesophyll tissue* made up of chlorophyll-bearing cells. Just beneath the upper epidermis, the mesophyll is known as *palisade tissue,* because the chlorophyll-bearing cells are column-shaped and are arranged side by side perpendicular to the surface of the leaf. The mesophyll below the palisade is known as *spongy tissue* in which the irregular-shaped cells surround the intercellular air spaces. The veins of the leaf extend through the spongy tissue. Each vein consists of a vascular bundle with its thick-walled xylem cells toward the upper side and the thinner-walled phloem toward the lower. The smaller veins contain only tracheids, while the larger ones contain tracheids, sieve tubes, and companion cells. The chlorophyll of the palisade and spongy tissues manufactures plant food through the process of photosynthesis.

IV. THE FLOWER

A flower is really a series of whorls of modified leaves borne at the end of a stem (Figs. 55, 57, 58, and 71). Flowers vary greatly in different plants, but the more important structures and function may be ascertained from the simple flower of the buttercup (*Ranunculus sp.*) (Fig. 70). The end of the stem which bears the floral leaves is called the receptacle. The outer whorl of floral leaves is called the calyx, which is composed of five small, yellowish-green sepals. Within the calyx is the more conspicuous corolla composed of five larger yellow petals. The petals and sepals together constitute the perianth. Passing inward from the corolla we find numerous filamentous stamens, each of which consists of a stalklike filament and an enlarged anther at its free end. The hollow anther contains microspores (pollen grains). The pollen grains develop into male gametophytes. In the center of the flower are whorls of small, green, pointed, oval carpels. Each carpel consists of (1) a basal saclike ovary, which contains a female ovule; (2) a hooklike, pointed, distal end, known as the stigma to receive pollen; and (3) a style, which connects the stigma with the ovary. The stigma, style, and ovary constitute the pistil. The ovule of the flower is attached to the ovary and consists of a megasporangium (nucellus). The megasporangium forms four megaspores, only one of which develops into a female gametophyte. The union of a male gametophyte with the female gametophyte within the ovary constitutes fertilization, which results eventually in the development of a seed.

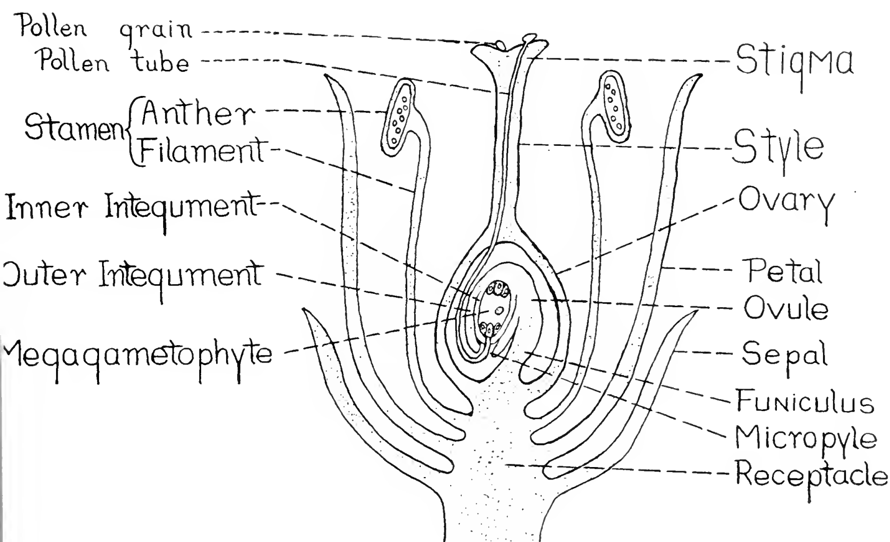


Fig. 71.—Diagram of a flower (in section) to show parts and fertilization. The anther contains pollen grains which escape to the stigma. The stamens are also known as microsporophylls. The pistil consists of the stigma, style, and ovary. The pistil may consist of a single, basal carpel (megasporophyll, or ovule-bearing "leaf") or of two or more fused carpels. The micropyle permits the entrance of the pollen tube into the female megagametophyte (egg sac). Ovules later become seeds. The pollen tube and its contained pollen grains constitute the male microgametophyte. The tube nucleus (of the pollen grain) germinates and forms a pollen tube through which the generative nucleus (of the pollen) follows to the ovule where fertilization occurs. The generative nucleus divides into two sperm (male gametes); one sperm unites with the egg to form the embryo; the other sperm fuses with the two polar nuclei (shown at top of megagametophyte) to form the food endosperm.

V. ABSORPTION BY PLANTS

Water.—Higher plants absorb water and inorganic salts by means of the fine, transparent root hairs located near the tip of their roots (Fig. 57). The root hairs are really extensions of the epidermal cells and are in close contact with the film of water which surrounds the individual grains of the soil. Water passes from this film through the cell wall and plasma membrane of the root hairs and the epidermis of the root tip. Water is not absorbed by any other part of the root, stem, or leaves. The absorption of water depends on the osmotic pressure of the soil water and the osmotic pressure of the protoplasm within the cells. Water supplies two elements, hydrogen (H) and oxygen (O), for plant use, in addition to serving as a vehicle for the entrance of essential inorganic salts. Only a small part of the absorbed water remains in a plant as will be seen when transpiration is considered.

Inorganic Salts.—Soils usually contain a variety of salts, some of which can be used by a plant. Certain of these salts are selected by the plant and absorbed for its future use. Plants require certain essential salts which contain the following chemical elements: calcium (Ca), potassium (K), nitrogen (N), phosphorus (P), magnesium (Mg), sulfur (S), and iron (Fe). These are rarely found in the soil as elements but are frequently combined into such usable compounds as calcium nitrate, $Ca(NO_3)_2$; potassium nitrate, KNO_3; potassium phosphate, KH_2PO_4; magnesium sulfate, $MgSO_4$; iron phosphate, $FePO_4$. The quantity and quality of the chemicals in the soil, together with its water content, to a great degree determine the structure and functions of the plant growing in that particular type of soil.

VI. TRANSPIRATION BY PLANTS

The roots continually absorb water which is conducted by the xylem through the stems and leaves (Figs. 53 and 55 to 60). Most of this absorbed water is given off by the leaves through the process of transpiration. The epidermal cells of the leaf contain a waxy substance (cutin) which prevents any great loss of moisture through those cells. Most of the transpiration occurs through the minute stomata scattered throughout the upper and lower epidermis, particularly the latter. The xylem tissues transport the water to the cells of the mesophyll of the leaf. From the spongy tissue of the mesophyll, the water escapes into the intercellular air spaces, from which it evaporates through the stomata. This escape of water is regulated by the pair of semicircular guard cells which surround each stoma. The opening of each stoma is regulated by the guard cell and this is influenced by the amount of humidity in the surrounding atmosphere. Transpiration results in a constant current of water through the plant. This circulation transports foods and wastes from one part of the plant to another.

VII. CONDUCTION OF LIQUIDS

The constant absorption of water by roots and the loss of water by transpiration in the leaves result in a constant flow of water and its absorbed materials through the plant. Water absorbed by a root hair is passed into the cortex of the root, then to the endodermis, to the pericycle, and finally into the xylem of the root. From the root xylem it passes into the xylem of the stem which is connected with the veins of the leaves. From the veins the water passes to the mesophyll cells of the leaf. From these cells it escapes into the intercellular air spaces and hence outside through the stomata.

The three factors which explain the ascent of water and dissolved materials in a plant are (1) root pressure, (2) tensile strength of water, (3) transpiration. The differences in osmotic pressures, in the protoplasm of the root hair cells and the soil water, result in *root pressure,* which causes an absorption of water by the roots and a tendency to force it upward. A thin, continuous column of water is found in the small xylem vessels. Under such conditions, the *tensile strength of water* is great enough to resist successfully forces tending to pull the column apart. Hence, the column of water when once started will not be easily broken. A loss of water by *transpiration* in the leaf results in its replacement from deeper tissues. This is accomplished by the upward pull on the water column in the xylem tissues. The xylem seems to conduct materials upward, while the phloem transports food materials from the point of their manufacture to their places of use and storage. This is often downward through the stem. The medullary rays of the stem conduct foods and water radially (Figs. 53 and 57).

VIII. MANUFACTURE, DISTRIBUTION, AND STORAGE OF FOODS BY PLANTS

Plants without chlorophyll, such as bacteria, yeasts, and molds, select and absorb their foods from the materials on which they grow. Chlorophyll-bearing plants combine carbon dioxide and water to form carbohydrates in the presence of light through the process of photosynthesis.

In higher plants the carbon dioxide is taken from the air by the leaf and the water is supplied by the roots. The carbon dioxide enters the leaf through the stomata and intercellular air spaces (Figs. 53, 57, and 60) and diffuses into the chlorophyll-bearing mesophyll cells. The chlorophyll combines this gas with the water brought to the mesophyll tissues by the xylem tissues of the root and stem. Less than 4 per cent of the light energy falling on a leaf is used in the photosynthetic process; part of the additional energy absorbed by the leaf increases its temperature and part is eliminated with the water during transpiration.

The green color of the chloroplasts in plants is due to a mixture of four pigments: two green ones, chlorophyll A ($C_{55}H_{72}O_5N_4Mg$) and chlorophyll B ($C_{55}H_{70}O_6N_4Mg$), and two yellow ones, carotene ($C_{40}H_{56}$) and xanthophyll ($C_{40}H_{56}O_2$). The term chlorophyll is often used for the mixture of these four pigments. Light is essential for the development of chlorophyll as is shown by the pale color of leaves grown in darkness. We do not know how chlorophyll unites carbon dioxide and water, but since it does not contribute to the product formed and is not itself used up in the process, it is surmised that it acts as a catalytic agent. The process may be illustrated by the following chemical equation:

$$\underset{\text{water }(H_2O)}{\text{6 molecules}} + \underset{\text{carbon dioxide }(CO_2)}{\text{6 molecules}} + \underset{\text{energy}}{\text{Light}} \rightarrow \underset{(C_6H_{12}O_6)}{\text{Carbohydrate}} + \underset{(6O_2)}{\text{Oxygen}}$$

It will be noted that oxygen is a by-product of the process. Part of this oxygen may be used by the plant for metabolic purposes and the remainder eliminated. Part of the carbohydrates is oxidized, thus liberating usable energy for plant use, but a much larger part is chemically transformed by the plant into (1) components of living protoplasm, (2) reserve foods, such as sugars, starches, proteins, and fats, and (3) other substances, such as oils, resins, pigments, enzymes, vitamins, etc. Plants form proteins by adding to the carbohydrates such elements as nitrogen and sulfur and, in some cases, phosphorus. The living plant oxidizes many of its substances, thus liberating energy for its various metabolic activities.

General Consideration of Photosynthesis.—Photosynthesis is one of the most important of living processes because, directly or indirectly, it provides most of the foods, fuels, clothing, and shelter for living organisms. Photosynthesis (Gr. *photos,* light; *synthesis,* put together) is a constructive or anabolic process. Chlorophyll (Gr. *chloros,* green; *phyllon,* leaf) serves as an absorber of the light and no doubt has much to do with the physical and chemical reactions necessary to transform the radiant (kinetic) energy into the potential energy of the sugar. Photosynthesis is also known as "carbon assimilation" or "carbon fixation."

The photosynthetic apparatus is made of the chlorophyll-bearing chloroplasts which in higher plants are usually most abundant in the chlorenchyma (mesophyll) tissues of the leaves (Figs. 57 and 60), although they may be present in any living plant tissues exposed to light. Recent investigations with the electron microscope reveal that the chloroplasts in plant cells contain tiny green bodies of chlorophyll known as *grana* (Fig. 72). The latter increase in size until they divide to form two new chloroplasts. Chlorophyll is also present in the mosses, ferns, and algae. In certain algae the green chlorophyll may be masked by other pigments which are considered in greater detail in other parts of the book. In addition to chlorophyll, the chloroplasts may contain two other pigments: a yellow pigment called *xanthophyll* (Gr. *xanthos,* yellow; *phyllon,* leaf) and an orange pigment called *carotene.* The latter was formerly called carotin and was named because of its abundance in carrots. The yellow pigments are more resistant than chlorophyll to low temperatures, drought, minimum light, diseases, and injuries. Consequently, in the fall when some or all of the above factors may be present and the chlorophyll begins to disintegrate, the yellow pigments may play important roles. Chlorophyll was first named by Caventou and Pelletier (1819), but it was isolated and its chemical composition determined in 1912 by Willstätter and his associates.

The chloroplasts in different species of plants vary greatly, some functioning in temperatures above 50° C. Inman found several species of blue-green algae in Yellowstone National Park growing in a temperature of 70° C. Other chloroplasts function in temperatures below −25° C. These are extremes and undoubtedly most chlorophyll functions best in less extreme temperatures. Some plants photosynthesize in full sunlight while others function better in shaded environments. Diffuse light for the necessary period of time is most favorable. It is believed that the same type of chlorophyll is present in all species of plants. The total quantity of chlorophyll in a plant averages about 1 per cent of the total dry weight of that plant. The average plant makes about 1 Gm. of carbohydrate per square meter of leaf surface per hour under average conditions.

Most photosynthesis is accomplished in leaves because (1) their arrangement and position permit them most effectively to receive air and light; (2) in form they are relatively thin and broad to enable them to

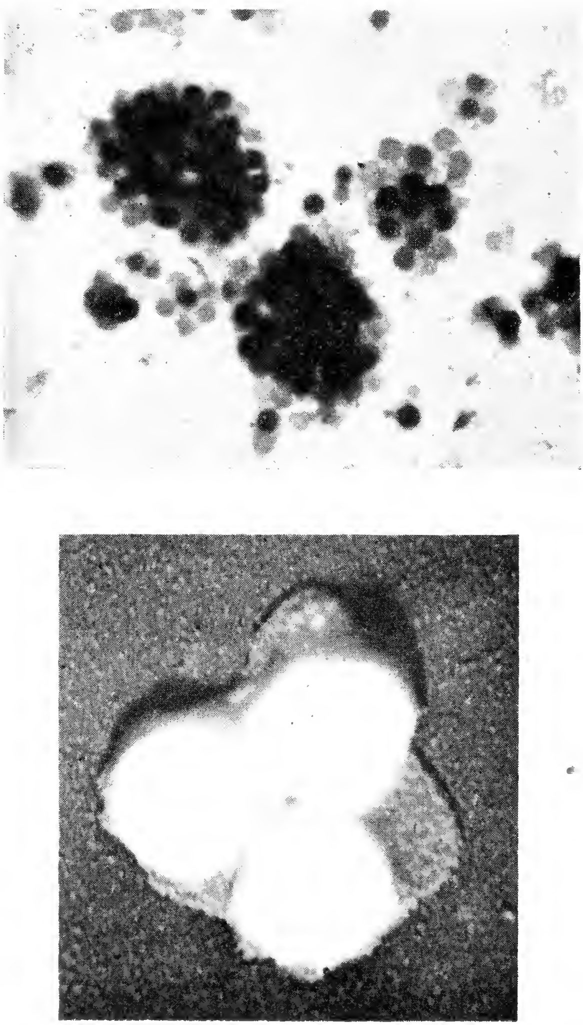


Fig. 72.—Electron micrographs of individual chloroplasts from spinach leaves, showing the tiny spherical bodies, called grana, within each chloroplast. These spinach chloroplasts show grana and matrix, while three grana are enlarged, shadowed with gold. (From Granick, S., & Porter, K. R.: Am. J. Botany **34:** 545, 1947.)

absorb a maximum of heat and light; (3) they are well supplied with transportation vessels (veins ending in the mesophyll tissue) to transport water and minerals to the photosynthesis apparatus and carbohydrates away from that apparatus; (4) their transparent cuticle and epidermis permit the entrance of heat and light but prevent excessive evaporation of moisture; (5) their spongy mesophyll tissues with their air spaces communicate through the stomata with the outside to permit the necessary exchange of gases; (6) they possess a maximum of chloroplasts for uniting carbon dioxide and water. In algae the water and carbon dioxide enter through the cell membranes.

Theories and Early Work on Photosynthesis.—Our present knowledge of this phenomenon, like that of many of the great concepts, is due to facts acquired by long, laborious experiments and observations by many workers over a long period of time. Bonnet (1769) noticed bubbles of gas coming from living grape leaves immersed in water but no bubbles from boiled water. Priestley (1774) found that plants could improve the air which had been rendered unfit by animals, hence suggesting the exchange of carbon dioxide and oxygen between animals and plants. Ingen-Housz, a Dutch physician (1779), showed that this purification of the air was accomplished only by green plants and only in light. Senebier (1782) showed that carbon dioxide was absorbed by plants for nutritional purposes. De Saussure (1804) showed that plants returned an amount of oxygen to the air which was about equal in volume to the amount of carbon dioxide they had removed. He also proved that the absorption and decomposition of carbon dioxide by a plant resulted in an increase in weight of that plant. Boussingault (1860-1890) carefully measured the carbon dioxide taken in by a plant and the oxygen given off, thereby establishing their equality in volume. Sachs (1862) concluded that starch grains in the green chloroplasts were the product of photosynthesis in the presence of light. He also suspected that there were intermediate products leading to the formation of starch. He discovered that starch disappears from leaves at night and reappears the next day. He proved that oxygen is a by-product of the process. Von Baeyer (1870) formulated the formaldehyde hypothesis of photosynthesis in which he stated that small amounts of formaldehyde (CH_2O) were formed from water and carbon dioxide.

The theories which have been proposed for explaining photosynthesis are based on the supposed intermediate products of the photosynthetic process. One theory is based on the supposition that formic acid and formaldehyde are intermediate products and, even though they may be poisonous, it is theorized that they are joined to some other group so quickly that they do not have time to produce toxic effects on the living protoplasm. The successive steps might be stated as follows:

(1) CO_2 (Carbon dioxide) + H_2O (Water) → H_2CO_3 (Carbonic acid)

(2) H_2CO_3 + H_2O → CH_2O_2 (Formic acid) + H_2O_2* (Hydrogen peroxide)

(3) CH_2O_2 + H_2O → CH_2O (Formaldehyde) + H_2O_2*

(4) By adding successive CH_2O → $C_6H_{12}O_6$ (Sugar)

Another theory suggests that the intermediate product of photosynthesis may be a complex chlorophyll compound. It is known that chlorophyll absorbs certain photons of light (radiant energy), thus becoming chemically active. When in this state the chlorophyll probably unites with carbon dioxide and water to form an unstable, intermediate product. An enzyme converts the chlorophyll compound to sugar. The successive steps might be stated as follows:

(1) CO_2 (Carbon dioxide) + H_2O (Water) + Chlorophyll† + Light energy → Chlorophyll carbonate

(2) Chlorophyll carbonate + Enzyme† + H_2O → Sugar + O_2

Recent experiments on photosynthesis by Graffon, Brown, and Fager utilizing radioactive tracer technics, seem to reveal that there is a primary, intermediate product of carbon dioxide and water formed which is known as "Factor B." The latter is chemically unidentified at present but behaves like an acid and is rapidly used by the plant in its metabolic processes. Proper identification of this factor and future work with radioactive chemicals which can be traced may assist in the explanation of the process.

Biochemical Aspects of Photosynthesis.—Plants do not derive their foods, as usually stated, from the soil. Plants cannot live alone on the inorganic salts and water absorbed by the root hairs from the soil but must have proteins, carbohydrates, and fats just as animals must. Both plants and animals require much of the same type of food, but the green

*Split by emzymes into water and oxygen.

†In the process the chlorophyll and enzyme are converted to their original state.

plants can manufacture their own foods from raw materials (water and carbon dioxide) while animals cannot.

Algae absorb carbon dioxide through their surface from their surroundings, while higher plants usually take it through the regulating stomata of the leaf epidermis. The water and its contained salts are osmosed into the roots by means of numerous root hairs. From the roots these materials are conducted by means of the xylem tissues of the roots and stems to the veins of the leaves. The carbon dioxide of the air is being constantly used by the many green plants, but the supply is replenished by such sources as animal metabolism, the combustion of fuels, industrial combustions, volcanic eruptions, etc.

Willstätter (1912) showed that chlorophyll actually consists of a mixture of two substances which he called chlorophyll A and chlorophyll B. Both these chlorophylls may form green crystals when extracted with ethyl alcohol. They may be separated from each other by their different solubilities in organic solvents. Chlorophyll A is blue-green in transmitted light and blood red in reflected light. Chlorophyll B is yellowish-green in transmitted light and brownish-red in reflected light. Chemically, chlorophyll is an ester (a combination of an acid and an alcohol). In both chlorophylls about 2.7 per cent of magnesium is the center. Iron is necessary for the plant to manufacture chlorophyll, but no iron enters into the composition of the chlorophyll. It is evident that the two chlorophylls are quite similar in most respects, differing only in the amounts of hydrogen and oxygen.

Biophysical Aspects of Photosynthesis.—Chlorophyll has the physical property of selectively absorbing certain wave lengths of light while other wave lengths are transmitted. When a green leaf, or a solution of chlorophyll, is placed between a source of light and a prism, dark bands appear in the spectrum (Fig. 368), showing that some of the light is absorbed by the chlorophyll, while the rest of the light is passed through the chlorophyll or reflected from the leaf surface. The color of a leaf is green because those wave lengths are not absorbed by the leaf but are reflected from its surface to the eye. In strong sunlight absorption is greatest at the red end of the spectrum where the wave lengths are longer (0.00076 mm. long). In diffuse light more absorption occurs at the violet end with its shorter wave lengths (0.00039 mm. long). The red wave lengths are more efficient because of the presence of more energy. It is well known that "the photosynthetic work accomplished varies directly with the energy absorbed from the light regardless of the wave length." The physicist, Langley, determined the distribution of energy in the spectrum as follows:

SPECTRUM REGION	PERCENTAGE OF TOTAL ENERGY
Infrared	62—63
Visible spectrum	37.0
Ultraviolet	0.6

About 63 per cent of the total energy has no value in the photosynthetic process, because none of the infrared waves are used. The relation between light and photosynthesis is considered in another part of this chapter.

Chlorophyll also possesses the optical property of fluorescence. In reflected light it appears blood red due to the fact that part of the light waves falling on it are transformed and reflected with an altered wave length.

Influential Factors in Photosynthesis.—

1. **The Carbon Dioxide Supply:** The quantity of carbon dioxide in the air is a very important factor in photosynthesis. The average amount in the air is about three parts per 10,000 (0.03 per cent). This amount is usually too small for a maximum of photosynthesis because experiments show that many of the common plants could use efficiently up to 1 per cent. Certain plants might even use higher concentrations. Increased carbon dioxide must be accompanied by corresponding increases in temperature and illumination if maximum use of the gas is to be made. Approximately 50 per cent of the dry weight of a plant body is composed of carbon which for the most part must come from the air. The application of additional amounts of carbon dioxide to such crops as tomatoes, potatoes, beets, and carrots increased their yield from 30 to 300 per cent. A tree with a dry weight of 1,000 pounds must secure 500 pounds of carbon from approximately 1,427,000 cubic yards of carbon dioxide from the air. Under natural conditions, the amount of carbon dioxide in the air is probably a limiting factor in the rate of photosynthesis.

2. **Quantity and Quality of Light:** The quantity (intensity), quality (wave lengths), and the duration of light all affect the rate of photosynthesis. Certain plants apparently require small amounts of light for the process. A lighted match held for one second 10 cm. away from a green alga (*Chorella sp.*) will initiate the process with the evolution of

oxygen. Moonlight is sufficient to continue the process in certain algae. While some photosynthesis can occur in all parts of the visible spectrum, not all parts of the spectrum are of equal value. In general, the red end of the spectrum is twice as valuable as the blue end. The lowest rate occurs in the green region; the highest rate, in the red end; infrared radiations (Fig. 368) are not used at all; ultraviolet radiations are used to a limited extent. While the rate of photosynthesis is highest in the red end because of its greater energy value in sunlight and stronger absorption of light by chlorophyll in this region, the absence of blue-violet light decreases the rate of photosynthesis. This may explain the lower rates of photosynthesis under artificial lights, which may be deficient in the blue-violet rays.

Brown has shown that in bright sunshine a sunflower leaf receives 600,000 units (gram calories) of radiant energy per square meter per hour with the formation of 0.8 Gm. of carbohydrate. Of all the light which falls on a leaf, only about 3.5 per cent is absorbed by the chlorophyll proper. Raber states that the chlorophyll apparatus has an efficiency rate of about 15 per cent.

Up to a certain point the rate of photosynthesis increases as the intensity of light increases. There are variations, but most plants require light much below the intensity of strong sunlight at noon. Usually there is more light available in nature than plants use, provided other factors are normal.

The duration or length of time a plant is in the light affects the amount of carbohydrate produced. This is an important factor in autumn and winter when light is available for shorter periods. Plants need for maturation and growth a certain number of light energy units, the unit being the product of the light intensity and the duration of time. In general, if other factors are constant, a weak light acting for a long time may have the same effect as a stronger light acting for a shorter time. The growth of plants and the ripening of their products can be speeded up by increasing the duration of light by using artificial light. Differences in light intensities and duration in various parts of the country influence the rate of photosynthesis in those different areas.

3. **Water Supply:** Since carbon dioxide is combined photosynthetically with the constituents of water, the latter becomes a limiting factor, especially if present in minimal quantities. However, increasing the water supply will increase photosynthesis only up to a certain point. If water is so deficient as to cause wilting of leaves, there probably is insufficient water for photosynthesis. The wilting may close the stomata

of the leaves, thus inhibiting the normal entrance of carbon dioxide. Water is also necessary to transport the soil salts in solution.

4. **Temperature:** In general, the rate of photosynthesis rises in a geometrical way as the temperature rises from the minimum toward the maximum. For every 10 degree rise in temperature, the rate of photosynthesis increases an average of 2.4 times, until a maximum of about 35° C. is reached, beyond which no increase in the rate occurs. In fact, beyond 35° C. the rate may even decrease. Certain conifers accustomed to cold climates may photosynthesize at –25° C., while the minimum for most plants is about 0° C. The maximum for most plants is about 45° C.

5. **Soil Salts, Including Magnesium and Iron:** Iron salts in the cells probably act as catalyzers in the photosynthesis process, although iron does not enter into the composition of chlorophyll. Magnesium is the central constituent of chlorophyll, and consequently the quantity available will influence the formation of chlorophyll, and this in turn will determine the rate of photosynthesis. Excesses of salts in the soil retard photosynthesis by inhibiting the osmosis of water by the root hairs. Salts in the plant liquids also may influence the normal functioning of the leaf stomata, and hence influence the entrance of carbon dioxide.

6. **Internal Factors, Including Chloroplasts and Enzymes:** Chlorophyll is absolutely essential for photosynthesis, and the amount of carbohydrate manufactured varies almost directly with the amount of chlorophyll in the chloroplasts. Fruits and other plant products are directly influenced by the number and size of the leaves with their contained chlorophyll. The removal of some of the leaves shows the important quantitative relation between chlorophyll and the food manufactured. Damage to leaves produced by hail, storms, and insects causes a corresponding decrease in photosynthesis.

Willstätter and Stoll theorize that a specific enzyme is associated with chlorophyll in photosynthesis. The action of this enzyme is accelerated as temperature rises, which may explain in part the effect of increased temperature. However, acceleration of the enzyme leads to increased photosynthesis only when an abundant supply of chlorophyll is present, the latter absorbing more of the necessary light energy. Probably in plants with a minimum of chlorophyll it is the lack of light absorption that limits the rate of photosynthesis, while in plants high in chlorophyll content the activity of the enzyme may be the limiting factor. Many factors operate simultaneously in the photosynthesis process and the amount of carbohydrate produced depends on their joint action. What may be a limiting factor in one plant under certain conditions may not be a limiting factor in another plant under different conditions.

The anatomic construction of the leaves and their stomata influence photosynthesis. Foreign materials, dirt, and rain in the stomata inhibit the exchange of gases, and hence influence photosynthesis. The predominance of stomata on the underside of leaves makes this a factor of less importance than if the stomata were on the upper surface.

7. **Atmospheric Pressure:** Variations in atmospheric pressure decidely influence photosynthesis; when the pressure is high, the rate is increased.

Applied and Commercial Aspects of Photosynthesis.—In most plants the demonstrable products of photosynthesis are sugars and starch. Starch is an ideal storage product because it cannot pass through the cell walls due to its insolubility. Some plants, such as the onion, produce no starch, while others produce an oil instead of starch. The carbohydrates formed by photosynthesis are the building stones of which the plant builds proteins, fats, oils, etc., as shown by the following:

Carbohydrates (glucose, cane sugar, starch)	+	Nitrogen Phosphorus Sulfur	→	Amino acids (each molecule has the amino or NH_2 group)	→	Proteins

Carbohydrates (by fermentation) →	Glycerin	↘	Fats
Carbohydrates (by oxidation) →	Fatty acids	↗	

Most of the radiant energy absorbed by green leaves is transformed into heat energy which through radiation raises the temperature of the surrounding air. In this manner some of the heat energy of the sun is captured and radiated for use by other living organisms. Some of this heat energy also vaporizes the water within the leaf. Some of the light energy absorbed by chlorophyll may be transformed into electric energy, which may explain some of the electric phenomena of living plants.

The close chemical relationship between chlorophyll A and the blood pigment *(hematin)* has caused much scientific investigation. When chlorophyll is decomposed by acids or alkalies, the residue *(hemopyrrole)* has a chemical composition similar to that of hematin which is derived from the decomposition of red blood pigment. In hemopyrrole the metallic element involved is magnesium; in hematin it is iron.

Chlorophyll has long been considered to be of dietary value to animals although its exact significance has not been determined. More experiments on plant pigments, hormones, vitamins, and other biochemical phenomena may give us additional information.

Ganong states that many of our common plants produce as an average about 1 Gm. of carbohydrate per square meter of leaf surface per hour. This may seem insignificant, but, when we consider all the green plants which photosynthesize, the total quantity produced is tremendous. In 1930, sugar beets and sugar cane produced photosynthetically in the world about 32,000,000 tons of sugar over and above what they used themselves. The United States produced about 1,500,000 tons. The carbohydrates made photosynthetically are used by the plant in digestion, translocation, respiration, assimilation, storage, and synthesis into proteins, fats and oils, or other types of carbohydrates. When we consume plants we utilize those products which they formed but did not use for their own needs.

Plants use the products which they have photosynthesized in many ways as shown by the following: (1) They may be digested into soluble forms; (2) they may be translocated to other parts of the plant; (3) they may be synthesized into proteins, fats, oils, or other carbohydrates; (4) they may be oxidized through fermentation or respiration to liberate

Products Resulting From Photosynthesis*
(Including Years in Which Data Were Selected)

PRODUCT	WORLD	UNITED STATES
Oats (average 1921-30)	4,491,000,000 bu.	1,285,513,000 bu.
Corn (average 1921-30)	4,144,000,000 bu.	2,712,430,000 bu.
Wheat (average 1921-30)	4,081,000,000 bu.	831,578,000 bu.
Rye (average 1921-30)	1,664,000,000 bu.	56,269,000 bu.
Barley (average 1921-30)	1,636,000,000 bu.	237,395,000 bu.
Rice (1930-31) China excluded	137,000,000,000 lb	1,248,000,000 lb
Beet and cane sugar (1930-31)	64,000,000,000 lb	3,000,000,000 lb
Cotton (average 1927-30)	12,715,000,000 lb	7,000,000,000 lb
Hemp (1927)	1,622,000,000 lb	2,000,000 lb
Coffee	3,000,000,000 lb	
Tea	1,760,000,000 lb	
Cocoa beans (1926)	1,000,000,000 lb	
Beans (dry) (1931-32)	4,004,000,000 lb	1,266,000,000 lb
Apples (1932)		140,000,000 bu.
Oranges (1932)		49,000,000 boxes
Grapefruit (1932)		13,000,000 boxes
Lemons (1932)		7,000,000 boxes
Rubber (average 1925-29)	2,000,000,000 lb	
Turpentine (average 1925-29)		6,000,000 gal.
Rosin (average 1925-29)		500,000,000 lb
Lumber		41,000,000,000 bd. ft.
Wood pulp (1930)		7,000,000 cords

*The total value of all farm products in the United States alone averages between 15 and 20 billion dollars annually.

energy; (5) through assimilation and growth they may build new tissues; (6) they may be stored in roots, seeds, or stems for future use or for the use of animals.

It is believed that coal, peat, petroleum, natural gas, and similar fuels are the result of decomposition of living organisms of many years ago. These remains originally were made by the plant through the process of photosynthesis and the radiant energy stored in these fuels in the form of potential energy. When these fuels are used today, this energy is released. The amount of photosynthesis which has taken place in all the green plants of the past is beyond our imagination. The amount of material produced each year by present-day plants through the process of photosynthesis is beyond computation.

IX. RESPIRATION BY PLANTS

During respiration there is an absorption of oxygen and a liberation of carbon dioxide. Respiration occurs continuously in the living protoplasm of all animal and plant cells. In this respect it differs from photosynthesis which occurs only in chlorophyll-bearing cells of green plants in a proper source of light energy. These two phenomena have been contrasted in a previous chapter. During respiration the molecules of the plant materials are broken down into simpler forms, and the stored chemical energy is liberated in such a form as to be utilized by the plant. During photosynthesis, light energy is absorbed and used by the plant. Animals confiscate energy when plants are consumed. All the energy used by plants and animals in their activities is derived, directly or indirectly, from the sunlight. For instance, when such a sugar as glucose is oxidized by respiration, the equation is as follows:

$$\underset{(C_6H_{12}O_6)}{\text{Glucose (sugar)}} + \underset{(6O_2)}{\text{Oxygen}} \rightarrow \underset{(6CO_2)}{\text{Carbon dioxide}} + \underset{(6H_2O)}{\text{Water}} + \underset{\text{released}}{\text{Energy}}$$

In many respects this equation is the reverse of the equation of photosynthesis.

X. CORRELATION AND PLANT HORMONES

Correlation in plants by means of chemical hormones recently has been realized as being of utmost importance. The presence of specific chemical substances in plants (of certain species, at least) is known to play an important role in plant metabolisms and in the correlation of the plant as a whole. Plant hormones might be defined as chemical substances naturally produced in minute quantities by plants, stored in certain regions, and later transported to other regions to produce regulatory effects on the development and growth of that organism. The term hormone (Gr. *hormao,* excite) means "to arouse to activity." Hormones in plants are normally produced in very minute quantities but apparently are sufficient to perform their specific functions. Much of the experimental evidence of the past years concerning the activity of plant growth hormones has helped to explain normal growth, tropisms (responses) to gravity, tropisms to light, and similar phenomena. Plant hormones, like animal hormones, are produced in one part of the plant

CHARACTERISTICS OF PLANT GROWTH HORMONES

NAME	CHEMISTRY	MELTING POINT	EFFECTS OF ACIDS AND ALKALIES	FUNCTIONS WITHIN THE PLANT
Auxin A or auxentriolic acid	$C_{18}H_{32}O_5$	196° C.	Stable in acid; sensitive to alkali	Promotes cell elongation in the direction of the long axis of tissues; growth of leaves and stems is dependent on it, while root growth is inhibited by it
Auxin B or auxenolonic acid	$C_{18}H_{30}O_4$	183° C.	Destroyed by acid and by alkali	Same as above
Heteroauxin or 3-indole acetic acid	$C_{10}H_9O_2N$	165° C.	Sensitive to acid; stable to alkali	Same as above

(usually young, vigorously growing parts) and transported to another part of the organism where they actively control specific phenomena, depending on the type of hormone in question. The tropic responses of plants to two of the most important environmental stimuli, gravity and light, are associated definitely with the movement of plant hormones ("auxins") from one region of a stimulated plant organ to another. This phenomenon is known as the growth hormone explanation of tropisms. Several different plant hormones have been found naturally present: (1) auxin A, (2) auxin B, and (3) heteroauxin, which seems to be the most widely distributed of the present hormones. Another plant hormone, *traumatin* (Gr. *trauma,* wound) seems to initiate and influence healing of plant wounds.

In young plant tissues the hormones move only in a morphologically basipetal direction ("polar transportation"), but in older tissues they move in either direction. In very old inactive tissues there is probably very little, if any, movement. The plant hormones may be transported in the following ways: (1) by diffusion, (2) by protoplasmic streaming, (3) by the transportation or circulatory system of the plant, if such is present, (4) by an electrical phenomenon in which they are moved toward a positively charged pole because of changes in electrical potential within the plant. A similar phenomenon in animals has been suggested by recent experimental evidence. In spite of the fact that plant hormones can be extracted from plants, there is no chemical test which provides a simple and efficient means of qualitative and quantitative detection of the minute amounts of them in living plants. However, certain physiologic methods are now being perfected by means of which the hormone concentration can be determined.

XI. GROWTH OF PLANTS, POLARITY, MORPHOGENESIS

Plants increase in size by mitosis (cell division) or by an increase of the size of the cells without increasing the number. In many instances growth is probably the result of both these phenomena occurring at the same time. There is a limit to the size to which a cell can grow and normally carry on its metabolic activities. After a certain size is reached, mitosis must occur and the two resulting cells must increase in size by assimilating foods brought to them. It is not known precisely how the living protoplasm in these plant cells assimilates this food. Undoubtedly, the various food elements are built up and held together by energy supplied to the plant, principally through oxidation of food materials. The actual rate of growth of a particular plant, or any of its parts, is influenced by such factors as (1) the specific inheritance of those cells, (2) the quantity and quality of available foods, (3) the age of the plant, (4) the amount of available oxygen, and (5) the presence of specific plant hormones.

Generally speaking, plant growth hormones bring about growth if such conditions as water supply and foods are satisfactory. It is believed that no plant growths can take place without the presence of the specific plant hormones previously described. The hormone auxin in minute quantities promotes the elongation of cells (stretching) in the direction of the long axis of an organ, such as a stem or branch. In this case auxin is said to promote "polarized growth"; that is, growth in length rather than in another direction. This is particularly true in younger tissues. After tissues have reached a certain age, growth occurs in such a manner that the tissue increases in diameter. In all instances growth is dependent on plant hormones.

Polarity (L. *polus,* pole) is a phenomenon in which there exists structural and functional direction due to complex internal factors. For example, experiments show that certain plant stems (such as willow, etc.) when cut into sections and suspended in humid air will develop shoots from the distal end and adventitious roots from the proximal end. This proves that these stems possess a permanent physiologic difference between the two ends which is called *growth polarity.* If the experiment is performed in moist soil, roots may form on the original distal end of the stem (when placed in the soil) but they will form more slowly and less extensively than on corresponding stems whose proximal ends are placed in the soil. So these stems seem to have a prospective "shoot end" and prospective "root end" which shows polarity in the stem.

Polarity seems to be present in individual cells, parts of organs, entire organs, etc., in which functional polarity accompanies structural polarity. *Hormonal polarity* exists in which the movements of plant hormones (auxins, etc.) are primarily polar, taking place primarily from the more distal (apical) to the more basal (proximal) parts of a plant structure. This distribution and presence of hormones in certain regions of plants explain some of the many growth and behavior phenomena of plants.

Electrical polarity is experimentally proved in which the distal (apical) end of stems is electropositive, while the basal (proximal) part is electronegative. A similar electrical polarity exists in cells. All of these polarities seem to be inherent and usually fixed and ordinarily cannot be changed materially by environmental conditions.

When living cells pass through their enlargement stages, they undergo *differentiation* (L. *differe,* to differ) in which division of labor and differences in structure and form occur, depending on the various functions to be performed. These causes of differentiations are due to hereditary determiners in each species of plant, being transmitted from one generation to the next. Environmental conditions, at times, may modify these differentiations of cells but only quantitatively and not permanently. This study of differentiation is called *morphogenesis* (mor fo -jen′ e sis) (Gr. *morphe,* form; *genesis,* origin).

XII. PLANT TROPISMS (REACTIONS)

Each species of plant is affected in specific ways by external and internal factors. Light, heat, moisture, chemicals, gravity, and atmosphere are a few of the influential external factors, while the chromosomes and their genes, the chemical constituents of the protoplasm, and the chemical hormones are important internal factors. External environmental conditions which cause a plant to react are known as external stimuli. A reaction to a stimulus which possesses direction is known as a tropism. The following tropisms are common in plants:

Phototropism (Reaction to Light).—The stems usually grow toward light (positive phototropism), while roots usually grow away from light (negative phototropism).

Geotropism (Reaction to Gravity).—Stems are generally negatively geotropic, while most roots are positively geotropic.

Chemotropism (Reaction to Chemicals).—This reaction is exhibited by plants in various ways, depending upon the quality and quantity of the chemical and the species of plant.

Thermotropism (Reaction to Heat).—Certain plant structures grow toward heat, while others grow away from it, depending on the quantity and quality of the heat and the species of plant. The reaction of cold (the absence of heat) is also important and characteristic.

Hydrotropism (Reaction to Moisture).—Roots tend to be positively hydrotropic, or grow toward a supply of moisture, because one of their functions is to supply water to the plant.

Thigmotropism (Reaction to Contact With Solid Objects).—The small tendrils of certain plants are stimulated by contact with solid objects so that the tendrils grow around that object. This contact stimulates the cells of that particular region so as to produce an unequal rate of mitosis in the two sides of the tendril. This unequal rate of growth results in the curving of the tendril around the solid object.

A young stem always bends toward the light because of a greater concentration of growth hormone on the darkened side of the stem. One possible explanation for this is that it is at least partly due to a light-induced change in the electric potential across that stem. In a similar manner the various tropisms are thought to be determined and influenced by the actions of the various hormones present in the plant. This is known as the hormone explanation of tropisms.

XIII. PLANT PIGMENTS

The structures and functions of pigments in the plant kingdom are not well understood at the present time. There is no doubt that pigments play important roles, but only future experiments in this field will reveal their true significance. It is commonly known that a variety of pigments exist in leaves, flowers, seeds, stems, and fruits. Certain unicellular and simple multicellular plants have pigments whose functions are not definitely established. The blue-green algae (phylum *Cyanophyta*) contain a blue pigment, phycocyanin, in addition to the green chlorophyll and yellow pigments. The red algae (phylum, *Rhodophyta*) contain a red pigment, phycoerythrin, in addition to the green chlorophyll. The brown algae (phylum *Phaeophyta*) contain a brown pigment, fucoxanthin, in addition to the green chlorophyll. The green algae (phylum *Chlorophyta*) contain green chlorophyll which predominates over the carotene and xanthophyll pigments. The diatoms (phylum *Chrysophyta*) have a yellowish-brown pigment in addition to their green chlorophyll. A brief summary of the pigments of higher plants is given in the accompanying table.

Green pigments, such as chlorophyll, may occur in any part of a plant which is exposed to light, although they also occur without light in such tissues as lemon and melon seeds, in embryos and endosperm, certain fruits, and in the wood of many Rosaceae. Chlorophyll A in alcoholic solution appears blue-green by transmitted light and blood red by reflected light and has a blood red fluorescence. Chlorophyll B in alcoholic solution appears yellow-green by transmitted light and has a brownish-red fluorescence. The formation of chlorophyll is dependent on (1) iron, which is necessary to form chlorophyll but is not a part of the pigment; (2) at least a minimum of light to develop chlorophyll from the unstable pigment chlorophyllogen, although certain algae, young ferns, and the seedlings of certain conifers become green in darkness; (3) moderate temperature for an optimum formation of chlorophyll, because there is no greening at very low or very high temperatures; (4) an excess of oxygen which seems necessary for greening; (5) the proper quantity and quality of carbohydrates; (6) certain mineral salts, especially magnesium, which is an important constituent of chlorophyll.

Yellow pigments may occur in any part of a plant and their presence is not related to the presence of light. One important yellow pigment is xanthophyll (Gr. *xanthos*, yellow; *phyllon*, leaf), which is common in the leaves of elms, birches, and poplars. Xanthophyll is also found in animals in egg yolk and yellow feathers. Xanthophyll is one of several pigments known as carotinoids which form about 0.5 per cent of the weight of fresh leaves. In the fall, as chlorophyll decomposes, the carotinoids become visible, often together with the red anthocyanins in leaves. From its chemical formula xanthophyll appears to be merely an oxidation product of carotene which is another carotinoid pigment.

Another carotinoid pigment is carotene (Gr. *karotin*, carrot yellow), which is almost insoluble in alcohol (cold) and which forms flat rhombic

SUMMARY OF PIGMENTS IN HIGHER PLANTS

PIGMENT	COLOR	CHEMICAL CHARACTERISTICS	PERCENTAGE IN LEAVES	OCCUR IN PLASTIDS	IN SOLUTION	EXAMPLES
Chlorophyll A	Bluish-green	$C_{55}H_{72}O_5N_4Mg$	62.0	Yes	Bluish-green with a deep red fluorescence in alcoholic solution	In leaves of most higher plants
Chlorophyll B	Yellow-green	$C_{55}H_{70}O_6N_4Mg$	22.0	Yes	Yellow-green with a brownish-red fluorescence in alcohol	In leaves of most higher plants
Xanthophyll	Yellow-orange	$C_{40}H_{56}O_2$	9.3	Yes		Leaves of elm, birch, and poplar; in the fall this pigment becomes visible when chlorophyll disappears
Carotene	Yellow-orange	$C_{40}H_{56}$	5.5	Yes	Nearly insoluble in alcohol	Same as xanthophyll above
"Flavones" or flavonols	Yellow	Yellow crystals with high melting point		No?	Deep yellow or orange-yellow with alkali	Occurs as glucosides (sugar plus flavone) in such plants as osage orange, sumac, yellow wood, snapdragon, and onion (skins)
Anthocyanins	Red	Closely related to the glucosides ($C_3H_6O_5$); usually require sunlight for their development		No; they are in solution in cell sap	Red or purple in acid solution and green or blue in alkaline or neutral solutions	"Delphinidin chloride" in grape, red hollyhock, red petunia, violet, etc. Pelargonin in red geranium, red and purple aster, scarlet sage Cyanidin in red dahlias, poppies, cornflower, fruits of cherry, currant, and strawberry Peonidin in red peonies

crystals. It is widely distributed in the green parts of plants, but it is also found in flowers, fruits, seeds, roots, and certain fungi. It is present in large quantities in carrots. The carotene content of leaves varies with the seasons because its formation is dependent on light. Its function is not clear, but its tendency to unite with oxygen may be significant in photosynthesis where reduction of compounds containing oxygen occurs.

Flavones (L. *flavus,* yellow) are yellow pigments in such plants as yellow wood *(Morus),* osage orange *(Maclura,)* and sumac *(Rhus).* They are not so common in yellow flowers and leaves where the color is due to carotinoids. Flavones are probably oxidation products, the exact functions of which are not clear at present. They are responsible for the yellow color of onion skins and certain snapdragons. In most plants they occur as glucosides.

Red pigments known as anthocyanins (Gr. *anthos,* flower; *kyanos,* dark blue) are dissolved in the cell sap of such structures as certain flowers, fruits, and leaves, beet roots, red cabbage, etc., where they give red, purple, or bluish colors. Anthocyanins absorb some light energy which is converted into heat. The latter increases the temperature, which accelerates the metabolic activities of the cell and probably aids in protecting the plant from the lowered temperature of the surrounding air. This is plausible in view of the fact that anthocyanins are more common in leaves in the fall than in summer. Anthocyanins develop more abundantly in all parts of a high alpine plant than in the lowland plant, even in plants of the same species. For example, the common weed, the yarrow *(Achillea millefolium),* has white flowers in lowlands and southern regions but has red flowers on high mountains and in the far north. Anthocyanin formation depends on (1) the presence of sugars, (2) a certain amount of light (they are "sun pigments"), although they also develop in the roots of beets and in the outer part of radish roots which do not contact light; and (3) a lower temperature, which naturally must be above freezing. A few examples of anthocyanins which occur naturally are red plums, red bananas, red rose, red berries, red geranium, red hollyhock, red hyacinths and tulips, the bracts of the Poinsettia, the scarlet oak, scarlet maple, and similar materials.

In general, plant pigments have been credited with such functions as follows: (1) An aid in respiration. The relationship between anthocyanins and easily oxidizable sugars suggests a possible correlation between the processes of oxidation and respiration. Carotene is oxidizable into xanthophyll. Red anthocyanins may be changed to blue ones by oxidizing and reducing enzymes. (2) An aid in photosynthesis by absorbing usable light. It is known that certain anthocyanins can absorb certain light rays which the chlorophyll cannot, thus supplying the latter with energy. (3) Absorbers of heat rays which protect chlorophyll against too strong light and secure a maximum of energy. Red pigments in autumnal leaves and fruits absorb more energy, which hastens the maturing and ripening processes. (4) Attractions and repellents for animals. Certain colors and odors attract animals to plant flowers, thus ensuring their pollination. Most insect-pollinated flowers are brightly colored and have strong odors. (5) Osmotic constituents of cells. Anthocyanins and other soluble pigments are important osmotic constituents of cells and thus are associated with the passing of materials through cell walls.

Plant pigments play a very important role in the autumnal coloration of leaves. This phenomenon varies from year to year in its duration and in the degree of its magnificence. As cooler weather comes, the green chlorophyll disintegrates. This permits the yellow carotinoid pigments to become visible, and, if sugars are present, the reds and lavenders of the anthocyanins also appear as they are formed. Bright days in early fall produce abundant sugars upon which the bright yellows and reds depend. Plants rich in sugars, such as maples and birches, are likely to be bright red and yellow. Brown colors are due to flavones, and more often to tannins in the cell walls. The leaves of oaks and beeches are rich in tannin, hence are likely to be brown. Although the phenomenon of autumnal coloration is not completely understood, sufficient data have been secured to explain the process in a general way.

QUESTIONS AND TOPICS

1. Describe briefly each of the five general regions of the root.
2. Discuss briefly each of the primary and secondary tissues of the mature region.
3. Describe the general anatomy and physiology of (1) stems, (2) leaves, and (3) flowers.
4. Explain how absorption occurs and the importance of this phenomenon.
5. Discuss the purposes of transpiration in higher plants.
6. How are liquids conducted in higher plants?
7. Discuss the manufacture, distribution, and storage of foods in plants.
8. Describe the method of respiration in plants.
9. Explain the phenomenon of correlation in plants, including the characteristics and functions of auxins and heteroauxins.
10. Discuss briefly the methods of growth in higher plants.
11. Classify plant tropisms and give explanations for these vital phenomena.
12. Classify plant pigments and give characteristics and functions of each pigment.

13. Write a brief article explaining the phenomenon of autumnal coloration of leaves.
14. Describe the process of photosynthesis, including the biophysical and biochemical factors which may influence it.
15. List the sources of foods, fuels, shelter, and textiles which are dependent upon photosynthesis.
16. Discuss the various types of polarity with examples of each.
17. Define differentiation and morphogenesis, with examples of each.

SELECTED REFERENCES

Avery and Johnson: Hormones and Horticulture, McGraw-Hill Book Co., Inc.
Boysen and Jensen: Growth Hormones in Plants, McGraw-Hill Book Co., Inc.
Curtis: The Nature and Development of Plants, Henry Holt & Co.
Curtis: The Translocation of Solutes in Plants, McGraw-Hill Book Co., Inc.
Curtis and Clark: Introduction to Plant Physiology, McGraw-Hill Book Co., Inc.
Dixon: The Transpiration Stream—University of London Press.
Eames and MacDaniels: An Introduction to Plant Anatomy, McGraw-Hill Book Co., Inc.
Ellis and Swaney: Soilless Growth of Plants, Reinhold Publishing Corp.
Gardner: Basic Horticulture, The Macmillan Co.
Gericke: The Complete Guide to Soilless Gardening, Prentice-Hall, Inc.
Hoagland: Inorganic Plant Nutrition, Chronica Botanica.
Jeffrey: The Anatomy of Woody Plants, University of Chicago Press.
Maximov: The Plant in Relation to Water, The Macmillan Co.
Meyer and Anderson: Plant Physiology, D. Van Nostrand Co., Inc.
Miller: Plant Physiology, McGraw-Hill Book Co., Inc.
Mitchell and Marsh: Growth Regulators, University of Chicago Press.
Pool: Flowers and Flowering Plants, McGraw-Hill Book Co., Inc.
Russel: Soil Conditions and Plant Growth, Longmans, Green & Co.
Schopfer: Plants and Vitamins, Chronica Botanica.
Seifriz: The Physiology of Plants, John Wiley & Sons, Inc.
Sharp: Fundamentals of Cytology, McGraw-Hill Book Co., Inc.
Skene: The Biology of Flowering Plants, The Macmillan Co.
Went and Thimann: Phytohormones, The Macmillan Co.
Wodehouse: Pollen Grains, McGraw-Hill Book Co., Inc.

Chapter 16

ECONOMIC IMPORTANCE OF PLANTS

Naturally, not all plants of economic importance or the economic importance of all plants listed can be fully considered in one chapter. Economic importance is considered from the beneficial as well as the detrimental standpoint. Certain phases of economic biology are also considered in the chapter on Applied Biology. Greater emphasis constantly is being placed on the economic importance of both animals and plants in everyday life. Consequently, a consideration of a few representative phases in courses in biology is essential. The following descriptions are representative but by no means complete. For more detailed discussions the reader is referred to books on economic botany.

I. ECONOMIC IMPORTANCE OF ALGAE (Figs. 29 to 33)

Certain blue-green algae (phylum *Cyanophyta*) may become so abundant in fresh water as to produce a distinct color, the so-called "water bloom." When they die and decay, they may give the water a very unpleasant taste and odor. Cattle have been known to die by drinking water in which they were very abundant. The larger brown algae (phylum *Phaeophyta*) are a source of such materials as iodine and potash. The red algae (phylum *Rhodophyta*) are sources of agar-agar which is used as a medium for the cultivation of bacteria as well as for a medicine. A jellylike food is obtained from the red alga known as "Irish moss." Certain types of red algae become encrusted with lime and thus help in the formation of the so-called "coral" reefs, atolls, and islands.

Because of their toughness, certain algae when dried are used in making fishing lines, handles for tools, and similar objects. Certain seaweeds (algae) as well as diatoms (phylum *Chrysophyta*) are used by various animals for foods.

Fossil diatoms form "diatomaceous earth" which forms the basis of many scouring or cleaning materials, such as metal polishers and tooth pastes. Certain diatoms, because of their fine, regular markings, are used as test objects for calibrating microscope lenses. Diatomaceous earth is also used as a heat-insulating material. It may also be molded into hollow cylinders or "bougies" used in making bacteriologic filters. Dynamite is made by absorbing nitroglycerin in diatomaceous earth.

II. ECONOMIC IMPORTANCE OF FUNGI (Figs. 34 to 42)

Fungi by their growth in foods, clothing, and lumber frequently destroy them or diminish their values. One of the principal wood-rotting fungi *(Merulius lacrymans)* attacks wood at rather low temperatures, about 15° C. These fungi do not thrive in water or water-logged soils because they are aerobic. Decay of wood thus occurs most rapidly near the ground- or water-line. Heartwoods are generally more resistant than sapwoods. Certain fungi, including bacteria, help in the necessary and desirable decay of plant and animal remains, thus removing them from the water and soil and rendering their constituents again available for use by future living organisms.

Certain types of mushrooms (class Basidiomycetes) are used as human foods. Several species are extremely poisonous and cause severe illness or death when eaten. Great care should be taken in the selection and use of mushrooms. Unless the collector is absolutely certain the species is nonpoisonous, he should discard it. In case of doubt, the specimens in question should be discarded. The flavors which are characteristic of certain cheeses are produced by specific fungi. The characteristic odors and tastes of Roquefort cheese and Camembert cheese are produced by the molds *Penicillium roqueforti* and *Penicillium camemberti,* respectively (Fig. 39).

Penicillium notatum, Aspergillus sp. (Fig. 73), and numerous other fungi produce penicillin and other antibiotic substances successfully used in the treatment of many diseases. Recent discovery of the remarkable curative values of penicillin and other antibiotic substances has stimulated great interest in the entire field of chemotherapy. In 1877, Pasteur and Joubert discovered that certain airborne organisms inhibited the growth of anthrax bacilli, and they suggested that antibiotics might be utilized in the treatment of certain infections. Dr. Alexander Fleming in London (1929), observing a plate culture of *Staphylococcus* organisms, noted the presence of a contaminating mold colony *(Penicillium notatum)* (Fig. 73) and noted that the *Staphylococcus* organisms surrounding the mold colony were undergoing lysis (destruction). Thus began the steps to obtain, cultivate, and purify the most remarkable chemical therapeutic agent for the treatment of certain types of bacterial infections. The progress made in the production and use of penicillin has been so great and fast that one can only guess of the possibilities of the future. Some of the characteristics of penicillin are as follows: it is a light brown powder (as now used); appears to be virtually nontoxic in doses required for therapeutic purposes; is highly selective in its action, being capable of destroying certain bacteria without injury to body cells; is highly soluble in water or saline solution; is stable to light but is affected by heat; when administered, it is rapidly excreted in the urine; is highly successful in the treatment of many diseases which heretofore have been difficult to treat.

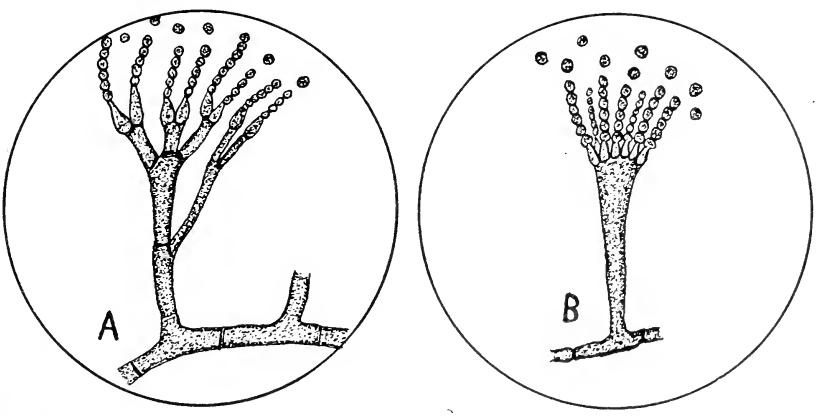


Fig. 73.—Two common fungi, *(A) Penicillium sp.* and *(B) Aspergillus sp.*, which produce penicillin and other antibiotic substances used in the treatment of numerous diseases.

In spite of the wide and successful use of penicillin, scientific workers are still attempting to discover other antibiotic substances which may be equally satisfactory. In fact, dozens of antibiotic substances are known to be produced by molds, bacteria, actinomyces, a certain unicellular Alga *(Chlorella sp.)*, certain weeds and flowering plants, soybean flour, common garlic, etc. All of them are being tested, and some show great promise.

Certain fungi kill insects which are harmful to man. Certain species of bacteria attack insects and may produce illness and cause death, although their specific pathogenicity has not been definitely proved. Bacteria and fungi aid in insect decay after death, thus returning their chemical constituents to the soil to be used by future organisms. A few species of slime molds (phylum *Myxomycophyta*) are parasites on living seed plants (Fig. 35).

There are two principal groups of yeasts: (1) the Saccharomyces (sugar fungi), which are harmless (Fig. 37) and (2) the Blastomyces (germ fungi), which are pathogenic. The harmless yeasts are of great importance in connection with the manufacture of wines and beers and in other industries which depend upon the fermentation of sugars and similar substances. The most common fermentation which yeasts are able to produce is the so-called alcoholic fermentation in which sugars are attacked, with the formation of ethyl alcohol and carbon dioxide. The various species of saccharomyces are able to ferment various sugars and related substances, forming a large number of end products, many of which are useful in industrial processes. The familiar "yeast cake" is composed of yeast cells mixed with a small quantity of starch. When harmless yeasts are added to bread dough, the cells multiply rapidly (if proper temperature exists) and ferment the sugars, thus giving off carbon dioxide. This harmless gas escapes through the dough and causes it to "rise." The gas leaves countless small holes which make the bread porous and light.

Certain fungi cause great economic losses by producing diseases of higher plants. A few representative examples are the white rust of radish, mustard, cress, and related plants; the chestnut blight, a fungus disease which has exterminated practically all our chestnut trees; corn smut; wheat rust; potato scab, which renders the skin of potatoes rough and unsightly; the ergot of rye, in which the fungus, Ergot *(Claviceps purpurea)* parasitizes the rye, resulting in poisonous, hypertrophied grains. Epidemics of ergotism have been frequent in the past, but modern methods of cleaning have eliminated it to a great extent. The ergot is a high-priced drug of high medicinal value.

Certain pathogenic fungi cause diseases in man and other animals. The following are rather common, representative types: (A) The pathogenic yeastlike fungus *(Blastomyces dermatitidis)* (Fig. 74, *A*) produces a chronic infection known as *North American blastomycosis (Gilchrist's* *disease)* characterized by suppurative and granulomatous lesions anywhere in the body but especially in the skin, lungs, and bone. The causal organism is a spherical, budding, yeastlike fungus. (B) The pathogenic yeastlike fungus *(Candida* [*Monilia*] *albicans)* (Fig. 74, B) causes a great variety of acute or subacute infections known as *moniliasis* in which lesions may be present in the mouth, skin, vagina, nails, or lungs, and even a septicemia, endocarditis, or meningitis. When the mouth is infected there are produced creamy-white patches of ulcers, and this disease is called *thrush.* The causal organism is a budding, yeastlike, mycelium-producing, nonascospore-forming, fungus. (C) The pathogenic fungus *(Coccidioides immitis)* (Fig. 74, *C*) causes a very common

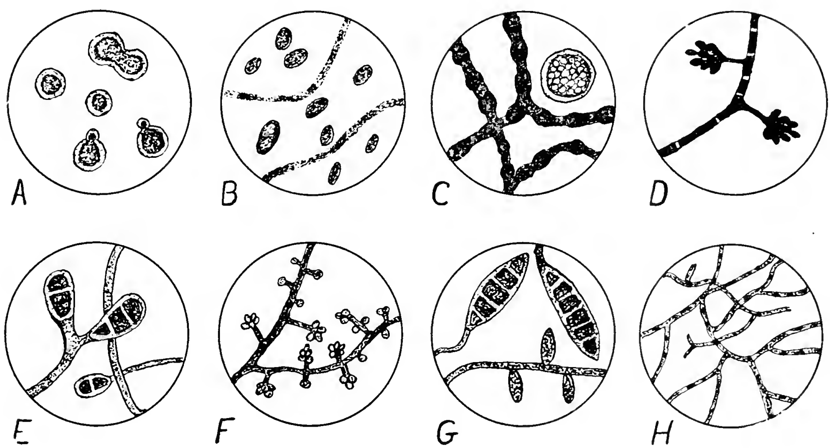


Fig. 74.—Pathogenic fungi, not drawn to scale and somewhat diagrammatic. *A, Blastomyces dermatitidis,* showing yeastlike budding cells; *B, Candida (Monilia)* albicans, showing yeastlike cells and hyphae; *C, Coccidioides immitis,* showing branching hyphae segmented into thick-walled arthrospores, and a thick-walled spherical structure (upper right) filled with endospores; *D, Sporotrichum schenckii,* showing branching, segmented hyphae with clusters of terminal conidia; *E, Epidermophyton floccosum,* showing hyphae with clavate, multiseptate macroconidia; *F, Trichophyton sp.,* showing hyphae with numerous single-celled microconidia; *G, Microsporum sp.,* showing hyphae with large multicellular macroconidia (above) and small, unicellular microconidia (below); *H, Actinomyces bovis,* showing delicate, branching filaments, very much like those of certain bacteria such as *Mycobacterium tuberculosis.* (From various sources.)

infectious disease known as *Coccidioidomycosis* which may be of two types: (1) primary (usually acute but benign self-limited respiratory infection) and (2) progressive (chronic malignant infection involving the skin, internal organs, or bones). The causal organism is a fungus whose hyphae are septate and branched and break into numerous rectangular or oval, thick-walled, infectious arthrospores. In lesions, however, *C. immitis* may appear as a spherical, thick-walled, nonbudding structure filled with numerous small endospores which reproduce the fungus within the tissues. (D) The pathogenic fungus *(Sporotrichum schenckii)* (Fig. 74, *D*) causes a chronic infection known as *sporotrichosis* characterized by the formation (in skin, lymph nodes) of nodular lesions which soften and break to form ulcers. The causal organism is a fungus whose hyphae are septate and branched and bear oval or pyriform (pear-shaped) conidia laterally or in groups at the ends of the lateral branches. (E) Several species of fungi, known collectively as *dermatophytes,* produce infectious skin diseases known as *dermatomycoses.* The specific clinical symptoms and the causal organism vary with the particular disease as shown by the following: (1) *"Athlete's foot" (Tinea pedis, ringworm of the feet)* is a world-wide infection of the skin of the feet (especially soles and between toes) caused by such fungi as *Epidermophyton floccosum* (Fig. 74, *E*) or various species of *Trichophyton* (Fig. 74, *F*). *Epidermophyton* hyphae bear the characteristic, large, clavate (club-shaped), multiseptate conidia and *Trichophyton* hyphae bear numerous, single-celled, thin-walled, oval or clavate conidia (singly or in clusters). (2) *Tinea corporis (ringworm of the body)* is an infection of the skin of the body caused by various species of the fungi, *Trichophyton* (Fig. 74, *F*) or *Microsporum* (Fig. 74, *G*), and is characterized by simple, or granulomatous lesions. *Microsporum* is composed of hyphae with (a) large, multicellular, thick-walled, rough, spindle-shaped macroconidia, and (b) small single-celled, clavate microconidia borne on the sides of the hyphae. (3) *Tinea capitis (ringworm of the scalp)* is a world-wide infection of the scalp and hair caused by various species of fungi, *Trichophyton* (Fig. 74, *F*) or *Microsporum* (Fig. 74, *G*), and is characterized by scaly, red lesions, and sometimes deep ulcerative lesions. (F) The pathogenic fungi *(Actinomyces bovis)* (Fig. 74, *H*) and several species of *Nocardia* cause a chronic, world-wide, systemic infection called *actinomycosis* or *lumpy jaw,* and is characterized by granulomatous lesions tending to break down and form abscesses which drain through multiple openings. The causal fungus, *Actinomyces bovis* (Fig. 74, *H*), is anaerobic, closely related to the bacteria, and composed of tangled masses of delicate, branching hyphae, while the species of actinomycetes belonging to the genus *Nocardia* are aerobic and may be inhaled with dust, straw, and other materials.

About 150 species of bacteria (phylum *Schizomycophyta*) are directly or indirectly responsible for human diseases. The following are a few common, representative human diseases of bacterial origin (Fig. 34):

Boils, carbuncles, abscesses, etc.	*Staphylococcus aureus*
Internal and general infections	*Streptococcus pyogenes*
Many cases of "sore throat"	*Streptococcus hemolyticus*
Erysipelas	*Streptococcus erysipelatis*
Scarlet fever	*Streptococcus scarlatinae*
Meningitis	*Diplococcus intracellularis*
Gonorrhea	*Neisseria gonorrhea*
Pneumonia	*Diplococcus pneumoniae*
Anthrax or splenic fever	*Bacillus anthracis*
Diphtheria	*Corynebacterium diphtheriae*
Typhoid fever	*Eberthella typhosa*
Paratyphoid fevers	*Salmonella paratyphi* (Type A) *Salmonella schottmülleri* (Type B) *Salmonella hirschfeldii* (Type C)
Tuberculosis	*Mycobacterium tuberculosis*
Leprosy	*Mycobacterium leprae*
Malta or undulant fever	*Brucella melitensis*
Plague or "black death"	*Pasteurella pestis*
Tularemia or "rabbit disease"	*Pasteurella tularense*
Whooping cough	*Hemophilus pertussis*
Tetanus or "lockjaw"	*Clostridium tetani*
Gaseous gangrene	*Clostridium welchii and others*
Botulism (toxic food poisoning)	*Clostridium botulinum*

From the consideration given above, one might imagine that all bacteria are harmful. This is not the case. Most bacterial organisms are neither harmful nor beneficial; less than three hundred have been specifically proved pathogenic, and an ever-increasing number is found to be very beneficial in many ways. Bacteria are valuable in decomposing plant and animal remains so that the original constituents may again be used by future living organisms. Bacteria are also employed in the process of tobacco curing as well as in the retting process followed in the preparation of flax for industrial purposes. Certain species of bacteria play an important role in the fermentation of sauerkraut, giving it the characteristic odor and flavor. Other species of bacteria are beneficially associated in the manufacture of butter, cottage cheese, and other cheeses. Specific bacteria are responsible for the use of free nitrogen of the air by the plants of the legume family. This is more fully discussed in the nitrogen cycle. Other organisms are also associated with other nitrogen transformations in the soil. The manufacture of vinegar is also dependent upon the fermentation of certain juices by acetic acid bacteria. It is thought that bacteria, and possibly other microorganisms, are responsible for the decomposition of the remains of organisms with the formation of crude oil and natural gas. It is also stated that certain specific kinds of bacteria are necessary for the desirable decomposition of waste materials in the human large intestine. Naturally, not all types would be desirable for this important work. If the bacterial flora of the large intestine is not normal, there may result a variety of abnormal conditions.

III. ECONOMIC IMPORTANCE OF BRYOPHYTES (Figs. 43 to 46)

Peat mass *(Sphagnum)* (Fig. 46) is used for packing materials in shipping, in surgical dressings, in gardening, and similar ways. In gardening the peat moss retains soil moisture and prevents weed growth. One species of sphagnum can absorb approximately twenty times its weight of water. Certain kinds of coal were formed by an accumulation of the remains of sphagnum mosses in swamps and open waters of past ages. Peat is formed by sphagnum moss and, when dried, is used as fuel in certain communities where other materials are not available. A few species of bryophytes are the sources of certain chemicals and medicines. Undoubtedly certain bryophytes are of some importance in the destruction of rock into soil. They may also aid in preventing soil waste by erosion. As compared with other phyla of plants, bryophytes are of small economic importance to man.

IV. ECONOMIC IMPORTANCE OF FERNS AND THEIR ALLIES (Figs. 50 and 51)

The larger roots of certain species of ferns contain considerable starch and are consequently used as food. Certain species of ferns contain a substance known as coumarin which is used in making certain perfumes. Other ferns contain such chemicals as tannin, aconitic acid, or ethereal oils which may be used for commercial purposes. Ferns have been used in the preparation of certain medicines. Certain varieties of ferns produce stock poisoning when eaten by domestic animals. The horsetails or scouring rushes *(Equisetum sp.)* (Fig. 49) may be used for scouring or polishing purposes. The growing of these plants along certain slopes of land may prevent soil erosion. The presence of horsetails along the edges of swamps may help in the transformation of the swamp into a marshlike area by retaining soil particles around them. They add to the land area in this manner at the expense of the water area.

Certain tropical club "mosses" are used for medicinal purposes. The spores of certain club "mosses" *(Lycopodium clavatum)* (Fig. 47) because of their oil content, are used in the manufacture of burning flashlights as well as certain kinds of dusting powders. The spores of certain club "mosses" or "ground pines" are very inflammable, for which reason they are used in fireworks under the name of vegetable sulfur. Certain types of coal were deposited in past ages through the carbonized remains of certain treelike club "mosses," scouring rushes, and primitive seed plants. In general, the ferns and their allies are of small economic importance today, although at one time they dominated the vegetation of the earth.

V. ECONOMIC IMPORTANCE OF GYMNOSPERMS (Figs. 52 to 54)

The cone-bearing trees, known as conifers, are ranked high in the production of valuable timber, as is verified by the use of yellow pines, redwoods, pitch pines, firs, cedars, hemlocks, and white pines. In 1930 over 7,500,000,000 board feet of yellow pine alone were cut in the United States. Pine lumber is one of the most valuable and widely used kinds because it is durable due to its composition, it is easily worked, and it is quite resistant to the attacks of insects, probably because of its resin content. Certain conifers are used extensively in the manufacture of wood pulp. Red cedars are used in making pencils, cigar boxes, chests, trunks, and posts. Conifers yield large quantities of resins, oils, and amber products used in arts, industries, and medicine. Examples are turpentine, balsam, spruce gum (for chewing gum), oil of juniper, and oil of savin. Certain species of pine provide edible seeds used by human beings for foods. The edible or nut pine of western United States and the sugar pine of California are examples. The barks of such conifers as hemlock and spruce furnish important materials for use in the tanning of skins of animals for leather. Thousands of youngsters, and probably as many adults, are made happy at Christmas time by the decorated conifers. This use of conifers for this purpose has become so extensive that the cultivation of desirable types has become necessary in order to supply the ever-increasing demands. The wood of spruce trees is particularly resonant so that it is used in making certain types of musical instruments. The remains of conifers are often found as fossils and as fossil-resin amber in which other fossils may have been imbedded.

VI. INDUSTRIAL PLANTS

Industrial plants may be considered as those which yield materials used in such industries and arts as spinning, weaving, dyeing, painting, paper making, building, tanning, sculpture, carving, manufacture of foods, medicines, etc.

Of the immense number of plants more or less important to man, only a few which yield such products and materials as fuels, oils, plant fibers, cork, woods, gums and resins, dyes or coloring materials, foods, beverages, flavoring substances, spices, savory substances, medicines and poisons will be considered.

Fuels.—A fuel may be defined as a plant substance which has stored the energy of the sun during its life and releases it upon burning or combustion.

Wood (when perfectly dry) consists of nearly 99 per cent combustible materials and 1 per cent inorganic matter, which remains as ash when burned. An increase in the water content of wood reduces its fuel value by taking the place of combustible material and also by using some of the heat produced to evaporate the water. Wood is the most widely used of all plant fuels.

Peat is a deposit of more or less carbonized plant substances which have accumulated and decomposed under pressure in wet marshes and bogs. Peat is a useful and efficient fuel in regions where coal is scarce. When buried a long time, the peat may resemble a soft brown coal.

Coal is the remains of ancient and extinct plants so changed under pressure that the resulting material is much harder and more completely reduced to carbon than peat. Coal has much more heating power than peat or wood.

Charcoal, which is nearly pure carbon, is made by burning wood in a minimum of oxygen, usually by burning piles of wood in mounds covered with earth. Charcoal is mixed with sulfur and saltpeter to make gunpowder. It is also used in making charcoal drawings and for a great variety of other purposes.

Coke, which is nearly pure carbon, is made by burning coal in a minimum of oxygen, usually by covering piles of burning coal, or in special coke ovens. Coke produces very little smoke.

Artificial gas is made by subjecting wood or coal to a high temperature and collecting and purifying the gases evolved. This gas is used in communities where natural gas is not available.

Natural gas is the product of plant decomposition in which there is produced a gas, the important constituent of which is methane (CH_4). It is used to a great extent for heating and cooking purposes, being transported many miles from "gas wells" to the consumer. This gas is usually formed under great pressure and rapidly and forcefully comes to the surface when a gas "pocket" is tapped by drilling.

Petroleum or **crude oil** is a dark-brown or yellowish-green inflammable liquid formed by the partial decay of organic ooze (foraminifera, diatoms, algae, etc.) by bacterial action, thus liberating fats and waxes to produce petroleum.

Kerosene is an inflammable liquid obtained by the distillation and purification of petroleum. It is used for heating, lighting, and cooking purposes where gases are not available.

Gasoline is a volatile and highly inflammable liquid obtained by the distillation and purification of petroleum. Its principal use is for motor fuel.

Oils.—Oils are very generally present in the plant kingdom as either volatile or fixed oils. Generally speaking, the volatile oils easily and quickly vaporize at ordinary temperatures, while the fixed oils do not. The fixed oils are chemical mixtures in various proportions of glycerides (glycerine and an acid). Examples of the volatile oils are oil of wintergreen, oil of cloves, oil of peppermint, etc. Examples of fixed oils are oil of almonds, peanut oil, olive oil, etc.

Plant oils are used (1) in flavoring materials, (2) as foods, (3) as medicines, (4) in industries in the manufacture of paints, printing inks, soaps, perfumery, lubricants, illuminants, etc.

Certain fixed oils are used to hold particles of coloring matter in suspension in paints. The oil permits the even application of the paint and its prompt hardening through the process of oxidation. Linseed oil, which is pressed from the seeds of flax, is an excellent "drying" oil whose properties may be improved by boiling (boiled linseed oil). For fine paints, such oils as nut oil (from nuts of English walnut) and poppy oil (from seeds of opium poppy) may be superior to linseed oils. In certain printing inks the linseed oil is boiled until it is very thick. Linseed oil is used extensively when united with resins to make varnish.

Any fixed oil with its contained glyceride (glycerine plus an acid) when combined with an alkali will form a soap. In this process the glycerine is given off as a by-product. A fixed oil plus potash or lye forms a "soft" soap. A fixed oil plus soda forms a "hard" soap.

As lubricants, only fixed oils which are nondrying can be used. The oil must be thin enough to penetrate to all parts and at the same time have a consistency which will withstand high temperatures and friction. Examples of such oils are crude oils, motor oils (refined crude oils), castor oil (from castor bean), olive oil, cotton-seed oil, rape oil (from certain varieties of turnip).

As illuminants, the fixed, nondrying oils serve best. Illuminating oils must volatilize but not too quickly; they must be inflammable but not dangerous or explosive. Among the illuminating oils are crude oils, kerosene, olive oil, peanut oil, rape oil, etc.

Plant Fibers.—Plants which produce fibers have contributed greatly to the advancement of civilization, and plants providing foods have been the most useful of all plants.

Plant fibers as well as animal fibers and skins have been utilized since prehistoric times for clothing, baskets, fish lines, bowstrings, snares, nets, etc. More recently such materials have been utilized for making brushes, paper, cellulose products, cordage, mattings, wickerwork, fabrics, packings, awnings, tapes, laces, straw hats, etc.

Cotton fibers cover the seeds of several species of cotton plants. These fibers are separated from the seeds by the machine known as the cotton gin. These fibers are then cleaned, combed, and spun into threads. The latter are woven into fabrics. The cleaned cotton fibers, when rolled into sheets, are known as cotton batting. The cotton fibers in the raw state are more or less covered with an oil which repels water. When this oil is removed, the end product is known as absorbent cotton. Absorbent cotton plus nitric acid plus sulfuric acid produces nitrocellulose (guncotton). Nitrocellulose dissolved in alcohol and ether forms collodion. Collodion when forced through fine openings into running water hardens into silklike fibers.

Flax fibers are practically pure cellulose which is obtained from the stems of the flax plant by a process of retting or rotting. These fibers are strong and fine and are used widely in making fine lace, linen, duck, canvas, and better qualities of paper. The retting process is a decomposition process due to the action of certain species of bacteria.

Hemp fibers, secured from the hemp plant, are coarser, longer, and stronger than flax and are used in making rope, twine, sailcloth, bags, and similar coarse fabrics.

Jute fibers are obtained from plants (linden family) closely related to flax, but the fibers are not so strong or durable and contain less cellulose. They are used in making burlap, bags, and similar coarse fabrics.

Manila hemp fibers are coarse and fine fibers obtained from the edge of the fleshy leaf stalks of the Manila hemp plant (banana family). The principal source is from the Philippine Islands. The fibers are much stronger than those of ordinary hemp and are used in making bags, mats, sailcloth, Manila paper, and similar materials.

Straw, which is the stalk, leaves, etc., of wheat, oats, rye, barley, and rice, is used for making hats, mats, baskets, paper, pasteboard, etc.

The ripened branches of the flower cluster of *broom corn* (grass family) yields a flexible, tough material from which various kinds of brooms are made.

The fibers split from the stems of *rattan* (palm family) are called reeds and are used in making baskets, cane seats, wickerware, coarse brushes, etc. The stems of the *bamboo* (grass family) are used quite extensively for various purposes. The fibers from the leaves and nut husks of the *coconut palm* (palm family) are used in the manufacture of door mats, cables, etc. *Punk* is a mass of slender fibers found within the rind of certain shelf fungi. It is used to stop bleeding in dentistry, as tinder to kindle fires, for making mats, etc.

Cork.—Cork is a light, compressible, nonfibrous, waterproof material secured from the outer bark of the cork oak (beech family). It contains about 75 per cent of a tallowlike, waxy substance known as suberin. The pores of the cork are channels through which air may enter the plant. The cork grows in layers, and unless the outer layers are carefully removed at certain intervals, the product is inferior. Slabs of cork of various thickness may be removed about every eight years, with the result that abundant quantities of homogeneous cork are obtained. The removal of this cork does not injure the tree; in fact, removal seems to be beneficial to it. There are many uses for cork, but the following are typical: floor coverings, lining for shoes and hats, stoppers, packing for fruits, and the making of artificial limbs, life preservers and fish-net floats.

Woods.—Wood is a comparatively hard mass of fibrous material cemented together and contains, in addition to the common substance cellulose, more or less of the substance lignin. The lignin is of unknown chemical composition, although it is similar to cellulose. The cellulose is distinguished from lignin by turning blue instead of yellow when treated with sulfuric acid and iodine.

The texture, strength, durability, and hardness of woods depend on the arrangement of the various materials of which the different varieties are composed.

The following are a few typical and representative uses of wood: wood pulp from certain trees, such as poplar and spruce, is used in the manufacture of paper; certain woods as spruce and white pine are shredded into excelsior; splints split from such hard woods as hickory and ash, which split easily, are used in making baskets and similar objects; houses and roofs; furniture and musical instruments; ships and canoes; barrels and casks; vehicles; road materials; railroad ties; poles, piling, and posts; industrial implements and tools; recreational equipment; toys, canes, pencils, matches, toothpicks, clothespins, etc.

The woods of many trees are of two kinds: sap wood and heart wood.

The sap wood is formed in certain trees next to the bark in successive layers as new wood. It conducts sap and consequently is called sap wood. Some of the plant foods are stored in this kind of wood. It is usually more massive and resistant in larger trees.

Sap wood after a certain time becomes stronger, more compact, and somewhat drier. It no longer carries sap and is known as heart wood. It differs in color from the sap wood because of the stored, useless plant by-products. This color of heart wood frequently makes it more desirable for manufacturing purposes.

Gums and Resins.—The two most common **elastic gums** are *India rubber* or *caoutchouc* (pronounced koo′chuk) and *gutta-percha*. Both are tough, waterproof, somewhat elastic solids which separate as a curd from the milky juices of a number of tropical plants and of several of our native plants, particularly goldenrod. It becomes hard when dried or heated. The principal source is the Brazilian rubber tree (spurge family).

Rubber was early used to rub out pencil marks; hence the name rubber; the India part of the name was derived from the fact that it was imported from the West Indies.

Rubber has a great variety of uses, among which are manufacture of boats, overshoes, waterproof garments, tires, bands, toys, bottles, cushions, insulators, fountain pens, etc.

The quality of rubber was improved by Charles Goodyear in 1844 by adding sulfur to the caoutchouc and subjecting the mixture to considerable heat. This process was known as vulcanization. When a large amount of sulfur is added to caoutchouc, a hard rubber known as vulcanite is produced.

Gutta-percha differs from India rubber in being more firm and rather inelastic below 50° C. Like caoutchouc, it is flexible, tough, a poor conductor of electricity and heat, and impervious to moisture. It is obtained from juices by tapping several different species of trees closely related to the taban tree (sapodilla family). It is similar in chemical composition to caoutchouc in that they both contain hydrogen and carbon. Gutta-percha contains in addition certain resinous substances which are formed by oxidation. Gutta-percha is used in making surgical instruments, ornaments, golf balls, coverings of cables, tubes, etc.

Resins are like the elastic gums in that they are secured from certain plants by tapping them for their juices. Resins are mixtures of several different oxidized hydrocarbons (hydrogen and carbon). They are inflammable, insoluble in water, usually liquids which harden when oxidized. The common resin is obtained from the pitch or resinous sap of pine trees. Sometimes a gum and resin are united as a gum resin, such as asafetida. Resinous materials of various types are common in many plants. Two common examples are rosin and copal. Rosin is the most widely used of resinous materials. It is one of the products which remain when turpentine is distilled. Turpentine flows from the pine and other cone-bearing trees. Rosin is used in the manufacture of varnish, yellow soap, certain cements, sealing wax, cheap candles, certain medicinal ointments, etc. Copal is the name applied to a large variety of resins which occur naturally in hard, amberlike masses. Corpal is used in the manufacture of certain types of varnish. Amber is a yellowish, translucent, fossilized resin resembling copal. It is used in the manufacture of pipe stems, amber beads, and certain types of varnish. When polished by friction, it becomes highly electric.

Coloring Matters (Dyes).—Coloring matters of various kinds are quite common in the plant kingdom but often of questionable or unknown benefit to the plant which produces them, in which case they are probably waste products of their metabolic activity.

Indigo blue ($C_{16}H_{10}N_2O_2$) was first used in India many hundreds of years ago and is derived from *indican* ($C_{26}H_{31}NO_{17}$), an aqueous extract from the leaves of the indigo plant (pulse family).

Haematin ($C_{16}H_{12}O_6$) is a violet-purple dye derived from the colorless material *haematoxylin* ($C_{16}H_{14}O_6$) obtained from the logwood tree (pulse family).

Gamboge is a resinous, gummy material secured from the bark of various species of gamboge trees (gamboge family). When solidified, the bright, transparent, yellowish material is used as a coloring material in lacquers, varnishes, and certain paints.

Tanbark is obtained from the bark of such trees as chestnut, oak, willow, spruce, hemlock, and larch. The bark is rich in tannin ($C_{14}H_{10}O_9 + 2H_2O$), which is used in medicine, in dyeing, and in the manufacture of ink and leather. In the preparation of skins by the process of tanning, the tannic acid combines with the skins of animals to render them soft, pliable, and useful.

Foods.—Foods may be defined as chemical substances which, when taken into an animal body, supply energy, help build body materials, or regulate metabolic processes. Vitamins are of the latter group and the various types are quite well represented in the plant kingdom. In fact, our chief natural sources of the various types of vitamins depend directly and indirectly on plant materials.

Of the great varieties of foods, only the following will be considered briefly: cereals, nuts, legumes, vegetables, and fruits.

The **cereals** most commonly used are corn, wheat, oats, rice, barley, rye, and buckwheat. Corn (Figs. 58 to 60), which was originally grown principally for food, has become the basis of a large number of commercial products such as corn syrup, corn starch, corn oil, dextrine (for pastes), and cellulose for paper pulp and building materials (from stalks and husks). The hulls of oats contribute an important chemical solvent known as furfural, from which plastic materials used in manufacturing phonograph records, etc., are made.

Nuts are edible kernels protected by shells. Among the more common are birch family (filbert or hazelnut), beech family (chestnut), walnut family (black walnut, butternut, or white walnut, hickory nut, pecan, etc.), myrtle family (Brazil nut), palm family (coconut).

Among the various *legumes* used for food are pulse family (garden peas, garden beans (Figs. 55 and 56), lima beans, etc.)

Among the common *vegetables* are nightshade family (white potato), morning-glory family (sweet potato), sunflower family (artichoke, lettuce, etc.), parsley family (celery), goosefoot family (spinach), lily family (onion, asparagus, etc.), mustard family (cabbage, cauliflower, kohlrabi, Brussels sprouts, etc.)

Some of the common *fruits* are gourd family (pumpkin), nightshade family (tomato, egg plant), rose family (apples, pears, quinces, plums, cherries, raspberries, etc.)

Beverages.—Coffee *(Coffea arabica)* is obtained from green, oblong berries which grow on an evergreen plant. The plant grows to a height of 20 feet but usually is pruned to 6 or 8 feet in order to secure uniform flavor and ripeness, as well as to make it easier to harvest. The plants bear when four years of age. The plants produce a great number of white flowers with a jasmine-like fragrance which rivals that of an orange blossom. The flowers produce the green berries, which develop in six months into bright red berrylike cherries. When ripe, their color is dark red. The coffee "cherries" each contain two seeds of coffee beans with their flat sides face to face. The three coverings are removed in the preparation process. These evergreen coffee plants grow at high altitudes (1,500 to 6,000 feet above sea level). One tree yields from one to twelve pounds, depending on its size. The coffee plant is indigenous to Eastern Africa and is cultivated in tropical countries, such as Brazil, Central America, Java, Sumatra, and Ceylon. Coffee was probably first used in Arabia or Abyssinia in the ninth century. The Arabians called it "kawah" from which the names kaffee and coffee eventually were derived. By 1696 it had reached the island of Java which was destined to continue its contribution for many years. In fact, even today some say a "cup of Java" instead of a "cup of coffee."

When dried, ground, and boiled, the coffee beans contain 1 to 2 per cent of a crystalline alkaloid known as caffeine which acts as a poison when taken in larger doses. They also contain from 3 to 5 per cent of tannin, 10 to 12 per cent of fatty oils (palmitin and olein), 15 per cent of glucose and dextrin, 12 per cent of proteins. The aroma is due to a volatile oil known as coffeol which is developed during the roasting process.

Tea is made by steeping the dried leaves of the tea plant (*Thea sinensis*) which is an evergreen shrub or tree indigenous to Eastern Asia and extensively cultivated in China, Japan, Java, Brazil, France, and to some extent in the southern United States. The dried leaves contain from 1 to 3 per cent of the crystalline alkaloid theine and 10 per cent of the astringent tannin. The flavor is due to a volatile oil developed during the curing process.

Cocoa is prepared from a dark-brown powder which is obtained from the seeds of the small tree *Theobroma cacao.* The fruit is large, fleshy, yellowish-red, ovoid, and contains five rows of ovoid seeds, ten or twelve in each row. The seeds contain from 1 to 3 per cent theobromine (a crystalline alkaloid), 15 per cent proteins, 15 per cent starch, 40 to 50 per cent of a fixed oil known as cacao butter, 0.3 per cent caffeine, 0.5 per cent sugar, and a red color due to the process of fermentation. The aroma of cacao arises during the process of fermentation. The flavor is mild, and frequently spices and vanilla are added to make chocolate.

The cacao tree is indigenous to the countries on the Gulf of Mexico and is cultivated in several tropical countries. The raw seeds are bitter; a great part of the bitterness is eliminated by the process of fermentation to which the seeds are subjected in preparing them for use.

Alcoholic beverages are made by the fermentation action of certain yeasts and bacteria on the sugars in the grains, flowers, berries, or fruits of various plants. The alcoholic content of the so-called spirituous liquors (whisky, gin, brandy, rum) is much higher (40 to 60 per cent) than that of beer and wine and they are made by a process of distillation. Whisky is distilled from liquors made from corn, rye, or wheat. Gin is distilled from beer made from the above grains, to which a flavor (usually the volatile oil of juniper berries) is added. Brandy is distilled from wine. Rum is distilled from molasses.

Flavoring Substances.—Flavoring substances are extracted from plants and are usually in liquid forms. The flavor is due to the presence of certain volatile oils. The following will suffice to illustrate:

Vanilla is obtained from the pods of vanilla beans borne on a high-climbing plant *(Vanilla planifolia)* of the orchid family. The mature, yellow fruits are cured by alternately steaming and drying, until they acquire the odor and dark-brown color of the commercial product. **Lemon flavor** is obtained from the peel or rind of the fruit of the lemon which yields the oil of lemon. The lemons are borne on shrublike trees *(Citrus medica,* subspecies *Limonia).* **Rose flavor** is obtained from the petals of roses. **Wintergreen flavor** is obtained from the leaves and fruit of the plant *Gaultheria procumbens.* The leaves contain the true oil of wintergreen, which consists almost entirely of methyl salicylate. It contains alcohol and an ester giving the characteristic odor.

Peppermint flavor is obtained from an herb *(Mentha piperita)* of the mint family.

Spearmint flavor is obtained from the leaves and flowers of an herb *(Mentha spicata)* of the mint family.

Orange flavor is obtained from the rind of the fruit of the orange tree *(Citrus aurantium).* The oil contained in the rind of the fruit is known as oil of orange peel.

Spices.—Spices are usually powdered, aromatic substances secured from certain plants. The aroma is due to specific volatile oils which evaporate easily, dissolve readily in alcohol, and leave no oily stain on paper. The following list will illustrate the members of this group:

Black mustard is obtained from the seed of *Brassica nigra* of the mustard family. **Nutmeg** is a berry obtained from the evergreen tree *Myristica fragrans* of the nutmeg family. **Mace** is the dried, fleshy network which surrounds the nutmeg seed or kernel. **Ginger** is obtained from the rootlike, underground stem of the plant *Zingiber officinale* of the ginger family. **Cinnamon** is the young bark of the tree *Cinnamomum zeylanicum* of the laurel family. **Cloves** are the dried flower buds of the tree *Caryophyllus aromaticus* of the myrtle family. **Red pepper** is obtained from the dried, berrylike fruits of the shrub *Capsicum annum* of the nightshade family. **Black pepper** is obtained from the dried, unripe berry of the plant *Piper nigrum* of the pepper family. **Allspice** is obtained from the dried fruit of the evergreen tree *Pimenta officinalis* of the myrtle family.

Savory Substances.—Savory substances are aromatic and are either the herbs, seeds, or seedlike fruits of plants which possess specific volatile oils. They are usually used whole rather than in powder form. The following will illustrate this group:

Garden sage is the fresh or dried herb of the plant *Salvia officinalis* of the mint family. **Sweet marjoram** is the fresh or dried herb of the plant *Originum marjorana* of the mint family. **Parsley (garden)** is the fresh or dried herb of the plant *Petroselinum sativum* of the parsley family. **Thyme** is the fresh or dried herb of the plant *Thymus vulgaris* of the mint family. **Summer savory** is secured from the fresh or dried plant *Satureia hortensis* of the mint family. **Caraway** is the seedlike fruit of the plant *Carum carvi* of the parsley family. **Anise** is the seedlike fruit of the plant *Pimpinella anisum* of the parsley family. **Coriander** is obtained from the plant *Coriandrum sativum* of the parsley family.

Medicines and Poisons.—A medicine may be defined as any substance to prevent, relieve, or cure a disease. A poison may be defined as any substance or agency (exclusive of injurious physical, mechanical, or bacterial agencies) which is capable of destroying life or injuring health when applied externally or administered in moderate doses internally.

Some plants contain certain substances which, unless taken in large doses, are not poisonous, but on the other hand may be somewhat stimulating, soothing, slightly irritating, or even more or less nutritious. Substances of this kind may be illustrated by the following:

Castor oil is secured from the seeds of the castor oil plant *(Ricinus communis)* of the spurge family. It acts as an irritant and lubricant. **Cacao butter** is the fixed oil of cacao seed obtained from the plant *Theobroma cacao* (silk-cotton family). It is used for soothing or lubricating purposes. The **oils of olives** and **almond** may be used for the same purposes. **Asafetida** is obtained by drying the juices from the roots of the asafetida plant *(Ferula assafoetida)* of the parsley family. Asafetida is an ill-smelling substance used for medical purposes and sometimes used in small quantities as flavoring for sauces and gravies.

Numerous plants produce gelatinous materials used as medicines themselves or used in the preparation of medicines. The following will illustrate a few of this type:

Gum arabic is made principally from the juice of the gum arabic tree *(Acacia senegal)* of the pulse family. This gum contains a carbohydrate called arabin ($C_{12}H_{22}O_{11}$) which has the same formula as cane sugar. When arabin is boiled with dilute acid, the sugar, arabinose, is formed. **Gum tragacanth** is made from the juice of the stem of the tragacanth shrub (*Astragalus gummifer*) of the pulse family. This gum contains a carbohydrate tragacanthin ($C_6H_{10}O_5$). **Licorice** is secured from the roots of the licorice plant *(Glycyrrhiza glabra)* of the pulse family. **Gelatinous materials** are obtained from Irish "moss" *(Chondrus crispus)* (Fig. 33) and from Iceland "moss" *(Cetraria islandica)*.

Certain plants contain various poisonous substances which prove harmful when eaten. The following examples are typical:

Jimson weed or **thorn apple** *(Datura stramonium)* of the nightshade family is quite common around farm buildings. It is sometimes mistaken for other plants and eaten with fatal results. **Indian poke** *(Veratrum viride)* of the lily family has been mistaken for other plants and eaten with dangerous results. **Common pokeweed** *(Phytolacca decandra)* of the pokeweed family is often eaten like asparagus. Unless the leaves, roots, seeds, and fruits are thoroughly boiled in many changes of water, death may result. **Monkshood** *(Aconitum napellus)* of the crowfoot family is common in gardens and has produced fatal results when eaten. **Deadly water hemlock** *(Cicuta maculata)* of the parsley family is frequently confused with other plants found in swampy regions. **Poison hemlock** *(Conium maculatum)* of the parsley family is very common along roadsides and may prove fatal when the seeds, leaves, or roots are eaten. The roots and bark of the **elder** *(Sambucus canadensis)* of the honeysuckle family and the **locust** *(Robinia pseudacacia)* of the pulse family are sometimes fatal. Every part of the **Indian tobacco plant** *(Lobelia inflata)* of the bellflower family, which is common in pastures, is highly poisonous. The wilted leaves and the kernels of the cherry stones of the **wild black cherry** contain prussic acid, which is very dangerous to man and cattle. **Sheep laurel** *(Kalmia augustifolia)* and **mountain laurel** *(Kalmia latifolia)* of the heath family are among the most deadly of our poisonous plants. **Poisonous mushrooms,** such as the death cap *(Amanita phalloides)* and the fly amanita *(Amanita muscaria),* are extremely dangerous. Unless one knows mushrooms very well, there is a great possibility of eating the poisonous varieties.

A few poisonous drugs of plant origin may be listed as follows:

Opium is obtained from the dried, milky juice of the seed pods of the opium poppy *(Papaver somniferum)* of the poppy family. Opium contains numerous alkaloids and is used to induce sleep, to relieve pain, and for certain relaxations. **Morphine** ($C_{17}H_{19}NO_3$) is one of the most important alkaloids present in the opium poppy. **Tobacco** is the dried and cured leaves of the *tobacco plant.* The tobacco plant of Virginia is *Nicotiana tabacum* of the nightshade family. The tobacco leaves possess an aroma which is due to a volatile substance. The chief active constituent of tobacco is an alkaloid known as *nicotine* ($C_{10}H_{14}N_2$) which is a very potent poison. **Quinine** ($C_{12}H_{24}N_2O_2$) is an alkaloid obtained from the bark of the *calisaya tree (Cinchona calisaya)* of the madder family. Quinine is a deadly poison to the protozoan parasites which cause malarial fever (Fig. 176). **Strychnine** ($C_{21}H_{22}N_2O_2$) is an alkaloid obtained from the seeds of the *nux vomica tree (Strychnos nux-vomica)* of the logonia family. **Atropine** ($C_{17}H_{21}NO_3$) is an alkaloid obtained from the roots and leaves of the *belladonna plant (Atropa belladonna)* of the nightshade family. It is used in the examination of the eyes. **Cocaine** ($C_{17}H_{21}NO_4$) is an alkaloid secured from the dried leaves of the coca shrub *(Erythroxylon coca)* of the coca family. It is used to counteract pain. **Aconitine** ($C_{33}H_{45}NO_{12}$) is the active alkaloid principle derived from the dried tubers of the monkshood plant *(Aconitum napellus)* of the crowfoot family. It is used as a cardiac and respiratory sedative.

Certain of our plants poison the skin when they or their products come in contact with it. The following examples are typical:

Poison ivy *(Rhus toxicodendron)* of the sumac family produces the well-known effects of itching, and eruption, swelling of the skin of susceptible persons, especially women and children. Poison ivy plants may be distinguished from other viny plants by their white fruits and three leaflets. The poisonous principle is a fixed oil known as *cardol.* **Poison sumac** *(Rhus vernix)* of the sumac family produces itching, eruption, and swelling of the skin of susceptible persons. The active principle is a fixed oil similar to the one in poison ivy if it is not identical. Poison sumac plants can be distinguished from common sumacs by (1) greenish-white color of their drooping fruit or flower clusters, (2) their smooth twigs and leaves, and (3) the even edges of the leaflets. The application of a concentrated solution of sugar-of-lead in 60 per cent alcohol every few hours is useful in poison-ivy and poison-sumac poisoning. Instead, a strong solution of baking soda (sodium bicarbonate) may be applied as soon after exposure as possible. **Parsnip** and **carrot roots** and herbs affect certain persons much in the same manner as described above. Some persons are poisoned when preparing them for eating. Certain of our common **orchids,** known as *yellow lady slipper (Cypripedium parviflorum)* and *showy lady slipper (Cypripedium hirsutum)* of the orchid family produce symptoms similar to those described above because of a fixed oil similar to cardol.

QUESTIONS AND TOPICS

1. What is meant by an economically important plant?
2. In which phylum are the plants of greatest economic importance? Give proof to justify your conclusions.
3. List the various ways in which a knowledge of economically important plants may be of value.
4. Can you think of any plants which might be improved? What methods would you suggest for such improvements?
5. Define bacteria. Why are they classed as plants?
6. How many species of bacteria are fairly well known? What percentage of the total is in one way or another detrimental to man? How many are beneficial to man?
7. List the more common diseases of (1) man, (2) animals, and (3) plants which are caused by bacteria, giving the causal organism for each disease.
8. Write an article on the so-called galls of plants, including the causes and economic importance.
9. Give the values of a knowledge of plants in such professions as (1) medicine, (2) dentistry, (3) horticulture, (4) agriculture, (5) landscaping, (6) forestry, (7) pharmacy, (8) business, and (9) everyday living by nonprofessional people.
10. Write an article on antibiotics, including the specific organism from which each is derived, and including their uses in the prevention and treatment of certain diseases.
11. List some important diseases produced by (1) yeasts and (2) fungi, giving the causal agent for each disease.

SELECTED REFERENCES

Bessey: Textbook of Mycology, The Blakiston Co.
Brown, Panshin, and Forsaith: Textbook of Wood Technology, McGraw-Hill Book Co., Inc.
Dorrance: Green Cargoes, Doubleday, Doran & Co., Inc.

Fernald and Kinsey: Edible Wild Plants of Eastern North America, Idlewild Press.
Heald: Introduction to Plant Pathology, McGraw-Hill Book Co., Inc.
Hill: Economic Botany, McGraw-Hill Book Co., Inc.
Horn: This Fascinating Lumber Business, Bobbs-Merrill Co., Inc.
Jones: Economic Geography, The Macmillan Co.
Peattie: Cargoes and Harvests, D. Appleton-Century Co., Inc.
Record: Identification of the Timbers of Temperate North America, John Wiley & Sons, Inc.
Robbins: Biology of Plant Crops, The Blakiston Co.
Robbins and Ramaley: Plants Useful to Man, The Blakiston Co .
Stanford: Economic Plants, D. Appleton-Century Co., Inc.
Stevens: Plant Disease Fungi, The Macmillan Co.
Westcott: Plant Disease Handbook, D. Van Nostrand Co., Inc.
Wilson: Trees and Test Tubes, Henry Holt & Co., Inc.
Wilson et al.: New Crops for the New World, The Macmillan Co.
Wolf and Wolf: Fungi (2 vols.), John Wiley & Sons, Inc.

Part 3
ANIMAL BIOLOGY

Chapter 17
SURVEY OF THE ANIMAL KINGDOM

A detailed study of the entire animal kingdom cannot be made because there are over 800,000 species (different kinds) which are more or less well known. Only a few species which are representative of the various subdivisions of the animal kingdom will be considered.

In order to study representative species of the animal kingdom scientifically, a system of classification must be used whereby all investigators in all parts of the world may study the same species of animal and call them by the same scientific name. Without scientific names and classification, students in various parts of the country may apply dozens of entirely different names to the same animal. For instance, such names as night crawlers, fishworms, or groundworms might be applied in different localities to the same earthworm, which, by biologists the world over, is known by its scientific name of *Lumbricus terrestris.* On the other hand, if the term night crawler were applied in various communities to any animal which crawled at night, there would be great confusion and many entirely different animals would have the same common name.

Greek and Latin are used in classification and scientific names because they are universally understood and because they are not susceptible to changes in each local community. Because of their standardization throughout the world, they are extremely desirable for scientific purposes.

Complete scientific descriptions and classifications of animals also make it possible to identify accurately unknown animal species no matter when or where found. Without scientific terms and classifications, each investigator would have to make his own classification and follow his individual ideas of naming. If this procedure were universally followed, an investigator would be unable to know if he were studying a previously described species or if he really had a new one.

For convenience, the entire animal kingdom is divided into several main groups or phyla (singular, phylum). All the animals included in any particular phylum have certain characteristics in common. These characteristics in the future will be considered as general characteristics in each phylum.

If our classification were carried no further than phyla, there would be so many differences among the various members that the system would be practically useless. Consequently, all the members of a phylum which have in common one or more arbitrarily chosen characters are placed in a subdivision known as a class. In a similar manner each class is divided into orders, each order into families, each family into genera (singular, genus), each genus into species. The scientific name of any particular animal is composed of its genus and species. For instance, man has the scientific name of *Homo sapiens,* the former being the genus, the latter the species.

Approximate Number of Species in the Animal Kingdom

PHYLA	CLASS		TOTAL FOR PHYLA
Protozoa			15,000
Porifera			3,000
Coelenterata			9,500
Ctenophora			100
Platyhelminthes			6,000
Nemathelminthes			8,000
Trochelminthes (Rotifera)			1,000
Echinodermata			6,000
Annelida			7,500
Mollusca			75,000
Arthropoda			
	Crustacea	20,000	
	Onychophora	50	
	Diplopoda (Millipedes)	1,000	
	Chilopoda (Centipedes)	1,000	
	Insecta	625,000	
	Arachnoidea	28,000	
			675,050
Chordata	Miscellaneous	2,000	
	Pisces (Fishes)	14,000	
	Amphibia	2,000	
	Reptilia	4,000	
	Aves (Birds)	14,000	
	Mammalia	4,000	
			40,000
			846,150*

*Does not include all individuals or groups.

In a general survey of the animal kingdom each phylum of animals will be considered from the following standpoints: general characteristics of the phylum and classification of each phylum into classes or other subdivisions.

Phylum 1. Protozoa (pro to -zo' a) (Gr. *protos,* first; *zoon,* animal)

General Characteristics

Most Protozoa are microscopic although a few are visible to the naked eye, some forms being two-thirds of an inch long. All Protozoa are animals, each of which is composed of a single cell (unicellular). This makes them the most simply constructed of all animals. Protozoa exhibit most of the activities which characterize the higher, multicellular animals although in a simpler manner. Certain types of Protozoa are colonial; that is, a number of individuals of one species may be more or less associated in the form of a colony. All Protozoa are complete animals but are without true tissues and organs. Structures similar to true organs of higher animals or which perform functions comparable to organs of higher types are known as organelles. Protozoa were first discovered by Leeuwenhoek, a Dutch naturalist (1632-1723). Many types of Protozoa are parasitic, thus living in or on the bodies of living plants or other living animals. Under such conditions they sometimes produce disease and thus are known as pathogenic Protozoa. For a more detailed discussion consult the chapter on economic importance of animals, and the chapter on unicellular, microscopic animals. Number of species of Protozoa, 15,000.

Classification of the Phylum Protozoa

Class 1—Sarcodina (sar ko -di' na) (Gr. *sarx,* protoplasm or flesh).—These unicellular animals possess protoplasmic pseudopodia ("false feet").

Subclass A—Rhizopoda (ri -zop' o da) (Gr. *rhiza,* root; *pous,* appendage or foot).—These Protozoa "creep" by means of pseudopodia of one kind or another.

Examples: *Amoeba proteus* (Figs. 75, 157, and 159), *Endamoeba histolytica* (Fig. 264), and various other amoeboid types (Fig. 75).

Subclass B—Actinopoda (ak ti -nop' od a) (Gr. *aktin,* ray; *pous,* appendage).—These amoeboid Protozoa are spherical, floating forms with radiating, raylike, unbranched pseudopodia.

Examples: *Actinophrys* (Fig. 75) and *Thalassicola* (Fig. 75).

Class 2—Mastigophora (mas ti -gof' o ra) (Gr. *mastix,* whip; *phoreo,* to *bear) or* **Flagellata** (flaj el -la' ta) (L. *flagellatus,* whip).—These Protozoa travel by means of one or more whiplike flagella, and are commonly called flagellates.

Subclass A—Phytomastigina (fi to mas ti -ji' na) (Gr. *phyton,* plant; *mastigion,* whip or flagellum).—These flagellated Protozoa somewhat resemble plants. Colored bodies known as chromatophores (kro' má to fors) (Gr. *chroma,* color; *phoreo,* to bear) are usually present.

Examples: *Euglena* (Figs. 76 and 173), *Phacus* (Fig. 76), *Trachelmonas* (Fig. 76), *Paranema* (Fig. 76), Volvox (Figs. 174 and 175), *Chlamydomonas*

(Fig. 76), also considered as a plant, *Ceratium* (Fig. 76), *Chilomonas* (Fig. 76), *Uroglena* (Fig. 259), *Dinobryon* (Fig. 260), and *Synura* (Fig. 261).

Subclass B—Zoomastigina (zo o mas ti -ji′ na) (Gr. *zoon,* animal; *mastigion,* whip or flagellum).—These flagellated Protozoa are animal-like and do not possess chromatophores.

Examples: *Mastigamoeba* (Fig. 76), *Tetramitus* (Fig. 76), *Monosiga* (Fig. 76), *Bodo* (Fig. 76), *Cercomonas* (Fig. 76), and such pathogenic species as *Trypanosoma gambiense* (Fig. 263), which causes African sleeping sickness, and *Trypanosoma brucei* (Fig. 266), which causes a serious disease in animals in Africa (see chapter on Economic Importance of Animals).

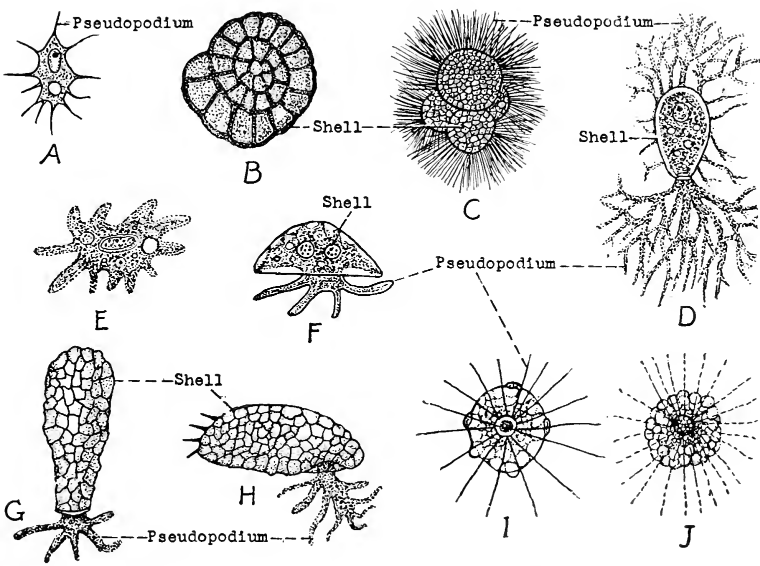


Fig. 75.—Representative protozoa of the class *Sarcodina. A, Protomonas amyli; B, Rotalia beccarii; C, Globigerina bulloides; D, Allogromia sp.; E. Amoeba proteus; F, Arcella vulgaris; G, Difflugia oblonga; H, Centropyxis aculeata; I, Actinophrys sol; J, Thalassicola nucleata.* (All enlarged and somewhat diagrammatic.

Class 3—Sporozoa (spo ro -zo′ a) (Gr. *spora,* spore or seed; *zoon,* animal). —These Protozoa possess no locomotor organelles in the adult stages, although in certain immature stages they may move about by different means. All species reproduce by spores which are small bodies surrounded by a resistant membrane (sporocyst). All species are parasitic and none appears in fresh water. The adults absorb foods through their cells. Many Sporozoa have a very complicated life cycle, spending part of their life in one species of animal and probably another part of the cycle in a different species. The animals in which such parasites live are known as hosts.

Examples: *Monocystis* (Fig. 77), a parasite of worms and arthropods; *Plasmodium malariae* (Fig. 176), which causes human malaria (quartan type) with an attack of fever every seventy-two hours; *Plasmodium vivax,* which causes human malaria (tertian type) with an attack every forty-eight hours; *Plasmodium falciparum,* which causes human malaria (subtertian or estivo-autumnal type) with a daily attack, or more or less constant fever; and *Babesia bigemina* (Fig. 267), which causes Texas fever of cattle. Sporozoan diseases are considered in greater detail in other chapters.

Class 4—Infusoria (in fu -so′ ri a) (L. *infusus,* crowded or poured into).—These Protozoa, commonly called "infusorians," are very numerous in fresh water

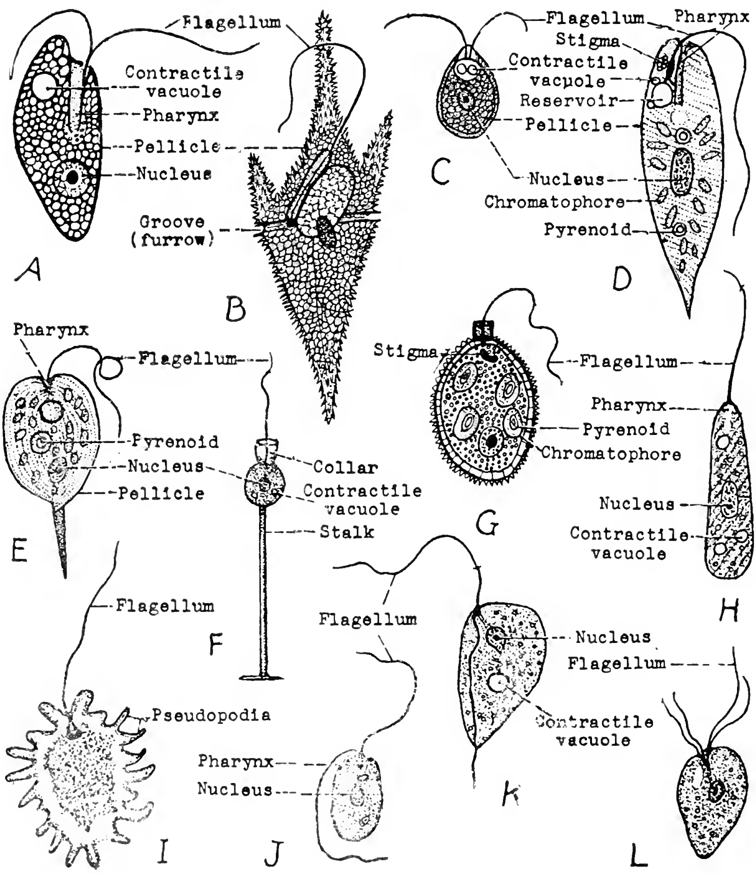


Fig. 76.—Representative protozoa of the class *Mastigophora.* *A, Chilomonas paramecium; B, Ceratium hirundinella; C, Chlamydomonas monadina; D, Euglena viridis; E, Phacus longicaudus; F, Monosiga robusta; G, Trachelomonas hispida; H, Peranema trichophorum; I, Mastigamoeba aspera; J, Bodo caudatus; K, Cercomonas longicauda; L, Tetramitus rostratus.* (All enlarged and somewhat diagrammatic.)

and in cultures or infusions of decomposing materials. Hairlike cilia are present at some stage in their life.

Subclass A—Ciliata (sil i -a′ ta) (L. *cilium,* hairlike cilia).—Numerous hairlike cilia are present in the adults for locomotion and for securing food. A permanent mouth and gullet are usually present.

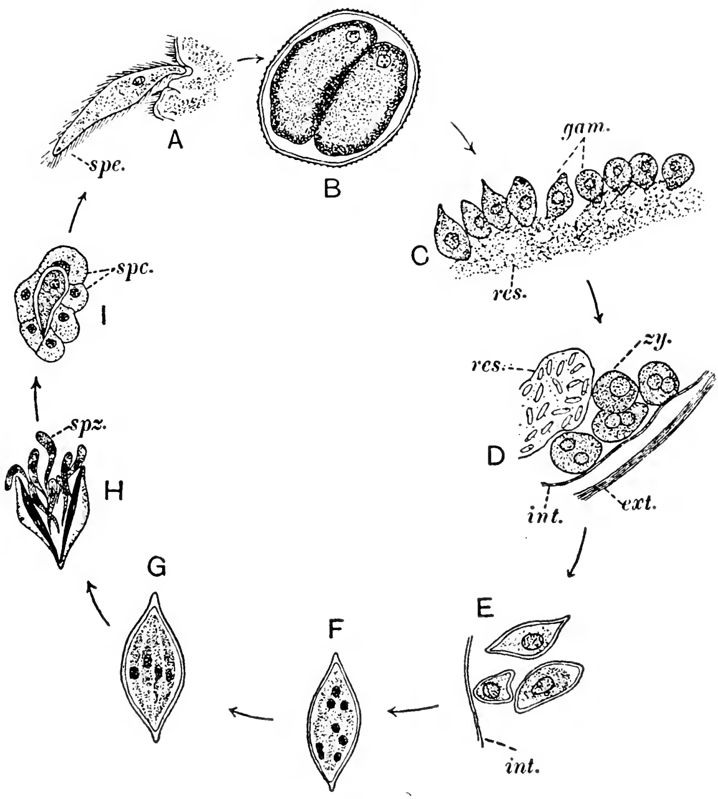


Fig. 77.—Life cycle of Monocystis, a gregarine protozoan of the class *Sporozoa.* This is a common parasite in the seminal vesicle of the earthworm. *A,* Mature individual (trophozote) attached to the seminal funnel of the earthworm; *B,* two gametocytes, having formed a cyst around them; *C,* formation of gametes (sex cells); *D,* conjugation of gametes to form a zygote; *E,* zygotes which have become encysted spores; *F,* single spore whose original nucleus has divided into eight nuclei; *G,* fully developed spore containing eight sporozoites; *H,* eight sporozoites escaping from the sporocyst (spore case) into the intestine of a new earthworm and eventually into its seminal vesicles; *I,* infestation of the sperm mother cells of the seminal vesicle of the earthworm; *spe,* tails of withered sperms adhering to the parasite; *gam,* gametes (sex cells); *res,* residual protoplasm; *int,* endocyst (internal coat of the gamocyst); *ext,* epicyst (external coat of the gamocyst); *zy,* zygote; *spz,* sporozoites; *spc,* sperm mother cells of the seminal vesicle. (From Borradaile and Potts: The Invertebrata. By permission of The Macmillan Company and the Cambridge University Press, Publishers.)

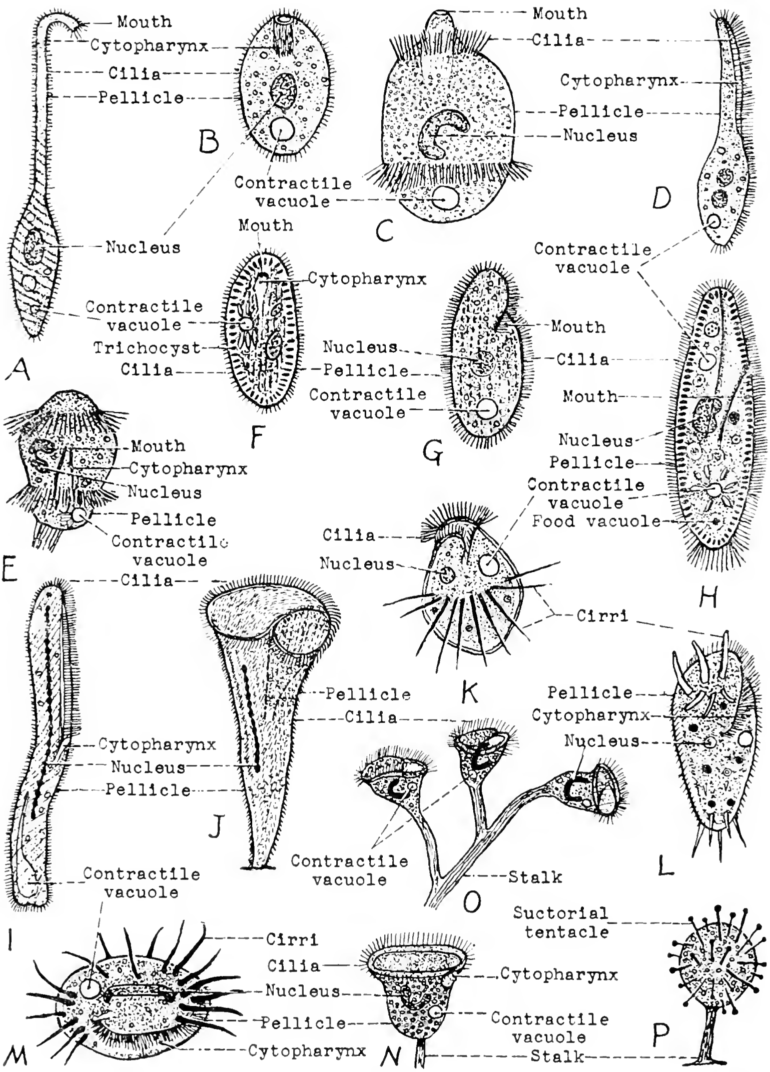


Fig. 78.—Representative protozoa of the class *Infusoria*. *A, Lacrymaria olor; B, Prorodon griseus; C, Didinium nasutum; D, Lionotus fasciola; E, Urocentrum turbo; F, Frontonia leucas; G, Colpoda campyla; H, Paramecium caudatum; I, Spirostomum ambiguum; J, Stentor sp.; K, Halteria grandinella; L, Stylonychia mytilis; M, Euplotes charon; N, Vorticella campanula; O, Carchesium polypinum; P, Podophrya fixa.* Cirri are fused cilia. All protozoan forms are shown enlarged and somewhat diagrammatically.

Examples: *Paramecium* (Figs. 78, 163, 170, and 171), *Vorticella* (Figs. 78, 79, and 80), *Stentor* (Fig. 78), *Lacrymaria* (Fig. 78); *Prorodon* (Fig. 78), *Didinium* (Fig. 78), *Lionotus* (Fig. 78), *Urocentrum* (Fig. 78), *Frontonia* (Fig. 78), *Colpoda* (Fig. 78), *Opalina* (Fig. 265), *Spirostomum* (Fig. 78), *Bursaria* (Fig. 258), *Balantidium* (Fig. 262), *Halteria* (Fig. 78), *Stylonichia* (Fig. 78), *Euplotes* (Fig. 78), *Carchesium* (Fig. 78).

Subclass B—Suctoria (suk -to' ri a) (L. *suctum,* suck or attach).—The adults are sedentary and without cilia, but they have tubelike sucking structures with which to secure food. The immature larval stage is ciliated; hence, free swimming; eventually it attaches itself and transforms into an adult.

Example: *Podophrys* (Fig. 78).

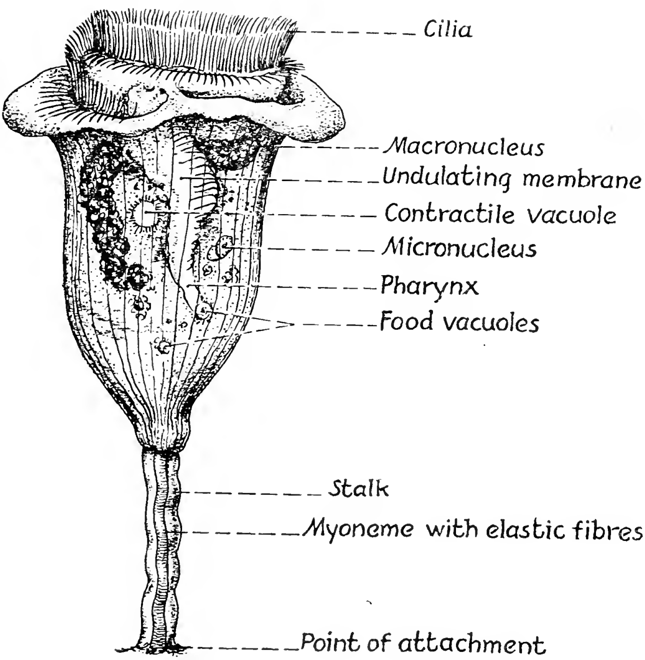


Fig. 79.—Vorticella, a protozoan of the class *Infusoria,* subclass *Ciliata* (highly magnified).

Phylum 2. Porifera (po -rif' er a) (L. *porus,* a pore; *ferro,* to bear)

General Characteristics

This phylum includes all the animals known as sponges. They all contain systems of canals which are connected with pores located in the body wall. Sponges are multicellular and usually have irregular habits of growth. Depending upon the species, they have either radial symmetry (*Scypha*) (*Grantia*) or asymmetry (commercial sponges). With the exception of about fifty species, most sponges live in salt waters of the ocean (marine). They are attached to rocks and other submerged objects. Many species contain gray, red, green, or brown pigments. The type of skeleton of the sponge depends upon the species. The following kinds of skeletons are common: (1) spicules of silicon (siliceous), (2) spicules of calcium carbonate (calcareous), (3) fibers of spongin (horny).

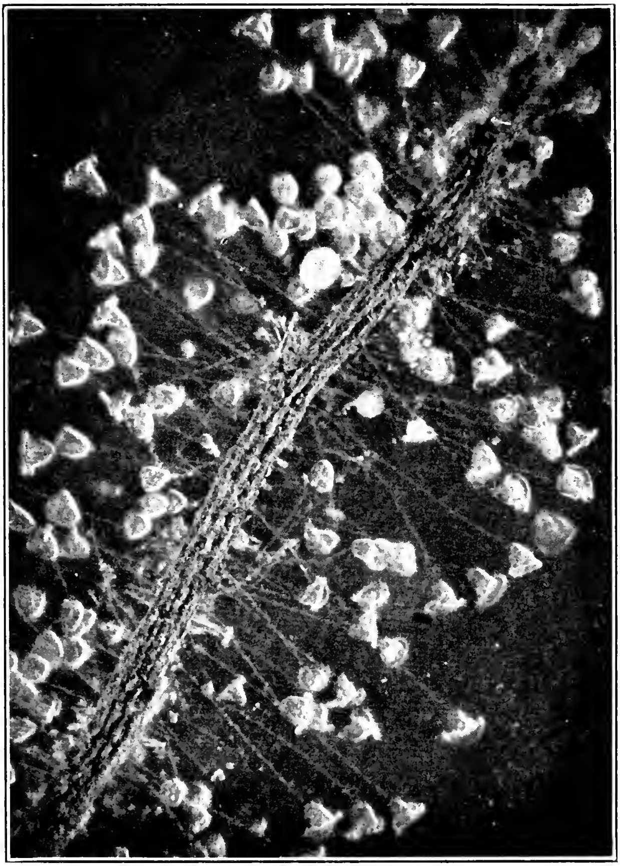


Fig. 80.—A number of Vorticella (class *Infusoria*) shown attached to an object by means of the contractile stalk. (Copyright by General Biological Supply House, Inc., Chicago.)

The various classes into which the phylum is divided are determined by the type of skeleton. The body wall of sponges is diploblastic (two layers of cells); a non-cellular middle layer is known as the mesenchyme (mesoglea). The external cellular layer is known as the ectoderm; the internal cellular layer, as the entoderm. Number of species of Porifera, 3,000.

CLASSIFICATION OF THE PHYLUM PORIFERA

Class 1—Calcarea (kal -ka' re a) (L. *calcarius,* lime).—The skeleton is composed of spicules of calcium carbonate (calcareous). The sponges are mostly gray or white, living in shallow sea water.

Examples: *Scypha (Grantia)* (Figs. 81, 82, and 87) and *Leucosolenia* (Figs. 83 and 84).

Class 2—Hexactinellida (hek sak ti -nel' i da) (Gr. *hex,* six; *aktin,* rays).—The skeleton of these deep-sea sponges is composed of six-rayed spicules of silicon (siliceous) which may in certain species be fused into a continuous skeleton resembling spun glass.

Example: *Venus's flower basket* (Fig. 85).

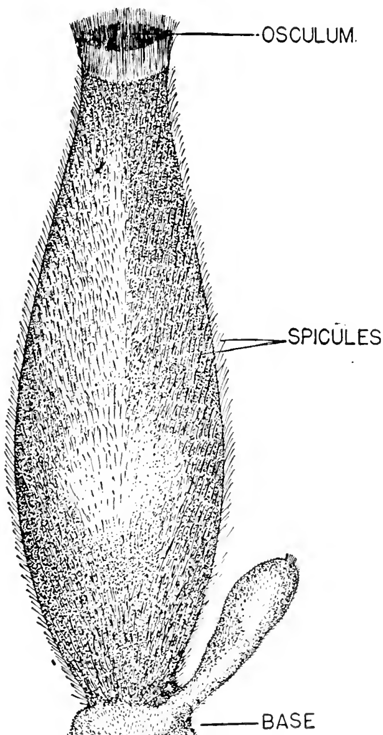


Fig. 81.—A simple sponge, Scypha (Grantia) of the class *Calcarea.* A young bud is also shown. The entire organism is somewhat diagrammatic and enlarged. (From Parker and Clarke: Introduction to Animal Biology, The C. V. Mosby Co.)

Class 3—Demospongiae (de mo -spon' ji e) (Gr. *demos,* people; *spongos,* sponge).—These commercial sponges usually possess skeletons of spongin fibers alone or spongin fibers associated with spicules of silicon. These sponges have a complicated system of canals.

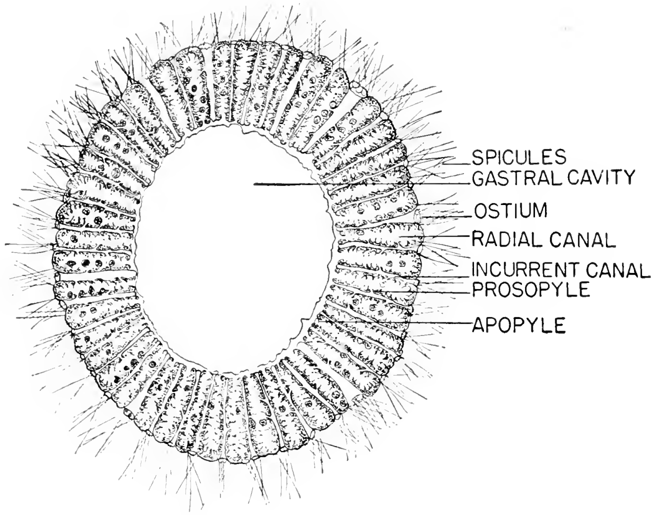


Fig. 82.—Cross section of a sponge, Scypha (Grantia), somewhat diagrammatic. The ostium is also known as the incurrent pore, the radial canals as the excurrent canals, the prosopyle as the connecting canal (between radial and incurrent canals), the apopyles as excurrent pores. (From Parker and Clarke: Introduction to Animal Biology, The C. V. Mosby Co.)

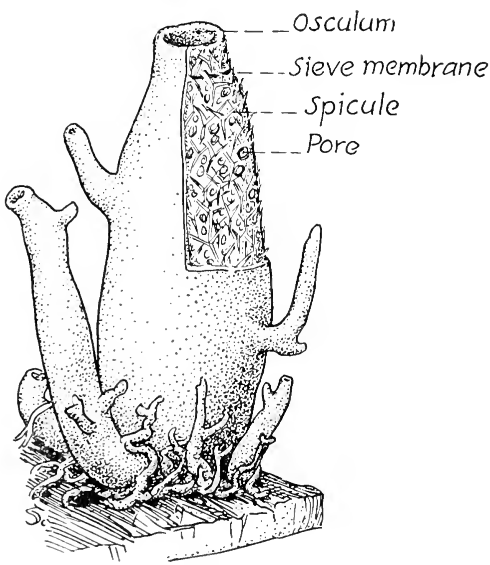


Fig. 83.—Leucosolenia, a small colony of a simple sponge of the class *Calcarea*. In the upper right quarter the outside covering has been removed to show the structures beneath. (See also Fig. 84.)

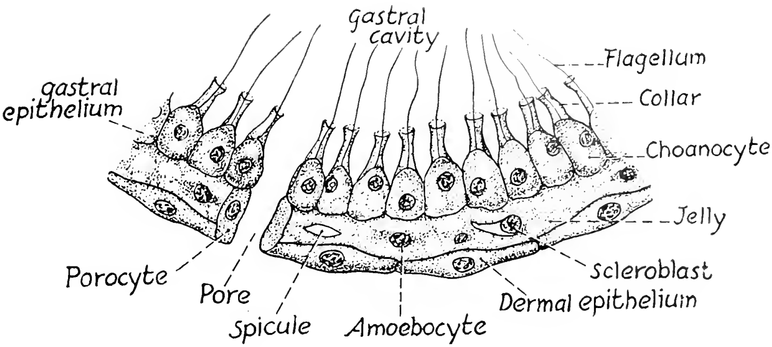


Fig. 84.—A cross section of part of a simple sponge (*Leucosolenia sp.*), showing the structures in detail.

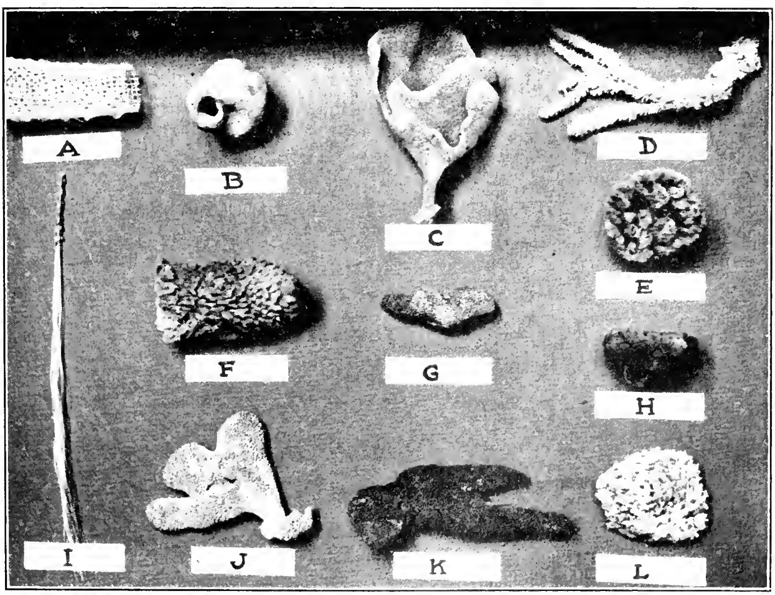


Fig. 85.—Twelve different species of sponges: *A*, *Euplectella sp.* (Venus's *flower* basket, from the Philippine Islands); *B*, *Suberites domuncula* (from the Mediterranean); *C*, *Phyllospongia velum* (paper sponge, from Africa); *D*, *Pandaros sp.* (finger sponge, from the West Indies); *E*, *Euspongia officinalis* (grass sponge, from Nassau); *F*, *Tuba plicifera* (tube sponge, from the Bahamas); *G*, *Pachychalina rubens* (purple sponge, from the Bahamas); *H*, *Euspongia sp.* (hard head sponge, from Nassau); *I*, *Hyalonema sieboldii* (glass rope sponge, from Japan); *J*, *Hircina ignobilis* (Hircina sponge, from Africa); *K*, *Verongia sp.* (Verongia sponge, from the West Indies); *L*, commercial sheep's wool sponge (from Nassau).

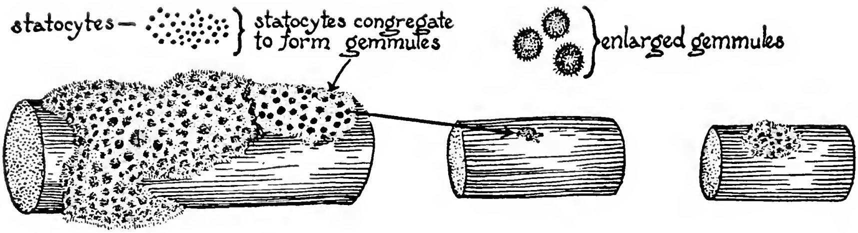


Fig. 86.—Spongilla, a fresh water sponge. Diagrams show the congregation of special cells (statocytes) to form gemmules from which a new colony of Spongilla may arise. (Copyright by General Biological Supply House, Inc., Chicago.)

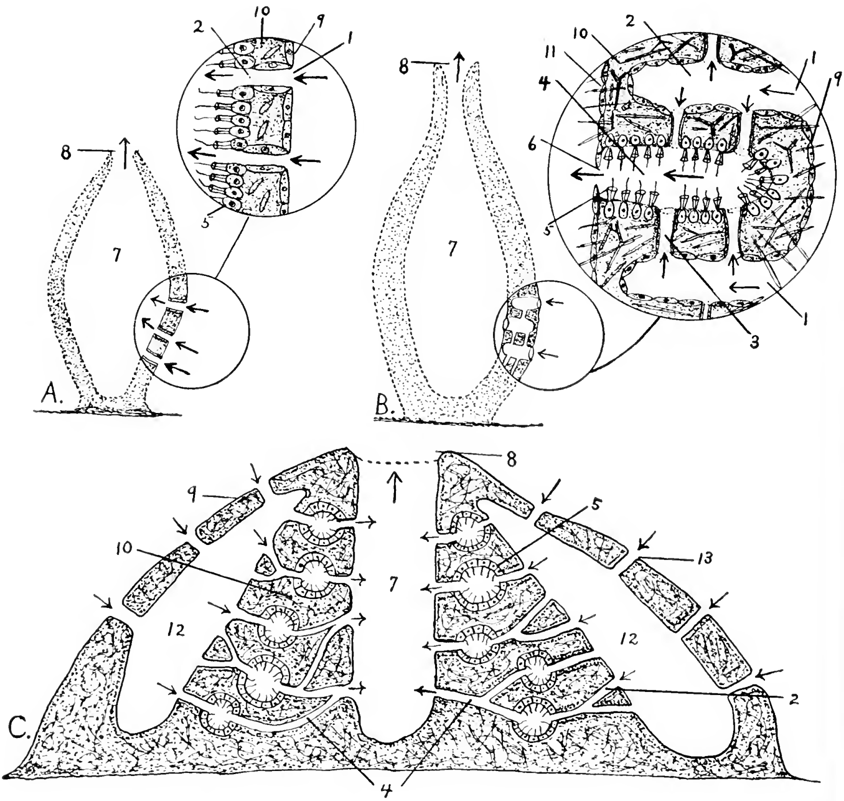


Fig. 87.—Types of sponges shown in section with the pores and canals represented somewhat diagrammatically. Arrows show the direction of water flow *A,* Asconoid type, such as Leucosolenia; *B,* syconoid type, such as Scypha (Grantia); *C,* leuconoid (Rhagon) type, as in commercial sponges.

1, Incurrent pore (ostium).
2, Incurrent canal.
3, Connecting structure (prosopyle).
4, Excurrent (radial) canal.
5, Flagellated cell (choanocyte).
6, Apopyle (excurrent pore).
7, Gastrocoel or spongocoel (central cloacal cavity).
8, Osculum.
9, Dermal epithelium.
10, Mesenchyme.
11, Gastral epithelium.
12, Subdermal cavity.
13, Dermal pore or ostium.

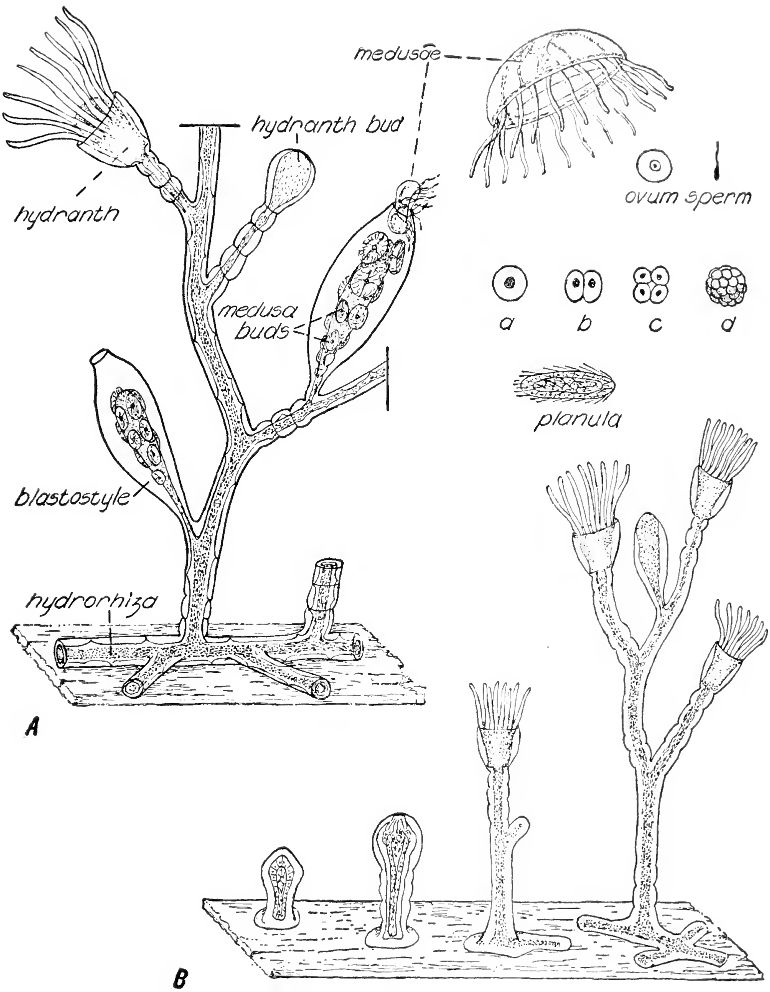


Fig. 88.—Life cycle of Obelia, a coelenterate of the class *Hydrozoa,* showing alternation of generations. *A,* Portion of a colony with its medusae and the ovum and sperm. The sperm fertilizes the ovum to form the zygote, *a,* which divides by mitosis to form two cells, *b,* then four cells, *c,* then a mass of cells known as the blastula, *d,* and eventually the ciliated planula. *B,* Developing a new colony from the attached planula. (From Curtis and Guthrie: Textbook of General Zoology, published by John Wiley & Sons, Inc.)

Examples: *Bath (commercial) sponges* (Fig. 85, L); Spongilla, a fresh-water sponge (Figs. 86 and 87).

Phylum 3. Coelenterata (se len ter -a' ta) (Gr. *koilos,* hollow; *enteron,* digestive tract)

General Characteristics

This phylum includes a number of frequently unnoticed marine animals and a few fresh-water forms, such as Hydra and a few fresh-water medusae. The animals are multicellular and possess a single, hollow, central gastrovascular cavity

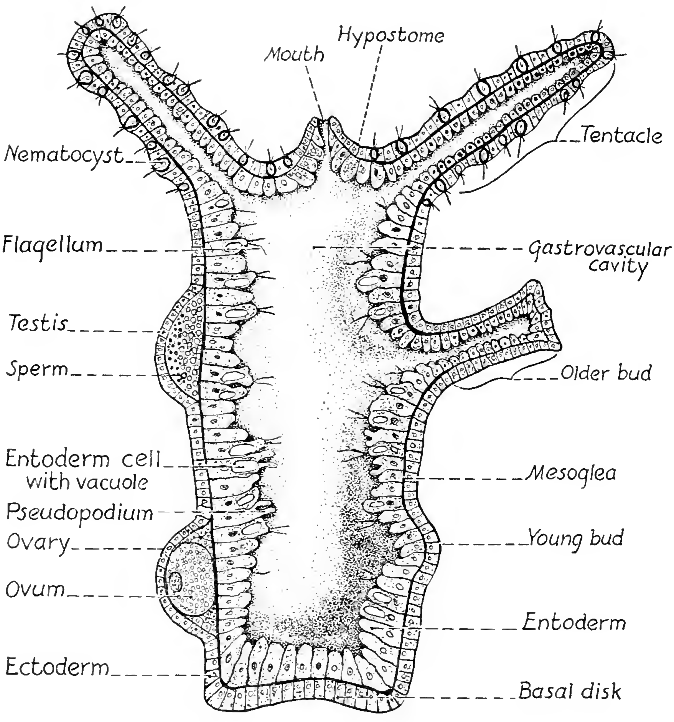


Fig. 89.—Hydra, a fresh-water coelenterate, in section, much enlarged and somewhat diagrammatic.

(enteron). There is no anus. The body wall is diploblastic, being composed of two layers of cells, the outer ectoderm and the inner entoderm. Between these two is a noncellular layer, the mesoglea. Tentacles are characteristically around the mouth. The tentacles and body wall contain peculiar structures known as nematocysts (stinging cells). Coelenterates possess radial symmetry, there being from four to six antimeres (parts of a radially symmetrical animal). Many of the coelenterates are sedentary, while certain species are sessile for at least part of the time. The life cycle typically involves an alternation of generations (meta-

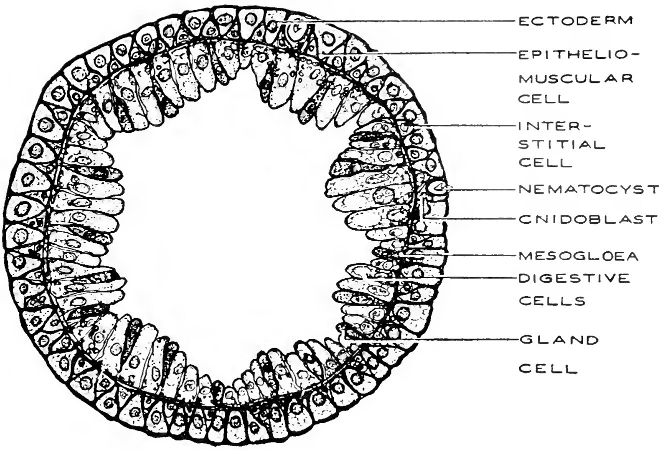


Fig. 90.—Cross section through the body of Hydra. The central space is the gastrovascular cavity (enteron). (Drawn by Titus C. Evans, from Potter: Textbook of Zoology, The C. V. Mosby Co.)

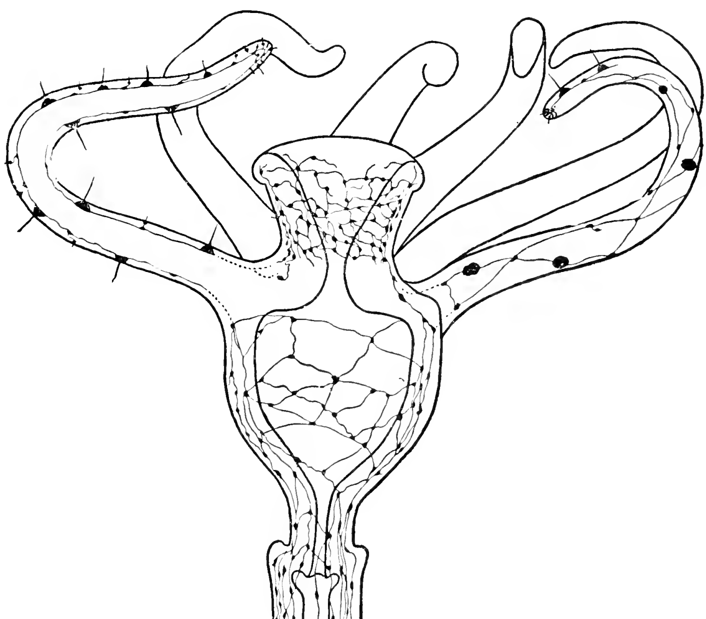


Fig. 91.—Nervous system of a coelenterate. (From Herrick: Neurological Foundations of Animal Behavior, published by Henry Holt and Company.) (After Max Wolf, 1904.)

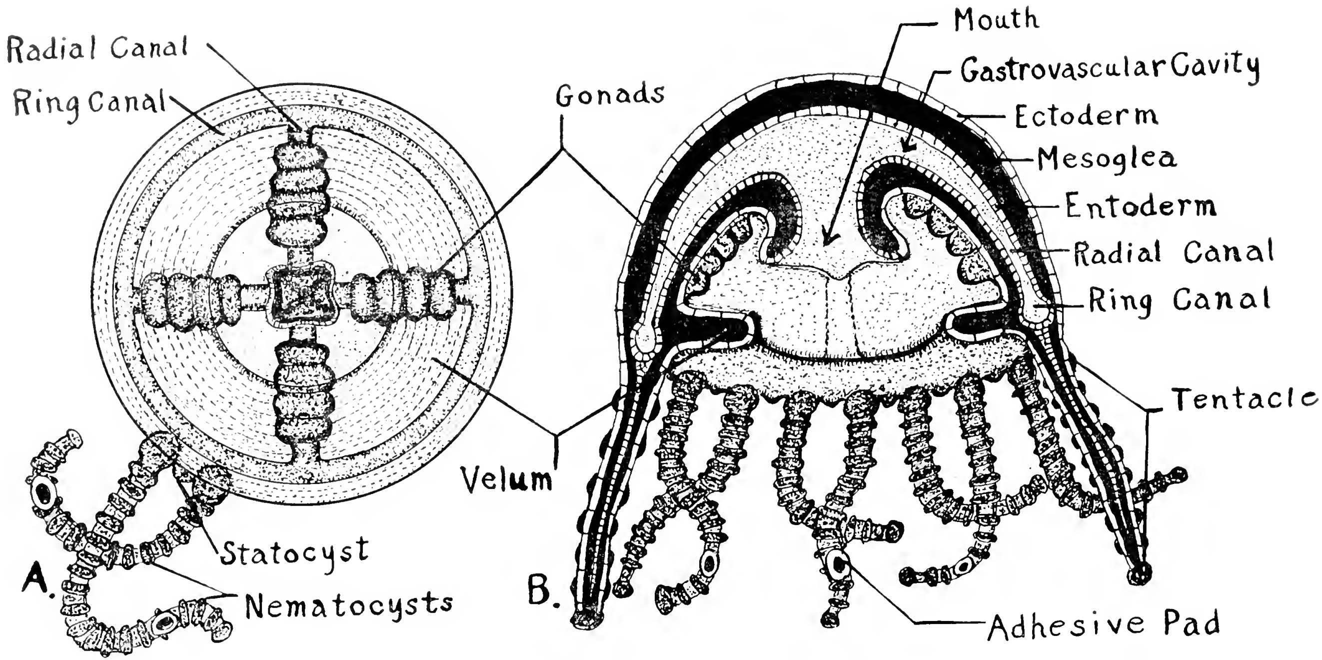


Fig. 92.—*Gonionemus sp.*, a common jellyfish (medusa) of the phylum *Coelenterata*, class *Hydrozoa*. *A*, *Medusoid* stage showing the under or subumbrellar view; *B*, medusoid stage showing a half-section. The hydroid stage of this animal is small and inconspicuous and is usually not studied. For the hydroid stage see another animal, Obelia, in which the medusoid stage is small and is usually not studied. All are drawn somewhat diagrammatically.

genesis) between the hydroid (hydralike) and medusoid (medusa-like) stages. Not all coelenterates have metagenesis. Obelia illustrates a type which has metagenesis by having both a hydroid and medusoid stage in its life cycle (Fig. 88). Number of species of Coelenterata, 9,500.

CLASSIFICATION OF THE PHYLUM COELENTERATA

Class 1—Hydrozoa (hi dro -zo′ a) (Gr. *hydra,* water; *zoon,* animal).—These coelenterates possess a gastrovascular cavity which is not held in position by membranous mesenteries. They do not possess a true gullet or stomodaeum as do the Anthozoa. Sex cells are discharged directly to the exterior. Certain species have alternation of generations (metagenesis), while others do not. When a medusa is formed in the life cycle, it has a velum (membrane on the under surface).

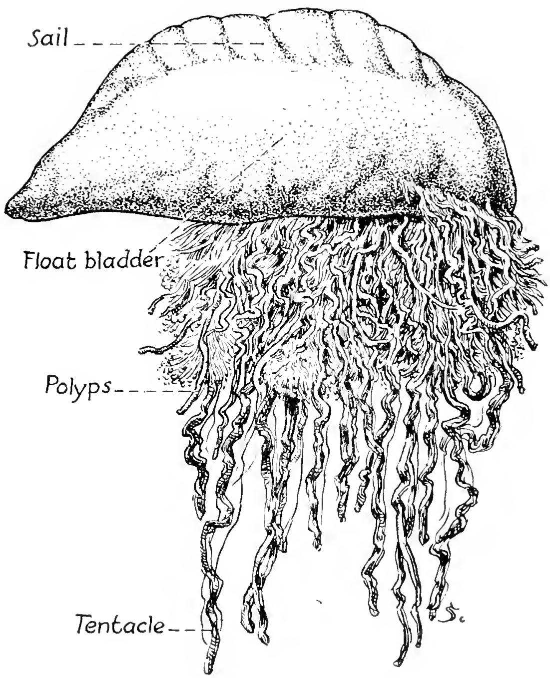


Fig. 93.—Portuguese man-of-war (*Physalia sp.*) of the phylum *Coelenterata,* class *Hydrozoa.* This colonial coelenterate floats on the surface of the sea. Male and female zooids, vegetative polyps, and long tentacles with nematocysts are suspended from the float bladder.

Examples: *Hydra* (Figs. 89, 90), *Obelia* (Fig. 88), many of the smaller *jellyfishes (medusae), Gonionemus* (Fig. 92), and *Portuguese man-of-war* (Fig. 93).

Class 2—Scyphozoa (si fo -zo′ a) (Gr. *skuphos,* cup; *zoon,* animal).—These types have their gastrovascular cavity held in position by membranous mesenteries.

A stomodaeum (gullet) is present in certain species and absent in others. All scyphozoa are carnivorous and marine. They are usually free floating, although at times they may be sedentary. Sizes range from one inch to four feet in diameter. They have a very inconspicuous hydroid stage in their life cycle. The medusa stage is large and without a velum. The medusa of the scyphozoa can be distinguished by notches (usually eight) in the margin of the umbrella.

Examples: *larger jellyfishes* such as *Aurelia* (Fig. 94).

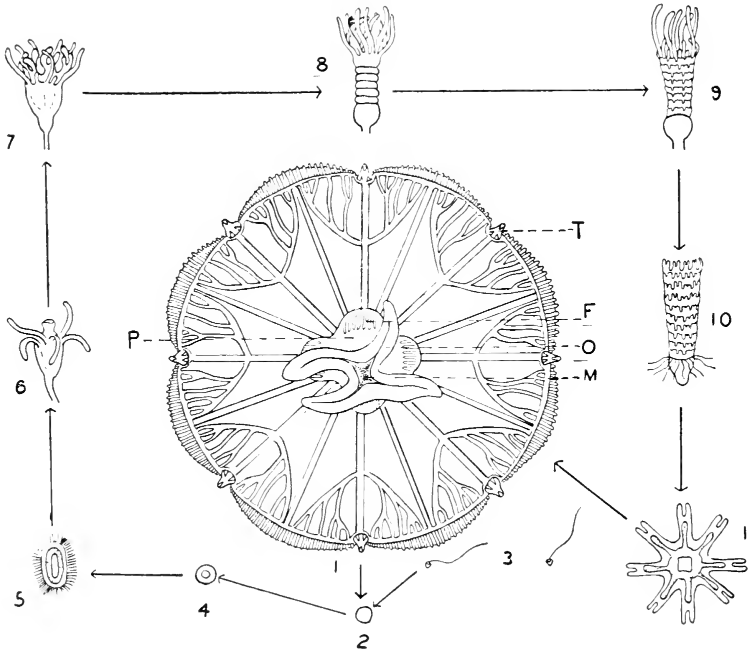


Fig. 94.—Diagram of the life history of the jellyfish (*Aurelia aurita*) of the phylum *Coelenterata,* class *Scyphozoa.* *1,* Adult jellyfish (medusa); *T,* tentaculocyst (for equilibrium); *F,* gastric filaments (with nematocysts); *O,* oral arm; *M,* mouth; *P,* gastric pouch; *2,* egg; *3,* sperm (from another adult); *4,* zygote (fertilized egg); *5,* planula (ciliated larva); *6, 7,* stages in the development of the scyphistoma; *8-10,* stages in the development of the strobila; *11,* ephyra (immature medusa). (From White: General Biology, The C. V. Mosby Company.)

Class 3—**Anthozoa** (an tho -zo′ a) (Gr. *anthos,* flower; *zoon,* animal).—The hydroid polyps have a well-developed stomodaeum (gullet) which is fastened to the body wall by a number of radially arranged membranous mesenteries. Most of the polyps produce a colony by budding, although a few are solitary. This colonial organization gives the effect of a flower; hence, the name Anthozoa. Several species secrete a calcareous skeleton known as coral. There is no medusa stage in the life cycle.

Examples: *Sea anemone* (Metridium) (Fig. 95) and most of the *stony corals, sea pens, sea fans, precious corals* (Fig. 96).

Phylum 4. Ctenophora (te -nof′ o ra) (Gr. *ktenos*, comb; *phoreo*, to bear)

GENERAL CHARACTERISTICS

Ctenophores are jellyfish-like marine animals which are found in warm seas. They are free swimming because of eight bands of vibratile swimming plates composed of rows of fused cilia radially arranged. Many Ctenophores possess solid, contractile tentacles. *Beroë sp.* (Fig. 97) is an exception. With one exception, Ctenophores possess no nematocysts (stinging hairs). Ctenophores are nearly

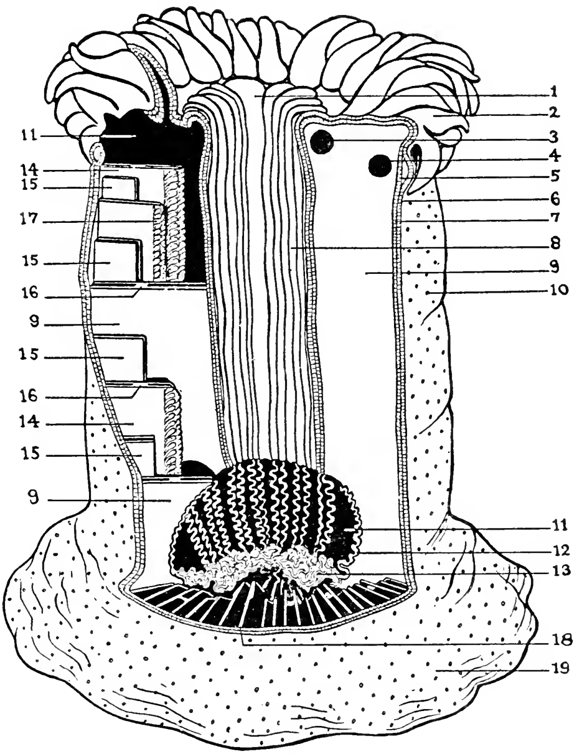


Fig. 95.—Sea anemone (*Metridium sp.*) of the phylum *Coelenterata*, class *Anthozoa*, dissected to show internal structures. *1,* Siphonoglyphe or ciliated groove in the side of gullet; *2,* tentacle; *3,* inner ostium through which water passes; *4,* outer ostium; *5,* ring muscle; *6,* ectoderm; *7,* entoderm; *8,* gullet; *9,* primary mesentery extending from gullet to the body wall; *10,* cinclides or special apertures in body wall; *11,* gastrovascular cavity or radial chambers, six in number; *12,* mesenteric filament; *13,* acontia or special threads armed with nematocysts (acontia may be protruded through the mouth or cinclides); *14,* secondary mesentery; *15,* tertiary mesentery; *16,* retractor, muscle; *17,* gonads or sex organs (diecious); *18,* directive mesenteries, one pair at each end of the gullet (stomodaeum), opposite the siphonoglyphe, having their longitudinal muscles turned away from one another; *19,* basal disk (Copyright by General Biological Supply House, Inc., Chicago.)

transparent with changeable colors and are often phosphorescent at night. They are triploblastic (ectoderm, mesoderm, entoderm), while the Coelenterates are diploblastic (ectoderm, entoderm). Ctenophores possess bilateral symmetry in part and radial symmetry in part (biradial symmetry). They are hermaphroditic; one row of testes lies beside a row of ovaries against each longitudinal canal. Ctenophores are also called comb jellies because of their eight rows of comblike

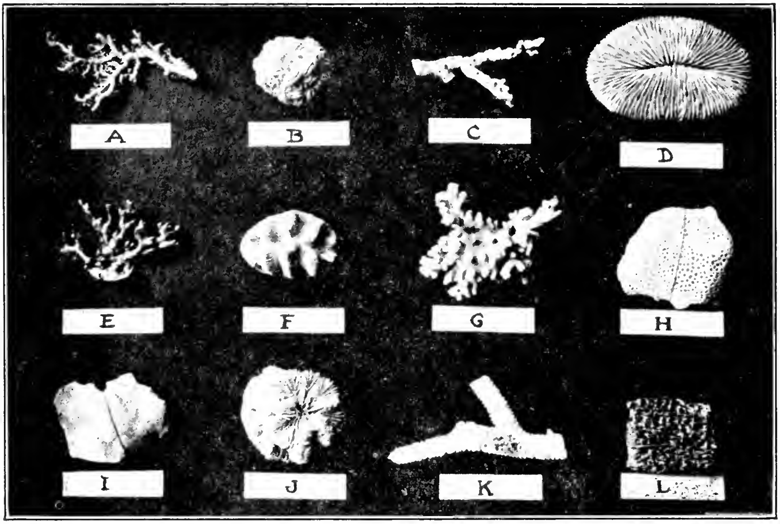


Fig. 96.—Twelve different species of corals of the phylum *Coelenterata,* class *Anthozoa.* *A, Stylaster sanguinea* (hydroid coral, from Samoa); *B, Dichocoenia porcata* (from Andros Island); *C, Oculina sp.* (eyed coral, from the Bahamas), *D. Fungia sp.* (mushroom coral from the Fiji Islands); *E, Distichophora nitida* (hydroid coral, from Samoa); *F, Manicina areolata* (from the Bahamas); *G, Pocillopora sp.* (from the East Indies); *H, Siderastraea galaxea* (star coral, from the Bahamas); *I, Millepora sp.* (hydroid coral, from the West Indies); *J. Isophyllia dipsacea* (rose coral, from the Bahamas); *K, Madrepora sp.* (branching coral from the Indian Ocean); *L, Tubipora musica* (organ-pipe coral, from Singapore).

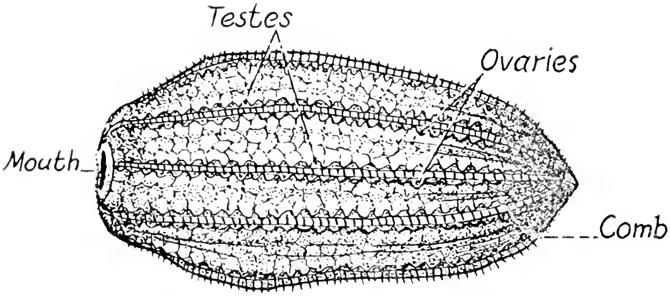


Fig. 97.—Thimble comb-jelly (*Beroë sp.*) of the phylum *Ctenophora.*

locomotor organs (Fig. 97) and their jellylike bodies. Other species are called sea walnuts because of their walnutlike shapes. Number of species in the phylum Ctenophora, 100.

Classification of the Phylum Ctenophora

Class 1—Tentaculata (ten tak u -la′ ta) (L. *tentare,* to feel).—These Ctenophores possess contractile, sensory tentacles.

Class 2—Nuda (nu′ da) (L. *nudus,* bare or devoid of).—These Ctenophores are without tentacles; the body is thimble-shaped; mouth and pharynx are large.
Example: *Beroë* (Fig. 97).

Phylum 5. Platyhelminthes (plat i hel -min′ thez) (Gr. *platus,* broad or flat; *helmins,* intestinal worm)

General Characteristics

These animals are flattened dorsoventrally and possess bilateral symmetry. The body is elongated and unsegmented (nonmetameric). The animals are triploblastic, having three primary germ layers, the ectoderm, mesoderm, and entoderm. There is no true body cavity (coelom). Certain species have branched, tubular intestines (gastrovascular cavity) with a mouth. The spaces between the organs and the body wall are occupied by a connective tissue called parenchyma. No anus is present. Certain species are parasites and pass through a number of complex stages in the bodies of several species of animals during their life cycle. Some flatworms live in fresh water; others, in salt water; a few are terrestrial. Number of species of Platyhelminthes, 6,000.

Classification of the Phylum Platyhelminthes

Class 1—Turbellaria (tur be -la′ ri a) (L. *turbo,* disturb).—These turbellarians are free living in fresh, salt, or brackish water or moist soils. They possess a ciliated ectoderm or epidermis. Special ectodermal cells produce rodlike bodies known as rhabdites or they secrete mucus. They possess two prominent light-sensitive eye spots. In general, they have remarkable powers of regeneration of lost parts (Fig. 28) and also illustrate the phenomenon of axial gradient.
Example: *Planaria* (Figs. 177, 178, and 179).

Class 2—Trematoda (tre ma -to′ da) (Gr. *trema,* a pore; *eidos,* resemblance). —The trematodes are flat and leaflike in shape and possess one or more ventral suckers at or near the posterior end and in the anterior or mouth region. The ectoderm is nonciliated but hardened in the adult. They are either endoparasites or ectoparasites.
Example: *Liver fluke* (Figs. 180, 181, and 374).

Class 3—Cestoda (ses -to′ da) (Gr. *kestos,* a girdle; *eidos,* resemblance).—The cestodes possess a scolex and a body made of a linear series of proglottids. Each of these proglottids is really an individual in itself, so that the entire cestode, strictly speaking, is unsegmented. All cestodes are endoparasites. They have no mouth and no alimentary canal because of their parasitic habits. They inhabit the alimentary canals of a great variety of vertebrate animals during some stage of their life cycle. The cuticle of the adult is not ciliated.
Examples: *Tapeworms* (Figs. 182, 183, and 268).

Life Histories of a Few Typical Flukes (Trematodes)

PARASITE	ADULT STAGES	IMMATURE STAGES	DISTRIBUTION
Sheep Liver Fluke *(Fasciola hepatica)*	Sheep (liver), cattle, hogs, man	Snail *(Lymnea)*, water, soil, grass	Present in United States; common in Europe
Chinese Liver Fluke *(Clonorchis sinensis)*	Man (liver), cat, dog, mammals (flesh-eating)	Snails, fresh-water plants, water	China, Japan, Korea, Indo-China
Oriental Intestinal Fluke *(Fasciolopsis buski)*	Man (China), pigs (Formosa)	Snails, fresh-water plants, water	China, Formosa, India, Indo-China, Sumatra
Human Blood Fluke *(Schistosoma mansoni)*	Man (large intestine)	Snails, water	Africa, West Indies, North and South America (tropics)
Human Blood Fluke *(Schistosoma japonicum)*	Man, dog, cat, pig, cattle	Snails, water	Japan, China, Philippines
Egyptian Blood Fluke *(Schistosoma haematobium)*	Man (bladder, rectum), monkey	Snails, water	Near East, Africa, Portugal, Australia
Oriental Lung Fluke *(Paragonimus westermani)*	Man (lung), dog, cat, pig, tiger	Snails, fresh-water crabs and crayfish	America, Japan, Philippines, China, Peru

Life Histories of a Few Representative Tapeworms (Cestodes)

PARASITE	ADULT STAGE	IMMATURE STAGE
Pork Tapeworm *(Taenia solium)*	Man (intestine)	Pig
Beef Tapeworm *(Taenia saginata)*	Man	Cattle
Dog and Cat Tapeworm *(Taenia pisiformis)*	Dog, cat	Rabbit, mouse
Dog Tapeworm *(Dipylidium caninum)*	Dog, cat, man (intestine occasionally)	Lice and fleas of dog, cat, man
"Gid" Tapeworm *(Multiceps multiceps)*	Dog	Sheep (brain and spinal cord) (causing "gid" or "staggers"
Hydatid Tapeworm *(Echinococcus* granulosus)	Dog, cat, wolf and other carnivorous mammals	Man, monkey, cattle, sheep, pig, cat, dog, etc. (in liver, lungs, brain)
Fish Tapeworm *(Diphyllobothrium latum)*	Man, cat, dog, fox and other fish-eating mammals	Fresh-water fishes and copepod crustacea
Rat Tapeworm *(Hymenolepis diminuta)*	Rat, mice, man (occasionally)	Such insects as flea, earwig, flour beetle, meal moth, etc.
Sheep Tapeworm *(Moniezia expansa)*	Sheep, goat, etc.	Free-living mite *(Galumna)*

Phylum 6. Nemathelminthes (nem a thel -min′ thez) (Gr. *nema,* thread or round; *helmins,* intestinal worm)

General Characteristics

These worms are elongated, slender, cylindroid, and with no internal or external segments (nonmetameric). They are bilaterally symmetrical. The animals are triploblastic, having three primary germ layers: ectoderm, mesoderm, and entoderm. The alimentary canal has a mouth at the anterior end and an anus on the ventral side near the posterior end. There are no cilia on any part of the body. The cavity between the internal organs and body wall is filled with loose, mesenchymal tissue and probably is not a true coelom. The tubular sex organs (gonads) are usually in separate individuals (diecious). Different species vary in length from 0.01 to 1 meter. Nemathelminthes live in fresh and salt water, damp earth, decaying matter, or parasitically in animals and plants. Certain forms *(Trichinella)* live for a time embedded in the tissues, producing the disease trichinosis in man, pigs, and rats. Such forms as the hookworm and *Ascaris* are parasites in man and lower animals. Certain microscopic forms (vinegar eel) live in vinegar. Number of species of Nemathelminthes, 8,000.

Classification of the Phylum Nemathelminthes

Class—Nematoda (nem a -to′ da) (Gr. *nematos,* thread; *eidos,* form).—The body is elongate, slender, cylindrical, and often tapered at the ends. There are no segments but lateral lines are present. The digestive tract is straight and nematodes have no proboscis. A resistant cuticle is shed (moulted) at intervals. As a group they inhabit almost every possible habitat, many species living freely in fresh water, salt water, or soil, while many other species parasitize other animals and plants. (See table on p. 298.)

Order 1—Ascaroidea (as kar -oid′ e a) (Gr. *askaris,* intestinal worm).—These organisms are free living in soils, fresh water, or salt water, or they may be parasitic. The mouth usually has three lips. This order includes the majority of the nematodes.

Examples: Human ascaris *(Ascaris lumbricoides)* (Fig. 184), sheep ascaris *(Ascaris ovis),* human pinworm *(Enterobius vermicularis),* horse pinworm *(Oxyuris equi),* a parasite of hundreds of plants (potato, tomato, lettuce, trees, and weeds) *(Heterodera [Caconema] radicicola),* and "vinegar eel" *(Turbatrix [Anguillula] aceti)* (Fig. 98), living in vinegar, stagnant water, and decaying materials.

Order 2—Strongyloidea (stron jil -oid′ e a) (Gr. *strongylos,* round).—All of these worms are parasitic. They frequently enter the body through the skin or in water. The esophagus is club shaped and is without a posterior bulb. Males have caudal bursae; they are supported by rays. These parasites produce many common diseases.

Examples: American hookworm *(Necator americanus)* (Fig. 99), European hookworm *(Ancylostoma duodenale),* ground itchworm *(Ancylostoma braziliense),* and bird gapeworm *(Syngamus trachea).*

Order 3—Filarioidea (fil ar -oid′ e a) (L. *filum,* thread).—All of these worms are parasitic, living in the blood, lymph, connective tissues, or muscles of higher animals (vertebrates); they require an insect host for their trans-

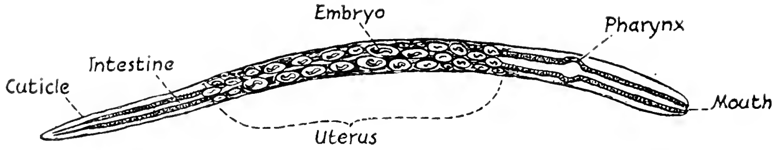


Fig. 98.—"Vinegar eel" (*Turbatrix* [*Anguillula*] *aceti*) of the class *Nematoda*, phylum *Nemathelminthes* (much enlarged).

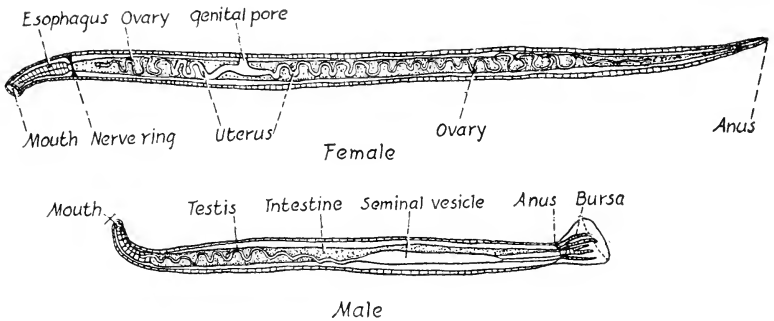


Fig. 99.—American hookworm (*Necator americanus*), adults, of the phylum, *Nemathelminthes*. The actual length of the female is 10 mm., and of the male, 7 mm.

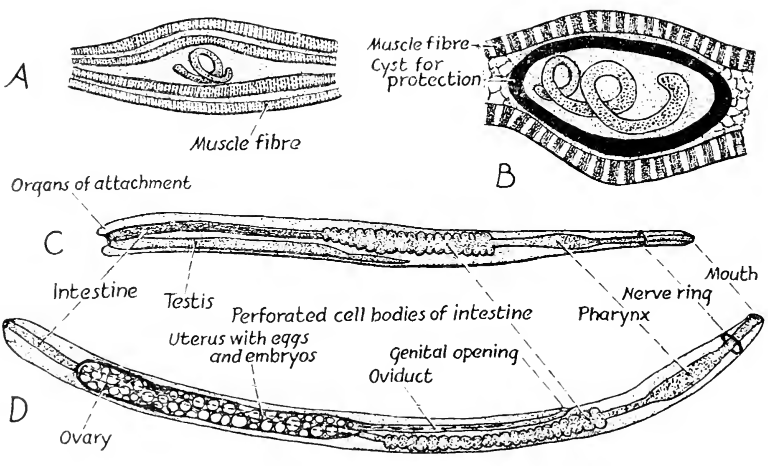


Fig. 100.—Trichina or "pork worm" (*Trichinella spiralis*) of the phylum *Nemathelminthes*. *A*, Trichina between muscle fibers; *B*, trichina between muscle fibers and surrounded by a cyst; *C*, trichina (male); *D*, trichina (female).

mission. The esophagus is without a bulb; the mouth has a pair of lateral lips or may be lipless. They are the cause of many diseases.

Examples: Human filarial elephantiasis worms, *Wuchereria (Filaria) bancrofti* (Fig. 101), which causes human elephantiasis by obstructing the flow of lymph, especially through the lymph glands (is transmitted by nocturnal mosquitoes), guinea worm or "fiery serpent" *(Dracunculus medinensis)* which is an inhabitant of the skin of human beings, dogs, etc., and the "eye" worm *(Loa loa)* which affects the human eye.

Order 4—Trichinelloidea (trik i nel -oid′ e a) (Gr. *trich.* hairlike).—All are parasitic. The body is divided into a more or less distinct esophageal region and a posterior region; the esophagus is a nonmuscular tube of cuticle embedded in a single layer of epithelial cells. Females have a single ovary with a duct; males have one spicule or may have none.

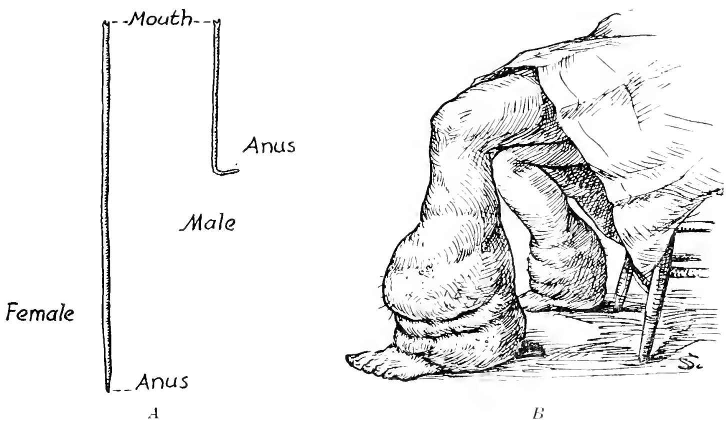


Fig. 101.—*Wuchereria* (*Filaria*) *bancrofti* of the class *Nematoda,* phylum *Nemathelminthes.* *A,* Causes of human elephantiasis; *B,* a chronic enlargement and hardening of the skin, particularly of the legs. Note the comparative sizes of the male and female.

Examples: Human Trichina or pork roundworm *(Trichinella spiralis)* (Fig. 100) which causes human trichinosis when improperly cooked pork is eaten (the saclike cysts in which the immature stages are spent may be so numerous that 100,000 may be present in one cubic inch of meat). The worms may be present in the muscles of man, dogs, rats, pigs, rabbits, and mice. Human whipworms *(Trichuris trichiura)* inhabit the cecum and appendix of man.

Phylum 7. Trochelminthes (trok el -min′ thez) (Gr. *trochos,* wheel; *helmins,* worm) or **P. Rotifera** (ro -tif′ er a) (L. *rota,* wheel; *fero,* to bear)

General Characteristics

Rotifers (Fig. 102) are very common, small, aquatic animals found mostly in fresh water, although some are marine and a few are parasitic. They are characterized by a bandlike disk of cilia (trochal disk) around the mouth at the anterior

LIFE HISTORIES OF A FEW REPRESENTATIVE NEMATODES
(UNSEGMENTED ROUNDWORMS)

PARASITE	ADULT STAGES	IMMATURE STAGES
Human or Pig Roundworm *(Ascaris lumbricoides)*	Man, pig	Soil, water, pig, man (lung)
Human Pinworm *(Enterobius vermicularis)*	Man (intestine, cecum)	
American Hookworm *(Necator americanus)*	Man (skin, intestine, heart, lungs, trachea)	Soil (moist)
European Hookworm *(Ancylostoma duodenale)*	Man (skin, intestine, heart, lungs, trachea)	Soil (moist)
Elephantiasis (Filarial) Worm *(Wuchereria bancrofti)*	Man (blood stream, lymph, lungs, skin)	Mosquito
Guinea (Filarial) Worm or "Fiery Serpent" *(Dracunculus medinensis)*	Man (beneath skin)	Fresh-water crustacean *(Cyclops)*, water
Pork Roundworm or Trichina *(Trichinella spiralis)*	Man (intestine, muscles)	Pig, rat, cat, dog, flesh-eating animals
Bird Gapeworm *(Syngamus trachea)*	Fowls, wild birds (trachea) (cause of gapes)	Soil, earthworms
Human Whipworm *(Trichuris trichiura)*	Man (cecum, appendix)	
Common Garden Nematode *Heterodera* [*Caconema*] *radicicola)*	Hundreds of plants, crops, trees, etc. (especially in roots)	Soil
Vinegar "eel" *(Turbatrix* [*Anguillula*] *aceti)*	Vinegar	

end. Because of the wheel-like movements of these cilia, the animals are commonly called rotifers or wheel animalcules. The body is somewhat cylindrical, bilaterally symmetrical, and covered with a transparent cuticle. The latter is divided into sections which may be telescoped into each other when the animal contracts. The movements of a pair of chitinous, chewing jaws (mastax) distinguish the living rotifers. A cavity (probably not a true coelom) contains the alimentary canal and a pair of excretory tubes which empty their wastes into a bladder which contracts at intervals, expelling them through the anus (cloacal opening). A forked posterior tail ("foot") is provided with pedal (cement) glands for adhesion. Certain rotifers may resist drying for years and be carried by dust particles in their dried state. Hence, rotifers are among the most widely distributed of animals. Different species of rotifers vary in shape from the free-swimming spheroid forms that float near the surface to the wormlike bottom dwellers or the flowerlike attached types. In certain species, several individuals are grouped in a colony. Some species dwell in tubes of materials made from their surroundings. The life cycles are quite complicated. Three types of eggs are produced: (1) large, thin-shelled summer eggs which develop parthenogenically (without fertilization) into females, (2) small, thin-shelled summer eggs which develop parthenogenically into males, and (3) thick-shelled winter eggs which when fertilized develop into females. The winter eggs may remain alive in a dormant state for years, developing when suitable conditions occur. Number of species of Rotifers, 1,000.

CLASSIFICATION OF THE PHYLUM TROCHELMINTHES (ROTIFERA)* (FIG. 102)

In the classification of the rotifers, the following characteristics are used: (1) the presence of one or a pair of ovaries; (2) whether males are usually present but degenerate; males unknown; or males fully developed; (3) absence or presence of lateral antennae on the body. If desired, the student is referred to a more complete classification in other books.

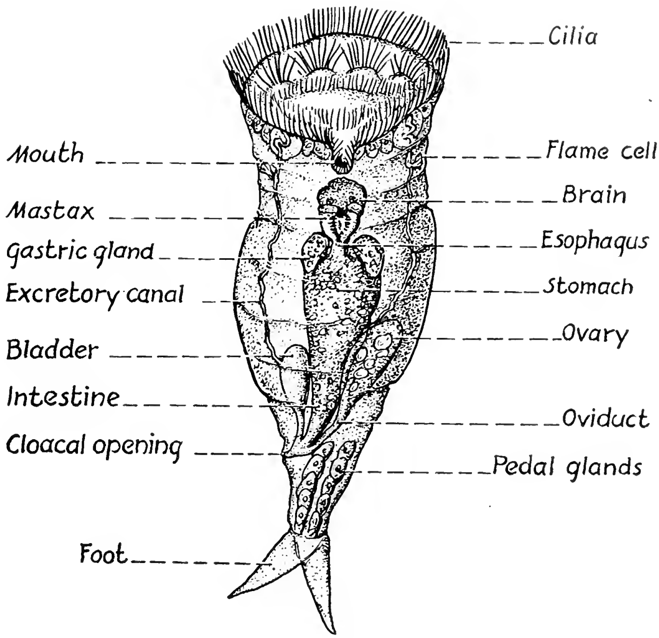


Fig. 102.—A female rotifer (much enlarged) of the phylum *Trochelminthes* (Rotifera).

Phylum 8. Echinodermata (e ki no -dur′ ma ta) (Gr. *echinos,* spiny; *dermos,* skin or covering)

GENERAL CHARACTERISTICS

The echinoderms have a spiny skeleton of calcareous plates which usually covers the body. The adults have radial symmetry with five antimeres (divisions of a radially symmetrical animal). The larvae have bilateral symmetry. The adult animals are triploblastic, having three primary germ layers: ectoderm, mesoderm, and entoderm. An anus is usually present. The coelom (body cavity) is well developed. The type of locomotion which is peculiar to many types of echinoderms is accomplished by tube feet. These are branches of the water vascular system which is a division of the coelom. All echinoderms are marine. Many species have great powers of regeneration, particularly after autotomy (Gr.

*Sometimes the term *Rotifera* is used as a class under the phylum *Trochelminthes*.

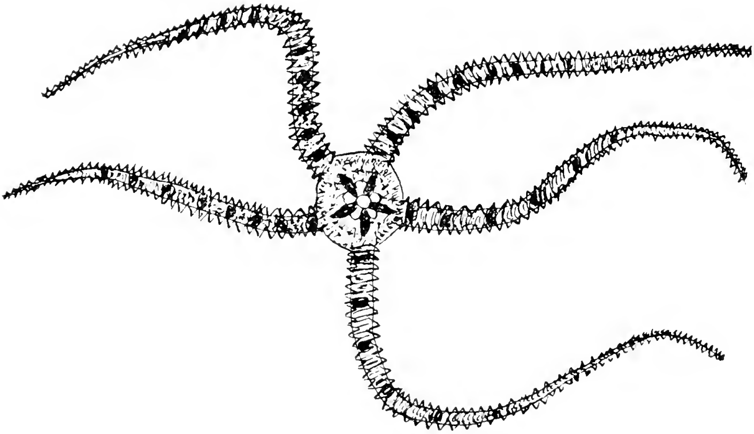


Fig. 103.—Brittle star (oral view) of the phylum *Echinodermata,* class *Ophiuroidea.*

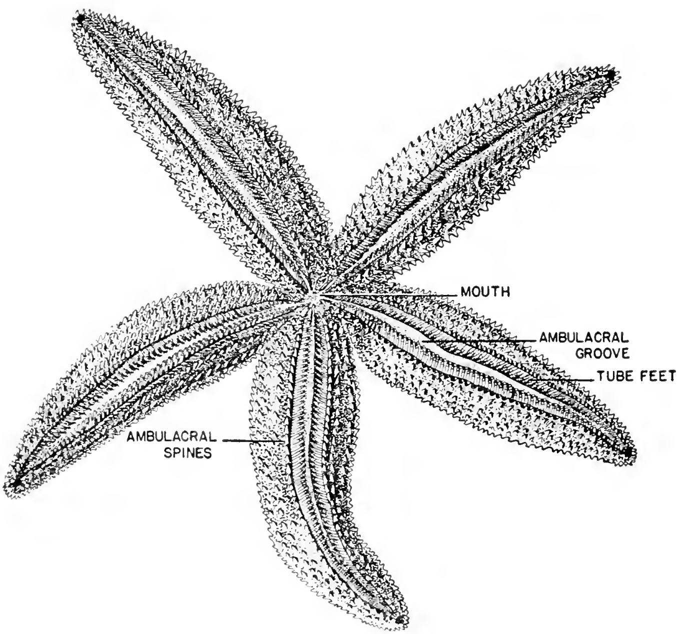


Fig. 104.—Starfish from the oral or under side, showing the rows of tube feet extending from the ambulacral grooves. The long, movable ambulacral spines protect the tube feet when the latter are retracted within the groove. Similar oral spines surround the mouth for protection. (From Parker and Clarke: An Introduction to Animal Biology, The C. V. Mosby Co.)

autos, self; *tome,* cutting or mutilating) (Fig. 28). The eggs of many species lend themselves admirably for experiments on artificial parthenogenesis (development of the egg without fertilization). Number of species of Echinodermata, 6,000.

CLASSIFICATION OF THE PHYLUM ECHINODERMATA

Class 1—Asteroidea (as ter -oi' de a) (Gr. *aster,* star; *eidos,* resemblance).—These are typically free-living, five-rayed (pentamerous) types with the five rays

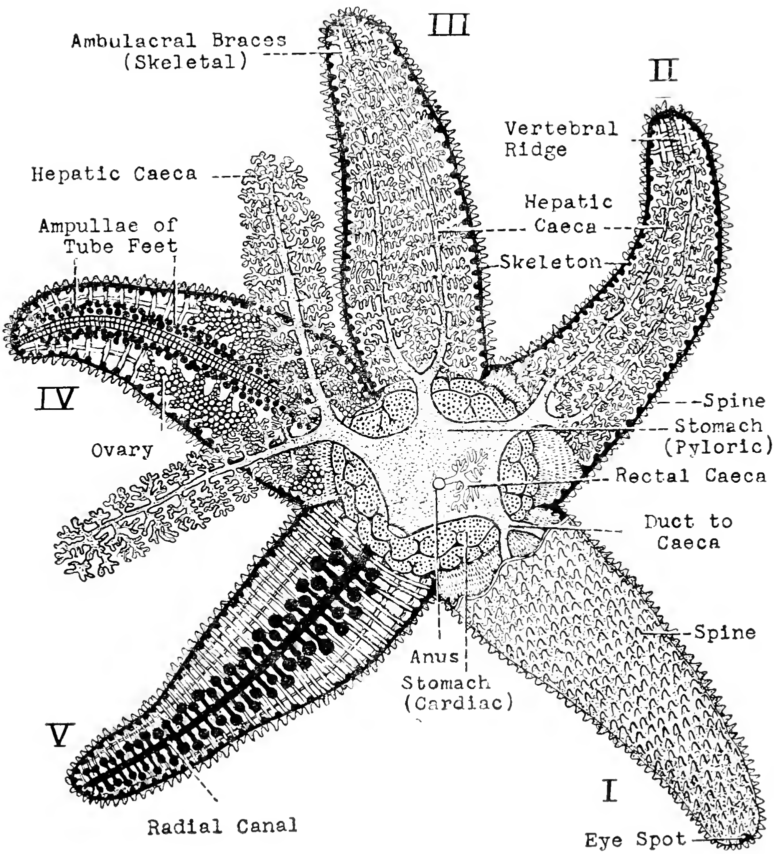


Fig. 105.—Common starfish (*Asterias forbesi*) dissected from the aboral surface to show the digestive, locomotor, reproductive, and skeletal systems. *I,* Arm or ray, showing aboral surface covered with spines; *II* and *III,* arms with aboral surface removed; *IV,* arm with aboral surface removed and the hepatic caeca moved to show the bulblike ampullae of the tube feet, etc.; *V,* arm with internal organs and vertebral ridge removed to show the four rows of ampullae of the tube feet, the connecting canals, and the radial canal (all of the water vascular system).

or arms not sharply marked off from the central disk. The internal visceral organs extend into the arms. There is a distinct ambulacral groove on the ventral side of the arms. There is a true coelom (body cavity). The body is somewhat flattened. The anus and madreporite plate (entrance of water vascular system) are located on the dorsal, upper aboral side.

Example: *Starfish* (Figs. 104 to 107 and 328).

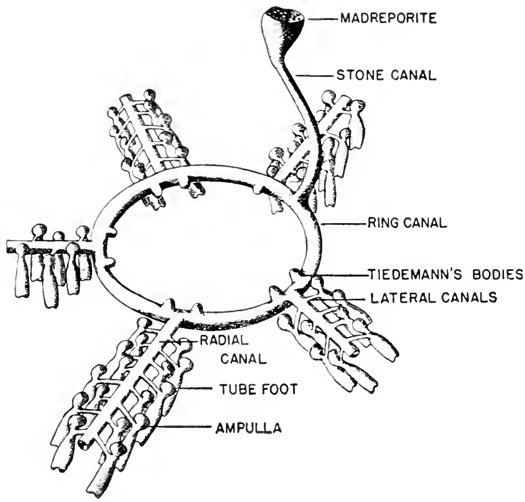


Fig. 106.—Water-vascular system of starfish somewhat diagrammatic. The madreporite is a porous plate on the upper surface of the starfish, between the bivium rays, through which the water enters. The ring canal is also known as the circular or circumoral canal. There are nine Tiedemann's bodies (the tenth is replaced by the stone canal), which produce the amoebocytes found in the fluid within the water-vascular system. The lateral canals are also known as connecting canals. (From Parker and Clarke: An Introduction to Animal Biology, The C. V. Mosby Co.)

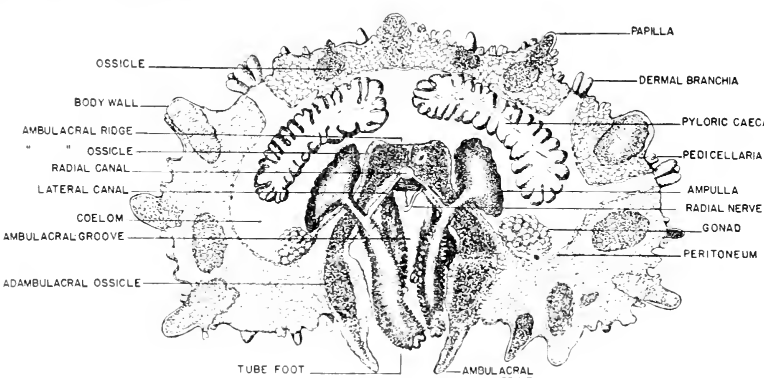


Fig. 107.—Cross section of a starfish arm or ray, somewhat diagrammatic. (From Parker and Clarke: Introduction to Animal Biology, The C. V. Mosby Co.)

Class 2—Ophiuroidea (of i u -roi′ de a) (Gr. *ophis,* snake; *oura,* tail; *eidos,* resemblance).—These are typically free-living, five-rayed (pentamerous) types with the five flexible rays or arms sharply marked off from the central disk. There are no caeca and reproductive organs in the arms. There are no ambulacral grooves. The body is somewhat flattened. There is no anus. The madreporite plate is on the dorsal upper surface. The tube feet are modified and serve only as tactile organs.

Examples: *Brittle* or *serpent star* (Fig. 103) and *basket star.*

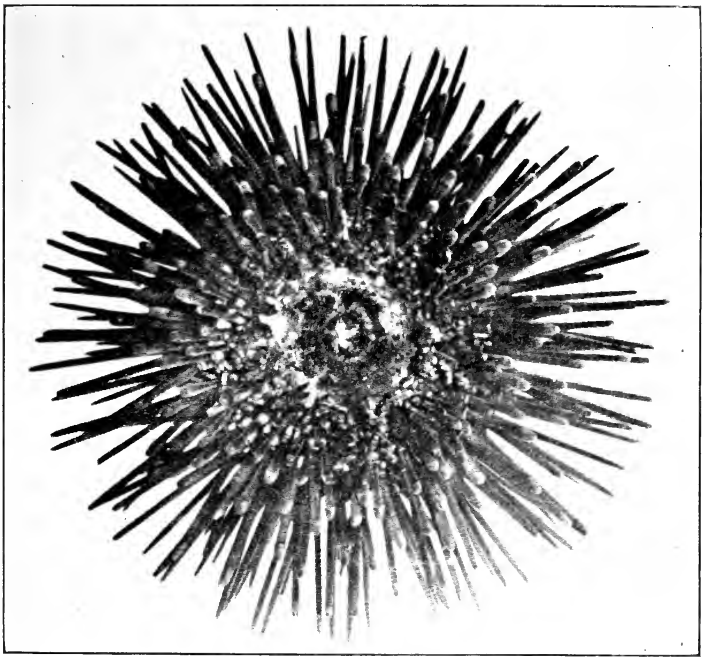


Fig. 108.—Purple sea urchin (*Arbacia punctulata*) of the phylum *Echinodermata,* class *Echinoidea,* from the oral or under side. Note the five sharp white teeth (Aristotle's lantern) in the center. (From Coe: Echinoderms of Connecticut, State Geological and Natural History Survey of Connecticut, Bulletin 19.)

Class 3—Echinoidea (ek i -noi′ de a) (Gr. *echinos,* hedgehog; *eidos,* resemblance).—These are free-living types but may be sedentary. There are no free arms or rays, the space between them being more or less filled in. The test or skeleton is composed of twenty columns of firmly united calcareous plates bearing movable spines. These include five pairs of ambulacral rows (perforated for the exit of tube feet) and five pairs of interambulacral rows of plates.

Examples: *Sea urchin* (Figs. 108 and 109), *sand dollar* (Fig. 110), and *heart urchin.*

Class 4—Holothurioidea (hol o thu ri -oi′ de a) (Gr. *holos,* whole; *thurios,* rushing).—These echinoderms have soft, elongated, ovoid, muscular bodies with rather isolated, small, calcareous plates. Branched, contractile tentacles surround the mouth. Five rows of radially arranged rows of tube feet extend the length of the body. The external surface is free from spines, cilia, and pincerlike pedicellaria. The madreporite is internal. The sea cucumbers move about freely in a lateral position near the bottom of the sea. They possess remarkable powers of autotomy and regeneration. When stimulated, the muscles of the body wall contract and set up an enormous pressure in the fluid of the body cavity. As a result, many of the internal organs are pushed out and surround an attacking enemy. The lost organs are usually soon regenerated.

Example: *Sea cucumber* (Fig. 111).

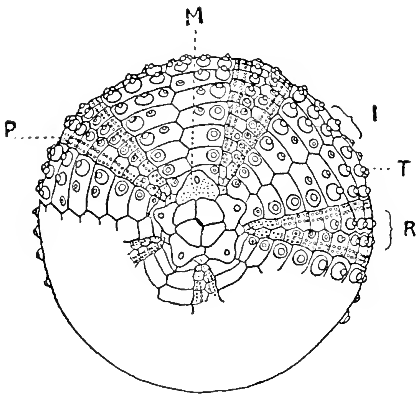


Fig. 109.—Diagram of the skeleton or "test" (with spines removed) of purple sea urchin (*Arbacia punctulata*) of the class *Echinoidea*. Outline of plates of the aboral surface, showing the four plates of the periproct (center) surrounded by the five ocular and five genital plates at the ends of the ambulacral, *R*, and interambulacral, *I*, zones, respectively; one genital plate marked *M* is the madreporite plate; the ocular plate is smaller than the genital plate and is located in the angle between two of the latter; *T*, tubercles for attachment of spines; *P*, pores for the tube feet. (From Coe: Echinoderms of Connecticut, State Geological and Natural History Survey of Connecticut, Bulletin 19.)

Class 5—Crinoidea (kri -noi′ de a) (Gr. *krinos*, lily; *eidos*, resemblance).—The five arms generally are branched with many smaller pinnules which give a lilylike appearance. The tentacles are like tube feet but without the pouchlike ampullae. The aboral plate usually has a heavy jointed stalk for temporary or permanent attachment. Certain species have small holdfasts; others are secondarily free swimming. Fossil remains of crinoids are very common in limestone strata.

Examples: *Stone lily, feather star* (Fig. 112) and *sea lily*.

Phylum 9. Annelida (a -nel′ i da) (L. *annellus*, a little ring; *eidos*, resemblance).

General Characteristics

These worms are elongated with a linear series of internal and external ringlike segments (metameres). They possess bilateral symmetry. *Setae*, or skin

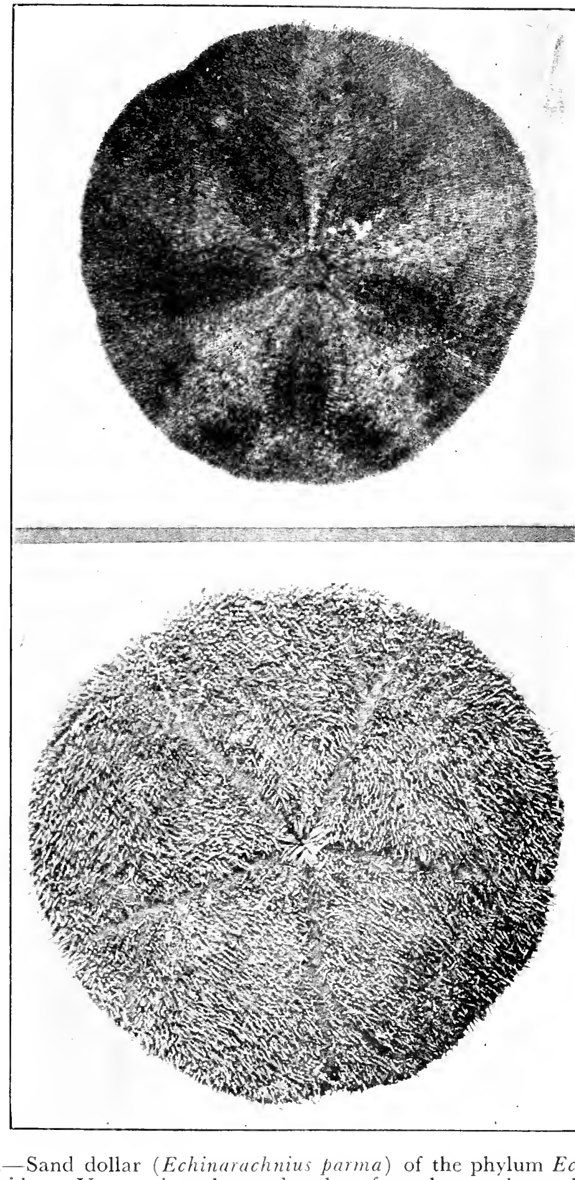


Fig. 110.—Sand dollar (*Echinarachnius parma*) of the phylum *Echinodermata*, class *Echinoidea*. Upper view shows aboral surface; lower, the oral surface. In the aboral view, the darker ambulacral areas, or "petals," are shown. In the oral view, the ambulacral areas are shown as narrow furrows radiating from the central mouth. (From Coe: Echinoderms of Connecticut, State Geological and Natural History Survey of Connecticut, Bulletin 19.)

bristles, are common in many species. The animals are triploblastic, having three primary germ layers: ectoderm, mesoderm, and entoderm. All species possess a true coelom (body cavity), although it may be small in some types, such as leeches. They possess a complex closed circulatory system. Some species are aquatic, some terrestrial, and others marine. Number of species of Annelida, 7,500.

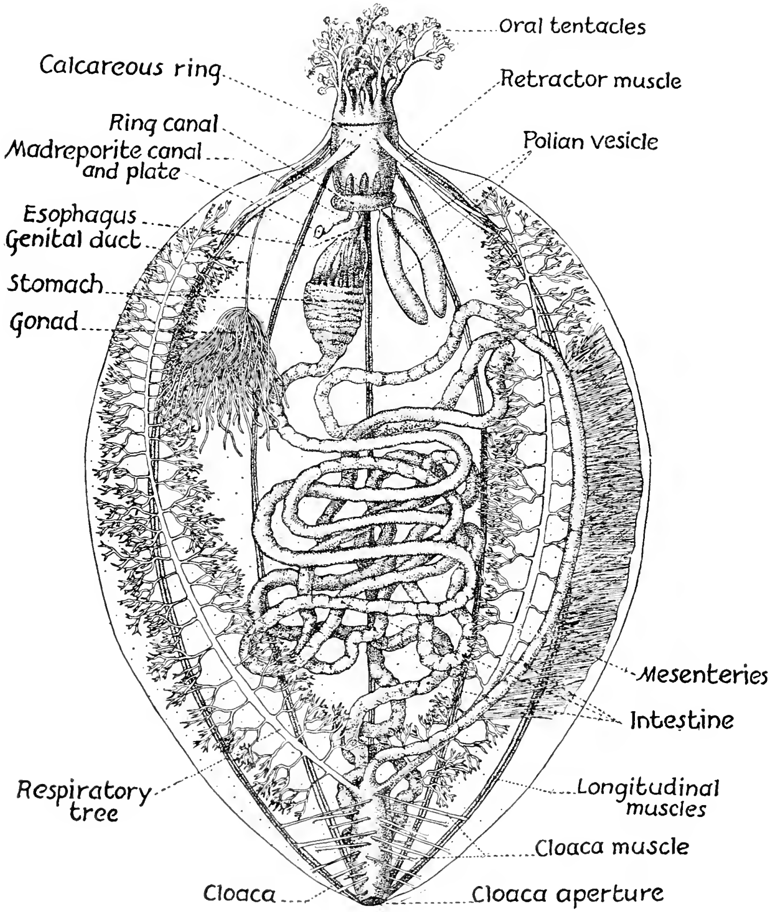


Fig. 111.—Sea cucumber (*Thyone briareus*) of the phylum *Echinodermata,* class *Holothurioidea,* shown in longitudinal section and somewhat diagrammatically. (From Coe: Echinoderms of Connecticut, State Geological and Natural History Survey of Connecticut, Bulletin 19.)

Classification of the Phylum Annelida

Class 1—Archiannelida (ar ki a -nel′ i da) (Gr. *archi,* primitive; annelida). —These are primitive marine annelids which lack both bristlelike setae and parapodia (flat organs of locomotion and respiration).

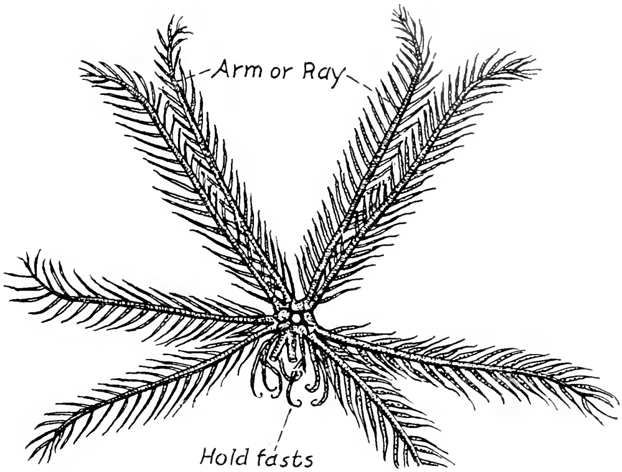


Fig. 112.—Feather star (*Antedon sp.*) of the class *Crinoidea,* phylum *Echinodermata.* Oral view showing only four of the five branched arms, each with many small pinnules. The "hold fasts" attach it to the ground.

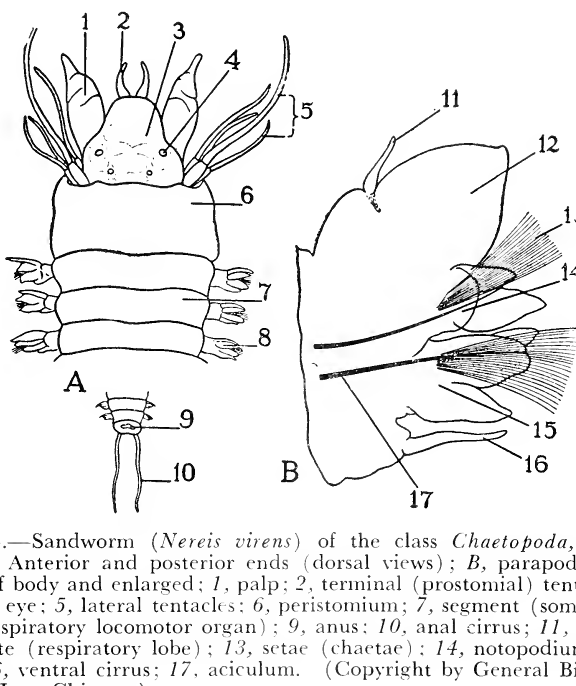


Fig. 113.—Sandworm (*Nereis virens*) of the class *Chaetopoda,* phylum *Annelida. A,* Anterior and posterior ends (dorsal views); *B,* parapodium removed from side of body and enlarged; *1,* palp; *2,* terminal (prostomial) tentacle; *3,* prostomium; *4,* eye; *5,* lateral tentacles; *6,* peristomium; *7,* segment (somite); *8,* parapodium (respiratory locomotor organ); *9,* anus; *10,* anal cirrus; *11,* dorsal cirrus; *12,* gill plate (respiratory lobe); *13,* setae (chaetae); *14,* notopodium; *15,* neuropodium; *16,* ventral cirrus; *17,* aciculum. (Copyright by General Biological Supply House, Inc., Chicago.)

Example: *Polygordius* (about two inches long, and internally resembles the earthworm).

Class 2—Chaetopoda (ke-top′ o da) (Gr. *chaite,* bristle; *pous,* appendage).—Terrestrial, marine, or fresh-water annelids possessing chitinous bristlelike setae (chaetae) embedded in pits of the integument and moved by means of attached muscles. The coelom is divided by numerous intersegmental septa (partitions).

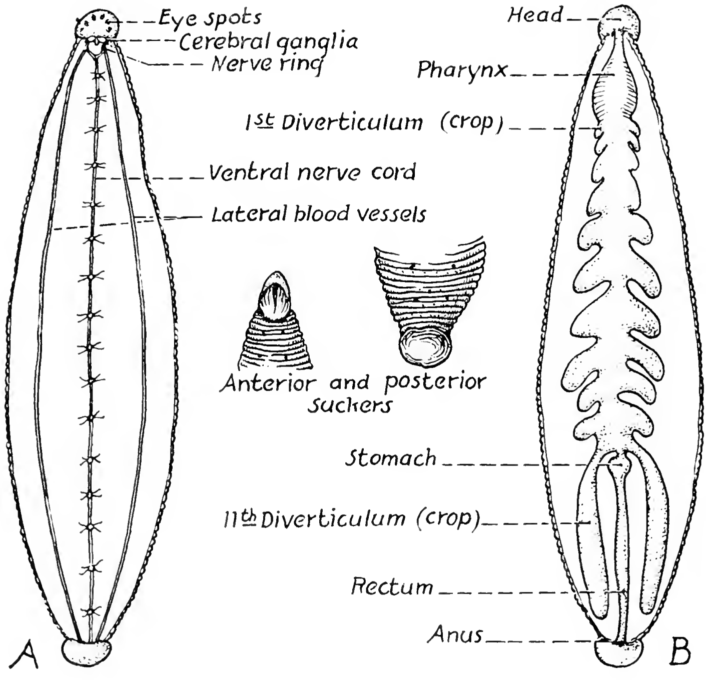


Fig. 114.—Common leech of the class *Hirudinea,* phylum *Annelida,* dissected from the dorsal side to show the nervous and circulatory systems, *A,* and the digestive system, *B.* The anterior and posterior suckers of the ventral side are shown separately.

Order 1—Polychaeta (pol i-ke′ ta) (Gr. *poly,* many; *chaeta,* bristles).—Marine types with many setae situated on flat, fleshy lateral outgrowths known as parapodia (used for locomotion and respiration). These worms usually have a well-developed head bearing appendages. The sexes are separate. There is a free-swimming, ciliated larval stage known as a trochophore (Gr. *trochos,* wheel; *phoreo,* to bear).

Example: Sandworm (Clamworm) (Fig. 113).

Order 2—Oligochaeta (ol i go-ke′ ta) (Gr. *oligo,* few; *chaeta,* bristles).—This order consists mostly of terrestrial and fresh-water annelids with few setae, no parapodia, and no distinct head with appendages. Both sexes are in the same individual (hermaphroditic or monecious). There is no trochophore larval stage in its embryologic development.

Example: Earthworm (Figs. 185 to 190).

Class 3—Hirudinea (hir u -din' e a) (Gr. *Hirudo,* leech).—Leeches have dorsoventrally flattened bodies with anterior and posterior suckers for attachment and blood sucking. There are no setae or parapodia. The real and visible segments have from two to fourteen external grooves to each real segment (depending on the species). The coelom may be small because of the growth of mesenchyme cells. Both sexes are in the same individual.

Example: Leeches (Fig. 114).

Phylum 10. Mollusca (mol -lus' ka) (L. *mollis,* soft)

General Characteristics

Mollusks have soft bodies with no true skeleton, although many types secrete one or more external calcareous shells from a fold of the body wall. These

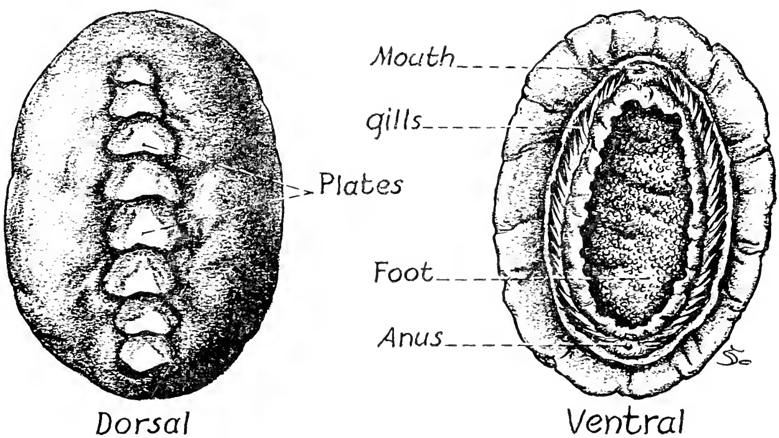


Fig. 115.—Chiton (*Katharina sp.*) of the class *Amphineura,* phylum *Mollusca.*

animals are nonmetameric (unsegmented) and possess either bilateral symmetry or asymmetry, depending on the species. The animals are triploblastic, having three primary germ layers: ectoderm, mesoderm, and entoderm. The coelom (body cavity) is secondarily obliterated and is divided into a pericardial cavity (around the heart) and a cavity around the reproductive organs. Mollusks possess a mantle cavity between the main body and the mantle (enclosing envelope). A ventral muscular foot for locomotion is usually characteristic. Number of species of Mollusca, 75,000.

Classification of the Phylum Mollusca

Class 1—Amphineura (am-fi-nu' ra) (Gr. *amphi,* on both sides; *neura,* nerves).—These forms are widely distributed marine types which possess bilateral symmetry with two nerves running the length of the animals. They often have a series of calcareous plates (usually eight) on the dorsal side. Several pairs of gill filaments may be present for respiration.

Example: *Chiton* (Fig. 115).

Class 2—Gastropoda (gas -trop′ o da) (Gr. *gaster,* belly or stomach; *pous,* foot).—The body is more or less spirally coiled with part of the digestive tract in the muscular foot. Gastropods possess a distinct head, foot, and mantle cavity.

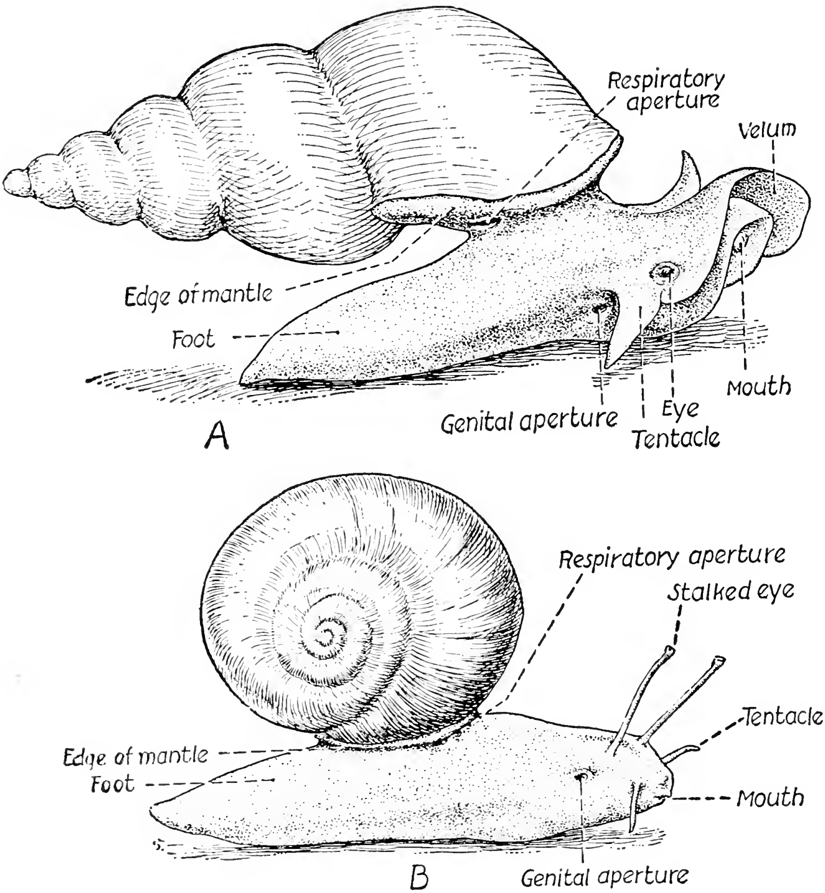


Fig. 116.—*A,* Fresh water snail (*Lymnea sp.*); *B,* land snail (*Humboldtiana sp.*). Bodies are expanded from the shell. (From Potter: Textbook of Zoology, The C. V. Mosby Co.)

The latter contains a mantle for respiration. The shell is in one piece and coiled. In such types as the slugs the shell is absent. The shell is asymmetrical, but the head and foot show bilateral symmetry.

Examples: *Snails* (Figs. 116, 117, and 119), *slugs, limpets,* and *whelks.*

Class 3—Pelecypoda (pel e -sip' o da) (Gr. *pelekos,* hatchet; *pous,* foot) or class *Lamellibranchiata* (L. *lamina,* thin sheet; *bronchiatus,* having gills).—The mantle cavity has gills which are usually lamellate (sheetlike). The muscular foot, which is used for locomotion, somewhat resembles a hatchet. The calcareous shell consists of paired valves, which are secreted by the bilobed *mantle.* The pelecypods are bilaterally symmetrical. They are all aquatic and most of them are marine. None possess head, tentacles, or eyes.

Examples: *Mussels, clams* (Figs. 118, 120, 121), *oysters, scallops,* and *shipworms* (Fig. 122).

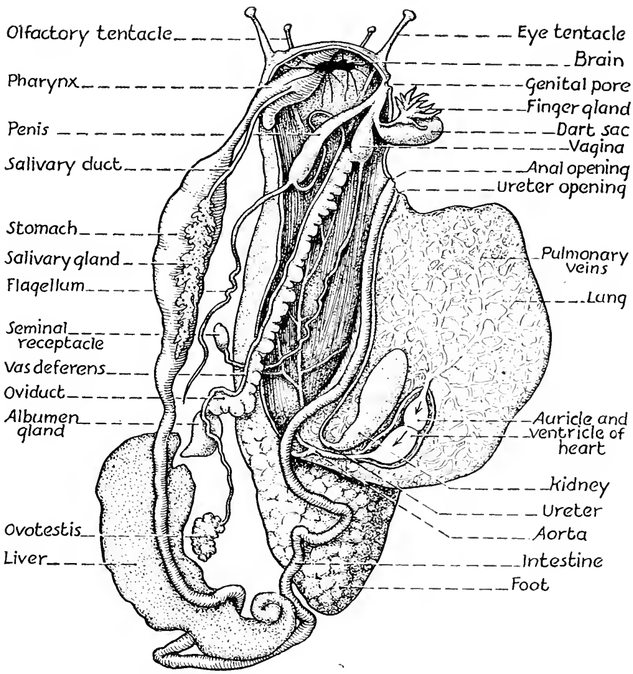


Fig. 117.—Anatomy of the snail (*Helix pomatia*), the roof of the pulmonary sac cut at the left and turned to the right; the pericardium and visceral sac opened and the viscera or internal organs somewhat separated. The finger gland is also called the accessory or mucous gland.

Class 4—Cephalopoda (sef al -op' o da) (Gr. *kephale,* head; *pous,* foot).—The head and foot are fused to form a tentacled secondary head. Suckers are present on the tentacles. They possess external bilateral symmetry. The nervous system is well developed in the head.

Examples: *Squid* (Fig. 123), *octopus* (Fig. 124), *cuttlefish,* and *nautilus.*

Class 5—Scaphopoda (ska -fop' o da) (Gr. *skapho,* a boot; *pous,* foot).—These elongated marine types possess a trilobed foot for boring in the sand. The

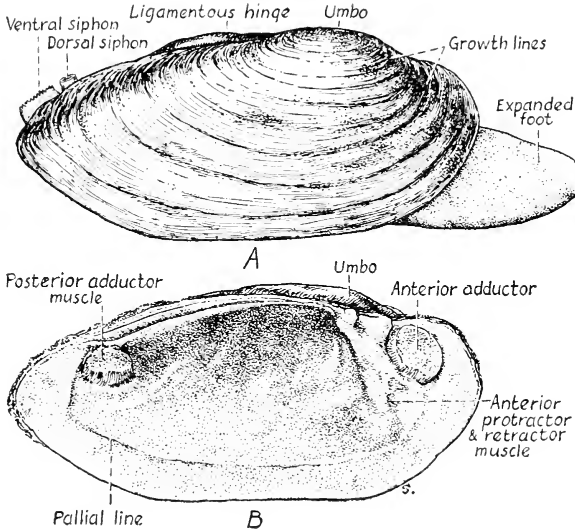


Fig. 118.—Fresh water clam (*Lampsilis anodontoides*) of the phylum *Mollusca*, class *Pelecypoda*. External, *A*, and internal, *B*, shell features. (From Potter: Textbook of Zoology, The C. V. Mosby Co.)

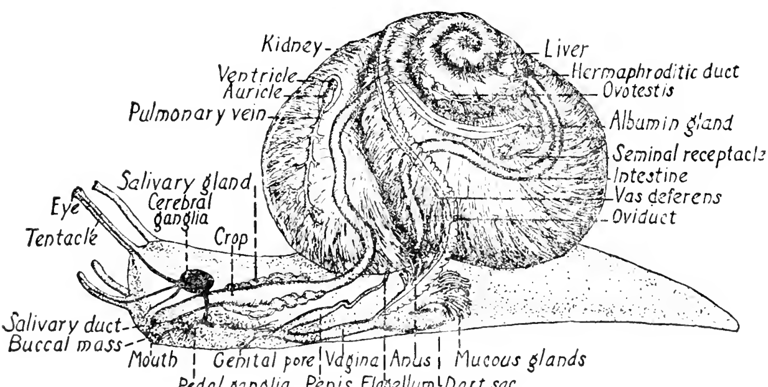


Fig. 119.—Internal anatomy of a snail (*Helix sp.*) with shell removed. (From Potter: Textbook of Zoology, The C. V. Mosby Co.)

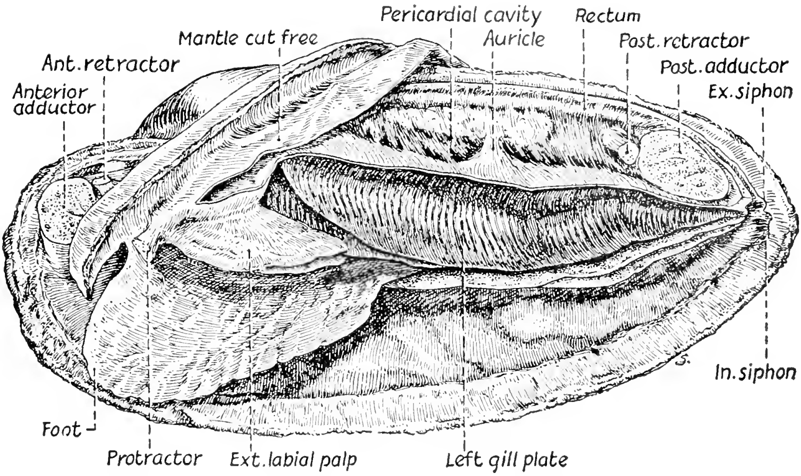


Fig. 120.—Fresh water clam (*Lampsilis anodontoides*) with the left mantle partially removed and turned back to expose the underlying organs. (From Potter: Textbook of Zoology, The C. V. Mosby Co.)

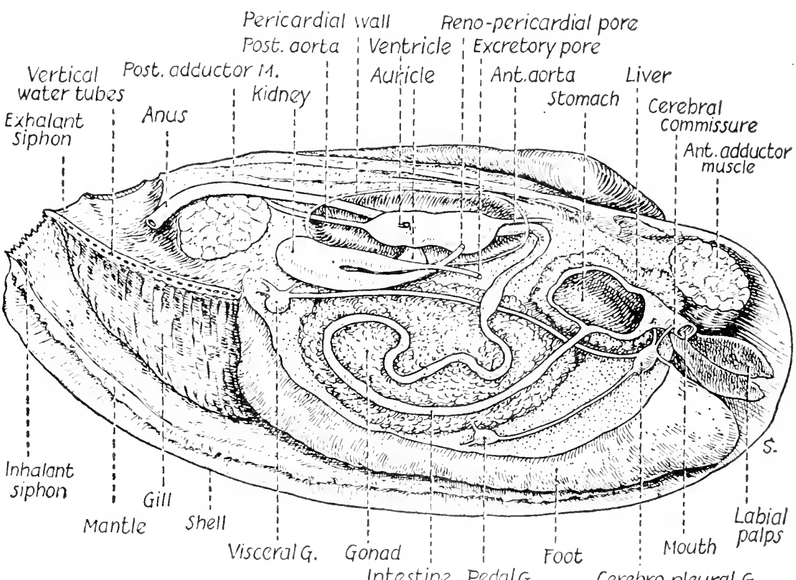


Fig. 121.—Fresh water clam (*Lampsilis anodontoides*) showing internal organs. (From Potter: Textbook of Zoology, The C. V. Mosby Co.)

tuskshaped, calcareous shell is secreted by the mantle. They possess bilateral symmetry and the head is rudimentary.

Example: *Tooth shell (Dentalium)* (Fig. 125).

Phylum 11. Arthropoda (ar -throp'o da) (Gr. *arthron,* jointed; *pous,* appendage, or foot)

General Characteristics

Paired, jointed appendages are present on all or some of the segments of the body. An exoskeleton of chitin is secreted by the cells just beneath it. Chitin (Gr. *chiton,* a tunic or covering) is a protein material and has the formula ($C_{50}H_{30}O_{19}N_4$). The external, dissimilar segments (metameres) are well defined, but the internal segments are largely obliterated. The body possesses regional specialization (certain regions for specific purposes) and is bilaterally symmetrical.

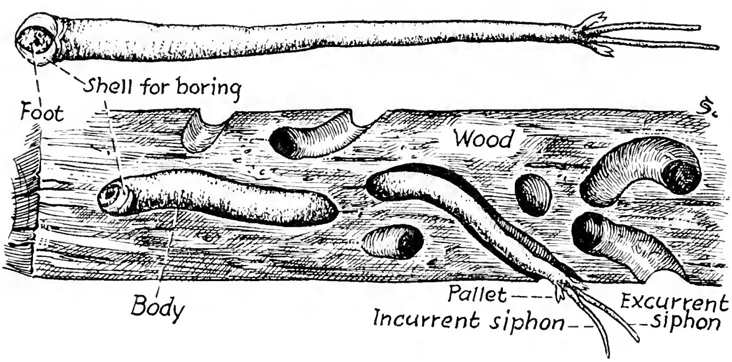


Fig. 122.—The shipworm (*Teredo navalis*) of the class *Pelecypoda,* phylum *Mollusca.* The shipworm is shown somewhat diagrammatically in its burrow in a piece of wood. The modified bivalve shell and the siphons are characteristics of mollusca.

The animals are triploblastic, having three germ layers: ectoderm, mesoderm, and entoderm. The coelom (body cavity) is rather poorly developed, it being replaced by a *hemocoel* (Gr. *hema,* blood; *koilos,* cavity) filled with blood. The mouth and anus are on opposite ends of the animal. A tubular heart and its aorta are dorsal to the alimentary canal. Blood sinuses are commonly distributed throughout the tissues. The nerve cord with its ganglia is ventral to the alimentary canal. The paired cerebral ganglia are anterior and dorsal to the alimentary canal (as in the earthworm). The cerebral ganglia are connected with the ventral nerve cord by a nerve ring. The muscles of the body are usually striated (striped). Number of species of Arthropoda, 675,050.

Classification of Arthropoda (see table on pp. 318 and 319)

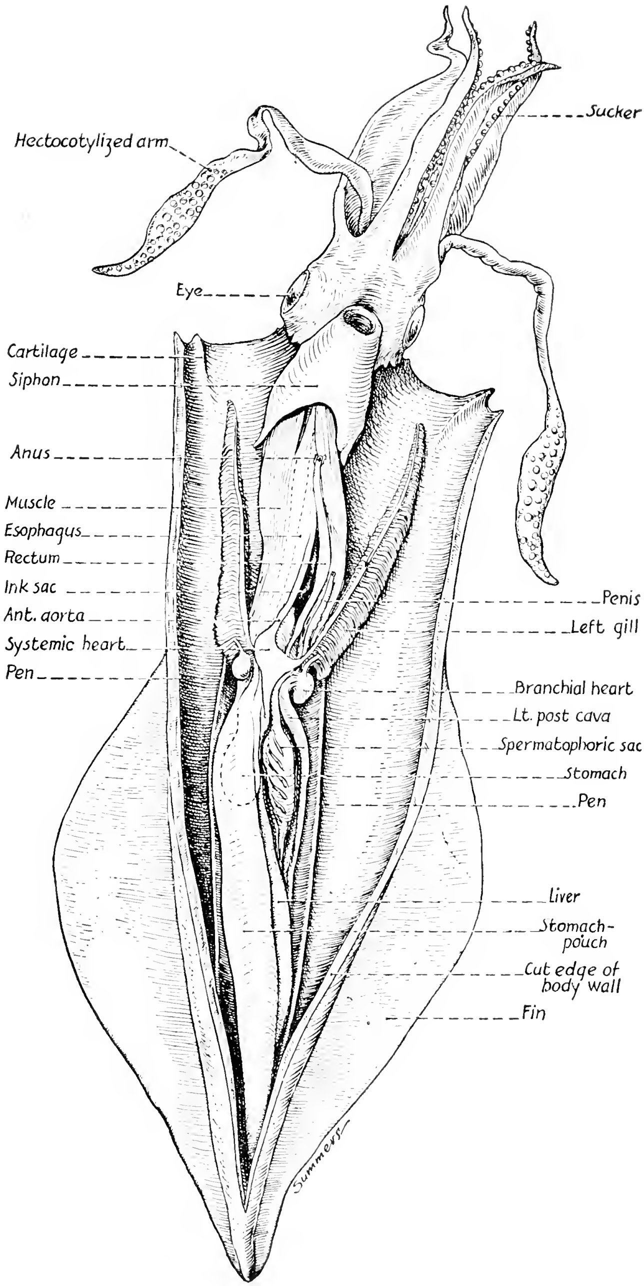


Fig. 123.—The squid (*Loligo sp.*) of the class *Cephalopoda*, phylum *Mollusca*. Dissected to show internal anatomy. (From Potter: Textbook of Zoology, The C. V. Mosby Co.)

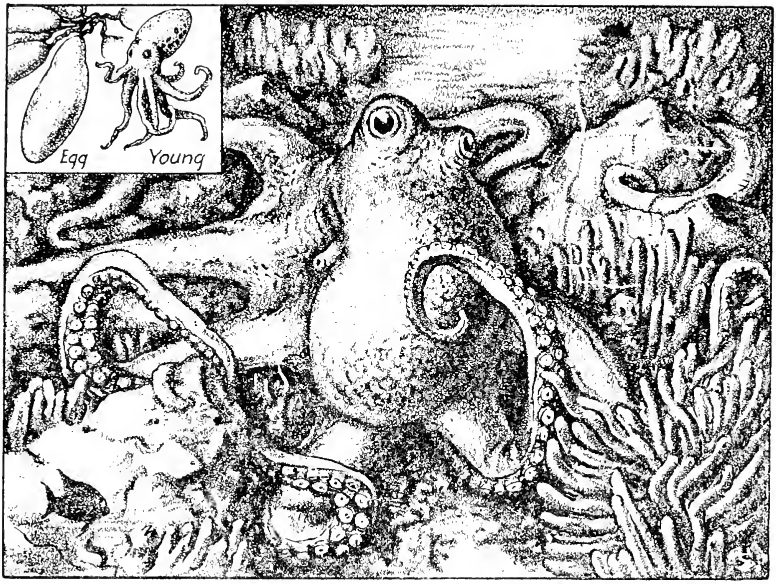


Fig. 124.—Octopus or "devilfish" of the class *Cephalopoda,* phylum *Mollusca.*

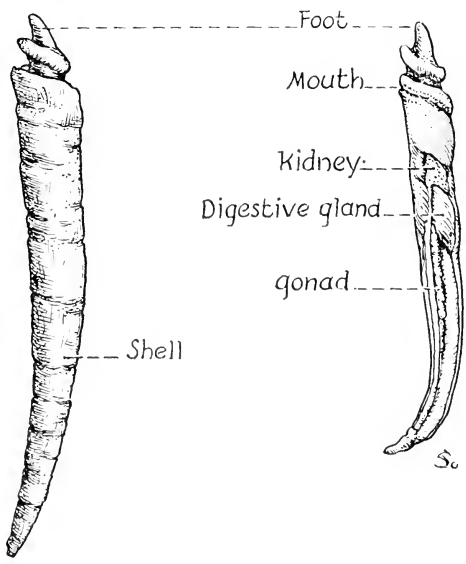


Fig. 125.—Tooth shell (*Dentalium sp.*) of the class *Scaphopoda,* phylum *Mollusca.* At the right the shell is removed to show the internal organs.

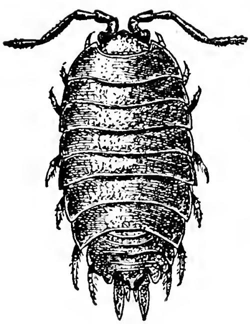


Fig. 126.

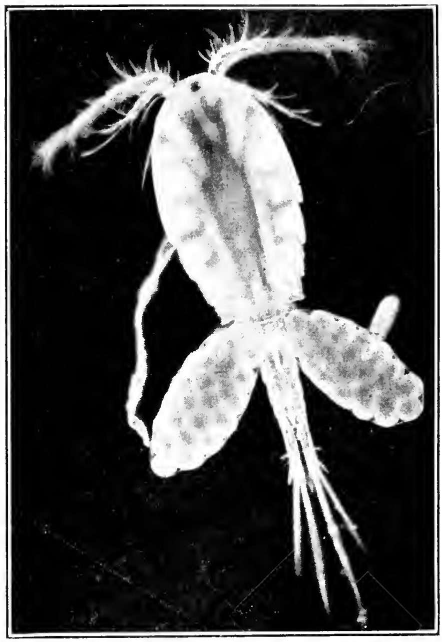


Fig. 127.

Fig. 126.—Sowbug (*Porcellio laevis*) of the class *Crustacea,* phylum *Arthropoda.* Much enlarged. A terrestrial type common in dark, damp places. (From Popenoe: Mushroom Pests and How to Control Them, U. S. Department of Agriculture, courtesy of Bureau of Entomology and Plant Quarantine.)

Fig. 127.—Copepod water flea (*Cyclops*) of the class *Crustacea,* phylum *Arthropoda.* The paired egg sacs are shown near the tip of the body of the female. Found in fresh water. (Copyright by General Biological Supply House, Inc., Chicago.)

Classification of Arthropoda

CLASS	EXAMPLES	ANTENNA	HABITAT	RESPIRATION	WINGS	LEGS	MISCELLANEOUS
1. *Crustacea* (krus -ta′ she a) (L. *crusta*, skin)	Crayfish (Figs. 128 to 130 and 307) Lobster Shrimp (Fig. 131) Crab (Fig. 132) Barnacle (Fig. 133) Water flea (Fig. 134) Sow bug (Fig. 126) Cyclops (Fig. 127)	2 pairs	Aquatic for most species (few are parasitic)	Gill breathing	None	Numerous	Body composed of head, thorax, and abdomen; head and thorax may be fused into a cephalothorax
2. *Onychophora* (on i -kof′ o ra) (Gr. *onux*, claw; *phoreo*, to bear)	Peripatus (Fig. 135)	1 pair	Terrestrial (moist places)	Trachea (air breathing)	None	Numerous	Primitive, tropical, or semitropical arthropods; possess paired, annelid-like nephridia; limited in distribution
3. *Chilopoda** (kai -lo′ po da) (Gr. *cheilos*, lip; *pous*, foot)	Centipedes (Fig. 135)	1 pair (long)	Terrestrial (moist places)	Trachea (air breathing)	None	Numerous (1 pair on most segments)	Long, slender bodies flattened dorsoventrally, having 15 to 173 segments; swift moving
4. *Diplopoda** (dip -lo′ po da) (Gr. *diploos*, double; *pous*, foot)	Millipedes (Fig. 135)	1 pair (short)	Terrestrial (moist places)	Trachea (air breathing)	None	Numerous (2 pairs on most segments)	Long, slender bodies subcylindrical, having 25 to 100 segments; slow moving

5. *Insecta*† (in -sek' ta) (L. *insectus*, cut into) or *Hexapoda* (hecks -ap' o da) (Gr. *hex*, six; *pous*, feet)	Bees (Figs. 195 to 200) Wasps (Fig. 306) Butterflies (Fig. 207) Moths (Figs. 300 to 302) True bugs (Fig. 287) Grasshoppers (Figs. 191 to 194 and 206) Flies Cicadas (Fig. 292), Beetles (Figs. 272, 295-297) etc.	1 pair	Terrestrial (some species live in water)	Trachea (air breathing)	2 pairs, 1 pair, or none (depending on the species)	3 pairs on thorax	Body composed of head, thorax, and abdomen; wings, if present, attached to thorax; many species are harmful; a few, beneficial; most species, as far as known, are neither Certain species have wings at certain stages of their lives and not at others (wingless)
6. *Arachnoidea* (ar ak -noi' de a) (Gr. *arachne*, spider)	Spider (Figs. 137 and 138) Scorpion (Fig. 138) Horseshoe crab (Fig. 136) Mites (Fig. 138) Daddy long legs (Fig. 138) etc.	None	Terrestrial	Trachea and book lungs (air breathing)	None	4 pairs	Head and thorax fused into a cephalothorax; abdomen present; no true jaws but 1 pair of nippers; some species are detrimental; a few, beneficial; most are neither

*The *Chilopoda* and *Diplopoda* are sometimes placed in a single class called *Myriapoda* (mir i -op' o da) (Gr. *myrios*, numberless; *pous*, foot).
†For a more complete description of insects and their characteristics, see other chapters.

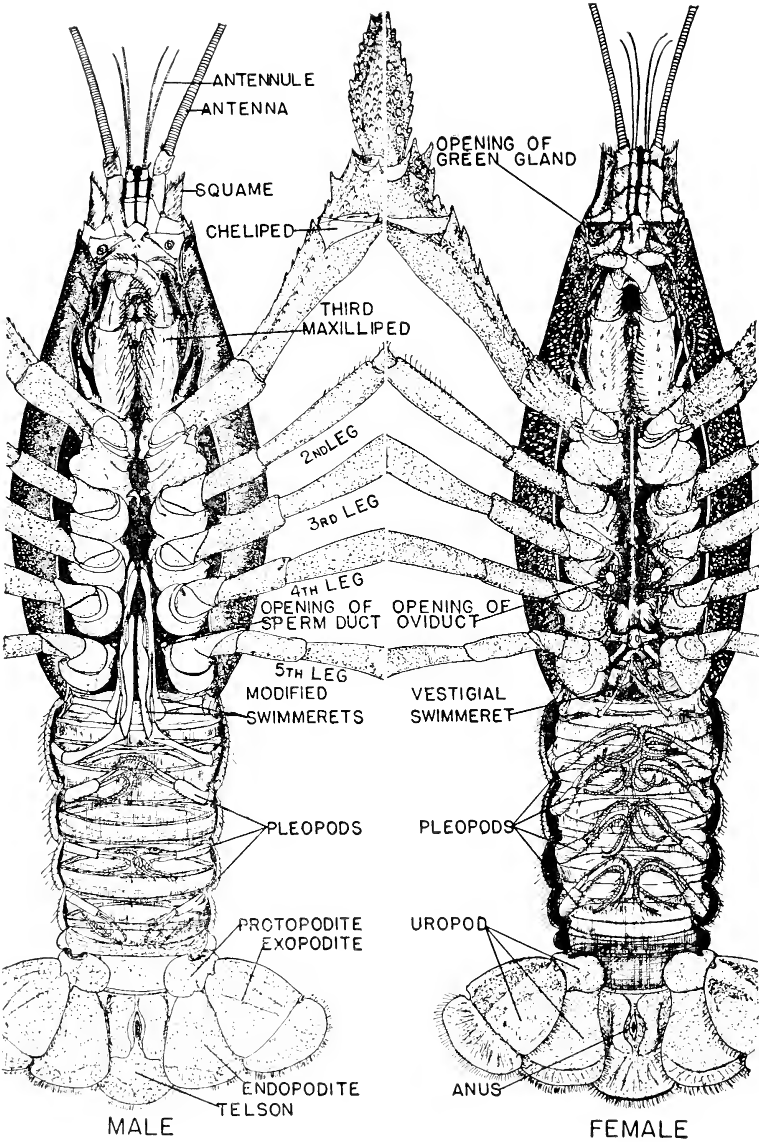


Fig. 128.—Crayfish, ventral view. The opening of the green gland (excretory organ) is on the base of the antenna. The first two pairs of appendages (antenna and antennule) are labeled; the third pair (mandibles), the fourth and fifth (maxillae), the sixth, seventh, and eighth (maxillipeds) are not labeled (except the third maxilliped); the ninth to the thirteenth (five pairs of walking legs) are shown only in part; the fourteenth and fifteenth (modified swimmerets) are large in the male for the transfer of sperm to the female (these swimmerets in the female are much smaller or vestigial); the sixteenth to the nineteenth (swimmerets or pleopods). The last pair of swimmerets, sometimes called the uropods, together with the telson constitute the tailfin for swimming backwards. (See Fig. 307.) (From Parker and Clarke: An Introduction to Animal Biology, The C. V. Mosby Co.)

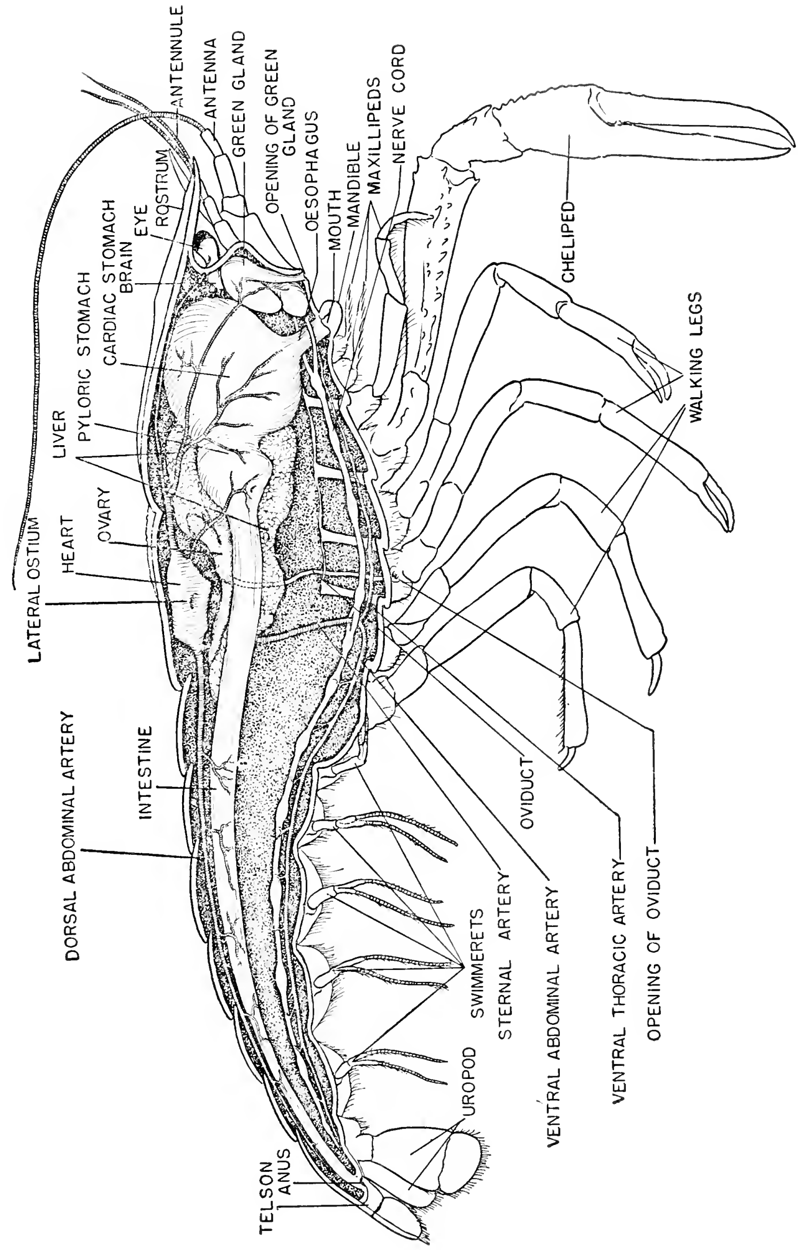


Fig. 129.—Median longitudinal section of a crayfish, showing internal organs. (From Parker and Clarke: Introduction to Animal Biology, The C. V. Mosby Co.)

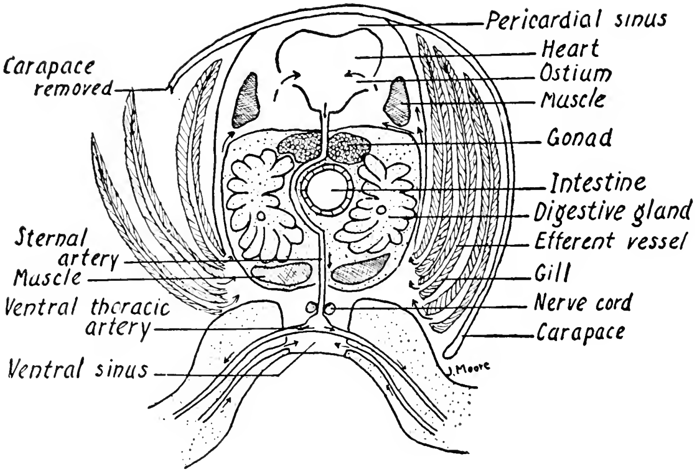


Fig. 130.—Diagram of cross section through the posterior thoracic region of a crayfish. Arrows show direction of blood flow. (From Potter: Textbook of Zoology, The C. V. Mosby Co.)

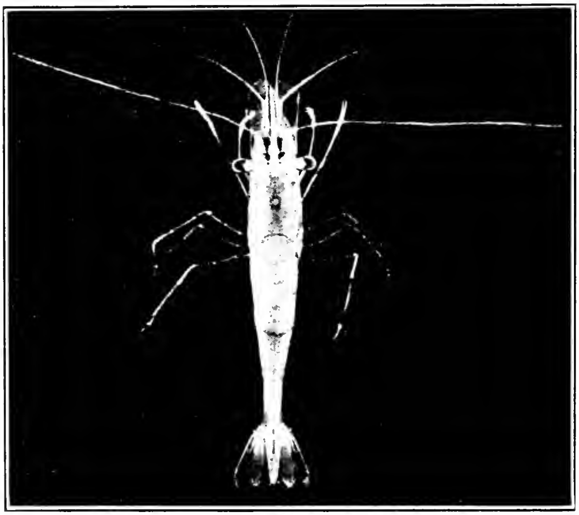


Fig. 131.—Fresh-water shrimp (*Palaemonetes sp.*) of the class *Crustacea,* phylum *Arthropoda.* (From a photograph by P. S. Tice. Copyright by General Biological Supply House, Inc., Chicago.)

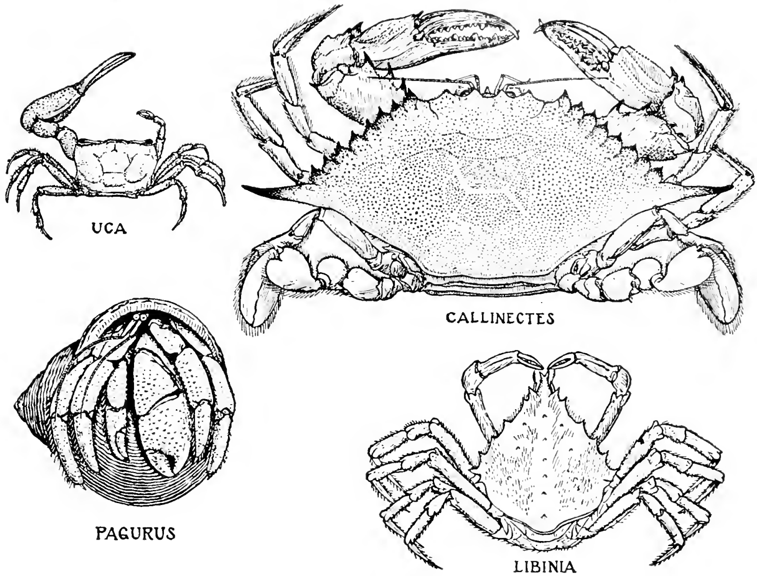


Fig. 132.—Representative crabs of the class *Crustacea,* phylum *Arthropoda.* Fiddler crab (*Uca*); blue edible crab (*Callinectes*); hermit crab (*Pagurus*); spider crab (*Libinia*). (Copyright by General Biological Supply House, Inc., Chicago.)

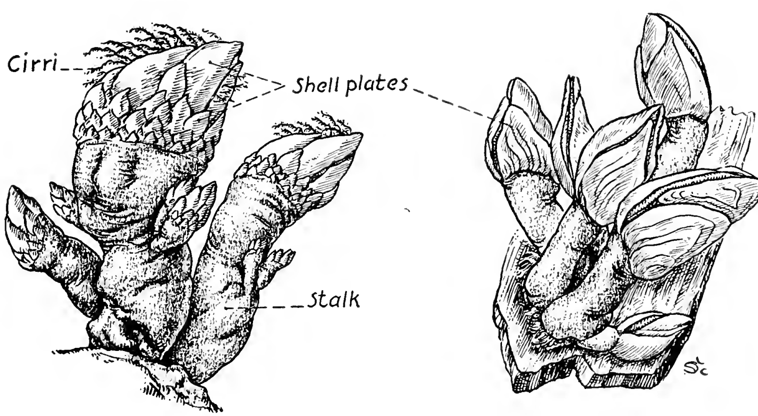


Fig. 133.—Barnacles of the class *Crustacea,* phylum *Arthropoda.*

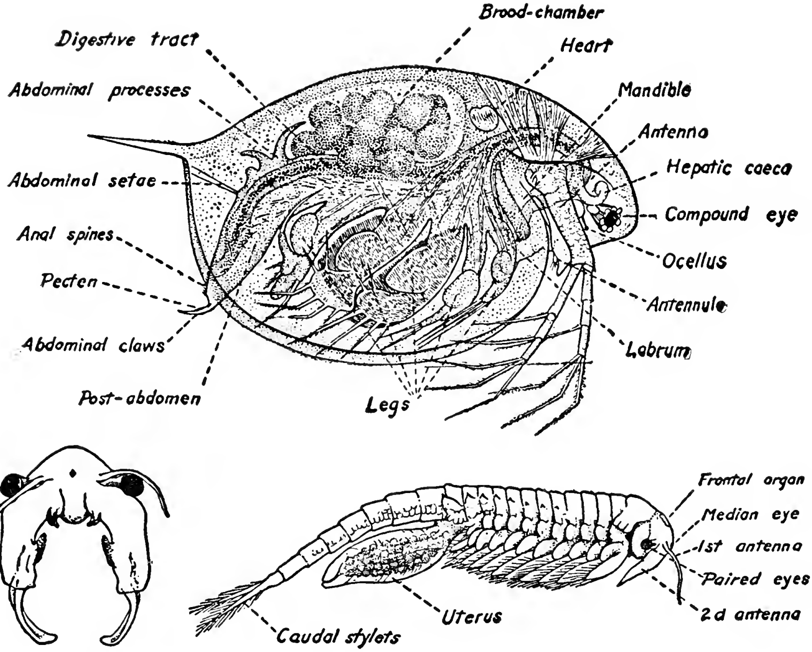


Fig. 134.—Representatives of the class *Crustacea,* phylum *Arthropoda.* *Above,* *The water flea* (*Daphnia pulex*). *Below,* The fairy shrimp (*Branchinecta packardii*), lateral view of female showing appendages and uterus filled with eggs; *left,* anterior view of a male showing the second antennae modified as clasping organs. (From Curtis and Guthrie: Textbook of General Zoology, published by John Wiley & Sons, Inc.)

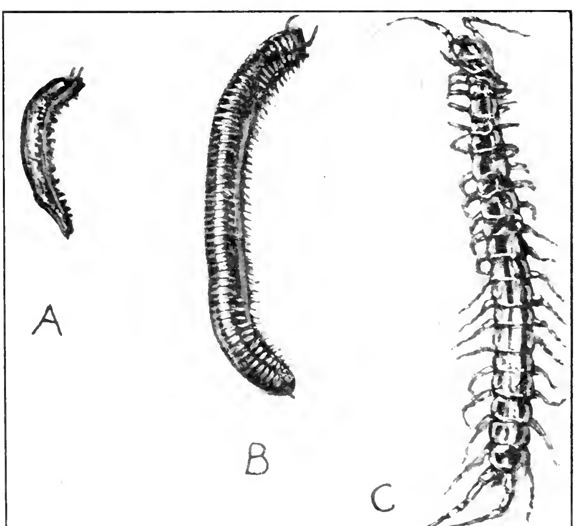


Fig. 135.—*A, Peripatus sp.,* an arthropod of the class Onychophora, with several annelid characters; *B,* a millipede of the class *Diplopoda,* phylum *Arthropoda; C,* a centipede of the class *Chilopoda.*

Phylum 12. Chordata (kor -da′ ta) (L. *chordatus,* having a rodlike chord)

General Characteristics

A dorsal, rodlike notochord (Gr. *noton,* back or dorsal; *chorde,* chord) is present as a cartilaginous or bony structure at some stage of life. A central, tubular nerve cord is located dorsally. Paired pharyngeal clefts (gill slits) are

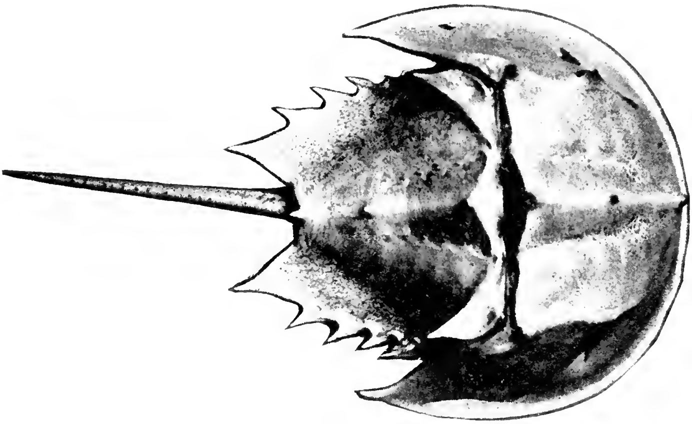


Fig. 136.—Horseshoe crab or king crab (*Limulus polyphemus*) of the class *Arachnoidea,* phylum *Arthropoda* (dorsal view).

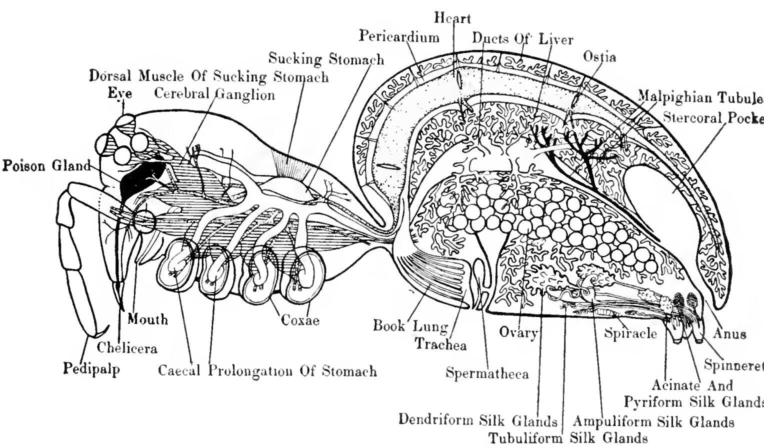


Fig. 137.—Spider, shown diagrammatically from the side, somewhat enlarged. (From Metcalf: Economic Zoology, published by Lea & Febiger.)

present for respiration purposes at some stage. In certain species, these clefts are no longer visible, as such, in the adult. The coelom (body cavity) is well developed. Bilateral symmetry is generally characteristic. The animals are triploblastic (ectoderm, mesoderm, entoderm). The body is metameric (segmented),

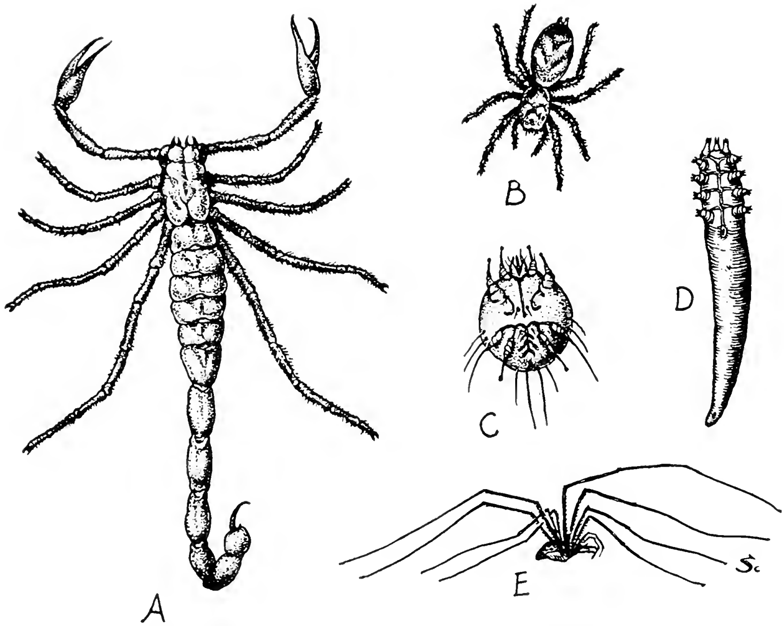


Fig. 138.—Representatives of the class *Arachnoidea,* phylum *Arthropoda. A,* Scorpion; *B,* jumping spider (*Attus sp.*); *C,* human itch mite (*Sarcoptes scabiei*), male, much enlarged; *D,* hair follicle mite (*Demodex folliculorum*), much enlarged; *E,* daddy-long-legs or harvestman (*Phalangium sp.*).

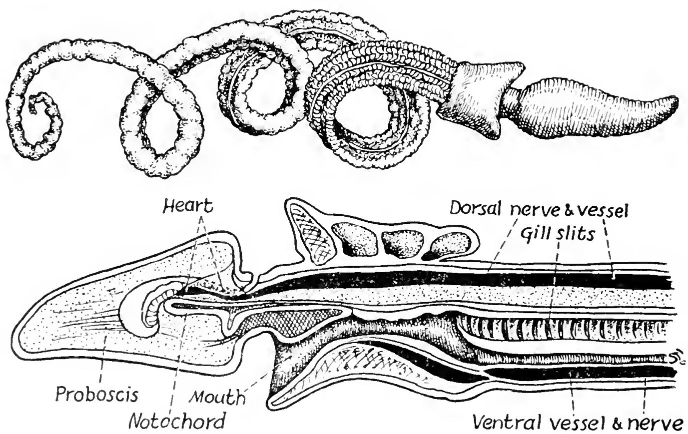


Fig. 139.—*Balanaglossus,* a marine chordate of the subphylum *Hemichordata.* Observe in the chordate characters, the gill slits, dorsal notochord, and dorsal nervous system in the section below.

although at certain stages the segments may be somewhat fused and difficult to distinguish. Mouth and anus are present. Number of species of Chordata, 40,000.

CLASSIFICATION OF THE PHYLUM CHORDATA

Subphylum 1—Hemichordata (hem i kor -da′ ta) (Gr. *hemi,* half; *chorde,* chord) or **Enteropneusta** (en ter op -nus′ ta) (Gr. *enteron,* digestive tract; *pneuma,* breathe).—These marine, wormlike animals have a short, dorsal notochord in the anterior end. Several pairs of permanent gill slits serve as respiratory organs, with the internal gills. The anterior end of the body usually has a collar and a fleshy proboscis. No cranium (brain case), jaws, vertebrae, or paired appendages.

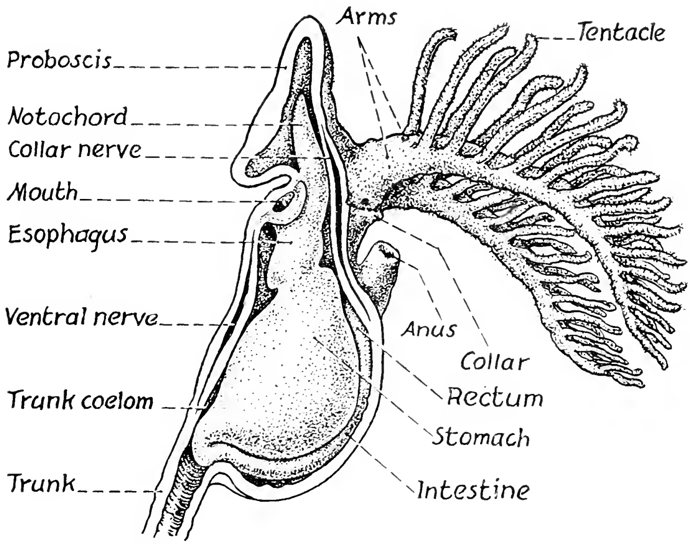


Fig. 140.—*Rhabdopleura,* a colonial chordate of the subphylum *Hemichordata.* Enlarged, partially dissected, and somewhat diagrammatic. Actual length, 0.1 mm. The collar nerve is also called the dorsal nerve.

Examples: *Balanoglossus* (Fig. 139), *Cephalodiscus,* and *Rhabdopleura* (Fig. 140).

Subphylum 2—Urochordata (u ro kor -da′ ta) (Gr. *oura,* tail; *chorde,* chord) or **Tunicata** (tu ni -ka′ ta) (L. *tunica,* a mantle).—These marine animals have small tadpolelike larvae with paired gill slits and both dorsal notochord and nerve cord in the tail. In the adult stage the body may be tubular, globose, or irregular in shape (depending upon the species), covered with a transparent tunic which is made of cellulose (a material common in plants). The adults are usually sessile (attached), with many gill slits, but the notochord is usually absent and the nervous system reduced. There are no cranium, jaws, vertebrae, or paired appendages.

Examples: Ascidians and Appendicularians (Fig. 141).

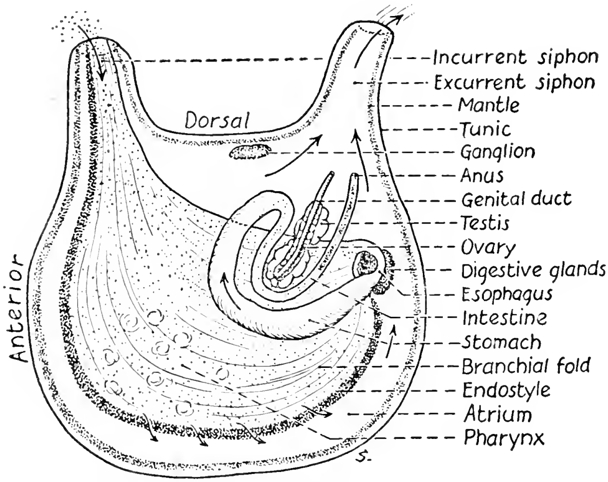


Fig. 141.—A typical ascidian or sea squirt (*Molgula manhattensis*) of the subphylum *Urochordata* (*Tunicata*). The diagram is from the left side of the body. The courses of water and food through the body are shown by arrows. (From Potter: Textbook of Zoology, The C. V. Mosby Co.)

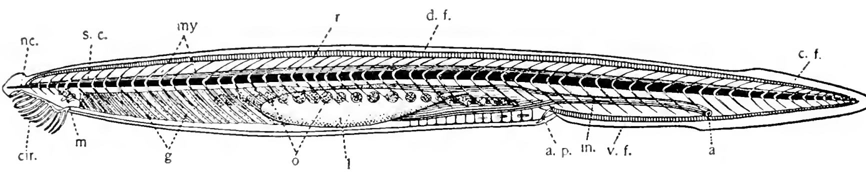


Fig. 142.—Amphioxus, a simple chordate, subphylum *Cephalochordata* (general structure of a lateral view). *nc,* Notochord; *s.c.,* spinal cord (nervous); *my,* myotomes (muscle segments); *r,* fin rays; *d.f.,* dorsal fin; *c.f.,* caudal fin; *cir,* cirri on edge of vestibule leading to the mouth; *m,* mouth surrounded by a fringed velum; *g,* gills (branchiae) constructed of alternate slits for the passage of water and supporting plates in the walls of which are blood vessels; *o,* ovaries; *l,* liver; *a.p.,* atrial pore; *in,* intestine from which the liver arises as a pouchlike diverticulum; *v.f.,* ventral fin; *a,* anus. (From Galloway: Textbook of Zoology. Copyright P. Blakiston's Son & Co., Inc., publishers.)

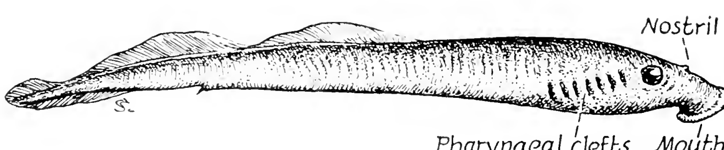


Fig. 143.—A lamprey of the class *Cyclostomata,* phylum *Chordata.* Note the circular, sucking mouth, the median unpaired nostril, the seven pharyngeal clefts ("gill slits"). Lampreys frequently attack fishes, causing their death.

Subphylum 3—Cephalochordata (sef a lo kor -da′ ta) (Gr. *kephale,* head; *chorde,* chord).—These marine animals have small, slender, elongate "fishlike" bodies which are distinctly segmented. The permanent dorsal notochord and nerve cord extend from the head to the tail (entire length of body). Many permanent, paired gill slits (pharyngeal clefts) are present in the pharynx. No cranium, jaws, vertebrae, or paired appendages.

Example: Amphioxus or lancelet *(Branchiostoma sp.)* (Fig. 142).

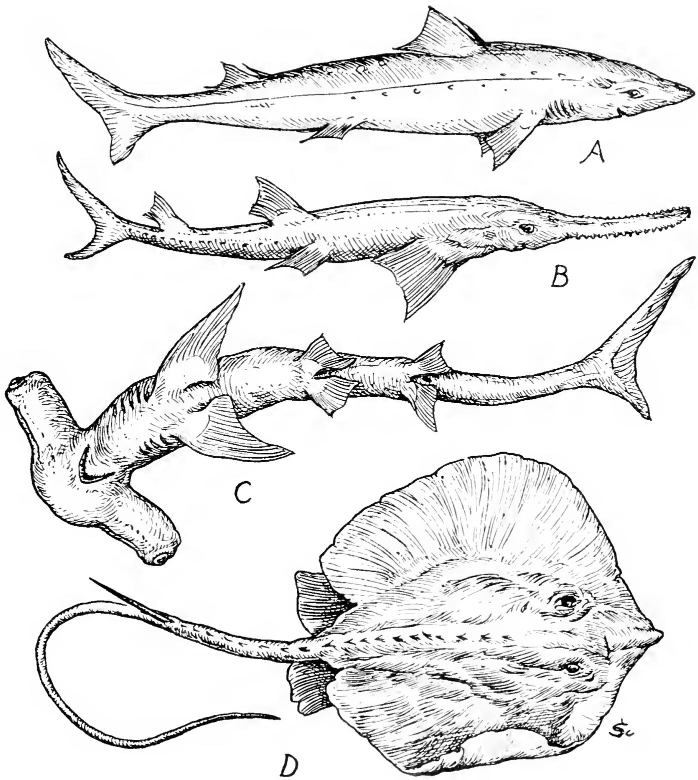


Fig. 144.—Representatives of the class *Elasmobranchii,* phylum *Chordata* (not drawn to scale). *A,* Spiny dogfish shark (*Squalus acanthias*); *B,* sawfish (*Pristis antiquorum*); *C,* hammer-head shark (*Sphyrna zygaena*); *D,* Southern sting ray (*Dasyatis americana*), common in the Gulf of Mexico.

Subphylum 4—Vertebrata (vur te -bra′ ta) (L. *vertebratus,* jointed) or **Craniata** (Kra ni -a′ ta) (Gr. *kranion,* cranium or head).—All vertebrates have a notochord at some stage of development. This is replaced by an axial skeleton composed of vertebrae in higher species. Both the axial and appendicular skeletons are internal. They all have a coelom (true body cavity) and are bilaterally symmetrical. The body is divided into head, thorax, and abdomen. A hollow

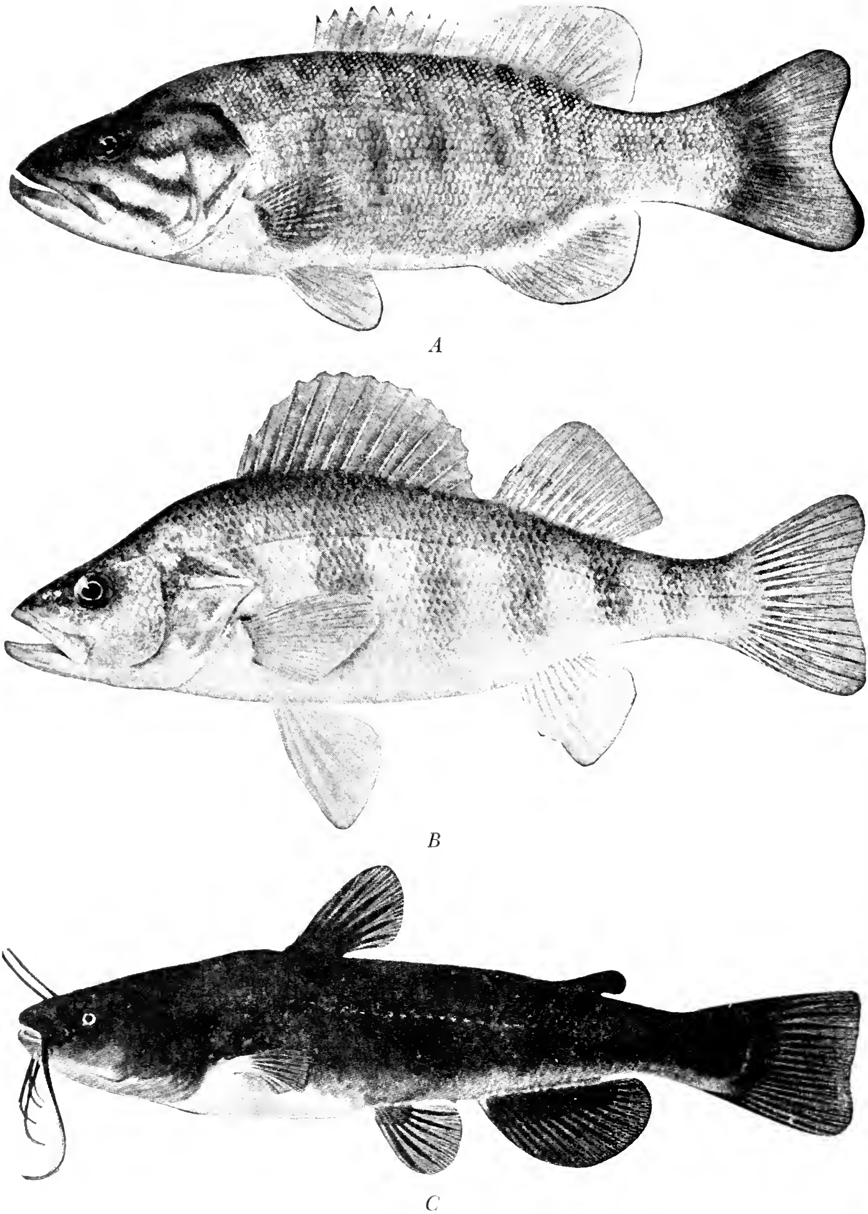


Fig. 145.—Representative fishes of the class *Pisces* (not drawn to scale). *A,* Small-mouth bass (*Micropterus dolomieu*); *B,* yellow perch (*Perca flavescens*); *C,* black bullhead (catfish) (*Ameiurus melas*). (From Wickliff and Trautman: Some Food and Game Fishes of Ohio, State of Ohio Division of Conservation and Natural Resources.)

central nervous system is dorsal to the digestive tract. All vertebrates have a ventral heart with two to four chambers, depending on the species (Figs. 364 and 365).

Class 1—Cyclostomata (si klo -sto′ ma ta) (Gr. *kyklos,* circle or round; *stoma,* mouth).—These possess a jawless, circular sucking mouth with a rasping tongue. They are aquatic, fishlike, and have a *median unpaired nostril.* There are no lateral appendages or fins. They possess no scales and a permanent notochord.

Examples: *Hagfishes* and *lampreys* (Fig. 143).

Class 2—Elasmobranchii (e las mo -brang′ ki i) (Gr. *elasmos,* plate; *branchia,* gills).—These types possess vascular gills or branchia supported by cartilaginous, platelike structures known as gill plates. They are fishlike animals with jaws, paired fins, and placoid (platelike) scales. They have a persistent notochord and a permanently cartilaginous skeleton. There is no air bladder. They are *cold blooded* (temperature varies with their surroundings).

Examples: *Sharks* and *skates, rays* (Fig. 144).

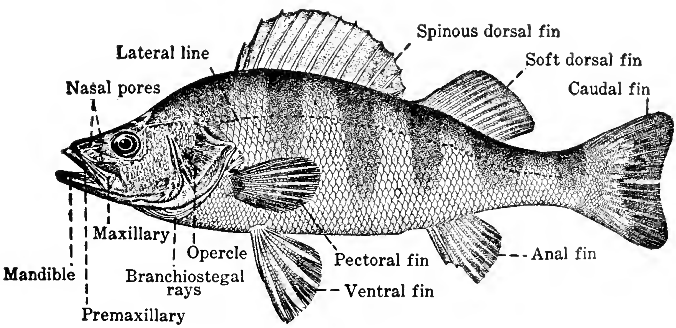


Fig. 146.—External features of the perch. (From Hegner: College Zoology. By permission of The Macmillan Company, publishers.)

Class 3—Pisces (pis′ ez) (L. *piscis,* fish).—These true fish have gills throughout life which are supported by bony or cartilaginous gill arches. Jaws are present. The two pairs of pectoral and pelvic fins and unpaired median fins are supported by fin rays. The skeleton is principally bony, although cartilage may also be found in certain regions. Scales are present in the skin. The air bladder (swim bladder) is primarily for hydrostatic purposes, for maintaining a certain level in water without muscular effort. They are cold blooded (their temperature varies with their aquatic surroundings). Their heart is two chambered (1 auricle and 1 ventricle). There are about 14,000 species of true fishes.

Examples: True fishes (Fig. 145), as *perch* (Figs. 146 and 147), *trout, bass, minnow, carp,* and *goldfish.*

Class 4—Amphibia (am -fib′ i a) (Gr. *amphi,* both; *bios,* life).—These aquatic or semiaquatic animals have gills during larval stages and paired lungs in adults (hence amphibious). The skin is slimy, smooth, moist, and usually

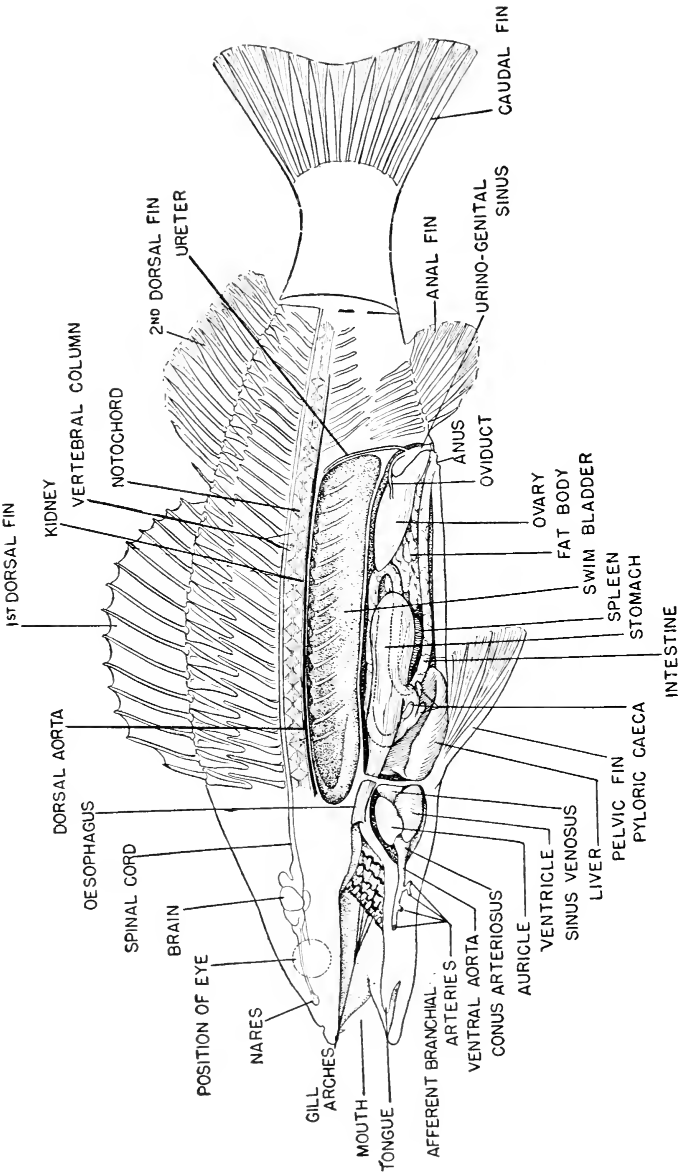
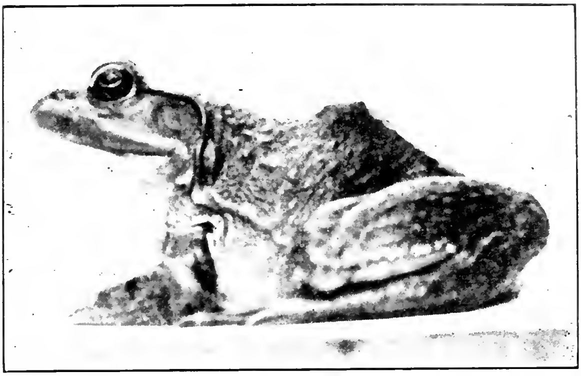


Fig. 147.—Median longitudinal section of yellow perch (*Perca flavescens*) of the class *Pisces* (somewhat diagrammatic). (From Parker and Clarke: Introduction to Animal Biology, The C. V. Mosby Co.)

scaleless. The paired legs usually have five digits. They are cold blooded. The heart is three chambered (2 auricles and 1 ventricle). There are about 2,000 species of Amphibia.

Examples: *Frog* (Figs. 208 to 219), *toads, salamanders,* and *newts* (Figs. 148-150).



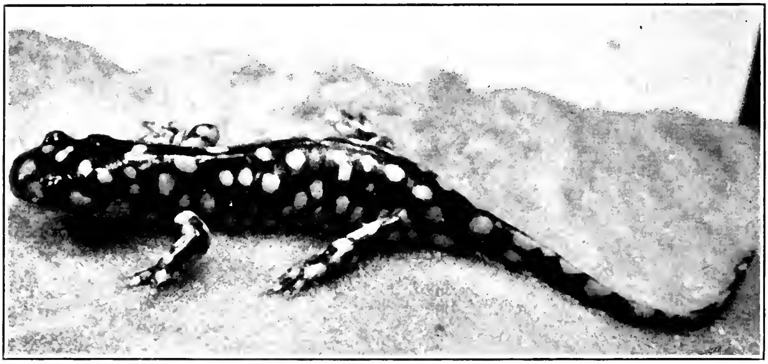
A.

B.

Fig. 148.—Representatives of the class *Amphibia* (not to scale). *A,* bullfrog (*Rana catesbiana*); *B,* common toad (*Bufo sp.*). (Copyright by General Biological Supply House, Inc., Chicago.)

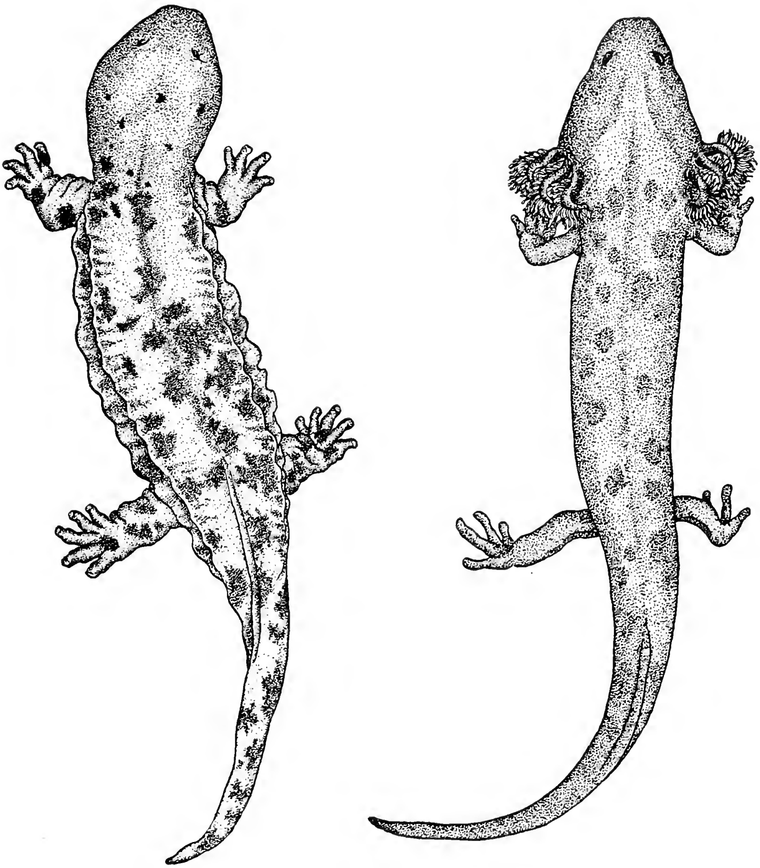
Class 5—Reptilia (rep-til′ i a) (L. *reptilus, reptile,* from *repere,* to crawl). —These animals have horny plates (scales) covering their body. They have paired lungs in the adult with no gills. They are cold blooded. Their heart is three chambered (2 auricles and 1 ventricle, the latter being partially divided). The cranium (brain case) articulates with the vertebral column by a single occipital condyle. Reptiles possess both amnion and allantois. There are 4,000 species of reptiles.

A.



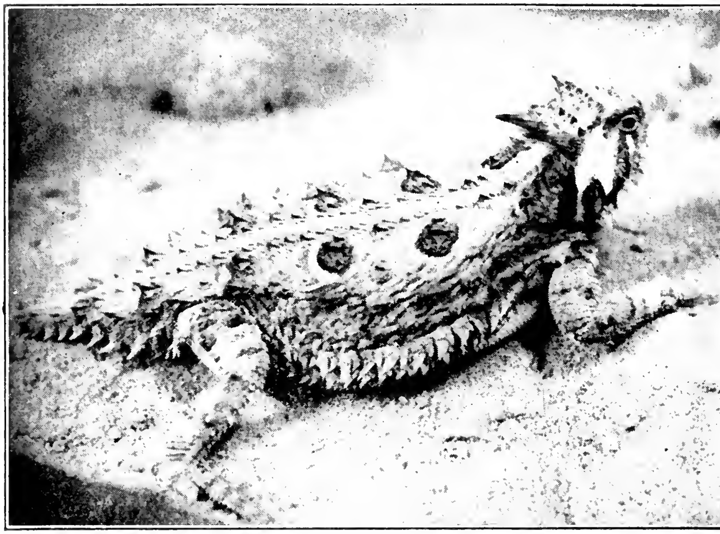
B.

Fig. 149.—Representatives of the class *Amphibia* (not to scale). *A*, Red-spotted newt (*Triturus viridescens*); *B*, tiger salamander (*Ambystoma tigrinum*). (Copyright by General Biological Supply House, Inc., Chicago.)

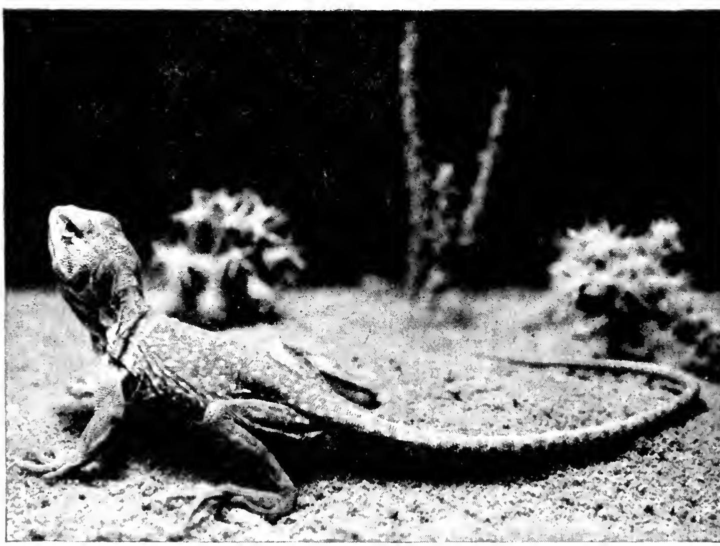


A. B.

Fig. 150.—Representatives of the class *Amphibia* (not drawn to scale). *A,* "Hellbender" salamander (*Cryptobranchus alleghenienisis*); *B,* "mud puppy" (*Necturus maculosus*). (Copyright by General Biological Supply House, Inc., Chicago.)

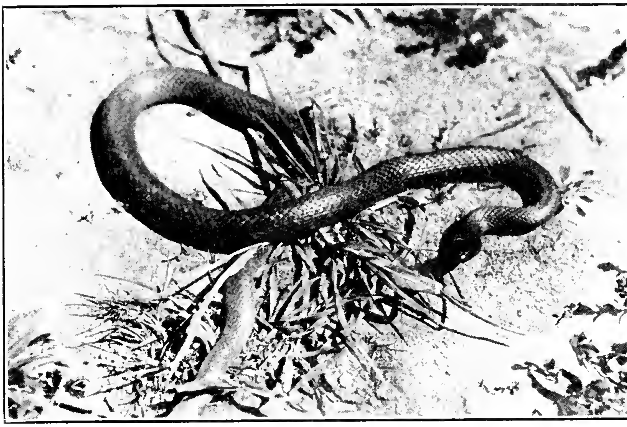


A.

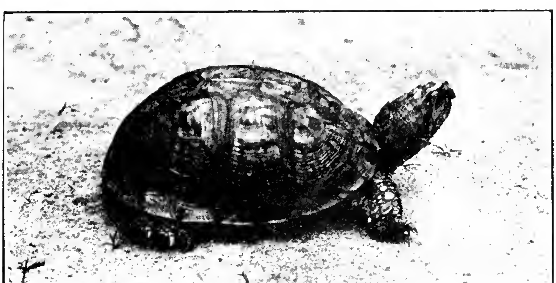


B.

Fig. 151.—Representative reptiles of the class *Reptilia* (not to scale). *A,* Horned "toad" (*Phrynosoma cornutum*); *B,* giant collared lizard (*Crotaphytus collaris*). (Copyright by General Biological Supply House, Inc., Chicago.)



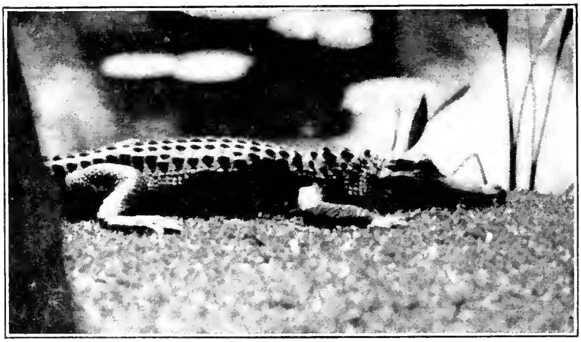
A.



B.

Fig. 152.—Representative reptiles of the class *Reptila* (not to scale). *A, Black* snake (*Zamenis constrictor*); *B,* box turtle (*Cistudo carolina*). (Copyright by General Biological Supply House, Inc., Chicago.)

A.



B.

Fig. 153.—Representative reptiles of the class *Reptilia* (not to scale). *A,* True chameleon (*Chameleon vulgaris*); *B,* American alligator (*Alligator mississippiensis*). (Copyright by General Biological Supply House, Inc., Chicago.)

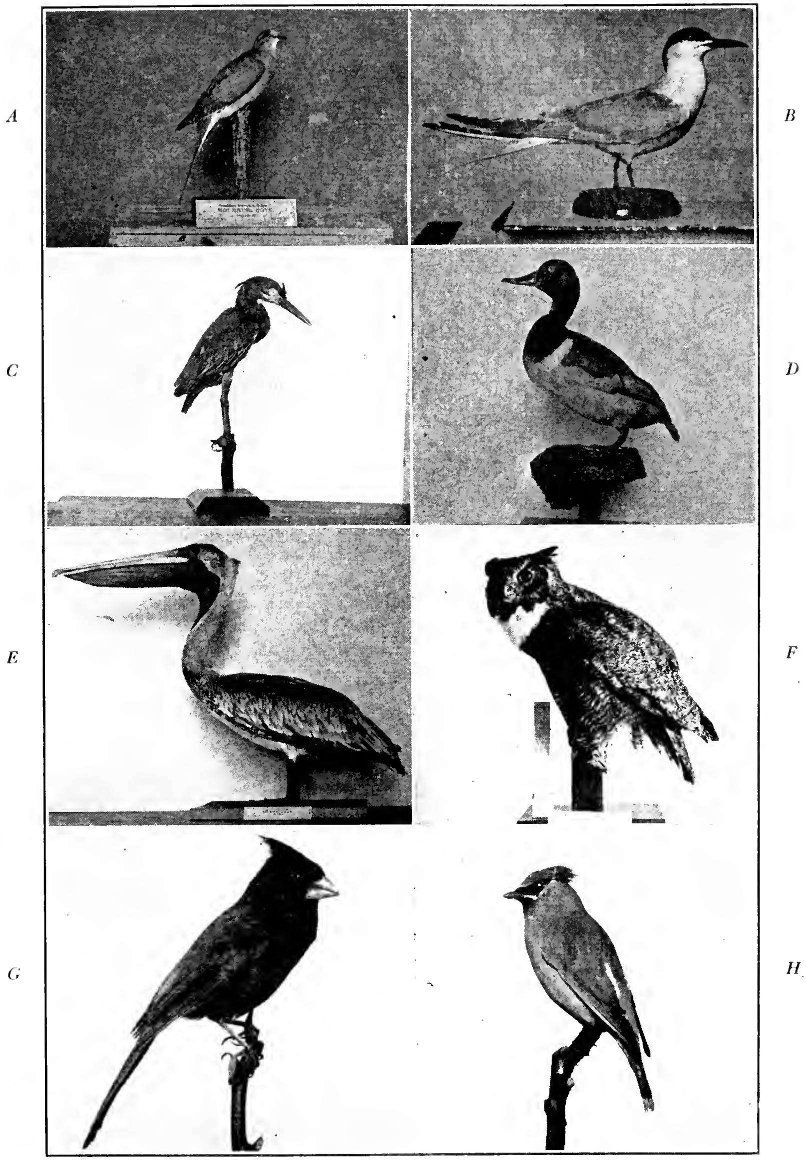


Fig. 154.—Representative birds of the class *Aves* (not to scale). *A*. Mourning dove (*Zenaidura macroura carolinensis*); B, common tern (*Sterna hirundo*); *C*, green heron (*Butorides virescens virescens*); *D*, ring-neck duck (*Marila collaris*); *E*, brown pelican (*Pelicanus occidentalis*); *F*, great horned owl (*Bubo virginianus virginianus*); *G*, cardinal (*Cardinalis cardinalis*); *H*, cedar waxwing (*Bombycilla cedrorum*). (Copyright by General Biological Supply House, Inc., Chicago.)

Examples: *Turtle* (Fig. 152), *snakes* (Fig. 152), *lizards* (Fig. 151), *crocodiles, chameleons* (Fig. 153), and *horned "toads"* (Fig. 151).

Class 6—Aves (a' vez) (L. *avis,* bird).—Feathers are distinctive of birds. Paired lungs are found in the adult. They are warm blooded with a more or less constant temperature which is usually 10° C. higher than mammals. The forelimbs are wings which are small in the ostrich and auk. All birds are terrestrial, although some may be associated with water. The heart is four chambered (2 auricles and 2 ventricles). There are 14,000 species of birds.

Examples: *Wrens, owls, sparrows, pigeons* (Fig. 155), *chickens, robins, eagles, turkeys, ducks, terns, gulls, hawks, coots, penguins,* and *ostrich* (Fig. 154).

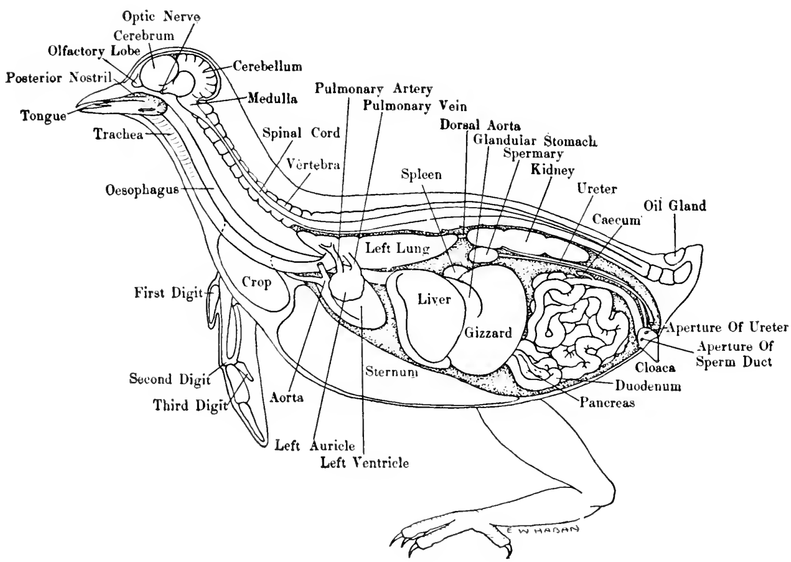


Fig. 155.—Diagram of the internal structures of a bird of the class *Aves.* (From Metcalf: Economic Zoology, published by Lea & Febiger.)

Class 7—Mammalia (ma -ma' li a) (L. *mamma,* breast).—The young mammals are suckled by mammary glands (few exceptions). They have paired lungs in the adults. They are warm blooded with a temperature around 37° C. regardless of surroundings. They possess hair (wool in some types) at certain stages. They heart is four chambered (2 auricles and 2 ventricles). The cranium (brain case) articulates with the vertebral column by means of two occipital condyles. There is a well-developed, usually convoluted brain. A muscular diaphragm separates the thorax and abdomen. A tubelike placenta attaches the unborn young to the mother. There are 4,000 species of mammals.

Examples: *Man* (Figs. 228 to 256), *cat, bat, whale, seal, monkey, kangaroo, elephant, dog, bear, antelope,* and *prairie dog* (Fig. 156).

A. B. C. D. E. F. G. H.

Fig. 156.—Representative mammals of the class *Mammalia* (not to scale). *A*, Orangutan (*Simia satyrus*); *B*, llama (*Lama huanacos*); *C*, American bison or buffalo (*Bison bison*); *D*, red fox (*Vulpes sp.*); *E*, Bactrian camel (shedding) (*Camelus bactrianus*); *F*, Russian bear (*Ursus sp.*); *G*, beaver (*Castor canadensis*); *H*, armadillo (*Dasypus sp.*). (Copyright by General Biological Supply House, Inc., Chicago.)

QUESTIONS AND TOPICS

1. Define the following terms: species, genus, class, and phylum.
2. Give all the reasons you can why a classification of animals must necessarily be a scientific one. Why can we not depend on the use of common names for particular animals in a classification? Why are Greek and Latin used in composing scientific names and classification?
3. Give the distinguishing characteristics of each phylum into which the animal kingdom is divided. Which phyla seem more closely related than others? What suggestions can you offer for this?
4. How many species of animals are there in each phylum? How many species are there in the animal kingdom? Tell how this number may vary.
5. Tell how the representatives of the various phyla increase in complexity as we observe them from the lower to the higher and complex phyla. What conclusions do you draw from this phenomenon?
6. Define the following types of symmetry: (1) asymmetry, (2) radial symmetry, and (3) bilateral symmetry. List the phyla and give the type or types of symmetry found in each. What conclusions can be drawn from these data?
7. What effect does attachment (nonlocomotion) of an animal have on (1) its general development, (2) its method of reproduction, (3) the dispersal of its offspring, and (4) the securing of food and elimination of wastes?
8. List the advantages and disadvantages of having the offspring dispersed in many directions from their place of birth.
9. What is meant by alternation of generations (metagenesis)? List all the advantages and disadvantages of metagenesis.
10. Which phylum do you think contains the most important animals? Why do you choose as you do? What makes an animal important?
11. Upon what does the economic importance of a particular animal depend?
12. In which phyla do we find a true body cavity (coelom)? Discuss the advantages and disadvantages of such a structure.
13. In which phyla do we find metamerism (segmentation)? What are the advantages and disadvantages of such construction?
14. Define (1) chordate, (2) invertebrate, and (3) vertebrate. Do all the animals in the phylum to which man belongs closely resemble man? Why do we place man, whales, bats, horses, cats, and monkeys in the class mammalia? Must all animals be absolutely alike in all respects to be classified together?

SELECTED REFERENCES

Alexander: Birds of the Ocean, G. P. Putnam's Sons.
Anthony: Animals of America ("Mammals of America"), Doubleday, Doran & Co., Inc.
Anthony: North American Mammals, G. P. Putnam's Sons.
Barbour: Reptiles and Amphibians, Houghton Mifflin Co.
Borrodaile and Potts: The Invertebrata, The Macmillan Co.
Breder: Marine Fishes of the Atlantic Coast, G. P. Putnam's Sons.
Brown: Selected Invertebrate Types, John Wiley & Sons, Inc.
Buchsbaum: Animals Without Backbones, University of Chicago Press.
Bullough: Practical Invertebrate Anatomy, The Macmillan Co.
Calman: Classification of Animals, John Wiley & Sons, Inc.

Ditmars: Reptiles of the World, The Macmillan Co.
Driver, E. C.: Name That Animal, Northampton, Mass., published by the author.
Eliot: Birds of the Pacific Coast, G. P. Putnam's Sons.
Guyer: Animal Biology, Harper & Brothers.
Hamilton: American Mammals, McGraw-Hill Book Co., Inc.
Hausman: Field Book of Eastern Birds, G. P. Putnam's Sons.
Hegner: Parade of the Animal Kingdom, The Macmillan Co.
Hegner: Invertebrate Zoology, The Macmillan Co.
Hegner: College Zoology, The Macmillan Co.
Hyman: The Invertebrates (Protozoa Through Ctenophora), McGraw-Hill Book Co., Inc.
Jacques: How to Know the Land Birds, William C. Brown Co.
Jordan: Fishes, D. Appleton-Century Co., Inc.
Kyle: Biology of Fishes, The Macmillan Co.
LaMonte: North American Game Fishes, Doubleday & Co., Inc.
Lutz: Field Book of Insects, G. P. Putnam's Sons.
MacGinitie and MacGinitie: Natural History of Marine Animals, McGraw-Hill Book Co., Inc.
Mathews: Field Book of Wild Birds and Their Music, G. P. Putnam's Sons.
Morgan: Field Book of Animals in Winter, G. P. Putnam's Sons.
Norman and Fraser: Field Book of Giant Fishes, Whales and Dolphins, G. P. Putnam's Sons.
Palmer: Field Book of Natural History, McGraw-Hill Book Co., Inc.
Pough: Audubon Bird Guide, Doubleday & Co., Inc.
Pearson: Birds of America, Doubleday, Doran & Co., Inc.
Pratt: Manual of Common Invertebrate Animals, A. C. McClurg Co.
Pratt: Manual of Common Land and Fresh Water Vertebrate Animals of the United States, P. Blakiston's Son & Co.
Rand: The Chordates, P. Blakiston's Son & Co.
Romer: The Vertebrate Body, W. B. Saunders Co.
Schmidt and Davis: Field Book of Snakes of the United States and Canada, G. P. Putnam's Sons.
Schrenkeisen: Fresh Water Fishes of North America, G. P. Putnam's Sons.
Swain: The Insect Guide, Doubleday & Co., Inc.
Walter and Sayles: Biology of the Vertebrates, The Macmillan Co.

Chapter 18

UNICELLULAR, MICROSCOPIC ANIMALS (PHYLUM PROTOZOA)

AMOEBA; PARAMECIUM; EUGLENA; VOLVOX; PLASMODIUM

AMOEBA

Amoeba (a -me′ ba) (Gr. *amoibe,* change) is a common fresh-water protozoan (pro to -zo′ an) (Gr. *protos,* first; *zoa,* animals) about 1/100 inch (0.2 mm.) in length. Under the microscope it appears as an *irregular, colorless, jellylike, granular mass* which is *changing its shape* by the formation of small fingerlike processes called *pseudopodia* (su do -po′ di a) (Gr. *pseudes,* false; *pous,* foot). A disk-shaped *nucleus,* containing *chromatin granules,* is not easily observed in living specimens. With high power, it will be observed that the living protoplasm has a *flowing (streaming) movement.* Many structures are more easily observed if the protozoan is killed and stained with a dye. Some of the more important characteristics of the common species (*Amoeba proteus*) are given briefly (Figs. 157 to 162).

Integument (Covering).—An outer, thin, clear *ectoplasm layer* (ek′ to-plazm) (Gr. *ektos,* outside; *plasma,* mould) is just external to the inner, granular *endoplasm* (en′ do plazm) (Gr. *endon,* within). Within the endoplasm are the nucleus, granules, vacuoles, etc., described below.

Ingestion and Digestion.—Food may be ingested at any point on the body surface but usually at the anterior end (part toward the direction of locomotion). Minute animals and plants are selected and surrounded by the *pseudopodia.* Then thin sheets of cytoplasm cover the food, eventually forming a *food vacuole* (vak′ u ol) (L. *vacuus,* empty). This temporary structure contains *water* and *digestive enzymes.* Digestion within the food vacuole takes place in an *acid environment* (as in the stomach of a higher animal) and later in an *alkaline environment* (as in the intestine of a higher animal). The digested foods are absorbed into the cytoplasm, and the food vacuole disappears. Within the cytoplasm the absorbed foods are *assimilated* (made into living protoplasm). Complex molecules of protoplasm are oxidized to release the energy needed for movement, locomotion, the production of heat, and other physiologic activities.

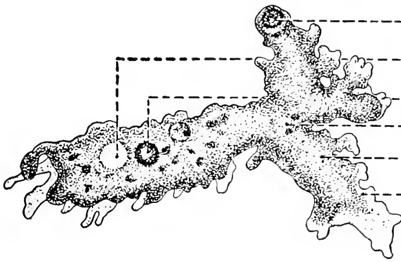


Fig. 157.—*Amoeba proteus* of the class *Sarcodina* (magnified and somewhat diagrammatic). (From Potter: Textbook of Zoology, The C. V. Mosby Co.)

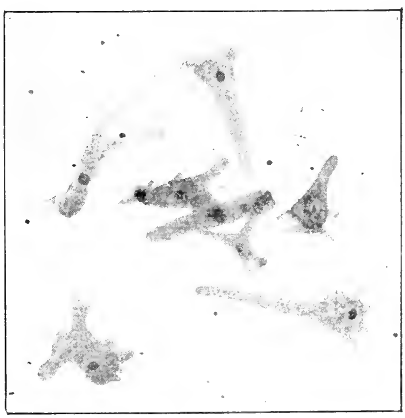


Fig. 158.—*Amoeba proteus* showing various shapes revealed by a photomicrograph. (From White: General Biology, The C. V. Mosby Co.)

Motion and Locomotion.—*Amoeba* moves from place to place (locomotes) and captures foods by the fingerlike *pseudopodia,* commonly referred to as "pseudopods." They may form on any surface by pushing out a blunt projection of clear ectoplasm into which flows the granular endoplasm. Two theories regarding the formation of pseudopodia are (1) the *surface tension theory,* based on changes in the tension of the surface of the amoeba, and (2) the *viscosity theory,* based on the tendency to resist changes in the shape or arrangement of parts.

Circulation.—There is no circulatory system, but the flowing of the protoplasm naturally circulates the contents of the cell by a process known as *cyclosis* (sik -lo′ sis) (Gr. *kyklosis*, whirling around).

Respiration.—Oxygen, required for various metabolic activities, is dissolved in the water and is taken in through the body surface. Carbon dioxide passes out through the surface as well as being expelled by the *contractile vacuoles.*

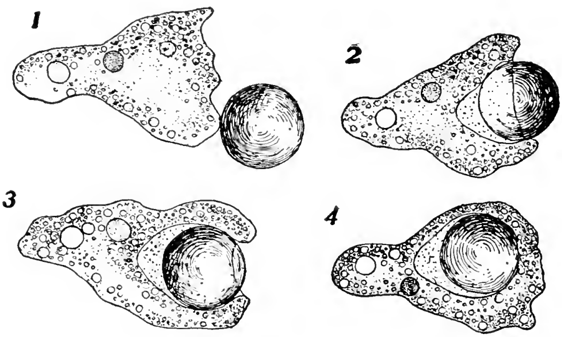


Fig. 159.—*Amoeba* ingesting another protozoan, an encysted Euglena. (From Jennings: Behavior of the Lower Organisms, published by the Columbia University Press.)

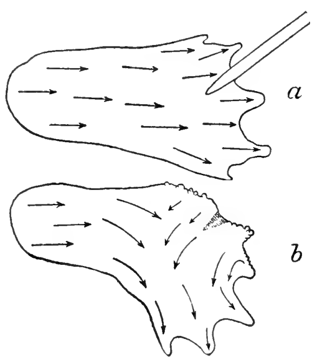


Fig. 160.—Negative reaction of Amoeba to contact or mechanical stimulation. Arrows show the movement before and after stimulation with a glass rod at the anterior end, *a*. As a result, the part is contracted, the currents are changed, and a new pseudopodium is sent out at *b*. (From Jennings: Behavior of the Lower Organisms, published by Columbia University Press.)

Excretion and Egestion.—A clear, spherical *contractile vacuole* collects wastes and, at somewhat regular intervals, it is carried to the body surface where it contracts and forces its fluid contents out of the body. The contractile vacuole is not permanent and it disappears at each contraction. A new one forms by the fusion of droplets of liquid. Indigestible and partially digested food particles are egested at any point of the surface, there being no special opening to the outside. Ordinarily, the wastes include solids, fluids, minerals, urea, carbon dioxide, etc.

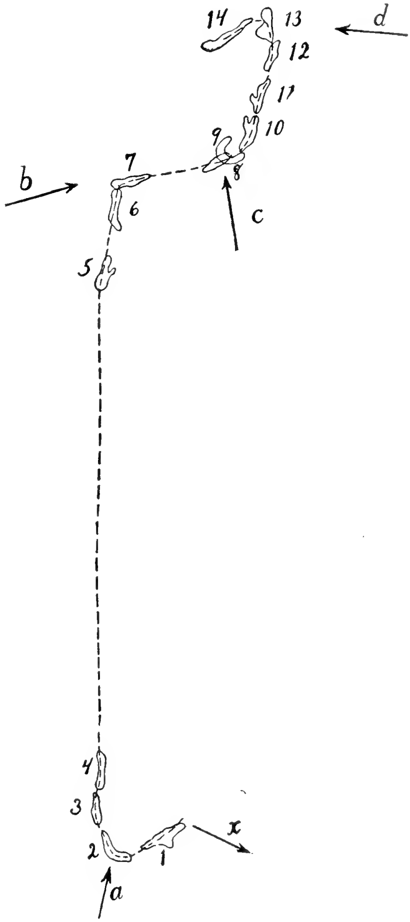


Fig. 161.—Reaction of *Amoeba* to light, in which it moves away from the source of light. The arrows at *a, b, c,* and *d* indicate the successive directions of the light and the numbers indicate the successive positions occupied by the Amoeba. (From Jennings: Behavior of the Lower Organisms, published by Columbia University Press.)

Coordination and Sensory Equipment.—Even though an amoeba is small and rather simply constructed, its different parts must be properly coordinated in order that it may perform the numerous activities essential for its life. This is accomplished by the properties of its living protoplasm without the benefit of any specialized sensory or nervous equipments. *Amoeba* responds to a number of types of *stimuli* (environmental factors), and its reactions to them are called its *responses.* Such activities as changes in shape, formation of pseudopodia, locomotion, capture of foods, etc., constitute its *behavior.* These changes may be due to external, as well as internal, factors. Movement toward a stimulus is called a *positive reaction;* movement away from a stimulus, a *negative reaction.* These two reactions may be influenced by the quantity and quality of the particular stimulus. The following reactions are typical:

1. **Contact** (*thigmotropism* or *thigmotaxis*) (thig -mot′ ro pizm; thigmo -tak′ sis) (Gr. *thigema,* touch; *trope,* turn; *taxis,* arrangement): At first the Amoeba may cease locomotion and then move away.

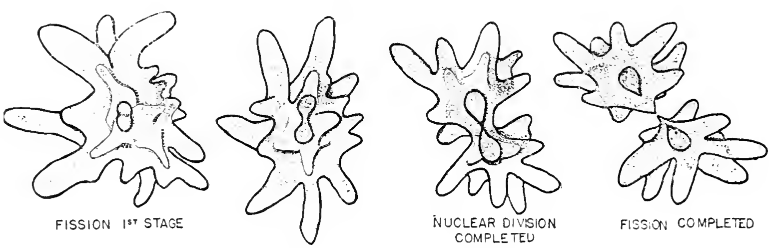


Fig. 162.—Reproduction of Amoeba by binary fission. Note how the nucleus divides and how the cells eventually separate to form two Amoebae. (From Parker and Clarke: Introduction to Animal Biology, The C. V. Mosby Co.)

2. **Chemicals** (*chemotropism* or *chemotaxis*) (ke -mot′ ro pizm; kem otak′ sis) (Gr. *chymos,* juice): The reaction is negative to such chemicals as sodium chloride, cane sugar, and acetic acid, but it is positive to certain foods and other chemicals, depending upon the concentration, etc.

3. **Temperature** (*thermotaxis* or *thermotropism*) (ther mo -tak′ sis; ther -mot′ ro pizm) (Gr. *therme,* heat): The reactions vary with the temperature, but movements stop if the temperature is decreased sufficiently. Response is negative to higher temperatures.

4. **Light** (*phototaxis* or *phototropism*) (fo to -tak′ sis) (fo -tot′ ropizm) (Gr. *phos,* light). The response is negative to strong light but may be positive to weak light.

Amoeba may also be affected by such stimuli as gravity, electrical currents, water currents, etc.

Reproduction.—The principal method of reproduction is by *binary fission,* in which a full-sized Amoeba divides into two parts. The *nucleus* divides by *mitosis* (Fig. 162) and the *cytoplasm* elongates and divides into two parts. The entire process occurs in less than thirty minutes at 30° C. After fission, the young amoebae grow rapidly, reaching mature sizes about three days after fission.

PARAMECIUM

Paramecium (par ah -me′ se um) (Gr. *paramekes,* oblong) is a large, fresh-water protozoan commonly called the "slipper animalcule" because of its fancied resemblance to a slipper. A common type, *Paramecium caudatum* (ko -da′ tum) (L. *cauda,* tail) has a tuft of tail-like cilia at the posterior end and may be about 0.3 mm. long, while *P. aurelia* (o -re′ li a) (L. *aurum,* gold or brown) may be less than 0.2 mm. long. Most of the infusoria (in fu -so′ ri a) (L. *infusus,* poured into or crowded) possess (1) a large *macronucleus* (Gr. *makros,* large) composed of a number of small, complete nuclei and (2) a small *micronucleus* (Gr. *mikros,* small). *P. caudatum* has a blunt anterior end, and the posterior end is somewhat pointed (Figs. 163 to 172).

Integument (Covering).—Two types of cytoplasm, as in *Amoeba,* are (1) an outer, clear layer, the *ectoplasm,* and (2) an inner *endoplasm* with larger *granules.* A distinct *pellicle* (pel′ i kel) (L. *pellis,* skin) covers the ectoplasm. If a drop of 35 per cent alcohol is added to a drop of paramecium culture, the pellicle may be observed to separate from the ectoplasm. Under high power, the pellicle is seen to be made of six-sided *hexagonal areas* (noncellular) produced by ridges on the surface (Fig. 170). One *cilium* projects from the center of each hexagonal area. The cilia arise from *basal granules* within the protoplasm and are called *microsomes* (mi′ kro som) (Gr. *mikros,* small; *soma,* body). Spindle-shaped cavities called *trichocysts* (trik′ o sist) (Gr. *thrix,* hair; *kystis,* sac) are embedded in the ectoplasm just beneath the surface. These baglike cavities are filled with a liquid which solidifies into long, jellylike *threads* when expelled to the exterior. Each trichocyst opens through a *pore* on the ridges of the hexagonal areas. The poisonous trichocyst fibers serve as weapons of defense. They may be observed to discharge if a small amount of acetic acid is added to a drop of culture. The basal granules are connected by *longitudinal fibers.*

Motion and Locomotion.—Fine, hairlike *cilia* (sil′ i a) (L. cilium, hair) are regularly arranged over the entire external surface. These beat rhythmically and backward, thus propelling the animal forward. The rhythmic strokes are diagonal; hence, the body is rotated on its long axis. The greater rate of action of cilia in the oral groove tends to swerve the paramecium to the left. All these actions locomote the animal in a *spiral path,* usually to the left.

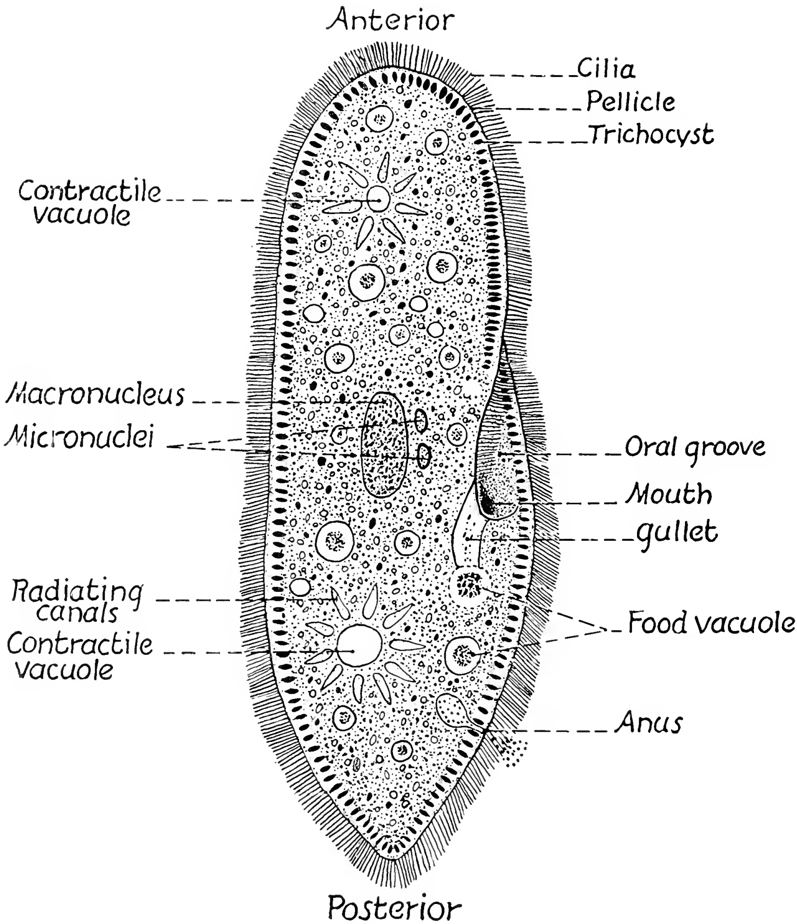


Fig. 163.—*Paramecium aurelia,* a protozoan of the class Infusoria.

Ingestion and Digestion.—A funnel-shaped *oral groove* extends from the anterior end backward and obliquely toward the middle of the animal. The *cell mouth* or *cytostome* (si′ to stom) (Gr. *kystis,* hollow; *stoma,* mouth) is at the posterior end of the oral groove and opens into a short, tubelike *gullet* or *cytopharynx*. The side of the animal with the oral groove is known as the *oral* or *ventral* side; the opposite, as *aboral* or *dorsal*. The *cilia* within the oral groove and gullet propel certain foods toward the *food vacuole*. Foods consist principally of bacteria and other small protozoa. Numerous food vacuoles (droplets of water with

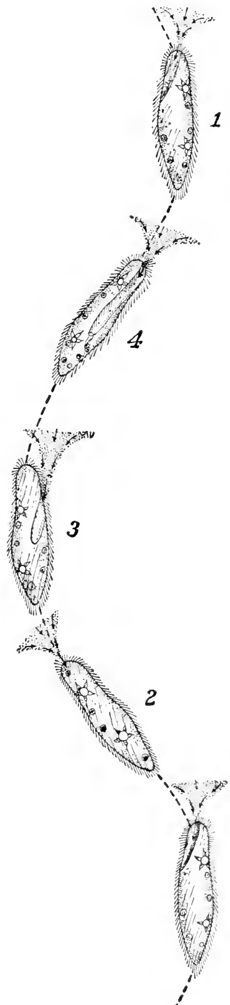


Fig. 164.—Paramecium showing spiral locomotion. *1, 2, 3, 4, 1* show successive positions occupied. Dotted areas show currents of water drawn from the front. (From Jennings: Behavior of the Lower Organisms, published by the Columbia University Press.)

suspended foods) of various sizes and in various stages of food digestion can usually be seen. Food vacuoles are formed at the posterior end of the gullet. When filled, the food vacuole is pinched off by the cytoplasm and it moves away in the flowing cytoplasm. *Digestion* occurs within

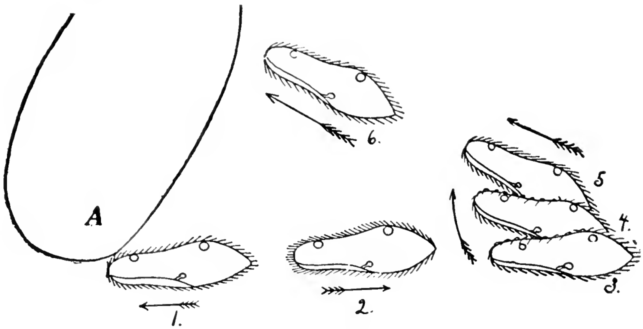


Fig. 165.—The "avoiding reaction" of a Paramecium. *A,* Solid object a source of stimulation; *1-6,* successive positions occupied by the Paramecium in attempting to avoid the object; rotation on its long axis also occurs but is not shown in the diagram. (From Jennings: Behavior of the Lower Organisms, published by Columbia University Press.)

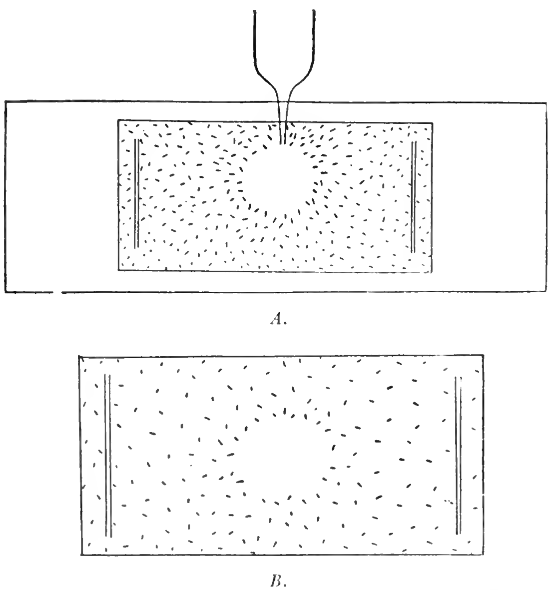


Fig. 166.—Reaction of Paramecium to salt solution. *A,* Method of introducing a drop of 0.5 per cent of NaCl solution; *B,* four minutes later. (From Jennings: Behavior of the Lower Organisms, published by Columbia University Press.)

the food vacuoles because of the contained *digestive enzymes* secreted by the cytoplasm. Foods are *absorbed* and *assimilated* into living protoplasm.

Circulation.—There is no special circulatory equipment, but the foods, wastes, etc., are circulated by the natural streaming of the cytoplasm and is known as *cyclosis.*

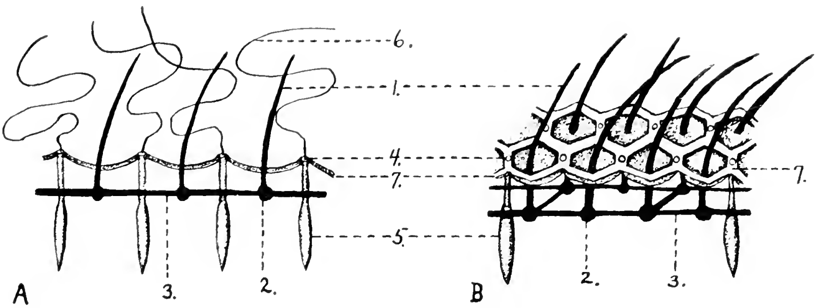


Fig. 167.—Neuromotor mechanism (in part), trichocysts, and cilia of *Paramecium sp. A,* Section showing trichocysts attached to the ridges of the hexagonal depressions of the pellicle; *B,* surface and side view, showing the coordinating fibers which connect the basal granules which control the actions of the cilia. *1,* Cilium; *2,* basal granule of cilium; *3,* interciliary fibril to connect basal granules; *4,* trichocyst pore; *5,* trichocyst; *6,* discharged trichocyst; *7,* hexagonal area of pellicle. (From various sources, from data discovered by Lund.)

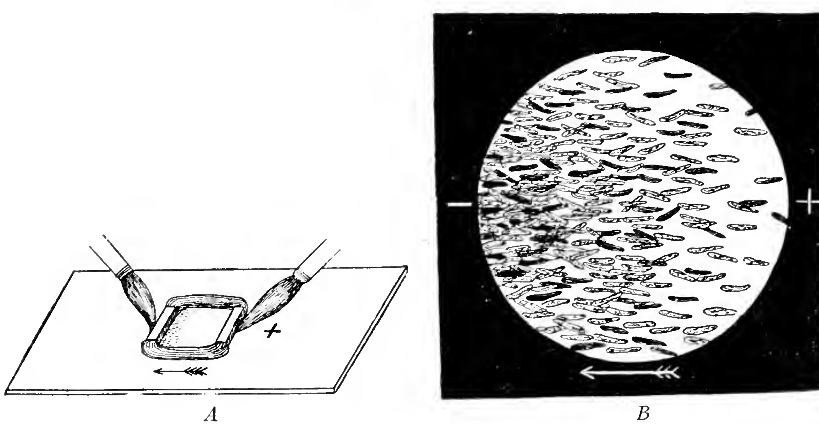


Fig. 168.—Galvanotropism (reaction to electricity) shown by Paramecia. *A,* General appearance of the apparatus and Paramecia reacting to electric current. The current is passed through a cell with porous walls by means of unpolarizable brush electrodes. Paramecia have moved toward the negative pole or cathode. *B,* Magnified view showing movement toward the cathode. (From Jennings: Behavior of the Lower Organisms, published by Columbia University Press.)

Respiration.—Oxygen is taken in from the water through the *body surface.* Carbon dioxide passes out through the *body surface* as well as through the *contractile vacuoles.*

Excretion and Egestion.—A large *contractile vacuole* is usually located *near each end* of the body. Each contractile vacuole has *radiating canals*

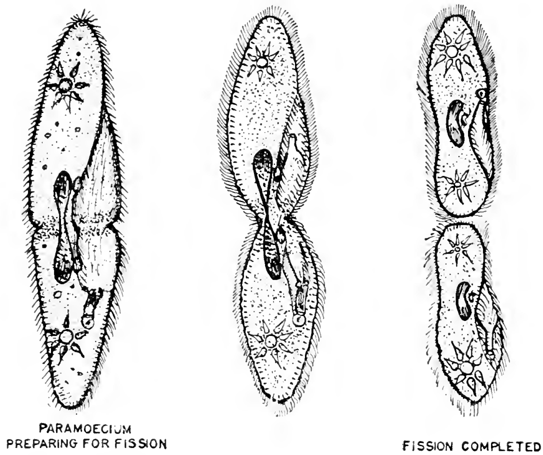


Fig. 169.—Paramecium reproducing by asexual, binary fission (transverse division), shown diagrammatically. Note the division of the nuclei, gullet, and contractile vacuoles. (From Parker and Clarke: Introduction to Animal Biology, The C. V. Mosby Co.)

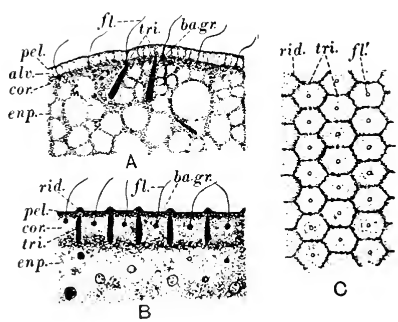


Fig. 170.—Structure of the ectoplasm of typical Protozoa of the class *Infusoria. A, Frontonia leucas* (cross section); *B, Paramecium sp.* (cross section); *C, Paramecium sp.* (surface view); *pel.,* pellicle; *cor.,* cortex; *tri.,* trichocyst; *enp.,* endoplasm; *fl.,* cilium; *ba. gr.,* basal granule (microsome) at the base of each cilium; *alv.,* alveolar layer of minute regular vacuole; *rid.,* surface ridges of the pellicle; *fl'.,* point of insertion of cilium in the middle of each hexagonal area; hexagonal areas are formed by the striations of the pellicle. (From Borradaile and Potts: The Invertebrata. By permission of The Macmillan Company and the Cambridge University Press, publishers.)

(from six to eleven) which collect wastes and transport them to the contractile vacuole. The latter discharges wastes to the exterior through a pore. After each discharge, a new contractile vacuole is formed. Contractions may occur every twenty to thirty seconds, depending upon numerous factors. Wastes may also diffuse through the pellicle. An *anal spot* posterior to the oral groove may be observed as it discharges solid particles.

Coordination and Sensory Equipment.—Paramecia respond to stimuli as do many other protozoa. When certain stimuli are encountered, a paramecium may reverse its cilia and swim backward a short distance. Using its posterior end as a pivot, the anterior end then swings about in a circle, testing for the stimulus. When no longer stimulated, the cilia

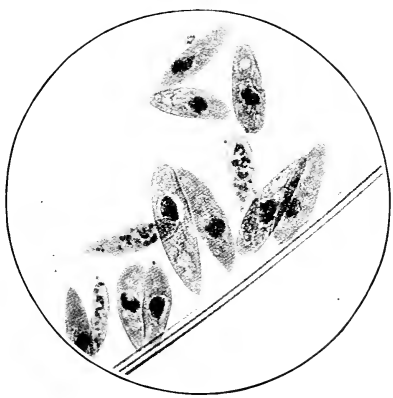


Fig. 171.—Paramecium. Photomicrograph of specimens in conjugation. (Copyright by General Biological Supply House, Inc., Chicago.)

move the animal forward again. This is the so-called *"avoiding reaction."* The optimum temperature for paramecia is slightly less than 30° C. When stimulated by heat, a paramecium displays the avoiding reaction, moving toward less heat. Sodium chloride gives a negative chemotaxic reaction, while a weak solution of acetic acid may even attract paramecia. They do not seem to be visibly affected by ordinary light. The *longitudinal fibers* at the *basal granules* of the cilia are probably for the purpose of coordinating the actions of the cilia (Fig. 170).

Reproduction.—*Paramecium* divides transversely by *binary fission* (Fig. 169). Occasionally, this is interrupted by a temporary union of two individuals through a process called *conjugation* (L. *com,* together; *jugare,* to join) (Fig. 171) in which there is a reciprocal *fertilization.*

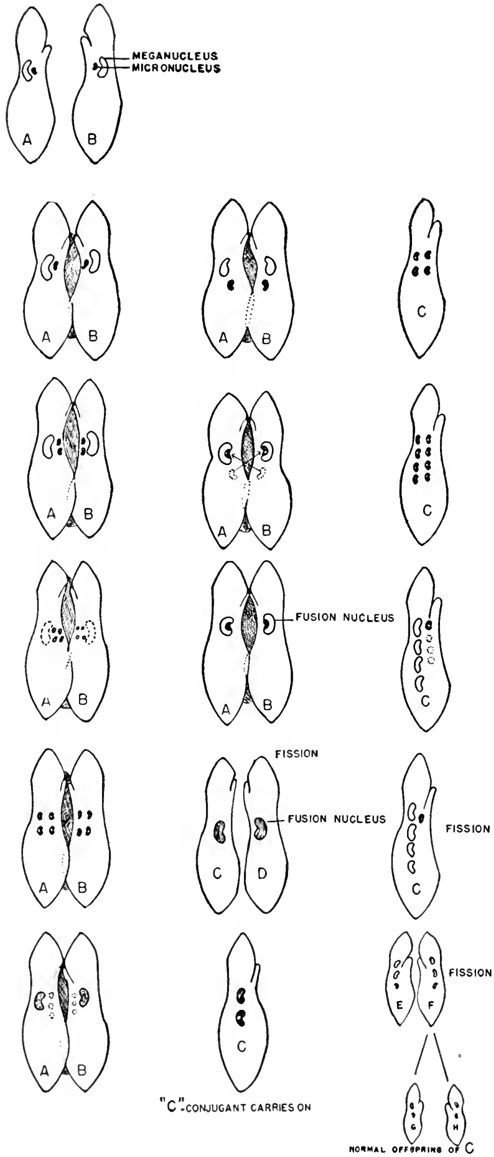


Fig. 172.—*Paramecium caudatum* reproducing by conjugation, shown diagrammatically. The meganucleus is also known as the macronucleus. (From Parker and Clarke: Introduction to Animal Biology, the C. V. Mosby Co.)

Two individuals construct a *"protoplasmic bridge"* between their oral surfaces, and certain of their *reorganized nuclear materials* migrate to the opposite paramecia (Figs. 171 and 172). Fusion of nuclear materials results in fertilization, which is somewhat like sexual reproduction, although no sex cells are actually formed. *Paramecium aurelia* has been carried in a culture continuously for a period of over forty years, and neither conjugation nor death from age have occurred, yet fission took place at a vigorous, normal rate. It has been found that there are eight distinct races of paramecia, each with its *inherited characteristics. Paramecium aurelia* has been found to have at least two *mating types* called types I and II. Neither of these will conjugate with one another, but mating type I must conjugate with mating type II. In order to rejuvenate certain paramecia, conjugation must take place between different strains, while in other species rejuvenation is accomplished by inbreeding or even self-fertilization.

It has been discovered recently that the cytoplasm contains a system of particles which have the property of self-duplication, a property similar to that of chromosomes and genes of the nucleus. Such a system of *cytoplasmic genes* are called *plasma genes* to distinguish them from nuclear genes. The plasma genes play important roles in the *heredity* of paramecia.

Another method of reproduction is known as *autogamy* (o -tog′ a my) (Gr. *autos,* self; *gamos,* marriage) and consists of a *nuclear reorganization of a single individual.* It involves *meiosis* (mio′ sis) (Gr. *meion,* smaller) in which there is a reduction of nuclear materials from the diploid (double) to the haploid (single) condition. It also includes *self-fertilization.* This method is used by paramecia under certain conditions.

It has been discovered recently that there are races of paramecia which produce and liberate a substance in their cytoplasm which kills animals of other races. The two races have been called *"killers"* and *"sensitives."* This killer substance is called *"paramecin,"* and one particle of it (*kappa particle*) can kill a sensitive paramecium. Killers may have hundreds of these kappa particles in their cytoplasm, while sensitives have none. Hence, these kappa particles are *cytoplasmic genes* called *plasma genes.*

EUGLENA

Euglena (u -gle′ na) (Gr. *eu,* good; *glene,* pupil of the eye) is a common, fresh-water *flagellated* protozoan. Two common species are *Euglena viridis* (vir′ i diz) (L. *viridis,* green) and *Euglena gracilis* (gras′ il-is) (L. *gracilis*, slender). These flagellates belong to the class *Mastigophora* (mas ti -gof′ o ra) (Gr. *mastix*, whip; *phoreo*, to bear) because of a whiplike flagellum (L. *flagellatus*, whip). Because *Euglena* has certain plantlike characteristics, it is frequently claimed to be a plant by the botanists. We might well compromise and call it a plant-animal. *E. viridis* is about 0.1 mm. long, blunt at the anterior end, and with a pointed posterior end. An ovoid or spherical *nucleus* contains a central body, the *endosome* (Fig. 173).

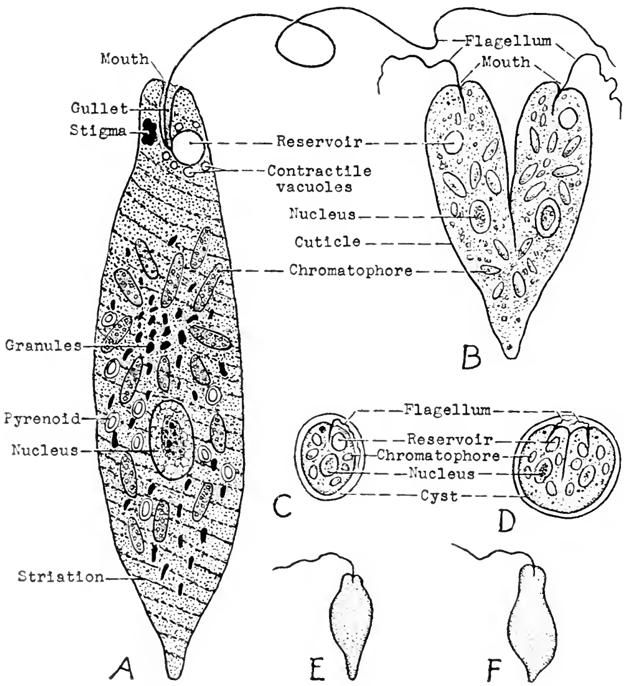


Fig. 173.—*Euglena viridis*, a protozoan of the class *Mastigophora*. *A*, Free-swimming adult (highly magnified); *B*, reproduction by longitudinal binary fission; *C*, euglena rounded and protected by cyst; *D*, longitudinal fission within cyst; *E* and *F*, shapes (in outline) assumed by Euglena. (All enlarged and somewhat diagrammatic.)

Integument (Covering).—A tough, flexible, external *pellicle* (cuticle) has longitudinal, parallel, thickened *striations* which give the body rigidity.

Ingestion and Digestion.—A funnel-shaped *cytostome* (cell mouth) leads to a *cytopharynx* (gullet). The latter has an enlarged *reservoir* at its base. A contractile vacuole next to the permanent reservoir arises by the flowing together of several smaller vacuoles, and it discharges wastes into the reservoir.

Suspended in the cytoplasm are numerous *green, chlorophyll-bearing chromatophores* (kro′ mat o for) (Gr. *chroma,* color; *phorein,* to bear) known specifically as *chloroplasts.* In each chloroplast is a *pyrenoid* (pi-re′ noid) (Gr. *pyren,* fruit-stone; *eidos,* like) which probably forms a starchlike *paramylum* (pa -ram′ i lum) (Gr. *para,* beside; *amylon,* starch). The latter may be free in the cytoplasm in the form of rods, disks, etc. Euglenae *photosynthesize* most of their foods (holophytic nutrition) in a plantlike manner, although they may absorb certain foods through the general body surface by saprophytic nutrition. It is debated whether Euglenae ingest solid foods through the cytopharynx.

Motion and Locomotion.—A *long, vibratile flagellum,* arising from two *axial filaments* within the body, extends out through the cytostome. The flagellum consists of a contractile *axial filament,* or *myonemes* (mi′ on-em) (Gr. *myo,* muscle; *nema,* thread), composed of a bundle of fibers and surrounded by a *sheath* of protoplasm. A Euglena may be propelled in a *spiral path* by the actions of the flagellum at the anterior end. Euglena may also contract the body to assume a variety of shapes and to move by what is called *euglenoid movement.*

Circulation.—Foods, wastes, etc., are circulated through the cytoplasm by the flowing of the protoplasm and is known as *cyclosis.*

Respiration.—Respiration takes place through the *general body surface.* Possibly some of the carbon dioxide is used in photosynthesis, and some of the oxygen from photosynthesis is used for its various activities.

Excretion.—A *contractile vacuole,* next to the permanent *reservoir,* arises by the flowing together of several smaller vacuoles and collects and discharges wastes into the reservoir. From the latter the wastes pass to the gullet and out the cytostome. It is not unusual for wastes to be eliminated through a mouthlike opening in lower types of animals.

Coordination and Sensory Equipment.—A *light-sensitive, red, eye spot* or *stigma* (Gr. *stigma,* mark) is near the anterior end of the body. A fine, delicate, fiberlike *rhizoplast* (ri′ zo plast) (Gr. *rhiza,* root; *plastos,* formed) extends from the nucleus to the reservoir. Euglenae swim toward ordinary light (positive phototaxis) to assist in photosynthesis but swim away from direct sunlight which may be harmful. The *avoiding reaction* is frequently observed.

Reproduction.—*Binary longitudinal fission* occurs by a splitting of the body at the anterior end which continues posteriorly until completed. The nucleus, chloroplasts, etc., also divide. Occasionally, a Euglena throws off its flagellum and surrounds itself with a thick, gelatinous *cyst* (Gr. *kystis,* bag) to resist drying conditions. Sometimes longitudinal fission may occur while the animal is *encysted* and new flagella are formed. As many as thirty-two Euglenae in one cyst have been observed. When proper conditions are encountered, the cyst breaks and the Euglenae emerge to assume an active life again.

VOLVOX

Volvox (vol′ vox) (Gr. *volvo,* turn) is a *colonial protozoan* in which thousands of *body (somatic) cells* are associated to form a hollow, water-filled, globe-shaped *colony.* A common species is *V. globator* (L. *globus,* ball). Because *Volvox* contains certain plantlike characteristics (chlorophyll, cellulose), it might be considered as a plant-animal (Figs. 174 and 175).

Integument.—The body wall consists of *cellulose,* a material common in plants. A gelatinous *matrix* (mat′ riks) (L. *mater,* mother) serves as an intercellular substance to bind adjacent cells together. The cells are arranged in a single layer, and many of them bear two flagella.

Motion and Locomotion.—Most of the body cells bear *two flagella* whose lashing movements give the colony a rotating locomotion. The male sperm are also supplied with flagella.

Ingestion and Digestion.—Most of the body or *somatic cells* (so-mat′ ik) (Gr. *soma, body*) contain *chlorophyll* by means of which carbon dioxide and water may be combined to form foods by *photosynthesis* in the presence of energy-supplying *light.* There is *no cytostome* so solid foods cannot be ingested. Chlorophyll is borne in *chloroplasts.*

Circulation.—There is no special circulatory equipment, but materials are probably circulated by the flowing of the cytoplasm (cyclosis).

Respiration.—Respiration probably takes place through the *general body surface.* Possibly some of the carbon dioxide is used in photosynthesis, and some of the oxygen from photosynthesis is used for its various activities.

Excretion.—Most of the body cells contain a *contractile vacuole* which collects wastes and throws them to the outside. Since the colony is only one cell in thickness, possibly each cell can easily rid itself of its waste materials.

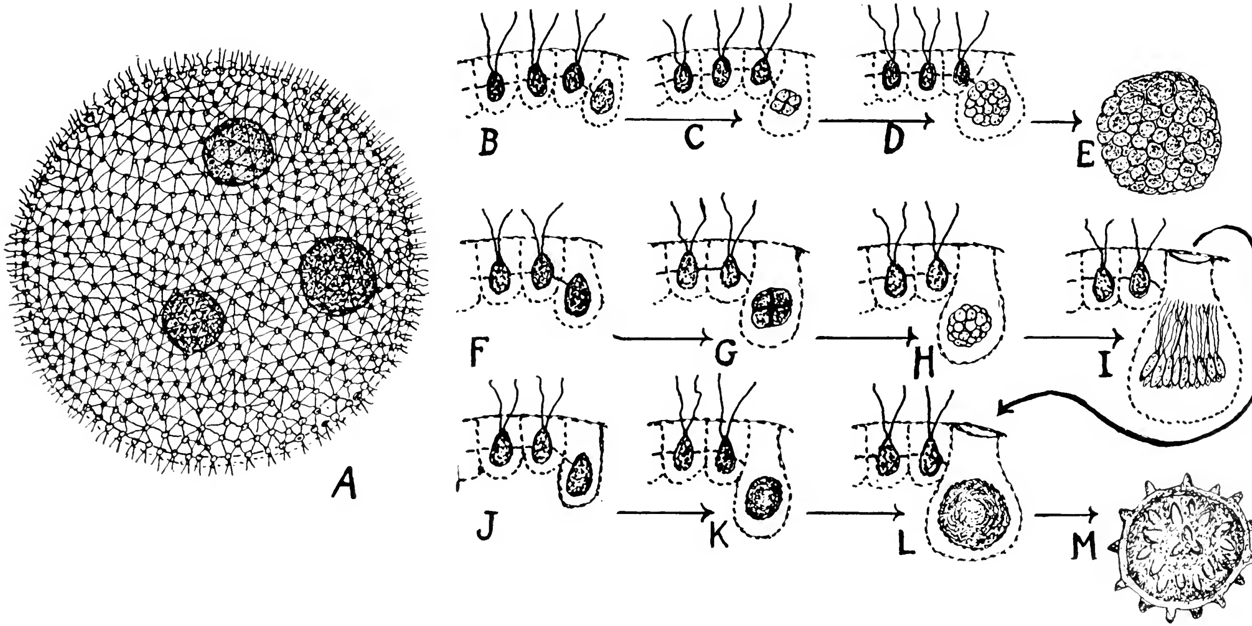


Fig. 174.—Volvox, a colonial protozoan of the class *Mastigophora*. *A*, Colony with hundreds of vegetative cells, each with flagella, showing three immature colonies within; *B-E*, formation of a new colony by parthenogenesis (without fertilization) in which a cell loses its flagella and divides by mitosis to form a new colony; *F-I*, formation of male gametes (sex cells); *J-L*, formation of an ovum (egg or female gamete) and its fertilization by a male sperm to produce a zygospore, *M*, which is quite resistant and from which will develop a new colony. (See Fig. 175.)

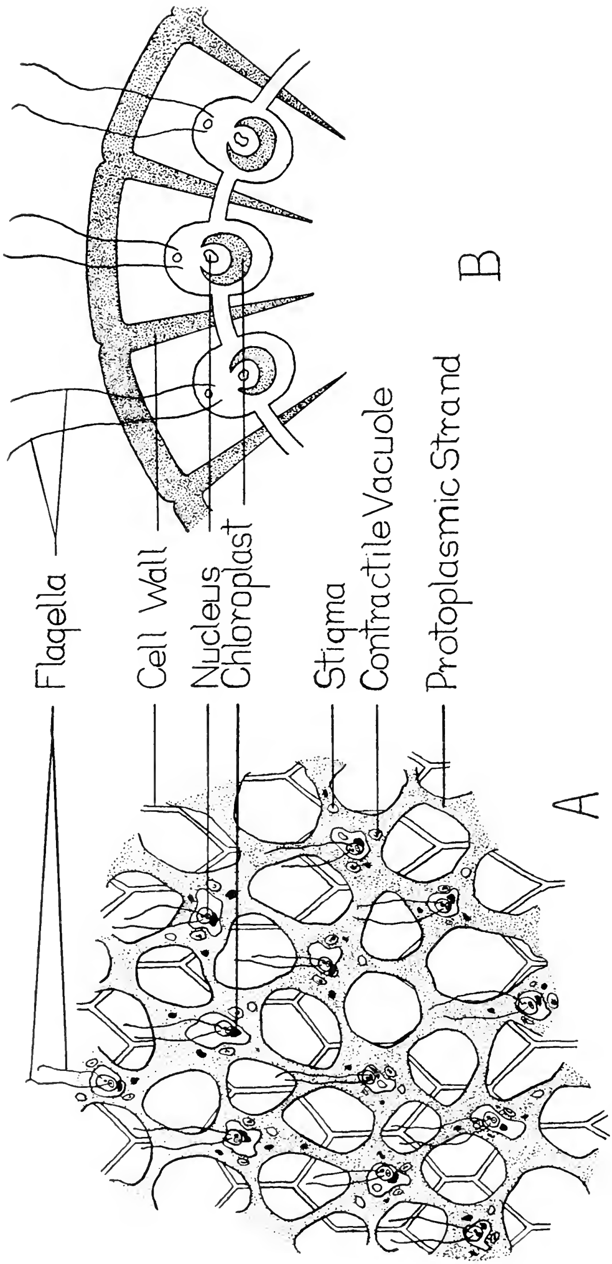


Fig. 175.—Volvox showing detailed structures somewhat diagramatically. *A*, Surface view showing "protoplasmic strands" connecting adjacent cells; *B*, side view showing chloroplast, nucleus, etc.

Coordination and Sensory Equipment.—The thousands of body cells in the colony are connected by *protoplasmic strands* (Fig. 175) to establish *physiologic (functional) continuity* between these cells. Through these structures, coordination between the various parts of the colony may be accomplished. Most body cells contain an *eye spot (stigma)* which is light sensitive and probably assists in orientation for photosynthesis.

Reproduction.—Reproduction occurs by *asexual* and *sexual methods.* In asexual reproduction, certain cells of the colony without flagella increase in size and are called *parthenogonidia* (par then o go -nid′ i a) (Gr. *parthenos,* virgin; *gonos,* offspring; *idion,* diminutive). These divide to form numerous cells which form a new colony. This method of *developing an egg without union with a sperm* is known as *parthenogenesis* (par then o -jen′ e sis) (Gr. *parthenos,* virgin; *genesis,* origin or descent).

The sexual method consists in the formation of *flagellated male sperm* and *nonflagellated female eggs.* Within the colony, certain cells, by simple division, form a *sperm bundle* which may contain over 100 spindle-shaped *sperm* (male gametes). Other cells divide and produce as many as 50 large *eggs* (female gametes). One sperm fuses with (fertilizes) an egg (inside the colony) to form a *zygote* (zygospore) which surrounds itself with a resistant wall to withstand the winter. When proper conditions are encountered, the zygospore breaks the wall and by division forms a new colony. In *Volvox* the colony consists of two types of cells; the true somatic body cells and the true reproductive germ cells (either male or female).

PLASMODIUM

Plasmodium (plaz -mo′ di um) (Gr. *plasma,* mold or form; *eidos,* like) belongs to the class *Sporozoa* because it reproduces by means of *spores. Plasmodium vivax* (vi′ vax) (L. *vivere,* long live) causes the so-called *tertian type of human malaria* (L. *tertianus,* thrice) with an attack of fever every forty-eight hours (third day); *P. malariae* causes *quartan malaria* (L. *quartus,* fourth) with an attack every seventy-two hours (every fourth day); *P. falciparum* (L. *falix,* sickle) produces *aestivo-autumnal malaria* (L. *aestivus,* summer) with daily attacks or more or less constant fever. The life cycles of these three species of *Plasmodium* differ only in minor details. Malarial fever is transmitted by the bite of the diseased female mosquito (not the male) of certain

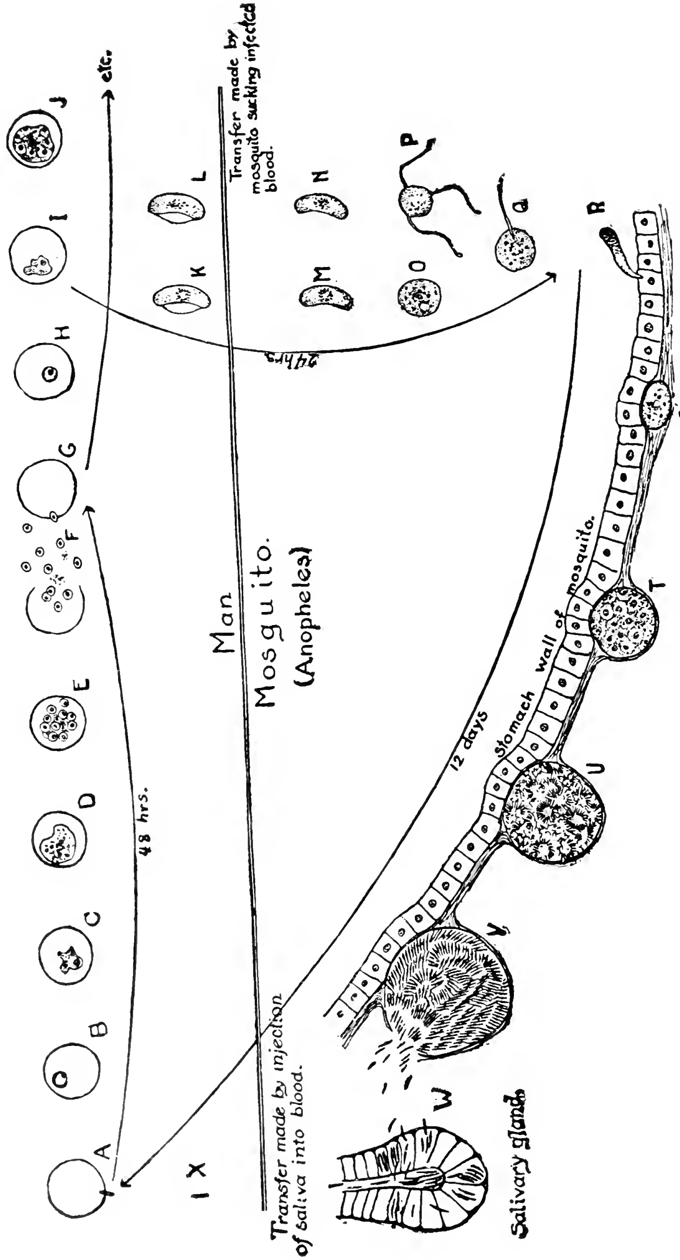


Fig. 176.—For legend, see opposite page.

Fig. 176.—Life cycle of the protozoan malarial parasite (Plasmodium) of the class *Sporozoa*. The asexual stages of the parasite occur in man, while the sexual stages occur in the body of the female mosquito (Anopheles). *A, Sporozoite* (spindle-shaped spore) from salivary gland of the mosquito, entering human red blood corpuscles; *B*, young "ring" stage; *C, trophozoite* (ameboid stage) feeding on the blood corpuscle protoplasm; *D*, adult trophozoite, known as a *schizont*, ready to sporulate by undergoing multiple nuclear division, thus producing numerous daughter cells (*merozoites*), which are liberated into the blood stream and attack other corpuscles. Some *merozoites* develop into schizonts, while others develop into sex cells (*gametocytes*); *E*, merozoites formed by sporulation; *F, G*, liberation of *merozoites* from one corpuscle and entrance into another; *H, I*, and *J*, repetition of growth, sporulation, etc.; *K*, *female gametocyte* in human blood; *L*, male gametocyte in human blood; *M, N*, same in mosquito stomach; *O*, *mature female gametocyte* (egg or macrogamete); *P*, *male gametocyte* ("flagellated body") with several elongated male gametes (sperm or microgametes) being extruded; *Q*, fertilization; *R*, motile, wormlike *ookinete* resulting from fertilization, enters wall of mosquito stomach; *S, T*, and *U*, stages in developing spore-filled capsule (*oocyst*) on outer wall of mosquito stomach; *V*, mature oocyst breaks and liberates its spindle-shaped *sporozoites* into body cavity; *W*, *sporozoites* enter salivary glands of mosquito; *X*, injection of *sporozoites* from female mosquito into human blood stream. (From Chandler: Introduction to Human Parasitology, published by John Wiley & Sons, Inc.)

species which happen to carry the sporozoite (spore) stage of the malarial parasite. The female mosquito of the genus *Anopheles* (an -of′ el ez) (Gr. *anopeles,* hurtful) transmits malaria, while the ordinary mosquito of the genus *Culex* (ku′ leks) (L. *culex,* gnat) does not (Figs. 176, 202, and 303).

Motion and Locomotion.—In the adult stages *Plasmodium* does *not possess locomotor organelles,* although certain immature stages may be motile. These will be noted later in the discussion of reproduction.

Ingestion and Digestion.—Sporozoa have *no digestive organelles* but they absorb foods from their surroundings. Since they are parasitic, they undoubtedly enjoy many "precooked" meals at the expense of the hosts.

Circulation.—The Sporozoa are so small that they do not require circulatory equipments but can rely upon the flowing of protoplasm (cyclosis) within their cells.

Respiration.—The limited oxygen requirements are probably supplied by taking it in through the general body surface.

Excretion.—The parasitic sporozoa, taking in foods from their hosts, probably do not need to excrete great quantities of wastes and do so through the general body surface.

Coordination and Sensory Equipment.—The parasitic habits probably explain the absence of specific sensory equipments.

Reproduction.—The spindle-shaped spores, called *sporozoites* (spo ro-zo′ ites) (Gr. *sporos,* spore; *zoon,* animal) (Fig. 176), in the saliva of a diseased female mosquito are thrust into the human wound by the biting mouth parts and enter the human red blood corpuscles where they become amoeba-like *trophozoites* (trof o -zo′ ite) (Gr. *trophe,* nutrition; *zoon,* animal) which feed at the expense of the red blood corpuscles. In about fifty hours the trophozoite becomes a *schizont* (shiz′ ont) (Gr. *schizein,* divide), which divides (sporulates) to form from fifteen to twenty-four *merozoites* (me ro -zo′ ite) (Gr. *meros,* part; *zoon,* animal). The merozoites are liberated into the blood stream in about eight hours and attack other red blood corpuscles. The time of liberation of merozoites parallels the attack of fevers and chills. Some merozoites develop into additional schizonts again, while other *merozoites* became *sex cells,* called *gametocytes* (gam′ et o site) (Gr. *gamos,* spouse; *kytos,* cell). These *male* and *female gametocytes* may be picked up by the biting female mosquito from the blood stream of a malarial patient. The female gametocyte forms a *macrogamete* (egg). The male gametocyte forms from six to eight elongated *microgametes* (sperm). A sperm and egg fuse to form a *zygote* which changes into a motile, wormlike *ookinete* (o o -kin′ et) (Gr. *oon,* egg; *kine,* motile) which enters the wall of the mosquito stomach. Here the ookinete forms a round *oocyst* (o′ o sist) (Gr. *oon,* egg; *kystos,* sac) which, after six to seven days, forms hundreds of spindle-shaped *sporozoites* which eventually go to the salivary glands of the mosquito, ready to be transferred by a bite. Formation of spores from a fertilized zygote is called *sporogony* (spo -rog′ o ne) (Gr. *sporos,* spore; *gonos,* to produce), but if formed from unfertilized cells it is called *schizogony* (skiz -og′ o ne) (Gr. *schizein,* to cleave).

QUESTIONS AND TOPICS

1. List all the characteristics which protozoa, as revealed by your studies, have in common.
2. Make a table of the protozoa studied, showing all differences between them.
3. Explain specifically why certain protozoa are considered as plant-animals.
4. Describe each of the following for the protozoa studied: (1) integument, (2) motion and locomotion, (3) ingestion and digestion, (4) circulation, (5) respiration, (6) excretion and egestion, (7) coordination and sensory equipment, and (8) reproduction.
5. Why do unicellular protozoa not have organs and tissues? What are such structures called in protozoa?
6. What characteristics of living protoplasm did you observe in your studies of protozoa?
7. In the light of the numerous abilities of protozoa to live successfully, would you consider them simple or complex? Explain.
8. Discuss the economic importance of protozoa, both detrimentally and beneficially.
9. Explain the complex life cycle of such a protozoan as *Plasmodium,* including the stages in proper sequence, the different hosts, and the detrimental effects of the different stages.
10. Explain the significance of parthenogenesis as revealed by certain protozoa.
11. List the conclusions you can draw from the observations made on protozoa.

SELECTED REFERENCES

Calkins: Biology of the Protozoa, Lea & Febiger.
Calkins: The Smallest Living Things, The University Society.
Calkins and Summers: Protozoa in Biological Research, Columbia University Press.
Hegner: Invertebrate Zoology, The Macmillan Co.
Hegner: College Zoology, The Macmillan Co.
Hegner and Taliaferro: Human Protozoology, The Macmillan Co.
Hyman: The Invertebrates (Protozoa to Ctenophora), McGraw-Hill Co., Inc.
Kudo: Handbook of Protozoology, Charles C Thomas, Publisher.
Minchin: An Introduction to the Study of Protozoa, Lea & Febiger.
Morgan: Field Book of Ponds and Streams, G. P. Putnam's Sons.
Needham and Needham: Guide to the Study of Fresh Water Biology, Comstock Publishing Co., Inc.
Ward and Whipple: Fresh Water Biology, John Wiley & Sons, Inc.

Chapter 19

FLATWORMS AND ROUNDWORMS (PHYLUM PLATYHELMINTHES and PHYLUM NEMATHELMINTHES)

PLANARIA (DUGESIA); LIVER FLUKE; TAPEWORM; ASCARIS

Planaria *(Dugesia)* (pla -nar′ i a) (Gr. *planos,* wandering) and the liver fluke *Fasciola hepatica* (fas -i′ o lah) (L. *fasciola,* a band) (he pat′ i ka) (Gr. *hepar,* liver) belong to the Phylum *Platyhelminthes* (plat i hel -men′ thez) (Gr. *platus,* flat; *helmins,* worm).

PLANARIA (DUGESIA)

The common, free-living, fresh-water planarian is *Dugesia tigrina,* formerly called *Planaria maculata.* Its upper surface is *spotted,* brown and white, while the lower is grayish. The body has *bilateral symmetry* and may be 20 mm. long (Figs. 177 to 179).

Integument.—The *ectoderm,* a thin layer of external, *ciliated cells,* called the *epidermis,* secretes *mucus* which may give protection and diminish friction. Rodlike *rhabdites* (rab′ dite) (Gr. *rhabdos,* rod) embedded in the epidermis are discharged for offensive purposes. The *entoderm* is a single layer of elongated, epithelial cells and lines all branches of the digestive tract. The middle, cellular *mesoderm* is composed of large amoeboid cells. Hence, planaria is *triploblastic,* being composed of cellular ectoderm, mesoderm, and entoderm. There is *no true body cavity.*

Motion and Locomotion.—The entire surface is covered with hairlike *cilia,* although they are more numerous on the flat, ventral side. Three sets of *muscles,* longitudinal, circular, and oblique, in the body wall aid in locomotion. Mucus secreted at the anterior end reduces friction during locomotion.

Ingestion and Digestion.—The *pharyngeal chamber,* with its cylindrical, muscular *pharynx* and *mouth* at its tip, is located midway between the anterior and posterior ends of the body (Fig. 177). The *intestine* joins the pharynx and has one *anterior* and two *posterior main branches,* each with numerous, smaller, *lateral branches* or *diverticula* (di ver -tik′ u la) (L. *de,* away; *vertere,* to turn). The intestine serves as a *gastro-vascular cavity* (gas tro -vas′ ku lar) (Gr. *gaster,* stomach or digestive; L. *vasculum,* vessel or circulatory) in which both digestion and circulation take place. The pharynx may be everted and protruded through the ventral surface as a tubular *proboscis* (pro -bos′ is) (Gr. *proboskis,*

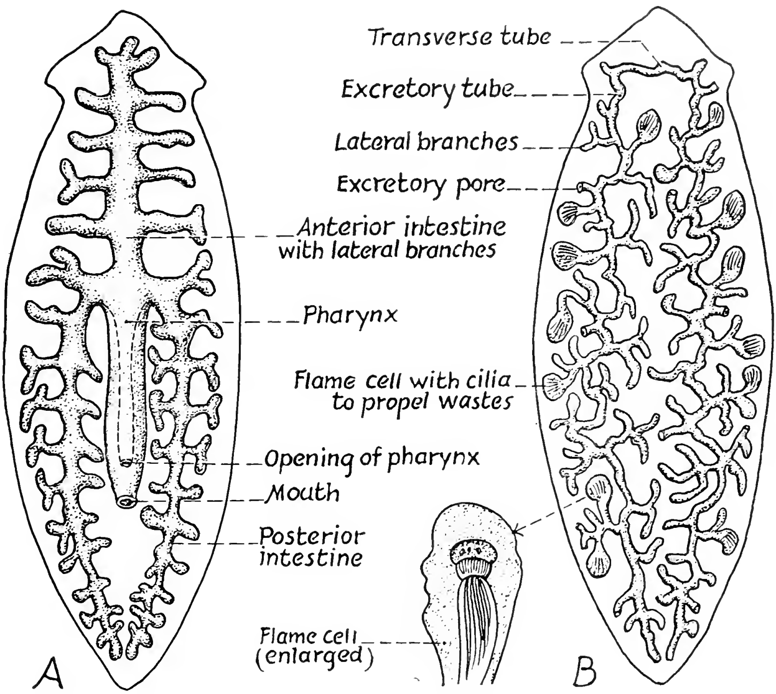


Fig. 177.—Planaria of the phylum *Platyhelminthes,* class *Turbellaria,* showing the digestive system, *A,* and the excretory system, *B.*

trunk) when feeding. Part of the foods are digested within the intestine by *digestive juices* secreted by cells which line it. This is called *extra-cellular digestion* (outside of cells). Other foods are digested by digestive juices within *food vacuoles* within these cells. This is called *intra-cellular digestion* (within cells). There is *no anus,* and wastes are eliminated through the mouth, which is a rather common practice in many lower animals.

Circulation.—There is *no special circulatory system,* but the branched intestine serves as a gastrovascular cavity in which foods, wastes, water, etc., circulate.

Respiration.—Respiration takes place through the *general body surface* as well as through the surface of the *intestine* (gastrovascular cavity).

Excretion and Egestion.—Wastes are eliminated from the intestine through the mouth. Coiled *excretory tubes* run lengthwise along the

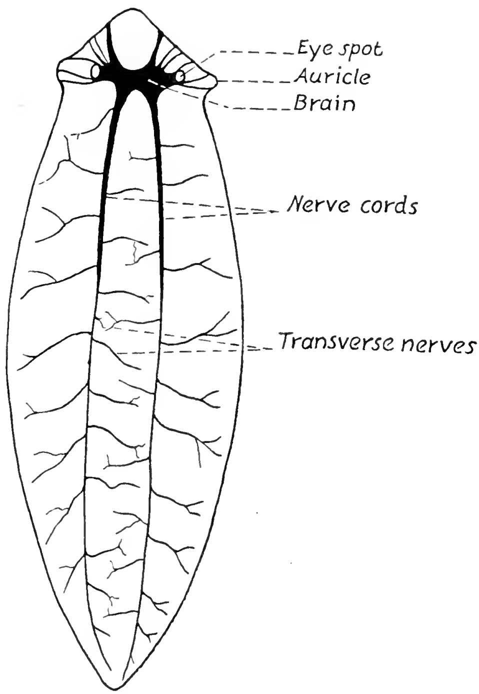


Fig. 178.—Nervous system of Dugesia (Planaria). Observe the nerves leading from the brain to the auricle.

two sides of the body and are connected near the anterior end by a *transverse tube.* This system opens exteriorly through small *excretory pores* on the dorsal surface behind the eye spots. Additional openings along the excretory tubes may exist. The small lateral branches of the tubes divide, redivide, and terminate in a large, hollow, *flame cell.* The latter contains a bunch of motile *cilia* to propel wastes. The motile cilia tend to flicker like a flame; hence, "flame cell" (Fig. 177).

Coordination and Sensory Equipment.—A bilobed, diffuse mass of nerve cells known as the *cerebral ganglion* (brain) is located beneath the pair of sensitive *eye spots* just posterior to the pair of sensitive *auricles.* Numerous nerves connect the brain with the sense organs in the anterior part of Planaria. Two *ventral nerve cords* extend backward, laterally

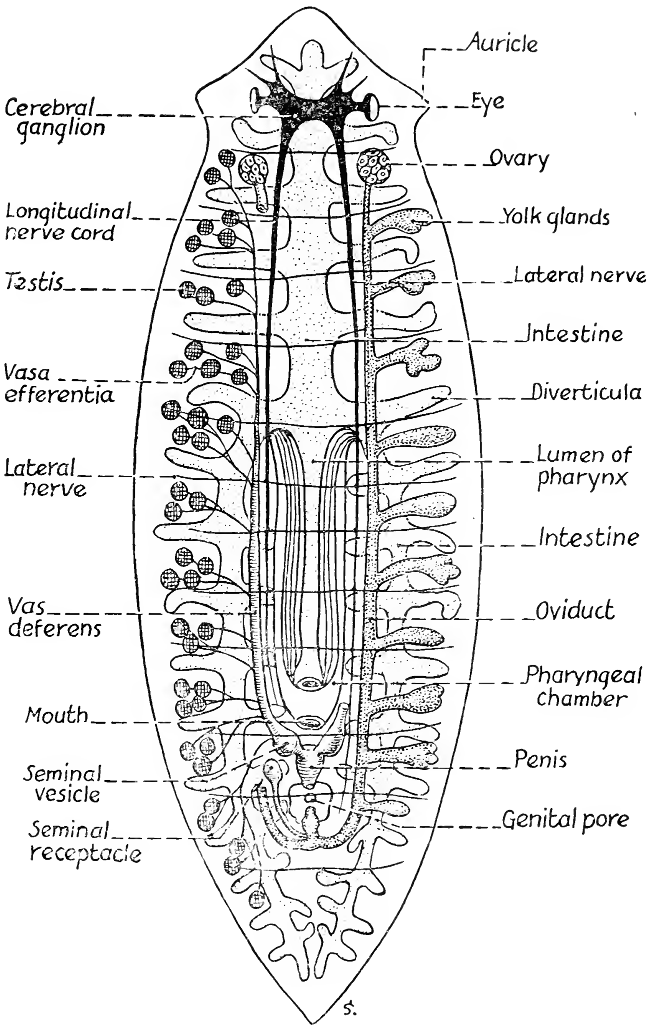


Fig. 179.—Dugesia (Planaria) (reproductive system). The male organs are shown on one side only. (From Potter: Textbook of Zoology, The C. V. Mosby Co.)

and longitudinally, to the posterior part of the body. Several *transverse nerves* connect the two ventral nerve cords (Fig. 178) *Ciliated pits* on either side of the head contain special sensory cells.

Planaria illustrates *axiate organization.* It has (1) a *primary anteroposterior axis* and (2) a *secondary ventrodorsal axis.* When the primary axis is considered, we find an *axial gradient of metabolic activity* which decreases as we proceed from the anterior end toward the posterior end. In other words, the more highly active areas of the anterior regions, because of their activity, assume a control over the less active posterior regions as we progress in sequence from anterior to posterior. When the secondary ventrodorsal axis is considered, we find the greatest activity in the ventral side. Activity gradually decreases as we go toward the dorsal side. When these two axes are considered at the same time, the region of greatest activity is located at the anterior end near the ventral side. Planaria also has *bilateral symmetry* in which the right and left halves are similar to each other. Because of the axial gradient, Planaria may be cut transversely into pieces and each segment under proper conditions will regenerate and eventually assume its normal activities with new centers of control established in each piece (Fig. 28).

Planaria responds to a variety of stimuli. One pair of dorsal *eye spots* are sensitive to light. One pair of lateral *tactile olfactogustatory auricles* connected with the brain are affected by touch and certain chemicals (L. *tactus,* touch; L. *olfacio,* smell; L. *gustus,* taste).

Reproduction.—Both male and female sex organs are present in the same Planaria; thus it is *monecious* or *hermaphroditic* (mo -ne′ si us; her maf ro -dit′ ik) (Gr. *monos,* one; *eikos,* house) (Gr. *hermaphroditos,* combining both sexes). However, self-fertilization probably does not occur, but *cross fertilization* is used (Fig. 179). The *male organs* include numerous spherical *testes* scattered throughout the body. The testes are connected by *sperm ducts* or *vasa deferentia* (singular, vas deferens). Each of the pair of large sperm ducts enlarges at its posterior end into a *seminal vesicle* (L. *semen,* seed; *vesica,* bladder). The latter connect with the muscular *copulatory penis.* The sperm produced by the testes are collected by the vasa deferentia and carried to the seminal vesicles until transferred by the penis to the opposite animal during copulation. The penis projects into the *genital chamber* located posterior to the pharynx. The sperm are transferred by the penis to the *seminal receptacle (copulatory sac)* of the opposite animal during copulation. The saclike seminal receptacle is connected by a tube with the genital chamber.

The *female organs* include a pair of spherical *ovaries* near the anterior end. Each is connected by means of an *oviduct* with the genital chamber. A series of *yolk glands* empty yolk (food) for the eggs into the oviduct. After copulation the sperm leave the seminal receptacle, travel up the oviducts toward the ovaries, and fertilize the eggs as they leave the ovary. As the fertilized eggs pass down the oviducts, they are surrounded by yolk cells from the yolk glands. In the genital chamber clumps of eggs and yolk cells are surrounded by a shell-like *egg capsule (cocoon)*. Each cocoon may contain as many as ten eggs and hundreds of yolk cells for nourishment. The cocoons are passed to the outside through a *genital pore*. The eggs develop in two to three weeks into miniature worms without a reproductive system. The reproductive organs of adults degenerate after each breeding and are later regenerated. This might explain the absence of reproductive systems in certain adults.

Planaria also reproduces *asexually* by *transverse fission*. Ordinarily Planaria constricts just behind the pharynx, and after several hours the two parts separate. The anterior part regenerates the missing posterior part, while the posterior part regenerates an anterior part, with all missing structures eventually replaced. Because of *axiate organization,* Planaria shows a remarkable ability to replace missing parts. This *axiate gradient of metabolic activity* can be demonstrated by the relative amounts of oxygen used, and the amounts of carbon dioxide given off, by the different levels from one end of the animal to the other. Planaria may be carefully cut into pieces to illustrate this remarkable ability to regenerate. If properly conducted, this makes one of the most interesting exercises in the laboratory.

LIVER FLUKE

The liver fluke, *Fasciola (Distomum) hepatica,* is a parasitic *trematode* (trè′ ma tode) (Gr. *trema,* pore; *eidos,* resemblance) which in its adult stages may live in the liver of sheep, cows, pigs, and occasionally man. The immature stages are found in the bodies of a specific kind of water snail, with a few special stages in water, or on vegetation. The adults are flat and leaflike. The body is *triploblastic* (Figs. 180, 181, 374).

Integument.—The *ectoderm* is a thick, heavy, elastic *cuticle* which protects the adult from the host which it parasitizes. The *entoderm* lines the alimentary tract. The *mesoderm* is represented by muscles, excretory organs, reproductive organs, and parenchyma. The *paren-*

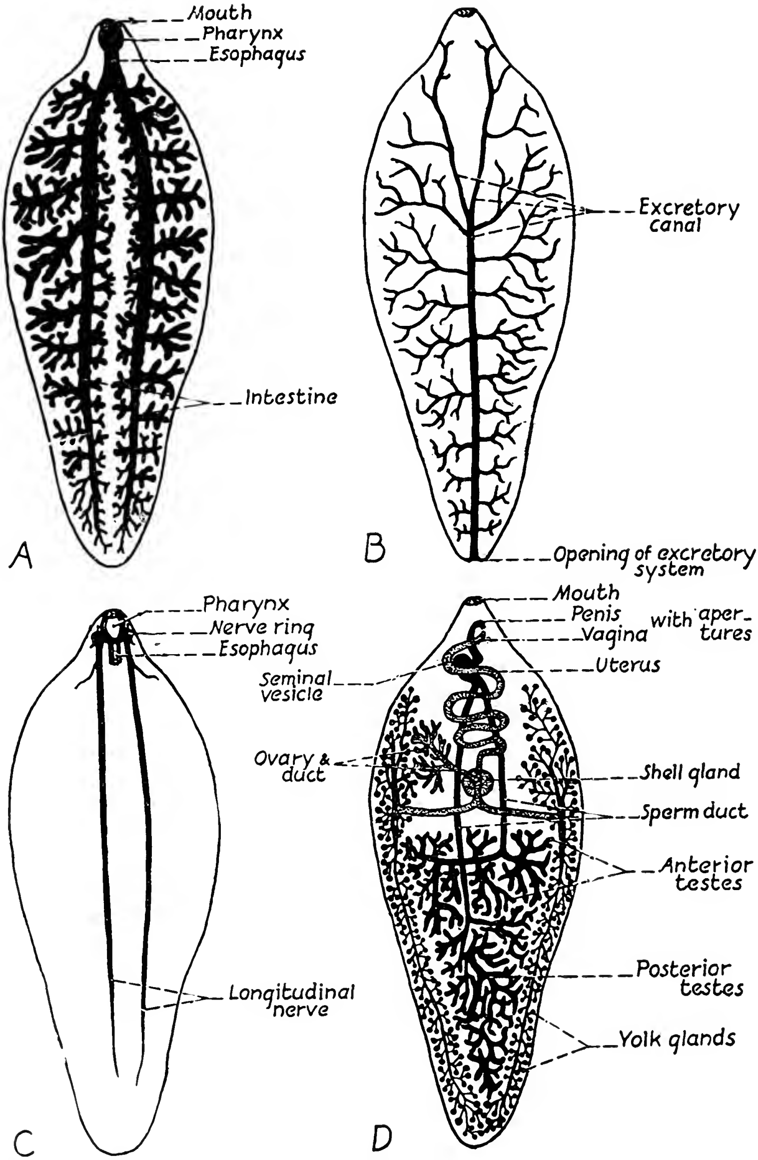


Fig. 180.—Liver fluke (*Fasciola hepatica*) of the phylum *Platyhelminthes*. *A,* Digestive system; *B,* excretory system; *C,* nervous system; *D,* reproductive system. All are much enlarged and somewhat diagrammatic.

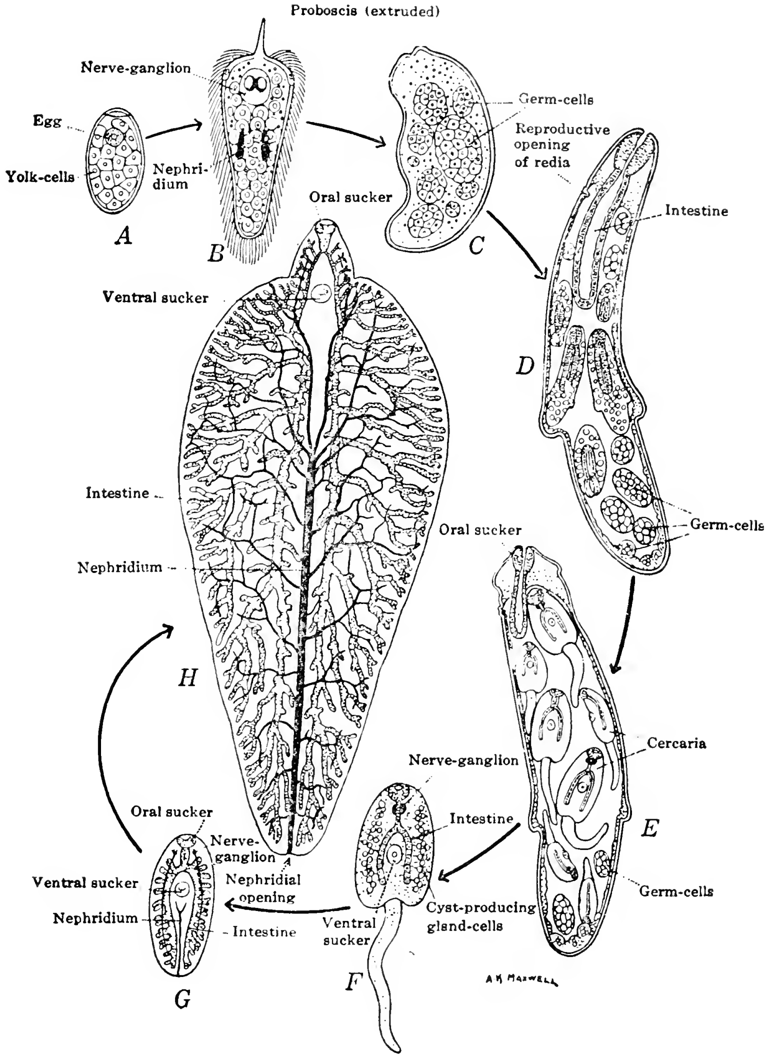


Fig. 181.—Diagrams to show the life cycle of the liver fluke (*Fasciola hepatica*). *A,* Egg in a case; *B,* miracidium (ciliated larva); *C,* sporocyst; *D,* redia (early stage); *E,* redia (later stage containing cercaria); *F,* cercaria with motile tail; *G,* cercaria (encysted and without tail); *H,* adult fluke in the liver of the sheep, where it produces, perhaps, 500,000 eggs when sexually mature. Only digestive and excretory systems are shown in this adult. (Consult Fig. 180, *D* for reproductive system.) (From Hegner: College Zoology. By permission of The Macmillan Company, publishers.)

chyma (par -eng′ ki ma) (Gr. *para,* beside; *engchyma,* infusion) is a loosely organized tissue between the alimentary tract and the body wall in which the internal organs are embedded, there being no true coelom.

Motion and Locomotion.—The body consists of three layers of *muscles:* circular, longitudinal, and diagonal (oblique).

Ingestion and Digestion.—A *mouth* lies in the center of a muscular, disk-shaped *anterior (oral) sucker.* A *ventral sucker* serves for attachment. The *mouth* leads into a short *pharynx,* the latter connects with the *esophagus,* and the esophagus leads to the *intestine,* with its *two main branches* and numerous smaller ones. The digestive cavity serves as a gastrovascular cavity for digestion and circulation.

Circulation.—There is *no special circulatory system,* although circulation is accomplished by the digestive tract (gastrovascular cavity).

Respiration.—Respiration occurs through the *general body surface.* Being parasitic, the oxygen needs are probably not great.

Excretion.—The external *excretory pore* (nephridial opening) is located at the posterior end of the body. There is only one main *excretory canal* with its numerous *branches* which extend to all parts of the body. Undigested materials may be eliminated through the mouth.

Coordination and Sensory Equipment.—The nervous system consists of a *brain* (nerve ring) in the anterior part of the body. Two *longitudinal nerves* extend posteriorly from the brain. The general structure resembles that in Planaria.

There is *no special sensory equipment* in the adult stage which is parasitic within the body of the host.

Reproduction.—The external *genital opening* is located between the mouth and the ventral sucker. Both *male and female reproductive organs* are present in the adult fluke; hence, it is *monecious (hermaphroditic).* Their arrangements may be studied in Fig. 180, *D.*

The various stages in the *life cycle* in the two hosts may be studied in Figs. 181 and 374. One adult fluke may produce over 500,000 eggs, and 200 flukes in the bile ducts of a sheep liver may thus produce 100,000,000 eggs. The eggs pass from the sheep liver to the intestine where they are passed with the feces. When in water, an egg produces a *ciliated larva* called a *miracidium* (mir a -sid′ i um) (Gr. *meirakion,* stripling). The latter swims until it bores into the body of a certain species of fresh-water snail *(Lymneae).* In two weeks it changes to a saclike *sporocyst* (spor′ o sist) (Gr. *sporos,* spore; *kystis,* sac). Each of the numerous *germ cells* within a sporocyst develops into a second type of larva called the *redia* (re′ di a) (after Redi, an Italian scientist). Redia in turn give origin to one or more generations of *daughter redia,* after which they form a third type of tailed larva called a *cercaria* (ser -ka′ ri a) (Gr. *kerkos,* tail). The cercaria leave the body of the snail, swim for a time if water is available, and then *encyst* on grass or other vegetation. If the vegetation is eaten by a sheep, the cyst wall is dissolved by the digestive juices and the cercaria travel to the bile ducts of the liver where mature flukes develop in about six weeks.

TAPEWORM

The pork tapeworm lives as an adult in the alimentary canal of man. It has the scientific name *Taenia solium* (te′ ni a; so′ li um) (L. *taenia,* ribbon; *solus,* alone). A closely related species, the beef tapeworm

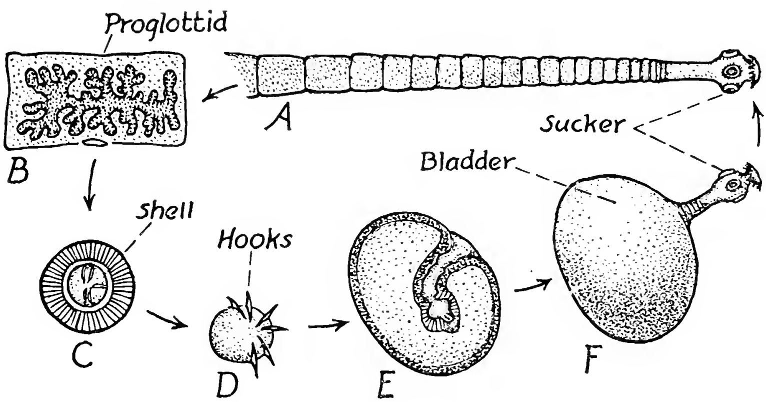


Fig. 182.—Development and life history of the pork tapeworm (*Taenia solium*). *A,* The anterior part of the tapeworm, showing the scolex with its suckers and hooks, as well as young proglottids; *B,* mature proglottid with multibranched uterus containing eggs; *C,* egg with embryonal shell (striped); *D,* larva with three pairs of hooks and without shell; *E,* cyst stage (shown in section) with scolex inside; *F,* more advanced stage with scolex everted and the bladder attached. Stage *F* develops into the first stage, thus completing the life cycle. Stages A and B are present in the human intestine; stages C and D in the pig intestine; stage E in pig tissues; stage F, again in human body.

(which also parasitizes man), is called *T. saginata* (sag i -na′ ta) (L. *saginare,* to fatten). *T. solium* has an enlarged *scolex* (sko′ lex) (Gr. *skolex,* worm) which contains *hooks* and *suckers.* *T. saginata* has no hooks. A large string of linearally arranged parts known as *proglottids* (pro -glot′ id) (Gr. *pro,* before; *glottis,* tongue) are attached to the *neck.* One worm may become several feet long and contain hundreds of proglottids. The latter are formed by *budding* (strobilization) from the

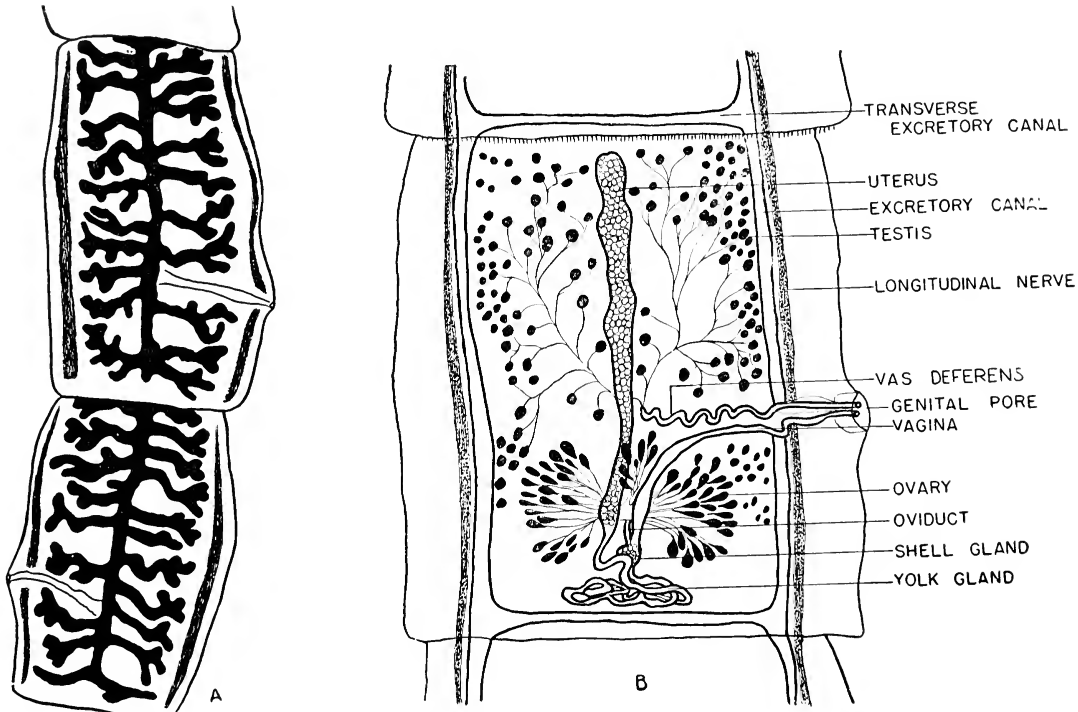


Fig. 183.—Tapeworm. *A*, Proglottids showing branched uterus; *B*, diagrammatic representation of a sexually mature proglottid. (From Parker and Clarke: Introduction to Animal Biology, The C. V. Mosby Co.)

neck, so that the newest proglottids are nearest the neck. The older ones at the opposite end of the worm may break from the series and be passed with the feces (Figs. 182 and 183).

Integument.—An external, very thin *cuticle* may give slight protection to the parasite against the host.

Motion and Locomotion.—The tapeworm is moved primarily with the contents of the alimentary canal, although the *hooks* and *suckers* on the scolex attach the anterior end.

Ingestion and Digestion.—There is *no alimentary tract,* and the general body surface absorbs digested foods from the intestine of the host. There is *no true coelom.*

Circulation.—There is *no circulatory system* required because foods are absorbed through all surfaces of the body.

Respiration.—What little oxygen that is probably needed because of its parasitic habits may be taken in through the general body surface.

Excretion.—A pair of *longitudinal excretory canals* whose *branches* end in *flame cells* open to the exterior, at the posterior end of the proglottid, where wastes are eliminated.

Coordination and Sensory Equipment.—The nervous system is similar to that of Planaria and the liver fluke (cerebral ganglia, lateral nerve cords), although not so complex. The parasitic habits probably explain the *absence of sensory equipment,* although suckers and hooks are present for attachment.

Reproduction.—A mature proglottid contains both *male and female sex organs* which may be studied in Fig. 183. The *eggs* develop into six-hooked *embryos.* If eaten by a pig, they bore through the wall of the digestive tract and enter the skeletal muscles or other organs where they *encyst.* Within the protective *cyst,* a *scolex* develops from the cyst wall and then everts. The larva is called a *bladderworm* or *cysticercus* (sis-ti -ser′ kus) (Gr. *kystis,* bladder; *kerkos,* tail). If insufficiently cooked pork containing cysticerci is eaten by man, the bladder part is cast off and the scolex attaches to the human intestine and a series of proglottids is formed by budding at the neck.

ASCARIS

A common roundworm, parasitic in the human intestine, is *Ascaris lumbricoides* (as′ kar is lum bri -koid′ ez) (Gr. *askaris,* intestinal worm; L. *lumbricus,* earthworm; Gr. *eidos,* form). It has a long, slender,

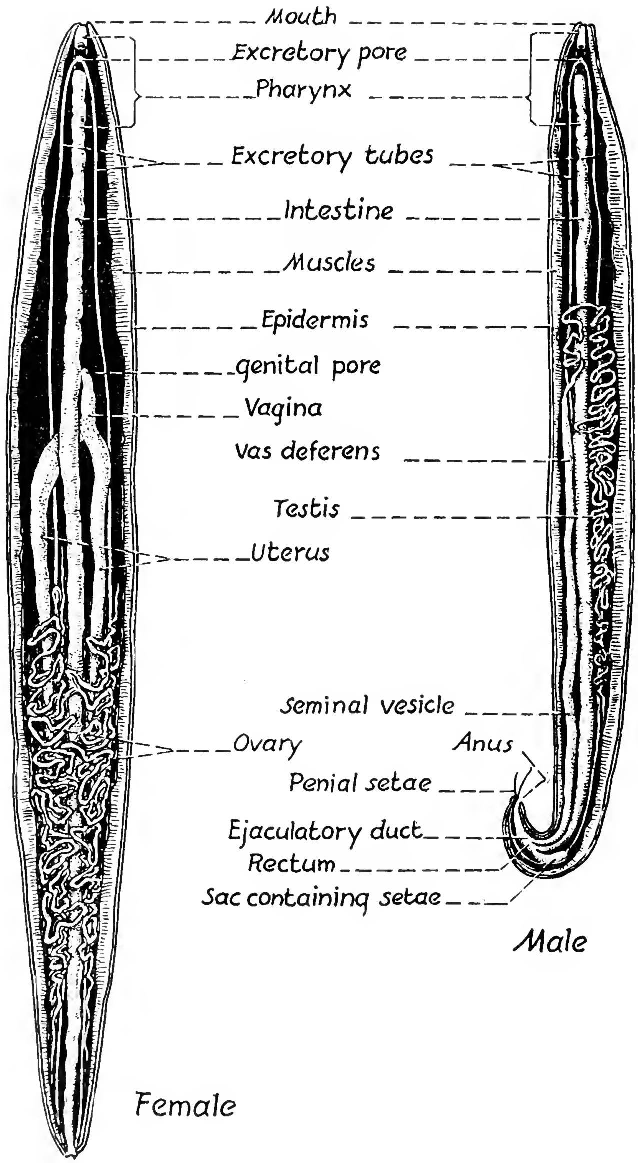


Fig. 184.—The parasitic human roundworm, *Ascaris lumbricoides,* phylum *Nemathelminthes,* dissected to show internal structures.

smooth, unsegmented body with somewhat pointed ends. The *sexes are separate,* the *female* being larger (five to eleven inches long); the *male* is usually smaller with a bend in the posterior part of the body. Because the two sexes can be distinguished by means other than the sex organs, they are said to illustrate *sexual dimorphism* (di -mor′ fizm) (Gr. *di,* two; *morphe,* form). A pair of broad *lateral lines* on either side point out the pair of excretory tubes beneath. No cilia are present on the outside of the adults (Fig. 184).

Integument.—The external, transparent *cuticle* is usually smooth and glistening, with very fine *striations.* A cellular *hypodermis* lies beneath the cuticle. Between the body wall and the digestive tract is a cavity which contains large, *giant cells* loosely arranged to form *mesenchyme tissue* (mes′ eng kime) (Gr. *mesos,* middle; *engcheim,* pour in). The latter contains spaces known as *vacuoles,* but there is probably no true coelom.

Motion and Locomotion.—*Muscle cells* in the body walls may cause a limited amount of locomotion as the worms are moved along by the intestinal contents of the host.

Ingestion and Digestion.—The *mouth* at the anterior end has one *dorsal* and two *ventral lips* which are finely toothed and which bear nipplelike *papillae* (pa -pil′ i) (L. *papilla,* nipple). A straight *pharynx* connects with the muscular, sucking *esophagus* which joins a straight, nonmuscular *intestine,* ending in the *anus* at the posterior end of the animal. The muscular esophagus sucks fluids from the intestine of the host. The posterior part of the intestine is the *rectum* (rek′ tum) (L. *rectus,* straight).

Circulation.—Because of the slender body and the absorption of foods through the long intestine, *no special circulatory system* is required.

Respiration.—The parasitic habits and the comparative inactivity preclude any need for a special respiratory system.

Excretion.—The pair of longitudinal *excretory tubes* embedded in the pair of lateral lines open to the exterior by one *excretory pore* on the ventral surface near the anterior end. There are *no flame cells.* Undigested materials may be eliminated by the *intestine.*

Coordination and Sensory Equipment.—A *ring of nervous tissue* encircles the esophagus and gives off a large *dorsal nerve cord* and a large *ventral nerve cord.* The two cords may be connected by other nerve rings. There is *no special sensory equipment.*

Reproduction.—The *sexes are in separate animals;* hence, they are *diecious* (di -e′ si us) (Gr. *di,* two; *oikos,* house). The *male reproductive organs* include one coiled, threadlike *testis* which leads into a tubular *vas deferens.* The latter joins a wider *seminal vesicle* which connects with a muscular *ejaculatory duct,* opening into the *rectum.* One pair of *spicules,* called *penial setae,* protrude from the anus and assist in transferring sperm to the female during copulation.

The *female reproductive organs* include one pair of coiled, threadlike *ovaries,* each connected with a larger *uterus.* The two uteri unite to form a short, muscular *vagina* (va -ji′ na) (L. *vagina,* sheath). The latter empties through the *genital pore* about one-third the length of the body from the anterior end.

Fertilization occurs in the uteri and each *egg* is then enclosed by a shell of *chitin* (ki′ tin) (Gr. *chiton,* tunic or covering), after which it passes from the genital pore. One female may possess more than 25,000,000 eggs, and a mature female may lay 200,000 daily. They are laid inside the host intestine and pass with the feces. The eggs are resistant and may remain alive in the soil for months. When eggs which contain *embryos* are ingested through the mouth, infestation may result. The ingested eggs hatch in the intestine, where the embryonic *larvae* bore through the intestinal wall into the lymphatic vessels or capillaries. They eventually enter the right side of the heart, from which they pass in successive stages to the lungs, trachea, esophagus, stomach, and intestine. This entire journey requires a little more than a week.

QUESTIONS AND TOPICS

1. List all the ways in which Platyhelminthes and Nemathelminthes differ.
2. List the characteristics which planaria, the tapeworm, and the liver fluke have in common.
3. Make a table of the animals studied, including all the ways in which they differ.
4. Describe each of the following for each animal studied: (1) integument, (2) motion and locomotion, (3) ingestion and digestion, (4) circulation, (5) respiration, (6) excretion and egestion, (7) coordination and sensory equipment, and (8) reproduction.
5. Discuss the significance of (1) bilateral symmetry, (2) triploblastic, (3) sexual dimorphism, and (4) hermaphroditism.
6. Discuss specifically what effects prolonged parasitism seems to have had on such systems as the digestive, circulatory, and sensory of the parasite.
7. Discuss the phenomenon of axiate organization and its significance.
8. Discuss specifically the structures and abilities which certain parasitic worms possess whereby they are able to live successfully in spite of many obstacles. Explain how the production of large numbers of offspring enters into this consideration.

9. Explain the complex life cycle of the liver fluke, including the stages in correct sequence, the different hosts, and the detrimental effects of the various stages.
10. Discuss the economic importance of flatworms and roundworms.
11. Explain why the digestive system is considered a gastrovascular cavity in certain types of worms.
12. List the conclusions you can draw from your studies of flatworms and roundworms.

SELECTED REFERENCES

Cameron: The Internal Parasites of Domestic Animals, London.
Chandler: Introduction to Human Parasitology, John Wiley & Sons, Inc.
Craig and Faust: Clinical Parasitology, Lea & Febiger.
Faust: Human Helminthology, Lea & Febiger.
Gamble: Platyhelminthes; in vol. 2, Cambridge Natural History, The Macmillan Co.
Hegner, Root, Augustine, and Huff: Parasitology; With Special Reference to Man and Domestic Animals, D. Appleton-Century Co., Inc.
Mackie, Hunter, and Worth: Manual of Tropical Medicine, W. B. Saunders Co.
Ward and Whipple: Fresh Water Biology, John Wiley & Sons, Inc.

Chapter 20

A SEGMENTED WORM—EARTHWORM (PHYLUM ANNELIDA)

The common earthworm is *Lumbricus terrestris* (lum′ bri kus te -res′-tris) (Gr. *lumbrikus,* earthworm; L. *terra,* earth). Its body is elongated, soft, and segmented. It burrows in the soil by forcing the soil through its alimentary tract and passing this soil on the surface as "castings." A conspicuous saddlelike *clitellum* (kli -tel′ um) (L. *clitellae,* pack-saddle) is present (segments XXXI to XXXVII). A *true body cavity* or *coelom* (se′ lom) (Gr. *koilos,* hollow) exists internally and communicates with the exterior by means of *dorsal pores* in the mid-dorsal line at the anterior edge of each segment from VIII to the posterior end of the body. Membranous, internal *septa* (L. *septum,* partition) separate adjacent segments (Figs. 185 to 190).

Integument.—The thin, noncellular, transparent *cuticle* of ectodermal origin is iridescent because of its *striations* to refract light to produce various colors. The cuticle contains pores of glands located in the *epidermis (hypodermis)* just beneath. Four pairs of chitinous, bristlelike *setae* (se′ ti) (L. *seta,* bristle) are located in *seta sacs* in each segment (Fig. 187).

Motion and Locomotion.—An outer layer of *circular muscles* and an inner layer of *longitudinal muscles* in the body wall aid in locomotion. Four pairs of bristlelike *setae* per segment are moved by *protractor* (pro-trak′ tor) (Gr. *pro,* forth; *tractus,* to draw) and *retractor muscles* (re -trak′ tor) (L. *retrahere,* to draw back) at their bases. Each seta is set in a *seta sac.* The setae are set at certain angles to provide friction or to reduce it as desired.

Ingestion and Digestion.—The foods of earthworms consist of dead plant and animal materials and soils rich in organic substances. Living materials are rarely molested. A fleshy *prostomium* (pro -sto′ mi um) (Gr. *pro,* before; *stoma,* mouth) projects over the mouth at the anterior end. The mouth leads into a *buccal pouch* which connects with a thick,

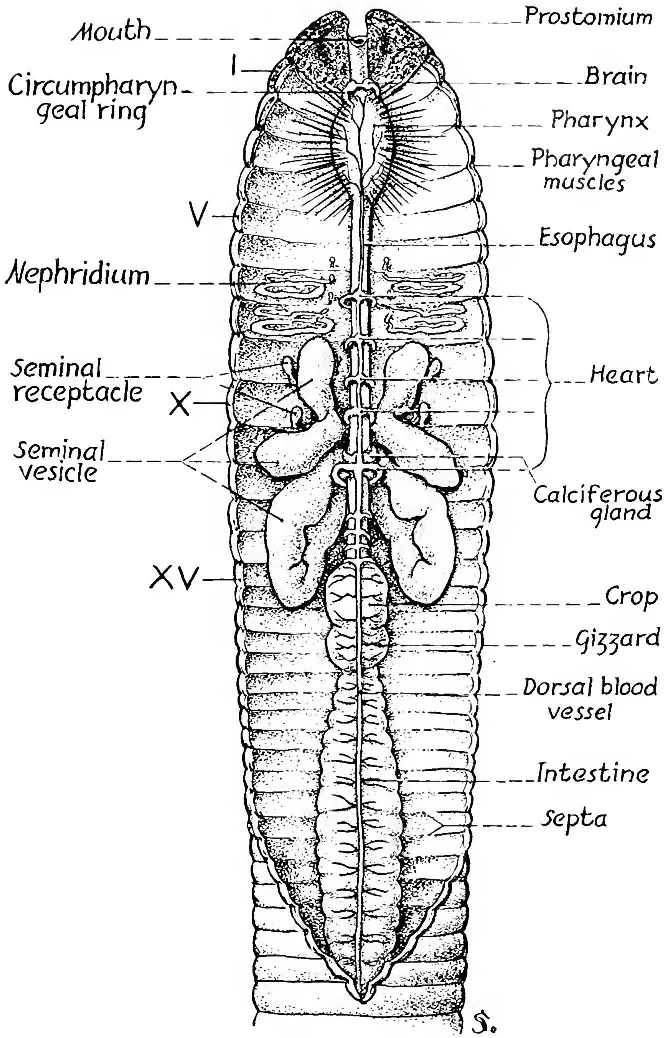


Fig. 185.—Earthworm (*Lumbricus terrestris*) dissected from the dorsal side to show internal structures of the anterior end somewhat diagrammatically. *I, V, X, XV,* Number of segments or somites. Nephridia are shown only in a few segments. There may be slight variations in the location of certain structures in different earthworms.

muscular, sucking *pharynx.* Muscles attached to the outside of the pharynx contract and expand it to cause suction. A narrow *esophagus* connects the pharynx with the large, thin-walled *crop* which is used for storage. Posterior to the crop is the thick, muscular *gizzard* for grinding by means of grains of sand and similar materials. The gizzard leads to the long *intestine,* with its deep, dorsal fold, the *typhlosole* (tif′ lo sole) (Gr. *typhlos,* blind; *solen,* channel). The latter increases the absorbing surface of the intestine and is filled with *chlorogen cells* (klo -rog′ o jen) (Gr. *chloros,* greenish-yellow) which probably aid in digestion of foods and elimination of wastes. The *anus* is at the posterior end of the earthworm.

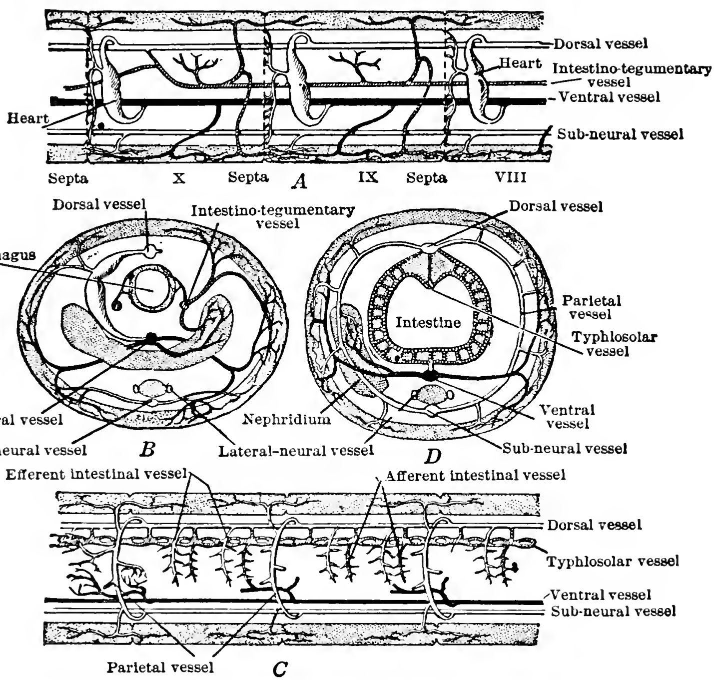


Fig. 186.—Earthworm circulatory system (somewhat diagrammatic). *A,* Longitudinal view in segments VIII, IX, and X; *B,* cross section of same region; *C,* longitudinal view in region of intestine; *D,* cross section of same region. (From Hegner: College Zoology. By permission of The Macmillan Company, publishers.)

Three pairs of *calciferous glands* (kal -sif′ e rus) (L. *calx,* lime; *ferro,* to carry) near the esophagus secrete *calcium carbonate (lime)* into it to neutralize acid foods as well as to line the tunnels (burrows) through

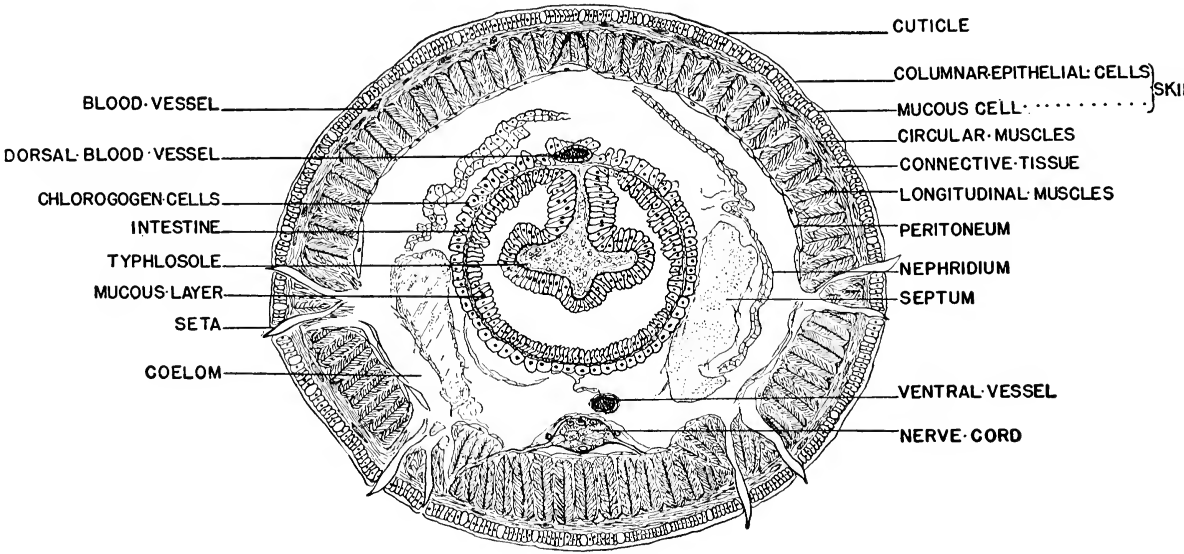


Fig. 187.—Cross section of earthworm posterior to clitellum (cut between septa). (From Parker and Clarke: Introduction to Animal Biology, The C. V. Mosby Co.)

which the worm crawls. These plastered tunnels prevent their collapse and allow moisture and air to penetrate the soil. In this way the earthworms cultivate the soil.

Enzymes of the *digestive juices* act on foods in a manner similar to that of higher animals, as shown by the following table:

ENZYME	FOOD ACTED ON	PRODUCTS FORMED
Trypsin	Proteins	Peptones
Diastase	Carbohydrates	Sugars
Steapsin	Fats	Fatty acids and glycerin

Absorption in the earthworm occurs through the walls of the intestine, being assisted by the amoeboid action of some of the lining epithelial cells. Some absorbed foods are placed in the *coelomic cavity* where they are circulated by the *coelomic fluid.* Other absorbed foods are placed in the *circulatory system* to be taken to various parts of the body.

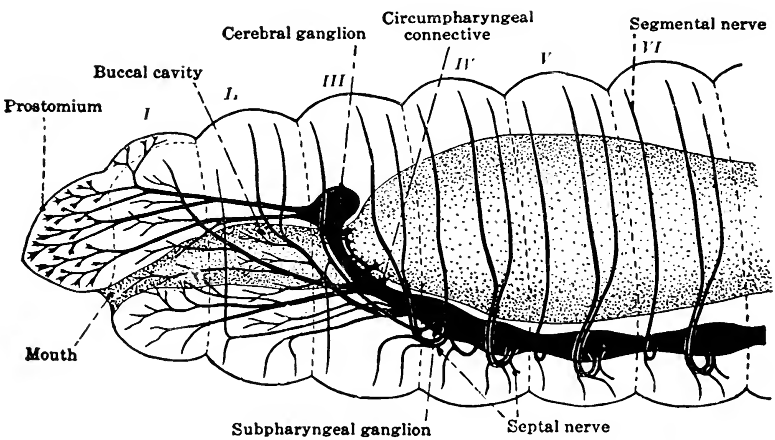


Fig. 188.—Earthworm nervous system. Side view of anterior end with the cerebral ganglion and larger nerves. (From Hegner: College Zoology. By permission of The Macmillan Company, publishers.) (After Hess.)

Circulation.—A complex system of blood vessels forms a so-called *"closed type"* of circulatory system. A closed system is one in which the blood flows, more or less continuously, in the vessels, with only a limited amount of its constituents passing in and out through their walls. The more important parts of the system are: (1) a *dorsal blood vessel* dorsal to the digestive tract, (2) a *ventral vessel* ventral to the digestive tract, (3) five pairs of pulsating, looplike *heart arches* in segments VII to XI which connect the dorsal and ventral vessels, (4) a *subneural vessel* beneath the ventral nerve cord, (5) two *lateral neural vessels* on either side of the nerve cord, (6) numerous *branches* from the vessels with their thin-walled *capillaries* (kap′ i lar i) (L. *capillaris*, hair) to supply all body parts. The blood is propelled through the vessels by the peristaltic contractions of the hearts and dorsal blood vessel, thus forcing it from the posterior part of the dorsal vessel toward the anterior end.

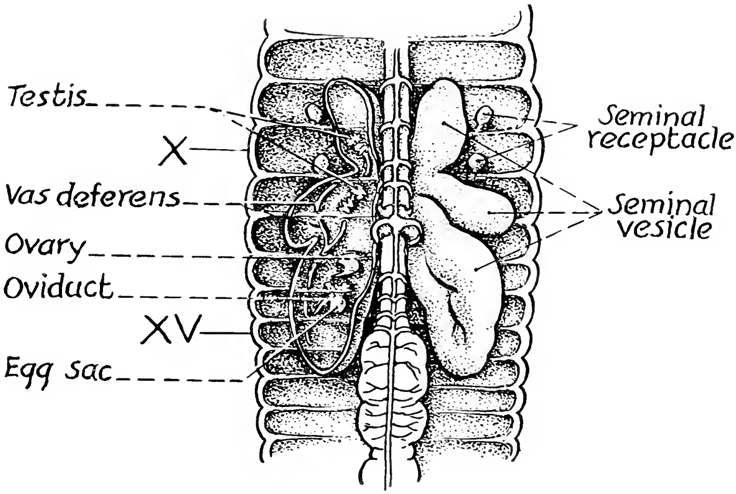


Fig. 189.—Earthworm reproductive system with the seminal vesicles on the left dissected to show the male and female organs (see Fig. 185).

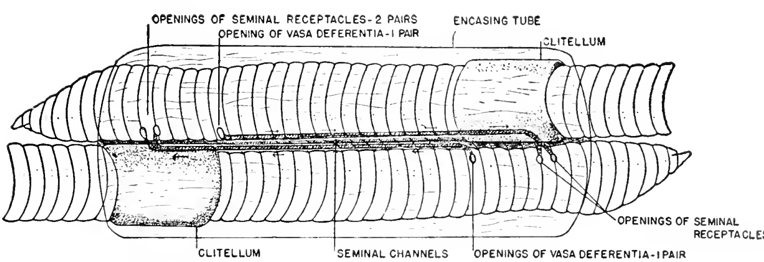


Fig. 190.—Reproduction in earthworms by copulation, shown somewhat diagrammatically. During copulation, the ventral surfaces of the two worms are in contact, with the anterior ends pointing in opposite directions. A slimy tube secreted by the clitellum of each animal surrounds the two worms, and a pair of temporary seminal channels is formed on the ventral surface of each worm, so that sperm expelled from the vasa deferentia of one worm travel to the openings of the seminal receptacles of the other, within which they are stored. (From Parker and Clarke: An Introduction to Animal Biology, The C. V. Mosby Co.)

Valves in the hearts and dorsal vessel prevent the backward flow. Blood is returned from the body wall to the lateral neural vessels, in which it flows posteriorly, eventually re-entering the dorsal blood vessel.

The blood of the earthworm consists of (1) liquid *plasma* with its oxygen-carrying red pigment, *hemoglobin,* dissolved in it and (2) numerous colorless *white blood cells* resembling those of human blood and with possibly similar functions. The blood *carries absorbed foods* from the digestive tract to all parts of the body, *transports wastes* rapidly from the tissues to the organs of elimination, and *exchanges oxygen and carbon dioxide* by coming near the body surface.

When the liquid portion of the plasma of the blood passes out through the walls of the blood vessels into the tissues and organs, it is known as *lymph.* The latter consists of (1) liquid *plasma* of the blood which has osmosed from the blood vessels, (2) numerous colorless *leucocytes,* (3) *foods* contained within the lymph plasma and secured from the blood, (4) *wastes* secured from the tissues, which are either carried by the lymph toward the organs of excretion or placed into the circulatory system to be carried to the excretory organs, and (5) *oxygen* on its way from the blood to the tissues and *carbon dioxide* on its way from the tissues to be eliminated.

The *lymph* fills the coelom (body cavity) and occupies smaller spaces within the tissues and organs. It is from these cavities that the lymph functions. Lymph is circulated by the *muscular movements* of the body or of the internal organs.

Respiration.—There is *no respiratory system* but oxygen is obtained and carbon dioxide eliminated through the moist body surface. Many thin-walled capillaries just beneath the cuticle make the exchange of gases possible. Excess water around the animal interferes with respiration, which partly explains why earthworms are "rained out" after a rain.

Excretion and Egestion.—A pair of *nephridia* (ne-frid′ i a) (Gr. *nephros,* kidney) is present in each segment (metamere) except the first three and the last one. The internal, free end of each is a ciliated, funnel-shaped *nephrostome* (nef′ ro stome) (Gr. *nephros,* kidney; *stoma,* mouth) which selects the wastes from the coelomic fluid. The nephridia select the wastes and pass them through the ciliated tubes to the exterior through openings called *nephridiopores.* The latter are located on the ventral side of the body just posterior to the segment in which their particular nephridia are located. *Chlorogogen cells* covering the intestinal wall and filling the typhlosole may act to eliminate wastes. Solids are eliminated through the *anus*.

Coordination and Sensory Equipment.—A bilobed *brain* (suprapharyngeal ganglion) is located dorsal to the pharynx near segment III. The *circumpharyngeal ring* or *commissure* encircles the pharynx and connects the brain with the *subpharyngeal ganglion* below the pharynx. The *ventral nerve cord* extends posteriorly from the subpharyngeal ganglion and has an enlarged *ganglion* (gang′ li on) (Gr. *ganglion*, little tumor) which gives origin to three pairs of *nerves* in each segment. These ganglia serve as subordinate "brains" where nerve impulses may be received and redirected. Nerves connect the various body segments to *coordinate* their various activities. The muscles of the setae are controlled in order to make them perform their functions properly.

There are *epidermal sense organs* in the peripheral tissues which when stimulated send impulses over nerves. *Sensory hairs* penetrate the cuticle and are connected with the nervous system. Earthworms react to light, contact, moisture, chemicals, sound, etc.

Reproduction.—Both *male and female sex organs* are present in the same earthworm; hence, it is *monecious (hermaphroditic)*. The *female organs include* one pair of small *ovaries* (segment XIII) not visible from the dorsal side, one pair of small *oviducts* which are modified nephridia (segment XIII), one pair of *egg sacs* connected with the oviducts (segment XIV), one pair of *oviduct openings* on the ventral side (segment XIV), two pairs of *seminal receptacles* (spermatheca) in segments IX and X, and two pairs of *seminal receptacle openings* between segments IX and X and X and XI. The *male organs* include two pairs of hand-shaped *testes* (segments X-XI) covered by the seminal vesicles and not visible from the dorsal surface, one pair of *vasa deferentia (sperm ducts)* with ciliated funnels (segments X to XV), one pair of *vasa deferentia openings* on the ventral surface (segment XV), and three pairs of large, conspicuous *seminal vesicles* (segments IX to XII). The bases of these vesicles are attached in these segments, although they may extend beyond them.

During *copulation* the ventral surfaces of two earthworms are in contact, with the anterior ends pointing in opposite directions. A slimy, bandlike *cocoon* (ko koon′) (Fr. *cocon*, cocoon) secreted by the *clitellum* encircles the two worms. A pair of temporary *seminal channels* is formed on the ventral surface of each worm, so that sperm expelled from the vasa deferentia of one worm travel to the openings of the seminal receptacles of the other, within which the sperms are stored. Copulation results in a mutual exchange of sperms but no discharge of eggs or fertilization at this time. One earthworm cannot fertilize its own eggs, but there is a mutual, cross-fertilization in the cocoon.

After copulation, the worms pull away from each other and half of the slimy band is slipped over the anterior end of each worm. In doing so, the eggs from the oviducts are discharged into the slimy tubes which also receive sperms from the seminal receptacles (segments IX and X). The elastic ends of the cocoons close to imprison sperm, eggs, and a liquid food for the developing embryos. A young worm eventually breaks from the cocoon and shifts for itself in the soil. After a few weeks the embryo becomes an adult.

QUESTIONS AND TOPICS

1. List the distinguishing characteristics of the phylum *Annelida.*
2. In what ways is the earthworm to be considered a higher type of animal than those studied previously? Be specific in your answer.
3. Explain and give the significance of (1) metamerism, (2) coelom, (3) "closed type" of circulatory system, (4) typhlosole, (5) hemoglobin, (6) lymph, (7) setae with their muscles, (8) calciferous glands, (9) triploblastic, and (10) clitellum.
4. Explain why earthworms appear to be "rained out" after a rain.
5. Discuss the economic importance of earthworms.
6. Explain the advantage of having both male and female sex organs in the same earthworm, especially when the method of copulation is taken into consideration.
7. In what specific ways are the nervous system and sensory equipment more highly developed than in animals studied previously? What is the significance of this?
8. Describe each of the following in the earthworm: (1) integument, (2) motion and locomotion, (3) ingestion and digestion, (4) circulation, (5) respiration, (6) excretion and egestion, (7) coordination and sensory equipment, and (8) reproduction.
9. Why do you think an earthworm needs so many pairs of nephridia? Explain.
10. List the conclusions you can draw from your studies of the earthworm.

SELECTED REFERENCES

Beddard: Earthworms and Their Allies, Cambridge University Press.
Buchsbaum: Animals Without Backbones, University of Chicago Press.
Darwin: The Formation of Vegetable Mould Through the Action of Worms, London, John Murray Co.
Hegner: Invertebrate Zoology, The Macmillan Co.

Chapter 21

COMMON INSECTS—GRASSHOPPER AND HONEYBEE (PHYLUM ARTHROPODA; CLASS INSECTA)

GRASSHOPPER (Figs. 191 to 194)

Insects are *air-breathing arthropods* with bodies divided into *head, thorax,* and segmented *abdomen.* The head bears *one pair of antennae* and the thorax bears *three pairs of jointed legs.* The grasshopper is a rather desirable type for study because it is large and less specialized than many other types. Although there are many different species of grasshoppers which vary in certain respects, the following descriptions apply in general to most species which are available for study: Grasshoppers have enlarged hindlegs, sound-producing and sound-receiving structures, leathery forewings, and membranous hindwings. On either side of the head is a *compound eye.* On top of the head are *simple eyes,* called *ocelli* (o -sel′ i) (L. *ocellus,* little eye). Grasshoppers have *chewing mandibles* (mandibulate mouth parts) which may be studied in Fig. 192. Grasshoppers belong to the order *Orthoptera* (or -thop′ ter a) (Gr. *orthos,* straight; *ptera,* wings).

Integument and Skeleton.—A flexible, noncellular, *chitinous cuticle* also serves as an *exoskeleton* (ek so -skel′ e ton) (Gr. *exo,* external; *skeletos,* hard) to which organs, muscles, and tissues are attached on the inside. The cuticle is secreted by a cellular *hypodermis* beneath it. The chitin chemically has the formula $C_{30}H_{50}O_{19}N_4$. Beneath the hypodermis is a *basement membrane.*

Internally the cavity in the body is *not a true coelom* but a *hemocoel* (he′ mo sele) (Gr. *haima,* blood; *koilos,* hollow), being filled with organs and a colorless *blood.* When the animal grows, it sheds its chitin at intervals by the process of *moulting* or *ecdysis* (ek′ di sis) (Gr. *ekdyein,* to shed). The liquid secreted by the hypodermis hardens into new chitin.

Motion and Locomotion.—Grasshoppers may walk or jump by means of the three pairs of *jointed legs* or fly by means of two pairs of *wings.*

Each leg consists of a series of segments: the *coxa* (kok′ sa) (L. *coxa,* hip) attached to the thorax, *trochanter* (tro -kan′ ter) (Gr. *trochanter,* runner), *femur* (fe′ mur) (L. *femur,* thigh), *tibia* (tib′ ia) (L. *tibia,* shin), and *tarsus* (tar′ sus) (Gr. *tarsos,* sole of foot). The latter is segmented, the proximal segment bearing three *pads* and the distal one a pair of *claws.* Between the claws is a fleshy *pulvillus* (pul -vil′ us) (L. *pulvilus,* small cushion). The *forewings* are leathery and unfolded and cover the folded membranous *hindwings.* Chitinized, tubular *veins* in the wings give strength. The fine, strong, *striated muscles* attached to the inside of the chitinous skeleton help to move wings, legs, mouth, parts, etc.

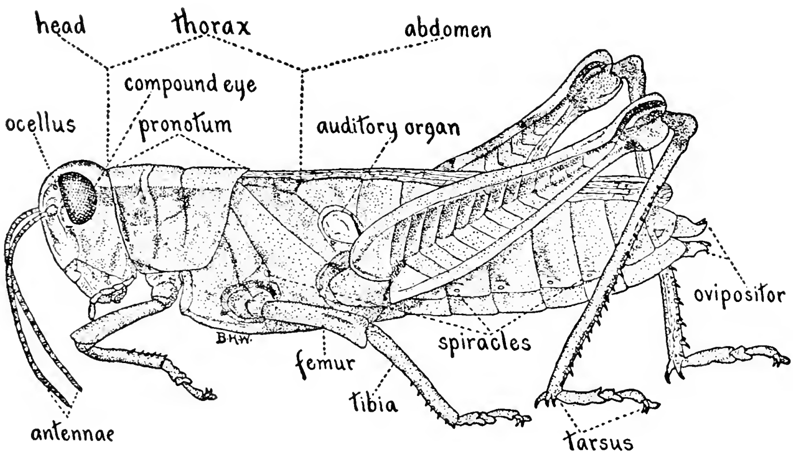


Fig. 191.—Grasshopper (*Melanoplus vittatus*) with wings removed. Female. (From Walden: Orthoptera of Connecticut, State Geological and Natural History Survey of Connecticut, Bulletin 16.)

Ingestion and Digestion.—The foods of grasshoppers consist of vegetation which is chewed by the pair of *chitinized mandibles* (man′ di bel) (L. *mandibulum,* jaw) which move from side to side rather than up and down. The principal parts of the digestive system include (in sequence) (1) a *mouth,* with a pair of *salivary glands* to secrete digestive juices, and the various *mouth parts* (Fig. 192), (2) a tubular *esophagus,* (3) an enlarged *crop* for storage, (4) a *gizzard* (proventriculus) for grinding, (5) a *stomach* with eight double, glandular, cone-shaped *gastric caeca* (se′ ka) (L. *caecus,* blind) for the secretion of digestive juices, (6) a *large intestine* with its delicate *Malpighian tubes* (after Malpighi, an Italian scientist), and (7) a *small intestine* which expands into a *rectum* (rek′ tum) (L. *rectus,* straight) opening through the *anus* (a′ nus) (L. *anus,* anus). Other types of insects have different kinds of mouth parts. Some have a sucking (siphoning) mouth part (Fig. 201), while others have a piercing-sucking type (Fig. 202).

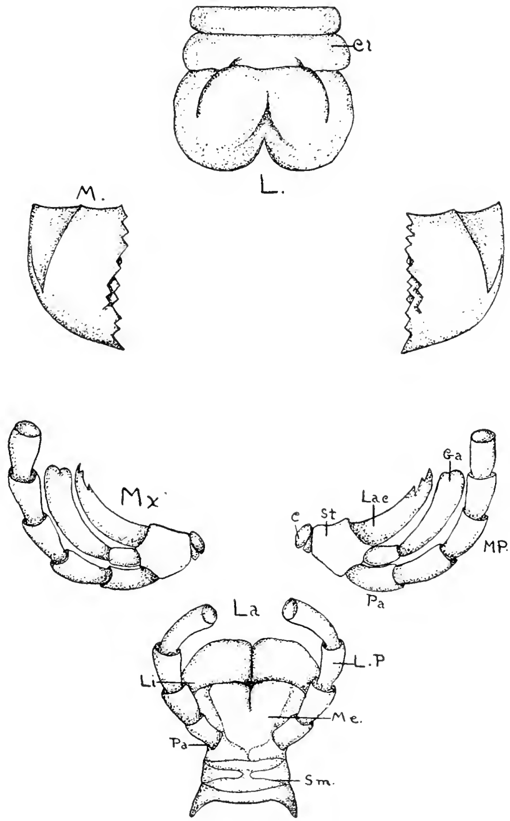


Fig. 192.—Chewing mouth parts of the grasshopper (*Rhomaelia microptera*). *L,* Labrum (upper lip); *M,* mandible (jaw); *Mx,* maxilla; *La,* labium; *Cl,* clypeus; *C,* cardo; *St,* stipes; *Lac,* lacinia; *Ga,* galea; *Mp,* maxillary palp; *Pa,* palpifer; *Me,* mentum; *Sm,* submentum; *Li,* ligula; *LP,* labial palp. (From White: General Biology, The C. V. Mosby Co.)

Circulation.—A single, tubular *heart* in the dorsal side of the abdomen is divided by *valves* into a series of *chambers,* each with a pair of *ostia* (os′ ti a) (L. *ostium,* door) for the entrance of blood from the surrounding *pericardial sinus* (Gr. *peri,* around; *kardia,* heart) (si′ nus) (L. *sinus,* cavity). *Valves* close the ostia when the heart contracts. A tubular *aorta* (Gr. *aorta,* the great artery) extends anteriorly from the heart and opens into the body cavity known as a *hemocoel* in the region of the head. The hemocoel contains the internal organs and circulates the *colorless blood.* This so-called "open system" of circulation causes the blood to flow in vessels only part of the time; most of the time it flows in *tissue spaces* or *sinuses* in the body and appendages. The blood

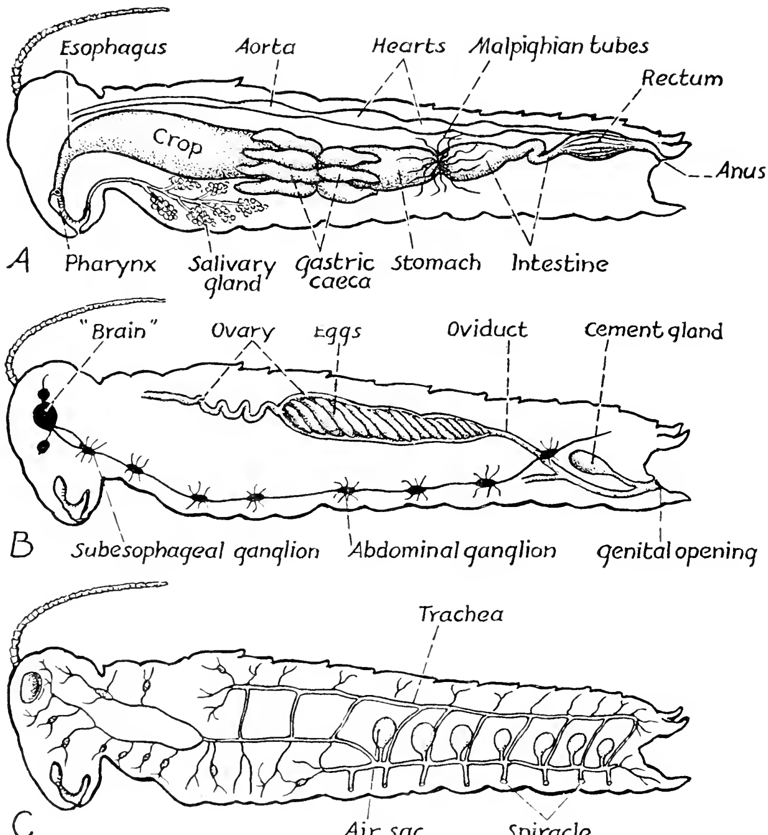


Fig. 193.—Internal anatomy of the grasshopper. *A*, Digestive and circulatory systems; *B*, reproductive and nervous systems; *C*, respiratory system.

flows from the heart through the aorta into the hemocoel from which the various systems receive nourishment. Eventually the blood returns to the pericardial sinus. The liquid *plasma* of the blood contains colorless *white blood corpuscles* or *leucocytes* (lu′ ko site) (Gr. *leukos,* white; *kytos,* hollow or "cell").

Respiration.—The thorax is divided into three segments (anterior, *prothorax;* middle, *mesothorax;* posterior, *metathorax*). Ten pairs of external openings or *spiracles* (spi′ ra kel) (L. *spiraculum,* air-hole) open into the *tracheal (respiratory) system* on either side of the mesothorax and metathorax. The spiracles permit the entrance of oxygen and the exit of carbon dioxide. The tubular *tracheae* ramify to all parts of the body and may have enlargements called *air sacs.* The blood does not play an important role in respiration (Fig. 194).

Excretion and Egestion.—The coiled *Malpighian tubules* in the hemocoel collect wastes and empty them into the large intestine. Solid materials are eliminated through the anus.

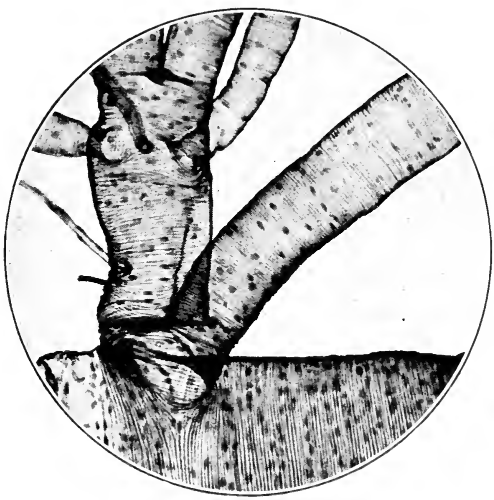


Fig. 194.—Photomicrograph of a portion of grasshopper trachea with its branching tubules, both large and small. The tracheal rings and nuclei are quite distinct. (Copyright by General Biological Supply House, Inc., Chicago.)

Coordination and Sensory Equipment.—A dorsal brain (three pairs of ganglia) is connected by a pair of *circumesophageal connectives* with a *subesophageal ganglion.* The *ventral nerve cord* continues posteriorly, with a pair of large *ganglia* in each thoracic segment and five pairs of *ganglia* in the abdomen. A *sympathetic nervous system* supplies the spiracles, muscles of the digestive system, etc.

The *compound eyes* are covered with a cuticular *cornea* (L. *corneus,* horny) divided into numerous hexagonal *facets* (L. *facies,* face). Each facet is the external surface of a unit called an *ommatidium* (om a -tid′- i um) (Gr. *ommation,* little eye; *idion,* diminutive). Each ommatidium is composed of a long visual rod, and the various ommatidia are separated from each other by a layer of dark pigment cells. Such an arrangement gives *mosaic vision* in which each ommatidium receives a portion of the image.

Each simple eye or *ocellus* consists of a group of cells, the *retinulae* (L. *rete,* net); a central optic rod, the *rhabdom* (Gr. *rhabdos,* rod); and a transparent, cuticular "lens." The ocelli probably function as light-perception organs.

The pair of jointed, threadlike *antennae* (an -ten′ i) (Gr. *ana,* up; *teino,* stretch) bear sensory *bristles* probably for olfactory (ol -fak′ to ri) (L. *olere,* to smell; *facere,* to make) purposes. Organs of *taste* (gustatory) are located on the mouth parts. Hairlike organs of *touch* (tactile) are present on various body parts but particularly on the antennae. The pair of sound-receiving *auditory organs* located on the sides of the first abdominal segment consists of a membranous *tympanum* (tim′ pa num) (Gr. *tympanon,* drum) which covers an *auditory sac.*

Reproduction.—The *sexes are in separate grasshoppers (diecious).* The female possesses a conspicuous *ovipositor* (o vi -poz′ i tor) (L. *ovum,* egg; *ponere,* to place) at the tip of the abdomen for depositing eggs. In the female, one pair of *ovaries* produce *eggs* which are discharged into a pair of *oviducts.* The latter unite to form a vagina connected with the *genital pore* between the parts of the ovipositor. A *seminal receptacle* (spermatheca) connected with the vagina receives sperm from the male during copulation and releases them to fertilize eggs. A secretion of the *cement gland* may stick eggs together as they are deposited.

In the male, one pair of *testes* discharge *sperm* into a pair of *vasa deferentia* (sperm ducts) which unite to form the *ejaculatory duct* that opens at the posterior end of the abdomen. *Accessory glands* secrete a fluid into the ejaculatory duct to aid in the transfer of sperm to the female. Eggs are fertilized by sperm when they are deposited. A young grasshopper which hatches from an egg is called a *nymph* (nimf) (Gr. *nymphe,* immature stage) and resembles an adult without wings. As the grasshopper grows, it must shed its chitinous exoskeleton at certain intervals by the process of *ecdysis* (moulting). Adult wings are eventually formed from wing buds.

HONEYBEE (Figs. 195 to 200)

The honeybee, *Apis mellifica* (L. *apis,* bee) (me -lif′ i ka) (L. *mellificus,* honey), belongs to the order *Hymenoptera* (hi men -op′ ter a) (Gr. *hymen,* membrane; *ptera,* wings) because of its two pairs of membranous wings. Honeybees are more highly specialized in life habits and structure than grasshoppers. Colonies of honeybees consist of (1) *workers* which are females with undeveloped reproductive organs, (2) male *drones,* and (3) female *queens.* A typical colony may contain 50,000 workers, a few hundred drones, and one adult queen. The

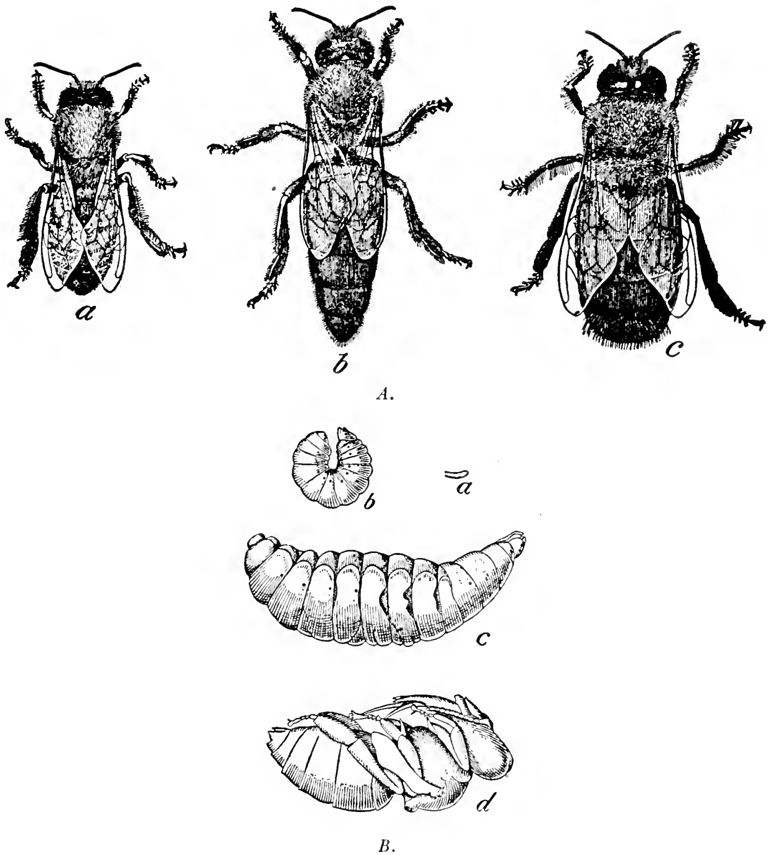


Fig. 195.—Castes and development of the honeybee (*Apis mellifica*) of the order *Hymenoptera.* In *A,* the adults, *a* is a worker; *b,* a queen; *c,* a drone. In *B,* the immature stages, *a* is an egg; *b,* young larva; *c,* old larva; *d,* pupa. (From Phillips: Bees, U. S. Department of Agriculture, courtesy of Bureau of Entomology and Plant Quarantine.)

drones and queen are for reproductive purposes. Hymenoptera are characterized by having their mouth parts modified for both sucking and biting (chewing). The body is divided into *head, thorax,* and abdomen.

The thorax is divided into an anterior *prothorax,* a middle *mesothorax,* and a posterior *metathorax.* The abdomen is also segmented.

Integument and Skeleton.—A tough, flexible *cuticle* covers the body and serves as an *exoskeleton* to which muscles and organs are attached internally. *Chitin* is a protein substance ($C_{30}H_{50}O_{19}N_4$). The cavity is a *hemocoel,* which carries blood.

Motion and Locomotion.—Locomotion is accomplished by two pairs of *wings* and three pairs of jointed *legs* (Fig. 197). The *wings* consist of a double layer of transparent *membranes* between which is a network of *veins* to strengthen them. When at rest, the wings are folded. During flight they are extended, and the fore- and hindwings are locked together by a row of tiny *hooks* on the front margin of the hindwings. Wings may vibrate over 400 times per second during flight.

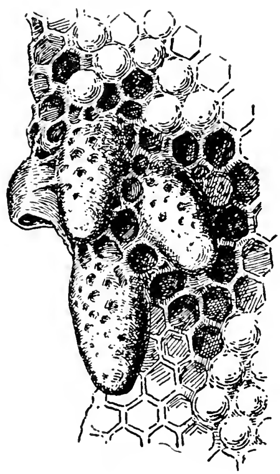


Fig. 196.—Comb cells made by the honeybee. Note the baglike cells on the surface in which the queen develops. (From Phillips: Bees, U. S. Department of Agriculture, courtesy of Bureau of Entomology and Plant Quarantine.)

The three pairs of legs are much more specialized than those of the grasshopper (Fig. 197). Because of their complexity and differences, each leg will be considered separately.

Prothoracic Leg (First): (1) An oblong *coxa* next to the thorax, (2) a short *trochanter,* (3) a long *femur* with branched, *pollen-carrying hairs,* (4) a *tibia* with *pollen-carrying hairs* and a flat, movable, spinelike *velum* (ve′ lum) (L. *velum,* covering), (5) a segmented *tarsus,* the proximal segment of which may be called the *metatarsus* and which

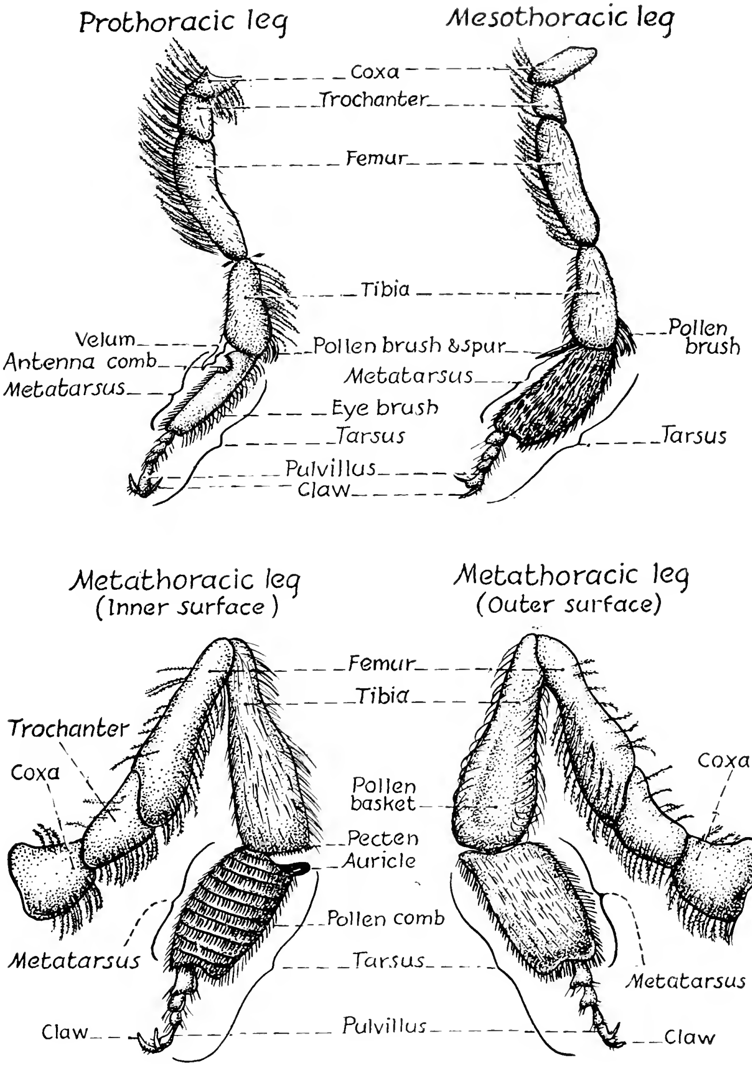


Fig. 197.—Legs of a worker honeybee (*Apis mellifica*) of the order *Hymenoptera*.

bears a semicircular *antenna comb.* The latter together with the velum constitute the *antenna cleaner,* through which the antenna may be drawn to remove materials. On the opposite margin of the tibia from the velum is the *pollen brush,* composed of curved bristles. The last (distal) tarsal segment has *claws* with a padlike *pulvillus* between them. The latter secretes a sticky substance for adhering.

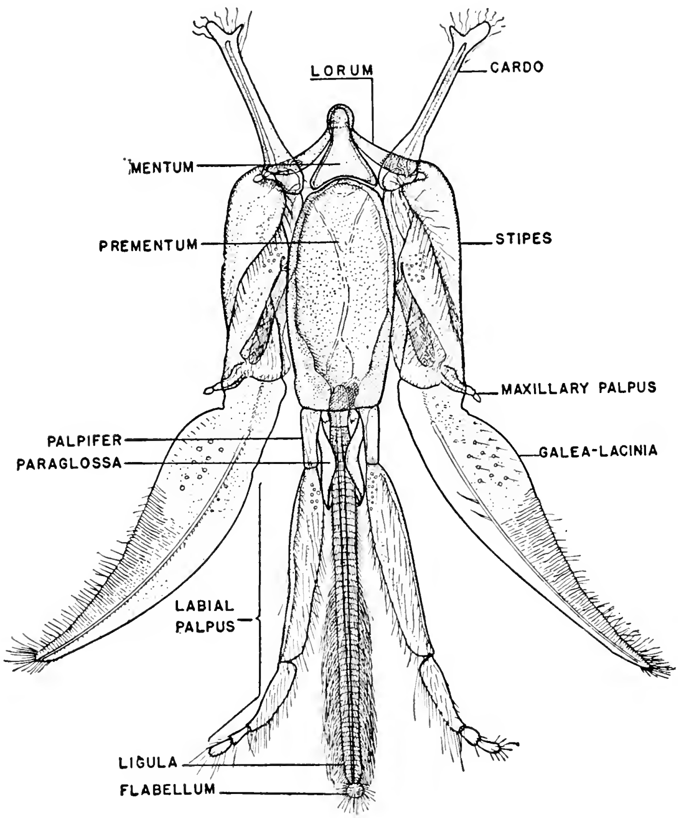


Fig. 198.—Honeybee worker mouth parts, much enlarged. The galea-lacinia is also known as the maxilla. The ligula is known as the glossa or tongue. The flabellum is also known as the bouton or labellum. The labial palps and the ligula together constitute the lower lip or labium. (From Parker and Clarke: Introduction to Animal Biology, The C. V. Mosby Co.)

Mesothoracic Leg (Second): The segments are the same as on the first pair of legs. A long *pollen spur* on the distal end of the tibia is used to remove pollen from the pollen basket and to clean wings. For other structures, see Fig. 197.

Metathoracic Leg (Third): The *pollen basket* is located on the outer, concave surface of the tibia, and long hairs curve over its depression somewhat to cover it. A pincerlike structure between the tibia and metatarsus

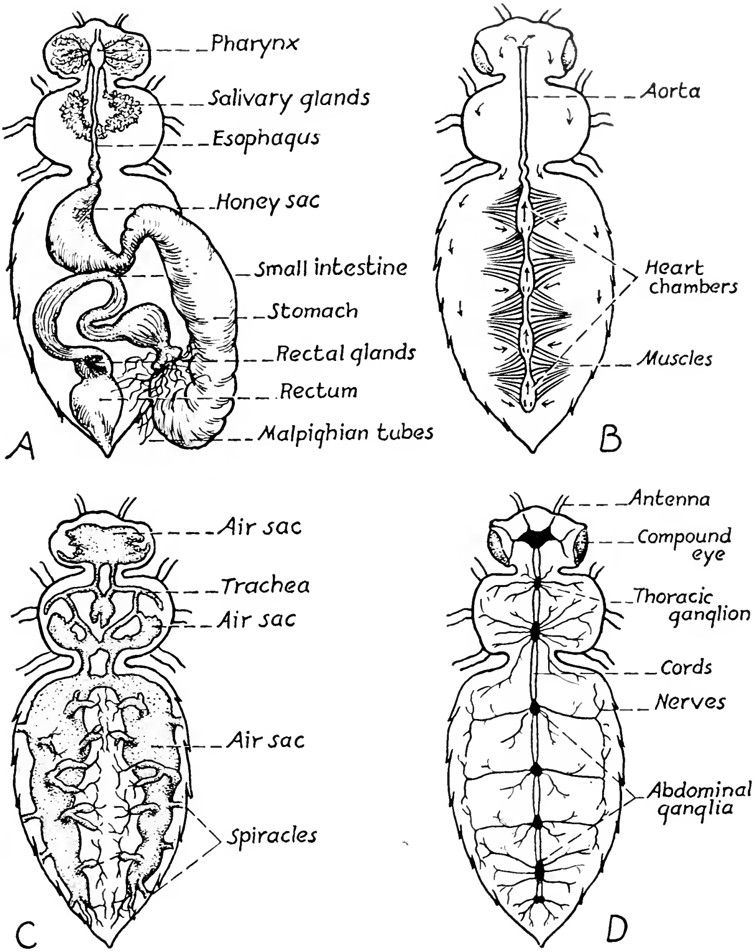


Fig. 199.—Internal anatomy of a worker honeybee. *A,* Digestive system; *B,* circulatory system; *C,* respiratory system; *D,* nervous system.

is composed of rows of spines, the *pecten* (pek′ ten) (L. *pecten,* comb), and a liplike *auricle* (or′ i kel) (L. *auricula,* small ear). The pecten and auricle convey pollen to and pack pollen into the pollen basket. On the inner surface of the metatarsus are numerous, transverse rows of stiff, bristlelike *pollen combs* to comb out pollen from various body parts and to handle wax. The *wax* is secreted in flat scales by a glandular area on the underside of the abdomen. The wax is masticated by the mandibles before it is used in building the "cells" of the honeycomb.

Ingestion and Digestion.—The mouth parts may be studied from Fig. 198. One pair of smooth *mandibles* lies beneath the upper lip (labrum) and are used in masticating wax. The *sucking mouth parts* assist the

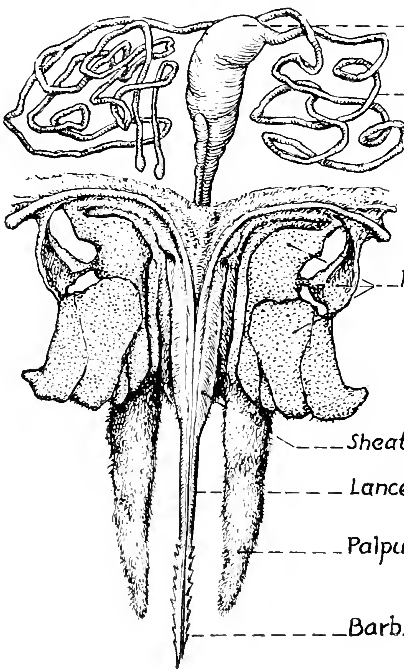


Fig. 200.—Sting apparatus of the worker honeybee (*Apis mellifica*). Drawn with the parts somewhat separated.

suction of the *pharynx* to convey fluids into the digestive tract. A long *esophagus* extends from the pharynx to the large *honey sac (crop)* in the abdomen. A large cylindrical *stomach* leads into the *intestine* and the latter joins the *rectum* which ends in the *anus*.

The *nectar* of flowers is sucked up and stored in the honey sac where it chemically changes into *honey*. The latter is regurgitated into the "cells" of the honeycomb. Here the honey is still further dehydrated by currents of air which are caused by the rapid vibrations of the wings.

A minute drop of poison from the sting helps to preserve the honey. An average colony of bees in an average season may collect about forty pounds of honey.

Pollen is rich in protein which honey lacks, so pollen (*"bee bread"*) is essential in the diet of bees. The pollen collected in the pollen basket is placed in certain "cells" of the honeycomb. *"Bee-glue"* or *propolis* (Gr. *pro,* for; *polis,* city) is a resin collected from plants and is used in filling cracks, cementing loose parts, etc. Various types of cells constitute the honeycomb (Fig. 196).

Circulation.—A long, delicate, tubular, muscular *heart* in the mid-dorsal region of the body discharges the *colorless blood* toward the head region. Blood enters the heart through five pairs of *ostia,* each pair leading into a *chamber* of the heart. *Valves* prevent the backflow into the body during contraction. Blood discharges at the head region and passes through the *hemocoel* (body-circulatory cavity). From the latter it reenters the heart chambers. The blood *plasma* contains *white blood corpuscles.*

Respiration.—Respiration occurs through pairs of very small *spiracles* located along the sides of the thorax and abdomen and leading into a branched system of *tracheae* to convey air to all body parts. Certain trachea may possess enlarged *air sacs.*

Excretion.—Numerous, hollow, glandular, threadlike *Malpighian tubules* excrete wastes into the intestine much in the same manner as in grasshoppers.

Coordination and Sensory Equipment.—A large *"brain (supraesophageal ganglion)* in the dorsal part of the head supplies nerves to the eyes, antennae, etc. The brain is connected by a *ring* (nerves) to the *subesophageal ganglion* which supplies nerves to the mouth parts. A *ventral nerve chain* extends posteriorly from the subesophageal ganglion along the midventral side of the body. The chain is a *double nerve strand* and connects with two *thoracic ganglia* and five *abdominal ganglia* (Fig. 199, *D*).

The hairlike end organs of the sense of *touch (tactile)* are present on various body parts but are particularly numerous on the tip of the antennae. The pair of jointed, hairy *antennae* have numerous, sound-sensitive pits which are thought to be for *auditory* purposes. Other pits on the antennae are thought to be for *olfactory* purposes. Bees seem to use the scent-detecting mechanism for discovering food and for mating between drone and queen. A worker bee is able to transmit to the antennae of other workers the "scent information" necessary to direct the latter to newly discovered food supplies. The so-called "tongue" bears numerous, bristlelike *taste setae.* Bees can be trained to estimate time intervals, because some have been trained to come to a source of food at regular intervals. The pair of large *compound eyes,* on the top and side of the head, are constructed and function similar to those of the grasshopper previously described. The color sense of bees is better adjusted to the shorter wave lengths of the light spectrum; that is, toward the blue end of the spectrum. Three small *simple eyes (ocelli)* are present on the dorsal side of the head.

The *sting* is a modified ovipositor which is used for protection (Fig. 200). Males do not have a sting. It is composed of two straight, grooved *lancets* (darts) with *barbs* at the tips and with muscles for their operation. A large, storage *poison sac* is connected with the base of the sting. Two *acid glands* and an *alkaline gland* mix their secretions to form the poisonous material which is injected when the bee stings. After stinging, the worker leaves the sting, poison sac, glands, etc., and the bee dies.

Reproduction.—The worker honeybee contains only vestigial (vestij′ i al) (L. *vestigium,* trace) reproductive organs since it is an undeveloped female. The reproductive organs of the *male (drone)* include one pair of bean-shaped *testes* which produce *sperm* that are carried away by one pair of slender *vasa deferentia.* The latter expand to form the *seminal vesicles* for sperm storage. The two seminal vesicles combine to form one *ejaculatory duct* which leads to the *copulatory mechanism.* One pair of large *accessory glands* secrete and empty nourishment into the ejaculatory duct.

In the *female (queen),* one pair of large *ovaries* produces *eggs* which are carried by one pair of *oviducts.* The latter unite to form one tubular *vagina* leading to the exterior. A *spermatheca* attached to the vagina stores sperm received from the male during copulation. The queen is fertilized once in a lifetime, during a nuptial flight during swarming, and the sperms remain alive for years in the spermatheca. As an egg passes down the ovary toward the oviduct, its receives a *shell* with a small opening, the *micropyle,* through which a sperm may enter. A queen may lay an unfertilized egg to develop a drone or fertilized eggs to develop females, either queens or workers. A queen may lay 1,500 eggs per day for weeks at a time, and she may live several years. The eggs are small, oblong, and bluish-white. Fertilized eggs are placed in worker or queen cells of the honeycomb; unfertilized eggs, in the drone cells. A wormlike, whitish *larva* ("grub") hatches from the egg in four days. All larvae are fed on a specially prepared and predigested mixture of honey and pollen ("royal jelly") for a few days, after which the drone and worker larvae are fed on plain honey and pollen, while the queen larva is kept on the "royal jelly" diet. This continuity of special food causes the larva to develop into a queen instead of a worker. After six days a larva develops into a *pupa* (pu′ pa) (L. *pupa,* puppet) enclosed in a silken *cocoon.* A worker pupa changes into an adult bee in about thirteen days, a queen in about seven days and a drone in about fifteen days (Figs. 195 and 196).

QUESTIONS AND TOPICS

1. List the distinguishing characteristics of the class *Insecta.*
2. List the characteristics which grasshoppers and honeybees have in common.
3. List the ways in which grasshoppers and honeybees differ, being specific in the various details.
4. Why are insects placed in the phylum *Arthropoda?*
5. Explain and give the significance of (1) ecdysis, (2) chitin, (3) hemocoel, (4) spiracle, (5) ostia, (6) Malpighian tubules, (7) ommatidia, and (8) sinus.
6. Explain each of the following for the grasshopper and honeybee: (1) integument, (2) motion and locomotion, (3) ingestion and digestion, (4) circulation, (5) respiration, (6) excretion and egestion, (7) coordination and sensory equipment, and (8) reproduction. In what specific ways have these shown an improvement over the same i n lower types of animals?
7. Contrast the types of mouth parts in the grasshopper and honeybee.
8. Contrast each of the three legs of the grasshopper with the same leg of the honeybee, including the major differences. Which insect would you consider the more specialized in this connection?
9. Describe the structure and function of a compound eye.
10. Contrast the types of metamorphosis in the grasshopper and honeybee.
11. Discuss the economic importance of grasshoppers and honeybees.
12. Discuss the colonial life and the various castes of honeybees.
13. Discuss the structure and functions of the so-called "open type" of circulatory system.
14. List the advantages and disadvantages of a separate tracheal system of respiration.
15. Why is it scientifically incorrect to say honeybees gather honey?
16. List the conclusions you can draw from your studies of the grasshopper and honeybee.

SELECTED REFERENCES

Brues: Insects and Human Welfare, Harvard University Press.
Blatchley: Orthoptera of North-eastern America, Indianapolis, Nature Publishing Co.

Duncan and Pickwell: The World of Insects, McGraw-Hill Book Co., Inc.
Fabre: Book of Insects, Tudor Publishing Co.
Hegner: Invertebrate Zoology, The Macmillan Co.
Hermes: Medical Entomology, The Macmillan Co.
Matheson: Medical Entomology, Comstock Publishing Co., Inc.
Matheson: Entomology for Introductory Courses, Comstock Publishing Co., Inc.
Michener: Comparative External Morphology, Phylogeny and Classification of Bees, Bull. 82, American Museum of Natural History.
Phillips: Beekeeping, The Macmillan Co.
Ross: Textbook of Entomology, John Wiley & Sons, Inc.
Snodgrass: Anatomy and Physiology of the Honeybee, McGraw-Hill Book Co., Inc.
von Frisch: Bees, Cornell University Press.
Wellhouse: How Insects Live, The Macmillan Co.
Wheeler: Social Life Among the Insects, Harcourt, Brace and Co., Inc.
Wheeler: Foibles of Insects and Men, Alfred A. Knopf, Inc.

Chapter 22

IDENTIFICATION AND CLASSIFICATION (TAXONOMY) OF INSECTS

Since insects are of such great economic importance, so numerous and ubiquitous in their distribution, it seems desirable that one should know something about them. Even from such a limited study as suggested here, many benefits from esthetic and practical standpoints may be derived. Possibly, a maximum of benefits, with a minimum of time expended, may be secured by a study of the various representative orders. The information is given in table form in order to expedite the work and to make pertinent contrasts and comparisons more easily. The more important features used in the differentiation of the orders include wings, mouth parts, and type of metamorphosis.

Depending on the species, the sex, or even the particular stage of the life cycle, insects may have two pairs of wings or one pair of wings or may be wingless. Typically, most insects have two pairs of membranous wings which vary as to shape, construction, venation, foldings, etc. When at rest each species has a particular method of holding the wings which is taken into consideration in classification. Typically, only one order (*Diptera*) has one pair of wings, the second pair being represented by a pair of threadlike knobbed *halters* (hal -te′ rez) (Gr. *halter*, weight or balancer). The forewings of such forms as the *Orthoptera*, *Coleoptera*, and *Dermaptera* are thickened for protection. The forewings of the *Hemiptera* are thickened only at the base. The particular type of wing venation is also taken into consideration in classification. In some species, one sex has wings, while the opposite sex is wingless. For example, the male canker worm moth has two pairs of wings, while the female is wingless.

Insect *mouth parts* may be for (1) *chewing* (mandibulate) (Fig. 192) or (2) *sucking*. Mouth parts consists typically of a flaplike upper lip (*labrum*), a pair of upper jaws (*mandibles*), a pair of lower jaws (*maxillae*), and a lower lip (*labium*). In addition, there may be, in certain species, one or two organs, the membranous *epipharynx* and the tongue-like *hypopharynx* (Fig. 202). The jaws operate horizontally rather than up and down. The maxillae and labium are each supplied with a pair of sensitive feelers (*palpi*). Mouth parts vary greatly with the different species. Among certain insects with sucking mouth parts, there are variations. For example, in the mosquito (order *Diptera*) (Fig. 202) the mouth parts are modified for piercing in addition to sucking, while the butterfly (order *Hymenoptera*) (Fig. 201) sucks nectar from flowers with a tubular proboscis.

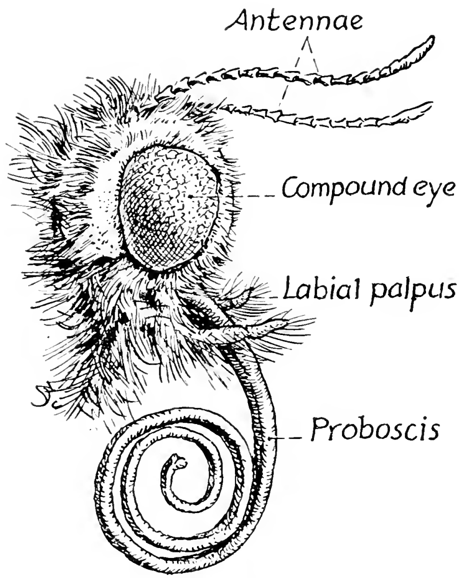


Fig. 201.—Butterfly head and mouth parts, the latter in the form of a siphoning (sucking) proboscis which may be uncoiled when used.

Many insects in their life cycles undergo remarkable changes in form and size. These changes in structure and form undergone by an organism from the embryo to the adult stage constitute *metamorphosis* (met a-mor′ fo sis) (Gr. *meta,* change; *morphe,* form). The *life cycle* (Gr. *kyklos,* circle) includes the various stages through which an individual passes from one adult stage to the next adult stage. There are different systems of classifying the types of insect metamorphosis but the following is typical:

1. **No Metamorphosis.**—In this type the *egg* develops into a form which is practically the same as the adult, although smaller. Briefly, the stages are *egg, adult, egg* (Figs. 203, 204, 273, 274).

2. **Incomplete Metamorphosis.**—In this type the *egg* develops into a *nymph,* specifically known as a *naiad* (ni′ ad) (Gr. *naias,* water nymph), which does not resemble the adult in general characteristics or in manner of life. In each of the orders that possess incomplete metamorphosis the *naiads develop in water, with aquatic respiratory organs,* while the *adults are terrestrial (aerial) with air-breathing organs.* The changes in body form are more marked than in gradual metamorphosis but are much less marked than in complete metamorphosis. Briefly, the stages are *egg,* aquatic *naiad,* terrestrial, aerial *adult, egg* (Fig. 205).

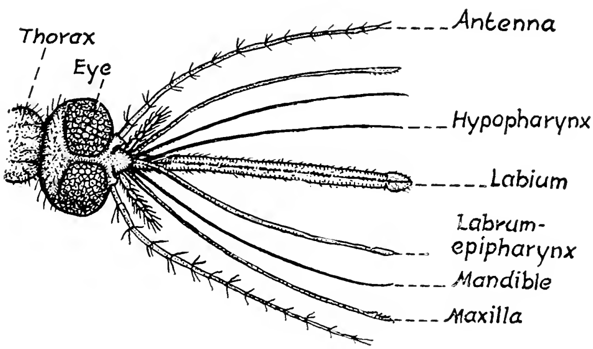


Fig. 202.—Piercing-sucking mouth parts of a mosquito (*Culex sp.*) of the order *Diptera.* Mouth parts are separated and enlarged.

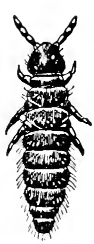


Fig. 203.

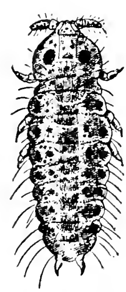


Fig. 204.

Fig. 203.—Snow flea (*Achorutes nivicola*) of the order *Collembola,* much enlarged. (From Kellogg: American Insects, Henry Holt & Co.)

Fig. 204.—Springtail (*Achoreutes armatum*) of the order *Collembola,* much enlarged. A spring beneath the tip of the abdomen for springing purposes is not shown. (From Popenoe: Mushroom Pests and How to Control Them, U. S. Department of Agriculture, courtesy of Bureau of Entomology and Plant Quarantine.)

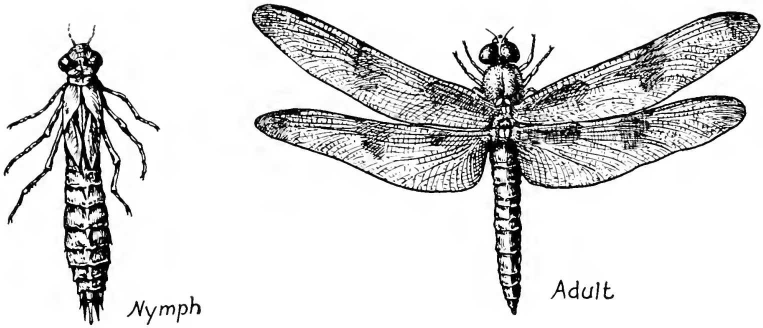


Fig. 205.—Dragonfly of the order *Odonata* (class *Insecta*) illustrating incomplete metamorphosis (development). The nymph (naiad) has large eyes and developing wings. The naiad stage is aquatic in incomplete metamorphosis. The adult shows large compound eyes and the characteristic jointlike nodus at the front margin of the wing.

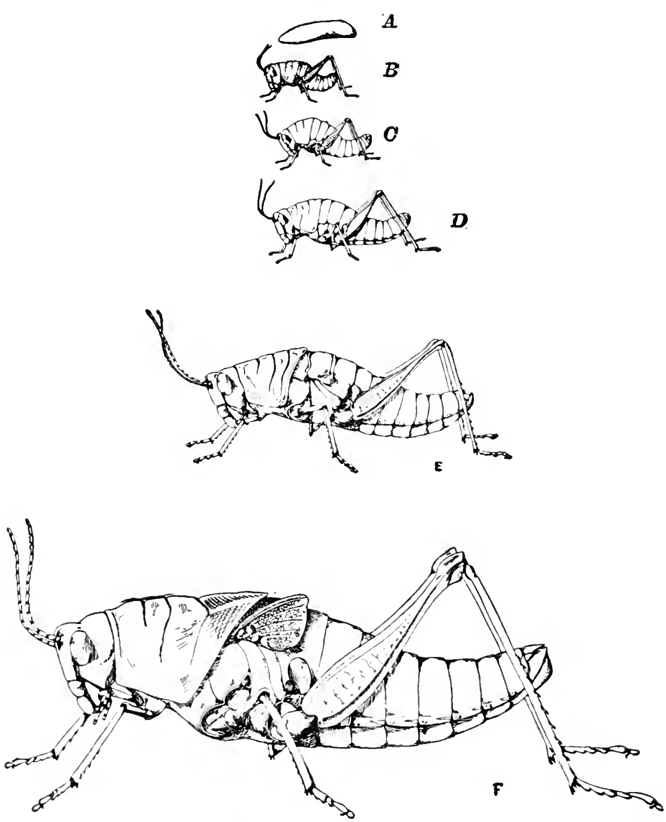


Fig. 206.—Gradual metamorphosis of a grasshopper (*Rhomaelia sp.*). *A*, Egg; *B*, nymph just hatched; *C-F*, successive stages in development. (Original drawing by Eleanor Sloan Hough, from White: General Biology, The C. V. Mosby Co.)

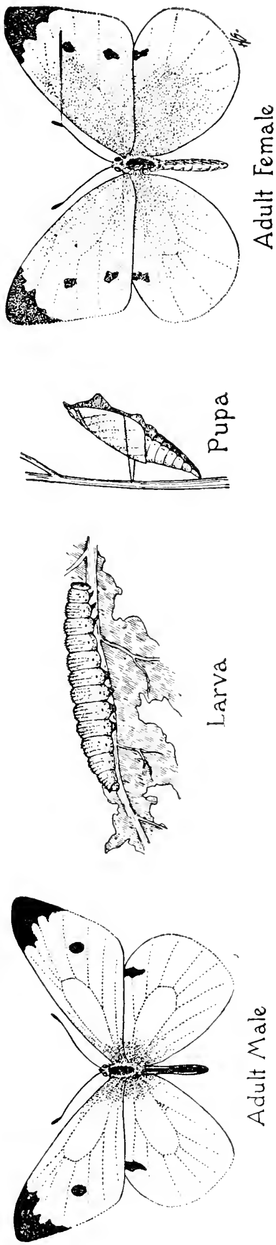


Fig. 207.—Complete metamorphosis of a cabbage butterfly (*Pieris rapae*). Note differences in the adult male and female. The egg develops through successive stages (instars) of the larva into the pupa (chrysalis). The adult emerges from the pupa. (Copyright by General Biological Supply House, Inc., Chicago.)

ORDERS OF THE CLASS INSECTA (INSECTS) OF THE PHYLUM ARTHROPODA

NAME OF ORDER	EXAMPLES	WINGS	MOUTH PARTS	METAMORPHOSIS	MISCELLANEOUS
1. *Thysanura* (thi sa -nu' ra) (Gr. *thysanos*, tassel; *oura*, tail)	Bristletails, silverfish (Fig. 273)	Wingless	Chewing	None	Abdominal segments not reduced in number; caudal cerci usually many jointed and filiform; long, jointed antennae; common in moist, dark places
2. *Collembola* (kol -emb' o la) (Gr. *colla*, glue; *embolon*, bar)	Springtails, "snowfleas" (Figs. 203, 204, and 274)	Wingless	Chewing	None	Abdominal segments reduced to 6 in number; first abdominal segment has a vestigial glue-forming structure; fourth abdominal segment bears a ventral springing organ; third abdominal segment bears a spring catch; common under decaying leaves, bark
3. *Ephemerida* (ef e -mer' i-da) (Gr. *ephemeros*, daily) or *Ephemeroptera*	Mayflies (Fig. 275)	Usually 2 pairs; delicate, triangular, membranous with finely netted veins; forewings large, hindwings small (or absent); wings upright when at rest	Vestigial in adult; chewing in naiad	Incomplete	Adults take no food and live for a day; 2 or 3 long "tails" at tip of abdomen; serve as fish food
4. *Odonata* (o do -na' ta) (Gr. *odous*, tooth or tusk)	Dragonflies, damselflies (Figs. 205 and 277)	2 pairs; long, similar, membranous, finely netted veins; hindwings as large or larger than forewings; each wing has a jointlike nodus near middle of front margin	Chewing	Incomplete	Large head; large compound eyes; long, slender, tusklike body; very small antennae; adults feed on insects

5. *Plecoptera* (ple -kop'-ter a) (Gr. *plekos*, folded; *ptera*, wings)	Stoneflies (Fig. 278)	2 pairs; membranous, netted; hindwings usually longer than forewings and folded when at rest	Chewing	Incomplete	Larval naiads live in water under stones; 1 pair of tail-like, jointed cerci at tip of abdomen; serve as fish food
6. *Mallophaga* (ma -lof' a ga) (Gr. *mallos*, wool; *phagein*, to eat)	Biting bird lice such as chicken lice, cattle lice, etc. (Fig. 280)	Wingless	Chewing	Gradual (or none)	Flat, broad, louselike body with broad head; sharp claws; parasites on skin, hair, and feathers of birds and mammals
7. *Anoplura* (an o -ploo'-ra) (Gr. *anoplos*, unarmed; *oura*, tail)	True lice such as human head lice, human body lice, dog lice, rat lice, etc. (Fig. 287)	Wingless	Piercing-sucking	Gradual (or none)	Flat, broad body with free horizontal head; fleshy, unjointed proboscis; parasitic and feed on blood of mammals; eggs called "nits"
8. *Orthoptera* (or -thop' ter-a) (Gr. *orthos*, straight; *ptera*, wings)	Grasshoppers, katydids, cockroaches, crickets, walking sticks, praying mantis, etc. (Figs. 191, 192, 283, 284, and 329)	2 pairs (usually); forewings leathery (wing covers) but with veins; hindwings delicate, folded like a fan when at rest; some species have vestigial wings, others are wingless	Chewing	Gradual	Most species live on vegetation; mantes feed on other insects
9. *Isoptera* (i -sop' ter a) (Gr. *isos*, equal; *ptera*, wings)	Termites (Fig. 279)	2 pairs; long, narrow, similar, and lie flat on back when at rest and shed after swarming; certain castes with small wing buds; workers and soldiers wingless	Chewing	Gradual	Social insects living in a colony with several castes (usually 4); abdomen broadly attached to thorax; workers and soldiers usually dirty white in color; build earthen tubes for passageways

Orders of the Class Insecta (Insects) of the Phylum Arthropoda—Cont'd

Name of Order	Examples	Wings	Mouth Parts	Metamorphosis	Miscellaneous
10. *Corrodentia* (kor o -den'-shi a) (L. *corrodens*, gnawing)	Booklice (found in old papers), barklice (feed on plants) (Figs. 285 and 286)	Booklice wingless; barklice have 2 pairs of membranous with few cross-veins; forewings larger than hindwings; wings held rooflike when at rest	Chewing	Gradual	Booklice are minute, soft-bodied, and grayish-yellow in color; barklice have oval bodies with free head; feed on vegetation
11. *Thysanoptera* (thi sa -nop'-ter a) (Gr. *thysanos*, fringe; *ptera*, wings)	Thrips, such as, grass thrips, onion thrips, fruit thrips, wheat thrips, etc. (Fig. 281)	2 pairs (usually); long, similar, narrow, membranous, not folded; few veins; fringed with long hairs; some species wingless	Piercing-sucking	Gradual	Minute, slender body; feet have bladderlike organs for clinging
12. *Hemiptera* (he -mip'-ter a) (Gr. *hemi*, half; *ptera*, wings)	True bugs, such as stink bugs, squash bugs, assassin bugs, chinch bugs, water striders, back swimmers, bedbugs, etc. (Figs. 288 and 290)	2 pairs or wingless; forewings thickened at base, with thinner extremities which overlap on back; hindwings membranous and folded	Piercing-sucking (beak)	Gradual	Beak arises from front of head; many species on vegetation
13. *Homoptera* (ho -mop'-ter a) (Gr. *homos*, same; *ptera*, wings)	Cicadas, leaf-hoppers, tree-hoppers, plant aphids, scale-bugs, spittle-insects, etc. (Figs. 289 and 291 to 293)	2 pairs or wingless; membranous wings are usually of same thickness throughout; usually held sloping at side of body when at rest; many wingless forms	Piercing-sucking (beak)	Gradual	Beak arises from hind part of lower side of head; many species on vegetation

14. *Dermaptera* (dur -map′- ter a) (Gr. *derma*, skin; *ptera*, wings)	Earwigs (Fig. 282)	Some forms wingless, others with 2 pairs; forewings short, leathery, veinless, and meet in middle of back; hindwings large, membranous, folded crosswise and lengthwise	Chewing	Gradual (or none)	One pair of pincerlike cerci at tip of abdomen; narrow, flat body; not common in U. S.
15. *Neuroptera* (nu -rop′- ter a) (Gr. *neuron*, nerve; *ptera*, wings)	Dobson flies, ant lions, aphis lions (lacewing flies) (Fig. 294)	2 pairs; thin, similar, membranous, with many nervelike veins; held rooflike when at rest	Chewing	Complete	Many species are predacious; larvae may suck blood from their prey
16. *Coleoptera* (ko le -op′- ter a) (Gr. *coleos*, sheath; *ptera*, wings)	Beetles, such as tiger beetles, ladybird beetles, June beetles, click beetles, ground beetles, weevils, curculios, etc. (Figs. 295 to 297)	2 pairs; forewings greatly thickened (wing covers, or elytra); hindwings membranous, folded; elytra usually meet in line down the back; in some species hindwings absent; few species are wingless	Chewing	Complete	Chitinous covering is usually heavy; vary in size from minute to very large; very common in many places
17. *Mecoptera* (me -kop′- ter a) (Gr. *mecos*, long; *ptera*, wings)	Scorpion flies (Fig. 298)	2 pairs or wingless; wings long, similar, narrow, membranous with many cross veins and dark spotted; some species vestigial or wingless	Chewing (at tip of deflexed beak)	Complete	Male abdomen resembles that of a scorpion but not a sting; long, slender antennae; head prolonged into a long beak with mouth parts at tip
18. *Trichoptera* (tri -kop′ ter a) (Gr. *trichos*, hair; *ptera*, wings)	Caddice flies (Fig. 299)	2 pairs; membranous with long, silky hairs; hindwings usually shorter and broader; wings folded rooflike when at rest	Vestigial (in adults)	Complete	Soft, mothlike insects; live near water; frequently attracted by light; larva resembling an aquatic caterpillar usually dwells in caddice cases formed of stones

ORDERS OF THE CLASS INSECTA (INSECTS) OF THE PHYLUM ARTHROPODA—CONT'D

NAME OF ORDER	EXAMPLES	WINGS	MOUTH PARTS	METAMORPHOSIS	MISCELLANEOUS
19. *Lepidoptera* (lep i -dop′- ter a) (Gr. *lepido*, scale; *ptera*, wings)	Moths, butterflies, skippers (Figs. 201 and 300 to 302)	2 pairs; membranous but covered with overlapping scales	Sucking (in adult)	Complete	Scales cover body; many have beautiful colors; moth antennae usually featherlike; butterfly and skipper antennae usually with a club at tip; larvae known as catepillars; moths usually nocturnal; butterflies and skippers diurnal
20. *Diptera* (dip′ ter a) (Gr. *dis*, two; *ptera*, wings)	True flies, mosquitoes, crane flies, robber flies, bot flies, blow flies, gnats, midges, etc. (Figs. 202 and 303)	1 pair; transparent and attached to mesothorax; second pair represented by a pair of threadlike, knobbed halters (for balancing); few species wingless	Sucking (or piercing-sucking	Complete	Head of adult attached to thorax by a slender neck; compound eyes usually large
21. *Siphonaptera* (si fon -ap′- ter a) (Gr. *siphon*, tube; *a*, without; *ptera*, wings)	Fleas, such as human fleas, rat fleas, dog and cat fleas (Fig. 304)	Wingless	Piercing-sucking	Complete	Small, oval body compressed laterally (sidewise); legs for leaping; head broadly attached to thorax; integument with bristles; larvae slender, legless and with distinct head with chewing mouth parts
22. *Hymenoptera* (hi men -op′- ter a) (Gr. *hymen*, membrane; *ptera*, wings)	Honeybees, bumblebees, true ants, wasps (solitary and social); sawflies; ichneumon wasps; gallflies etc. (Figs. 195 to 200, 305, and 306)	2 pairs; similar, membranous, thin, with few veins; forewings larger than hindwings; wings held together by rows of hooks during flight; some species wingless	Chewing (or chewing and sucking)	Complete	Many species live in complex colonies; abdomen of females usually has a sting, pincer, or saw

3. **Gradual Metamorphosis.**—In this type of development the changes are gradual (Fig. 206) and the *egg* develops into a young *nymph which resembles the adult in general body form and lives in the same general kind of environment as the adult.* There is a gradual growth of the body, wings, and appendages. Briefly, the stages are *egg, nymph* (air breathing), *adult* (air breathing), *egg.*

4. **Complete Metamorphosis.**—In this type the *egg* hatches into a "wormlike" *larva* (lar′ va) (L. *larva,* mask) which changes into a quiescent *pupa* (pu′ pa) (L. *pupa,* baby), and the latter in turn develops into an *adult* (Fig. 207). The larva bears almost no resemblance in form to the adult. Commonly, the larvae of the *Coleoptera* are known as *grubs,* those of the *Diptera* as *maggots,* and those of the *Lepidoptera* as *caterpillars.* Even though the pupa stage is usually nonmotile, internally great changes occur. For example, the larva enters to become the pupa, but an entirely different adult emerges from the pupa. Great structural and physiologic changes take place in this so-called "inactive" pupa. At the same time, the pupa always "knows" the specific kind of adult it is to produce. The markings on adults of certain species are so accurately formed that they are used in classification and identification. In complete metamorphosis, the stages are *egg, larva, pupa, adult, egg.*

QUESTIONS AND TOPICS

1. What are the principal points used in the classification of insects into orders?
2. Learn the exact spelling, correct pronunciation, derivation and examples of each order of insects.
3. From a study of the table and typical, representative insects, describe each of the following: mouth parts, types of metamorphosis, number and structure of wings.
4. Describe each of the types of metamorphosis in detail with examples of each.
5. How can we differentiate between the biting bird lice (*Mallophaga*) and the true lice (*Anoplura*)?
6. How can we differentiate between fleas (*Siphonaptera*) and lice?
7. How can we differentiate between termites (*Isoptera*) and true ants (*Hymenoptera*)?
8. Do all insects have the same type of mouth part in the embryo and adult stages? Give specific examples to prove this point.
9. How many pairs of legs do all adult insects possess? How many antennae?
10. Why are insects classified as arthropods?
11. What is the method of respiration of adult insects?
12. How can we differentiate in general between moths and butterflies?
13. List all the benefits which you have derived from such a study of insects.

SELECTED REFERENCES

Brues and Melander: Classification of Insects, Harvard University Press.
Chu: How to Know the Immature Insects, William C. Brown Co.
Comstock: An Introduction to Entomology, Comstock Publishing Co., Inc.

Essig: College Entomology, The Macmillan Co.
Frost: General Entomology, McGraw-Hill Book Co., Inc.
Jacques: How to Know the Insects, William C. Brown Co.
Lutz: Fieldbook of Insects, G. P. Putnam's Sons.
Metcalf and Metcalf: A Key to the Principal Orders and Families of Insects, North Carolina State College.
Needham et al.: Culture Methods for Invertebrate Animals, Comstock Publishing Co., Inc.
Peterson: A Manual of Entomological Equipment and Methods (Part I), Edwards Bros., Inc.
Peterson: A Manual of Entomological Equipment and Methods (Part II), John S. Swift Co., Inc.
Swain: The Insect Guide, Doubleday & Co.

Chapter 23

THE FROG—AN AMPHIBIOUS VERTEBRATE ANIMAL

The common leopard frog is known as *Rana pipiens* (ra′ na pip′ i enz) (L. *rana,* frog; *pipiens,* piping). Its body is smooth and covered with *mucus* secreted by glands in the skin. Like many lower vertebrates, the frog has the ability to change color due to changes in the *black and yellow pigment cells* in the skin. Because of its coloration the frog is afforded a certain degree of protection from enemies. This is known as *protective coloration.* When in water, the frog need keep only the tip of the nose above the surface because of the location of the *nostrils* (external nares). Two large *eyes* are located on the top of the head. The *tympanum* (eardrum) is external and just posterior to each eye. The body may be divided into head and trunk. The latter bears two pairs of *appendages,* but there are *no claws* upon the toes.

Integument and Skeleton.—The *skin* does not fit tightly and is composed of (1) a rather thin outer layer called the *epidermis* and (2) a thicker, inner layer the *dermis (corium)* (Fig. 208). The *epidermis* consists of several layers of cells: (1) the outer ones, composing the *stratum corneum* (stra′ tum kor′ ne um) (L. *stratum,* layer; *corneus,* horny), are flat, compact, and horny (shed several times during the active season when the frog moults) and (2) the inner ones, next to the dermis, composing the *Malpighian layer,* are columnar and by mitosis give origin to the outer layer. The *dermis* consists of connective tissues in which are glands, blood vessels, pigments (Fig. 209), nerves, muscle fibers, and lymph spaces. The *dermis* is made of (1) an outer layer, called the *stratum spongiosum,* consisting of loose connective tissue and containing (a) *pigment bodies* which give the frog its spotted pattern (pigments may also be present in the epidermis), (b) small spherical *mucous glands* which pour a slimy secretion out upon the surface of the skin, (c) larger spherical *poison glands* which secrete a whitish, acrid fluid for protection. and (d) numerous *sensory* and *tactile papillae* (just below the epidermis) for sensory purposes and (2) the *stratum compactum* consisting of dense connective tissues in which the fibers run somewhat parallel to the surface of the skin and among which are blood vessels. The smooth, scaleless, hairless skin functions as an organ of respiration as well as gives pro-

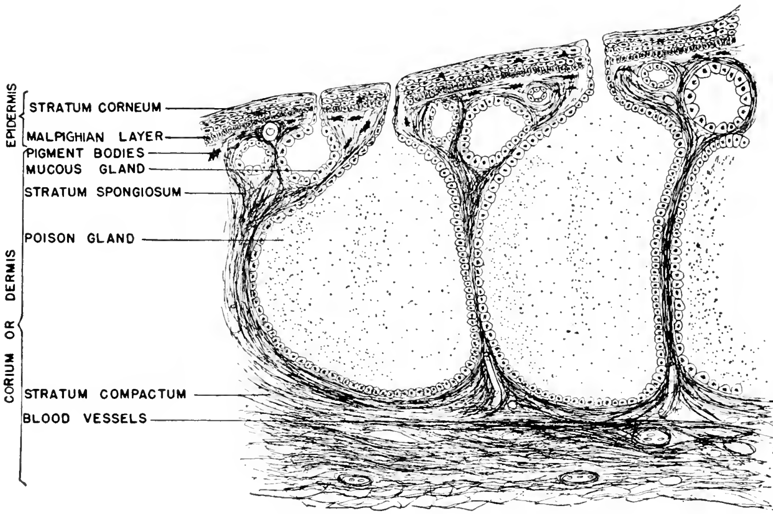


Fig. 208.—Skin of frog (cross section and somewhat diagrammatic). Compare this with human skin (Fig. 228). (From Parker and Clarke: An Introduction to Animal Biology, The C. V. Mosby Co.)

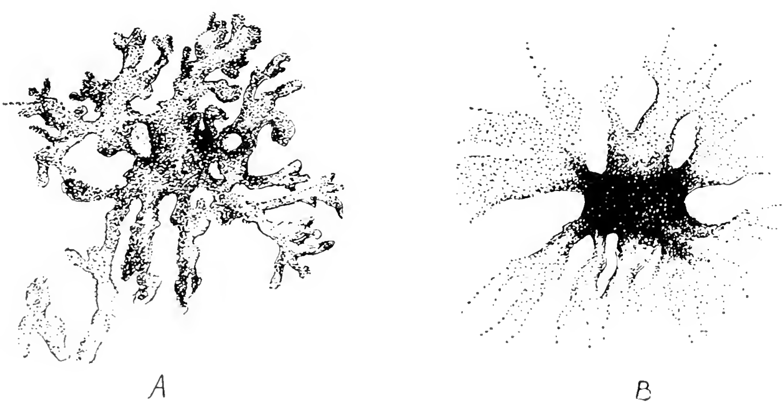


Fig. 209.—Pigment melanophore from the frog (*Rana temporia*). *A*, Pigment distributed in response to light; *B*, pigment contracted. (From Potter: Textbook of Zoology, The C. V. Mosby Co.; redrawn and modified from Noble: Amphibia of North America, McGraw-Hill Book Co., Inc.)

tection and serves for sensory purposes. The pigment bodies are responsible for some protective coloration.

The bony endoskeleton (Fig. 210) consists of (1) an *axial skeleton (skull and vertebral column)* and (2) *appendicular skeleton (pectoral girdle* with its *forelimbs* and *pelvic girdle* with its *hindlimbs).* The frog has no ribs. Most of the bones of the *skull,* except those of the *upper*

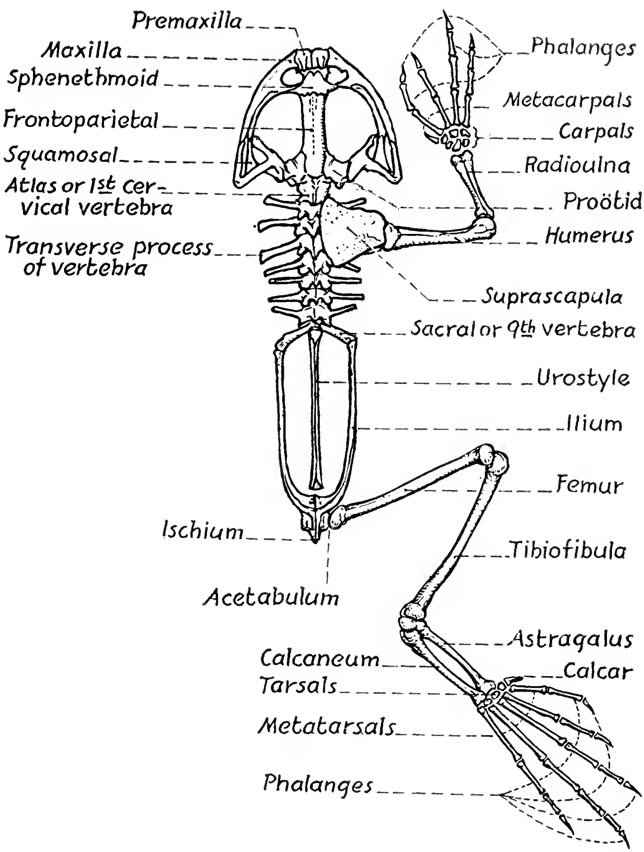


Fig. 210.—Skeleton of frog (dorsal view, appendages of left side not shown). The acetabulum is not a bone but the joint at the proximal end of the femur.

and *lower jaws* and the *hyoid bone* to which the tongue is attached, form the *brain case (cranium).* The brain and spinal cord connect through a large opening *(foramen magnum)* at the base of the cranium. The cranium articulates with the *first vertebra (atlas)* by means of a pair of rounded prominences, the *occipital condyles.* The pair of *proötid* bones, one on either side of the posterior part of the cranium (Fig. 210), forms the rounded *auditory capsule* that encloses the *inner ear.* Forming the dorsal roof of the cranial cavity are two bones, the *frontoparietals,* each formed by the fusion of a frontal and a parietal bone in the young frog. At the anterior end of the brain case is the tubular *sphenethmoid* which is divided by a transverse septum into two chambers. The anterior chamber is divided longitudinally by a median septum and contains the posterior part of the olfactory sacs (nasal capsules). The posterior chamber is part of the cranial cavity and contains the olfactory lobes of the brain. A pair of triangular *nasal bones* help to form the dorsal wall of the olfactory sacs. A pair of *vomer bones* helps to form the ventral wall of the olfactory sacs and also helps to form the roof of the mouth. The vomer bones bear *vomerine teeth* on the ventral surface. The *upper jaw (maxilla)* consists of a pair of premaxillae, a pair of *maxillae,* and a pair of *quadratojugal bones* (Fig. 210). The first two bear teeth. The *lower jaw (mandible)* is the only part of the two jaws that moves. The jaws are attached to the cranium by a *suspensory apparatus,* of which the *squamosal* (Fig. 210) is a part. The *hyoid apparatus* consists of a large flat, diamond-shaped plate of cartilage in the floor of the mouth cavity. Rods of cartilage and bone extend anteriorly and posteriorly from its central plate. The posterior rods extend backward to the glottis which they help to support.

The *vertebral column* consists of nine *vertebrae* (Fig. 210) and a bladelike posterior *urostyle.* A typical *vertebra* consists of (1) an oval, basal *centrum* (for articulation), (2) *neural arch* through which the spinal cord passes, (3) a single *dorsal spine* (neural spine) attached to the neural arch and (4) a pair of *transverse processes* (except on the atlas) which extend laterally for the attachment of muscles. The articulating processes at each end of the neural arch are called *zygapophyses.* Ligaments hold the vertebrae together but allow a certain amount of movement.

The *pectoral girdle* to which the forelimbs are attached is not attached to the vertebral column by bones but by means of muscles. Compare this attachment with that in man (Fig. 229). The *sternum ("breast bone)* is located on the ventral median line and is composed of a number of bones and cartilages. The ventral part of the pectoral girdle consists of an anterior *clavicle* and a *posterior coracoid.* Other smaller bones go to make up this part of the girdle. The dorsal part of the girdle is composed of the bony *scapula* dorsal to which is the cartilaginous *supra-*

scapula (Fig. 210). The *glenoid fossa* is the cavity with which the *humerus* of the forelimb articulates. The *radioulna* of the forearm is a fusion of radius and ulna bones. Contrast this with man (Fig. 229). The *wrist* consists of six bones *(carpals)*. The *hand* is supported by five *metacarpals*. Distal to the hand are the bones of the digits or fingers *(phalanges)*.

The *pelvic girdle* (Fig. 210) to which the hindlimbs are attached is attached to the transverse processes of the ninth or sacral vertebra. The girdle is composed of a pair of long *ilium bones* (plural ilia), a pair of *ischium bones,* and a pair of *pubis bones*. These three pairs of bones articulate so that a cavity is formed (*acetabulum*) with which the *femur* of the hindlimb joins. The anterior part of the acetabulum is formed by the ilium and the posterior by the ischium, while the ventral part is formed by the cartilaginous pubis. The *tibiofibula* is a fusion of the tibia and fibula bones. Contrast this with man (Fig. 229). The *tarsals* (ankle bones) are arranged in two rows, the proximal one consisting of long bones, the *astragalus* and *calcaneum*. Contrast this with man. The distal row contains a series of smaller bones. Distal to this are the five elongated *metatarsals* (foot). Of the five *toes (digits* or *phalanges),* the first and second contain two *phalanges* each, the third and fifth, three *phalanges* each, and the fourth, four. On the tibial side of the first toe there is an additional or accessory digit called the *calcar* or *prehallux*. There are *no claws*.

Motion and Locomotion.—Well-developed and complex *muscles* are present in the body, appendages, and head (Fig. 211). Minor muscles move the lower jaw, aid in breathing, pump blood, secure foods, eliminate wastes, and produce sounds by means of the vocal apparatus. The muscles attached to the skeleton are called *skeletal muscles*. Each has an *origin* which is the more fixed end and an *insertion* which is the more movable end. Pulsating *lymph "hearts"* (two near the third vertebra and two near the end of the vertebral column) force lymph into the transverse iliac and internal jugular veins.

Ingestion and Digestion.—Living insects, worms, and similar organisms are captured by a rather sticky, extensile *tongue* attached at its front end (Figs. 212 and 213). The tongue is thrown forcibly forward by the rapid filling of a *lymph space* beneath it. The large *mouth cavity* bears cone-shaped *teeth* on the upper jaw. The two vomer bones in the roof of the mouth bear *vomerine teeth*. A constricted, horizontal slit separates the mouth cavity from the *esophagus*. The *stomach* is crescent shaped and is composed of a large, anterior *cardiac part* and a constricted, posterior *pyloric part* which connects with the coiled *small intestine.* The latter consists of an anterior *duodenum* and a much coiled

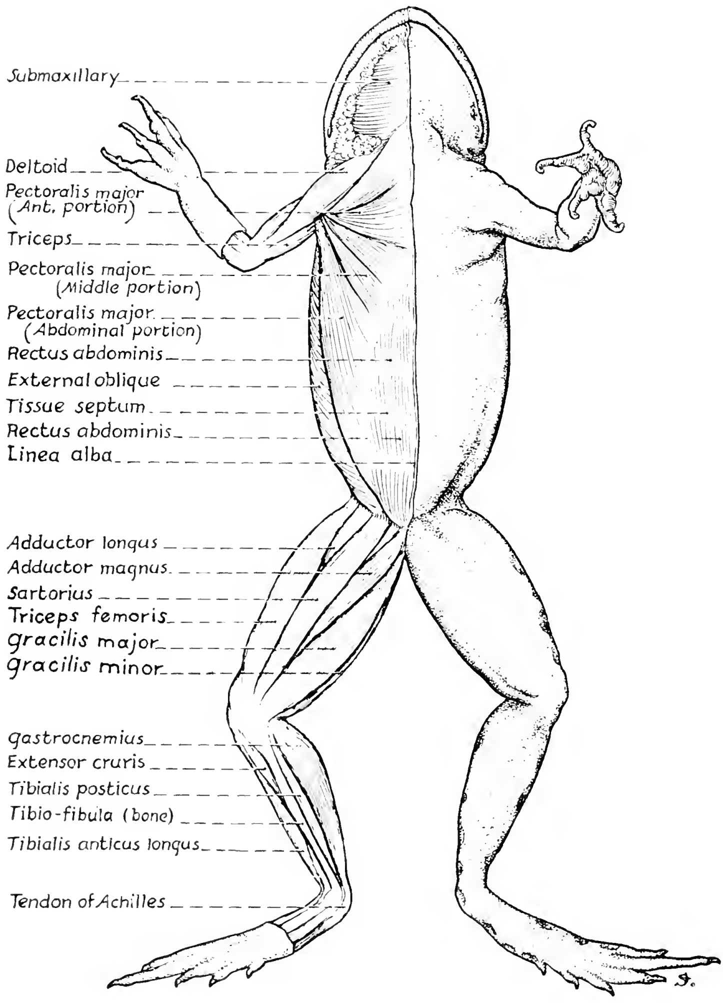


Fig. 211.—Muscles of the frog (ventral view). Only the superficial muscles are shown. The linea alba is a white line separating the right and left rectus abdominis muscles. The triceps femoris has three heads one of which is the vastus internus. The gracilis major is sometimes called the rectus internus major. The gracilis minor is sometimes called the rectus internus minor. The muscles are drawn somewhat diagrammatically, and some variations may be observed in different frogs.

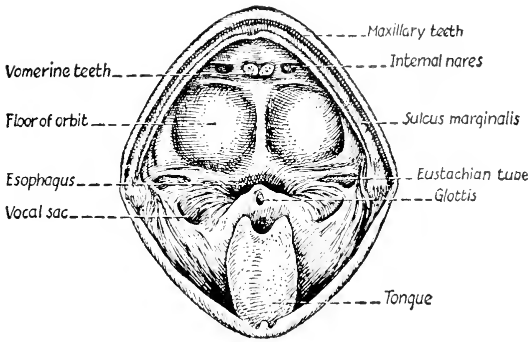


Fig. 212.—Mouth of bullfrog opened to show internal structures. (From Potter: Textbook of Zoology, The C. V. Mosby Co.)

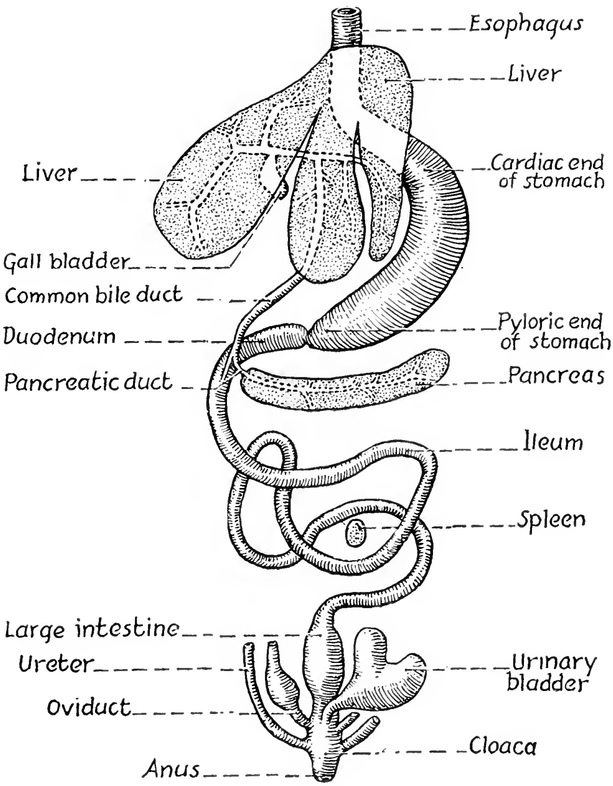


Fig. 213.—Frog digestive system with associated organs.

ileum which widens into the *large intestine.* The latter connects with the saclike *cloaca.* The latter also receives tubes from the kidneys and reproductive system. The cloaca empties to the exterior through the *anus* which is located between the two hindlegs.

The *pancreas* is a much-branched, tubular organ which lies between the stomach and the duodenum. It passes its alkaline *digestive juices* into the common *bile duct* (Fig. 213). The large, reddish, trilobed *liver* secretes an alkaline *bile* which is carried to the *gall bladder* from which it enters the duodenum together with the pancreatic juices through the common bile duct.

The Physiology of Digestion: Digestion breaks down complex, insoluble foods, such as proteins, fats, and carbohydrates, into simple, soluble compounds capable of being absorbed by the cells and assimilated into living protoplasm. The foods in the cells are constantly being used and must be replaced in order to supply energy and chemical substances to carry on the various life activities.

Uses of Foods in the Body of the Frog

FOOD TYPES	USES	HOW USED	WHERE STORED	BY-PRODUCTS
Carbohydrates	Serve as fuel and furnish energy; may help build certain tissues	Unite with oxygen through the process of oxidation	As glycogen (animal starch) in the liver, muscles, ovaries, nerves, and skeleton	Carbon water dioxide,
Fats	Same as above	Same as above	As adipose tissue in the body, in the liver, in the fat bodies	Carbon dioxide, water
Proteins	Build living tissues; repair destroyed tissues	Broken down for the release of energy and their constituent elements	Probably all parts of the body	Urea, carbon dioxide, water

The various foods are acted upon by specific *enzymes* (ferments) which hasten the above conversion processes without being used up themselves. Because enzymes are so important, it may be well to list briefly some of their more important characteristics. *Enzymes are manufactured by living protoplasm* from foods and other materials which are brought to it. *Enzymes are specific* for certain substances. For example, the enzyme pepsin acts only on proteins and not on carbohydrates or fats. *Enzymes have an optimum temperature* at which they can act most efficiently. A temperature of 100° C. usually destroys the action of enzymes, while at 0° C. they are usually rendered very inactive. They also usually *react* *best in a definite acid or alkaline environment.* If too much acid or too much alkali is present, a specific enzyme may not function, while it might do so if the acid-alkaline reaction were changed to its specific optimum. They are *powerful chemical substances* because a small amount may produce a large reaction. Their *chemical composition is unknown,* but they are probably of protein makeup. They cause chemical changes in other substances without, or with very slight, destruction of their own substance. Many, if not all, *enzymes may be stored in an inactive state* in cells until they are needed later.

Changes Which Foods Undergo: In the *mouth* there are no mastication, no digestion, and no enzymes (no glands). In the *esophagus* certain glands produce an alkaline *mucous secretion* which becomes active when mixed with the acid gastric juice secreted by the glands in the walls of the stomach. The *cardiac end of the stomach* has long, tubular, branched, deeply set *glands* for the secretion of *mucus.* The *pyloric end of the stomach* has short, tubular, shallow *glands* for secreting *gastric juice* which contains the enzyme *pepsin* and about 0.4 per cent *hydrochloric acid* (HCl). In other words, the reaction is as follows:

Pepsin + *HCl* + *Proteins* → *Soluble Peptones*

After the partially digested foods pass the pyloric valve from the stomach into the duodenum, they are mixed with the alkaline *pancreatic juice* which is secreted by the pancreas and brought to the *duodenum* by the *pancreatic ducts.* The alkalinity of the pancreatic juice is due to sodium carbonate (Na_2CO_3). The three specific enzymes of the pancreatic juice are (1) *amylopsin,* (2) *trypsin,* and (3) *steapsin.* Their specific actions are shown:

Amylopsin + *Starch* → *Maltose* (double sugar)
Trypsin + *Proteins* or *Peptones* (in an alkaline reaction) → *Amino Acids*
Steapsin + *Fats* → *Glycerin* + *Fatty Acids*

The *hepatic cells* of the tubular glands of the *liver* secrete a greenish *bile* which is stored in the *gall bladder* until needed. The bile is mixed with the pancreatic juice in the *common bile duct* before they enter the duodenum. Certain *bile enzymes* convert fats, when in an alkaline environment, into a soapy emulsion capable of osmosing through the intestinal walls into the blood and lymph systems. The liver also stores *glycogen* or animal starch $(C_6H_{10}O_5)_n$. This is changed by certain liver enzymes into usable sugar when needed. Wastes are also eliminated with the bile from the liver.

The production and roles of *intestinal juices* and their *enzymes* in the frog are not well known, but they are probably similar to those in higher animals. Possibly starches may be converted into sugars in the intestine. The various types of foods acted upon by specific enzymes in their proper environments are eventually *absorbed* by the cells of the intestine and passed into the lymph and blood vessels by which they are transported to body tissues to be utilized.

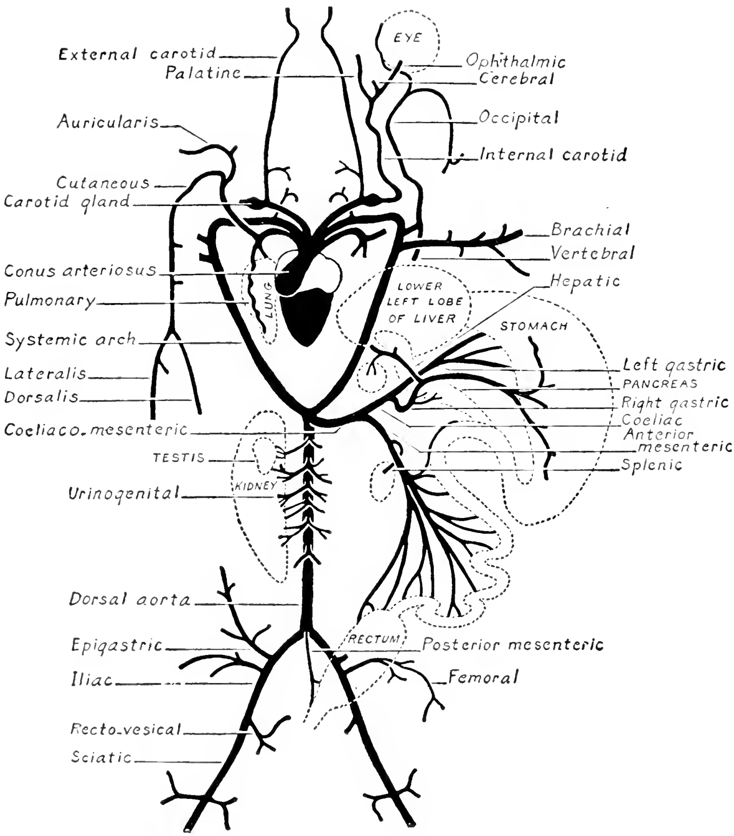


Fig. 214.—Arterial system of the bullfrog (ventral view). (Drawn by Ruth M. Sanders, from Potter: Textbook of Zoology, The C. V. Mosby Co.)

Circulation.—The *heart*, located within the thin, saclike *pericardium*, is three chambered, being made of two thin-walled *auricles* (right and left) and one muscular, cone-shaped *ventricle* (Figs. 214, 215, 364, and 365). A thick-walled, tubular *truncus arteriosus (conus arteriosus)* arises from the base of the ventricle. A thin-walled, triangular *sinus venosus,* located on the dorsal side of the heart, is connected with the right auricle. In the adult frog the blood is pumped from the ventricle into the truncus arteriosus which has branches as shown in the diagram of the arterial system on page 432. Study this diagram, noting the relationships of the various parts of the arterial system.

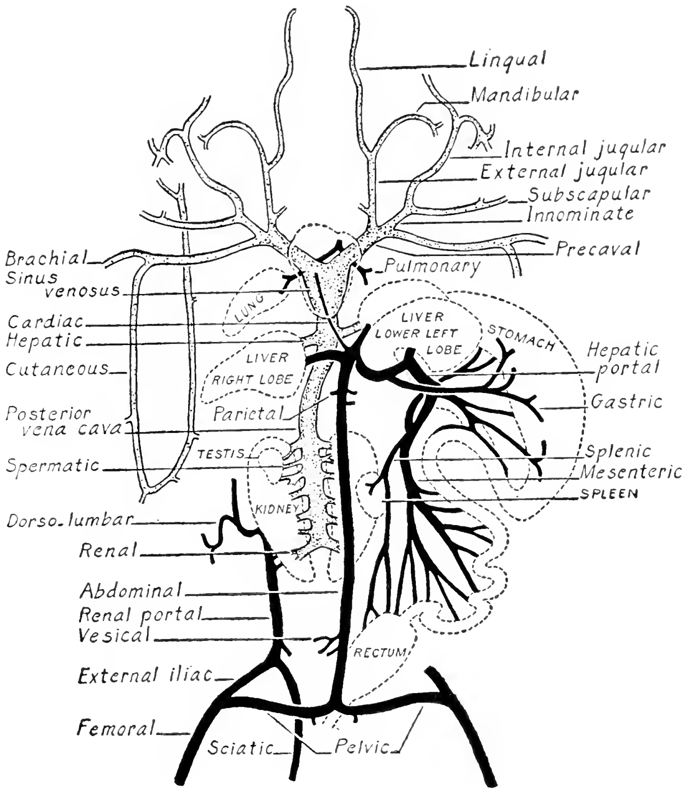


Fig. 215.—Venous system of the bullfrog (ventral view). (Drawn by Ruth M. Sanders, from Potter: Textbook of Zoology, The C. V. Mosby Co.)

After passing from the arteries into thin-walled *capillaries,* the blood is returned from the various tissues and organs of the body by a system of *veins* (Fig. 215). The *right* and *left pulmonary veins* return the oxygenated (aerated) blood from the right and left lungs to the *left auricle.* The blood from all other parts of the body is returned to the *sinus venosus* through three large *veins* known as (1) the *posterior vena cava* (post-

Arteries of the Circulatory System of the Frog

(Showing Branches and Distribution)* (Fig. 214)

VENTRICLE → TRUNCUS ARTERIOSUS →

- R. common carotid
  - R. external carotid (or R. lingual) (tongue, thyroid, hyoid, etc.)
  - R. internal carotid
    - R. palatine (roof of mouth)
    - R. cerebral (brain)
    - R. ophthalmic (right eye)
- R. pulmocutaneous
  - R. pulmonary (right lung)
  - R. cutaneous
    - R. auricularis (right lower jaw, etc.)
    - R. dorsalis (skin of right back)
    - R. lateralis (skin of right side)
- R. aortic arch or R. systemic arch
  - R. laryngeal (larynx)
  - R. occipitovertebral
    - R. occipital (jaws and nose)
    - R. vertebral (vertebral column)
  - R. esophageal (esophagus)
  - R. subclavian (shoulder) → R. brachial (arm)

(Note: The arteries of the left side of the body are similar to those on the right as described above and have the same names. This is also true for the branches of the common iliac, below.)

- Dorsal aorta (union of right and left aortic arches)
  - Coeliacomesenteric
    - Coeliac
      - Hepatic (liver)
      - Gastric (stomach)
      - Pancreatic (pancreas)
    - Anterior mesenteric
      - Intestinal (intestine)
      - Splenic (spleen)
      - Hemorrhoidal (cloaca)
  - Urogenital (4 to 6 pairs) (reproductive organs, kidneys, fat bodies, etc.)
  - Lumbar (1 to 4 pairs)
  - Posterior mesenteric (rectum and [uterus of female])
  - R. common iliac
    - R. hypogastric (urinary bladder)
    - R. femoral (anterior part of right thigh)
    - R. sciatic (right hind limb)

*R., right.

(Note: All the veins labeled *R.* have their corresponding veins on the left side, having the same names and emptying into the same places as those on the right. Both right and left auricles empty into the ventricle.)

Veins of the Circulatory System of the Frog
(Showing Branches and Origin)* (Fig. 215)

R. Lingual (tongue, floor of mouth)
R. mandibular (mandible)
R. thyroid (thyroid)
} R. external jugular

R. internal jugular (head, brain, eye, etc.)
R. subscapular (right shoulder)
} R. innominate

R. musculocutaneous (side of body and head)
R. brachial (right forearm)
} R. subclavian

} R. precaval or R. anterior vena cava } → Sinus venosus → Right auricle

R. pulmonary (right lung) ——————————→ Left auricle

(Note: Veins from the left side of the body are similar to those described above, having the same names and emptying into the same places as those on the right.)

Splenic (spleen)
Intestinal (intestine)
Pancreatic (pancreas)
Duodenal (duodenum)
Gastric (stomach)
} Hepatic portal → Abdominal; → Liver

R. femoral (thigh)
R. sciatic (hindleg)
R. dorsolumbar (body wall)
} → R. pelvic; → R. renal portal

Cardiac (heart)
Vesical (bladder)
R. pelvic
} → Abdominal → *Liver* → R. hepatic → { Postcaval or Posterior vena cava } → Sinus venosus → R. auricle

→ R. renal portal → *Right Kidney* → { Renal veins (4 to 6 pairs) }

R. spermatic or R. ovarian
Renal veins (4 to 6 pairs)
} → { Postcaval or Posterior vena cava } → Sinus venosus → R. auricle

*R., right.

caval) with its branches, (2) the *right anterior vena cava* (right precaval) and its branches and (3) the *left anterior vena cava* (left precaval) and its branches. The blood from the sinus venosus enters the right auricle. The right and left auricles send their blood into the one ventricle which forces its mixture of oxygenated blood (from the left auricle) and nonoxygenated blood (from the right auricle) into the truncus arteriosus through three pocket-shaped *semilunar valves.* The venous part of the frog circulatory system is shown in the diagram on page 433. Compare and contrast the diagram of the venous system with the diagram of the arterial system.

Frog blood (Fig. 12) is quite complex and consists of: (1) Oval, biconvex, nucleated *red blood corpuscles (erythrocytes)* which contain *hemoglobin.* The latter unites temporarily with oxygen in the lungs and skin to form *oxyhemoglobin,* which in turn gives up its oxygen to cells and tissues when or where it is needed. (2) Amoeboid *white blood corpuscles (leucocytes)* which are able to move independently and are of different sizes. They pass through the walls of blood vessels and tissues. They destroy bacteria and other organisms by ingesting them, thus serving to prevent infections. (3) The *spindle cells* are frequently spindle shaped and upon their disintegration assist in the clotting of blood. Blood corpuscles originate principally in the marrow of the bones but may also increase in numbers by division within the blood vessels after being formed. (4) The *plasma* or liquid part of the blood carries foods, wastes, proteins, mineral salts, etc. Blood coagulates, especially after injuries, to form a clot which includes fibrin, red and white corpuscles, tissue cells, etc.

Respiration.—In the earlier, tadpole stages, *external gills* are present for respiration, but these are later covered to form *internal gills* which communicate with the exterior through a small opening. The internal gills are eventually absorbed and typical *lungs* develop in the air-breathing adult frog. In the adult frog respiration takes place through the *skin* and *lungs,* probably more through the former than the latter. During hibernation the lungs are inactive, yet skin respiration continues, even though the rate may be reduced (Fig. 208). In lung respiration the air is admitted into the *mouth cavity* (Fig. 212) from the outside through the *external nares (nostrils)* and then through the slitlike *glottis* into the short, tubular *larynx;* from the latter the air passes into the *trachea* (windpipe) and finally into the thin-walled, saclike, paired *lungs.* The *lungs* are ovoid, distensible, and internally divided by *folds (septae)* into a number of compartments known as *alveoli* (al-ve′ o li) (L. *alveolus,* small cavity) to increase the surface exposed to the air. Thin-walled capillaries line the inner surfaces of the alveoli and permit the exchange of oxygen and carbon dioxide between the air in the lungs and the blood in the circulatory system. The amount of exchange of these gases depends upon the concentration of each on either side of the lung and blood vessel membranes. Air is forced into the lungs through the slit-like *glottis* by closing the *nares* and contracting the floor of the mouth. It is expelled from the lungs through the glottis into the mouth cavity by the contraction of the muscles of the body walls. Air may be expelled or drawn into the mouth through the nares by closing the glottis and alternately raising or lowering the floor of the mouth. *Sounds* may be produced by forcing air back and forth through the glottis (Fig. 212).

Oxygen unites temporarily with the *hemoglobin* of the *red blood corpuscles,* forming *oxyhemoglobin.* The latter carries oxygen to the tissues and cells where it is given up if needed. The latter is determined by the amount of oxygen present in the tissue, the activity of the tissue, etc. The carbon dioxide is removed from tissues by the *plasma.*

Excretion.—Some of the wastes are excreted by the frog *skin* and *intestine* (Figs. 208 and 213), but many are taken from the blood by a pair of elongated *kidneys* in the dorsal abdominal cavity. Internally, a kidney contains a number of *Malpighian bodies,* each consisting of an enclosing membrane known as *Bowman's capsule,* which surrounds a coiled mass of thin-walled capillaries known as a *glomerulus* (glo -mer′ u lus) (L. *glomus,* ball). Wastes are collected from the blood in the glomeruli and carried by *uriniferous tubules* to *collecting tubules* and thence to the tubular *ureter* and finally to the saclike *cloaca* (klo -a′ ka) (L. *cloaca,* sewer) (Fig. 213). From the latter the urine may be stored in the thin-walled, distensible *urinary bladder,* which voids only at certain intervals. Ciliated, funnel-shaped *nephrostomes* in the ventral part of the kidney open into the *coelom,* from which wastes may be secured and later eliminated.

Coordination and Sensory Equipment.—The nervous system may be divided into (1) *central nervous system,* consisting of brain and spinal cord, (2) *peripheral nervous system,* consisting of ten pairs of cranial nerves and ten pairs of spinal nerves, and (3) *sympathetic nervous system,* consisting of nerves and ganglia which supply the internal (visceral) organs (Figs. 216 and 217).

The *brain* has the following structures: (1) two small, fused *olfactory lobes* for the sense of smell, (2) two large, elongated *cerebral hemispheres* of uncertain function, (3) two large *optic lobes* for the sense of sight, (4) the well-developed midbrain, (5) the small, narrow *cerebellum* of uncertain function, and (6) the wide *medulla oblongata* which connects with the enlarged portion of the spinal cord. When the brain (except the medulla oblongata) is removed, the frog is still able to breathe, jump, swim, swallow food, and use its sense of equilibrium.

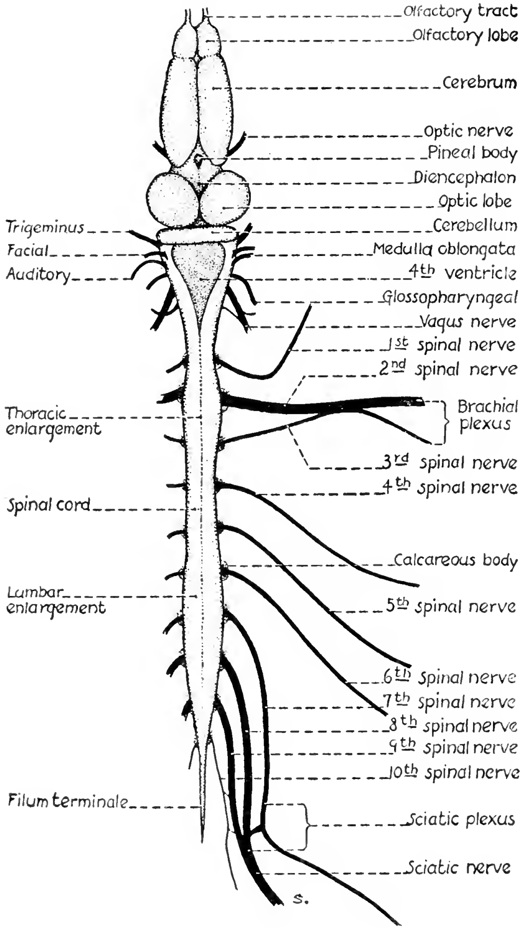


Fig. 216.—Nervous system of a frog (dorsal view). (From Potter: Textbook of Zoology, The C. V. Mosby Co.)

On the ventral side of the *brain,* the following structures are distinguishable: (1) *optic chiasma,* or the crossing of the optic nerves, (2) the *hypophysis* (pituitary body), and (3) *infundibulum.*

The *spinal cord* has a *dorsal median fissure* and a *ventral median fissure.* The cord is composed of a central mass of *gray matter* (principally nerve cells) in the shape of the letter H and an outer mass of *white matter* made up of nerve fibers. The hollow *central canal* extends throughout the entire cord and may be seen in the middle of the crossbar of the H in a cross-section of the spinal cord (Fig. 17). The central canal connects anteriorly with the cavities (ventricles) of the brain. The spinal cord has two surrounding membranous *meninges,* the outer one being called the *dura mater* and the inner, the *pia mater.*

There are ten pairs of *spinal nerves,* each arising from the gray matter of the spinal cord by a *dorsal root* and a *ventral root* (Fig. 17). The union of these two roots at the side of the cord forms a spinal nerve. Each spinal nerve passes out between the bony arches of adjacent vertebrae.

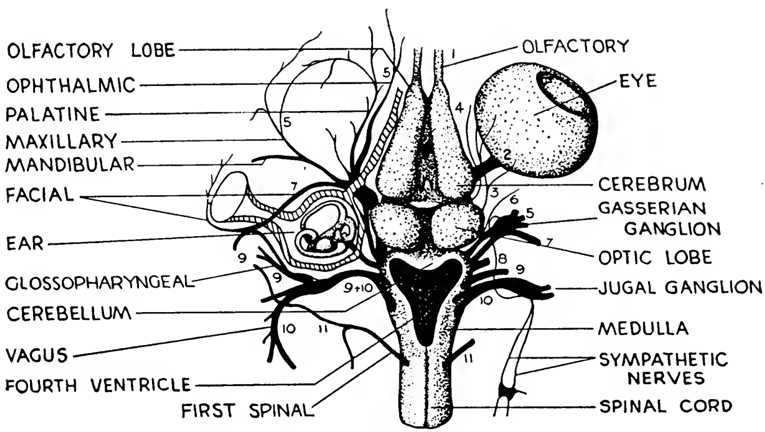


Fig. 217.—Brain and cranial nerves of the bullfrog (*Rana catesbeiana*) shown somewhat diagrammatically from the dorsal side. *1* to *10* show the cranial nerves; *11,* the first pair of spinal nerves. Certain cranial nerves show some of their branches. (From Atwood: A Concise Comparative Anatomy, The C. V. Mosby Co.)

The *sympathetic nervous system* consists of two main trunks which parallel the spinal cord, one on either side of it. Each *trunk* has ten ganglia or enlargements where the ten pairs of spinal nerves unite with it.

The *skin,* because of its contained *sensory nerve endings,* receives *tactile, chemical, heat,* and *light stimuli* (Fig. 208). The paired *eyes* have a large, spherical *lens* which, in other respects, resembles the eyes of other vertebrates. There are three *eyelids:* the rather motionless *upper lid,* the *lower,* which is fused with the *third eyelid* or *nictitating membrane* (L. *nictare,* to beckon). The lens permits objects to be seen at definite distances, especially moving objects. The *pupil* contracts and regulates the amount of light which enters. The sensitive *retina* within the eye is stimulated by light and transfers the impulses to the *optic nerve* which carries them to the *brain* to give the sensation of sight. The eyes lie in *orbits* (sockets) at the side of the skull and are moved by six *eye muscles* known as *external* and *internal recti,* the *superior* and *inferior recti,* and the *superior* and *inferior oblique muscles.*

The Number, Name, Origin, Distribution, and Function of the Cranial Nerves of Vertebrates

NUMBER	NAME	ORIGIN	DISTRIBUTION	FUNCTION
I	Olfactory	Olfactory lobe	Mucous membrane lining the nose	Sensory (smell)
II	Optic	Second vesicle of forebrain (diencephalon)	Cells of the retina of the eye	Sensory (sight)
III	Oculomotor	Ventral part of midbrain	Superior, inferior, internal recti; and inferior oblique muscles of the eye	Motor (movement of the eye)
IV	Trochlear (Pathetic)	Dorsal part of midbrain	Superior oblique muscle of the eye	Motor (eye movement)
V	Trigeminal	Laterally from the medulla (hindbrain)	Face, tongue, and mouth, and to the muscles of the jaws or mandibles	Sensory and motor
VI	Abducens	Ventral part of the medulla	External rectus muscle of the eye	Motor
VII	Facial	Laterally from the medulla	Muscles of face, roof of mouth, hyoid, etc.	Motor (principally)
VIII	Auditory (Acoustic)	Laterally from the medulla	Cells of the semicircular canal and other parts of the inner ear	Sensory (hearing and equilibrium?)
IX	Glossopharyngeal	Laterally from the medulla	Membranes and muscles of tongue and pharynx	Sensory and motor
X	Vagus (Pneumogastric)	Laterally from the medulla	Heart, lungs, pharynx, stomach, intestine, visceral arches, etc.	Sensory and motor
XI*	Spinal accessory	Laterally from the medulla	Muscles of the shoulder, etc.	Sensory and motor
XII*	Hypoglossal	Ventral part of the medulla	Tongue and neck muscles	Motor

*The XI and XII pairs are not present in fishes and amphibia.

The *tympanic membrane* of the outer ear communicates with the *inner ear* by a bony *columella* which vibrates with the sound stimuli received

(Figs. 216 and 217). The *auditory nerve* carries the impulses to the *brain,* where the sensation of hearing is really produced. There are no external ears. The *middle ear* communicates with the mouth cavity by means of the *Eustachian tube.* The latter aids in equalizing air pressures on the eardrums. The inner ear also contains organs of *equilibrium.*

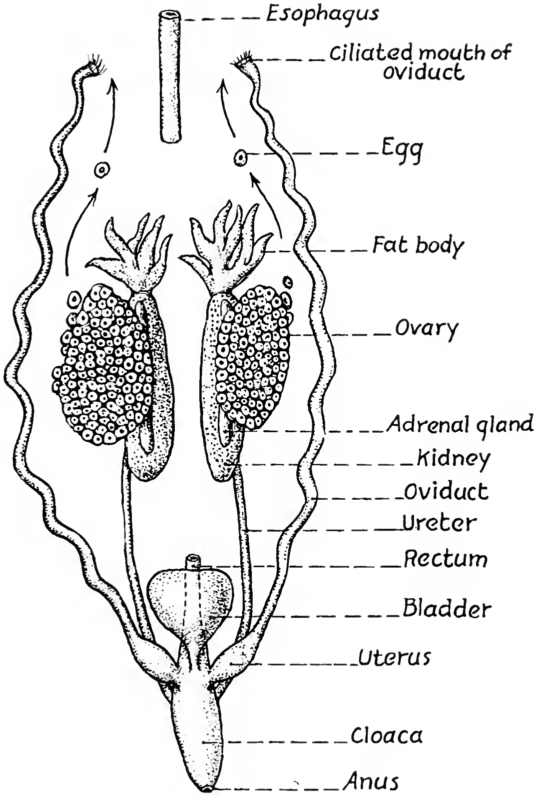


Fig. 218.—Urinogenital system of female frog (ventral view).

The *olfactory sense* is located in a pair of *nasal cavities* lined with folds of sensitive, epithelial, nasal membranes. The *external nares* (anterior nares) connect with the nasal cavity. The *internal nares* (posterior nares) connect the nasal cavity with the mouth cavity. The nares in amphibia and other vertebrates (above the fishes) are used for both respiratory and olfactory purposes. The *olfactory nerves* connect the epithelial nasal membranes of the nasal cavities with the *olfactory lobes* of the brain (Figs. 216 and 217). The elevated *papillae* of the mouth and tongue contain *organs* of *taste,* especially if foods and chemicals are in solution. Lateral sense organs are present in the tadpole stages only and are stimulated by vibrations of rather low frequency. Adult frogs do not have a lateral line.

Reproduction.—The *sexes* are *separate* (diecious) (Figs. 218 and 219). The *sperm* of the male arise in paired, small, oval *testes.* The sperm pass through the *vasa efferentia* into the *kidneys,* then by means of *Bidder's canal,* into the *ureter,* thence into the *cloaca,* and out through the *anus.*

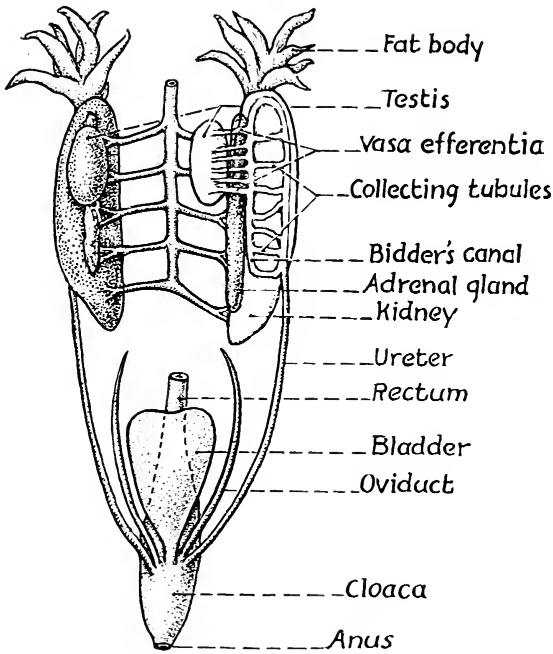


Fig. 219.—Urinogenital system of male frog (ventral view). On the right, the testis has been moved and the kidney dissected to show the internal tubes. The sperm pass from the testes through the vasa efferentia into Bidder's canal from which they pass out through the ureter. Part of the circulatory system and the adrenal (ductless) glands are also shown. Note the poorly developed rudimentary oviduct in the male.

The *eggs* arise in the large paired *ovaries,* and later break out through the walls of the enlarged ovary into the *coelom* (body cavity). From the latter the eggs eventually find their way into the much-coiled, paired *oviducts,* the funnel-shaped openings of which are located near the anterior edge of the abdominal cavity. The oviducts lead into the thin-walled *uterus* which leads into the *cloaca.* The latter leads to the *anus.* The eggs are given a coat of gelatinous food which is produced by *glan-*

dular cells of the oviduct. There are *no copulatory organs.* A yellowish, hand-shaped organ, known as the *fat body,* is located in front of each reproductive organ for the storage of food. There are *no amnion* and *no allantois* attached to the developing embryo as in reptiles and mammals. The embryology of the frog is considered in a special chapter.

QUESTIONS AND TOPICS

1. List the characteristics which place the frog in the phylum *Chordata,* subphylum *Vertebrata,* and class *Amphibia.*
2. Explain and give the significance of (1) protective coloration, (2) internal bony skeleton, (3) closed system of arteries, veins, and capillaries, (4) lymph, (5) lymph hearts, (6) three-chambered heart, (7) paired appendages with digits, (8) well-developed skeletal muscles which function in opposition, (9) erythrocytes which contain hemoglobin, and (10) special cells to assist in the clotting of blood.
3. Describe the structure and functions of the following for the frog: (1) integument, (2) motion and locomotion, (3) ingestion and digestion, (4) circulation, (5) respiration, (6) excretion, (7) coordination and sensory equipment, and (8) reproduction. In what specific ways have these shown improvements over the same in lower types of animals?
4. Explain (1) the origin and insertion of a muscle, (2) pectoral and pelvic girdles, (3) auricle and ventricle, (4) vasa efferentia and ureter, and (5) ureter and oviduct.
5. Describe the structure and functions of the various parts of the digestive system, including the physiology of digestion in detail.
6. Discuss the advantages of a three-chambered heart over a two-chambered one.
7. Explain how blood is carried to and from the lungs and skin.
8. Describe the blood of the frog, including advantages over blood of animals studied previously.
9. Explain how the circulatory system must be changed when a system of respiration (lungs and skin) is present.
10. Explain how the circulatory system must be developed when only one pair of kidneys excrete wastes.
11. Discuss the improvements in structure and functions of the nervous system and sensory equipment of the frog over animals studied previously.
12. List the number, names, origin, distribution, and functions of the ten pairs of cranial nerves in amphibia. In what ways do reptiles, birds, and mammals differ from amphibia and fishes in regard to cranial nerves?
13. List the conclusions you can draw from your studies of the frog.

SELECTED REFERENCES

Dickerson: The Frog Book, Doubleday, Page & Co.
Holmes: The Biology of the Frog, The Macmillan Co.
Kingsley: The Frog (Guide for Dissection), Henry Holt & Co., Inc.
Marshall: The Frog, The Macmillan Co.
Noble: Biology of the Amphibia, McGraw-Hill Book Co., Inc.
Shumway: The Frog (Laboratory Guide), The Macmillan Co.
Stuart: Anatomy of the Bullfrog (Laboratory Guide), Denoyer-Geppert Co.

Chapter 24

EMBRYOLOGIC DEVELOPMENT OF ANIMALS

ONTOGENY; PHYLOGENY; RECAPITULATION (BIOGENETIC) THEORY; MORPHOGENESIS

The embryologic stages undergone by an individual in its development from the zygote to the adult are considered as the life history of the individual or *ontogeny* (on-toj′ e ni) (Gr. *on,* being; *genos,* develop). A race of organisms, made up of successive generations of individuals also changes and evolves, and this developmental history of a race is known as *phylogeny* (fi-loj′ e ni) (Gr. *phylon,* race; *genos,* descent). The *recapitulation (biogenetic) theory* states that the life history of the stages of embryologic development of the individual (ontogeny) briefly *recapitulates* (repeats), in a modified manner, the evolution or stages of development of the race (phylogeny). Each organism tends in its individual life history to recapitulate the various stages through which its ancestors have passed in the development and evolution of their particular race. In other words, *ontogeny recapitulates phylogeny.*

Each multicellular animal begins its life as a *single, fertilized cell* which, according to the *recapitulation theory,* corresponds, in a general way, to the *unicellular Protozoa* in animal ancestry. Most multicellular animals (few exceptions) pass through an *embryologic two-layered stage* which is comparable to such *two-layered organisms* as *Hydra,* sponges, etc. In the higher multicellular animals there follows an *embryologic three-layered stage* which is comparable to the *three-layered organisms,* such as annelids, arthropods, chordates, etc. Many structures are developed in individual organisms which are similar to comparable structures in lower ancestral types of organisms. Embryonic pharyngeal clefts ("gill slits") appear in the developing embryos of all mammals because they developed in their ancestors. In certain adults, such as man, there are no visible pharyngeal clefts remaining, but the embryologic stages of the human being pass through these pharyngeal cleft stages nevertheless. The development of a four-chambered heart in a higher animal embryologically recapitulates the types of hearts found in the fishes, amphibia, reptiles, and birds. The fishes have typical two-chambered hearts, the amphibia have three-chambered hearts, the reptiles have three- or four-chambered hearts (depending on the type), the birds and mammals have four-chambered hearts.

One of the most important phenomena in the embryologic development of individual organisms is the actual origin and development of the definite structures and forms of specific tissues, organs, and systems. How do so many different kinds of structures originate within a single embryo? A study of the origin and development of the form and structure in organisms is known as *morphogenesis* (mor fo -jen′ e sis) (Gr. *morphe,* form; *genesis,* origin). Naturally, the *specific inheritance* of the particular embryo, together with the *influences of environmental factors,* both external and internal, are influential in determining morphogenesis. Many of these are not well understood, but the action and interactions of specific *genes,* as well as the action of the *cytoplasm,* assist in laying the groundwork or blueprint for the detailed construction of the individual. These are affected by physical and chemical factors (environmental) so that specific traits are developed. The earliest stages in the development of an animal seem to be influenced by the cytoplasm of the egg, which is maternal. Within each species of animal there is a certain pattern of development which is typical and normal. When this pattern is disturbed, either by genetic or environmental factors, there follow abnormal processes which cause abnormalities in growth and developments. The specific abnormalities depend upon the particular genetic materials involved or the quantity and quality of the environmental factors at work or both. Just after fertilization, various currents appear in the cytoplasm of the cells which initiate the developmental pattern unique for that species. Environmental influences may modify the normal cytoplasmic currents and thus alter normal development. Later developments appear to be influenced by chemical factors of the genes and cytoplasm and may also be affected by environmental factors. However, unless these conditions are extreme, development proceeds according to the normal pattern for that species.

It is thought that *genes* possess a high degree of autonomy (o -ton′-o mi) (Gr. *autos,* self; *nemo,* distribute) and that they consist of highly specific nucleoproteins which may be constructed from the simple molecules of the nutrients of the cells. Many processes which occur in cells are the result of the actions of various *enzymes* which in turn are thought to be produced by gene action. It is believed that these enzymes are also protein in composition. It is thought that genes reproduce themselves, thus perpetuating their hereditary potentialities. There seems to be a relationship between the synthesis of enzymes and of new genes. It is theorized that an undifferentiated cell in a particular region gives origin to different and specialized cells (differentiated cells) because of cytoplasmic differences and that these differences which produce cells of different sizes, shapes, and functions are the result of *plasmogenes* in the cytoplasm. It is suggested that plasmogenes in the cytoplasm are produced by genes found in the nucleus.

EMBRYOLOGY OF THE FROG

The embryologic development of many of the animals is much the same, with only minor differences in certain stages. The embryology of the frog has been chosen to illustrate the general principles because (1) the frog has a rather typical, representative method of development and (2) the materials are usually available and rather inexpensive.

The sexes of the frog are in different animals (diecious). The male gametes (spermatozoa or sperm) produced by the male sex organs (male gonads or testes) unite with the female gametes (ova or eggs) produced by the female sex organs (female gonads or ovaries). This union forms the first cell of the embryo known as the *zygote.* The eggs are found in jellylike masses in fresh water pools and ponds in early spring. Each egg has several, thick, concentric layers of jelly known as the vitelline membrane and is about the size of a buckshot.

In two or three hours after fertilization the zygote divides by mitosis to form the *two-cell stage,* the two cells remaining in contact. Division in this case is known as total cleavage or *holoblastic* (Fig. 220, *A*). A second division occurs by mitosis in about one hour and at right angles to the first plane of division, thus forming the *four-cell stage.* These four, more or less equal, cells are called blastomeres (Fig. 220, *B*).

The next plane of cleavage is horizontal and slightly above the middle or equator, thus dividing each of the four previous cells by a transverse division to form the *eight-cell stage.* Of these eight cells, four are pigmented, smaller, located at the animal pole, and known as *micromeres;* the other four are unpigmented, larger, located at the vegetal pole, and known as *macromeres* (Fig. 220, *C*).

These cells continue to divide until there are a large number of cells, all of which are closely packed together in a somewhat solid mass known as the *morula stage.* The micromeres continue to divide more rapidly than the macromeres at this time. It is evident that growth cannot continue indefinitely in this manner, or the animal would be solid without

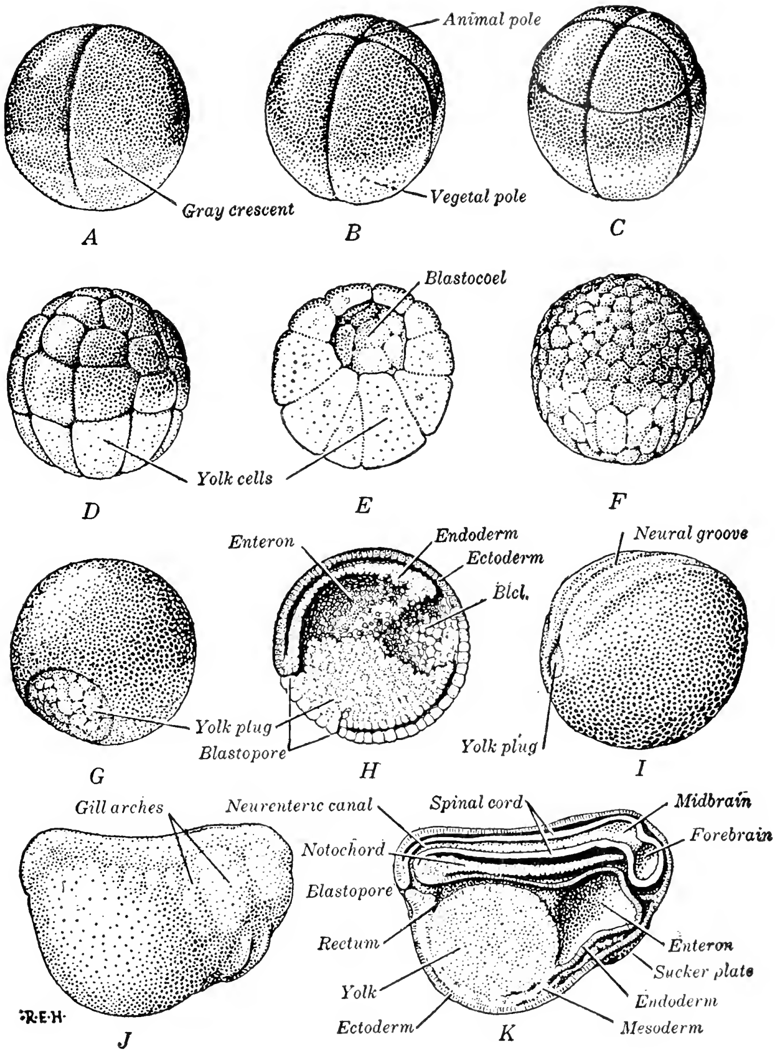


Fig. 220.—Embryology of the frog. *A, B, C,* Two-, four-, and eight-cell stages of dividing egg; *D,* early blastula; *E,* section of *D; F,* late blastula; *G,* early gastrula with very small ectodermal cells overgrowing other cells; *H,* section of *G,* showing germ layers, blastocoel (*Blcl*), etc.; *I,* late gastrula with neural groove; *J,* older gastrula with neural groove closed and assuming a tadpole form; *K,* section of *J* (see also Fig. 221). (From Woodruff: Animal Biology. By permission of The Macmillan Company, publishers.)

cavities in which tissues and organs could be placed. Consequently, at a certain stage in the cleavage process, the cells of the morula stage all line up in a very definite fashion to form a one-layered, hollow sphere known as the *blastula* or *hollow sphere stage* (Fig. 220, *D, E, F*). This sphere has a central, fluid-filled cavity known as the blastocoel or segmentation cavity. This blastula stage consists of (1) an outer, transparent, jellylike capsule; (2) a dark, pigmented animal hemisphere, composed of smaller and more numerous cells (ectoderm); and (3) a light-colored, unpigmented vegetal hemisphere which floats downward and is composed of larger and fewer cells (entoderm). The vegetal cells are quite large and contain yolk or food which is supplied to the cells of the animal hemisphere. This arrangement makes the wall of the blastula on the vegetative side much thicker than it is on the upper or animal side. The active growth in this stage occurs, primarily, in the animal hemisphere region.

The *gastrula* or *yolk plug stage* follows the blastula and is formed as follows: At a certain point between the animal and vegetal hemispheres, the vegetal cells turn inwardly into the blastocoel or segmentation cavity (Fig. 220, *G, H*). The pigmented animal cells (ectoderm) grow over the lighter colored, unpigmented vegetal cells (entoderm) and fold in with them to some extent at that point. Thus, an inner area or layer of cells is continuous with the outer layer. Because of more rapid mitosis, the animal hemisphere continues to grow almost entirely over the vegetal, leaving a small, light yolk plug exposed. The space between the boundaries of the infolded layers of cells, which surrounds the yolk plug, is the blastopore or primitive mouth. The ingrowth of the latter is shown on the surface by a thin, crescent-shaped fold or groove. The outer layer of cells is known as the ectoderm and is continuous with the inner inturned layer or entoderm. The point where the entoderm cells of the vegetal region turn in is one side of the yolk plug and is known as the dorsal lip of the blastopore. This inturned entoderm forms a cavity known as the archenteron or primitive intestine (primitive gut). The blastocoel now appears as a reduced cavity at the opposite side and is gradually being crowded out by the developing archenteron and the entoderm. The indentation on the opposite side of the yolk plug from the dorsal lip of the blastopore is known as the ventral lip of the blastopore.

The *neural groove stage* (Fig. 220, *I*) follows the gastrula stage. The neural groove, which is the forerunner of the future nervous system, begins as a small depression on the dorsal side of the blastopore and grows anteriorly along the dorsal side of the embryo as a thickened neural plate (medullary plate) in the ectoderm (Fig. 222). During this time, the embryo grows longer and has definite anterior and posterior ends. A thickened fold at each margin of the original neural plate forms a neural fold (medullary fold). These folds at first are flat and far apart. Later they arch toward the median dorsal line and unite to form the future neural tube. At this time the neural plate sinks to form a definite neural groove along the middorsal side of the embryo. The neural groove is composed of ectoderm cells (Fig. 222).

An elongated mass of cells dorsal to the archenteron forms the long, rodlike notochord which may still be connected with the entoderm from which it originates. The mass of cells at either side of the neural groove is known as the mesoderm (middle germ layer) (Fig. 222).

The *neural tube stage* closely follows the neural groove stage (Fig. 220, *J*). The two neural folds on the dorsal surface of the embryo at this time have met and fused into an elongated neural tube (Fig. 222). At this stage the latter probably will be free from the outer ectoderm from which it originated. The anterior part of the neural tube constricts and enlarges by well-regulated mitosis to form the future fore-, mid- and hindbrains. The notochord is now free from the archenteron and is just below the neural tube (Fig. 222).

The mesoderm completely surrounds the archenteron ventrally, and near the middorsal part there appears a small split or break which is the forerunner of the coelom (body cavity). This break continues ventrally, thus forming the body cavity between the two layers of the mesoderm. The inner layer of the mesoderm, known as the splanchnic layer, lies next to the entoderm, while the outer layer, known as the somatic layer, lies next to the ectoderm. The cells of both ectoderm and entoderm are now quite distinct (Fig. 222).

The *larval stage with external gills* follows the neural tube stage. A pair of oval, thick-lipped suckers on the ventral side of the tadpole serve for attachment purposes. The stomodeum (primitive mouth) appears as an oval pit in front of the suckers. The olfactory pits are a pair of small depressions above and anterior to the stomodeum. The three pairs of external gills are fingerlike processes on either side of the head which act as specialized organs of respiration. The proctodeum (primitive anus) is located on the dorsoposterior part of the tadpole. A tail and a pair of eyes are also present (Fig. 221).

The *larval stage with internal gills* (Fig. 221) follows the stage with external gills. The external gills are now covered by a fold of skin known as the operculum (gill cover) which has a single opening called the spiracle. As the three pairs of external gills are resorbed, there are formed four pairs of internal, fishlike gills (Fig. 222). In this stage the suckers are small projections just behind the mouth. The mouth is surrounded by a number of small projections known as the circumoral papillae. The mouth also has a pair of horny jaws. The intestine shows through the transparent ventral body wall as a long, coiled tube. This great length of intestine suggests a typical vegetarian animal which the tadpole really is at this stage. The hindlimb buds appear as small outgrowths on either side of the anal opening. These buds will continue to grow by mitosis into the real hindlimbs.

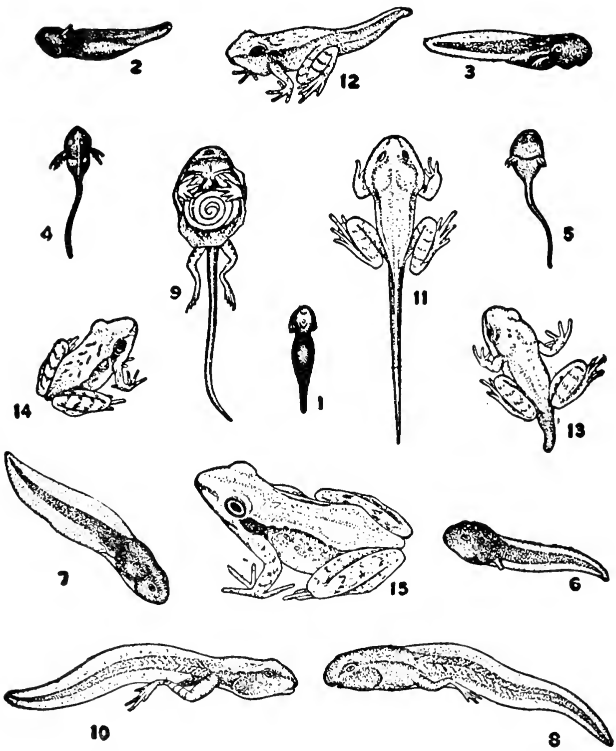


Fig. 221.—Metamorphosis of the frog (for previous stages, see Fig. 220). *1,* Tadpole just hatched; *2, 3,* older tadpoles, side view; *4, 5,* later stages, dorsal views showing external gills; *6,* tadpole with gills practically covered; *7,* older stage, right side showing hind limb; *8* and *10,* later stages, lateral view showing hind limb development; *9,* tadpole dissected to show internal gills, spiral intestine, and anterior legs developed within the operculum; *11,* advanced tadpole just before metamorphosis; *12, 13, 14,* stages in metamorphosis, showing gradual resorption of tail; *15,* young frog after metamorphosis. (From Woodruff: Animal Biology. By permission of The Macmillan Company, publishers.)

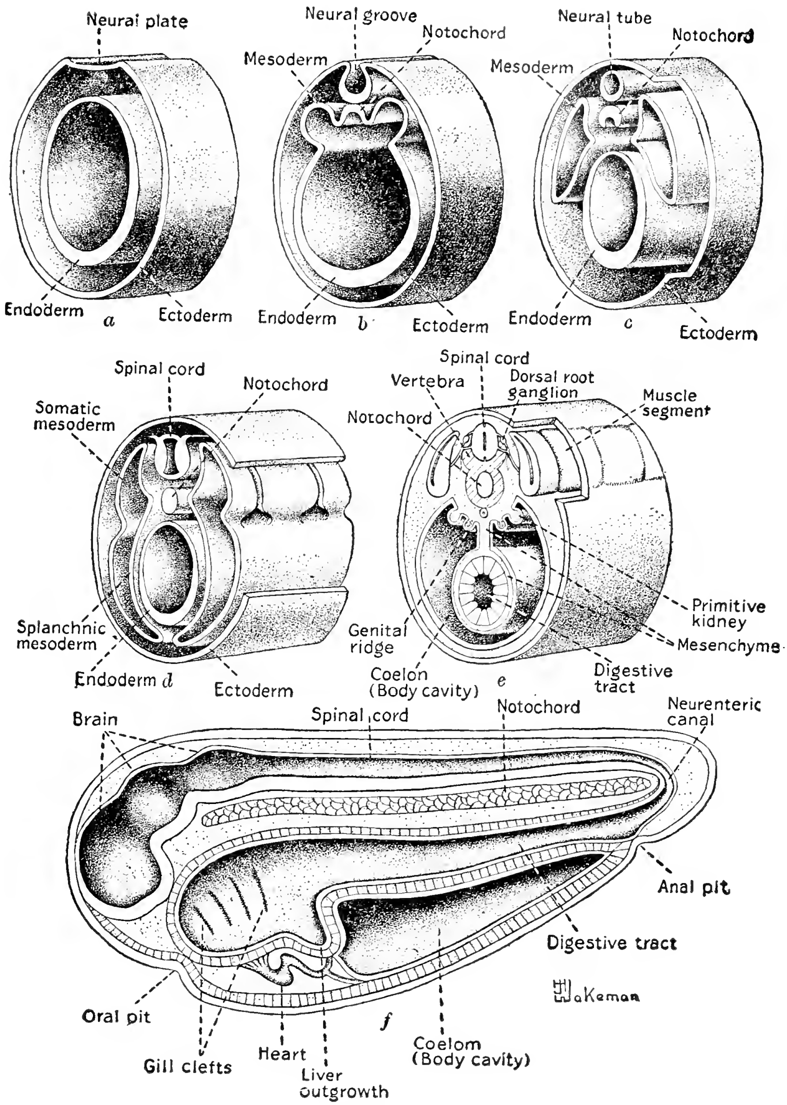


Fig. 222.—Development of a vertebrate, shown somewhat diagrammatically. Stages *a-e* are cross section of mid-body region. *a,* Neural plate stage; *b,* neural groove stage; *c,* neural tube stage; *d,* spinal cord stage; *e,* spinal cord stage still later; *f,* embryo cut lengthwise to show internal structures. (From Being Well Born, by Michael F. Guyer. Copyright 1927. Used by special permission of the publishers, The Bobbs-Merrill Company.)

The so-called later stages of development (Fig. 221) follow the stages described above. The front limb buds appear and develop into typical front legs. The tail gradually is resorbed and disappears, the materials being taken to the liver and stored. The internal gills are resorbed and their place taken with rapidly growing lungs. The adult frog is not aquatic but has lungs similar to other land-living (terrestrial) animals. The coiled intestine gradually shortens, which suggests a typical carnivorous (flesh-eating) animal, which the frog has now become.

EMBRYOLOGY OF MAN (MAMMAL)

Sperm which are produced by the male *testes* (Figs. 223 and 254) are deposited at copulation in the female vagina and swim by means of their whiplike *flagellum* through the glandular secretions along the wall of the *uterus* and finally to the paired *Fallopian tubes (oviducts)* (Fig. 255).

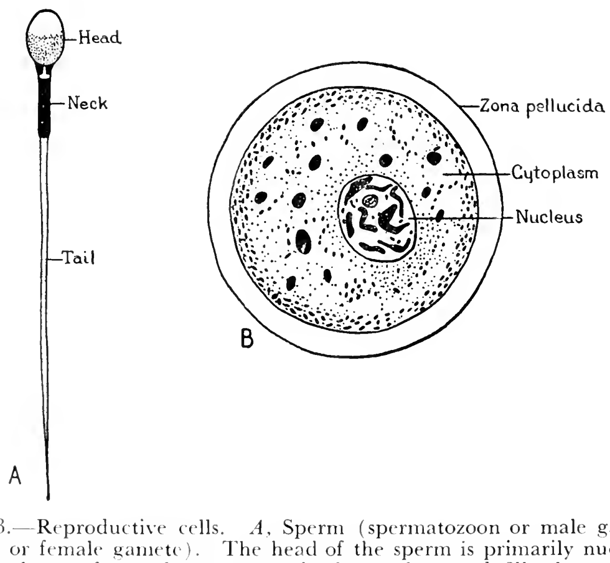


Fig. 223.—Reproductive cells. *A*, Sperm (spermatozoon or male gamete); *B*, ovum (egg or female gamete). The head of the sperm is primarily nuclear material; a thin layer of cytoplasm surrounds the nucleus and fills the remainder of the cell. The tail is also known as the flagellum by means of which the sperm moves. The zona pellucida of the ovum is an albuminous envelope. (From Francis, Knowlton, and Tuttle: Textbook of Anatomy and Physiology, The C. V. Mosby Co.)

The production of *ova (eggs)* by the female *ovary* is called *ovulation*. When the *Graafian follicle* which develops and encloses the developing ovum collapses and the wall of the *ovary* breaks (Figs. 223 and 255), the *ovum* is passed from the *ovary* into the abdominal cavity near the open-

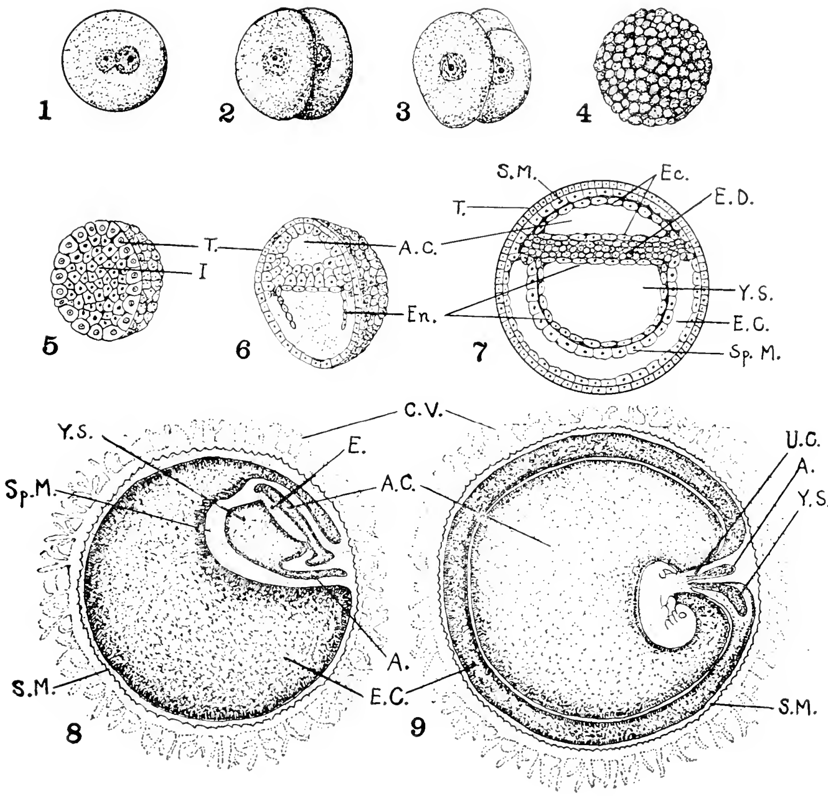


Fig. 224.—Cleavage, blastulation, gastrulation, and formation of three primary germ layers (ectoderm, mesoderm, entoderm) of mammalian embryo. The early stages have never been actually observed in human beings but probably resemble those of other mammals.

1, Fertilized egg cell; *2,* two-celled stage; *3,* three-celled stage; *4,* morula stage; *5,* morula stage in half-section, showing outer trophectoderm (*T*) and inner cell mass (*I*); *6,* blastocyst stage in half-section, showing amniotic cavity (*A.C.*) above, and a single layer of entoderm (*En.*); *7,* later blastocyst in median section, showing amniotic cavity (*A.C.*) and yolk sac (*Y.S.*) separated by a cellular mass constituting the embryonic disc or shield (*E.D.*), the latter eventually forming the embryo. The amniotic cavity is lined with ectoderm (*Ec.*) and the yolk sac with entoderm (*En.*) Observe the two types of mesoderm known as the somatic mesoderm (*S.M.*) and the splanchnic mesoderm (*Sp.M.*). Two layers of mesoderm form the extraembryonic coelom (*E.C.*) between them. *8,* Blastocyst containing human embryo (*E.*) about twenty-one days old, showing chorionic villi (*C.V.*) for securing nourishment; the allantois (*A.*); splanchnic mesoderm (*Sp.M.*); somatic mesoderm (*S.M.*); *9,* blastocyst containing human embryo about thirty-three days old and about 5.0 millimeters long, showing eye, pharyngeal clefts, front and hind limb buds, tail, and umbilical cord (*U.C.*). For older embryos see Fig. 225. The above stages are represented somewhat diagrammatically; from various sources.

ing *(ostium)* of the *Fallopian tube.* Through the action of the *cilia* which line the *Fallopian tube* the *ovum* is drawn into it, and *fertilization* usually takes place there, although, on rare occasions, the ovum may be fertilized while still in the abdominal cavity. In the latter case the developing embryo must be removed surgically. Unless the ovum is fertilized within a week after it is produced, it usually will not be. The *ovum (egg)* extrudes its *first polar body* at the time of ovulation and a *second polar body* upon fertilization. The ovum is now ready to *divide (cleave).*

Cleavage of the fertilized ovum (zygote) probably occurs in the Fallopian tube. The *first cleavage,* extending from the *animal pole* to the *vegetal pole,* results in two equal cells *(blastomeres)* (Fig. 224) which adhere to each other and are surrounded by an albuminous layer called the *zona pellucida.* The *second cleavage* is accomplished by one of the *blastomeres* dividing longitudinally at right angles to the first cleavage, to be followed by cleavage of the other blastomere, thus forming the *four-blastomere stage.* Cleavage continues until a small sphere of blastomeres the size of a pinhead is formed; this is known as the *morula stage.* The morula is still in the Fallopian tube but probably is approaching the *fundus (base)* of the *uterus.* It is thought that approximately one hundred hours are required for the fertilized ovum to develop to the *sixteen-cell stage of the morula.* The *morula* consists of (1) an outer layer of cells called the *trophectoderm* or *trophoderm* (Gr. *trophe,* nourishment; *ecto,* external; *derm,* covering) and (2) an *inner cell mass.* The cells of the *trophectoderm* increase so that the outer surface is much enlarged, thereby forming a saline-filled cavity *(blastocoel)* within the morula, which is now known as the *blastocyst (blastodermic vesicle)* (Fig. 224). Within ten days after fertilization the *blastocyst* has moved into the *uterus.* The latter has developed a thick, glandular layer which is stimulated by a ductless gland secretion, known specifically as *progestin,* to produce a sticky fluid by means of which the *blastocyst* adheres to the uterine wall. After a few hours the blastocyst begins to sink beneath the mucous layer of the uterus *(endometrium)* because the latter is eroded by *cytolytic action* of the trophectoderm cells of the blastocyst. This phenomenon is for the purpose of ensuring nourishment for the developing embryo until it can secure its own food.

The *inner cell mass,* near the point where it contacts the trophectoderm, forms the hollow *amniotic cavity* (Fig. 224). The free or unattached region of the *inner cell mass forms* a *yolk sac cavity* along the inner surface of the trophectoderm. The space betwen the yolk sac cavity and the trophectoderm is quite large. The yolk sac cavity contains no yolk (food), but its upper region will later form the roof of the alimentary canal. The *amniotic* and *yolk sac cavities* are separated by a cellular *embryonic disk (embryonic shield)* which will form the *embryo.* Its ventral layer is *entodermal,* its dorsal layer *ectodermal,* and the cells between the two are *mesodermal* (Fig. 224). *Mesoderm* is also formed between the yolk sac cavity and the trophectoderm and between the ectodermal lining of the amniotic cavity and the trophectoderm. The *trophectoderm* is now lined on the inside by a layer of *mesoderm* (Fig. 224), known specifically as *somatic mesoderm.* The trophectoderm and somatic mesoderm combined are known as the *chorion* because the latter, through minute projections *(villi),* contacts the blood vessels of the uterus in order to supply nourishment until the future blood system of the embryo is developed. Hence, the *entoderm* of the yolk sac cavity is covered with *splanchnic mesoderm,* while the *ectoderm* of the amniotic cavity is covered with *somatic* mesoderm (Fig. 224). The blastocyst also develops a third cavity, the *extraembryonic coelom,* located between the two separating layers of *mesoderm.* These two layers were originally one layer which was located between the entoderm of the yolk sac cavity and the trophectoderm.

In the next stages of development the *embryonic mass (embryo)* detaches itself partially from the inner surface of the *chorion,* grows rapidly, and forms a tubular outgrowth from the upper region of the yolk sac (Fig. 224). This outgrowth, called the *allantois* (Gr. *allanto,* sausage or tubular; *eidos,* form), grows toward the chorion and through the *body stalk,* by means of which the embryo is attached to the *chorion.* The yolk sac and allantois do not play as great a role in human embryologic development as they do in lower forms of organisms.

Between the third and fourth week of *gestation* (L. *gestatio,* carrying, pregnant) the *blastocyst* has enlarged so as to form a bulge on the surface of the uterus. The *embryo* soon pushes into the cavity of the *uterus,* being surrounded by the *amnion membrane* of the embryo (Gr. *amnion,* embryo covering). The *body stalk* now functions as the *umbilical cord,* the latter being continuous with the highly vascular, disk-shaped *placenta* which in turn is in contact with the blood vessels of the walls of the uterus.

About two-thirds of the *embryonic shield (embryonic disk)* previously mentioned will form the future head, while the remainder will form the neck, trunk, and tail. The two cellular layers of the *embryonic shield* consist of (1) the lower *entoderm layer* (nearest the yolk sac cavity) and

(2) the upper *ectoderm layer* which gives rise to the brain, spinal cord, outer skin, etc. Between the ectoderm and entoderm, on either side of the median line, and originating from both, there are formed two groups of cells: (1) the membranous *mesoderm (mesothelium)* and (2) a loosely arranged meshwork of cells called the *mesenchyme.* The ectoderm, mesoderm, and entoderm are known as the three *primary germ layers,* because from them arise all the tissues and organs of the future organism.

The tissues of the adult are derived from the *primary germ layers* as follows:

1. **From the Ectoderm**—The epidermis and its derivatives, as hair, nails, glands, lens of the eye; nervous tissues, including the neuroglia; the epithelium of the organs of special sense, of the mouth and its oral glands, of the hypophysis, of the anus, the amnion; the chorion; the smooth muscles of the iris (eye), and the sweat glands.

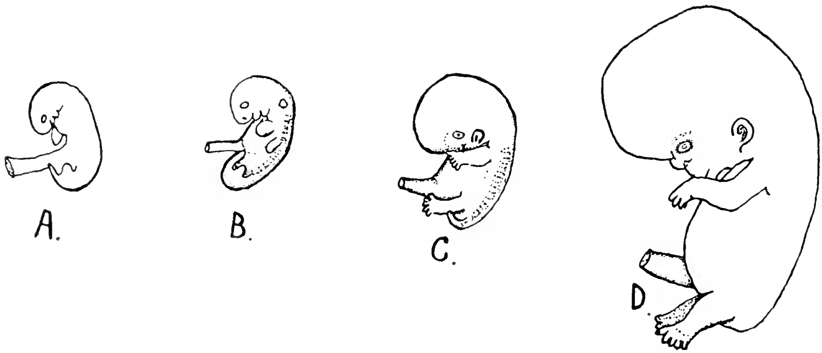


Fig. 225.—Human embryos. The membranes (amnion and chorion) have been removed to show the embryo. The approximate sizes and ages are given for each one. Drawn somewhat diagrammatically and somewhat enlarged. *A,* Thirty-three days old and 5 mm. long, showing the umbilical cord, pharyngeal clefts, tail, limb buds, eye, etc.; *B,* thirty-eight days old and 7.5 mm. long, showing the enlarging heart (shown just below the pharyngeal clefts), the beginning of the external ear, the myotomes (muscles) in the dorsal region; *C,* seven weeks old and 17 mm. long; *D,* about eight weeks old and 24 mm. long. (Modified from various sources.)

2. **From the Mesoderm**—The epithelial lining of the pericardium, pleura, peritoneum, urogenital system; striated muscles; smooth muscles; notochord; connective tissues, including cartilage and bone; bone marrow; blood; lining (endothelium) of the blood vessels and lymph system; lymphoid organs; the cortex of the suprarenal gland.

3. **From the Entoderm**—The epithelium of the pharynx and its derivatives, the thyroid, parathyroids, thymus, tonsils and auditory tube; the

digestive tract, including the liver and pancreas; the respiratory tract, including the lungs, trachea, and larynx; the bladder; the prostate; the urethra; the yolk sac; the allantois.

The detailed description of the embryologic origin of each tissue and organ cannot be given, but a few typical examples will be sufficient. As the embryo develops, the upper part of the *yolk sac* forms the tubular primitive *mid-* and *hindgut* with its outgrowth, the *liver,* when the embryo is about three weeks old. The saclike *"heart"* begins to beat soon after this time. By the third week the *yolk* sac has numerous

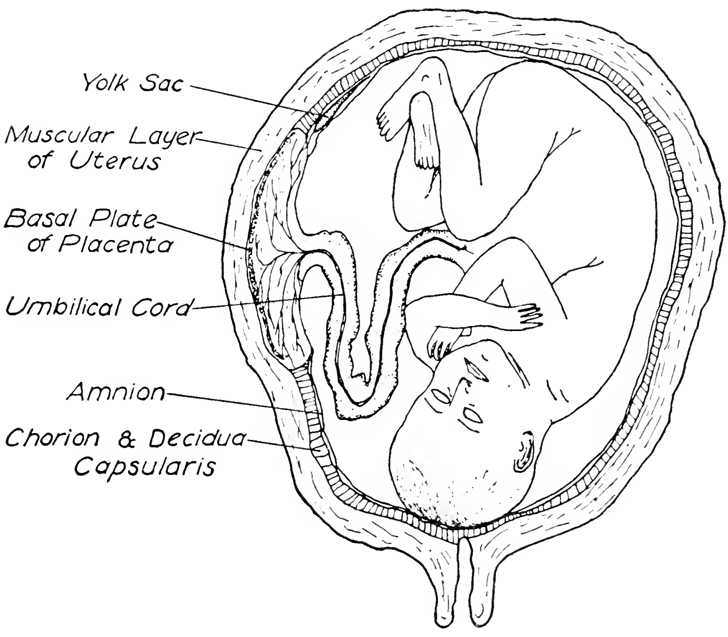


Fig. 226.—Human fetus shown in normal position in a section of the uterus. The chorion is the outer embryonic membrane and the amnion is the inner. (From Potter: Textbook of Zoology, The C. V. Mosby Co.; modified after Ahlfeld.)

"blood islands" for developing the embryonic *vitelline circulation.* The *embryonic disk* infolds (invaginates) to form a troughlike groove *(neural groove),* the open, upper side of which later closes to form a hollow tube *(neural tube).* From the anterior end of the tube will develop the various parts of the *brain* and *cranial nerves,* while the remainder forms the *spinal cord* with its *spinal nerves.*

Before five weeks the embryo externally shows a *head* with *rudimentary eyes,* an external *tail,* and a neck with four pairs of *gill arches* and four pairs of incompletely formed *slits* which somewhat resemble the gill-bearing arches of a fish (Figs. 224 to 227 and 363). There are numerous blood vessels here, but no true gills. These *gill arches* give rise to such structures as the following: from the *arches* arise muscles used in chewing food, middle ear bones, hyoid bone (at base of tongue), certain facial nerves and muscles, part of the cartilage of the larynx and its muscles; from the *slits between the arches* arise such structures as the Eustachian tubes, external ear passage, part of the tonsils, thymus, and parathyroids.

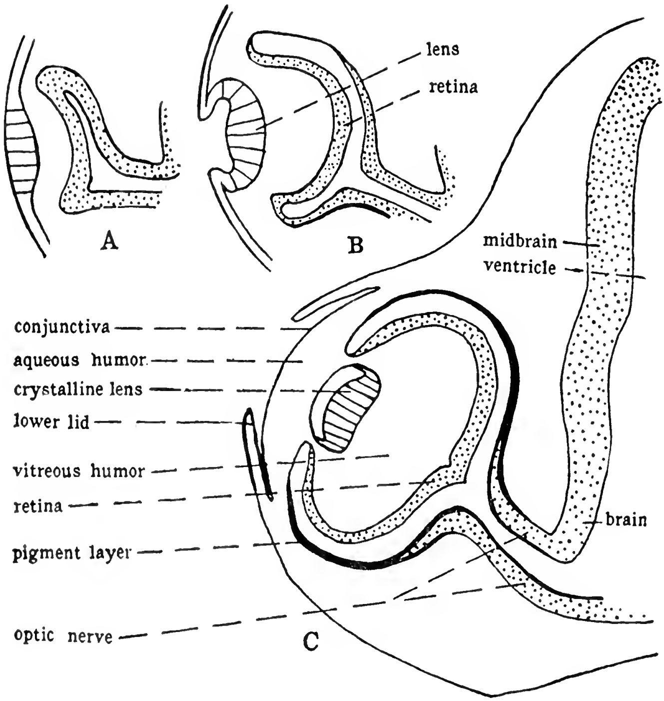


Fig. 227.—Stages in the development of the eye in embryos of a vertebrate animal shown somewhat diagrammatically. *A*, Thickening of the ectoderm of the side of the head as the optic cup begins to form on the end of the optic stalk; *B*, formation of the lens and the retina in the optic cup; *C*, later stage with parts labeled. (From Atwood and Heiss: Educational Biology, The Blakiston Co.)

QUESTIONS AND TOPICS

1. Describe the frog egg before development begins. Where and when can you find such eggs? Why are such eggs not deposited in the fall? What is the relationship between the dark pigment of the eggs and the source of heat energy for the development of the eggs?

2. Define (1) zygote, (2) morula, (3) blastula, (4) gastrula, (5) ectoderm, (6) entoderm, (7) blastocoel, (8) blastopore, (9) archenteron, and (10) cleavage.
3. Contrast micromeres and macromeres as to size, location, rate of division, and functions.
4. What system is first definitely differentiated in the developing frog? In man? Explain how and why it arises early.
5. Explain the origin of the notochord and its relationship to the nervous system.
6. Review the discussion on tissues and tell which tissues arise from each of the three germ layers.
7. What forces cause certain cells of an embryo to divide and develop at certain times and to remain rather inactive at other times?
8. Why is it undesirable for all cells of an embryo to divide at the same time? Explain the relationship between this and food supplies, waste accumulations, etc.
9. Explain the role of heredity in determining the time and rate of development of certain tissues at specific periods.
10. What controls the rate of mitosis in the anterior part of the neural tube, which through enlargements develops into the various regions of the brain?
11. Can the age of an embryo be approximately determined by the presence of specific embryonic structures?
12. In what ways do the various stages of the frog embryo and human embryo resemble each other? In what ways do they differ?
13. Describe the embryologic origin and development of such human tissues and organs as the instructor suggests.
14. Give a definition and an example of ontogeny, phylogeny, recapitulation (biogenic) theory, and morphogenesis.

SELECTED REFERENCES

Arey: Developmental Anatomy (Embryology), W. B. Saunders Co.
Bailey and Miller: Textbook of Embryology, William Wood & Co.
Corner: The Hormones in Human Reproduction, Princeton University Press.
Corner: Ourselves Unborn, Yale University Press.
Dodds: Essentials of Human Embryology, John Wiley & Sons, Inc.
Huettner: Fundamentals of Comparative Embryology of Vertebrates, The Macmillan Co.
Marshall: Vertebrate Embryology, G. P. Putnam's Sons.
McEwen: Vertebrate Embryology, Henry Holt & Co., Inc.
Parshley: The Science of Human Reproduction, W. W. Norton & Co., Inc.
Patten: Human Embryology, The Blakiston Co.
Patten: Embryology of the Chick, The Blakiston Co.
Patten: Embryology of the Pig, The Blakiston Co.
Potter: Fundamentals of Human Reproduction, McGraw-Hill Book Co., Inc.
Richards: Outline of Comparative Embryology, John Wiley & Sons, Inc.
Rugh: Experimental Embryology, John Wiley & Sons, Inc.
Weiss: Principles of Development, Henry Holt & Co., Inc.
Wieman: Introduction to Vertebrate Embryology, McGraw-Hill Book Co., Inc.

Chapter 25

BIOLOGY OF MAN

I. GENERAL ORGANIZATION OF THE HUMAN BODY

All human beings arise embryologically from a single cell (zygote) which is the result of the fertilization of an ovum (egg) by a male sperm. This zygote and all succeeding cells divide by mitosis to produce the organs, tissues, and cells of which the body is composed. When a child is born its body already is composed of approximately 26 trillion cells. It is suggested that the reader review the discussions of cells and tissues in previous chapters as well as the embryologic development of a human being.

In spite of the fact that there are so many cells in the human body, they are not all alike. In fact, early in the development of the embryo various cells are set aside (differentiated) to form the future organs and tissues. The human body is composed of the following systems of organs with their functions briefly stated.

Integumentary (Skin) System.—Protection, support, heat regulation, absorption, excretion, stimuli reception (Fig. 228).

Skeletal System.—Support, protection, posture, motion, locomotion, manufacture of blood corpuscles (by bone marrow), transmission of sound waves (ear bones) (Figs. 229 and 230).

Muscular System.—Locomotion, movements of parts of the body or organs, as stomach, heart, intestines, etc. (Figs. 232 and 233).

Digestive System.—Ingestion, digestion, and absorption of foods (Fig. 236).

Circulatory System.—Transportation of foods, wastes, heat, oxygen, carbon dioxide, and various secretions (Figs. 237 to 242).

Respiratory System.—Furnish oxygen and eliminate carbon dioxide and other waste products (Fig. 244).

Excretory System.—Secretion and elimination of waste products of cell and tissue metabolism (Fig. 245).

Nervous and Sensory System.—Receive stimuli; transmit and interpret impulses for purposes of correlation, secretion, movement, locomotion, behavior, etc.; centers of sight, hearing, taste, smell, equilibrium, etc.; memory; imagination (Figs. 246 to 251).

Endocrine (Ductless) Gland System.—Production of ductless gland secretions for the correlation and regulation of various body processes (Figs. 252 and 253).

Reproductive System.—Production of sex cells by the growth and development of which the species as well as the race will continue (Figs. 223 to 225, 254, and 255).

II. INTEGUMENT (SKIN) AND SKELETON

There are two distinct layers of the human skin: (1) the external *epidermis (cuticle)* and (2) the deeper *dermis (corium)* (Fig. 228). The epidermis is stratified squamous and columnar epithelium, contains no blood vessels, but has fine *nerve fibrils.* The *hair, nails,* and numerous glands are all modified epidermis. When we "peel" after a sunburn, the epidermis comes off in sheets or strips.

The human *epidermis* is composed of the following four layers: (1) The outer, thin *stratum corneum* is made of layers of cells, the lower layers of which are living and which replace the upper dead layers. The protoplasm of these cells contains a protein material, *keratin,* to prevent the excess loss of water. Many bacteria are probably harmed by the *acid* of this layer. (2) The next layer, the semitransparent *stratum lucidum,* is made of cells which are practically dead and which are renewed from below. (3) The next layer, the thick, granular *stratum granulosum,* contains some dead cells which are also replaced from below. (4) The lowest layer of the epidermis, the *stratum mucosum* or *Malpighian layer,* is made of several layers of columnar cells and contains the *pigments* of the skin. This layer gives rise to the upper layers of the epidermis.

The *dermis* or *corium* is well developed, thicker than the epidermis, and contains blood vessels, lymph vessels, nerves, and sense organs as well as hair follicles, glands, and papillae. The dermis is attached to the deeper tissues by a type of connective tissue known as *subcutaneous tissue.* The *dermis is characteristic of vertebrates* and is used when leather is "tanned." The dermis is composed of the following: (1) The superficial *papillary layer* contains numerous slight elevations called *papillae* in order to increase the surface for nerves, blood vessels, lymph vessels, sense organs, and glands. (2) The deeper *reticular layer* consists of bands of yellow elastic and white fibrous connective tissues which contain adipose tissue ("fat") and sweat glands.

In some parts of the human body the skin is very tightly attached to the deeper tissues, while in other parts it is loosely attached to permit free movements. On the inner surface of the hands and fingers and on the soles of the feet there are many minute ridges which increase friction and form the individually distinctive fingerprint and footprint patterns which remain constant throughout life. The dermis contains thousands of sensory nerve endings for the reception of heat, cold, pain, pressure, and touch (tactile) stimuli. Receptors for each of these sensations are present in all parts of the skin but some are much more concentrated in certain regions than in others. For example, tactile receptors (touch) are much more numerous on the finger tips than on the back of the hand.

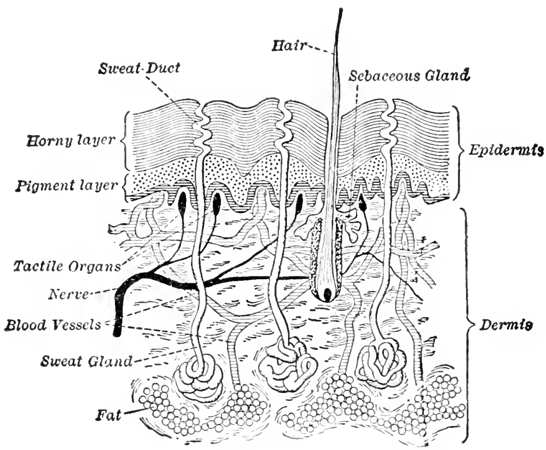


Fig. 228.—Human skin shown in cross section. The horny layer of the epidermis is composed of three parts: the outer part, stratum corneum, made of layers of flat cells containing keratin to prevent water loss; a middle part, stratum lucidum, composed of transparent cells; and a lower part, stratum granulosum, whose cells contain granules. The pigment layer of the epidermis is also known as the Malpighian layer or stratum mucosum. The dermis or corium has an upper or papillary layer containing papillae (elevations), nerves, tactile organs (sense of touch), blood vessels, sebaceous glands, etc.; and a lower or reticular layer containing sweat glands, fat (adipose tissue), etc. Contrast human skin with that of the frog (Fig. 208). (From Guyer: Animal Biology, Harper & Brothers.)

Accessory structures of the skin include hairs, oil glands, nails, teeth, and sweat glands (Fig. 228). The Malpighian layer of the epidermis is extended (invaginated) downward into the dermis to form the tube-like hair follicles. The cells at the base of a follicle produce the hair which is a fusion of epidermal cells supplied with keratin (a horny, protein material). When a hair is being formed, it first appears as a tiny elevation below the skin surface, later to be erupted. As more is produced, the hair is shoved farther from the skin surface. The part of the hair within the follicle is called the root, while the remainder is called the shaft. All skin is provided with follicles, except the palms of the hands, the soles of the feet, and the last portion of the fingers and toes. The consistency of the hair depends upon the structure of the follicle; a round follicle (in cross section) gives rise to straight hair, an oval follicle to curly hair, and a rather flat, ribbon-shaped follicle to wavy (kinky) hair. The color of the hair is determined by the quantity and quality of pigments present and their relation to the transparent air spaces within the hair. Loss of hair may be due to inheritance, certain diseases, or other environmental factors. Certain types of baldness are due to heredity. Fewer women than men are bald because the former more rarely inherit the necessary baldness-producing determiners. The base of each hair is supplied with a nerve and blood vessels for its nourishment. Smooth muscle fibers in the dermis are attached to the hair follicle so that the hair can be moved.

Sebaceous (oil) glands are formed by the invagination of the Malpighian layer of the epidermis into the dermis and are nearly everywhere associated with the hair follicles, being especially numerous on the face and scalp. The oily secretion passes from the glands into the hair follicle from which it passes to the surface, where the oil keeps the hair and skin from becoming dry and brittle and prevents undue evaporation or absorption of water and other liquids by the skin. Sometimes the glands become infected with pus-producing bacteria.

Nails are produced from closely packed epithelial cells along the furrow at the base of the nail. The nail is formed by a fusion of clear, dead, horny, keratinized cells to produce a solid plate.

Teeth are derived embryologically from epithelial tissues and are imbedded in the upper and lower jawbones for support and strength. The part of the tooth above the gum is called the crown and is covered with very hard enamel. The remainder of the tooth is composed of softer dentine with its central canal (pulp cavity) which in turn contains blood vessels and nerves. The teeth are attached to the jawbone by a substance called cementum. Man, like all mammals, has a temporary, "baby" set of teeth, twenty in number, which appear between six months and two and one-half years of age. The permanent set, thirty-two in number (Figs. 230, and 231), is composed (on each side

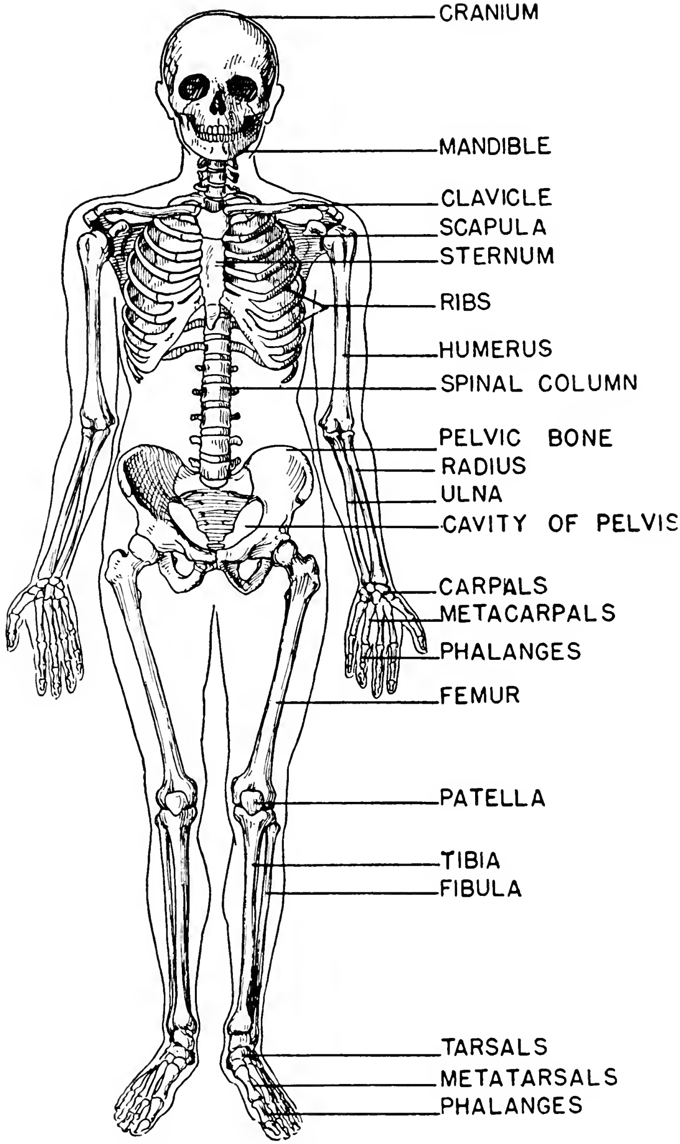


Fig. 229.—Human skeleton. The clavicle is commonly called the collar bone; the scapula, the shoulder blade; the patella, the kneecap. (From Parker and Clarke: An Introduction to Animal Biology, The C. V. Mosby Co.)

of each jaw) of two incisors ("front" teeth), one canine ("eye" tooth or cuspid), two premolars (bicuspids), and three molars. The last pair of molars ("wisdom teeth") is frequently not erupted until later in life, or not at all. Hence, the normal dental formula for man is:

$$I \frac{2}{2}; \ C \frac{1}{1}; \ P \frac{2}{2}; \ M \frac{3}{3} \text{ (for each jaw)}$$

The incisors are flat and sharp for cutting food as they overlap; the pointed canines correspond to the tusks of carnivorous animals and are

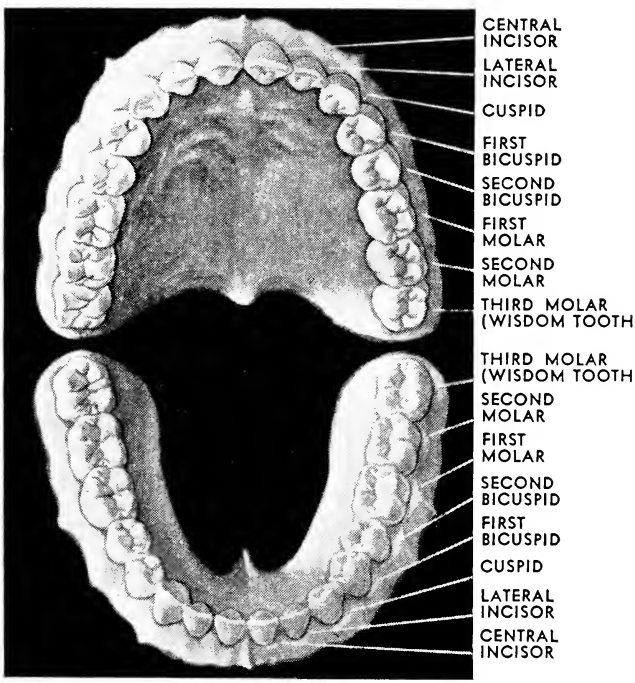


Fig. 230.—Chart showing the thirty-two permanent human teeth. (Courtesy of the American Dental Association.)

used for tearing foods; the broad-surfaced premolars have two elevations for grinding purposes; the larger molars have four or more elevations for grinding.

Sweat glands are present in all skin but are most numerous under the arms, on the forehead, on the soles of the feet, and on the palms of the hands. The coiled, tubular glands are located in the dermis and empty their excretions (sweat or perspiration) through pores on the skin surface. Over two million sweat glands in the entire skin eliminate over a quart of sweat per day under normal conditions. Under abnormal conditions, more or less than this amount may be excreted. Perspiring eliminates body wastes and regulates body heat through the evaporation of water. Heat which is produced in various tissues, especially muscles, is distributed by the blood throughout all parts of the body, thus producing an average, normal body temperature of 98° to 99° F.

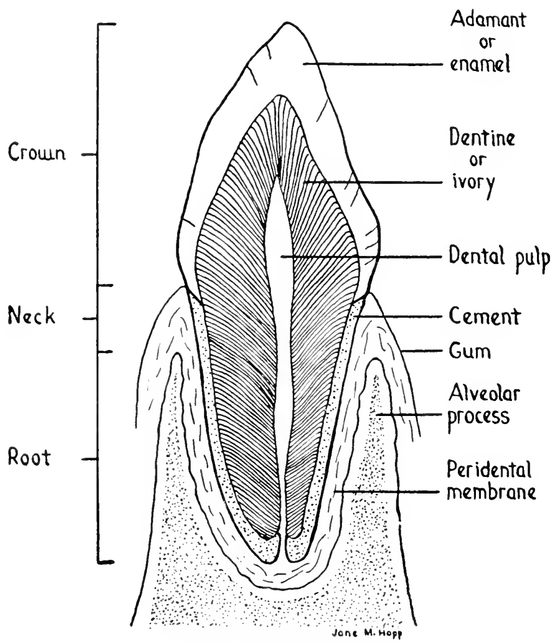


Fig. 231.—Human incisor tooth in vertical section. (From Francis: Introduction to Human Anatomy, The C. V. Mosby Co.)

Since the skin is well supplied with blood, it can efficiently act as a heat-regulating and heat-eliminating mechanism. Dilation (enlargement) of the blood vessels and relaxation of the muscle fibers of the dermis allow more blood to lose more heat, while a contraction of these blood vessels and muscles has the opposite effect. In addition to this loss of heat, the skin may also be cooled by the evaporation of sweat from the skin surface.

The functions of the human skin and its accessory structures may be summarized as follows: (1) regulation and elimination of heat; (2) excretion of wastes; (3) protection against injury, harmful light rays, loss of water, disease-producing organisms (bacteria, molds, parasites, etc.), (4) prevention of the absorption of various deleterious materials from our environment, (5) aid in normal respiration, (6) supply information about our environment through the various types of sensory end organs, and (7) to produce hair, nails, glands, and teeth each with their specalized functions.

The skeletal system consists of 206 named bones, cartilage, and ligaments, the latter to hold the other parts together and bind them into an efficient structure. The bones are illustrated in Fig. 229 and the names and numbers are given in table form so as to be easily memorized. It will be observed that the bones may be classified as to shape as follows: (1) long (arms, legs), (2) short (wrist), (3) flat (shoulder blade, patella, etc.), and (4) irregular (vertebrae). It will be noted that the teeth are not listed as part of the skeleton but are included with the integument because of their epithelial origin. By studying a human skeleton it will be evident that there are several types of joints, each with its specific functions. Joints may be classed as (1) immovable (irregular, dovetail connections [sutures] of the bones of the cranium) and (2) movable, with movements of various types for specific purposes. Movable joints may be further classed as (1) ball and socket (femur and pelvic girdle, humerus and pectoral girdle), (2) hinge (femur and tibia, humerus and ulna), (3) sliding (most of vertebrae), and (4) rotating (radius and ulna).

Bones, for the most part, originate in the embryo as cartilage; hence they are known as cartilage bones in contrast to the less common membrane bones which are formed by the gradual ossification of soft, fibrous, membranous tissues (skull bones). Certain parts of the skeleton remain as cartilage, such as the external ear, tip of the nose, tip of the breast bone, between the vertebrae, and articulatory surfaces of movable joints. The great strength, elasticity, and reduced friction make cartilage an efficient part of the skeleton.

Briefly stated, the functions of the human skeleton are (1) to form a framework to support other organs and give posture to the body, (2) to give protection to vital organs (such as brain, spinal cord, heart and lungs), (3) to form solid attachments for muscles so that they may act as a system of levers in motion and locomotion, (4) to store fat in the "fat" marrow, (5) to store certain mineral reserves, (6) to form blood corpuscles by the bone marrow, and (7) to transmit sound waves as accomplished by the hammer, anvil, and stirrup bones of the ears (Fig. 250).

Human Skeleton (see Fig. 229)

- Axial (80)
  - Skull
    - Cranium (8) (Brain Case)
      - Occipital (base of skull) (1)
      - Parietal (top of head) (2)
      - Frontal (forehead) (1)
      - Temporal (above ears) (2)
      - Ethmoid (back of nose) (1)
      - Sphenoid (back of eye) (1)
    - Face (14)
      - Mandible (lower jaw) (1)
      - Maxilla (upper jaw) (2)
      - Palate (2)
      - Malar or zygomatic (cheek) (2)
      - Lacrimal (inner orbit) (2)
      - Inferior turbinated (nose) (2)
      - Vomer (nasal septum) (1)
      - Nasal (bridge of nose) (2)
  - Ear bones (6)
    - Malleus (hammer) (2)
    - Incus (anvil) (2)
    - Stapes (stirrup) (2)
  - Vertebral column (26)
    - Cervical (neck) (7)
    - Thoracic (chest) (12) with ribs
    - Lumbar (lower trunk) (5)
    - Sacral (sacrum) (1)*
    - Coccygeal (caudal or tail) (1)†
  - Hyoid (base of tongue) (1)
  - Sternum (breast bone) (1)
  - Ribs (24)
- Appendicular (126)
  - Pectoral (shoulder) girdle
    - Clavicle (collar bone) (2)
    - Scapula (shoulder blade) (2)
  - Arms
    - Humerus (2)
    - Radius (2)
    - Ulna (2)
    - Carpals (wrist) (16)
    - Metacarpals (hand) (10)
    - Phalanges (fingers) (28)
  - Pelvic (hip) girdle (2)‡
  - Legs
    - Femur (thigh) (2)
    - Tibia (shin) (2)
    - Fibula (2)
    - Tarsals (ankle and heel) (14)
    - Metatarsals (foot) (10)
    - Phalanges (toes) (28)
  - Knee cap (patella) (2)

This does not include the variable number of *sesamoid bones* (ses′ a moid) (L. *sesamon*, sesame seed; *eidos*, like) embedded in the tendons of the hand, knees, and foot, or the *wormian bones* (wur′ mi an) (after Worm, a Danish anatomist) which are isolated bones in the sutures or joints, especially of the skull.

The figures in parentheses give the number of bones of each type.

*Five bones fused.

†Four bones fused.

‡Three bones (ilium, ischium, pubis) fused.

III. MOTION AND LOCOMOTION IN MAN

The living bones of the human skeleton are the passive structures to which the active muscles are attached and by means of which various parts of the body are moved or the body as a whole is moved from one place to another (Figs. 229, 232, 233, and 249). There are over 400

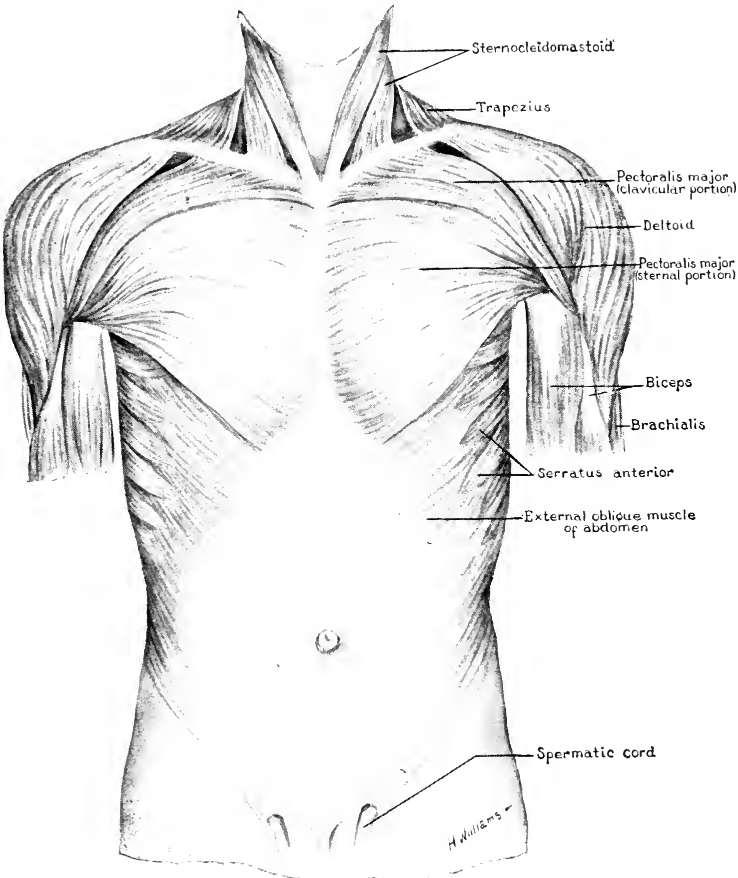


Fig. 232.—Human muscles (front view). (From Francis: Fundamentals of Anatomy, The C. V. Mosby Co.)

named muscles attached to the skeleton for the movement of parts of the body or for locomotion. These are the skeletal muscles and each is composed of cells with several nuclei (multinucleated). Skeletal muscles are under the control of the will (voluntary), are distinctly striated, have a rather rapid rate of action, and fatigue, rather quickly. Many unnamed, unstriated (smooth), mononucleated, muscle cells compose the muscles of the internal organs (viscera), such as the esophagus, stomach, intestines. These visceral muscles are not under the control of

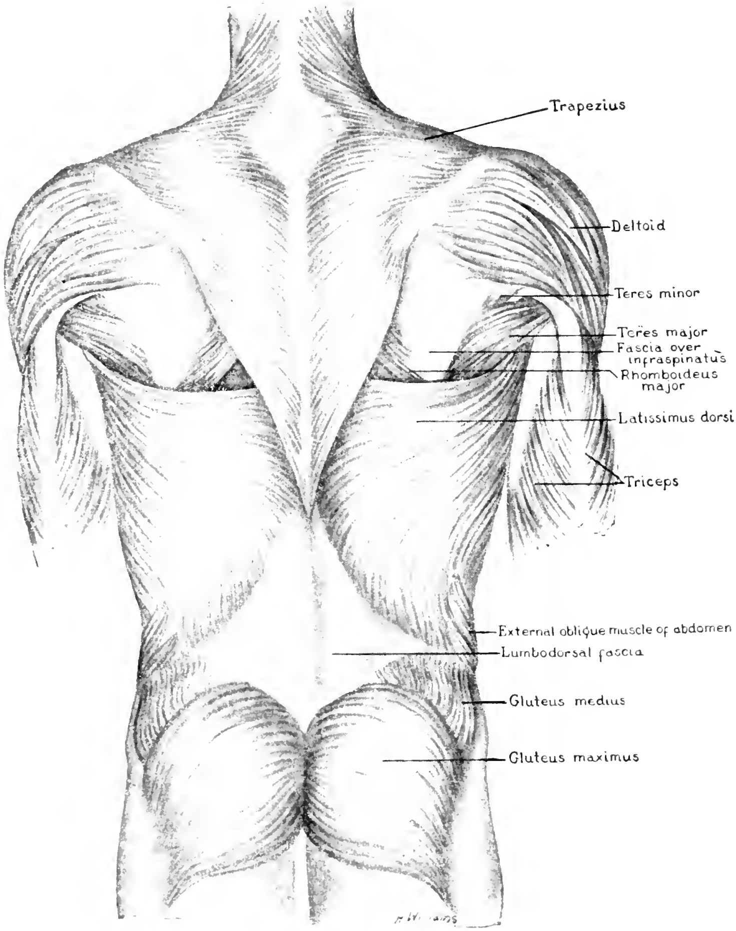


Fig. 233.—Human muscles (back view). (From Francis: Fundamentals of Anatomy, The C. V. Mosby Co.)

the will (involuntary), have a rather slow, rhythmic rate of action, and do not fatigue easily. Numerous, indistinctly striated, mononucleated, cardiac muscle cells compose the walls of the heart and arteries. Cardiac muscles have a variable rate of action and under normal conditions do not fatigue quickly. They are involuntary because our will cannot make them contract just so many times per minute. These various types of muscle tissues have been described earlier and the reader might well review them.

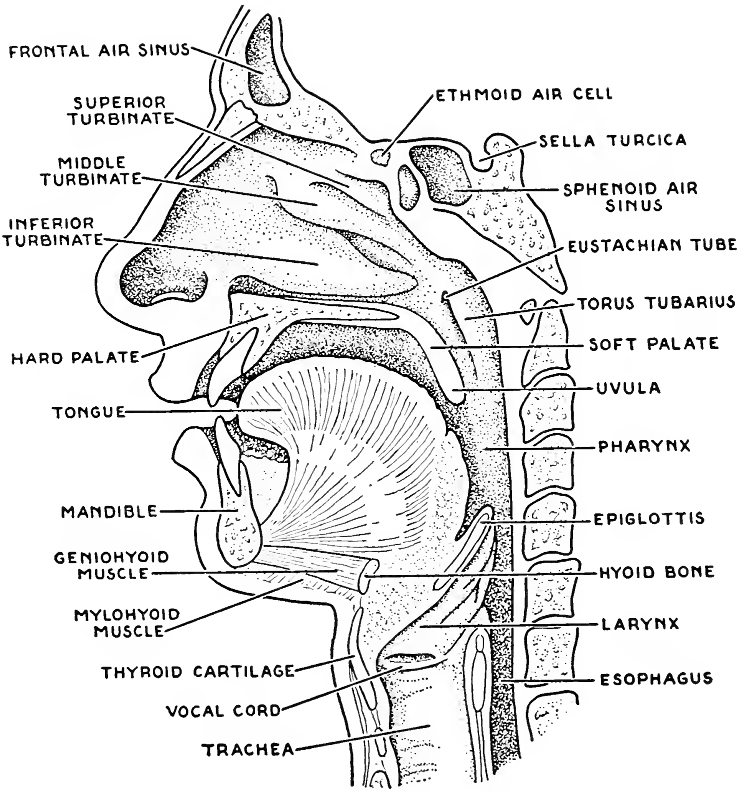


Fig. 234.—Face and neck in section showing parts of the respiratory and digestive systems. The common cavity where the two systems cross is known as the pharynx. The leaf-shaped epiglottis prevents food from entering the larynx from the pharynx. (From Zoethout and Tuttle: Textbook of Physiology, The C. V. Mosby Co.)

Skeletal muscles have one end rather solidly attached and known as the origin, while the other end is more movable and is known as the insertion. Study some muscles (Figs. 232 and 233), observing the origin and insertion of each. It will be noted that muscles of the body do not cross the median line; hence they are in pairs. Muscles which move a part away from the median line are called abductor muscles, while those which move a part toward the median line are called adductor muscles. Skeletal muscles are named in various ways: (1) after the name of the structure, or bone, with which they are associated (*triceps brachii,*

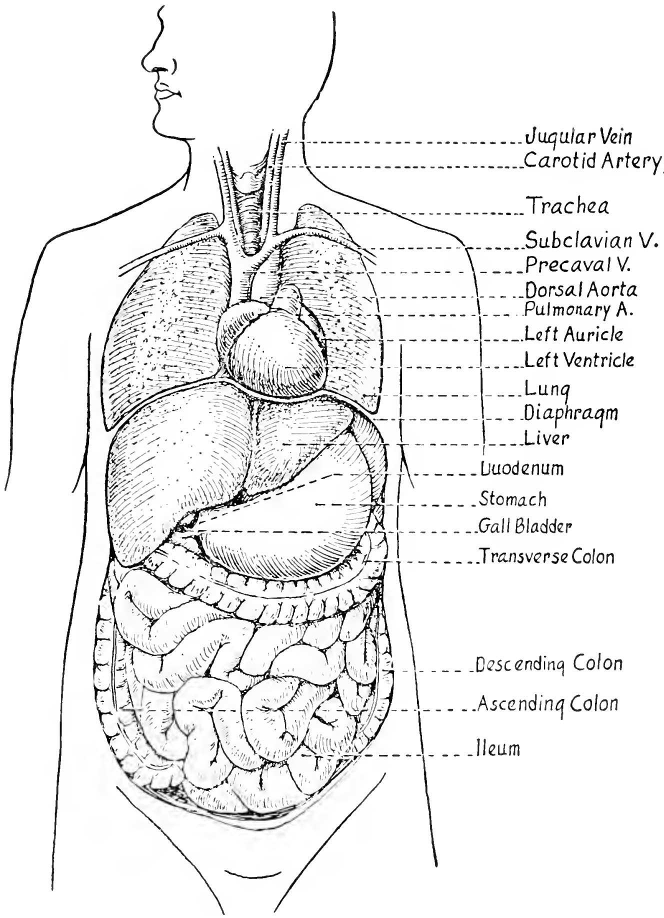


Fig. 235.—Human internal organs of the thoracic and abdominal cavities which are separated by the muscular diaphragm (see Fig. 236). (Drawn by Edward O'Malley, from Potter: Textbook of Zoology, The C. V. Mosby Co.)

muscle on the back of the upper arm, or brachium), (2) after the number of "heads" with which they originate (*triceps brachii,* meaning three heads; *biceps brachii,* two heads and located on the front of the upper arm), (3) after the shape of the muscle (*deltoid,* delta-shaped muscle of the top of the shoulder; *trapezius,* trapezoid-shaped muscle of the back), (4) after the direction in which they run (*external oblique,* strong muscle of the abdominal wall which lies obliquely), (5) after the length and size of the muscle (*peroneus longus,* large muscle attached to the fibula; *peroneus brevis,* smaller muscle attached to the fibula bone), (6) after

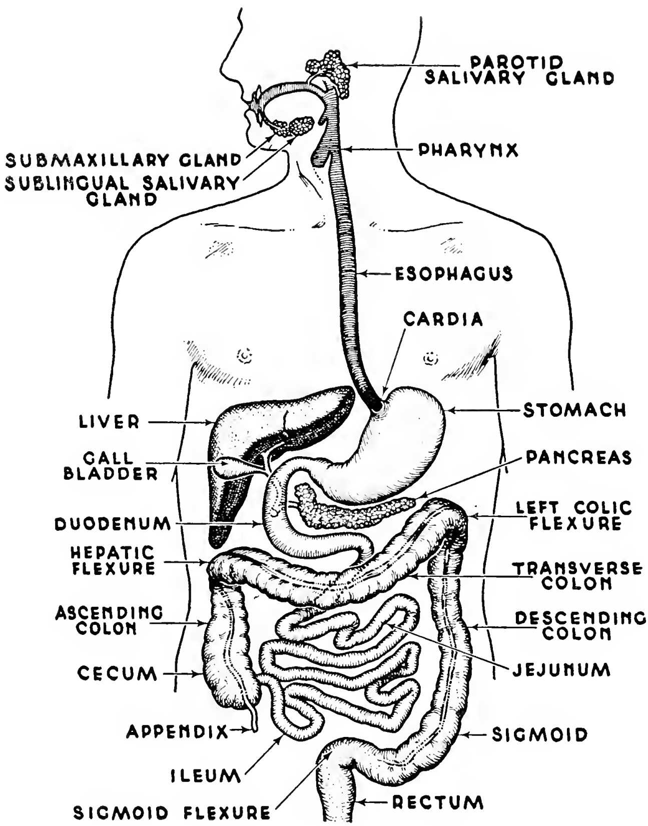


Fig. 236.—The human digestive system with accessory organs. (From Zoethout and Tuttle: Textbook of Physiology, The C. V. Mosby Co.)

the origin and insertion (*sternocleidomastoid,* which arises from the sternum and clavicle, and is inserted into the mastoid portion of the temporal bone of the skull), (7) after their location (*external intercostals,* superficial muscles between the ribs; *internal intercostals,* deeper muscles between the ribs), and (8) after their function (*adductor longus,* adduct the thigh toward the median line).

Muscles play an important role in the movements of many organs as will be observed by a study of such systems as the digestive (Fig. 236), respiratory (Figs. 234 and 244), circulatory (Figs. 237 to 241), excretory (Fig. 245), reproductive (Figs. 254 and 255), and special sense organs (Fig. 249). Certain movements are caused by cilia which line various areas, such as those of the nose and reproductive tubes.

IV. FOODS AND NUTRITION

A food may be defined as any substance which when ingested in the proper amount is absorbed from the digestive tract and contributes to the normal maintenance of the body. Foods are composed of such organic compounds as carbohydrates, fats, proteins, and vitamins and such inorganic substances as water and various inorganic salts. These food constituents are considered in detail elsewhere and the reader is referred to them. Of all the thousands of organic and inorganic substances, only a few serve as satisfactory human foods, probably because of man's limited number of enzymes by means of which he can digest them. Any animal in utilizing a substance for food purposes must get that substance into a condition which can be absorbed through the small openings in the semipermeable membranes which enclose the absorptive cells of the digestive tract. These openings may be of the size to permit the absorption of water molecules (two atoms of hydrogen and one atom of oxygen) but too small to permit the absorption of other foods the molecules of which are larger. Consequently, certain foods whose molecules are large (because of a great number of atoms which form these molecules) must be changed (digested) before they can be absorbed. For example, the molecule of sucrose (cane sugar) ($C_{12}H_{22}O_{11}$) must be digested to form two simpler monosaccharide molecules before it can be absorbed, while the simple molecule of glucose ($C_6H_{12}O_6$) is absorbed unchanged. Digestion is primarily a chemical process whereby the molecules of foods which are too large to be absorbed are changed so that they may be. This phenomenon is accomplished by hydrolysis which means "a change by the action of water." Hydrolysis is based on enzyme action in which water is added to the complex molecular arrangements of foods, thus disassociating the complex molecules into simpler, absorbable ones. The summary of the digestion of foods in man is given so that the stages can be easily memorized. For example, when one molecule of water (H_2O) is added to a molecule of sucrose (cane sugar) ($C_{12}H_{22}O_{11}$), the hydrolytic action results in two separate, absorbable molecules, each with the formula of ($C_6H_{12}O_6$). It must be remembered that the mere addition of water to a food will not result in digestion, but the specific action of digestive enzymes is necessary (consult table on Summary of Digestion, showing the enzymes and their roles).

After foods are digested and absorbed they can be made into a part of the living protoplasm. This phenomenon is called assimilation. In all probability assimilation, as well as other phenomena, is affected by certain specific vitamins, some of the better known being listed in a summary to expedite their mastery (Figs. 369 to 372). Vitamins may be considered as essential accessory substances present in variable amounts in different foods. Each vitamin has its unique function in the maintenance of normal body processes (consult summary of vitamins). Unlike other food components, such as carbohydrates, fats, proteins, and minerals, they do not provide energy or build tissues directly. Their function is to enable the body to use other foods properly in addition to performing other very essential functions. Vitamins vary in their chemical composition, their solubility in fat or water, their resistance to heat, and their inactivation by oxygen. The term vitamin, which was coined when vitamins were erroneously thought to be amines (containing an amine, NH_2) essential to life (vita), is still used today but may eventually be supplanted when more is learned about them and their chemical compositions are completely ascertained. Minerals are nutritional substances (inorganic) which, in combination with other food constituents, promote the formation and maintenance of various parts of the body structure. Each mineral not only aids in metabolic processes but actually forms a part of certain body fluids and tissues. Calcium aids in blood clotting and bone formation, while iron enters into the construction of the hemoglobin of the red blood corpuscle.

The human digestive system (Figs. 234 and 236) consists of: (1) The *mouth* with its numerous *taste organs,* a muscular *tongue,* thirty-two *teeth* (two incisors, one canine, two bicuspids, and three molars in each half of each jaw), and three pairs of *salivary glands* (the parotid, submaxillary, and sublingual glands) for the secretion of saliva (Fig. 236). (2) A tubelike *esophagus* with two layers of circular and longitudinal muscles for the peristaltic movement of foods. (3) The *stomach* with its three layers of muscles (the circular, oblique, and longitudinal), the anterior *cardiac part* (nearest the heart) in which foods are stored, and the posterior *pyloric part* principally for digestion. The stomach secretes *gastric juice* and *mucin.* (4) The *small intestine* for digestion and absorption which is composed of the *duodenum* (one foot long), the

SUMMARY OF IMPORTANT VITAMINS

VITAMIN	IMPORTANT SOURCES	FUNCTIONS	EFFECTS OF DEFICIENCY
A $C_{20}H_{30}O$ Fat-soluble Antiophthalmic	Fish liver oils, animal livers, egg yolk, butter, carrot, yellow squash, sweet potato, green vegetables Precursor is carotene ($C_{40}H_{56}$) in green vegetables	General health and vigor, resistance to skin infections, normal vision	Retarded growth, dry skin, inflammation of alimentary tract, kidneys and respiratory system, "dry eyes" xerophthalmia) (Fig. 370), night blindness (partial loss of sight in dim light)
B_1 Thiamin $C_{12}H_{17}N_4SO$ Water-soluble Antineuritic	Yeast, whole grains (cereals), vegetables (raw), fruits, egg yolk, liver, meats, milk, corn meal, peanuts Manufactured synthetically	Promotes normal appetite, digestion, and carbohydrate metabolism	Beriberi (human nervous disease) or polyneuritis (birds) (Fig. 371), loss of appetite and vigor, stunted growth, stiff, painful muscles, irritability and fatigue
B_2 Riboflavin (Vitamin G) $C_{17}H_{20}N_4O_6$ Water-soluble	Yeast, egg white, liver, kidney, green vegetables, fruits, milk, corn meal	Normal nutrition and growth	Scaly skin defects around ears and angles of mouth, itching, red eyes, disturbed metabolism, retarded growth
B_6 Pyridoxin $C_8H_{11}NO_3$	Yeast, wheat and corn germ, rice polishings, milk, livers of mammals Manufactured synthetically	Assumed to be essential for man but little is known; may assist in oxidation of food	Little is known for man, dermatitis in chicks and rats, paralysis in chickens
Niacin Nicotinic acid P-P Vitamin $C_6H_5NO_2$ Water-soluble Antipellagric	Liver, yeast, wheat germ, meat, egg yolk, green vegetables, adrenal gland Manufactured synthetically	Normal skin and digestion; affects cellular functions	Pellagra (lesions of the mucous membranes of mouth, gastrointestinal disturbances, mental disorders) in man (Fig. 372) and monkeys, pellagra in hogs, black-tongue in dogs
Pantothenic acid $C_9H_{17}NO_5$	Liver, kidney, rice bran, milk, yeast, molasses Manufactured synthetically	Functions unknown but seems essential for growth	Not known for man, causes pellagra-like symptoms in chickens, graying of black hair (rats)
B_{12} Rubramin Water-soluble Antianemic	Liver, liver extract	Treatment of pernicious anemia (by increasing red blood corpuscles, hemoglobin, and platelets), probably assists in maturing erythrocytes	Anemia which in certain cases may involve degeneration of spinal cord and inflammation of tongue, loss of strength, possible loss of appetite

SUMMARY OF IMPORTANT VITAMINS—CONT'D

VITAMIN	IMPORTANT SOURCES	FUNCTIONS	EFFECTS OF DEFICIENCY
C Ascorbic acid $C_6H_8O_6$ Water-soluble Antiscorbutic	Citrus fruits (lemon, orange), fresh fruits, certain fresh vegetables (cabbage, lettuce, potato, spinach, tomato, peppers) Manufactured synthetically	Protection against infections, assist in wound healing, normal teeth	Scurvy (affects bones, joints, mucous membranes; bleeding mucous membranes and beneath skin), fatigue, loss of weight, retarded growth, tooth decay
D Calciferol $C_{28}H_{44}O$ Fat-soluble Antirachitic	Animal fats, fish liver oils, milk, butter, egg yolk, oysters. Occurs in animals which manufacture it from ergosterol of plants when exposed to ultraviolet or sunlight	Normal bone growth, regulates calcium and phosphorus metabolism	Rickets (bone disease) in children, retarded growth, weak muscles, soft bones and defective teeth
E Tocopherol $C_{29}H_{50}O_2$ Fat-soluble Antisterility	Wheat germ, egg yolk, meats, lettuce, corn oil, cotton seed oil, alfalfa	Not known for man, normal production of male and female sex cells in rats	Sterility in rats and fowls, death of rats in uterus
H Biotin $C_{10}H_{16}N_2SO_3$	Vegetables, grains (cereals), nuts, eggs, liver, kidney Manufactured synthetically	Growth of man and other animals, occurs in higher animals and plants	Dry mucous membranes and skin
K $C_{31}H_{46}O_2$ Fat-soluble Antihemorrhagic	Liver, leafy vegetables (spinach, cabbage, etc.), soybean oil, alfalfa, grass	Normal blood clotting by producing prothrombin by the liver	Excessive bleeding because of delayed clotting

jejunum (eight feet long), and the *ileum* (twelve feet long). There are two layers of circular and longitudinal muscles for the peristaltic movement of foods. The inner walls of the small intestine are covered with large numbers of small, finger-shaped *villi* located on numerous *circular folds*. The villi and folds retain the foods for absorption and increase the absorbing area. (5) The *large intestine* or *colon* (five feet long) has two layers of circular and longitudinal muscles for the movement of foods and waste materials toward the anal opening. Faulty elimination of waste materials at the proper times from the large intestine results in their being reabsorbed. The large intestine has an enlarged pouchlike *cecum* at the junction of the small and large intestines, from which the pencil-shaped *vermiform appendix* arises. Inflammation of the latter is

Summary of the Digestive Processes in Man

REGION	SECRETION	ENZYME	REACTION	SUBSTANCES AFFECTED	PRODUCTS PRODUCED*
Mouth	Saliva (from salivary glands)	Ptyalin (diastase)	Alkaline	Starches (boiled)	Maltose (I)
Esophagus	None	None		None	None
Stomach	Gastric juice (from gastric glands of stomach)	Pepsin†	Acid	Proteins	Proteoses and peptones (I)
		Rennin	Acid	Milk proteins	Milk curdled; paracasein (I)
		Lipase (gastric)	Acid	Fats and lipins	Fatty acids and glycerin (F)
Small intestine	Bile (from liver)	None	Alkaline	Aids the pancreatic lipase to split fats into fatty acids and glycerin; no foods digested	
	Pancreatic juice (from the pancreas)	Amylopsin (diastase) (amylase)	Alkaline	Starches	Maltose (I)
		Steapsin (lipase)	Alkaline	Fats (emulsified)	Fatty acids and glycerin (F)
		Trypsin‡	Alkaline	Proteins, peptones, proteoses	Amino acids (F)
	Intestinal juice, or *Succus entericus* (from the intestine)	Erepsin	Alkaline	Peptones, proteoses	Amino acids (F)
		Maltase	Alkaline	Maltose	Dextrose (F)
		Lactase	Alkaline	Lactose (milk sugar)	Dextrose and galactose (F)
		Invertase or sucrase	Alkaline	Sucrose (cane sugar)	Dextrose and levulose (F)
		Enterokinase	Alkaline	‡Activates the inactive trypsinogen of the pancreatic juice and changes it into active trypsin (see above)	
Large intestine	None	None		None	None

*(I), Intermediate product; (F), final product.

†When acting with hydrochloric acid of the stomach.

‡The inactive trypsinogen of the pancreatic juice is changed into active trypsin by the enterokinase of the intestinal juice.

known as appendicitis. Extending upward on the right side from the cecum is the *ascending colon*. The *transverse colon* connects the latter with the *descending colon* which descends down the left side of the lower abdominal cavity. The *sigmoid* connects the lower end of the descending colon with the *rectum*. The latter empties externally through the *anus*. (6) The *liver* is the largest gland in the body and is divided into the *right* and *left lobes*. It is located just below the diaphragm and in the adult weighs about 2.8 per cent of the total body weight. The liver arises embryologically as an outgrowth of the duodenum and migrates to its normal position below the diaphragm. The liver manufactures *bile* from the red blood corpuscles and pours it into the *gall bladder* through the *cystic duct*. The *bile duct* leads from the gall bladder to the duodenum. (7) The *pancreas* is an elongated organ, about two by six inches, which lies between the stomach and the duodenum. In adult human beings it weighs about 2½ ounces. Certain cells of the pancreas secrete the *pancreatic juice* which is carried by the *duct of Wirsung* to the common bile duct. In some cases the duct of Wirsung and the common bile duct open separately into the duodenum.

V. CIRCULATION IN MAN

The circulatory system is a so-called "closed system" composed of a heart, contractile arteries, capillaries, and veins. The muscular, cone-shaped heart is about the size of a fist and is divided by a partition into right and left sides. Each side is divided into an upper chamber called the *atrium* (auricle)* and a lower, more muscular, *ventricle*. The very muscular *left ventricle* pumps oxygenated blood (Figs. 237 to 241) through the *aorta* (artery) to all parts of the body (except lungs). From all parts of the body (except lungs) blood is carried back to the *right atrium* through a series of *veins*. From the *right atrium* the blood passes through the *right atrioventricular valve* (tricuspid valve) into the *right ventricle* from which it is pumped through the *pulmonary arteries* to the lungs where it is oxygenated. The blood is returned from the lungs by *pulmonary veins* (two right and two left) to the *left atrium*, from which it passes through the *left atrioventricular valve* (bicuspid valve) into the *left ventricle*. The portion of the system which supplies the body is called the *systemic circulation* and the part which carries blood to the lungs to be oxygenated is the *pulmonary circulation*. These, however, are all one complete circulation unit.

*The terms atrium and auricle are sometimes used synonymously, as are auriculoventricular and atrioventricular, although there are minor differences. Atria is the plural of atrium.

The *heart* is enclosed by a double-walled membranous sac known as the *pericardium* whose surfaces are kept moist by a secretion of *serum* for lubricating purposes (Figs. 237 to 239). The walls of the atria and ventricles consist of (1) an inner epithelial lining known as the *endocardium* (Gr. *endo,* within; *cardium,* heart), (2) a middle muscular layer called the *myocardium* (Gr. *myo,* muscle), and (3) an outer, single layer of mesothelial cells called the *pericardium* (Gr. *peri,* around). In a heartbeat the contraction phase is called the *systole,* while the relaxation phase is called the *diastole,* and the two constitute a *"cardiac cycle."*

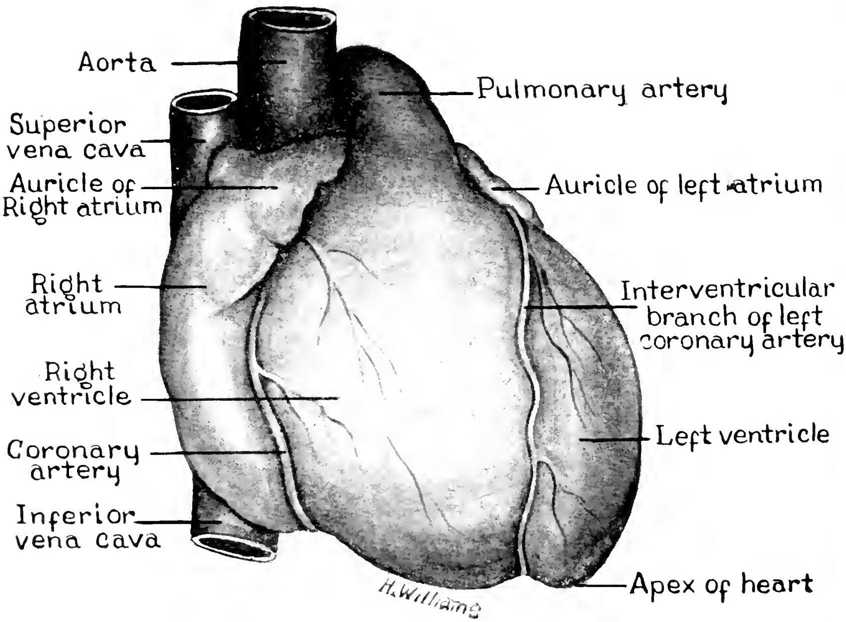


Fig. 237.—Human heart, front view, showing some of the blood vessels. The aorta (artery) carries blood from the left ventricle to all parts of the body (except lungs). The pulmonary arteries carry blood from the right ventricle to the lungs. The coronary arteries arise from the aorta to supply blood to the walls of the heart. Both the superior vena cava (also known as the precaval vein) and the inferior vena cava (known as the postcaval vein) return blood from the body (except lungs) to the right atrium. The atrium has an outpouching called the auricle because of its earlike shape. The pulmonary veins (two right and two left) return oxygenated blood from the lungs to the left atrium. The blood from the heart walls is returned by way of the coronary sinus (not shown) to the right atrium. The opening between the right atrium and right ventricle is closed by the right atrioventricular valve (tricuspid valve, because it has three cusps). The left atrium and left ventricle are separated by the left atrioventricular valve (mitral valve, has only two cusps). (From Francis, Knowlton, and Tuttle: Textbook of Anatomy and Physiology, The C. V. Mosby Co.)

When a heart beats 70 times per minute, a cardiac cycle requires less than one second. During contraction the heart undergoes electrical changes, the active cardiac muscle is electrically negative to an inactive cardiac muscle. These action currents can be recorded by a special instrument called the electrocardiograph. The record known as an electrocardiogram shows a series of waves which are correlated with heart actions.

Arteries (Figs. 237 to 241) are a series of vessels whose walls are rather thick, contractile, and elastic. They consist of (1) an inner layer of *endothelial cells* and elastic tissue, (2) a middle or intermediate layer of *muscle* and elastic tissue, and (3) an external layer of *elastic* tissues. Arteries carry blood away from the heart while veins carry blood back toward the heart.

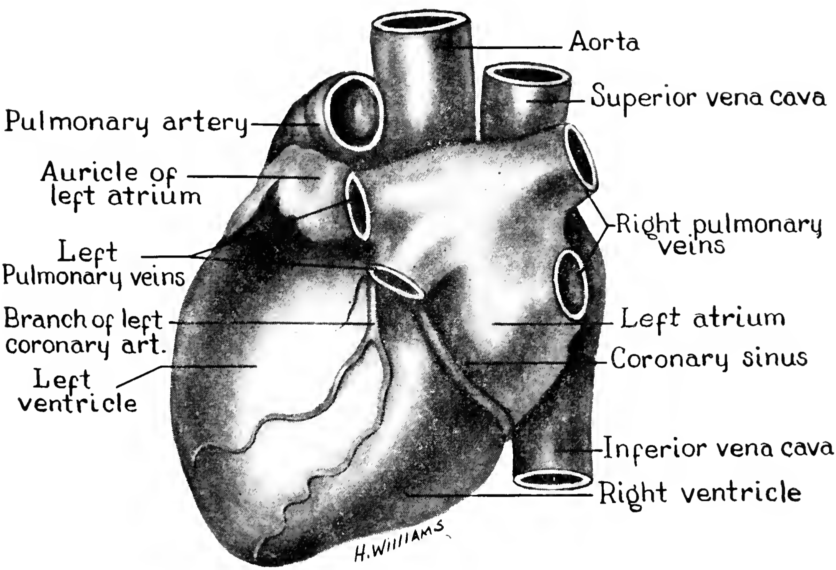


Fig. 238.—Human heart, posterior (back) view. (Compare with Figs. 237 and 239.) (From Francis: Introduction to Human Anatomy, The C. V. Mosby Co.)

Veins (Figs. 237 to 239) are a series of vessels whose structure resembles that of arteries, being composed of three layers, but whose walls are thinner and less elastic because of a poorly developed middle layer and the presence of very little muscle and elastic tissue. Certain veins, especially those of the lower extremities, have a series of *semilunar valves* to prevent the backflow of blood. In general, the *systemic veins* accompany the systemic arteries, frequently having the same names as the arteries. However, many *systemic veins* are distributed in two sets: (1) *deep* and *superficial veins* and (2) special veins, called the *portal system,* which carry the blood from the digestive tract back to the heart.

Three *systemic veins* return blood to the right atrium: (1) the *coronary sinus* (vein) returns blood from the heart walls, (2) *superior vena cava* (also called *precaval vein*) returns blood from the head, neck,

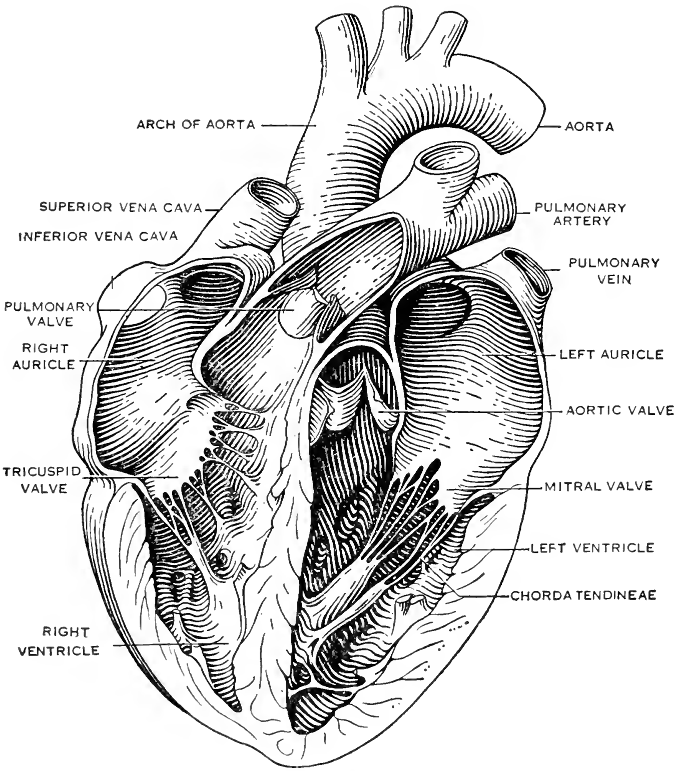


Fig. 239.—Human heart shown in longitudinal section. (From Haggard: Man and His Body; Copyright, 1927, 1938, by Harper & Brothers.)

thorax, and upper extremities, and (3) *inferior vena cava (postcaval vein)* returns it from the abdomen, pelvis, and lower extremities. The *superior vena cava* is formed by the union of the two *innominate veins,* and it receives the *azygos vein* which drains the abdominal region. Each *innominate vein* is formed by the subclavian vein and the *internal jugular vein* (blood from brain, etc.). The *external jugular veins* (right and left) receive blood from the face and scalp (regions supplied by the external carotid artery) and empty into the subclavians just before subclavian and internal jugular unite to form the innominate. The veins of the upper extremity enter the subclavian vein. The deep veins of the upper extremity accompany the corresponding arteries and have the same names: *axillary, brachial, radial,* and *ulnar veins.* The superficial veins of the upper extremity are (1) *cephalic,* (2) *basilic,* and (3) *median.* All arise from the dorsal part of the hand: the *cephalic* runs

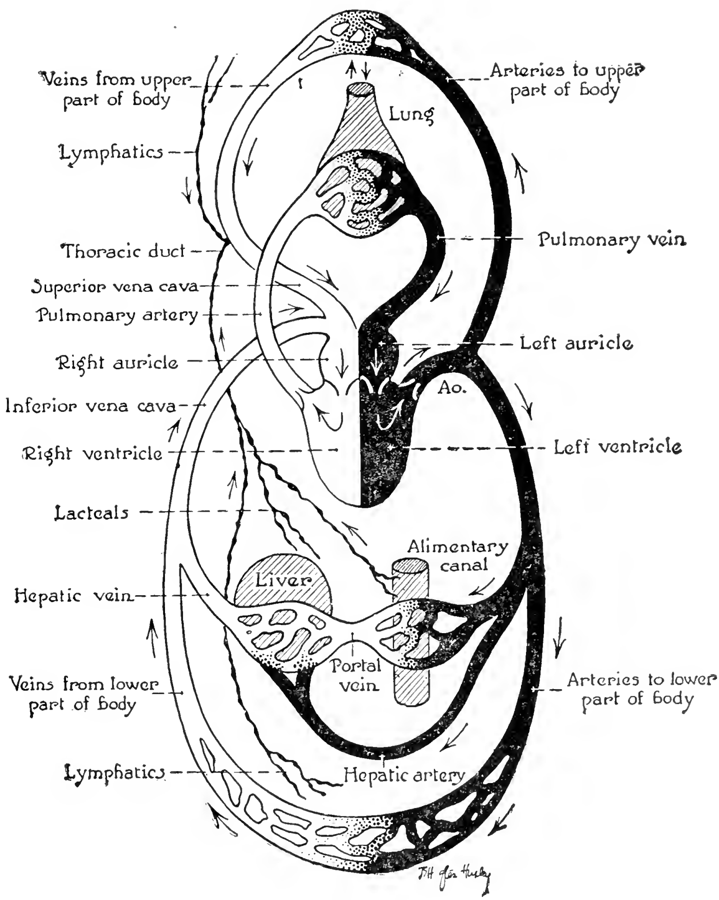


Fig. 240.—Diagram of circulation in a mammal. Only the general courses of circulation are shown diagrammatically. Arrows show the direction of blood flow. Oxygenated blood is shown in black; venous blood in white. The lymphatics are the black irregular lines. (See Figs. 237-239 and 241.) (From McClendon and Pettibone: Physiological Chemistry, The C. V. Mosby Co.)

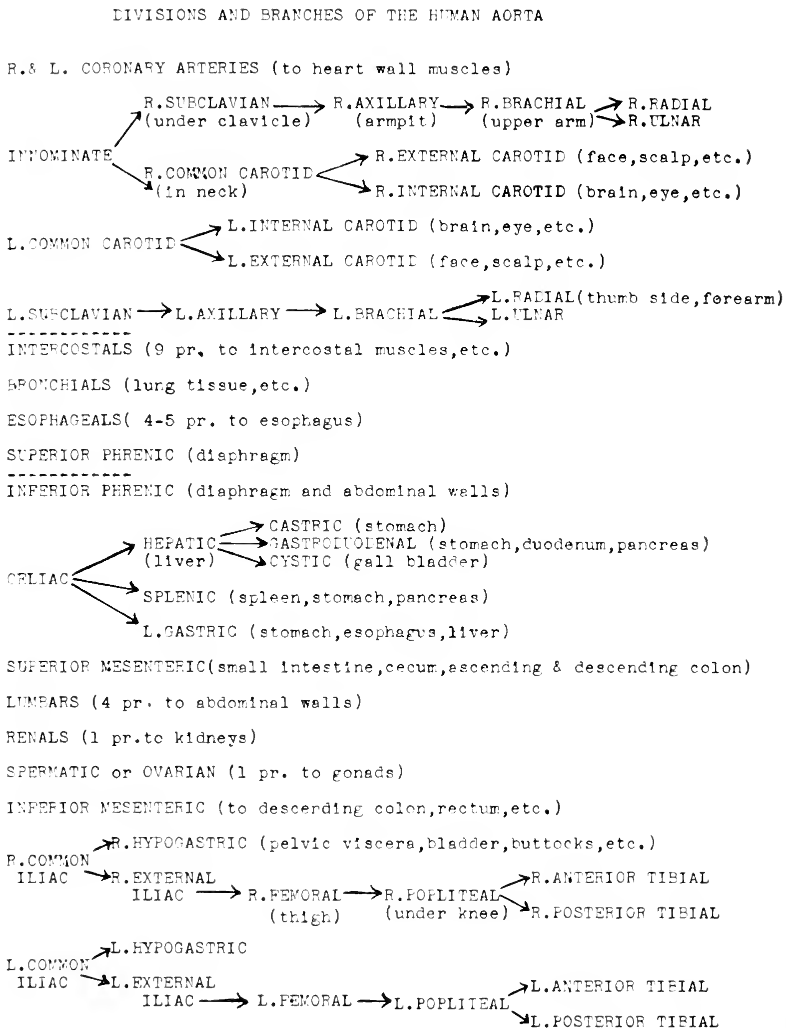


Fig. 241.—Divisions and branches of the human aorta (artery) which arises from the left ventricle of the heart. Most of the more important branches are given somewhat in the order of their origin. The coronary arteries arise from the ascending part of the aorta; the innominate, left common carotid and left subclavian from the aortic arch; the next four from the thoracic aorta; the last group from the abdominal aorta. *R*, right; *L*, left. Also listed are the regions in which the arteries travel or the tissues and organs to which they supply blood.

along the lateral surface of the arm and empties into the axillary; the *basilic* runs along the inner surface and empties into the axillary; the *median* runs between the other two and connects them.

The *inferior vena cava* is formed by the union of the *right* and *left common iliac veins* (at about the level of the fifth lumbar vertebra) and accompanies the aorta along the posterior abdominal and thoracic wall, receiving such veins as the *renal* (kidneys), *ovarian* or *spermatic* (gonads), *hepatic* (from liver), *lumbar* (back), *phrenic, intercostals* (between ribs, etc.). The deep veins of the lower extremity follow the arteries. The two superficial veins of the lower extremity are (1) the *great saphenous vein* which arises in the medial side of the foot, passes along the medial side of the leg, and empties into the femoral vein and (2) the *small saphenous* which arises in the lateral side of foot and empties into the popliteal vein. The veins which return the blood from the digestive organs constitute the *portal system* which detours the blood through the liver and then into the inferior vena cava. This blood is changed in several ways by the liver to prepare it for entrance into the general systemic circulation.

Capillaries are thin-walled vessels which form a network connecting the arteries and veins. The walls are a single layer of flat *endothelial cells.* The capillaries are so numerous that one can hardly touch any part of the body without touching capillaries. Through them the exchange of materials takes place because of their thin walls and the slow movement of the blood within. An average capillary is about 8 microns in diameter. Compare this with the diameter of a red blood corpuscle.

Functions of the Blood System

(1) *Respiratory*—transporting oxygen to the tissues and carbon dioxide from them; (2) *excretory*—carrying waste materials from the tissues to the organs of excretion; (3) *nutritive*—transporting sugars, amino acids, fats, minerals, and vitamins from the digestive system to the body tissues; (4) *regulatory*—transporting water to and from various organs so that the water content may be fairly constant, equalizing body temperature by carrying water throughout the body and giving it off from the vessels near the surface, distributing foods to the endocrine organs (ductless glands) and transporting secretions (hormones) produced by them; (5) *protective*—defending the body by means of the phagocytic action of certain white blood corpuscles, and the circulation of specific antibodies (antitoxins, etc.); (6) the *maintenance of the proper acid-alkaline* reaction of the various parts of the body.

Blood

Blood is a liquid tissue, sometimes classified with the connective tissues, sometimes separately. It consists of clear, straw-colored *plasma* in which are suspended the *red blood corpuscles (erythrocytes),* the various types of *white blood corpuscles (leucocytes),* and the *blood platelets,* the latter assisting in blood clot formation. Blood forms about one-thirteenth of the total body weight and in an average man totals about 6 liters (over 6 quarts). Arterial blood is bright red, while venous blood is dark red, depending upon the amount of oxygen present. Blood is somewhat viscous and slightly heavier than water. Blood is slightly alkaline (pH of 7.35).

Erythrocytes (e -rith′ ro site) (Gr. *erythros,* red; *kytos,* cell) constitute about 50 per cent of the volume of blood. When mature they are *without a nucleus* and consist of a supporting framework known as the *stroma* (Gr. *stroma,* bedding) and *hemoglobin* (he mo -glo′ bin) (Gr. *haima,* blood; *globos,* sphere). *Hemoglobin* consists of a protein and an iron-containing compound, the latter being responsible for the chemical affinity for oxygen. When hemoglobin carries oxygen, it is known as *oxyhemoglobin* and liberates its contained oxygen where needed. *Anemia* (an e′ me ah) (Gr. *an,* deficient; *aima,* blood) is a condition in which there is a decrease in the number of erythrocytes or in the amount of hemoglobin or in both. These conditions may occur from impaired blood formation or increased destruction of erythrocytes or both. When blood escapes from an injured blood vessel, it is known as a *hemorrhage* (hem′ or aj) (L. *haemorrhagia,* blood, to break). The following correlated measures are taken when a hemorrhage occurs: (1) clotting of blood at the site of the injury, (2) decrease in the general blood pressure, (3) contraction of the small vessels of the skin, muscles, and intestines in order to supply the vital parts of the body, (4) increase the blood volume by the contraction of the spleen which normally contains a large quantity of blood, and (5) passage of water and salts from the tissues into the capillaries because of increased osmotic pressure.

Leucocytes (lu′ ko site) (Gr. *leukos,* white; *kytos,* cell) because of their amoeboid movements are able to escape from the blood vessels and penetrate into the body tissues. Leucocytes may be classified as (1) *granulocytes* (granular leucocytes) with distinguishing granules in the cytoplasm and (2) *agranulocytes* (nongranular leucocytes) without granules in the cytoplasm. Because of the variations in the lobes of the nuclei of the granulocytes, the latter are sometimes referred to as *poly-*

morphonuclear leucocytes (poli mor fo -nu′ klear) (Gr. *poly,* many; *morphe,* form; L. *nucleus,* kernel or nucleus). They act as *phagocytes* (fag′ o site) (Gr. *phagein,* to eat; *kytos,* cell) by engulfing bacteria, cells fragments, and foreign materials. The granulocytes are classified in three groups according to the type of granules in their cytoplasm: (1) *eosinophils* (e o -sin′ o fil) (Gr. *eos,* dawn; *philein,* to love), which stain readily by eosin (acid) stains; (2) *neutrophils* (nu′ tro fil) (L. *neuter,* neither; Gr. *philein,* to love), which stain by neutral dyes; (3) *basophils* (ba′ so fil) (Gr. *basis,* base; *philein,* to love), which stain well with basic stains.

The *agranulocytes* lack cytoplasmic granules and are classified in two groups: (1) *lymphocytes* (lim′ fo site) (L. *lympha,* lymph or water; Gr. kytos, cell) and (2) *monocytes* (mon′ o site) (Gr. *monos,* alone; *kytos,* cell), both being formed in the lymphoid tissue. It is thought that

Human Blood

	RED BLOOD CORPUSCLES (ERYTHROCYTES)	WHITE BLOOD CORPUSCLES (LEUCOCYTES)	BLOOD PLATELETS
Nucleus	No nucleus when mature; nucleus when immature	Always nucleated (various kinds)	None
Shape	Flat, biconcave disks	Variable	Oval, biconvex disks
Motile	No	Amoeboid movement	No
Diameter	7.7 microns	8 to 15 microns (depending on type)	3 microns (average)
Hemoglobin	Present (in mature stage only)	None	None
Number	4,500,000 (women) and 5,000,000 (men) per cubic millimeter	5,000 to 9,000 per cubic millimeter	250,000 per cubic millimeter
Where formed	In adult—red bone marrow (of sternum, ribs, vertebrae, certain parts of femur, humerus and cranial bones) In embryo—bone marrow and liver	In red bone marrow and lymphoid tissue (depending on type)	Bone marrow
Where lost	Liver and spleen	Liver and lumen of intestine	Disintegrate rapidly which may explain variations in number
Length of life	Short (10 to 100 days)	Unknown	Unknown
Functions	Carry oxygen and aid in transportation of carbon dioxide	Protect against bacteria, cell fragments and foreign particles, repair tissues	Clotting of blood

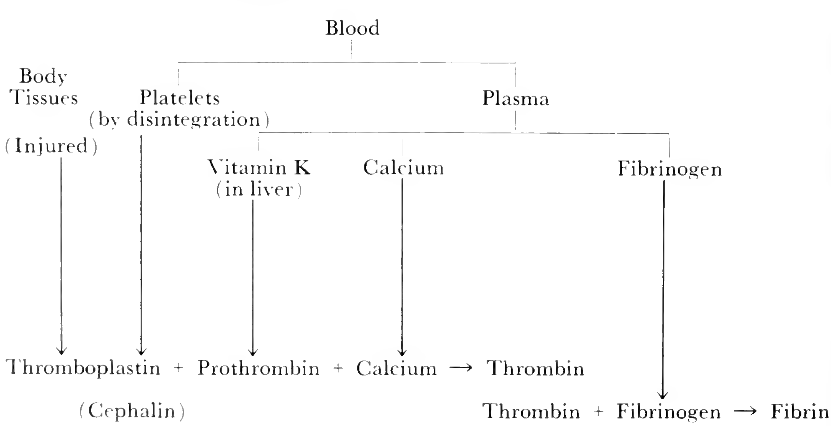
lymphocytes contribute to the repair of wounds by connective tissue formation and give origin to the monocytes. A summary of the various types of blood corpuscles and blood platelets is given in tables so they may be compared and contrasted more easily. A decrease in the number of leucocytes is called *leucopenia* (lu ko -pe′ ne ah) (Gr. *leukos,* white; *penes,* poor) and an increase is *leucocytosis* (lu ko si -to′ sis) (Gr. *kytos,* cell).

SUMMARY OF LEUCOCYTES

TYPE	PER CENT OF TOTAL LEUCOCYTE COUNT	DIAMETER IN MICRONS	CHARACTERISTICS
GRANULOCYTES 1. *Neutrophils*	65-75	10-12	Fine light blue cytoplasmic granules, 3 to 5 lobed nucleus
2. *Eosinophils (Acidophils)*	2-5	12	Bright red cytoplasmic granules (Wright's blood stain), nucleus with 2 lobes
3. *Basophils*	0.5	10	Large, dark purplish-blue cytoplasmic granules (Wright's stain), irregular nucleus, often S-shaped
AGRANULOCYTES 1. *Lymphocytes*	20-25	8	Thin layer of nongranular, robin's-egg blue cytoplasm (Wright's stain), large bright purple nucleus
2. *Monocytes*	3-8	15	Thick layer of nongranular cytoplasm, large horseshoe- or kidney-shaped, purple nucleus (Wright's stain)

Clotting (Coagulation) of Human Blood

The chemical process which blood undergoes when it clots is quite complicated. Several theories have been proposed to explain the process. A brief summary will illustrate the more important stages.



Thrombin (throm′ bin) (Gr. *thrombos,* clot) as such does not exist in significant amount in unshed blood or it might start the formation of a clot in normal, circulating blood, but the thrombin is thought to exist as inactive *prothrombin* (Gr. *pro,* before). In normally circulating blood it is thought that *heparin* (hep′ a rin) (Gr. *hepar,* liver) formed in the liver is combined with *cephalin (thromboplastin)* (sef′ a lin) (Gr. *kephalos,* head). Consequently, the lack of cephalin prevents the forming of thrombin from prothrombin; hence there is no clotting in normal circulating blood. When hemorrhage occurs (tissue injury and destruction of blood platelets), more cephalin is formed than can combine with the heparin. The excess *cephalin* combines with the *prothrombin* and *calcium salts* to form *thrombin.* The latter combines with a soluble protein of the blood plasma known as *fibrinogen* (fi -brin′ o jen) (L. *fibra,* band; Gr. *genos,* to produce) to form the *fibrin* (network of insoluble, contractile threads). Fibrin collects blood corpuscles and other available materials to form the *clot.* Vitamin K seems to be necessary for the formation (in the liver) of the prothrombin which is normally present in the plasma and has a life duration of only a few days. Vitamin K must have bile from the liver in order to be absorbed in the intestine and transported to the liver for the formation of prothrombin. Vitamin K may be ingested as such or may be manufactured from foods in the intestine. The formation of a clot within a blood vessel which is not severed is called a *thrombus* (Gr. *thrombos,* clot). This may be due to injury of the vessel wall from a blow or from toxins of bacteria which injure the blood platelets. If a part of a thrombus circulates in the vessels, it is called an *embolus* (em′ bo lus) (Gr. *embolos,* wedge). If the embolus should block circulation to a vital part, serious consequences may result.

Structure and Functions of Human Lymph

The composition of the lymph is similar to that of the blood plasma. It ranges from colorless to yellowish color, has an alkaline reaction, contains no blood platelets, clots slowly and not firmly, has a higher percentage of waste materials than blood, contains a lower percentage of nutrient materials than blood, may contain a few red blood corpuscles (erythrocytes), and contains lymphocytes (white blood corpuscles).

The lymph is derived from (1) the blood plasma by filtration through the thin walls of the capillaries and (2) secretions of the endothelial cells which line the numerous capillaries.

The functions of human lymph may be summarized as follows: (1) It bathes all parts of the body not reached directly by the blood, thus supplying foods, oxygen, etc., and receiving carbon dioxide and wastes. There is a continuous interchange between the blood plasma and the lymph through the processes of osmosis and diffusion. (2) It aids in the fight against foreign materials, such as bacteria and protozoa. (3) It helps to equalize body temperature. (4) It helps to regulate the acid-alkaline balance of the various parts of the body. (5) It helps to

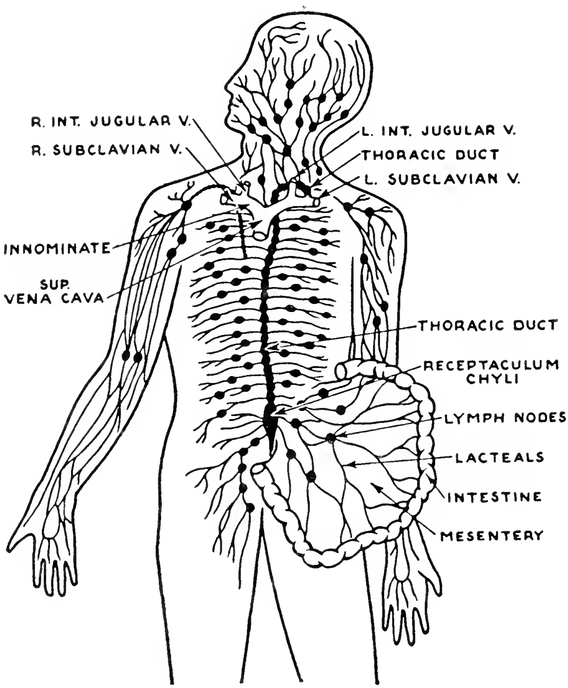


Fig. 242.—Lymph system and parts of certain veins of the upper part of the body. Lymph from the abdominal organs and lower limbs flows into the thoracic duct which empties into the left subclavian vein. The lymphatics from the left arm, and the left sides of the thorax, neck, and head also empty into the thoracic duct. Lymph from the right arm and the right sides of the thorax, neck, and head flows into the right subclavian vein. (From Zoethout and Tuttle: Textbook of Physiology, The C. V. Mosby Co.)

collect and transport fatigue products which are the result of cellular activity. (6) It probably aids in transporting enzymes and other secretions to various body parts (Figs. 240 and 242).

Human lymph may be found in various places and consequently may have a variety of functions. The principal locations are (1) in the lymph ducts and their enlargements, the lymph nodes, (2) in tissue spaces (tissue sinuses) or cavities in various tissues, (3) in the pleural cavity (around the lungs), (4) in the pericardial cavity (around the heart), (5) in the peritoneal cavity (abdominal cavity), (6) in the peri-neural cavities (spaces between the various linings of the brain and spinal cord), and (7) in the lacteals or lymphatics which originate in the small fingerlike villi of the intestine. Fats are absorbed from the intestine by the lacteals and eventually placed in the blood stream.

Human Blood Groups

The various types of human blood are classified as (1) Groups A, B, AB, and O, (2) Groups M and N, and (3) Rh positive and Rh negative. These are considered later in this chapter under Inheritance of Human Traits.

VI. RESPIRATION IN MAN

Respiration may be defined as the supplying of oxygen to all cells of the body and the removal of carbon dioxide from them. *Breathing* may be defined as the rhythmic *inhalation* of air into the *lungs* and the *exhalation of carbon dioxide* and other gases from them (Fig. 244). The composition of inhaled (inspired) air and of exhaled (expired) air is:

	INHALED AIR (PER CENT)	EXHALED AIR (PER CENT)
Oxygen	20.96	15.8
Carbon Dioxide	0.04	4.0
Nitrogen	79.00	80.2

Respiration is controlled by the *respiratory center* of that portion of the brain called the *medulla oblongata* (Fig. 247), whose activity is influenced by nerve impulses over afferent nerves leading to it and by chemicals which influence the center either directly or reflexly. During inhalation the size of the thorax (Fig. 243) is increased by contraction of the respiratory muscles, thereby decreasing the pressure within the lungs and allowing the greater pressure of the external air to force it into the lungs until the pressures are equalized. During exhalation the size of the thorax is decreased by relaxation of the respiratory muscles, thus forcing out a certain quantity of the air from the lungs and allowing a certain amount to remain. In adults, during rest, the normal rate of respiration varies from 12 to 20 per minute, although these figures may vary with different individuals. A certain amount of respiration takes

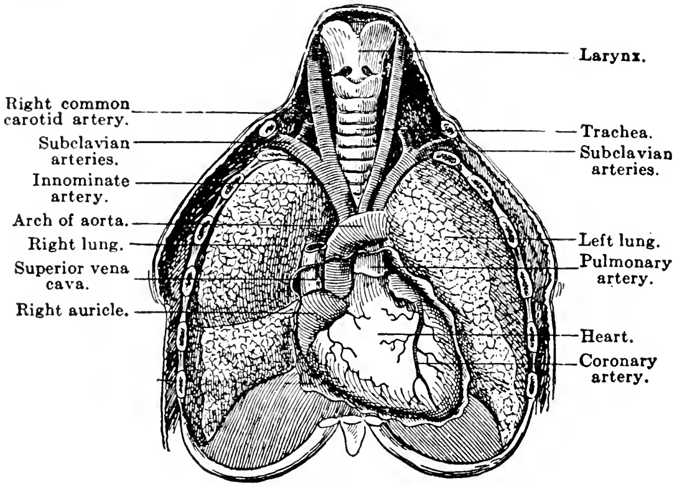


Fig. 243.—Organs of the human thoracic cavity. (From Turner: Personal and Community Hygiene, The C. V. Mosby Co.; after Ingals.)

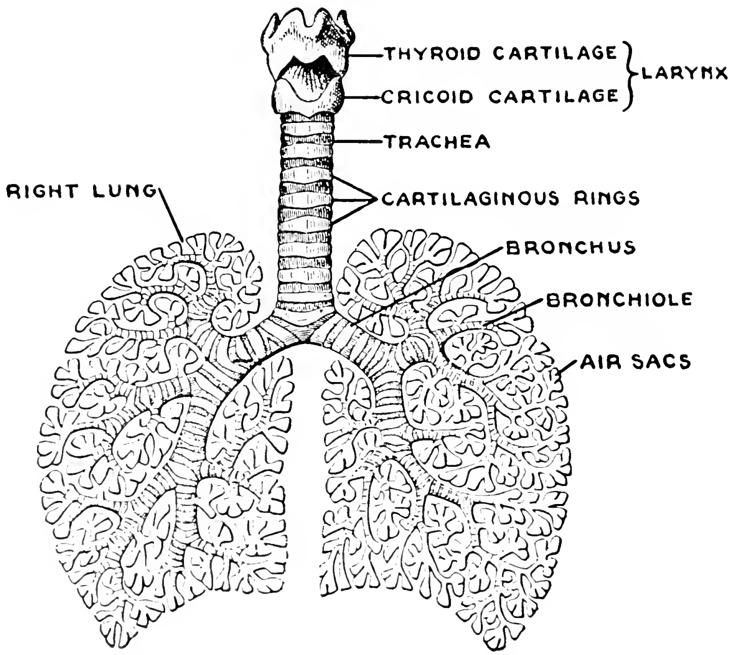


Fig. 244.—Human respiratory system shown in section. The walls of the air sacs are dilated to form alveoli whose thin walls are covered with a network of capillaries for the exchange of gases. (From Zoethout and Tuttle: Textbook of Physiology, The C. V. Mosby Co.; after Dalton.)

place through the integument (skin) (Fig. 228) which has been previously described. However, it is estimated that the total inner surface of the lungs is about 90 square meters or more than one hundred times the total skin area of the body. The vital capacity of the average adult lungs represents the maximum volume which can be exchanged in a single respiration. This is about 4,000 c.c. (eight pints), although it varies with different individuals and conditions. The following phenomena occur in the lungs: (1) loss of about 5 per cent of the oxygen from the inhaled air, (2) gain of about 4 per cent of carbon dioxide, (3) gain of about 1 per cent of nitrogen, (4) saturation of the expired air with moisture (about 1 pint daily), (5) warming the expired air to nearly that of the blood (98.6° F.), thereby losing body heat, (6) transfer of oxygen and carbon dioxide through the thin-walled air sacs of the lungs (Figs. 234, 235, 243, and 244).

Respiration involves (1) the exchange of gases between the respiratory membrane and the capillaries of the pulmonary circulation within the lungs, known as *external respiration* and (2) the exchange of gases between the capillaries of the systemic circulation and the body tissue known as *internal respiration*.

The *respiratory system* is composed of the nose, pharynx, larynx (voice box or "Adam's apple"), trachea (windpipe), bronchi, and lungs (Figs. 234, 235, 243 and, 244). The nose is divided by a partition (septum) to form two wedge-shaped cavities which are lined by a highly vascular, mucous membrane, the upper layer of which is ciliated. Sinuses in the bones are associated with the nasal cavities so that inflammations may spread to the sinuses easily. The lateral surface of each nasal cavity has three light, spongy, bony projections called *conchae* to make the upper part of the nasal passages very narrow. The nose has the following functions: (1) to act as a sounding board for the voice (organ of phonation), (2) to give warmth and moisture to the inhaled air, (3) to remove dust and other foreign materials by hair, cilia, and mucus (secreted by goblet cells), and (4) to detect odors by means of the olfactory nerve endings in the upper passages.

The *pharynx* is a common cavity (Fig. 234) which connects the nasal cavities with the larynx as well as the mouth with the esophagus. Because of this dual function it is impossible to inhale air and swallow food at the same time.

The *larynx* is a cartilaginous box which forms the prominence in the midline of the front part of the neck. Within the laryngeal cavity are two folds of mucous membrane extending from front to back but not quite meeting in the middle. Embedded in the edges of these folds are fibrous and elastic ligaments which constitute the *true vocal folds (vocal cords)*, because they function in voice production as air passes between them. Above the vocal folds are two smaller folds which do not aid in voice production but protect the larynx during swallowing, help keep the true vocal folds moist, and assist in holding the breath. They are called the *false vocal cords*. The opening between the true vocal folds is the *glottis*. The size of the glottis and the tension of the vocal folds regulate the tone produced. The glottis is protected above by a leaf-shaped fibrocartilage called the *epiglottis*.

The *trachea* is a membranous tube about four inches long located in front of the esophagus. The walls are strengthened by sixteen to twenty cartilaginous, C-shaped structures. It extends from the lower end of the larynx to the two branches, each of which is known as a *bronchus* (plural, bronchi). Each bronchus divides and subdivides, the smallest branches being the *bronchioles*. Each bronchiole terminates in a series of saclike *air cells (alveoli)*. The thin-walled alveoli are surrounded by thin-walled *capillaries* through which the exchange of gases occurs.

The two *lungs* are cone shaped and lie in the thorax (Figs. 235 and 243), being separated by the thick *mediastinum* which contains the heart, larger blood vessels, trachea, etc. The left lung is smaller and longer than the right because the heart occupies part of this space. Each lung is enclosed in a serous sac called the *pleura*, which consists of an outer layer, or *parietal pleura*, which adheres closely to the diaphragm and the walls of the thorax, and a *visceral pleura* which covers the lungs. The two pleurae are separated by a thin layer of *serum* to reduce friction. Inflammation of the pleura is called *pleurisy*.

VII. EXCRETION OF WASTES

The excretion of human wastes may be considered as the elimination from the body of the undesirable products of metabolism and other activities and includes liquids, gases, and solids (soluble and insoluble). The elimination of indigestible materials which have served no purpose might be considered as egestion.

Excretory organs and the waste materials eliminated may be summarized on page 493.

The pair of bean-shaped *kidneys*, located at the back of the abdominal cavity, one on each side of the vertebral column, select wastes from the blood brought to them and pass them through the *ureters* to the *urinary*

	PRIMARY	SECONDARY
Kidneys (Fig. 245)	Water, soluble salts	Carbon dioxide, heat
Lungs (Fig. 244)	Carbon dioxide (12 cubic feet daily)	Water (250 c.c. daily), heat
Skin (Fig. 228)	Water, salts, carbon dioxide, heat	Dead skin, nails, etc.
Alimentary canal (Fig. 236)	Solids, secretions	Water, carbon dioxide and other gases, salts, heat
Liver (Fig. 236)	Bilirubin formed from hemoglobin of blood and excreted by the intestine; collect end-products of protein metabolism and convert them into urea, etc., to be excreted by kidneys	

bladder where wastes are stored (Fig. 245). Each *kidney* consists of an outer cortical substance *(cortex)* and an inner medullary substance *(medulla)*. When examined microscopically, the cortex contains numerous

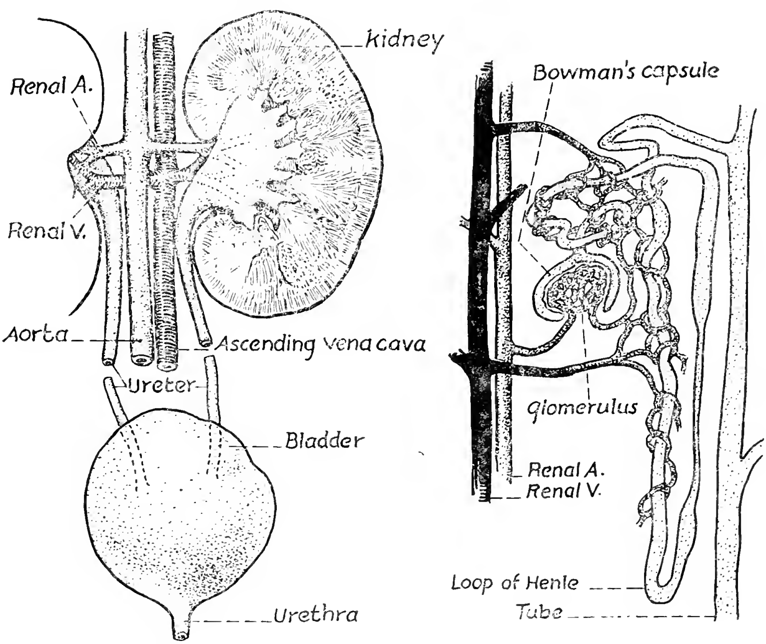


Fig. 245.—Human urinary system. One kidney has been dissected to show the internal structures. At the right, the details of the blood vessels and the collecting tubes are shown. The latter empty the urine into the enlarged end of the ureter which transports it to the bladder. The outer portion of the kidney is the cortical region (cortex) and the inner portion, which contains the numerous glomeruli and tubes, is known as the medullary region.

globelike *renal (Malpighian) corpuscles,* each of which is composed of (1) a coiled mass of thin-walled *capillaries* arising from the *renal arteries,* each mass being called a *glomerulus,* and (2) a thin double-walled enclosing *glomerular capsule (Bowman's capsule)* which is the beginning of a *renal tubule* (Fig. 245). The convoluted *renal tubules* travel irregularly and empty into the straighter *collecting tubes* which in turn pass the urine into the basinlike *pelvis* of the kidney from which it goes out through the *ureter* (Fig. 245). The blood from the *glomeruli* eventually passes from the kidney through the *renal veins* into the *ascending vena cava.* When examined microscopically, the medulla consists of cone-shaped *renal pyramids* whose apices are known as *renal papillae.* The *collecting tubes* empty at the apices of the *papillae,* which vary from eight to eighteen in number.

The *glomeruli* extract the wastes from the blood, thus helping to maintain the normal composition of the blood. The kidneys selectively extract almost all the protein waste, most of the salts not required by the blood, and about half of the excess water. They also extract foreign substances such as toxins. The quantity of urine secreted in twenty-four hours varies, but the normal average for a healthy adult is 1,200 to 1,500 c.c.

The contractions of the muscles in the walls of the *ureters* cause the urine to pass toward the muscular *bladder* located in the pelvic cavity. The bladder normally holds about one pint, and the contraction of its three layers of muscles forces the urine to the exterior through the tubular *urethra.*

VIII. COORDINATION IN MAN AND SENSORY EQUIPMENT

All living protoplasm is necessarily irritable or subject to stimulation. A *stimulus* is any external or internal substance, material, or condition which affects a cell or group of cells, thereby setting up a change known as a *response.* General types of *stimuli* are chemical, electrical, thermal, mechanical, radiant, and osmotic. General types of *responses* are movement, secretion, thermal, chemical, electrical, and photic. The responsive mechanisms of man are complex and varied. The three steps involved are as follows: (1) a special structure called a *receptor* must be stimulated; (2) some method of *conduction* of the effects of stimulation to (3) a specialized structure called an *effector* which must respond in some way. *Receptors* in man are frequently specialized epithelial cells in close association with the conductors. The following is a brief summary of the *receptors* of man:

1. *Chemoreceptors* (receptors sensitive to chemicals)
   (a) *Taste buds* on the tongue are clusters of specialized epithelial cells (Fig. 11) closely associated with nerves leading to the brain (Figs. 246 and 247).
   (b) Ends of sensory nerves in the nasal epithelium (Fig. 11) receive the stimuli of *odors*, thus giving us a sense of *smell*.
2. *Mechanoreceptors* (receptors sensitive to mechanical stimuli)
   (a) *Tactile (touch)* receptors *(Meissner's corpuscles)* over much of the body, but especially beneath the epidermis on the hands and within the digestive tract (hunger).

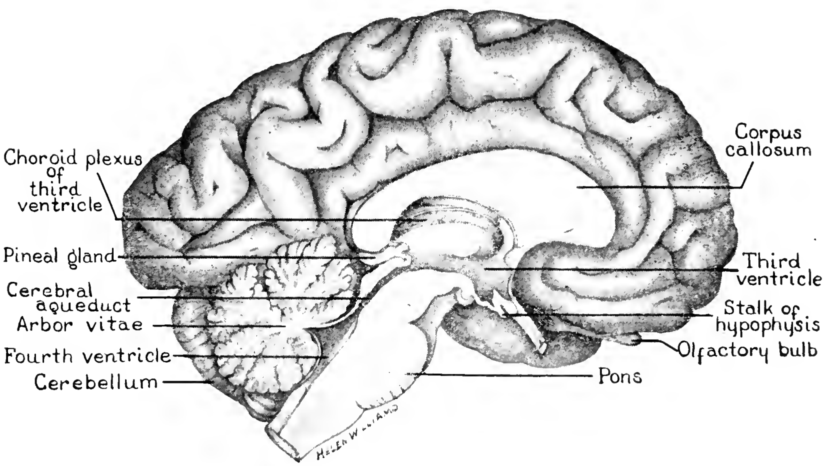


Fig. 246.—Human brain in sagittal section, showing the medial aspect of the left half. The convoluted cerebrum (cerebral hemisphere) is shown above the corpus callosum and the spinal cord below the pons. (From Francis: Fundamentals of Anatomy, The C. V. Mosby Co.)

   (b) *Auditory (hearing)* receptors which are vibrating "hair cells" located in the cochlea of the inner ear (Fig. 250). Sound waves enter the external ear and vibrate the *tympanic membrane* which transmits the vibrations along the *bones of the middle ear* (hammer, anvil, and stirrup bones). From the latter a fluid in the *cochlea* (resembling a snail shell) carries the vibrations to the "hair cells" which in turn set up action currents to be conducted over the *auditory (acoustic) nerve* to the temporal lobe of the brain (Fig. 247).

(c) *Receptors for equilibrium* located in the inner ear (Fig. 250). The *semicircular canals,* which are hollow and hairlined, contain fluid. Three canals in each inner ear are all at right angles to one another in three different planes. Movement of the fluid stimulates the hairs, giving a sensation of movement. The *saccule* and *utricle* are hollow organs lined with sensitive hairs and contain solid granules of calcium carbonate called *otoliths.*

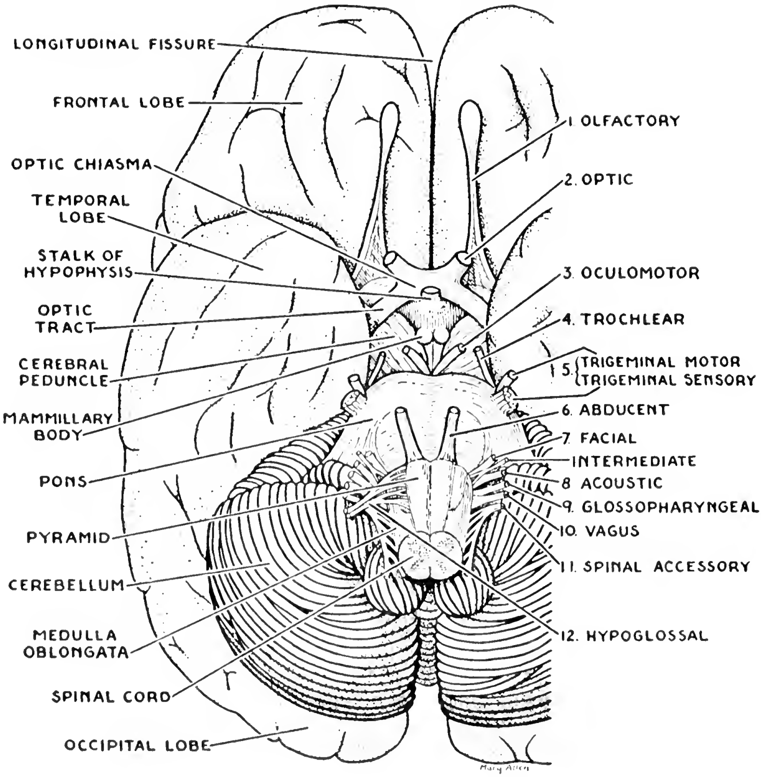


Fig. 247.– Human brain, from undersurface, with parts labeled and the twelve cranial nerves listed on the right. (From Zoethout and Tuttle: Textbook of Physiology, The C. V. Mosby Co.; after Morat.)

Head movements cause the latter to stimulate the hairs, giving a sensation of position.

(d) *Proprioceptors* (L. *proprieta,* property, condition), peripheral receptors of the afferent nerves in muscles, tendons, joints, which assist in the complex coordinated movements in locomotion and posture *(kinesthetic sense).*

3. *Photoreceptors* (receptors sensitive to light)
   In the human eye (Figs. 248 and 249) light waves pass through the transparent *cornea*, through the *aqueous humor*, and the *pupil* (opening in the colored *iris*), striking the *lens*. The latter changes its shape, thereby focusing the light and producing an image on the *rods* and *cones* (sensitive cells) of the *retina*. This starts a photochemical change in the photosensitive *visual purple* located in the cells of the retina. This change induces action currents in the *optic nerve* which carries them to the brain (Fig. 247).

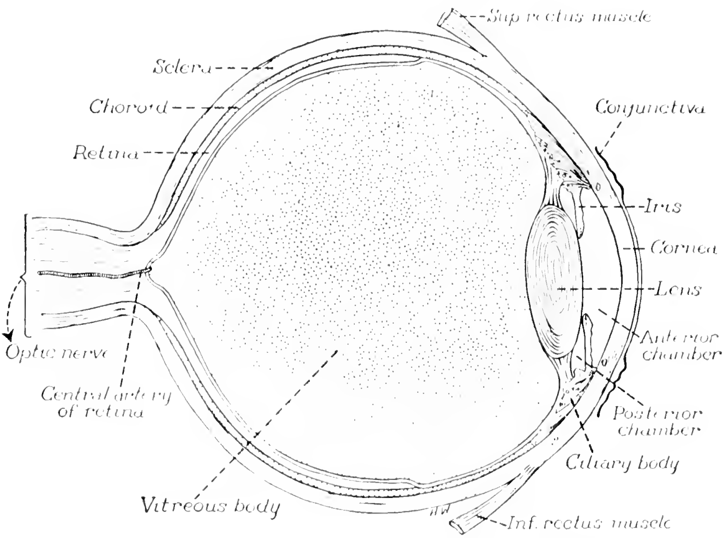


Fig. 248.—Human eyeball in vertical section shown diagrammatically. The anterior and posterior chambers contain aqueous humor; the vitreous body is a transparent jellylike substance; the circular opening in the iris is the pupil; the ciliary body is composed of bundles of smooth muscles to control the lens; the inner layer (retina) is composed of light-sensitive nerve cells. (From Francis: Introduction to Human Anatomy, The C. V. Mosby Co.)

4. *Thermoreceptors* (receptors sensitive to heat)
   These are located in the skin in various parts of the body.
5. *Osmotic receptors (thirst)* located in the mouth and throat
6. *Pain receptors* free nerve endings of sensory nerves located in various parts of the body.

The *effectors* in man are mainly *glandular* (for secretion) and *mechanical* (for movements). Secretions are produced by the protoplasm of cells from the food materials brought to them. In man there may be isolated secretory cells or groups of secretory cells associated together to form a secretory organ known as a *gland*. *Glands* may emit their secretions through permanent channels, as in the case of the salivary glands, or distribute them throughout the body by means of the blood stream and tissue fluids. The latter type of gland is called a *ductless (endocrine) gland*. These are considered in detail later in this chapter.

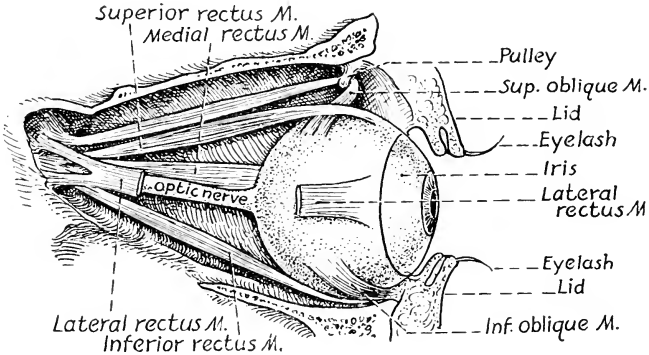


Fig. 249.—Human eye muscles and optic nerve. Observe that the muscles are in pairs but that the superior oblique runs through a pulley and is longer than the inferior oblique.

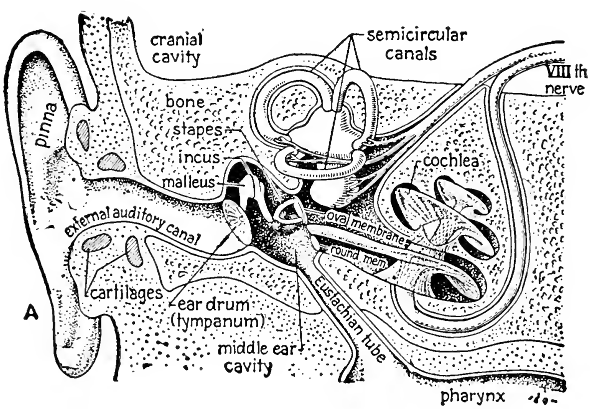


Fig. 250.—Human ear, in section, shown diagrammatically. The ear bones are malleus (hammer), incus (anvil), and stapes (stirrup). (By permission from General Zoology by Storer. Copyright, 1943. McGraw-Hill Book Company, Inc.)

The contraction of a muscle is accompanied by electrical, mechanical, and thermal changes. Contraction may be caused by nerve impulses or by chemical substances. When a muscle is stimulated there is a short *latent period* of about .01 of a second, followed by a *period of contraction* of about .04 of a second, then a *period of relaxation* (lengthening) of about .05 of a second. The contraction is brought about by energy released in the use of foods. Part of the energy associated with muscular activity is heat energy which explains the increase in temperature when muscles are active. Certain metabolic products, designated as *fatigue substances,* result in *muscle fatigue.* If a minimum supply of oxygen is present, muscles fatigue sooner if stimulated repeatedly. Recovery from fatigue results from the use or elimination of fatigue substances and the replenishment of the food supply, if this is necessary.

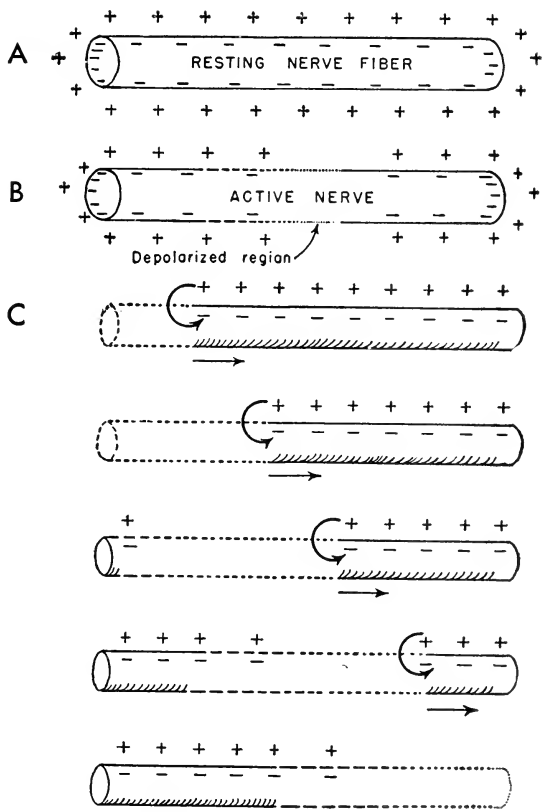


Fig. 251.—Membrane theory of nerve impulse transmission shown diagrammatically. *A,* Resting nerve, showing the polarized membrane (positive charges on the outside and negative charges on the inside); *B,* nerve conducting an impulse, showing, from left to right, the partially repolarized region behind the impulse, the depolarized region where the impulse is located, and the polarized region ahead of the impulse; *C,* passage of the impulse along the nerve shown in successive stages. (From Hunter and Hunter: College Zoology, W. B. Saunders Company.)

The *conductors in man* are (1) the *nervous system,* composed of the brain and cranial nerves, spinal cord and spinal nerves, autonomic nerves (Figs. 16, 17, 246, and 247) and (2) the *blood stream* (Figs. 237, 240, and 241) and the *tissue fluids.* The activities of various organs may be affected by chemical substances produced in other tissues and organs and carried by the blood, lymph, or body fluids. This is *chemical coordination,* and the substances, designated as *hormones,* are produced by ductless (endocrine) glands discussed later in this chapter.

Since much of the coordination of the many organs, tissues, and systems of the human body is due to the activities of the nervous system and its so-called *nerve impulses,* the nature and characteristics of the latter must be understood in order to appreciate the marvels of coordination of the various parts of the body.

Some of the more important characteristics of *nerve impulses* are as follows: (1) They are *electrochemical phenomena* (Fig. 251) in which a stimulus originates electrical changes in one part of a nerve fiber which in turn institutes similar electrical changes in adjacent parts of the fiber as the impulse travels along. According to the *polarized membrane theory of nerve impulse,* the semipermeable membrane surrounding each nerve fiber permits certain ions (charged chemical particles) to penetrate it but prevents others from doing so. Through normal metabolic activities of the nerve, the membrane is polarized (charged) by having an extra number of positive ions on its outer surface and an equal number of negative ions on its inner surface. The positive and negative ions do not neutralize each other normally because the membrane is impermeable to them. However, when stimulated at a certain point, the membrane is depolarized (loses the excess positive ions) and its permeability is increased so that the ions from an adjacent, nonactivated region pass through this depolarized region to neutralize each other. This results in depolarization (probably because of chemical actions) of this adjacent region, making it permeable to the movement of the ions from the next region, and so the impulse moves along the surface of the nerve fiber by a series of depolarizations (Fig. 251). After a period of time, a nerve over which an impulse has traveled becomes repolarized again with its positive ions on the outer surface of the membrane and negative ions on its inner surface. (2) After a nerve fiber has conducted an impulse, it undergoes certain chemical and physical changes ("recovery") over a definite period of time (0.001 to 0.005 second) and then it can transmit another impulse. The interval between consecutive impulse transmissions is known as the *refractory period.* (3) When a nerve fiber transmits an impulse, it uses more oxygen, gives off more carbon dioxide and heat, and expends more energy than when it is not transmitting impulses, which suggests the oxidative nature of the phenomenon. (4) Normally the *rate of travel of a nerve impulse* is independent of the intensity and nature of the stimulus, providing the stimulus is of a certain minimum intensity; in other words, stronger stimuli do not cause impulses to travel faster, because the energy for impulse conduction comes from the nerve and not the stimulus. This is known as the *all-or-none law* which implies that a stimulus of sufficient intensity results in an impulse independent of the strength or nature of the stimulus. In other words, stimuli result in an impulse—or they do not. The rate of travel of a nerve impulse may be dependent on the state of the nerve fiber, because certain drugs may retard or even prevent impulse transmissions. Advantage is taken of this in "blocking off" and preventing the transmission of certain impulses by the use of certain drugs. The speed of nerve impulses is much slower than the speed of electricity; hence they are not electric currents even though certain electrical phenomena may be associated with them. Injured or dead nerves are capable of conducting electrical currents, but they cannot transmit nerve impulses. The rate of impulse travel over a given nerve is the same whether the stimulus be chemical, heat, touch, electrical, etc. (5) It is thought that all types of nerve cells (sensory, motor, etc.) conduct impulses in a similar way and that the end result depends on the nature of the specific structure to which the impulses travel; impulses traveling from the ear to a certain part of the brain result is a sensation of sound; proper impulses traveling to muscles result in movements, etc. (6) Although impulses may be initiated anywhere along a nerve, they usually originate at one end only and travel toward the opposite end; that is, from the dendrite toward the axon. (7) Nerve fibers do not seem to fatigue so long as a sufficient supply of oxygen is present. (8) *Neurons* (nerve cells) consist of one or more *dentrites,* one or more *axons,* and a *cell body* with its *nucleus.* Adjacent neurons do not quite contact each other, and the small area between them is called a *synapse* (sin′ aps) (Gr. *synapsis,* union). It has been proved experimentally that in certain instances an impulse travels across the synapse from the tip of the axon of one neuron to the dendrite of an adjacent neuron because of a chemical secretion known as a *neurohumor,* produced by the tip of the axon. Because this neurohumor is produced by the axon and stimulates the adjacent dendrite, the impulse travels from the axon of one neuron to the dendrite of another neuron and not the reverse because dendrites are unable to secrete this substance. In certain synapses a much simpler type of impulse transmission may take place than what has been described. The rate of impulse transmission through a synapse is slower than along a nerve under ordinary conditions. In case the tip of an axon is adjacent to a gland or muscle, the neurohumor stimulates and causes a secretion, or a movement, accordingly. In the case of impulse transmission from nerve to muscle the chemical is specifically known as *acetylcholine*. The chemical known as *sympathin* between a nerve and the heart results in speeding up the latter. The explanation for a lack of continuous impulse transmissions through a synapse is based on the presence of an enzyme called *cholinesterase* which oxidizes (destroys) the acetylcholine, thus preventing a constant flow of impulses through a synapse. Impulses travel through when acetylcholine is present but do not when the latter has been destroyed by the cholinesterase. The natural resistance offered by synapses may be modified by nerve impulses. In some cases one impulse strengthens another and is known as reinforcement, while in other instances one impulse may cancel the effect of another which is called inhibition. Impulses may cross a synapse if reinforced by others or may not cross if they are inhibited. This complex reinforcement-inhibition relationship may explain many of the phenomena of the nervous system.

The human *brain* (Figs. 246 and 247) consists of (1) cerebrum, (2) cerebellum, (3) midbrain, (4) medulla oblongata, and (5) pons varolii.

Summary of the Human Nervous System

- Central nervous system
  - **Brain**
    - **Cerebrum**, which is large, ovoidal, convoluted, and made of two hemispheres with five lobes
    - **Cerebellum**, which is smaller, oval, nonconvoluted but with smaller furrows (sulci)
    - **Midbrain**, which is short and connects the cerebellum with the pons varolii
    - **Medulla oblongata**, which is pyramid shaped and continues with the spinal cord
    - **Pons varolii**, which is in front of the cerebellum between the midbrain and medulla oblongata and which connects the parts of the brain (Fig. 247)
  - **Cranial nerves** (12 pairs) and their end organs (Fig. 247)
  - **Spinal cord** for reflexes and pathways to and from the higher nervous centers (Fig. 247)
  - **Spinal nerves** (31 pairs) and their end organs
- Autonomic nervous system
  - **Sympathetic**, which has centers, ganglia, and plexuses in the cervical, thoracic, and lumbar regions of the spinal cord
  - **Parasympathetic**, which consists of the centers and ganglia of the cranial and sacral parts of the autonomic system
  - **Enteric**, which consists of the part of the autonomic system associated with the walls of the alimentary tract

The *cerebrum,* which is the largest and most prominent part of the brain, is divided into the *right* and *left cerebral hemispheres.* Each hemisphere is divided by *sulci* into five distinct areas known as *lobes* (frontal, parietal, temporal, occipital lobes, and the insula, the latter not visible from the surface). The outer layer of the cerebrum, known as the *cortex,* has numerous foldlike *convolutions* which greatly increase the surface area. Certain functions are localized in specific regions of the cerebral cortex as illustrated by the following: motor area, sensory areas (heat, cold, pain, touch, light pressure, muscle sense), auditory area, visual area, olfactory area (taste and smell), and speech area. Beneath the gray cortex of the cerebrum is a mass of nervous tissue known as *white matter.*

Spinal Nerves of Man

Cervical (neck)	8 pairs
Thoracic (thorax)	12 pairs
Lumbar (back)	5 pairs
Sacral (pelvis)	5 pairs
Coccygeal (tail)	1 pair
	31 pairs

The brain contains cavities *(ventricles)* as follows: (1) two *lateral ventricles,* one in each cerebral hemisphere; (2) the *third ventricle* behind the lateral ventricles and connected with each by an opening called the *foramen of Monro;* the *fourth ventricle* in front of the cerebellum and behind the pons and medulla, being connected with the third ventricle by a small canal called the *aqueduct of Sylvius.* The coverings of the brain are called *meninges* and are the same as for the spinal cord *(dura mater,* outer; *arachnoid,* middle layer; *pia mater,* inner). Thin layers of fluid separate the various layers.

Functions of the cerebrum in addition to those already mentioned are as follows: it governs all our mental activities (reason, will, memory, intelligence, higher feelings, and emotions); it is the seat of consciousness, interpreter of sensations, originator of voluntary acts; it is a control on many reflex acts which originate as involuntary (weeping, laughing, defecation, micturition, etc.).

The *cerebellum* (Figs. 246 and 247) lies at the base or posterior part of the brain. The outer, *cerebellar cortex* is made of *gray matter,* which is not convoluted but is traversed by numerous furrows *(sulci).* All functions of the cerebellum are below the level of consciousness, the main function being the *reflex control of skeletal muscle activities.*

The *midbrain* connects the cerebral hemispheres with the cerebellum and pons. Two pairs of round elevations, known as the *corpora quad-*

rigemina, act as centers for auditory and visual reflexes. Important pathways to and from other parts of the brain pass through the midbrain.

The *pons* (Figs. 246 and 247) lies in front of the cerebellum and above the medulla. Its fibers connect the two halves of the cerebellum and join the medulla with the midbrain.

The *medulla oblongata* (Figs. 246 and 247) lies between the pons and the spinal cord, being much like the latter structurally. The *fourth ventricle* of the brain is located within the medulla and connects with the central canal of the cord. The medulla contains such vital centers as cardiac, respiratory, and vasoconstrictor centers, the latter for the control of arterial pressure.

The twelve pairs of *cranial nerves* (Fig. 247) may be summarized as follows:

1. *Olfactory*—sense of smell
2. *Optic*—sense of sight
3. *Oculomotor*—control of following eye muscles: ciliary, inferior oblique, superior, inferior, and internal (medial) recti, sphincter of the iris of eye
4. *Trochlear (pathetic)*—superior oblique muscle of eye
5. *Trigeminal*—sensory to the head, motor for the muscles of mastication
6. *Abducent*—external (lateral) rectus of the eye
7. *Facial*—motor to the face and scalp; sensory to the tongue, secretory to the submaxillary and sublingual (salivary) glands of the mouth
8. *Acoustic (auditory)*—to cochlear part of the ear for hearing, to vestibular part of the ear for equilibrium
9. *Glossopharyngeal*—motor to pharynx; sensory to tongue, mucous membranes of pharynx, tonsils, Eustachian tube, tympanic cavity of the ear; secretory to the parotid gland (salivary) of mouth.
10. *Vagus (pneumogastric)*—sensory to larynx, trachea, lungs, esophagus, stomach, small intestine, part of large intestine; motor for respiration, heart action, digestion (inhibits heart action); secretory for gastric and pancreatic glands.
11. *Accessory*—the cranial part to the pharyngeal and superior laryngeal branches of vagus; the spinal part to the trapezius (of back) and sternocleidomastoid (neck) muscles
12. *Hypoglossal*—motor to tongue

The sensory nerves of the *skin* transmit sensations of *pressure, pain, heat,* and *cold* from the specific sense organs to the proper parts of the central nervous system to be interpreted (Fig. 246). Special sense organs in the muscles, called *muscle spindles,* originate the so-called *muscle sense* to tell the degree of contraction or the general condition of the muscles.

The human *taste buds* are the end organs of nerve filaments arising from the trigeminal, facial, and glossopharyngeal nerves (cranial nerves). The taste organs are located chiefly on the tongue, but also on the palate, epiglottis, and even vocal folds (Fig. 234). The human *auditory apparatus* (Fig. 250) consists of (1) an *external ear* with its *auditory canal* with a membranous *tympanum* (eardrum) at its inner end; (2) the *middle ear* with its *Eustachian tube* connecting it with the pharynx to equalize air pressure; the middle ear bones—*hammer* or *malleus*) (L. *malleus,* hammer), *anvil* or *incus* (L. *incus,* anvil), and the *stirrup* or *stapes* (L. *stapes,* stirrup); the two openings of the middle ear into the inner ear, which are known as the *fenestra vestibuli* (ovalis) and the *fenestra cochleae* (rotunda); (3) the *internal ear* with its *vestibule,* its snail-shell-like *cochlea,* and the three *semicircular canals;* the last serve the purpose of equilibrium; (4) the *auditory* or *acoustic nerve,* leading from the internal ear to the central nervous system.

The human *visual apparatus* (Fig. 248) consists of (1) the *eyeballs* with their six muscles for eye movement (the *superior* and *inferior recti muscles,* the *external* and *internal recti,* the *superior* and *inferior oblique muscles*) (Fig. 249), (2) the *lacrimal apparatus* to keep the eye moist and protect it, (3) the *conjunctiva* or mucous lining of the paired *eyelids* internally, (4) the *eyebrows* for protection; (5) the complicated apparatus of *lens, aqueous humor* (in anterior chamber), *vitreous body, iris, pupil, cornea,* and the sensitive *retina, choroid coat,* the *sclera,* etc., (6) the *optic nerve,* which transmits the stimuli recorded by the retina to the visual centers of the brain where the sensation of sight is really located.

The human *olfactory apparatus* consists of a fine network of *olfactory nerves* spread over the irregular surfaces of the superior nasal conchae and upper nasal septum (Fig. 234). These nerves terminate in *olfactory cells,* each with six to eight *hairlike processes.* The latter are affected by small particles of solids or gases in solution. The *olfactory nerve* carries the impulses to the olfactory center of the *brain* (Figs. 246 and 247).

The *spinal cord* consists of a *central canal* surrounded by a central core of *gray matter* which is surrounded by *white matter.* The gray matter in cross section resembles the letter H, the two forward projections being called *anterior columns* and the two backward projections, the *posterior columns.* The spinal cord serves as a center for *spinal reflexes* and as *pathways to and from the brain.* The *white matter* of the cord has (1) long *ascending tracts* to transmit afferent impulses from the spinal nerves to the brain and (2) long *descending tracts* to transmit efferent impulses from the motor centers of the brain to the anterior columns of the cord to control muscular movements.

The *autonomic nervous system* consists of (1) the *sympathetic (thoracolumbar)* which has centers, ganglia, and plexus in the cervical, thoracic, and lumbar regions of the spinal cord, (2) the *parasympathetic* (craniosacral) which consists of centers and ganglia of the cranial and sacral parts of the autonomic system, and (3) the *enteric* which consists of the part of the autonomic system associated with the walls of the alimentary tract. The autonomic nervous system innervates smooth muscles, cardiac muscles, and glands. The autonomic system is a highly important functional portion of the entire nervous system and not a self-controlling, independent, segregated unit, as the word autonomic might imply. In fact, the autonomic is one of the most essential parts of our vital nervous system.

IX. ENDOCRINE (DUCTLESS GLAND) SYSTEM OF MAN

The structure and functions of various organs in the human body are also affected by substances produced in other organs and transmitted primarily by the blood. This *chemical coordination* is brought about by specific chemical substances known as *hormones* (hor′ mon) (Gr. *hormaein,* to excite). These hormones are manufactured in certain organs from ingredients brought to them by the blood and carried away without the benefit of ducts. The more important ductless glands and their hormones and functions are given in summaries.

Endocrine glands (en′ do krin) (Gr. *endon,* within; *krinein,* to separate) and their secretions which contain the specific hormones are influenced by such factors as (1) the quantity and quality of foods brought to them by the blood, (2) the action of hormones from other endocrine glands, and (3) the action of certain parts of the nervous system such as the hypothalamus of the brain, the sympathetic nervous system, etc. Endocrine glands were studied separately, but recent work has shown the great interdependence of many of them, and this new approach has been profitable in getting a more correct picture of them. Regulating substances in invertebrate animals are probably present, but their roles and distribution are not well known. For example, it is probable that sex hormones may be present in certain annelids and crustacea. Color-influencing hormones which affect pigment cells have been studied experimentally in crustacea. Some endocrine glands, such as testes, ovaries, and pancreas, may function as both ductless and duct glands. Some endocrine glands, such as the pituitary, thyroid, parathyroids, and adrenals, function only as ductless glands. Several of them produce a number of hormones with more or less specific functions, which complicates the problem of investigating them.

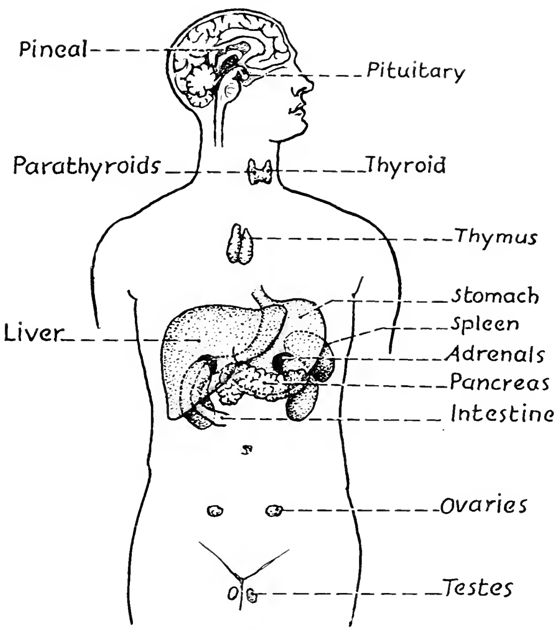


Fig. 252.—Approximate locations of endocrine (ductless) glands of human being.

The location and brief descriptions of some of the human endocrine glands are as follows:

1. **Pituitary (Hypophysis).**—Small (1 cm. diameter), reddish-gray; located at center of the base of the brain; composed of an anterior lobe, intermediate portion, and a posterior lobe which is connected with the hypothalamus of the brain; in certain animals the two lobes are separate (Fig. 252).

2. **Thyroid.**—A pair of shield-shaped glands connected by an isthmus and located in front of the trachea, just below the larynx; present in all vertebrates; thyroxin is an amino acid containing iodine.

3. **Parathyroids.**—Usually four small compact masses of cells closely associated with the thyroid but which differ from the latter structurally and functionally.

4. **Adrenals (Suprarenals).**—One soft, cup-shaped gland covering the upper part of each kidney; composed of an outer, pale pink cortex and a dark inner medulla, which differ as to embryologic origin, structure, and functions; the two parts are separate in certain lower vertebrates.

Fig. 253.—Cretin, 19 years of age, showing dwarfism, deficient bone development, thickened lips, thick pasty skin, etc. (From Bard: Macleod's Physiology in Modern Medicine, The C. V. Mosby Co.)

5. **Pancreas.**—This organ secretes digestive juices which are carried away by ducts, but certain clusters of cells (islands of Langerhans) are without a duct and secrete endocrine hormones; it is flat and irregular and lies in the curvature between the stomach and duodenum; weighs

about 3 ounces; insulin was extracted from pancreas by the Canadians, Banting and Best, in 1922 and has been used successfully in the treatment of sugar diabetes, which would otherwise be fatal because of the accumulation of toxic materials and constant loss of weight.

6. **Testes.**—Two ovoid bodies suspended in the scrotum; the seminiferous tubules produce sperm; the interstitial cells between the tubules secrete the endocrine hormones; castration (removal of testes) results in the lack of development of secondary sexual characters; such a man (eunuch) has a hairless face, high-pitched voice, and a tendency to obesity; castration is frequently used on domestic animals; it is doubtful if the administration of testicular hormones is of benefit in attempts at rejuvenation.

7. **Ovaries.**—Two bean-shaped organs (1½ inches long) attached to the abdominal cavity near the uterus; the outer layer of germinal epithelium produces eggs which are placed in internal follicles; each month one (or more) follicle with its egg fills with fluid, comes to the surface, and ruptures, thus releasing the egg into the oviduct; if after ovulation the egg unites with a sperm, fertilization results; the ruptured follicle fills with yellowish cells which constitute the corpus luteum (*corpus*, body; *luteum*, yellow); the latter is absorbed in two weeks if fertilization did not occur, but it enlarges and remains throughout the period of pregnancy.

8. **Placenta.**—This organ attaches the developing embryo to the wall of the uterus and supplies it with nourishment; during pregnancy a hormone similar to the luteinizing hormone of the pituitary is produced, and its presence in the urine can be used for testing early pregnancy when injected into nonpregnant, female animals such as rabbits, rats, mice, etc.

9. **Stomach.**—Certain cells of the lining of the stomach secrete a hormone which stimulates the stomach to form digestive enzymes.

10. **Duodenum (First Part of Small Intestine).**—Certain cells produce several kinds of endocrine hormones.

11. **Thymus.**—A fairly large gland of children in the upper part of the chest which regresses after puberty; no specific hormone has been isolated but it is thought to be associated with juvenile growth.

12. **Pineal (Epiphysis).**—One small, cone-shaped body located between the cerebral hemispheres dorsal to the pituitary; no specific hormone but it is thought to be associated with growth.

Summary of Endocrine (Ductless) Glands

ENDOCRINE GLAND	HORMONES AND FUNCTIONS
1. PITUITARY (pi -tu′ i ta ry) (L. *pituita*, phlegm) ("master gland" or "director gland")	ANTERIOR LOBE 1. *Growth-promoting (somatotropic, phyrone)*.—Regulates growth; deficiency in children results in dwarfs or midgets (usually well developed physically and mentally); excess secretion results in giants; oversecretion in adults results in acromegaly (enlarged facial features with long, broad jaws, and enlarged cheek bones, large barrel chest, enlarged joints of feet and hands) 2. *Diabetogenic (anti-insulin hormone)*—Increases blood sugar (effects opposite to those of insulin) 3. *Ketogenic (fat metabolism hormone)*—Controls fat metabolism and increases fat in liver 4. *Thyrotropic*—Stimulates thyroid gland 5. *Adrenotropic (adrenocorticotropic or ACTH)*—Stimulates cortex of adrenals to function normally 6. *Pancreotropic*—Stimulates pancreas 7. *Parathyrotropic*—Stimulates parathyroids 8. *Prolactin (lactogenic)*—Necessary for lactation (milk production) by mammary glands 9. *Follicle-stimulating (F. S. H., Gonadotropic)*—Controls growth of egg-bearing follicle in the female ovary; formation of sperm in seminiferous tubules of male testes 10. *Luteinizing (L. H.)*—Necessary for forming corpus luteum by rupturing follicle and liberating the egg and for forming male sex hormone by interstitial cells of testes POSTERIOR LOBE *Pituitrin* which probably contains the following hormones: 1. *Pitressin (pressor hormone)*—Increases blood pressure by contracting muscles of smaller arteries 2. *Pitocin (Oxytocic)*—Influences contraction of smooth muscles of uterus, particularly during childbirth 3. *Gastrotropic*—Controls secretions of stomach possibly by altering blood supply 4. *Galactogenic*—Increase milk flow possibly by acting on smooth muscles of mammary glands 5. *Antidiuretic*—Diminishes quantity of urine possibly by increased reabsorption of water from kidney tubules INTERMEDIATE LOBE 1. *Intermedin*—May affect metabolism in man; intensifies skin color of lower vertebrates by affecting color-bearing chromatophores

SUMMARY OF ENDOCRINE (DUCTLESS) GLANDS—CONT'D

ENDOCRINE GLAND	HORMONES AND FUNCTIONS
2. THYROID (thi′-roid) (Gr. *thyreos,* shield; *eidos,* resemble)	*Thyroxin (thyroglobulin)*—Controls rate of basal metabolism and normal body growth A. HYPERTHYROIDISM (OVERACTIVITY OF NORMAL-SIZED GLAND OR INCREASED GLAND) 1. *Exophthalmic Goiter*—thyroid may be enlarged with such symptoms as increased heartbeat, nervousness and restlessness, often protruding eyeballs, increased heat production and perspiration, increased blood pressure, muscular weakness, and tremors B. HYPOTHYROIDISM (UNDERACTIVITY) 1. *Simple goiter*—thyroid may be enlarged (not always) and thyroxin deficient because of lack of iodine; symptoms may resemble somewhat those of mild myxedema 2. *Myxedema*—Deficiency of thyroxin in adult may result in lowered metabolism and heat production, slow pulse, physical and mental lethargy; appetite usually normal with tendency to obesity; dry, waxy, puffy skin because of increased mucus beneath it; dry hair usually falls out. 3. *Cretinism*—Insufficient hormone during early life may result in improper development, physically, mentally, and sexually.
3. PARATHYROIDS (para-thi′ roid) (Gr. para, *beside;* thyroid)	1. *Parathormone (parathyrin)*—regulates calcium and phosphorus metabolism; proper amount necessary for normal bone development; too little parathormone lowers blood calcium and increases irritability of nerves and muscles; too much withdraws calcium from bones (soft bones); complete removal of parathyroids results in tetany or quick death (tremors and convulsions due to increased irritability of muscles and nerves because of lack of calcium)
4. ADRENALS (ad-re′ nal) (L. *ad,* to; *renes,* kidney) SUPRARENALS	CORTEX (OUTER LAYER) 1. *Cortin (probably several hormones?)*—Influences growth excretion, sugar metabolism, water balance, sodium, potassium, and chloride balance, normal sexual functioning; cortin deficiency in man may cause Addison's disease (bronzed skin, decreased heart action and blood pressure, muscular weakness, digestive upsets) MEDULLA (INNER PORTION) 1. *Adrenalin (adrenin, epinephrine)*—Increases glucose (sugar) of blood, heart rate, and blood pressure; in emotional stress the increased secretion may result in increased blood pressure and heart action, increased glucose production by the liver, increased saliva secretion, dilation of eye pupil, increased rate of blood coagulation, paleness of skin because arteries in it decrease in size
5. PANCREAS (pan′ kreas) (Gr. *pan,* all; *kreas,* flesh)	Produced by the Islands of Langerhans: 1. *Insulin*—Regulates glucose (sugar) metabolism and decreases blood sugar; deficiency causes sugar diabetes (excess sugar in blood and urine) 2. *Lipocaic*—Regulates fat metabolism in liver

SUMMARY OF ENDOCRINE (DUCTLESS) GLANDS—CONT'D

ENDOCRINE GLAND	HORMONES AND FUNCTIONS
6. TESTES (tes′ tes) (L. *testis,* testicle)	Produced by interstitial cells of testes: 1. *Testosterone*—Controls development of secondary sexual traits (hair growth on face and body; affects voice; develops size of pelvis; controls muscular development); may influence sex behavior 2. *Androsterone (androgen)*—Influences development of secondary sexual traits
7. OVARIES (o′ va ri) (L. *ovarium,* ovary)	PRODUCED BY FOLLICLE 1. *Estrone (estrin, theelin)*—Controls development of secondary sexual traits; growth of pubic hair; broadening of pelvis; development of uterus and vagina; change of voice; initiates development of mammary glands; controls onset of menstrual cycle. PRODUCED BY CORPUS LUTEUM 1. *Progesterone (progestin, corporin, lutin)*—Influences increased development of mammary glands, uterus and placenta during pregnancy; regulates menstrual cycle; prevents menstruation and formation of more follicles during pregnancy; sensitizes uterus wall for implanting fertilized egg on it 2. *Relaxin*—Relaxes the pelvic ligaments during labor of childbirth (parturition)
8. PLACENTA (pla -sen′ ta) (L. *placenta,* flat cake)	1. *Estrogen*—Influences development of secondary sexual female traits (effects similar to those of estrone) 2. *Emmenin*—May stimulate estrone production in ovary 3. *APL (anterior pituitary-like)*—Influences ovaries; may influence development of fetal sex organs, especially descent of testes from abdomen to scrotum
9. STOMACH (stum′ ak) (Gr. *stomachos,* gullet)	1. *Gastrin*—Stimulates certain stomach cells to secrete gastric juice for digestion
10. DUODENUM (of small intestine) (du o -de′-num) (L. *duodeni,* twelve)	1. *Secretin*—stimulates pancreas to secrete pancreatic juice for digestion 2. *Enterocrinin*—stimulates cells of duodenum to secrete intestinal juice (succus entericus) 3. *Enterogasterone*—diminishes movements of stomach under influence of fats 4. *Cholecystokinin*—Causes gall bladder to empty into intestine
11. THYMUS (thi′ mus) (Gr. *thymos,* thymus)	No specific hormone has been isolated, but it is suggested that it may retard sexual development in early life; may produce lymphocytes
12. PINEAL or EPIPHYSIS (pin′ e al) (e -pif′ i sis) (L. *pineus,* pine cone) (Gr. *epi,* upon: *phyein,* to grow)	No specific hormone has been isolated but it is thought that growth may be influenced by it
13. LIVER (A.S. *lifer,* liver)	An unknown hormone may stimulate the bone marrow to produce erythrocytes (as in anemia)

13. **Liver.**—Composed of four lobes located just beneath the diaphragm; an unknown hormone may stimulate the bone marrow to form erythrocytes.

The great complexity and interdependence of the various parts of the endocrine system may be observed from the following summary in which some of the more important functions are given with some of the participating hormones listed:

Digestion—Gastrin (stomach); secretin, enterocrinin, enterogasterone, cholecystokinin (intestine); gastroscopic, pancreotropic (pituitary)

Sugar metabolism—Insulin (pancreas); adrenalin, cortin (adrenals); diabetogenic (pituitary)

Fat metabolism—Ketogenic (pituitary); lipocaic (pancreas)

Calcium and phosphorus metabolism—Parathormone (parathyroids)

Sodium and potassium metabolism—Cortin (adrenal)

General metabolism—Thyroxin (thyroid); cortin (adrenal)

Excretion—Cortin (adrenal); antidiuretic (pituitary)

Growth regulation—Thyroxin (thyroid); growth-promoting (pituitary); cortin (adrenal); possibly thymus and pineal?

Sexual characters and reproduction—Testosterone, androsterone (testes); estrone, progesterone, relaxin (ovaries); follicle-stimulating, luteinizing, prolactin, galactogenic (pituitary); estrogen, emmenin, anterior pituitary-like (placenta); cortin (adrenals)

X. HUMAN REPRODUCTION AND DEVELOPMENT

The stages in human reproduction and development are somewhat similar to those of other higher vertebrates but, as might be expected, there are differences depending upon the species (Figs. 363 to 366). Many of the early stages of various vertebrates are so similar that it is difficult to distinguish them (Fig. 363). The stages in the embryologic development of a frog and of man are described somewhat in detail in Chapter 24.

The human *male reproductive system* (Fig. 254) consists of (1) a pair of *testes* suspended in the scrotum, (2) numerous *vasa efferentia* which lead into a single, highly convoluted *collecting tubule,* the two constituting the *epididymis* which is attached to each testis, (3) the pair of *vasa deferentia* (singular, *vas deferens*) or *sperm ducts* which lead from the collecting tubules to the pair of saclike *seminal vesicles,* just behind the bladder; (4) the small *prostate gland* surrounding the urethra and ejaculatory ducts, (5) the *ejaculatory ducts* leading from the seminal vesicles to the single tubular *urethra* which leads to the outside, and (6) the pair of small *Cowper's glands* posterior to the urethra and connected to it by a pair of small ducts.

The *testes* contain many *seminiferous tubules* which produce *sperm (spermatozoa)* by a proliferation of the *spermatogonia cells* (Fig. 351) which line the tubules. The number of sperm discharged at one time may be about two hundred million suspended in a small amount of *seminal fluid (semen).* The latter is secreted by the seminiferous tubules, epididymis, vas deferens, and primarily by the prostate and Cowper's gland. The *sperm* is extremely small and has a globular head with a nucleus, a neck, and a slender tail of cytoplasm (Fig. 223).

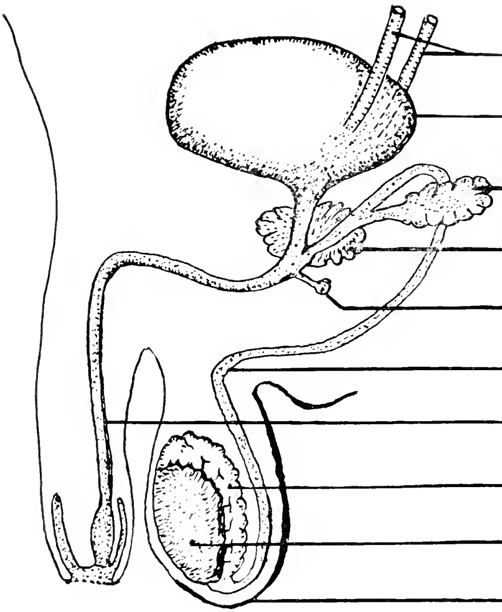


Fig. 254.—Reproductive organs of human (male). Side view and somewhat diagrammatic.

The human *female reproductive system* (Fig. 255) consists of (1) the pair of oval *ovaries* in the lower abdominal cavity and (2) the pair of *Fallopian tubes (oviducts)* the anterior ends of which are funnel shaped and lie near the ovary; the anterior opening of the tubes is the *ostium* (infundibulum) which picks up the *ovum (egg)* (Fig. 223) produced and liberated by the ovary; the *Fallopian tubes* carry the ovum to the pouchlike *uterus* in which the embryo develops; (3) the *vagina* which connects the uterus with the exterior. The walls of the *uterus* contain smooth muscles which contract vigorously under certain conditions, such as childbirth. The inner lining of the uterus, called the *endometrium,* is a heavy, mucous, glandular layer to which the fertilized ovum may adhere. The uterus is well supplied with blood vessels for the nourishment of the future embryo.

With the onset of sexual maturity *(puberty)* the female begins to *ovulate* (produce and mature an ovum in the ovary). The production and maturation of the ovum are illustrated in Fig. 351. The ovum is ripened within the ovary and released into the Fallopian tube where it may be fertilized by a male sperm, or die if not fertilized. The sperm have been deposited in the vagina during copulation and have moved up the Fallopian tubes. Each developing ovum in the ovary is contained within a

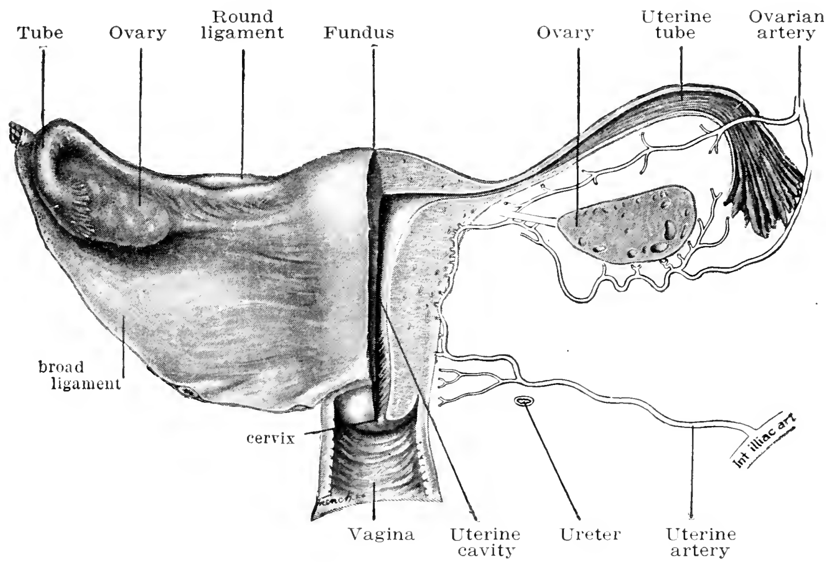


Fig. 255.—Human female reproductive organs showing the uterus, ovaries, and associated organs. The left half shows posterior (back) view and right half a diagrammatic section. The ovary reveals several internal follicles in which the ova (eggs) are formed. The uterine tube is also called the Fallopian tube. The outer, funnel-shaped end of the Fallopian tube (near the ovaries) opens into the body cavity. The round and broad ligaments give the tubes and ovaries support. (From Pitzman: Fundamentals of Human Anatomy).

Graafian follicle which in later stages of its development occupies a position near the surface of the ovary, appearing there as a small bump. In fact, an ovary may possess several *Graafian follicles* in various stages of development at the same time. When the ovum is mature, the follicle ruptures the wall of the ovary and deposits the ovum in the coelom (body cavity) from which it passes into the Fallopian tube. Most of the Graafian follicle cells remaining in the ovary organize themselves into a yellowish ductless gland called the *corpus luteum* (L. *luteolus,* yellowish), which is described in a summary of endocrine glands earlier in this chapter. If the ovum is not fertilized, the *corpus luteum* degenerates. The human ovum is very small (0.15 mm. in diameter) because of a minimum of food (yolk). Consequently, the developing embryo must have nourishment from the mother. The ovum while in the upper part of the Fallopian tube produces a small, nonfertilizable *polar body (polocyte)* (Fig. 351) and a second *polar body* after fertilization. Ovulation occurs at regular periodic intervals and the series of interrelated phenomena, including the preparation of the uterus for the implantation of the fertilized ovum, is called the *estrous cycle.* The *estrous cycle* in the human female occurs more or less within twenty-eight days but may be altered by mental shocks, psychic disturbances, worry, physical illness, climatic changes, etc. If fertilization does not occur, the superficial mucous layer of the uterus is shed and accompanied by rupturing of blood vessels (hemorrhage). This ends in *menstruation* in which tissues and blood leave the uterus through the vagina.

A study of the development of a human being will reveal (as in many other animals) numerous *vestigial (rudimentary) organs* which are reduced in size and are without appreciable use at present, although they may have been larger and functional in the past. Many of them seem to be in the process of disappearing, having served their period of usefulness. Over one hundred vestigial structures and organs occur in the human body, among the more common being (1) vermiform appendix, (2) special muscles to move the ears, (3) lobe at the bottom of the ear, (4) point ("Darwin's point") at inner curled ridge of the upper margin of the ear, (5) whitish nictitating membrane (third eyelid) in inner angle of the eye, (6) third molars ("wisdom teeth"), (7) hair on body, (8) special patterns or arrangements of hair on various parts of the body, (9) small muscles to erect body hair, (10) mammary glands in male, (11) segmented muscles of abdominal wall, (12) caudal (tail) vertebrae called the coccyx. Many of the vestigial structures of man have their homologous structures in related lower organisms in which cases they are functional. This is evidence that organisms have changed structurally and functionally; in other words, have evolved.

XI. DISEASES OF MAN

Disease may be defined as an abnormal or pathologic condition of any part of the body or mind. Diseases may be classified as (1) *infectious,* or those due to the presence of living organisms or their products, and (2) *noninfectious* (organic), or those due to a variety of causes other than living organisms. *Infectious diseases* may be classed as (1) *communicable,* or those transmitted naturally from one person to another and (2) *noncommunicable,* or those not contracted from another infected individual. Hence, pneumonia, tuberculosis, etc., are infectious, communicable diseases, while tetanus (lockjaw) is an infectious, noncommunicable disease. Sometimes the less desirable term, *contagious,* is applied to infectious diseases which are transmitted by direct contact ("catching"). Satisfactory progress has been made in this country against the infectious diseases, as is shown by the mortality (death) and morbidity (sick) rates. The *noninfectious diseases* include a wide variety of abnormal conditions of body and mind caused by an even greater variety of causes. Some of them such as pellagra, scurvy, etc. (discussed elsewhere) are grouped as vitamin deficiency diseases; others are due to chemical poisons; still others (sunstroke, concussions, frostbite, lacerations, etc.) are due to physical agents; and still others, such as Bright's disease (kidneys), cerebral hemorrhage, various types of heart diseases, psychosis, and imbecility, are due to derangement of tissues. Upon the basis of speed, diseases may be classed as (1) *acute* (sudden onset and a short period of rather severe illness with subsequent recovery or death) and (2) *chronic* (Gr. *chronos,* time) (gradual onset of symptoms and prolonged illness).

The various types of living organisms which may cause infectious diseases in man are bacteria, yeasts, molds, pathogenic protozoa, parasitic worms, ticks, mites, etc. Before an infection can occur, certain conditions must be fulfilled: (1) the living organisms must enter the body in sufficient numbers, (2) they must enter the body through the right channels, (3) they must maintain themselves in sufficient numbers to cause the disease, (4) the body being entered must be susceptible to the actions of the living organisms, and (5) the invading organisms must be sufficiently virulent or potent to produce the disease.

Numerous discussions and examples of infectious diseases caused by bacteria, yeasts, molds, pathogenic protozoa, parasitic worms, viruses, etc., are given in various parts of this book, to which the reader should refer.

Since earliest times man has been afflicted by diseases and has theorized as to their causes. The following, by no means a complete list, will suffice: (1) *Demonic theory*—the earliest primitive peoples believed that disease was due to evil spirits or demons. Consequently, they tried to prevent, treat, and cure diseases by scaring the demons by terrifying noises, using vile-tasting or -smelling medicines, by exorcising the demon, by wearing charms, etc. (2) *Humoral theory* of Hippocrates (460-395 B.C.) in which the body was thought to consist of four humors: blood, phlegm, black bile, and yellow bile. Disease was thought to ensue if too much or too little of one or another were present. Bloodletting was a common curative procedure. (3) *Pythogenic theory* of Murchison in which this Englishman, of about one hundred years ago, contended that diseases were due to dirt and filth. (4) *Germ theory* in which diseases were considered to be caused by minute organisms. Many individuals contributed their bit to this theory as the following will show: Leeuwenhoek (1632-1723) studied microorganisms with his crude microscope; Fracastorius, in 1546, suggested that infectious diseases were due to a living contagion; Plenciz, in 1764, theorized that each disease was caused by a specific microbe; Davaine, in 1850, proved that anthrax of cattle was due to rodlike organisms; Pasteur, in 1865, showed that the silkworm disease (pébrine) was due to protozoa; the German country doctor, Robert Koch (1843-1910), perfected many techniques in bacteriology and proved that the cause of tuberculosis is a bacterium, known today as *Mycobacterium tuberculosis*.

The mere presence of microorganisms in air, food, milk, and water is not sufficient to produce a disease in all instances. As stated above, certain conditions must be fulfilled before an infectious disease will develop. Among the most important deterrents to disease production in man are the various body defenses, as the following will show:

1. **Defenses (First line).**—*Skin*—acting as a mechanical barrier; *nose*—mucus collecting the organisms, cilia moving them toward the exterior, the enzyme lysozyme destroying bacteria, sneezing, coughing; *eyes*—washing organisms away mechanically by tears which also contain the enzyme lysozyme; *mouth*—mucous membrane acting as a mechanical barrier; *stomach*—acid of gastric juice; *intestine*—mucous membrane acting as a mechanical barrier, antagonistic action of other organisms within the intestine; *urethra*—action of urine.

2. **Defenses (Second line).**—(1) The production of *inflammations* in which many of the organisms which have penetrated the deeper tissues are trapped and destroyed (inflammations are usually characterized by redness and swelling due to increased supplies of blood; temperature, due to increased metabolic activity in the area; pain, due to the abnormal activities; pus formation in later stages due to the destruction of microorganisms and tissues); (2) *phagocytic action of certain white blood*

corpuscles in which the phagocytic cells engulf and destroy microorganisms in the various body tissues, in the blood stream, in lymph nodes, and in the phagocytic cells which line the capillaries of the liver and spleen.

3. **Defenses (Third line).**—Other defensive reactions of the body which depend upon previous or present contact with the infectious organisms are known as *immunologic reactions.* When infectious organisms or their poisons penetrate to the deeper tissues, the body may be stimulated to produce a series of substances which have the ability to destroy or inactivate the organisms and to neutralize their toxic products. These reactions are concerned with ridding the body of foreign proteins which have been brought in by the invading organisms or through some channel which is an unnatural method of entrance for that protein. These reactions manifest themselves only under certain conditions and only as a specific response to a specific protein. These reactions can, in a general way, be illustrated by the introduction of egg proteins or similar foreign proteins. If egg protein is introduced into the digestive tract it is digested and used in the natural building of protein substances in the body. However, if this egg protein is injected directly into the blood system, or in some other unnatural manner, the egg protein stimulates the body to form a specific substance which will react specifically with the egg protein. These specific substances appear in the blood stream and are known as *antibodies.* The proteins which stimulate their formation by the body are called *antigens.* For example, the foreign protein material of *diphtheria toxin* serves as the *antigen* to stimulate the body to produce the specific *antibody* known as *diphtheria antitoxin.* When the latter contacts diphtheria toxin, it neutralizes it, thus defending the body.

Some of the more common *antibodies* may be described briefly as follows:

1. *Antitoxins,* which are substances which neutralize specific toxins in an animal body or even in a test tube. They are formed only in an animal body in direct response to toxins produced by bacteria, plants, or animals; they are protein in nature and are affected by heat; they are specific in their action; i.e., diphtheria antitoxin reacts only with diphtheria toxin, and not with the toxins of tetanus, scarlet fever, gas gangrene, etc.

2. *Agglutinins,* which are antibodies that agglutinate (clump) the specific organisms which acted as antigens in their formation in a body. The agglutination may occur in the body (hence, defend it) or outside where it can be used for identifying specific organisms, for diagnosis of

certain diseases, etc. For example, if the blood serum of an animal immunized against typhoid organisms is mixed with a suspension of typhoid organisms, the latter are agglutinated. The blood serum from a person who has recovered from typhoid will likewise agglutinate typhoid organisms but not other organisms even though they are closely related to them.

3. *Precipitins,* which are antibodies with the power to precipitate (settle out) foreign proteins against which they have been formed. After precipitation the foreign proteins may be phagocytized in the body. Because precipitins are so specific, they are utilized in identifying specific proteins of various organisms and in establishing the parentage of offspring in certain medicolegal cases.

4. *Bacteriolysins,* which are antibodies which kill and dissolve the specific organisms which have stimulated the body cells to produce them. Immune blood sera containing these specific antibodies are commonly called *antibacterial sera* rather than antitoxin sera.

5. *Opsonins,* meaning "to prepare food for," which are antibodies which prepare bacteria so that they are more readily destroyed by the phagocytes. The numerous opsonins are specific and act on only one species of organism. The measurement of the opsonin content of blood serum is known as the *opsonic index.*

6. *Antiaggressins*—many bacteria secrete substances called *aggressins* which repel or kill leucocytes. The body responds by forming an *antiaggressin* to neutralize the aggressin thus protecting the leucocytes.

7. *Complement* and *amboceptor*—normal blood serum contains a substance called *complement;* immune serum contains other substances called *amboceptors,* which are specific for the antigen which has stimulated the body to form them. The two substances together aid in the destruction of invading pathogenic bacteria.

A phenomenon closely allied to antibody formation is known as *hypersensitivity,* which is a state of a body which shows increased reaction to a subsequent introduction of substances which provoked little or no reaction when first introduced. Excessive and severe hypersensitivity in animals and man is designated as *anaphylaxis* (meaning, "against protection," in contrast to *prophylaxis* which means "protection" or "prevention"). *Allergy* (Fig. 256) ("altered reaction") is applied to milder types of hypersensitivities in man. Some of the more common types of allergies are (1) those due to inhaling such protein antigens as pollens and dusts from animal hair, causing hay fevers, and certain types of asthma, (2) those due to ingesting certain foods, such as milk, straw-

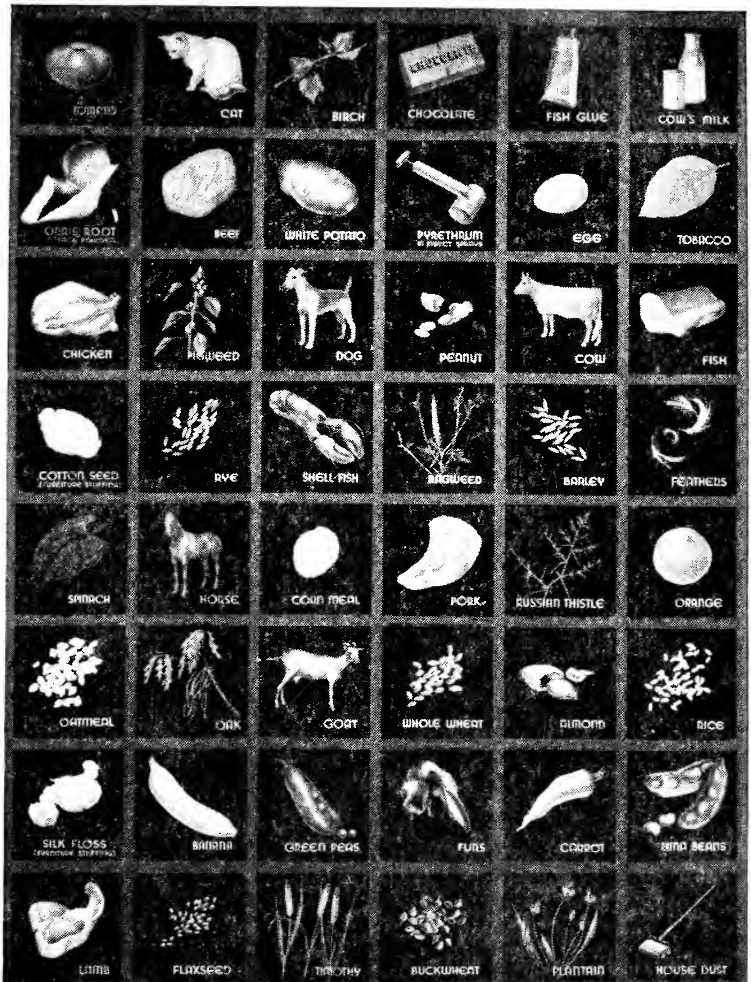


Fig. 256.—Forty-eight causes of allergic reactions. (Courtesy of Lederle Laboratories.)

berries, clams, eggs, sauerkraut, or certain drugs, (3) those due to contacting the skin with wool, silk, feathers, etc. About 10 per cent of our population suffers from some type of allergy which may be characterized by such symptoms as gastrointestinal disturbances, respiratory disturbances, skin eruptions, and even migraine headaches. Nonprotein allergies may be illustrated by formaldehyde, iodine, aspirin, and certain sulfonamide drugs.

Immunity in general may be considered as (1) *natural* or (2) *acquired. Natural immunity* is an innate characteristic which is determined genetically and does not depend upon the reactions of the body when in contact with an infectious organism. It may be influenced by malnutrition, fatigue, decreased temperature, certain anatomic structures, and certain physiologic reactions and varies with the individual. Man and cattle are naturally immune to hog cholera. *Acquired immunity* is not inherent in the protoplasm of that species but must be acquired either *actively* or *passively*. Immunity may be *acquired actively* by (1) having the disease, (2) being exposed repeatedly to quantities of the germ which are not sufficient to produce the disease, (3) being treated by the products of organisms. Immunity may be *acquired passively* by the administration of immune sera which contain the proper antibodies that the patient has had no part in actively producing. An advantage of passive immunization is the speed of protection, while its disadvantage is that it lasts only a short time.

XII. INHERITANCE OF HUMAN TRAITS

Much information regarding the inheritance of certain human traits has been secured in recent years by a study of lower animals as well as by the scientific study of human families. From these studies it is apparent that many human traits are inherited according to Mendel's laws just as are many of the traits of other animals and plants. Heredity of plants and animals, including man, is considered in Chapter 34. It will be noted that some traits are not inherited as simple Mendelian traits but are due to sex-linked, blended, or multiple-gene inheritances. One of the most valuable methods of studying human inheritance is the scientific assembling of accurate data in the form of "family trees" (Figs. 352 to 356). The correct interpretation of these data has contributed much to our knowledge of the methods of inheritance of specific human traits. Much is still unknown about certain traits, but additional information is constantly being added. Some of the difficulties encountered in the scientific study of human inheritance are: (1) the impossibility of securing complete and reliable data over a sufficient number of generations, (2) the great difficulty of securing reliable and complete data for all members of the family being studied, (3) the impossibility of the scientific observer to collect all the data firsthand and the frequent unreliability of data supplied by others who are insufficiently trained in heredity, (4) the small size of many families which does not always give a complete picture of the particular inheritance being studied, (5) the inability to cross or breed experimentally as has been done so profitably in lower organisms, and (6) the great length of time required for, let us say, three consecutive generations to display what they have inherited. In spite of these difficulties, much progress has been, and is being, made. This explains why it is unknown whether certain traits are inherited and why there is still a difference of opinion as to the exact method of inheritance of certain human traits.

It is known that there is a *continuity of germ plasm* (Figs. 350 and 351) connecting the individuals of all generations, and through which traits are transmitted to future generations. Body cells (somatic cells) with their traits develop from these germ cells with their germ plasm. The development of human traits depends upon the presence of specific genes within the chromatin materials of the germ plasm and the development of these genes in the proper environments as the body grows. Possibly the cytoplasm of these cells plays a greater role in inheritance than we have surmised in the past. Human heredity studies have usually concerned themselves with the more obvious traits (such as eye color, hair color, hair consistency, skin color), or certain abnormal traits (such as webbed toes, psychosis, etc.), but in all probability the more common traits (such as stomach, liver, intestines, etc) also have a structural and functional inheritance. Is it not possible that there is a typical Smith-family-type of stomach or a Jones-family-type of intestine? Because they have been considered to be of secondary importance such traits have not been generally studied. Infectious diseases are not believed to be inherited, as such, because the transmission of the causal agents for such diseases in the germ plasm would seriously affect or prevent the formation of the offspring. However, predisposing tendencies for certain diseases may be transmitted. Certain conditions have erroneously been thought to be inherited, when, as a matter of fact, they have been acquired by the offspring before or after birth.

The average person is interested primarily in whether a certain human trait is inherited and how. Many human traits are considered in

Chapter 34 (Heredity-Genetics) (Figs. 347 and 352 to 356). The reader is warned not to jump at erroneous conclusions in his attempt to interpret the inheritance of some of his own traits or those of families with which he is more or less familiar. Careful interpretations by experienced geneticists should be followed rather than depending upon our own limited knowledge.

Some of the most important data in human heredity are concerned with the inheritance of specific *blood groups.* It is known that blood from certain individuals when mixed frequently results in an *agglutination* (clumping) of the red blood corpuscles. Four types of human blood are known as Groups A, B, AB, and O. Agglutination occurs when certain groups are mixed and not when others are mixed. Agglutination of human blood depends upon the presence of (1) the specific substance known as the *agglutinogen* (a type of antigen) in the red blood corpuscles and (2) the specific substance known as the *agglutinin* (a type of antibody) in the blood plasma. Both of these are necessary for a blood to agglutinate, so naturally both cannot occur in the same person or his blood would agglutinate in his blood vessels. The two inheritable agglutinogens are known as A and B in man. Hence the following human blood groups are possible: An individual of group A has agglutinogen A in his red blood corpuscles; group B has agglutinogen B; group AB has both agglutinogens A and B; group O has neither agglutinogen. Whichever agglutinogen an individual has in his red blood corpuscles, the corresponding agglutinin (antibody) is absent in his blood plasma. When an agglutinogen is absent in his erythrocytes, the corresponding agglutinin is present in his plasma. A summary of the blood groups, their agglutinogens, agglutinins, etc., is given in the following table:

Human Blood Groups

BLOOD GROUP	AGGLUTINOGEN (ANTIGEN) IN RED BLOOD CORPUSCLES	AGGLUTININ (ANTIBODY) IN BLOOD PLASMA	MAY RECEIVE BLOOD FROM GROUP	MAY GIVE BLOOD TO GROUP	PER CENT OF THE WHITE POPULATION OF THE UNITED STATES REPRESENTED BY EACH BLOOD GROUP
O	None	a and b	O	O, A, B, AB	41
A	A	b	O, A	A, AB	45
B	B	a	O, B	B, AB	10
AB	A and B	None	O, A, B, AB	AB	4

Persons of type O are often called "universal donors" because their blood may be given safely without agglutination to any other person; persons of type AB are known as "universal recipients" because they can receive blood from any type.

Additional agglutinogens, known as M and N, have been found in human erythrocytes, but no corresponding agglutinins are reported. These M and N agglutinogens are inherited independently of the previous groups and are useful in identifying bloods but need not be considered in blood transfusions.

A third type of agglutinogen is known as the *Rh factor* because it was first discovered in the blood of the *Rhesus* monkey. The erythrocytes in about 85 per cent of the white people contain Rh agglutinogen; hence such persons are *Rh positive;* the remaining 15 per cent are *Rh negative.* Under normal conditions no agglutinin (antibody) is present in the blood plasma to react with the Rh agglutinogen. However, if an Rh-negative (Rh–) person receives Rh-positive (Rh+) blood by transfusion, there will be formed in the plasma of the recipient some Rh-positive agglutinins (anti-Rh-positive antibodies). When this recepient receives a second quantity of Rh-positive blood, the previously formed Rh-positive agglutinins will react with the Rh-positive agglutinogens (of second transfusion) with serious reactions. The Rh-positive agglutinogen was at first thought to be inherited as a dominant factor, but recent studies suggest that instead of just two types (Rh-positive and Rh-negative) there are eight or more alleles which may result in many genetically different combinations.

In human pregnancies, a Rh-negative mother and a Rh-positive father may have a Rh-positive offspring (inherited from its father). The Rh-positive factor of the embryo while in the mother may pass by blood through the placenta to stimulate the mother to produce Rh-positive agglutinins (antibodies). If the same two parents conceive a second child, the mother may pass some of her Rh-positive factor through the placenta to this second Rh-positive child and the reactions may cause destruction of erythrocytes in the latter. If extreme, the embryo may die prenatally (anemia) or it may die postnatally, but if not serious the infant may recover.

The inheritance of the type of blood (O, A, B, or AB) is due to a series of alleles (genes): allele A produces agglutinogen A; allele A^B produces agglutinogen B; allele a produces no agglutinogen, and the latter is recessive to the other two. Neither gene A nor A^B is dominant to the other. When both A and A^B are present, an individual of the AB group results. Blood types are inherited specifically and do not change; hence, blood tests may be used in certain cases of disputed parentage. These blood tests cannot prove that a certain man is the father of that particular offspring but only whether he could be the father. This means that a certain offspring might have been produced by any one of a number of individuals belonging to certain different blood groups. In other instances a certain child with a specific blood group could not have been produced by certain individuals of other definite blood groups. Information secured from types of blood is helpful in ascertaining certain racial and national information as well as in certain legal cases.

XIII. IMPROVEMENT OF THE HUMAN RACE—EUGENICS

The human race has only recently become interested in the scientific improvement of the members of which it is composed, in spite of the fact that men have for a long time attempted to create and maintain better and better types of plants and other animals. The individual member can be improved by bettering their environment, thereby permitting that which they have inherited (physically and mentally) to develop as far as possible. If all members of the race develop what they have inherited to a maximum, the race as a whole is benefited. However, it must be clearly understood that such benefits are purely temporary and do not improve the hereditary genes or factors of the individuals when these genes are transmitted to future generations. In other words, this temporary improvement in developed characteristics does not take the place of real improvement of the heredity mechanism. Man has attempted to improve the human race by preventing those with extremely undesirable mental or physical traits from propagating their kind. One procedure has been the segregation in institutions of those with undesirable traits, but the trouble has been that there are more afflicted than can be accommodated in our present institutions. Pressure has also been applied to release individuals who are lightly afflicted but who are potentially undesirable from a heredity standpoint. In some cases the afflicted have been protected in institutions until they are mature. They are then released to propogate their kind. Add to this the fact that the rate of reproduction of mentally deficient couples is about twice that of couples with high mentality.

Another procedure now legalized in many states is sterilization of certain classes of defectives of both sexes in such a way that reproduction of defective offspring is impossible, though the normal sexual relations of the married state are in no way affected. In each sex the method is simply to cut the ducts leading from the sex organs so that sex cells cannot pass. Careful and scientific study of the results of legalized and controlled sterilization in various states has indicated favorable progress. Wars of the past which have claimed many of our best youths have robbed us of countless good prospective parents of future offspring. It is also known that the number of children produced by parents possessing inferior traits is far greater than the number produced by superior parents. In a short time the entire race will be affected by this rapid increase in the less desirable traits. Every possible measure should be taken to increase the birth rate among the better endowed families rather than let it continue to decrease as at present. Every possible measure should be taken to reduce as far as possible the birth rate of undesirable parents. More of the better types of offspring, fewer of the poorer types, together with the best of environments (educational, religious, home, recreational, occupational, etc.) in which the inherited materials can develop, will improve mankind.

QUESTIONS AND TOPICS

1. List the systems of the human body with the important general functions of each.
2. Explain the phenomenon of cellular differentiation and its effects in the human body.
3. Explain why the human skin is sometimes spoken of as "the jack of all trades." Describe the anatomy of the skin layers and the functions of each.
4. Explain the origin of (1) teeth, (2) nails, (3) sebaceous glands, and (4) hair.
5. Explain why there are more men afflicted with inheritable baldness than women.
6. Describe the process of heat production, distribution, equalization, and elimination in the human body.
7. Contrast human and frog skins, giving differences in structure and functions.
8. Describe each of the embryologic origins of bones, with an example of each.
9. Compare and contrast the three types of muscle tissues in as many ways as possible from a structural and functional standpoint.
10. List several methods used in naming skeletal muscles.
11. Define the following terms as applied to muscles: origin, insertion, voluntary, involuntary, abductor, adductor, striated, and nonstriated (smooth).
12. Explain in detail the physiologic process of digestion of various foods in man.
13. Explain why all substances in nature are not desirable for human foods.
14. Explain specifically why we cannot inhale air and swallow food at the same time.
15. List the properties, common sources, and effects produced by each of the more common vitamins.
16. List the chemical formula for each vitamin, commenting on the similarity or dissimilarity of the various formulae. What does this mean?

17. Beginning at a certain point, trace the complete human circulation (naming all structures in proper sequence) back to the starting point.
18. Contrast in as many ways as possible from a structural and functional standpoint (1) arteries, (2) veins, (3) capillaries, and (4) lymph vessels.
19. Classify human blood corpuscles, giving the anatomy and physiology of each.
20. Explain in detail the theory regarding the clotting of human blood.
21. Describe in detail (1) external respiration and (2) internal respiration.
22. Classify human wastes, telling specifically how and where each is eliminated.
23. Explain coordination in man by (1) nervous system and (2) chemical substances.
24. Describe the structure and function of (1) the various kinds of receptors, (2) the various kinds of effectors, and (3) the different types of conductors.
25. Explain in detail the theory regarding the initiation and conduction of nerve impulses.
26. List the more important structural and functional characteristics of the parts of the human nervous system.
27. Describe the structure and important functions of each endocrine gland.
28. Explain the process of human reproduction, including the formation of sperm and egg and the stages of embryologic development.
29. List several vestigial structures in man and give their significance.
30. Classify human diseases and describe the various body defenses against infectious diseases.
31. Briefly describe some of the earlier theories of human diseases.
32. Give characteristics and functions of the important antibodies in man.
33. Explain the method of inheritance of such human traits as the instructor may suggest.
34. If you know the blood group of each of your parents, give all the possible blood group types in your family.
35. Discuss each of the methods for human race improvement, including the effectiveness of each method.

SELECTED REFERENCES

Amberson and Smith: Outline of Physiology, F. S. Crofts & Co.
Anthony: Textbook of Anatomy and Physiology, The C. V. Mosby Co.
Best and Taylor: The Living Body, Henry Holt & Co., Inc.
Carlson and Johnson: The Machinery of the Human Body, University of Chicago Press.
Clendening: The Human Body, Alfred A. Knopf, Inc.
Cowdry: Human Biology and Racial Welfare, Paul B. Hoeber, Inc.
Davenport: How We Came by Our Bodies, Henry Holt & Co., Inc.
Dorsey: Why We Behave Like Human Beings, Harper & Brothers.
Edwards: Concise Anatomy, The Blakiston Co.
Francis and Knowlton: Textbook of Anatomy and Physiology, The C. V. Mosby Co.
Gerard: The Body Functions, John Wiley & Sons, Inc.
Gruenberg and Bingham: Biology and Man, Ginn & Co.
Guyer: Speaking of Man, Harper & Brothers.
Hance: The Machines We Are, Thomas Y. Crowell Co.
Herrick: The Brains of Rats and Men, University of Chicago Press.
Hoskins: The Tides of Life—The Endocrine Glands, W. W. Norton & Co., Inc.
Kahn: Man: In Structure and Function (2 vols.), Alfred A. Knopf, Inc.

Kimber, Gray, and Stackpole: Textbook of Anatomy and Physiology, The Macmillan Co.
Marshall: Introduction to Human Anatomy, W. B. Saunders Co.
Millard and King: Human Anatomy and Physiology, W. B. Saunders Co.
Newman: The Nature of the World and Man, University of Chicago Press.
Scheer: Comparative Physiology, John Wiley & Sons, Inc.
Sherman and Lanford: Essentials of Nutrition, The Macmillan Co.
Sherman and Smith: The Vitamins, American Chemical Society.
Stanford: Man and the Living World, The Macmillan Co.
Turner: Endocrinology, W. B. Saunders Co.
Williams: Textbook of Anatomy and Physiology, W. B. Saunders Co.
Youmans: Nutritional Deficiencies, J. B. Lippincott Co.
Zoethout and Tuttle: Textbook of Physiology, The C. V. Mosby Co.

Chapter 26

ECONOMIC IMPORTANCE OF ANIMALS

Naturally, not all the animals of economic importance, nor the economic importance of all the animals listed, can be given in a short chapter. Economic importance is considered from the beneficial as well as the detrimental standpoints. Additional information along these lines may be found in the chapter on Applied Biology. The following examples are representative, but more detailed accounts should be read if these are not sufficient for the particular needs of the reader.

PHYLUM 1—PROTOZOA (SINGLE-CELLED ANIMALS)

Certain Protozoa which bear shells (class Sarcodina, order Foraminifera) leave a deposit of chalk after their death. The limestone pyramids of Egypt contain numerous, large Foraminifera. Other Foraminifera are useful in determining the proper places to drill oil wells. Foraminifera (Fig. 257) are of great geologic importance because they are common fossils from the Silurian rocks (395 million years ago) down to the present (Figs. 320 to 322).

Certain marine, fossilized types of Protozoa (class Sarcodina, order Radiolaria) are found in chalk, flint, slate, and deep-sea deposits. The siliceous skeletons of certain Radiolarians aid in the formation of flint.

Protozoa of various kinds may impart unpleasant odors, tastes, and colors to waters. For example, *Bursaria* (class Infusoria) produces a "salt marsh" odor in water (Fig. 258); *Uroglena* (class Mastigophora) produces a yellow color and a "codfishy" odor (Fig. 259); *Peridinium* (class Mastigophora) turns the sea water along the coasts of California and Australia a reddish color; *Dinobryon* (class Mastigophora), a colonial form, produces a "fishy," seaweed odor (Fig. 260); *Synura uvella* (class, Mastigophora) produces a bitter, spicy taste (like ripe cucumbers) and an "oily" odor in water (Fig. 261); *Noctiluca* (class Mastigophora) may be quite common in sea water, giving a reddish-brown color or a greenish-blue phosphoroscence at night.

A number of Protozoa produce a variety of human diseases, of which the following are typical and representative: *Balantidium coli* (class Infusoria) (Fig. 262) produces intestinal ulcers and a type of dysentery.

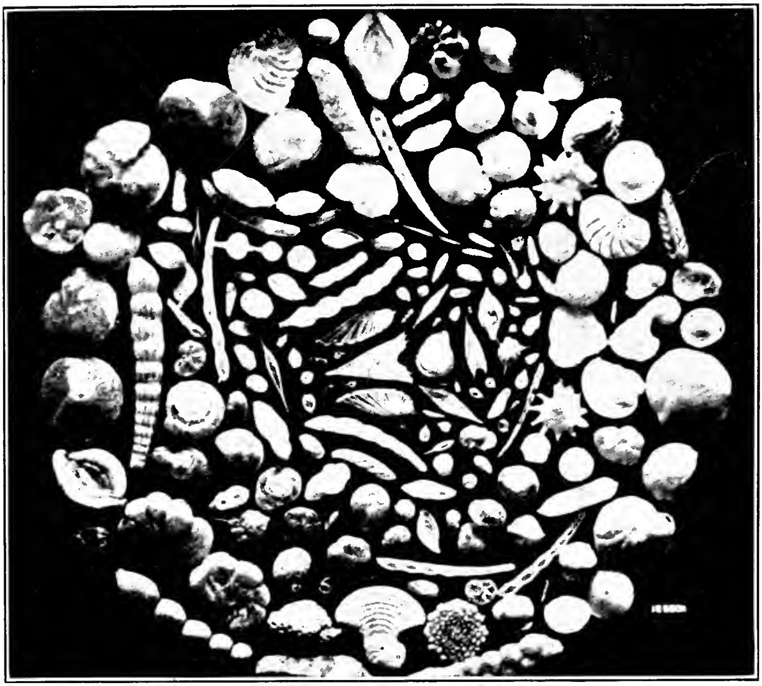


Fig. 257.—Various species of *Foraminifera* of the class *Sarcodina* (phylum *Protozoa*). (Courtesy of Victor Animatograph Corporation.)

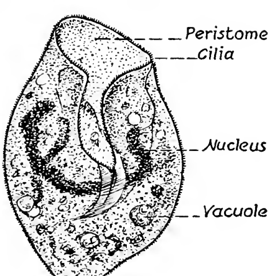


Fig. 258.

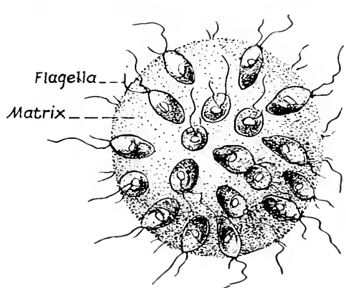


Fig. 259.

Fig. 258.—*Bursaria truncatella* of the class *Infusoria*, phylum *Protozoa*.

Fig. 259.—Spherical colony of the protozoan *Uroglena americana* (class *Mastigophora*).

Trypanosoma gambiense (class Mastigophora) (Fig. 263) produces African sleeping sickness; *Giardia intestinalis* produces a type of diarrhea. In the class Sarcodina, *Endamoeba histolytica* (Fig. 264) produces amoebic dysentery and ulcers and *Endamoeba gingivalis* is associated with *Pyorrhea alveolaris.* In the class Sporozoa, *Plasmodium vivax* produces tertian malarial fever with a characteristic chill every forty-eight hours

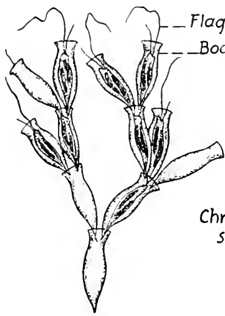


Fig. 260.

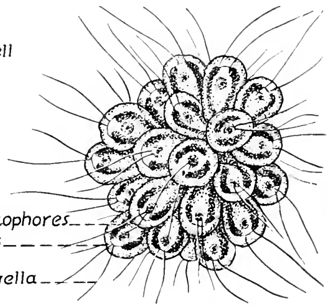


Fig. 261.

Fig. 260.—Branched colony of *Dinobryon sertularia,* a protozoan of the class *Mastigophora.* Note the flagella of unequal length.

Fig. 261.—Spherical colony of *Synura uvella,* a protozoan of the class *Mastigophora.* Note the flagella of unequal length; the chromatophores are paired color bands; spines are bristles on the body of each individual

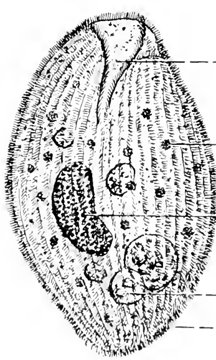


Fig. 262.—*Balantidium coli,* a protozoan of the class *Infusoria,* is associated with a type of diarrhea.

and for which quinine is specific treatment; *Plasmodium malariae* (Fig. 176) produces quartan malarial fever with its attacks of malaria at intervals of three days; *Plasmodium falciparum* produces estivoautumnal malarial fever (tropical malaria) with chills daily or at irregular intervals.

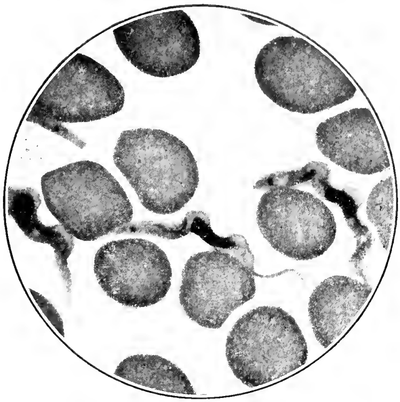


Fig. 263.—*Trypanosoma gambiense,* a protozoan of the class *Mastigophora,* is the cause of tropical sleeping sickness as found in central and western Africa. Observe the dark nucleus and the flagellum on the protozoa as they lie between the blood corpuscles. (Copyright by General Biological Supply House, Inc., Chicago.)

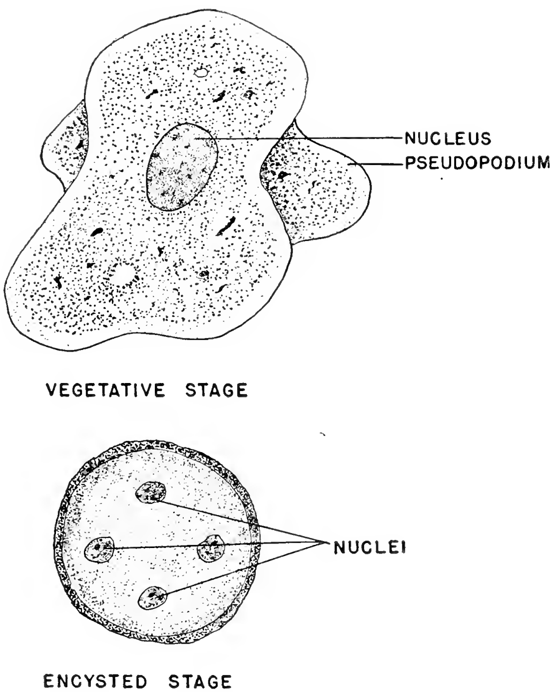


Fig. 264.—*Endamoeba histolytica* of the class *Sarcodina* is the cause of human amoebic dysentery. The vegetative stage frequently ingests red blood corpuscles. (From Parker and Clarke: Introduction to Animal Biology, The C. V. Mosby Co.)

Certain diseases of animals other than man are produced by Protozoa. The following are typical and representative: *Opalina* (class Infusoria) is responsible for a parasitic condition in the intestine of frogs (Fig. 265). In the class Mastigophora, *Histomonas meleagidis* produces "black-head" of turkeys; *Trypanosoma brucei* (Fig. 266) is carried by the tsetse fly

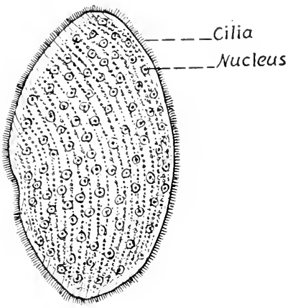


Fig. 265.

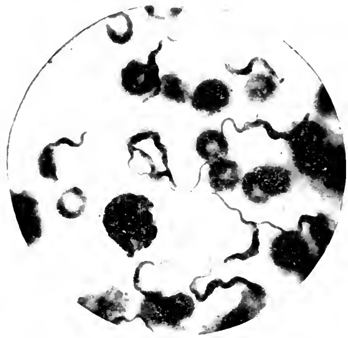


Fig. 266.

Fig. 265.—*Opalina ranarum,* a protozoan of the class *Infusoria,* is parasitic in frogs, worms, and mollusks.

Fig. 266.—*Trypanosoma brucei* of the class *Mastigophora* causes the deadly Nagana disease of various animals in Africa. This parasite is transmitted by the tsetse fly (*Glossina sp.*) (Copyright by General Biological Supply House, Inc., Chicago.)

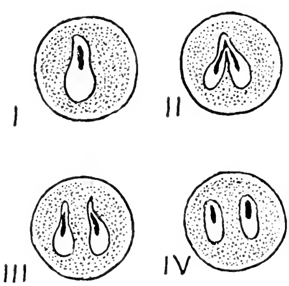


Fig. 267.—*Babesia bigemina,* a protozoan of the class *Sporozoa,* causes Texas fever in cattle. Four stages in red blood corpuscles are shown.

(Glossina morsitans) and causes the tsetse fly disease of cattle; *Trypanosoma evansi* produces a disease known as surra in cattle and horses; *Trypanosoma equiperdum* is responsible for the disease called dourine in horses. In the class Sporozoa, *Monocystis* parasitizes the seminal vesicles of the earthworm (Fig. 77); *Coccidia* produces red dysentery in calves; *Babesia bigemina* (Fig. 267) causes Texas cattle fever; *Nosema bombycis*

produces the silkworm disease (pébrine); *Pseudospora volvocis* is a parasite on another protozoan animal, *Volvox*.

Certain flagellated Protozoa (class, Mastigophora) live symbiotically in the intestines of wood-feeding termites ("white ants"). The Protozoa receive protection, in turn digesting the woody materials for use by the termites. Enzymes produced in the bodies of the Protozoa make the wood particles in the intestine of the termites available for the latter. The mutual benefit is classed as a case of symbiosis. *Cristispira* (class Mastigophora) frequently is found in oysters and clams. Certain ciliated Protozoa (class Infusoria) destroy bacteria in sewage disposal plants. This phenomenon is taken advantage of in the necessary destruction of sewage.

Certain types of Protozoa, especially in water, furnish foods for other animals. Protozoa are well adapted for laboratory experimentation for such studies of life processes, characteristics of living protoplasm, cell studies, and the effects of physical and chemical agents on living protoplasm, as well as many others. Many Protozoa are at present unknown, and many of those which have been studied are of unproved economic importance. Undoubtedly, future work will place many more in their proper places in the economies of Nature.

PHYLUM 2—PORIFERA (SPONGES)

Sponges furnish protection for both plant and animal organisms. They are not used as foods because of the presence of skeletal spicules, strong odors and tastes, poisonous ferments, and an extremely small amount of stored food material in their bodies. Boring sponges *(Cliona)* bore the shells of oysters and other mollusks for protection rather than for food. The siliceous sponges and certain Protozoa (order Radiolaria) initiate the process of flint formation. It is stated that beds of flint may be made from a mass of sponge skeletons within fifty years.

Fresh-water sponges (Fig. 86) frequently attach themselves to water pipes, reservoirs, water filtration equipment, and, together with other miscellaneous forms of life, form a feltlike mass which interferes with the water system.

Sponges may starve oysters and other shelled mollusks by attaching themselves to the shells and taking the food from the mollusks, and they may interfere with other forms of life in their vicinity by using the oxygen in the water.

Fossil sponges, similar to present-day forms, have been found chiefly in chalk and flint formations from the Cambrian period (550 million years ago) to the present.

The glass fibers of the glass sponges (Fig. 85) were formerly used in making "glass wool" which was used for filtering clumps of bacteria and in the manufacture of toys and ornaments. This type of wool is now made by melting glass and forcing it through small pores and rapidly cooling the fine fibers.

The commercial uses of sponges are too well known to require much elaboration. The annual value of the sponge industry is approximated at $2,000,000, while that of Florida alone approximates $700,000. Roman soldiers were said to have used sponges as drinking utensils many years ago.

The United States Department of Agriculture states that sponge spicules in the marsh soils of Florida wear away the shoes of men and the hoofs of animals in a short time in the attempts to reclaim such lands.

PHYLUM 3—COELENTERATA (HYDRA, CORALS, SEA ANEMONE, SEA CUCUMBER)

Hydra is slightly beneficial in that it captures mosquito larvae and other insects, but it is detrimental in that it also captures crustacea and worms which might profitably have been used as food by higher animals. Hydra has been observed actually to destroy young fishes in fish hatcheries. Hydra has been frequently used in experiments in grafting and regeneration.

Coelenterates, in general, are not commonly used as food by man but are eagerly devoured by fishes (Figs. 88 to 95). Sea anemones are used by Italians for food, in which case they are sold under the name of "Ogliole" (Fig. 95).

Coral reefs and islands may be formed by the limestone secretions of innumerable corals (Fig. 96) which structurally somewhat resemble the sea anemone. Such coral reefs may serve as protection or prove to be treacherous hazards in ocean travel. The Great Barrier Reef extends parallel to the northern coast of Queensland for over 1,000 miles and at a distance varying from 10 to 100 miles from the shore. Many of the islands of the Pacific are more or less of coral origin. Certain types of corals are used in the manufacture of jewelry or for ornamental purposes. The finest varieties of the rose pink coral cost about $500 per ounce. Pale pink Japanese coral necklaces are frequently valued at $5,000.

PHYLUM 4—CTENOPHORA (COMB JELLIES OR SEA WALNUTS) (Fig. 97)

Ctenophores are found in warm and temperate seas where they eat fish eggs, the larvae of crustacea, oysters, and other mollusks. Ctenophores are eaten by some marine animals. In the dark, they produce and emit a luminescent light from beneath their comb plates. Because of this phenomenon they are a source of much interest to the nocturnal visitor to the seashore.

PHYLUM 5—PLATYHELMINTHES (FLATWORMS)

The adults and larvae of tapeworms found in the alimentary canals of man and other animals interfere seriously with the digestion and absorption of foods (Figs. 182, 183, and 268). The larvae of certain dog tapeworms *(Echinococcus granulosus)* may form large vesicles or bladderlike structures in man. These structures are known as hydatids or hydatid cysts which may rupture with serious or fatal results. The larvae of the dog tapeworm *(Multiceps multiceps)* (Fig. 268) cause "staggers" or "gid" in sheep by lodging in the brain or spinal cord. Cattle, deer, and goats also may be affected. The broad fish tapeworm *(Diphyllobothrium latum)* may cause severe anemia in man. This form is transmitted by improperly cooked fish. In general, the tapeworms (class, Cestoda) are internal parasites usually present in the alimentary tract and requiring an invertebrate or another vertebrate animal as their secondary host.

There are many parasitic flatworms in mammals, birds, and fishes, although there is little danger of contracting disease if the meats are well cooked. All flatworms of the class Trematoda are parasitic either in or on the bodies of invertebrate or vertebrate animals. Fossils of flatworms are commonly encountered, although they occur from the Pennsylvanian epoch (255 million years ago) down to modern times (Figs. 320 to 322).

Planaria (Figs. 177 to 179) are used frequently in experiments in regeneration (Fig. 28) and grafting, for which they seem to be particularly qualified. Dr. C. M. Child, of the University of Chicago, experimented with Planaria and as a result elaborated his important Theory of Axiate Organization of Animals. According to this theory, there is in all animals a gradient of metabolic activity located along an imaginary axis. The most active end of the gradient exercises a functional dominance over all other lower regions. Planaria was used to illustrate a principle, which in all probability will also apply to many, if not all, other animals.

Liver flukes (Figs. 180 and 181) frequently live in the bile ducts of the liver of sheep, pigs, cows, etc., and occasionally in man. This parasitism causes the organs to rot or become otherwise affected. The sheep liver fluke *(Fasciola hepatica)* (Figs. 180, 181, and 374) spends part of its life history in the soil, on grass, and also in the body of a certain species of snail of the genus *Lymnaea*, which acts as a secondary host for the liver fluke.

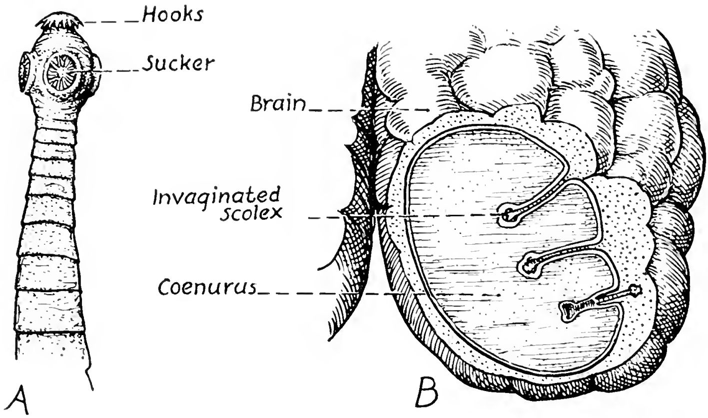


Fig. 268.—Gid tapeworm (*Multiceps multiceps*) causes "staggers" or "gid" in sheep by lodging in the nervous system. *A*, Anterior region of adult; *B*, portion of brain with a cyst. Such a cyst with several scoleces is known as a coenurus.

PHYLUM 6—NEMATHELMINTHES (ROUNDWORMS)

The number of parasitic roundworms is probably small in comparison with the number living freely in water and soil. Dr. N. A. Cobb estimates that the upper foot of arable soil contains thousands of millions per acre, where they constitute very important biologic and mechanical factors. Cobb also estimates that there are many thousands of species of roundworms which infest vertebrate animals, besides many thousands which infest such invertebrates as insects, worms, and crustacea. Roundworms are universally distributed, being present in the cold waters of the Antarctic, in hot springs, in the depths of the sea, and at high mountain altitudes. Geologically, the roundworms range from the Upper Paleozoic era (250-330 million years ago) to the present (Figs. 320 to 322).

Ascaris (Fig. 184) is a genus of roundworms which is parasitic in the intestines of frogs, hogs, calves, man, etc. *Ascaris lumbricoides* infests the small intestine of the hog; the stomach, causing nausea; the pancreas, causing jaundice; the lungs, causing "thumps." This species is sometimes called the human roundworm.

Trichinosis is a human disease (also affecting pigs and rats) which is produced by a certain order of roundworms *(Trichinelloidea)* when they are eaten in inadequately cooked meat from infested pigs. These worms are commonly called the "porkworm" (Fig. 100).

Elephantiasis is a human disease in which the limbs and other regions of the body swell to enormous size. This condition is caused by certain roundworms known as Filaria worms (order *Filarioidea*) (Fig. 101).

The hookworm disease is produced by a roundworm, *Necator americanus* (Fig. 99). Shiftlessness, loss of blood, anemia, a depraved appetite for dirt, paper, and plaster are common symptoms. Probably 2,000,000 human beings are afflicted, especially in warmer climates. The hookworm larvae enter through the skin of the body, especially the feet. Placing shoes on the feet of all persons will prevent the spread of this very important disease.

The human pinworm *(Enterobius vermicularis)* is a small, white roundworm, the female of which is 10 mm. long and the male about 3 mm. long. It is still a debated question as to the relationship between the larvae and eggs of the pinworm and appendicitis.

Gapes is a disease of poultry and game birds which is caused by the parasitic roundworm or "gapeworm" *(Syngamus trachea).* The roundworm, *Dictophyme renale,* infests the kidneys of dogs, cattle, horses, and man. The females of the species may be over three feet long.

Heterodera (Caconema) radicicola attacks the roots of such plants as potato, tomato, lettuce, turnips, and weeds, the irritation producing the characteristic swelling known as root knot or root gall.

The "vinegar eel" *(Turbatrix [Anguillula] aceti)* (Fig. 98) lives in vinegar and other sour materials. It is frequently used in experimentation.

PHYLUM 7—ROTIFERA OR TROCHELMINTHES (ROTIFERS) (Fig. 102)

Rotifers serve as food for higher forms of life. Certain Rotifers parasitize the intestine and coelom of worms as well as certain crustacea (phylum, Arthropoda). Rotifers are frequently used in experiments on bisexual and parthenogenetic development. Rotifers, in certain stages at least, are very resistant to freezing temperatures and dryness, thus initiating new food supplies for higher animals after such climatic conditions have passed.

PHYLUM 8—ECHINODERMATA (STARFISH, SEA URCHIN, SAND DOLLAR, ETC.)

The spines of echinoderms in general are a menace to those who frequent the seashores for bathing. The spines of sea urchins are used as slate pencils in certain regions of the world (Fig. 108).

Starfishes and other echinoderms are frequently used in experiments in artificial parthenogenesis, autotomy, embryology, and regeneration (Figs. 28 and 104 to 107). Starfishes forcibly open great numbers of oysters and clams and use them for food (Fig. 328). The remains of starfishes are frequently used as fertilizer. The eggs of starfishes and sea urchins are used for food. Dried sea cucumbers (class Holothurioidea), known as "trepang" or "beche-de-mer," are used for food in southern China, Queensland, and the South Pacific islands.

Geologically, the echinoderms are present from the Pennsylvanian epoch (255 million years ago) of the Paleozoic era down to the present (Figs. 320 to 322). Huge masses of limestone are frequently found to be composed of the remains of fossilized feather stars (Fig. 112).

PHYLUM 9—ANNELIDA (SEGMENTED WORMS)

Earthworms serve as food for higher animals, and probably even for certain tribes of savages (Figs. 185 to 190). By burrowing through the soil, they permit air and moisture to penetrate to the roots of plants. They rarely attack living plants. The "castings" of earthworms bring the more fertile portions of the soil in contact with the less fertile, thus resulting in a general mixing of it. Charles Darwin estimated that more than eighteen tons of earthy castings may be carried to the surface in a year on one acre of ground by 50,000 earthworms. Earthworms also help to destroy dead plant materials and change them into available and usable types for future living plants. Earthworms have been used experimentally in studies of regeneration and grafting. They may accidentally act as intermediate hosts in the transmission of the roundworm or gapeworm *(Syngamus trachea)*. This parasite need not pass through the earthworm as a host in all cases.

Certain marine, fresh-water, or terrestrial forms possessing setae (class Chaetopoda) have been found as fossils from the Cambrian period (550 million years ago) down to the present. These forms are among the earliest in geologic records (Figs. 320 to 322).

The "sandworm" or "clamworm" of the genus Nereis is used as food by marine animals (Fig. 113).

Leeches (class Hirudinea) (Fig. 114) are parasitic annelids which infest both vertebrate and invertebrate animals. They have been used as food by certain peoples. Medicinal leeches (Fig. 114) are used to draw blood in such conditions as "black eyes" and after contusions. Leeches produce a substance (hirudin) which prevents the clotting of blood. This enables the leech to secure blood as food after once attaching itself to its host. Leeches, because of their soft construction, have left no geologic records.

PHYLUM 10—MOLLUSCA (OYSTERS, CLAMS, SQUIDS, SNAILS, DEVILFISH, OCTOPUS)

Geologically, the Mollusca are found from the Cambrian period (550 million years ago) to the present time (Figs. 320 to 322). Clams and mussels were especially abundant in the Cretaceous (chalk) period in America.

Certain types of mollusk shells have been used as money in certain communities. Certain shells are used in button manufacture and are ground for chicken feed or used as fertilizer. Molluscan shells have been and are still being used as ornaments in a great variety of ways. The shells also may be used for road-building purposes. The "window-glass" shell of *Placuna placenta* (class Pelecypoda) is used as a window pane in certain parts of the tropics.

In the embryologic development of the fresh-water mussels, the so-called Glochidium stage attaches itself to the gills and fins of fishes, thus ensuring its distribution. Mollusca are especially suited for studies of growth because the shell is added and extended by the mantle as the animal grows. Oysters, scallops, clams, and mussels are used as food by man. Oysters and other Mollusca may be a means of transmitting typhoid fever and other diseases unless they are properly grown and transported. Rigid inspection has reduced this possibility to a great extent. Sometimes snails may attack the eggs of fishes in nests, others may destroy plants and vegetables, and still others may act as intermediate hosts to various parasites, transferring them to other animals.

Pearls are manufactured by pearl oysters, mussels, and clams by an accumulation of "nacre" or "mother-of-pearl" laid down in layers around such foreign substances as grains of sand, fragments of tissues, bits of shell, eggs, worms, small crustacea, and similar objects (Figs. 118, 120, and 121). In some instances foreign bodies are artificially introduced into the bodies of the mollusks and the layers of mother-of-pearl are added in concentric layers by the mollusk. Should we consider this an artificial or natural method of pearl formation?

The internal shell of the cuttlefish (class Cephalopoda) is sold as cuttle bone. This is used for food for birds and is porous and made largely of lime. Cuttlefishes or Sepias furnish the ingredients for sepia ink, which is used in art. India ink is made from the ink bags of fossil cuttlefishes. Ground cuttle bone is called "pounce" and is used by draftsmen to prevent blotting and used in medicine as an antacid.

The devilfish or Octopus (Fig. 124) sometimes attacks man, although not as frequently as once supposed. This type of mollusk is used for human food.

Snails are of medical and sanitary importance because they act as hosts to larval flatworms which may eventually become parasitic for higher vertebrate animals, including man. The European land snail *(Helix pomatia)* (Figs. 116, 117, and 119) is imported in large numbers for food and laboratory purposes. The snail is a great source of food in certain European countries, taking much the same status as the oyster in this country. In spite of many attempts at introduction, it has never pleased the palates of the American populace.

The giant land slug (class Gastropoda) is used by Indians of South America to manufacture the so-called "bird lime" to capture hummingbirds.

The boring snail *(Natica)* destroys other mollusks by boring into their shells and eating them. The borer *(Pholas)* (class Pelecypoda), because of its filelike shell, is able to bore through concrete and rocks, thus being of importance to shipping industries. The wood-boring shipworm *(Teredo navalis)* (class Pelecypoda) is able to destroy the wood of ships, wharves, and piles unless protected by concrete or creosote (Fig.122). They have been known to bore for a distance of more than two feet. Chitons (class Amphineura) are used for bait and human food (Fig. 115).

The squid (class Cephalopoda) is used for food. Squid oil is used by the Chinese as medicine and is used elsewhere for lubrication purposes (Fig. 123). The so-called "pen" is a thin, internal, chitinous shell embedded along the dorsal side. The *ink sac* discharges an inky secretion into the water to confuse enemies.

PHYLUM 11—ARTHROPODA (CRAYFISH, LOBSTER, CENTIPEDE, MILLIPEDE, INSECTS, TICKS, MITES, SPIDERS, ETC.)

The arthropods are so numerous and of so many varieties that a short discussion of their economic importance is quite difficult. The more representative examples of each of the classes of arthropods will be discussed.

Class Crustacea

Crayfishes (Figs. 128, 129, 130, and 307) and lobsters are used as food by man and other animals. There are two distinct genera of crayfishes in the United States: the genus *Cambarus* east of the Rocky Mountains and *Astacus* west of the Rockies.

The materials which crayfishes use as food vary greatly. Probably the materials most abundant and convenient are most frequently used by them for foods. The following have been used as sources of food by different species of crayfishes at various times: dead fish, clams, adult and larval insects, frogs, eggs of salamanders, toads, and frogs, eggs and adults of other crayfishes, dead leaves, such vegetable matter as young bean plants, young corn, potatoes, onions, buckwheat, and many other young plants.

The materials which lobsters use as food might be listed as follows: long-neck clams, hard-shell clams, conchs, dead and living fishes, eel-grass, etc.

The enemies of the crayfish include man, certain fishes (especially the black bass), many birds (such as the eagle and kingfisher), certain water snakes, common box turtle, and the larger salamanders.

The crayfish acts as a scavenger, thus cleaning many pools and streams which otherwise might retain their contained materials. They also injure dikes, dams, reservoirs, and levees by burrowing in them. Rather discouraging and unsuccessful methods for their extermination include drainage of the infested areas, scattering of unslaked lime over the infested area, pouring carbon bisulfide into their burrows.

Crayfishes have been used extensively for laboratory studies in neurology, homology (Fig. 307), reactions and behavior, and habits and activities. They may eventually take the place of our diminishing supply of lobsters as a source of food.

Certain crustacea, such as Daphnia (Fig. 134), Copepods, and many other similar types, are a great source of foods for fishes and other aquatic life at certain periods of their life history. Many crustacea (subclass Copepoda) (Fig. 127) are fish parasites.

Barnacles are degenerate crustacea (subclass Cirripedia) which encrust the bottoms and sides of ships, wharves, and piles, and are an annoyance to bathers, while other species act as *parasites* (Fig. 133).

The "sow bugs" or "wood lice" (subclass Malacostraca; order Isopoda) are grayish crustacea found in dark, moist places, usually under boards and rocks. They breathe by means of abdominal gills and feed on decaying vegetable matter, although they may attack living plants (Fig. 126).

Several species of shrimp (subclass Malacostraca; order Decapoda) are found along our coasts and are widely used for human food.

Several species of crab (subclass Malacostraca; order Decapoda) such as the blue crab or soft-shell crab, the painted crab, the rock crab and the oyster crab are commonly used for human food (Fig. 132).

In general, the crustacea are most cosmopolitan in their geographic distribution, thus ensuring their existence and consequently being either detrimental or beneficial. They also produce large numbers of offspring, which naturally affects their economic importance. Several deep-sea crustacea are phosphorescent and many have brilliant colors.

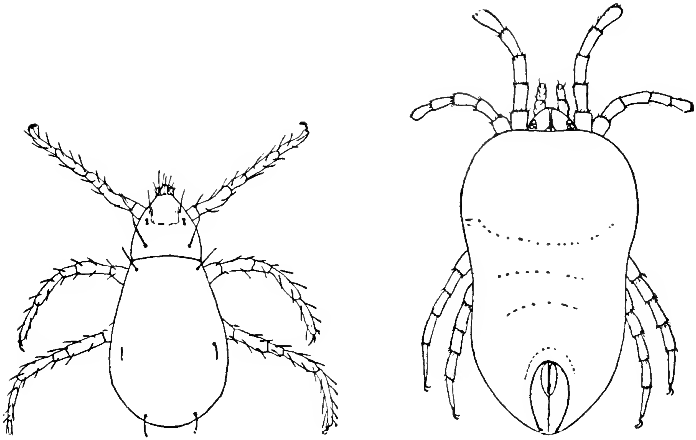
Class Diplopoda and Class Chilopoda

Very few of the millipedes (Fig. 135) are of economic importance. The common house centipede feeds on bedbugs, flies, and cockroaches (Fig. 135, *C*). It is not very poisonous to man. The venom of the large tropical centipedes may be fatal to man and other animals.

Class Arachnoidea

The "red spider," which is a mite, attacks nearly two hundred different plants, especially in greenhouses (Fig. 270).

The follicle mite *(Demodex folliculorum)* produces "blackheads" in man and other mammals by entering the hair follicles. The itch mite parasitizes the skin. The so-called chigger (the young of the harvest mite) burrows into the skin of man and other mammals, causing a severe irritation (Fig. 269). The common tick transmits the organisms which cause the disease of African relapsing fever (Fig. 138). Ticks and mites are rather small, being external or ectoparasites in many instances. Some forms burrow beneath the skin, causing rather severe irritations, while others merely suck blood from the host. Some types are able to transmit the causes of diseases from one host to another. An



A. B.

Fig. 269.—The "chigger" or harvest mite (*Trombicula sp.*) of the class *Arachnoidea,* highly magnified. The immature stage, *A,* burrows in the skin and has only three pairs of legs. The adult mite, *B,* has the typical four pairs of legs; hence, it is not a true insect. (From Chittenden: Harvest Mites, or "Chiggers," U. S. Department of Agriculture; courtesy of Bureau of Entomology and Plant Quarantine.)

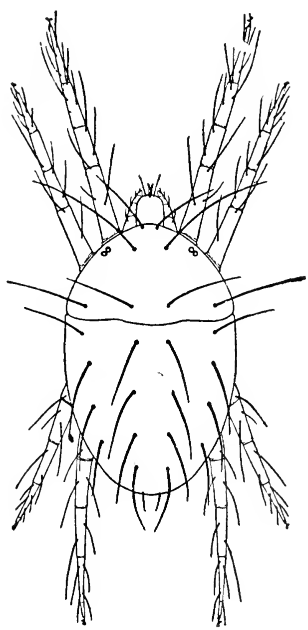


Fig. 270.—The red spider (*Tetranychus sp.*) of the class *Arachnoidea.* This adult female mite is greatly enlarged. (From McGregor: The Red Spider on Cotton. U. S. Department of Agriculture; courtesy of Department of Entomology and Plant Quarantine.)

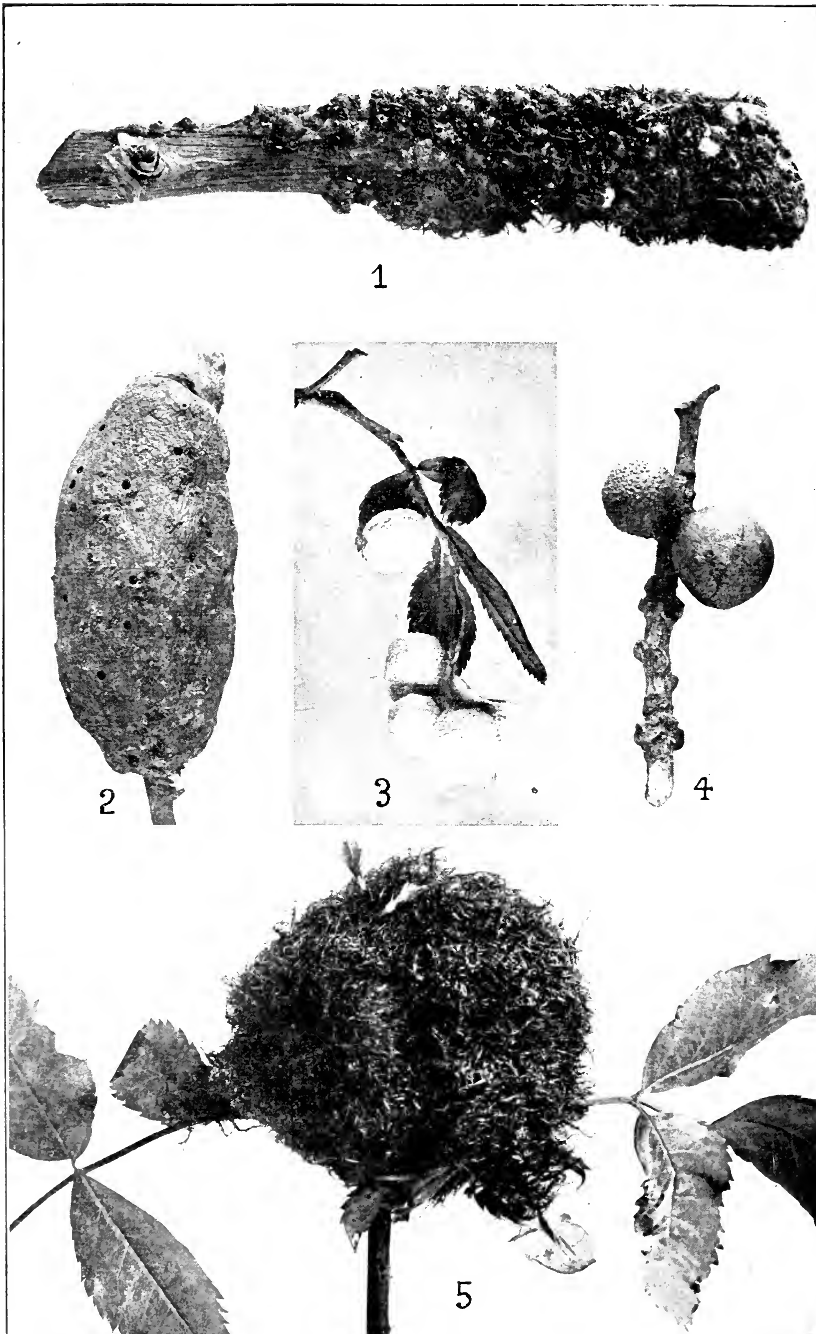


Fig. 271.—For legend, see opposite page.

example of this is the cattle tick which is able to transmit the cause of Texas fever, the loss from which amounts to over $100,000,000 annually in the United States.

The daddy longlegs or "harvestmen" (Fig. 138) feed on living insects and are thus of economic importance. Many of us as children have asked these interesting animals this question: "Which direction shall I go to hunt the cows?" We watched carefully to see which of the eight legs was moved. This was supposed to be the direction of our bovine search. Naturally and invariably, they had not been good herd masters for their leg movements always led us in the wrong direction.

The black widow spider is quite poisonous and is said to have caused a number of deaths. The web of certain spiders is used in the manufacture of certain scientific instruments. Comstock states that the *tarantula* or "banana spider" is not capable of seriously injuring man. If this is true, undoubtedly many fingers have been needlessly amputated and many hours of anxiety wasted.

The horseshoe crab or king crab *(Limulus)* of our Atlantic Coast feeds on worms and is used as hog feed and fertilizer (Fig. 136).

Class Insecta or Hexapoda

The economic importance of insects is so great and varied that only a few representative examples can be given. For a more complete discussion, textbooks in entomology and governmental publications are suggested for references.

General Usefulness of Beneficial Insects.—Tannic acid, secured from certain galls produced on plants by insects, is used for tanning animal skins for leather or fur. Many galls (Fig. 271) produced by insects contain ingredients for dyes and inks. Most of the common fruits, vegetables, and many ornamental plants are pollinated by insects. In order for clover seed to develop from clover flowers, the latter must be visited by some insect, usually some kind of bee. It has been observed that the production of fruits and seeds is materially increased if there is a hive of bees near by. This is quite profitable because the bees collect the nectar from the flowers and make it into honey, and in collecting

---

Fig. 271.—Several species of common galls produced on plants by insects of the order *Hymenoptera*. 1. Blackberry seed gall (*Diastrophus cuscutaeformis*); 2. knot gall (*Diastrophus nebulosus*); 3, mealy rose gall (*Rhodites ignotus*); 4, oak bullet gall (*Holcapsis globulas*); 5, mossy rose gall (*Rhodites rosae*). From Viereck: Insects of Connecticut, State Geological and Natural History Survey, Bulletin 22.)

nectar and pollen from various flowers they carry pollen from one flower to another, thus ensuring the pollination necessary for fruit and seed formation. Certain insects act as scavengers by destroying dead animals and plants. Others bury dung and carcasses. All of these cause these dead materials to be reverted to the soil where they can be utilized again by future plants.

Certain insects also serve as food for other animals which are valuable for us. Many game and song birds depend for the most part on insects for their natural diet. Many of our fishes use aquatic insects as foods. The large numbers of May flies which occur in fresh water at certain periods of the year are used in great quantities for this purpose. Racoons, skunks, and other wild, fur-bearing animals eat insects.

In many parts of the world such insects as crickets, grasshoppers, beetles, termites, aquatic bugs, bee larvae and pupae, and caterpillars are used as food by the more primitive races of men.

Insects promote soil fertility and improve soil conditions by serving as fertilizer and by burrowing throughout its layers, thus permitting air and moisture to penetrate to the roots of plants. Insects also destroy great numbers of weeds which might be harmful or at least take the nourishment away from more desirable plants. In this way insects are beneficial to man in helping him keep weeds somewhat under control.

Insects also have certain aesthetic values, because their colors, shapes, and patterns serve as models for decorators, artists, and milliners. The highly colored types are used for such ornaments as pins, necklaces, jewelry, and trays. They serve as subject matter and inspiration for poetry. The Oriental peoples train certain types of crickets for sport purposes. Fleas are trained for performances in flea circuses, not only for amusement but for financial reasons. Last but not least, insects afford much diversion and entertainment for the many amateurs who collect and study them.

Many types of insects are beneficial to man because they destroy other injurious types by capturing and devouring them. Many kinds live as parasites in or on the bodies of other more harmful types.

Scientific investigations of great value to man have been based on the study of insects. A study of the fruit fly or banana fly (Drosophila) has aided man materially in his study of heredity (Fig. 332). The psychology and behavior of higher animals frequently have been illuminated by a study of the simple tropisms and reactions of insects.

A study of coloration in insects undoubtedly has influenced the science of camouflage. It is a possibility that insect coloration may have suggested the idea of artificial camouflage in the beginning.

Injurious or Detrimental Insects in General.—The insects of this group might be considered from the following viewpoints: (1) those which annoy and attack man and other animals, (2) those which attack and injure plants and crops, and (3) those which destroy and diminish the values of man's commodities.

Insects may attack man in such ways as the following: They may live in or on the body as internal or external parasites. They may serve as secondary hosts for certain disease-producing organisms which without the insect could not exist for any period of time. Some species may inject poisons into the body by means of stingers, nettling hairs, or mouth parts. Others may influence the tastes and odors of foods because of repulsive odors and secretions which they produce.

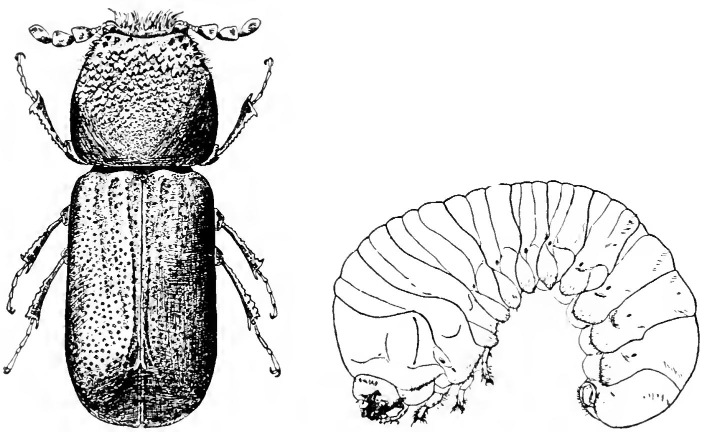
Insects may injure plants and crops in a great variety of ways. The examples given will at least give some idea of the methods in which this can be accomplished. They may attack the underground stems and roots; they may suck the vital sap; they may chew and destroy the flowers, bark, stems, and foliage; they may bore in stems, leaves, and fruits; they may construct damaging nests and shelters in various plants; they may deposit eggs in or on some part of the plant which will later develop into destructive forms; they may transport other injurious insects to new plants and establish them there at the expense of the latter; they may inject disease-producing organisms, such as bacteria, Protozoa, and fungi, into plant tissues; they may destroy parts of plants, particularly the leaves, which will prevent or hinder the normal process of photosynthesis. If this is done, normal growth and other plant activities may be highly impaired.

Insects may destroy and diminish the value of man's commodities, such as foods, clothing, books, furniture, papers, drugs, bridges, houses, lumber, collections of plants, and animals in museums. The above may be accomplished in many ways, as can be shown by the following examples: Insects may increase the expense and labor for sorting, packing, transporting, and preserving foods. Certain kinds, such as termites (Fig. 283), may destroy wooden houses, bridges, and similar articles. Clothes moths (Fig. 301) may destroy large quantities of clothing and upholstered furniture. Carpet beetles may destroy rugs, carpets, and similar objects. Papers may be destroyed by such insects as the silverfishes (Fig. 273). Foods may be contaminated by insect secretions, excretions, eggs, etc., even though the food may not be eaten by the insects themselves. Certain species of powder-post beetles (order Coleoptera), known as lead cable borers, eat holes through leaden coverings of aerial telephone cables, causing short circuits (Fig. 272).

Economic Importance of Representatives of the Orders of Insects.—

Order 1—Thysanura: The common silverfish, or bristletail, lives on starchy materials and such things as book bindings, wall paper paste, and starched clothing. They are particularly common in dark, moist places (Fig. 273).

Order 2—Collembola: The springtails (Figs. 204 and 274) are common under stones and decaying leaves and wood, etc., where they live on decaying materials. Sometimes certain kinds known as snow "fleas" (Fig. 203) are abundant on the surface of snow, where they appear as tiny black specks which spring away because of a special springlike structure on the ventral side of the abdomen. They may be a pest in maple sugar camps by collecting in large numbers in the collected sap.



A. *B.*

Fig. 272.—Lead-cable borer (*Scobicia declivis*) of the order *Coleoptera,* showing an adult, *A,* and larva, *B.* (From Burke, Hartman, and Snyder: The Lead-Cable Borer or "Short-Circut Beetle" in California, U. S. Department of Agriculture; courtesy of Department of Entomology and Plant Quarantine.)

Order 3—Ephemerida: The larvae and adult May flies (lake flies) (Fig. 275) are a source of food for fish. The larvae develop in water for one to three years, depending on the species. Especially during their emergence periods in the summer, their collection in large numbers and their decomposition around lights and on bathing beaches are great sources of annoyance. The adults cannot harm man because of the absence of stings and well-developed mouth parts.

Order 4—Odonata: The dragonflies ("darning needles") (Figs. 205 and 276) as adults and larvae are enemies of mosquitoes during the day, although many of the mosquitoes are active after dark. The adults and larvae of dragonflies and damselflies (Fig. 277) serve as food for aquatic and terrestrial animals.

Order 5—Plecoptera: The stonefly larvae (Fig. 278) live in running water under stones and serve as food for fish and other aquatic animals.

Order 6—Mallophaga: The biting bird lice (Fig. 279) eat the hair, epidermal scales, and feathers of mammals and birds. Their sharp claws produce irritations and bleeding which causes the host much annoyance and may even lead to infections. Birds often resort to dust baths in their attempt to combat the lice.

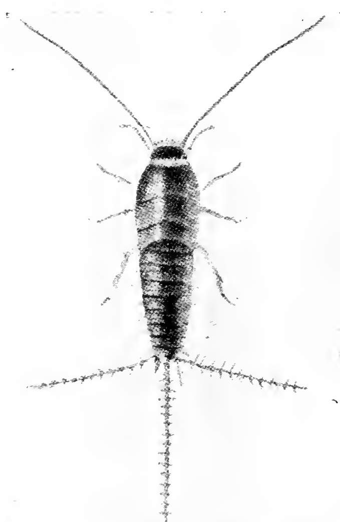


Fig. 273.

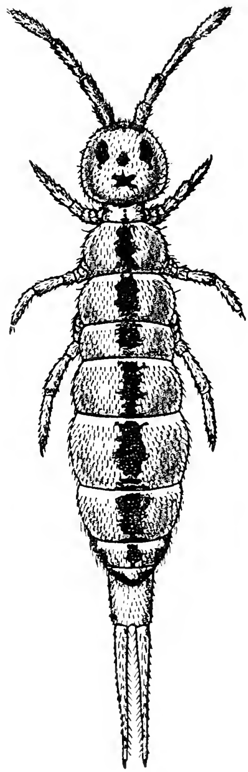


Fig. 274.

Fig. 273.—Silverfish or fish moth (*Lepisma saccharina*) of the order *Thysanura*. Dorsal view and much enlarged. (From Back: Silverfish, U. S. Department of Agriculture, courtesy of Department of Entomology and Plant Quarantine.)

Fig. 274.—Springtail (*Isotomurus palustris*) of the order *Collembola* (much enlarged). (From Folsom: Nearctic Collembola or Springtails, of the Family Isotomidae, U. S. National Museum, Smithsonian Institution.)

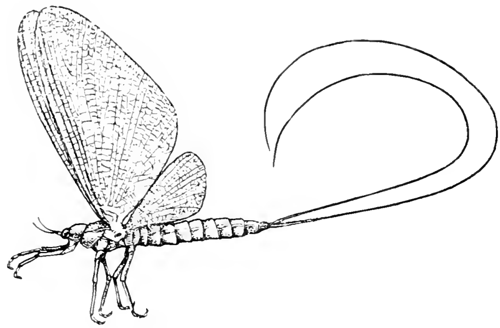


Fig. 275.—An adult Mayfly or lakefly of the order *Ephemerida*. Observe differences in fore- and hind-wings, and the long slender, many-jointed "tails" at the tip of the abdomen. The adult takes no food and lives a very short time, while the larva (naiad) with its abdominal tracheal gills develops in the water from one to three years (depending on the species).

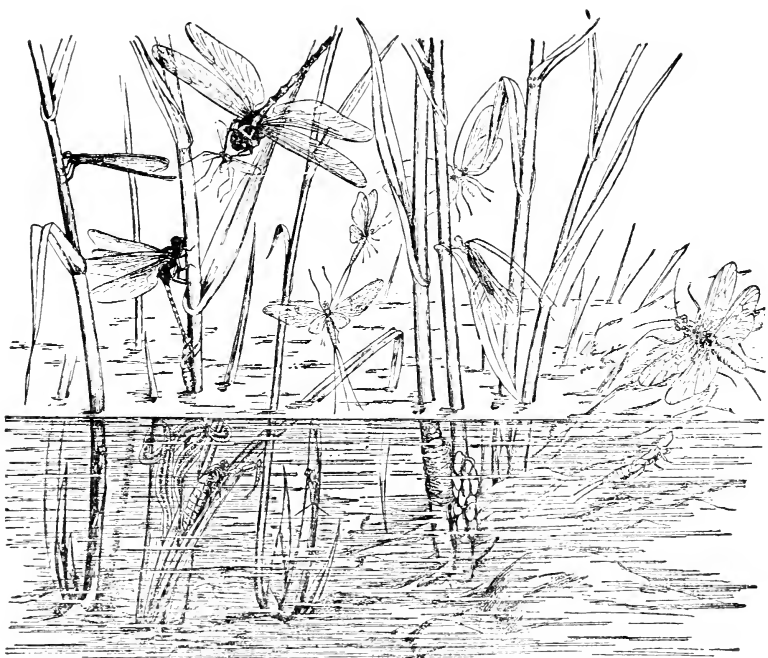


Fig. 276.—Representative insects of the orders *Odonata, Ephemerida, Trichoptera, and Plecoptera.* Immature stages in the water: adults above. (From Krecker: General Zoology, published by Henry Holt and Company, after Pearse.)

Order 7—Anoplura: These true lice are wingless parasites which suck juices from man and other mammals. The three common species which attack man (Fig. 280) are the head louse, the body louse, and the crab louse. The rat louse, dog louse, and hog louse attack other mammals. The true lice differ from the Mallophaga in having piercing-sucking mouth parts.

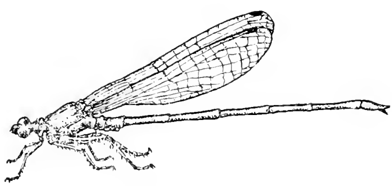


Fig. 277.

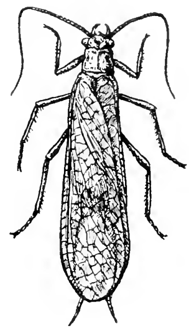


Fig. 278.

Fig. 277.—An adult damsel fly of the order *Odonata*. Note the position of the two pairs of wings when the insect is at rest.

Fig. 278.—Stone fly (adult) of the order *Plecoptera*. Note the pair of tail filaments at the tip of the abdomen and the resting position of the wings. In well-aerated water, the flat larva clings to stones; hence, the name stone fly. The larvae make excellent fish bait.

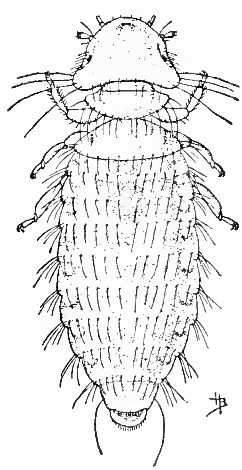


Fig. 279.—Biting bird louse (*Menopon pallidum*) of the order *Mallophaga*. A parasite from a chicken, much enlarged. (From Bishopp and Wood: Mites and Lice on Poultry, U. S. Department of Agriculture; courtesy of the Department of Entomology and Plant Quarantine.)

Order 8—Orthoptera: Extracts from the bodies of cockroaches (Fig. 281) are used to a certain extent for medicinal purposes. The four species of cockroaches in the United States attack foods, bedbugs, silverfishes, and other cockroaches. The "praying mantis" (Fig. 329) consumes other insects as food. The "walking sticks" feed on the foliage of trees and plants; they resemble the twigs that surround them in general shape, making them difficult to detect. The locusts or short-horned grasshoppers (Figs. 191 to 193) devour many kinds of vegetation and, when they migrate in swarms, may destroy all living plants in their paths.

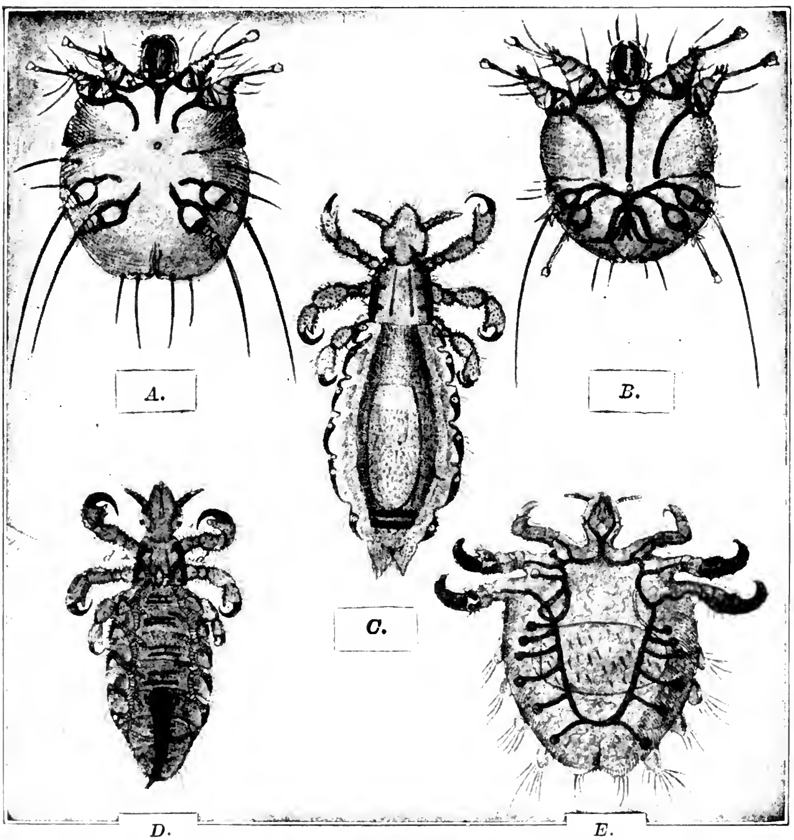


Fig. 280.—Parasitic mites (class *Arachnoidea*) and lice (class *Insecta,* order *Anoplura*). *A,* Human itch mite (*Sarcoptes scabiei*), female from ventral surface; *B,* male of mite shown in *A,* from ventral surface; *C,* body louse or "cootie" (*Pediculus corporis*); *D,* head louse (*Pediculus capitis*); *E,* crab louse (*Phthirius pubis*). (From Turner: Personal and Community Health. The C. V. Mosby Co.)

Certain species are used as food by savages and Orientals. The greenish katydids feed on leaves and tender plants, while they occasionally attack other insects. Their characteristic chirping in the evening is a source of amusement and joy unless it should become excessive and disharmonic. The long-horned or meadow grasshoppers consume large quantities of vegetation of the fields, including grains and grasses. Grasshoppers may destroy entire fields of crops, particularly in the West and South. The house cricket (Fig. 282) or true cricket produces the characteristic chirping and feeds principally on plants, although they may attack clothing. The mole cricket burrows in the ground and attacks plants, especially potatoes. The striped tree cricket attacks berry plants, grapevines, and other plants.

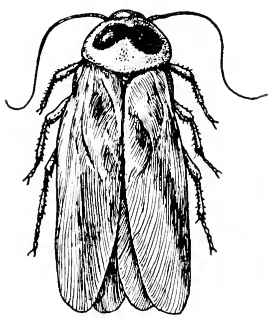


Fig. 281.

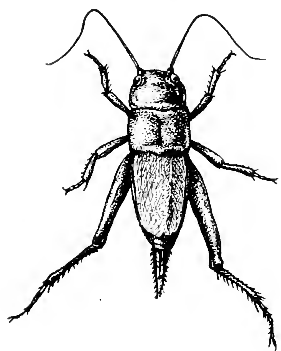


Fig. 282.

Fig. 281.—A common household cockroach of the order *Orthoptera*.
Fig. 282.—A common cricket of the order *Orthoptera* (class *Insecta*).

Order 9—Isoptera: The termites (Fig. 283) are social insects living in colonies. Originally they were abundant only in the tropics, but in recent years they have become a serious pest in the United States where they greatly damage structures which are made of wood. They live in dark places and may not be noticed by the untrained except during their so-called swarming periods. At other times they are usually unnoticed, which may lead one to believe they are not present. They may build earthen tunnels and pass through them out of sight. The colonies of certain species are underground in order to secure moisture and to prevent freezing in cold weather. They usually destroy only the inner parts of woods and rarely come to the surface, thus betraying their presence and great destruction. Sometimes, only the outer shell of a wooden

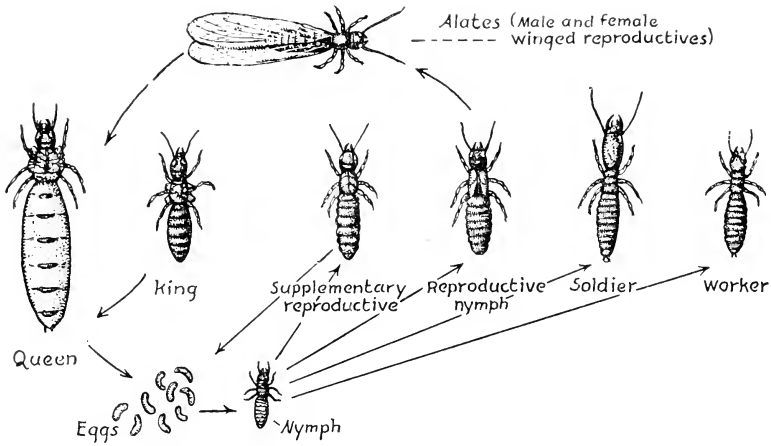


Fig. 283.—Castes and life history of termites (*Reticulitermes sp.*) of the order *Isoptera*.

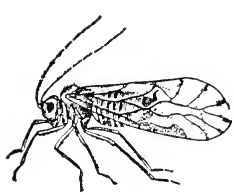


Fig. 284.

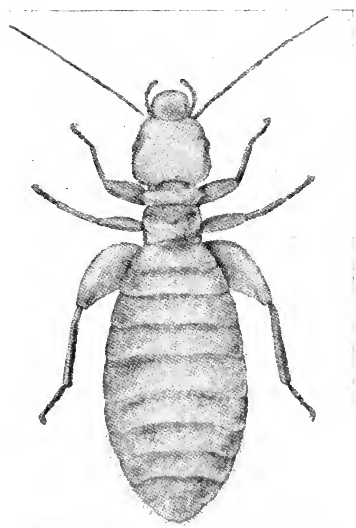


Fig. 285.

Fig. 284.—Bark louse (winged) of the order *Corrodentia*. (From Kellogg: American Insects, Henry Holt and Co.)

Fig. 285.—Book louse of the order *Corrodentia* (much enlarged). (From Back and Cotton: Stored-Grain Pests, U. S. Department of Agriculture; courtesy of Department of Entomology and Plant Quarantine.)

structure is all that remains. They may attack books, and at times even living plants. Qualified experts should be consulted if their presence is suspected.

Order 10—Corrodentia: The winged bark lice (Fig. 284) live on the various parts of higher plants, on lichens, etc. The wingless book lice (Fig. 285) devour paper, book bindings, etc.

Order 11—Thysanoptera: Several species of thrips are pests on such plants as wheat, oats, onions, grasses, and fruits (Fig. 286). Because of their small size, they are able to pass through window screens and may be quite annoying at times.

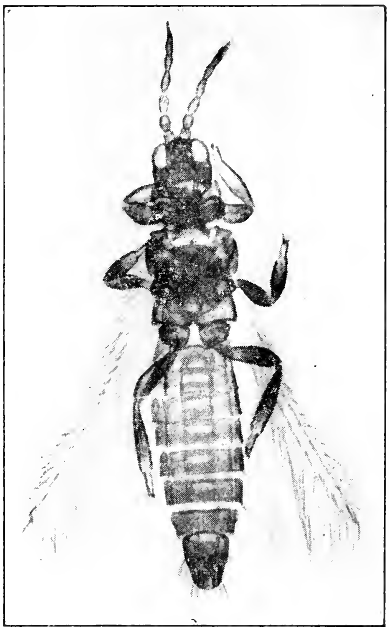


Fig. 286.—The thrips are small insects with long fringe on the wings, and belong to the order *Thysanoptera*. Much enlarged. (Copyright by General Biological Supply House, Inc., Chicago.)

Order 12—Hemiptera: The aquatic and terrestrial true bugs are included in this order. The chinch bug (Fig. 287) does great damage to corn and wheat crops. The squash bugs attack garden vegetables, especially squash and pumpkin. Bedbugs (Fig. 288) attack human beings by sucking blood and thereby cause certain diseased conditions. The assassin bugs attack other insects, such as the bedbug. At times they attack man. Are they to be considered man's friend or enemy? The leaf bugs consume large quantities of plant foliage and flowers. The giant water bugs are enemies of small fishes, tadpoles, and other insects. The harlequin cabbage bug is a serious pest of various garden plants, such as cabbage, Brussels sprouts, and others.

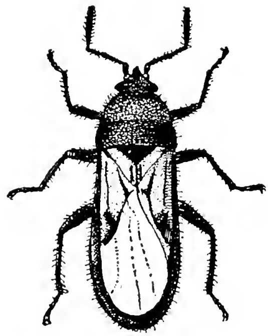


Fig. 287.—Chinch bug (*Blissus leucopterus*) of the order *Hemiptera*. Adult of long-winged form, much enlarged. (From Webster: The Chinch Bug, U. S. Department of Agriculture; courtesy of Department of Entomology and Plant Quarantine.)

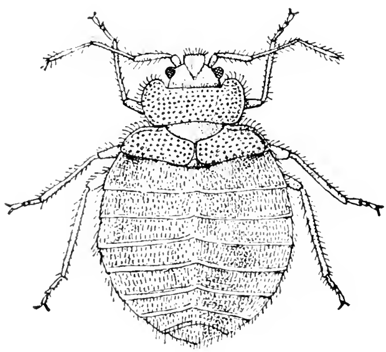


Fig. 288.—Mature bedbug (*Cimex lectularius*) of the order *Hemiptera*, much enlarged. (From Back: Bedbugs, U. S. Department of Agriculture; courtesy of Department of Entomology and Plant Quarantine.)

Order 13—Homoptera: Cochineal and crimson lake dyes or pigments are made from the bodies of certain scale insects found particularly on cactus plants. Shellac is a secretion from the glands on the backs of certain scale insects found particularly in India (Fig. 289). Such scale insects as the San José scale (Fig. 290), oyster shell scale, cottony cushion scale, and many others attack a great variety of plants, thus producing very extensive damage. The leaf hoppers are difficult to control, for they attack many types of plants. The rose leaf hopper is a typical form which is very destructive of rose plants. Aphids (plant lice) are small, very prolific Homoptera which attack a great variety of vegetation. Some of the more common forms are the grape Phylloxera, which causes decay by puncturing the roots of grapevines; the apple

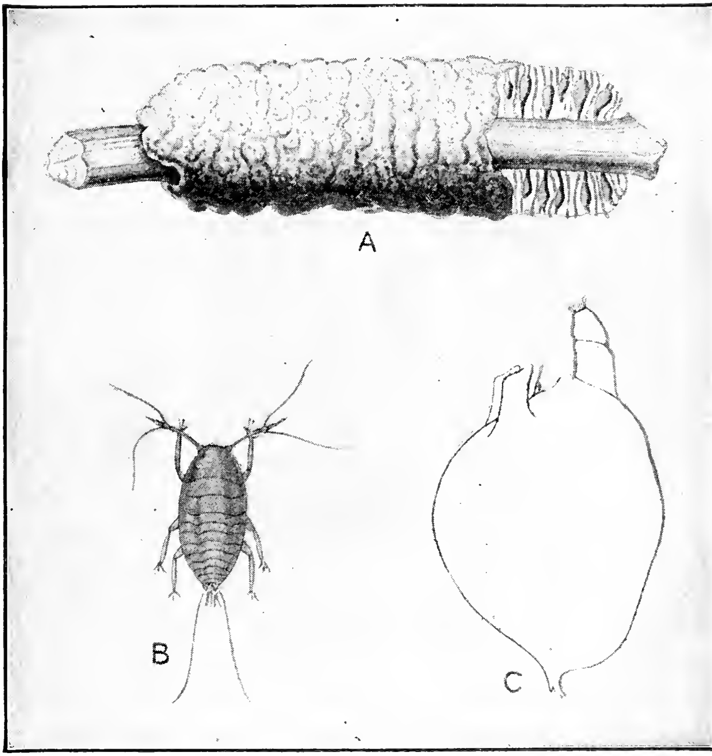


Fig. 289.—The lac insect (*Tachardia lacca*) of the order *Homoptera*. *A*, Piece of twig encrusted with lac; at right the wormlike lac insects are shown in their cells; *B*, young lac insect, greatly enlarged; *C*, body of an adult female lac insect freed from its resinous secretions. (Modified from Green: Coccidae of Ceylon, from Metcalf and Flint: Fundamentals of Insect Life, The McGraw-Hill Book Co., Inc.)

grain Aphid, which attacks the buds of apple trees, pear trees, hawthorn trees, as well as grasses and grains in warmer weather; the woolly apple Aphid, which (Fig. 291) attacks the roots and branches of apple trees. The cicadas are incorrectly called locusts. The 17-year cicada

(Fig. 292) spends over sixteen years of its life history as a larva in the soil. During the seventeenth year, the adult emerges and deposits eggs in the branches of trees, particularly fruit trees. The branches fall to the ground, where the eggs hatch into larvae, there to remain for another sixteen years. The destruction of the branches of trees by the egg-depositing process is very great. Sometimes all of the smaller branches are so badly punctured that they drop to the ground or at

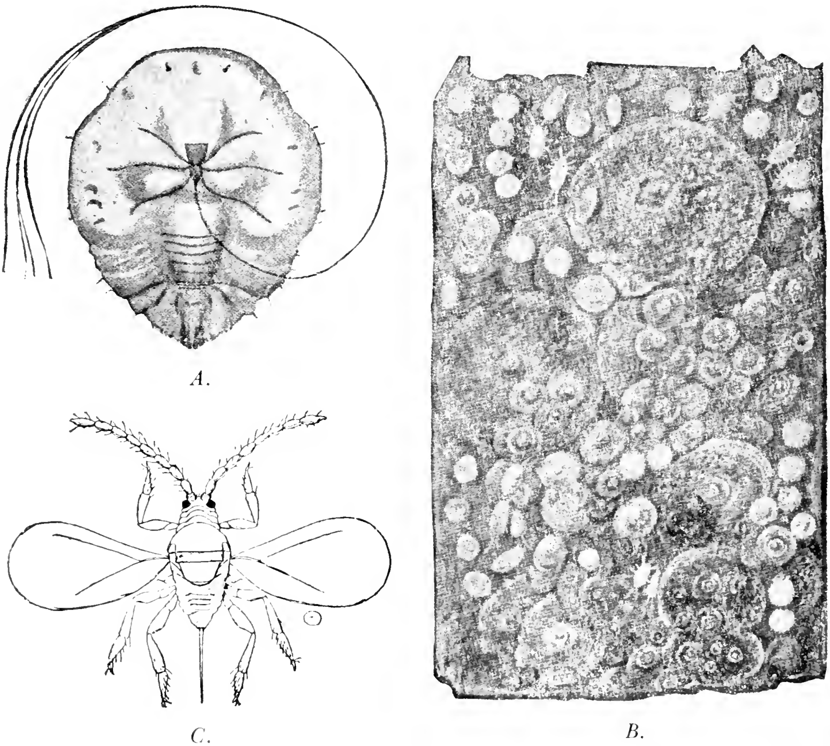


Fig. 290.—San José scale of the order *Homoptera*. *A*, Adult wingless female, ventral view, showing very long sucking setae; *B*, bark of tree showing young larvae and scales in various stages of development. The adult male, *C*, is winged. All much enlarged. (From Marlatt: The San José or Chinese Scale, U. S. Department of Agriculture; courtesy of Department of Entomology and Plant Quarantine.)

least die on the tree. All these branches should be removed and burned to destroy the eggs. The common cicada or harvest fly does damage by eating vegetation, although not to such an extent as the periodical 17-year cicada.

Order 14—Dermaptera: Earwigs (Fig. 293) feed on flowers and fruits at night but are rare in the United States. They are said to have damaged the eardrums of human beings by their pincerlike structures at the tip of the abdomen.

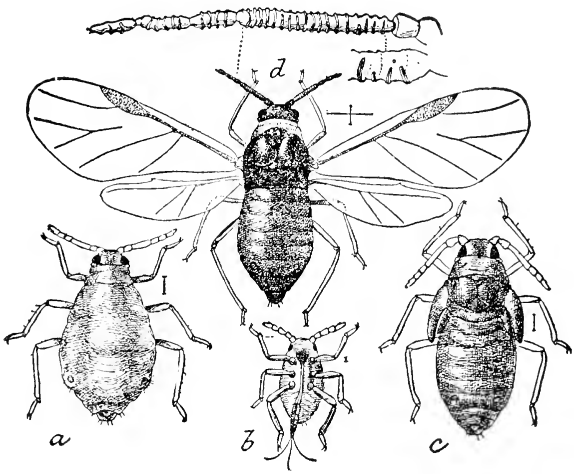


Fig. 291.—Woolly apple Aphid (*Eriosoma lanigera*) of the order *Homoptera*. *a,* Agamic female; *b,* larval aphid; *c,* pupa; *d,* winged female with the antenna enlarged above. All are greatly enlarged and with the customary woolly, waxy excretion removed. (From Marlatt: The Woolly Aphis of the Apple, U. S. Department of Agriculture; courtesy Department of Entomology and Plant Quarantine.)

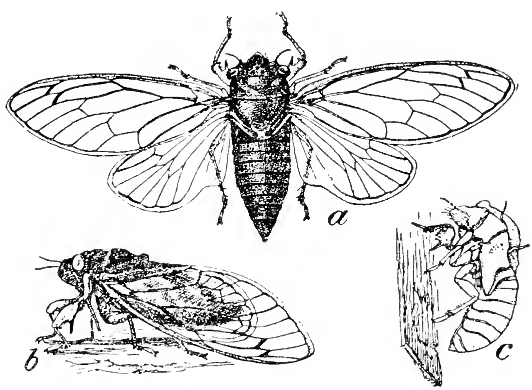


Fig. 292.—The periodical cicada (*Tibicina septendecim*) of the order *Homoptera*. *a,* Adult; *b,* adult, side view; *c,* shed pupal skin. (From Marlatt: The Periodical Cicada in 1911, U. S. Department of Agriculture; courtesy of Department of Entomology and Plant Quarantine.)

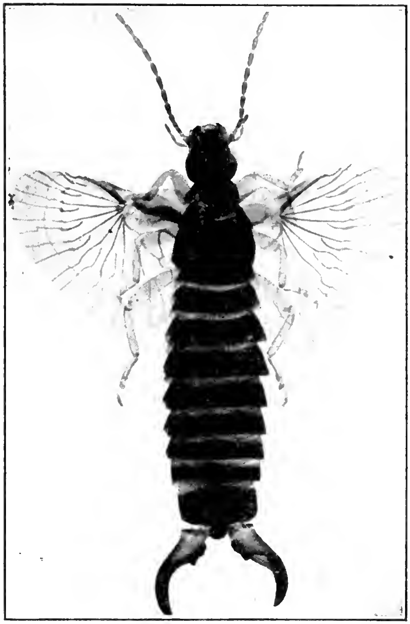


Fig. 293.—Photograph of an earwig of the order (*Dermaptera*) (*Euplexoptera*). (Copyright by General Biological Supply House, Inc., Chicago.)

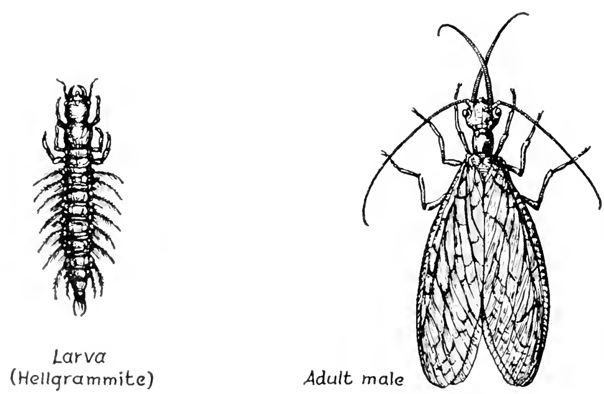


Fig. 294.—Dobson fly or horned corydalis (*Corydalis cornuta*) of the order *Neuroptera*. Observe the pair of large hornlike mandibles extending forward on the adult male: in the female they are much smaller. Note the short, hairlike tufts of tracheal gills on the abdomen of the larva which lives in water.

Order 15—Neuroptera: The larva (hellgrammite) of the Dobson fly is used as fish bait (Fig. 294). The larva of the lacewing fly (Aphis lion) destroys plant lice (Aphids) by sucking blood. The larvae of ant lions ("doodlebugs") wait at the bottom of a pit made in sand, dirt, or decayed wood, where they capture and destroy many types of insects.

Order 16—Coleoptera: The dried bodies of a certain European blister beetle known as "Spanish fly" are used as a source of cantharidin, which is used for medicinal purposes. The larvae of click beetles, commonly known as "wire worms," cause extensive damage in plants. The metallic wood-boring beetles injure shade, forest, and fruit trees by boring in them. Some of the so-called checkered beetles destroy some of the larvae of wood-boring insects. The so-called death-watch beetles damage wood greatly by boring in it. The light-producing secretion (luciferin) of fireflies (beetles) is used for illumination and is a source for study in the attempt to duplicate this material in the laboratory.

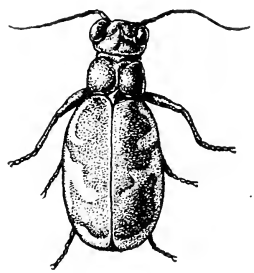


Fig. 295.—Tiger beetle of the order *Coleoptera*. Note the light markings on the wings.

This material gives off light with a minimum of heat. The tiger beetles (Fig. 295), both in the adult and larval stages, destroy large numbers of other harmful insects. Most of the ground beetles (Fig. 296) are predacious and attack such insects as leaf-eating insects, canker worms, cutworms, and the so-called tent caterpillars. The carnivorous water beetles attack numerous aquatic insects, including the mosquito. The ladybird beetles or "lady bugs" (Fig. 297) are predacious in both adult and larval stages, when they attack detrimental scale insects and plant Aphids in particular. They are consequently of great importance and the various species should be protected so that they may continue their useful habit. The Mexican bean beetle is rapidly becoming a serious pest of garden products. When bean plants are all destroyed, they do not hesitate to attack other plants. A certain species of powder-post beetle, known as the lead cable borer, makes holes in the lead coverings of telephone cables, thus causing short circuits and interruptions in service. The carpet beetles destroy large quantities of carpets, clothing, rugs, and feathers. The so-called buffalo moth (beetle) also destroys carpets, woolen fabrics, furs, and feathers. The saw-toothed grain

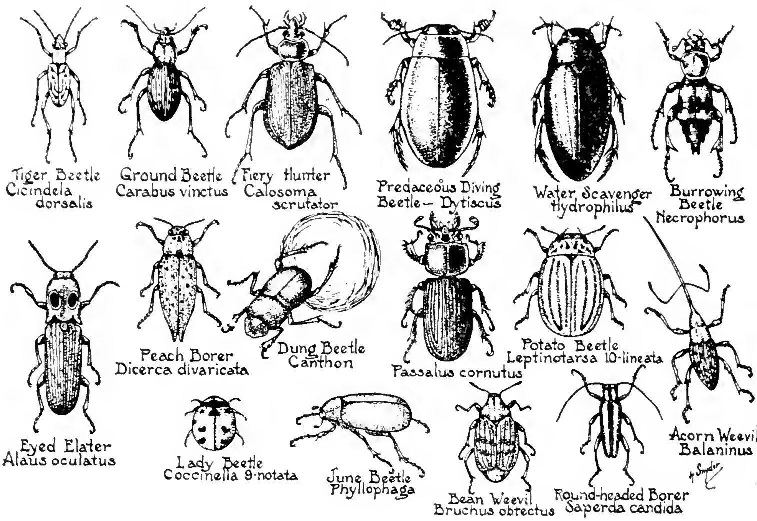


Fig. 296.—Common beetles of the order *Coleoptera*. (Copyright by General Biological Supply House, Inc., Chicago.)

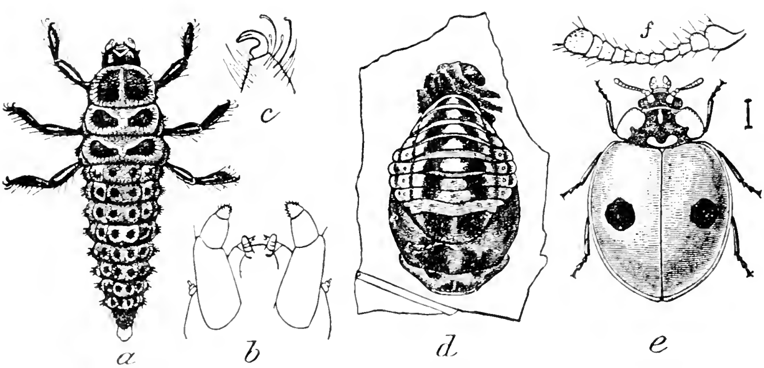


Fig. 297.—Two-spotted ladybird beetle (*Adalia bipunctata*) of the order *Coleoptera*. *a*, Larva; *b*, mouth parts of larva; *c*, claw of larva; *d*, pupa; *e*, adult; *f*, antenna of adult (all enlarged). (From Quaintance: The Aphides Affecting the Apple, U. S. Department of Agriculture; courtesy of Department of Entomology and Plant Quarantine.)

beetles are quite destructive of stored grains. The bean weevil (beetle) larva attacks bean and pea seeds, rendering them useless for planting or food purposes. The adult June beetle is a household annoyance in early summer, besides eating plant foliage. The larvae or white grubs do great damage to lawns and underground vegetation. The elm leaf beetle destroys large numbers of elm and other trees. The Colorado potato beetle destroys potato plants and other garden vegetation. This beetle migrated into Colorado from Mexico and has since spread to the East and West. The blister beetles, when dried and pulverized, produce a blister when applied to the human skin. The mealworm beetle is used as food for pet birds. It is quite common in grocery stores, flour mills, and granaries. The leaf-chafing beetles feed on the pollen, flowers, and leaves of plants. The Japanese beetle has been very destructive to plants, especially grasses, since its appearance in New Jersey in 1916 and its subsequent spread to other parts of the country. The bark beetles produce a damage of over $100,000,000 annually to forest trees in the United States. Many species of the so-called long-horned beetles are very destructive of shade, fruit, and forest trees. Some of the more common species are the maple tree borer and the apple tree borer. The cotton boll weevil causes millions of dollars' damage to cotton crops in the South. The scavenger beetles are quite beneficial because they bury or eat decaying materials, thus reverting them back to the soil where they can be used by future plants. This cleaning activity also rids the surface of the earth of them where they might be annoying if allowed to accumulate. What would be the condition of the earth if all the animals and plants of the past were still lying on the ground?

Order 17—Mecoptera: Both the larvae and adults of the scorpion flies (Fig. 298) are carnivorous and feed on numerous smaller insects.

Order 18—Trichoptera: The caddice flies (Fig. 299) are of no great economic importance. The aquatic larvae build characteristic protective cases of small rock, sand, leaves, and grass. The cases of each species are characteristic of that species. How do these supposedly stupid, aquatic larvae know what type of case pattern to build in order to display their characteristic racial coat of arms?

Order 19—Lepidoptera: The saliva of the silkworm (Fig. 300) produces the true silk of commerce. The larva of silkworms spins a cocoon of a single, continuous strand over 1,000 feet in length. This thread must be unravelled and woven together with others in order to make a single silk thread. Is it difficult to see what makes true silk cloth more expensive when one considers the great amount of material needed to make a single yard of it? The larvae of the army worms (certain moth larvae) migrate from field to field in armylike fashion and destroy large quantities of living plants, such as wheat, corn, oats, timothy, and other grasses. The larvae of the codling moth bore into the blossoms of the apple, eventually eating the core and seeds of the apple. Losses

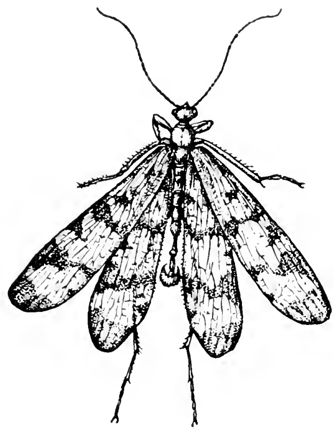


Fig. 298.—Scorpion fly of the order *Mecoptera* (class *Insecta*). Note the scorpion-like tip of the abdomen; hence, the name scorpion fly.

Fig. 299.—Caddice fly of the order *Trichoptera*. Adult and larva (in a case).

from such attacks of the codling moth amount to more than $12,000,000 annually. The larvae, or caterpillars, of the cabbage butterfly destroy the heart and leaves of large quantities of cabbage. The larvae of one type of gossamer-winged butterflies known as the harvester are carnivorous eating woolly Aphids. They are consequently of value to fruit growers. We wish the harvesters successful and prosperous lives. The larvae of the clothes moths (Fig. 301) produce great damage to furs and woolen clothing. There are two distinct kinds which may be distinguished by the kind of web which the larva builds in the cloth. The larvae of the European corn borer (Fig. 302) cause great damage to corn and a great variety of other plants. They attack and reside in such

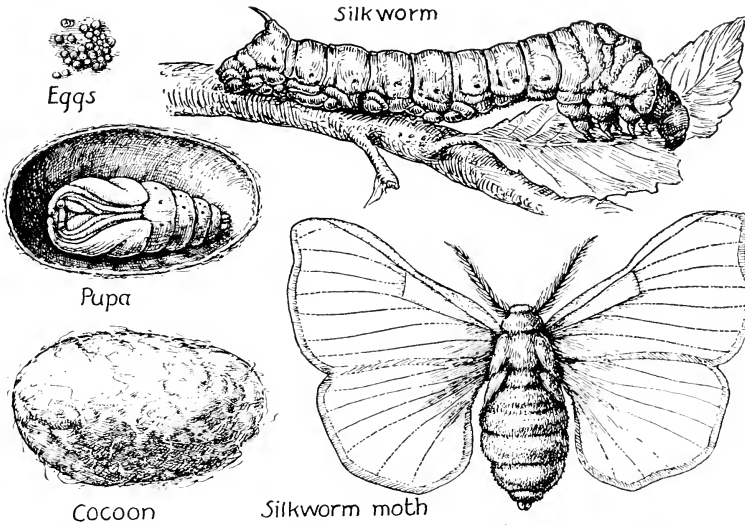


Fig. 300.—Silkworm (*Bombyx mori*), an insect of the order *Lepidoptera*. The larva or silkworm is shown feeding on a leaf. The pupa is shown with part of the cocoon removed. Note the silk threads on the cocoon.

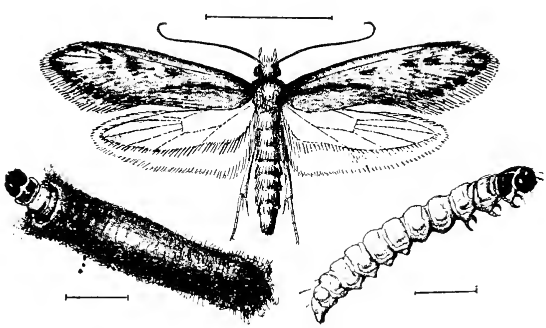


Fig. 301.—The case-bearing clothes moth (*Tinea pellionella*) of the order *Lepidoptera* (enlarged). Adult moth (above); larva (lower right); larva partially concealed in its portable case (lower left). The indistinct dark spots on the buff-colored forewings distinguish the adult from the adult webbing clothes moth, the wings of which are uniformly buff-colored. (From Back: Clothes Moths, U. S. Department of Agriculture; courtesy of Department of Entomology and Plant Quarantine.)

a great variety of plants that it is difficult ever to destroy all of them in a certain locality. The Mediterranean flour moth is a very common and injurious pest, especially in flour mills. The cotton worm and the cotton boll worm cause millions of dollars' damage annually to cotton. The various types of tussock moths attack numerous forest, shade, and fruit trees. The larvae of the grain moth bore into the grain of corn, wheat, and rye. The larvae of the black swallow-tail butterfly eat celery and parsley.

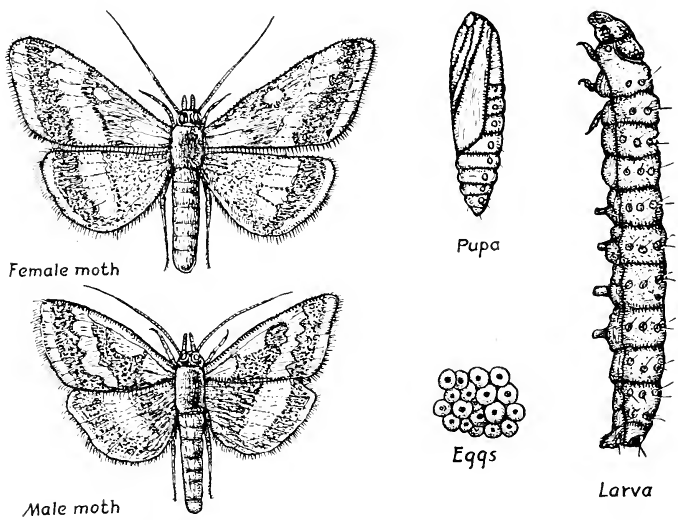


Fig. 302.—European corn borer (*Pyrausta nubilalis*) of the order *Lepidoptera*. The larva is the true borer in corn stalks and many other plants. The larva develops into the pupa, which in turn develops into the adult moth. The eggs laid by the female develop into the larvae.

Order 20—Diptera: The tachina flies are valuable enemies of leaf-eating beetles, locusts, and caterpillars, particularly those of the army worm. The common housefly, besides transmitting disease germs, such as typhoid and tuberculosis, carries the eggs of several species of parasitic flatworms. They also destroy foods by depositing their eggs in them. The horseflies attack horses, cattle, and human beings. The flesh flies and blow flies deposit eggs in meats. The eggs under proper conditions develop into maggots (larvae) which feed on the meat, thus rendering it unfit for use. The bee flies resemble true bees somewhat. Their larvae eat young grasshoppers, wasps, and bees, while the adults feed on the nectar of flowers. The banana flies (one of the fruit flies) are of great value for experimental studies in heredity. The adult flower

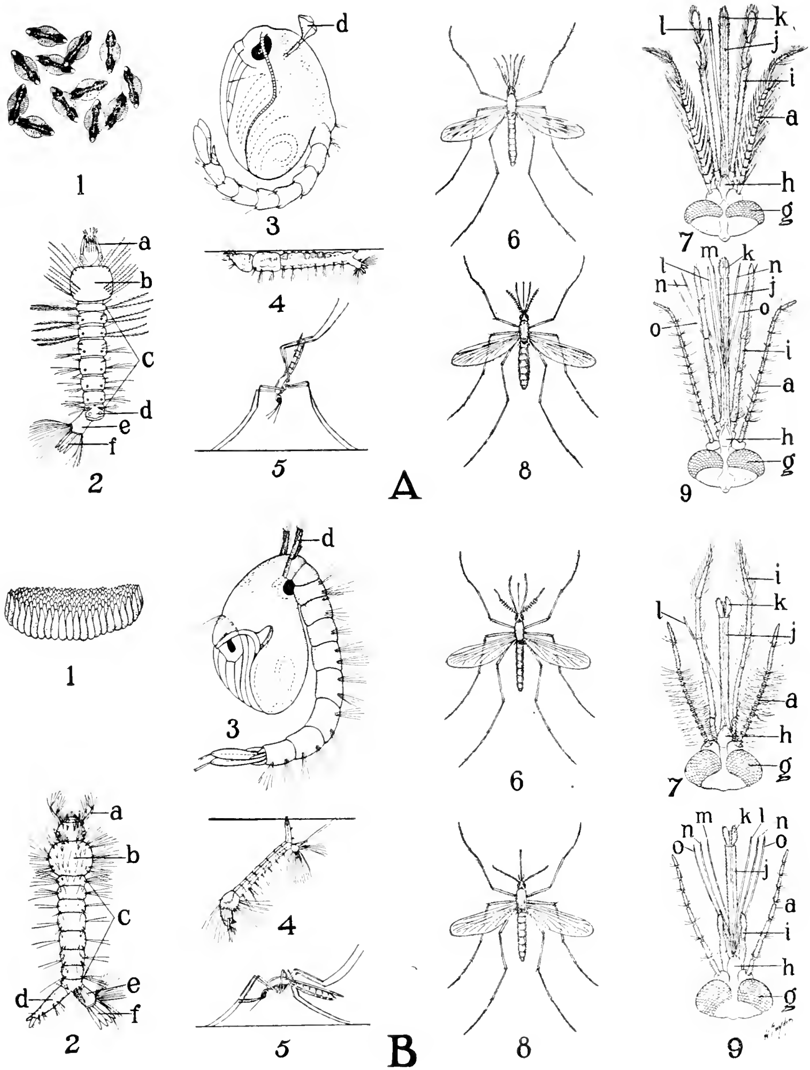


Fig. 303.—Life history and mouth parts of mosquitoes of the order *Diptera*. *A*, Malarial mosquito (*Anopheles*); *B*, common mosquito (*Culex*). *1*, Eggs; *2*, larva; *3*, pupa; *4*, larva in resting position; *5*, adult in resting position (contrast the two species); *6*, adult male; *7*, mouth parts of male; *8*, adult female; *9*, mouth parts of female. *a*, Antenna; *b*, thorax; *c*, abdomen; *d*, siphon; *e*, anal segment; *f*, gills; *g*, compound eye; *h*, clypeus; *i*, maxillary palpus; *j*, proboscis; *k*, labella; *l*, labrum epipharynx; *m*, hypopharynx; *n*, mandible; *o*, maxilla. (Copyright by General Biological Supply House, Inc., Chicago.)

flies live on pollen and nectar of flowers, while the larvae eat plant materials and other insects. The larvae of the ox-warble flies cause over $100,000,000 damage annually by ruining the hides of cattle by boring through the skin. The adult black flies are well-known pests because of their blood-sucking habits. Every hunter, fisherman, and out-of-door man has certainly been sufficiently annoyed to remember them well. Mosquitoes (Fig. 303) of the genus *Aedes* transmit the virus of yellow fever. Those of the genus *Anopheles* transmit the protozoa which cause human malaria (Fig. 176). Only the females of these two species are capable of carrying the germs because they suck blood, while the male

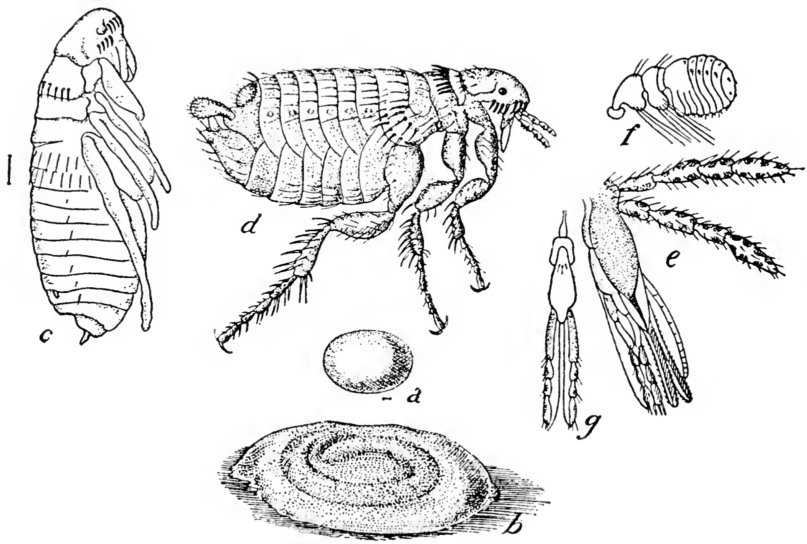


Fig. 304.—Dog and cat flea (*Ctenocephalus canis*) of the order *Siphonaptera*. *a*, Egg; *b*, larva in cocoon; *c*, pupa; *d*, adult; *e*, mouth parts of adult from side; *f*, antenna; *g*, labium (lower lip) from below (*b*, *c*, and *d*, much enlarged; *a*, *e*, *f*, and *g*, more enlarged). (From Howard: House Fleas, U. S. Department of Agriculture; courtesy of Department of Entomology and Plant Quarantine.)

probably feeds on the nectar of flowers. The females suck up the disease germs from the blood of the patient ill with the disease. The germs undergo part of their life cycle in the body of the insect and at the proper time are injected into a susceptible person bitten by the germ-carrying mosquito. The Hessian fly (one of the so-called gall gnats) produces over $10,000,000 loss annually to the wheat crop in the United States. The gall gnats deposit eggs in plant tissues. The eggs hatch into larvae which irritate the plant so that the latter produces abnormal, swollen enlargements known as galls (Fig. 271). Different types of galls on different kinds of plants are produced by specific kinds of insects. The crane flies resemble large mosquitoes, and the midges resemble small mosquitoes, for which they are both commonly mistaken.

Order 21—Siphonaptera: Fleas live among the feathers of birds and the hair of wild or domestic mammals. The human flea and the chigoe are important enemies of man. The latter burrows in the skin and is not the common chigger which is a mite belonging to the class Arachnoidea. The dog and cat flea is quite common and attacks dogs, cats, and human beings (Fig. 304). They most frequently breed in the dirt and filth, although they have recently been encountered in large quantities in the grass and weeds out of doors. The rat flea transmits the bacterium which causes bubonic plague from rats and ground squirrels to man. The larvae of fleas feed on decaying plant and animal matter so these should be destroyed in our attempt to eliminate the adult fleas.

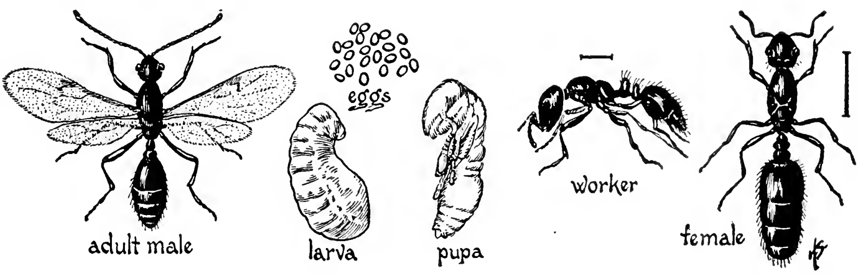


Fig. 305.—Development of the black ant (*Monomorium sp.*) of the order *Hymenoptera.* (Copyright by General Biological Supply House, Inc., Chicago.)

Order 22—Hymenopetra: Honeybees (Figs. 195 to 200) collect nectar from flowers which is changed chemically, dehydrated, and made into honey which is sealed in the wax "cells" of the honeycomb. Honeybees also pollinate certain types of flowers which they visit. Beeswax is secreted by glands on the underside of the abdomen. Bees have been studied extensively as representatives of social life among the animals. The so-called mud-daubing wasps construct nests of mud and catch other insects which are placed in these nests for food for the young wasps after they hatch. Other species of wasps excavate tunnels in the earth or dig cavities in wood. Yellow jackets build nests consisting of a series of combs surrounded by a paperlike covering. Bumblebees live in colonies in the summer and assist in pollination of clovers for seed production. Ants (Fig. 305) are colonial insects whose social life has been studied extensively. A colony, as in the case of social bees and wasps, contains different types of individuals (workers, males, female [queen]). The workers may be modified as soldiers or as small or large workers. Ants usually live in terrestrial tunnels, in hollow cavities in wood and plants, or in mounds in the ground. The leaf-cutting ant carries pieces of leaves into the nest where other workers make them into balls in which they cultivate and regulate a growth of fungus (a lower type of plant). In this way white masses of food are produced and stored for the colony. The carpenter ant builds its nest in the dead wood of trees and buildings, thus impairing their usefulness. The corn louse ant carefully uses and protects a very detrimental plant Aphid which attacks the roots of corn plants. In this way the Aphid is somewhat protected. The common red and black ants are common household pests which cause untold annoyance. They destroy large quantities of foods, grasses, and lawns.

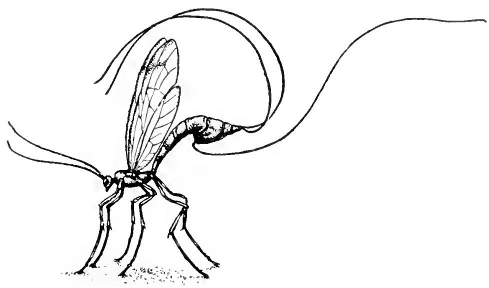


Fig. 306.—An adult ichneumon wasp of the order *Hymenoptera*. Note the long ovipositor by means of which eggs are frequently laid in the larvae of other insects and in which the eggs develop parasitically.

The "gall flies" (Hymenoptera) possess long ovipositors by means of which eggs are deposited in plant tissues. The plant is thus stimulated to develop abnormal, enlarged growths known as galls (Fig. 271). The gall naturally protects the young gall fly. The ichneumon wasps or flies (Fig. 306) are parasitic Hymenoptera which attack many injurious insects, such as tussock moths, cabbage butterflies, tent caterpillars, and corn borers.

PHYLUM 12—CHORDATA (LAMPREYS, SHARKS, FISHES, FROGS, REPTILES, BIRDS, AND MAMMALS)

This phylum of animals contains such a variety of types that it is difficult to discuss the economic importance of its members without taking each class by itself. The following examples of each class will suffice to give a representative idea of the group as a whole.

Class Cyclostomata (Cyclostomes)

The lampreys ("round mouths") feed on blood, mucus, and internal organs of fishes and crustaceans which they attack with their rasping mouth (Fig. 143). The flesh of certain lampreys is used as food.

Class Elasmobranchii (Sharks)

Several species of dogfish sharks destroy lobsters and fishes. Oil and fertilizers are manufactured from sharks. The skin of the dogfish shark is used as leather and shagreen. The teeth of sharks are used as weapons by certain people (Fig. 144).

Class Pisces (True Fishes)

Fishes (Figs. 145 to 147) furnish an important article of food. Cod-liver oil and halibut-liver oil are valued because of their high vitamin contents. Caviar is prepared from the salted roe of the sturgeons. Fish scales are used for ornamental purposes. The swim bladder of codfishes is used in the making of isinglass. Fishes are frequently used as fertilizer, the early settlers of this country many times placing a fish with the seeds they planted.

Class Amphibia (Frogs and Toads)

Frogs are used extensively as food, the breeding of large specimens for human consumption having become quite a business in itself. Frogs and toads destroy large numbers of harmful insects. Frogs are used extensively for laboratory studies in dissection and physiology.

Class Reptilia (Reptiles)

Reptiles are frequently of considerable benefit because they kill large numbers of obnoxious insects and other pests. Turtles and tortoises are used as food. Certain lizards (Iguana of tropical America) are used as food. The skins of crocodiles and certain snakes are used for manufacturing bags, boots, and cases. Tortoise shell, especially that from the horny covering of the carapace of the Hawk's bill turtle, is used in manufacturing combs and similar articles. There are only a few species of poisonous snakes in the United States, while the venomous types of the tropics cause a larger number of human deaths than any other group of tropical animals. The oils of the boa, rattlesnake, and copperhead are used for medicinal purposes. Musk, leather, and oils are secured from alligators (Figs. 151 to 153).

Class Aves (Birds) (Fig. 154)

Plumes and feathers are used for millinery purposes. Feathers are also used in manufacturing pillows. The flesh and eggs of domestic and game birds are used as food. Poultry products are valued at millions of dollars annually in the United States. Excretions and ejecta of certain species of birds are known as guano, which is used as fertilizer because of its high content of nitrogen and phosphoric acid. Game birds are a source of a great amount of sport. The equipment necessary for hunting them requires quite an expenditure of money when the entire country is taken into consideration. Certain birds are beneficial by destroying injurious animals, such as field mice, rabbits, ground squirrels, and insects, as well as the seeds of weeds. Other birds are detrimental because they destroy valuable animals as well as important plant and grains in large numbers.

Class Mammalia (Mammals) (Fig. 156)

The relations of mammals in general to man are so complex and varied that only a general account and a few suggestions can be given. More detailed books are suggested for reference studies.

Domestic animals are used extensively and for a variety of purposes. Cattle supply milk, meat, skins, hair, and hoofs. The cattle industry is one of the most important animal industries in this country. Sheep supply meat and wool for the manufacture of woolen garments. Goats serve as draft animals and as a source of meat and milk. Camels serve as draft animals and supply hair for the manufacture of fabrics and brushes. The llama is used for transportation in South America. The elephant is used for transportation and general labor. It supplies us with ivory. The dogs serve a great variety of purposes from the useful to the ridiculous. The dog was probably one of the first animals to be domesticated. Could man have selected a more faithful companion and servant?

Leather is made by "tanning" the hides of a number of animals, particularly those of cattle. Many animals are utilized in the manufacture of fertilizers. The horns and hoofs of animals are used in making glue. The skins of such animals as the otter, mink, weasel, marten, badger, wolverine, muskrat, skunk, fox, lynx, raccoon, and rabbit are used as sources of the various kinds of furs.

The destructive habits of such animals as rats, mice, and rabbits are well known and need not be discussed.

QUESTIONS AND TOPICS

1. What do we mean by the phrase economic importance?
2. (1) Summarize the economic importance of the representatives of each phylum of animals. (2) Which phylum, if any, contains animals of greatest economic importance? Why do you say so?
3. Discuss the ways in which biology may be of value to us in everyday life.
4. In what ways may a knowledge of biology be valuable to students of medicine? To students of dentistry? To students of pharmacy? To students of agriculture and horticulture?
5. Are all the beneficial forms of life found in one phylum? Are all the detrimental forms?
6. Must an animal or plant be beneficial or detrimental to man in order to be of economic importance? Explain your answer.
7. List as many departments of our national government as you can in which the economically important animals and plants are studied and the results of such studies disseminated and practically applied in your community.
8. What department of your state government is interested in the economic importance of animals and plants? Tell what it has done in your community in this connection.
9. Why does the federal government inspect plants and animals imported into this country?
10. List the general purposes of the National Association of Audubon Societies, 1974 Broadway, New York, N. Y.
11. List as many organizations as possible which are interested in out-of-door life. What does each attempt to accomplish?
12. Give a report on the nearest Federal or State fish hatchery, telling what is done there and what effect its work has on the average citizen.
13. Can you think of any animals or plants which might be improved? How?
14. List several new varieties of animals and plants which have recently been originated. Tell how each new kind was produced and why.

SELECTED REFERENCES*

Metcalf: Textbook of Economic Zoology, Lea & Febiger.
Reese: Economic Zoology, P. Blakiston's Son & Co.

*Also consult various textbooks on zoology, entomology, etc., references to which are made in various parts of the text.

Chapter 27

HOMOLOGY; ANALOGY; AUTOTOMY; REGENERATION; MORPHOGENESIS

HOMOLOGY (ho -mol′ o ji) (Gr. *homos,* same; *logos,* discourse)

Homologous organs or structures are those which are *fundamentally similar in structure and in embryologic development, having their origin in a common ancestral type.* The arms of man, the forelegs of cats, the wings of birds, etc., are structurally homologous and morphologically similar in spite of their apparent differences upon casual observation. If they are compared carefully and in detail, they will be observed to be quite alike. In this case, two homologous bones, one small and the other large, may make the over-all picture of the two appendages appear to be more different than they are fundamentally.

Several appendages on the same organism may show homology because of their similar embryologic origin and development as well as their similar structure in the adult. For example, the pairs of appendages on a crayfish or lobster (Figs. 128-130, 307) show homology, and since the appendages form a consecutive series, it may be called *serial homology.* The apparently different appendages of the crayfish have evidently developed from a fundamental type and in the adult are constructed along fundamentally similar lines, even though some of them perform different functions.

Likewise, the legs of different insects are structurally homologous (Fig. 308) since they are composed of fundamentally the same units, some of which may vary in size or shape, which makes the legs of different insects appear more different than they actually are.

Homologous structures or organs may have similar functions (for example, the legs of man and the hindlegs of cats, dogs, horses, etc.) or they may have different functions (for example, the arms of man and the wings of birds). A study of homology teaches that certain structures may be more closely related embryologically and structurally than a casual observation of them might reveal.

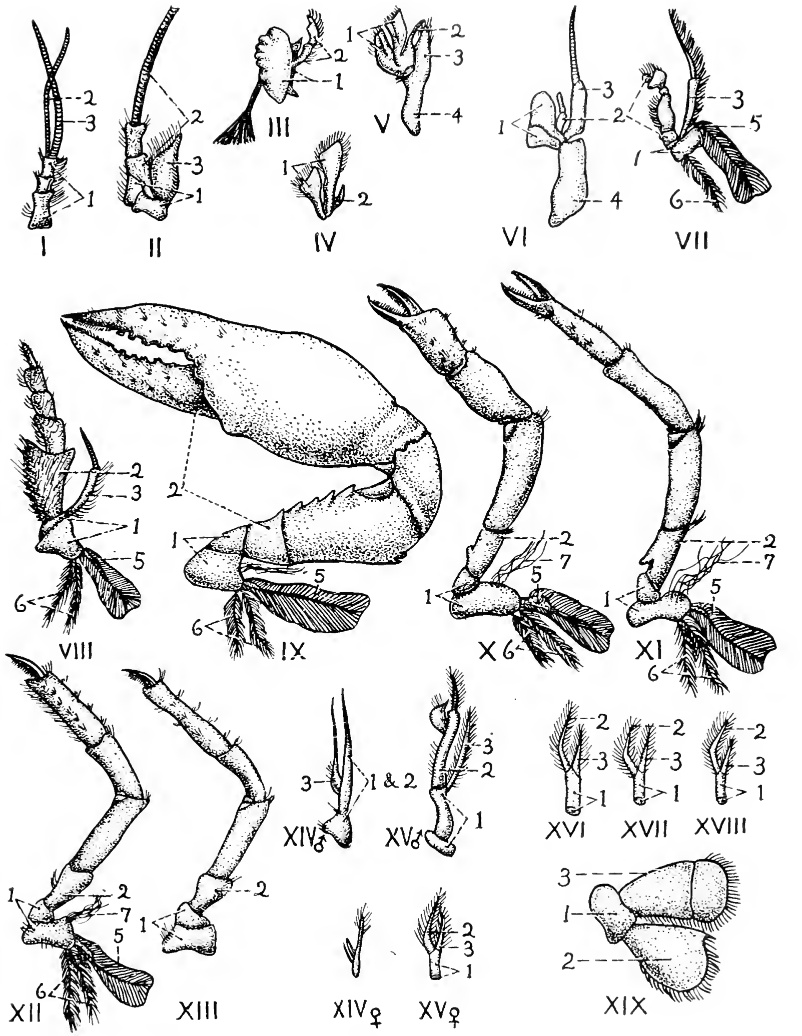


Fig. 307.—Crayfish appendages (*Cambarus sp.*) to show homology. Appendages are numbered from I to XIX; removed from the left side and drawn to scale. Appendages XIV and XV are drawn from both male and female crayfishes. *1,* Protopodite; *2,* endopodite; *3,* exopodite; *4,* epipodite; *5,* epipodite with gill filaments; *6,* gill with gill filaments; *7,* chitinous threads. Appendage I is the antennule (first antenna); II, the antenna; III, mandible for chewing; IV-V, first and second maxillae; VI-VIII, first, second, and third maxillipeds; IX-XIII, walking legs; XIV-XVIII, swimmerets; XIX, uropod (sixth swimmeret). (See Fig. 128.)

Certain corresponding parts on different plants appear to have originated from the same part of some common ancestor and to be structurally similar. Such are known as *homologous structures.* For example, the stamens and carpels of a flowering plant may be considered, in general, to be homologous with the scalelike sporophylls (spore-bearing leaves) of pine cones and the sporophylls of ferns. Pollen sacs and ovules may be considered homologous with sporangia.

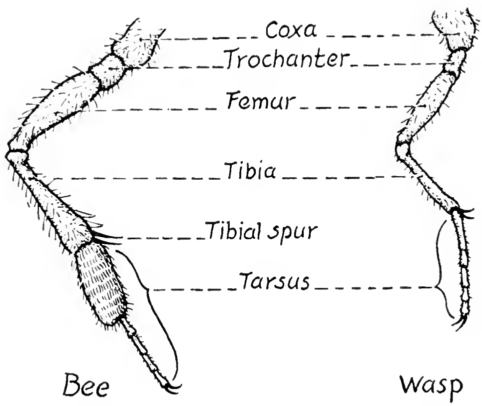


Fig. 308.—Legs of insects, showing similarity of structure in different species.

ANALOGY (a -nal′ o ji) (Gr. *analogia,* proportion)

Analogous organs or structures are *similar in function but are not related genetically and do not have a similar embryologic origin or morphologic structure.* For example, the wings of bats and butterflies are analogous because they are used for flying, but they are not homologous.

AUTOTOMY (o -tot′ o mi) (Gr. *autos,* self; *tone,* cutting)

Certain organisms such as sea cucumbers, starfishes, crayfishes, lobsters, etc., have the natural ability to sever (self amputate) a structure or organ at a definite, predetermined point or area. This phenomenon is called *autotomy.* In the crayfish and lobster there is a definite breaking point, varying with the appendage, and a new one similar to the lost one develops from the remaining portion. In certain crustaceans the appendage is flexed by muscles until it breaks at its breaking point. After the appendage is thrown off, a protective membrane is formed at the site of the injury to prevent hemorrhage until regeneration is accomplished.

If an arm of a starfish is injured, it is usually cast off near its base, and the arm with part of its central disk will regenerate a new starfish. The lost arm on the original starfish will also be regenerated (Fig. 28). Sea cucumbers (Fig. 111) when irritated may cast out their respiratory apparatus, and part, or all, of their intestine; in both cases the lost parts may be efficiently regenerated. Autotomy is an advantage since the wound heals more efficiently at the breaking point or area than if the injury had occurred elsewhere. The idea seems to be that it is more desirable to sacrifice an easily replaceable part than to jeopardize the total organism. Autotomy without the subsequent regeneration would not be very practical.

REGENERATION (re jen e -ra′ shun) (L. *re,* again; *generare,* to beget)

This phenomenon consists of the replacement or renewal of an organ or structure which has been lost or injured, whether by autotomy or otherwise (Fig. 28). Certain structures appear to be more easily regenerated than others. In fact, certain ones are never regenerated if once lost. Regeneration is common in such organisms as protozoa, sponges, *Hydra,* earthworms, planarians, starfishes, sea cucumbers, crayfishes, lobsters, etc. Usually a renewed structure resembles the lost one, but this is not always true. For example, the removal of a nonfunctional, degenerate eye from a so-called "blind" crayfish may result in the regeneration of a functional, antenna-like tactile organ. The rate of regeneration is influenced by such factors as the age of the organism, the extent of the injury, the specific tissue or organ involved, etc.

In protozoa, during reproduction, two entirely complete individuals may be formed from the two halves which have been divided by fission (Figs. 162 and 169). In many sponges, if the individual is cut into pieces, each piece will regenerate a normal animal. Bath sponges, if cut into pieces of about two cubic inches, will regenerate a sponge about six times this size in about two months. When certain species of sponges are broken up and strained through fine cloth so as to dissociate the cells, the latter will again fuse together and eventually form a sponge with its typical skeleton, pores, canals, etc.

Hydra (Fig. 28) may be cut into pieces and each part will regenerate an entire animal. The part with the tentacles produces a new individual. If split lengthwise into two or four parts, each part forms a normal individual. A hydra with two "heads" with tentacles can be produced by the splitting and separation of that region. Even pieces of hydra too small to regenerate themselves may fuse together and the mass then form a new hydra. Parts of one hydra may easily be grafted upon another.

If a planarian flatworm *(Dugesia)* is cut into two pieces, the anterior part will regenerate a posterior portion, while the posterior part will regenerate a new head. A middle piece may regenerate both head and posterior end. The head may regenerate another head, in rare instances.

A posterior end of an earthworm may regenerate an anterior end (Fig. 28). An anterior piece regenerates a posterior part. A posterior end under certain conditions may regenerate another posterior end which results in the eventual death of the individual. Pieces from several worms may be united (grafted) to form a longer worm.

In higher and more complex organisms the process of regeneration is more or less limited if not lacking entirely. In general, the less specialized tissues and structures have greater powers along this line than the more specialized structures. In man, such tissues as blood, bone, skin, etc., are replaced, while other tissues and organs are not.

Certain tissues which are injured or lost may be regenerated by the active tissues of a plant. The process is dependent upon (1) the quantity and quality of the auxins (plant hormones) present which initiate and control the growth, (2) an adequate supply of water, (3) a sufficient amount of energy and building materials supplied by such foods as carbohydrates and proteins, (4) the particular type and age of the tissue involved, etc. In general, the natural, inherent process of regeneration in plants starts with the forming of a protective layer over the injury and called a *callus* (ka′ lus) (L. *callium,* hard skin). The latter develops meristematic tissues from which the proper parts are regenerated. Roots may be regenerated on such stems as coleus, geraniums, willows, roses, etc. Roots may be regenerated on the leaves of begonias, African violets, etc. Stems may be formed from roots, and roots from roots. Regeneration is frequently taken advantage of in the commercial propagation of plants from cuttings. The latter phenomena are materially assisted through the use of certain plant hormones, which are considered in greater detail elsewhere in the text.

MORPHOGENESIS (mor fo -jen′ e sis) (Gr. *morphe,* form; *genesis,* origin)

This phenomenon includes the origin, differentiation, and development of specific structures, organs, or parts of organisms. In normal embryologic development of cells, tissues, organs, etc., of an organism, as well as in the regeneration of lost parts, there must be an inherent blueprint which is followed if the structure is to develop typically. Of what does this blueprint or master plan consist? Since all living organisms, according to the *cell principle,* are composed of cells, it would be surmised that cells form the basis for this origin and development. Evidence is available that this is true, but a cell is a complex structural unit composed of many integrated, component parts. Which parts specifically guide this remarkable phenomenon of living organisms? Experimental evidence, at least in certain organisms, suggests that the cytoplasm as well as the nucleus may play an important role in this connection. Experiments on the eggs of certain echinoderms suggest that cytoplasm from which all formal, organized nuclear material has been separated is capable of originating and developing the embryo up to a certain stage. Probably, beyond this stage the nuclear materials (genes, etc.) take over and influence the specific traits which develop. It is known that genes are units capable of self-duplication within the living cells, although their multiplication outside the living cell has not been observed to date. Since genes are known determiners of hereditary traits and are capable of multiplication in living cells, we have an explanation for the development of similar cells during the process of cell division.

However, a multicellular organism which arose from a single cell (zygote) is composed of thousands of cells, but the cells are not, and cannot, all be alike. Certain kinds must be differentiated (developed differently) so that the various types of tissues and organs may be formed. What forces control this differentiation? What changes occur in the organization of the protoplasm whereby different structures may arise from what was originally the same material? At present, scientists do not know the complete answer to this question. However, by the application of the scientific method in the study of these problems, bit by bit additional information is being secured. It is known that the abilities of a cell or tissue during embryologic development are influenced by (1) the inherent, intrinsic abilities of that cell or tissue and (2) the environmental forces around it.

By careful, scientific studies of the development of frog embryos, the embryologist Spemann found that each of the cells (of the two-celled stage) when completely separated by a fine hair loop would develop into a normal, although small, tadpole. What does this mean? Simply that each separated cell of the original pair is capable of forming a complete, diminutive individual whose genes are necessarily like those of its mechanically divorced partner. If the two cells had not been artificially separated, they would have collaborated to form the two sides of a complete individual. In other scientifically performed experiments it appears that stimulating chemical substances are produced which influence the development of structures in certain places, when and where such specific substances are formed. These specific chemical substances have been moved experimentally from one part of an animal to another part of the same animal with the subsequent development of a rather typical structure in the newly stimulated region. The stimulating influence may even be transplanted successfully to another animal. This suggests that not only genes are at work but the latter are influenced by environmental, chemical substances. Possibly the production of the specific chemical substances is influenced by the action of specific genes. It is to be expected that the type and amount of the development of a particular structure or ability will be influenced by such factors as (1) the specific genes involved, (2) the quality and quantity of the specific chemical substances available at that particular region, (3) the susceptibility of the particular tissue or organ involved, (4) the age of the organism itself, etc. Undoubtedly, enzymes, hormones, vitamins, and similar substances influence the specific type of development in an area where such substances are available in the proper quantity. It is known that these substances are usually specific; that is, they are capable of stimulating specific actions in certain places. In other words, the specific chemical stimulator must be present in the proper area in the proper amount, and the tissues, or organ, must be susceptible to its influence before a reaction can take place. Abnormalities of either tissue or stimulator may bring about abnormal reactions, or possibly none at all. A point to be borne in mind is that various forces are necessary to initiate and maintain a particular development, but there is also an equally important phenomenon of discontinuing development at the proper time. For example, the necessary factors must be present in order to develop a finger embryologically, but there must also be a cessation of development when the finger has reached normality. Undoubtedly, modifications of such factors are responsible for certain abnormal *anomalies* (a -nom′ a li) (Gr. *anomalos*, uneven). With the incidence of old age and its attendant atrophy of certain structures (and functions), we encounter other problems, probably the opposite of the morphogenic development type. Other closely related problems are those associated with the death of tissues and organisms as a whole. Causes and effects of death are still unknown, and much scientific work must still be done in this field.

Normal morphogenesis occurs when the correct balance between specific stimulators and susceptible structures is present. Occasionally, certain tissues will abnormally assume growths known as *neoplasms* (ne′ o-plazm) (Gr. *neos,* new; *plasma,* formation). If such a growth is harmful or malignant, we commonly refer to it as a *cancer* or *carcinoma* (kar′-sin o mah) (Gr. *karsinos,* crab, cancer). We commonly use the word *tumor* (tu′ mor) (L. *tumere,* to swell) if the growth in general is harmless or nonpathologic. Sometimes a neoplasm may grow only at its original site, but occasionally certain of the abnormal cells may circulate to other areas by *metastasis* (me -tas′ ta sis) (Gr. *meta,* change; *stasis,* place) and initiate abnormal growths in new places.

Plants also possess morphogenesis whereby tissues and organs are differentiated and developed. Quite different tissues and organs of plants must originate differentially from what appears to be similar cells and tissues. How can a plant develop such different structures from apparently the same cells and tissues? As in animals, so plant morphogenesis is influenced by the hereditary potentialities of the various species as well as by the presence of specific substances. Not only are specific genes involved, but plant hormones known as *auxins* (ok′ sin) (Gr. *auxein,* to increase) initiate and regulate many phases of plant growth and development. Auxins are organic acids which are synthesized by the living protoplasm in certain parts of plants. These auxins are specific, at least to a certain degree, and may affect organs in which they are formed or other tissues and organs to which they may be transferred. The latter seems to be primarily polar; that is, they are transferred largely in one direction. A more detailed consideration of auxins and their actions is given elsewhere.

QUESTIONS AND TOPICS

1. Learn the correct pronunciation, spelling, and derivation of each new term used in this chapter. Include as many typical examples of each as possible.
2. Contrast homology and analogy and give as many examples of each as possible.
3. Explain why it might be desirable or undesirable for living organisms to possess autotomy generally and extensively.
4. What benefits have you derived from a study of homology, analogy, autotomy, regeneration, and morphogenesis?
5. Explain why differentiation and growth are not necessarily synonymous.
6. Explain how each of the various factors may be influential in the process of differentiation in morphogenesis.
7. What is the relationship between genes and environmental chemical substances in the determination of specific traits?

8. Explain the results of abnormal morphogenesis, including examples.
9. In this connection, propose a method for the prevention of cancer or at least a scientific method for an investigation which might lead to its prevention.
10. Explain why it might be undesirable or desirable for living organisms to possess a high degree of ability to regenerate all types of structures easily. In considering this topic, bear in mind that Nature did not supply many of the higher, more complex tissues with this ability.

SELECTED REFERENCES

Arey: Developmental Anatomy (Embryology), W. B. Saunders Co.
Demerec: Advances in Genetics, Academic Press, Inc.
Goldschmidt: Physiological Genetics, McGraw-Hill Book Co., Inc.
Huxley and DeBeer: Elements of Experimental Embryology, Cambridge University Press.
Maximow and Bloom: Textbook of Histology, W. B. Saunders Co.
Morgan: Embryology and Genetics, Columbia University Press.
Muller, Little, and Snyder: Genetics, Medicine and Man, Cornell University Press.
Riley: Genetics and Cytogenetics, John Wiley & Sons, Inc.
Stern: Human Genetics, W. H. Freeman & Co.
Weiss: Principles of Development, Henry Holt & Co., Inc.
Wilson: The Cell in Development and Heredity, The Macmillan Co.

Chapter 28

EARLY MAN AND HIS RECORDS

HISTORY OF MANKIND AND HUMAN SOCIETY

Our knowledge of the gradual evolution of mankind from its early ancestry has been obtained in the last hundred years from fossils of ancient human beings, from their habitations, weapons, tools, records carved on stones, from sculpture and paintings. Early man probably gathered wild plants, roots, fruits, and seeds for his various needs and hunted wild animals for food, shelter, clothing, and crude implements. Domestication of animals and the cultivation of plants by man occurred many centuries ago. The cultivation of wheat and barley occurred in Egypt between 5,000 and 4,000 B.C. Cattle for milk production and horses for transportation probably were used in western Asia before 3,000 B.C. Sheep and asses were used by man in early Egypt. Early man probably ate raw foods, as the use of fire is associated with the Peking man. Today, the human being is the only living organism which utilizes cooked foods for a greater or lesser part of his diet. The human race is thought to have originated in Central Asia and to have migrated slowly in various directions. Man is thought to have arrived in America from Asia across Bering Strait, whose waters are shallow and sometimes solidly frozen in winters. Before Columbus discovered America in 1492, two great human cultures were present: the Incas in the Andes Mountains of South America, whose culture rests on earlier cultures dating back to before the Christian era, and the Mayas and Aztecs of Central America. The Mayas culture began before 3,000 B.C. None of these early American civilizations had Old World domestic animals, except dogs, but they had such New World plants as maize (corn), cotton, sweet potatoes, beans, tomatoes, peppers, squashes, peanuts, etc. These early accounts of ancient men are so interesting and extensive that the reader is referred to the many excellent sources now available.

All records of man in the past suggest that he has been a social animal, parents and children living in groups rather instinctively. Because of this method of living, the young were somewhat protected, profits from past experiences were made, surpluses could be accumulated and shared, forces could be combined against enemies, and affections and mutual regards developed. Several family groups combined to form a larger tribe, and tribal groups formed a society, with its inherent benefits and detriments. Naturally, individual and group antagonisms developed, with their attendant consequences. The rise and fall of civilizations have been, and are still, inseparable from the cultures of peoples; that is, from the skillful attempts with which they have kept themselves physically and mentally well, happy, and well supplied with the essentials of life and from the skillful uses that they have made (or should have made) of their surpluses of time, energies, and material things. The uses to which these surpluses are put are more important than the surpluses themselves. The progress of human civilization is in the hands of man himself.

EARLY MAN AND HIS RECORDS

Early man has left many interesting and valuable records (Fig. 309), by means of which we are able to get an idea of his physical and mental traits as well as his achievements and activities. In many instances rather complete skeletons of early man have been preserved in the depths of the earth's strata. These, together with his implements and tools, form the basis for our knowledge of our remote ancestors. Early man probably did not always bury his dead, so that extremely early records do not date before the Pleistocene epoch (Figs. 320 to 322). The most valuable records of early man date from the early Pleistocene epoch or possibly the very late Pliocene epoch. Many records of early man have been found, but the following are representative:

Java Ape-Man (Pithecanthropus erectus).—The skull cap, the left femur, and the lower jaw with three teeth were found near Trinil in Java in 1891 by Dr. Eugene Dubois. These remains are also known as the "Trinil Man." It is thought that this type existed during the first glacial age of the early Pleistocene epoch. His cranial capacity was about 950 c.c., which is approximately one-half that of an average modern European, but half as much again as that of a large gorilla. His higher psychic functions were limited because of the poorly developed frontal regions of his brain. The centers of taste, touch, and vision were probably well developed. He may possibly have used speech of some type. The skull cap was very thick and his forehead was low, receding, and with

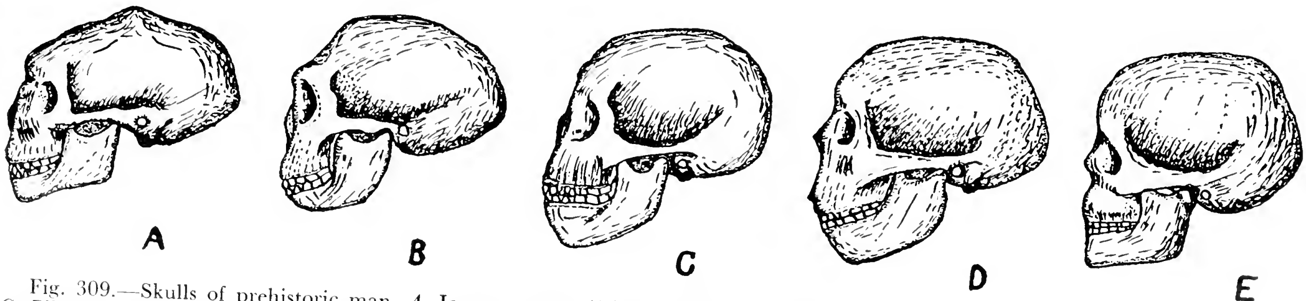


Fig. 309.—Skulls of prehistoric man. *A*, Java ape-man (*Pithecanthropus erectus*); *B*, Peking man (*Sinanthropus pekingensis*); *C*, Piltdown man (*Eoanthropus dawsoni*); *D*, Neanderthal man (*Homo neanderthalensis*); *E*, Cro-Magnon man (*Homo sapiens*). All skulls except the latter have been restored to a certain extent, and are sketched somewhat diagrammatically, and reduced in size. (From various sources and authors.)

massive supraorbital ridges. His skull was narrow. His jaw projected almost snoutlike. His average height was about 5 feet 7 inches. He lived on land and seems to have been more similar to man than any ape. He used sharpened sticks and stones for implements.

Peking Man (Sinanthropus pekingensis).—Skulls, teeth, and brain cases were found near Peking, China, in 1926 to 1928, by Dr. D. Black. This type is supposed to have lived during the first interglacial age of the early Pleistocene epoch. His cranial capacity was about 1,000 c.c.; hence his head was larger than that of Pithecanthropus. The brain case shows the brain to be human but small and comparing rather favorably with normal human brains of primitive men of today. Dubois thinks that this type may probably have been a variant member of the Neanderthal race, to be considered in a later paragraph. The walls of the skull were thick. The forehead was low, receding, and possessed heavy supraorbital ridges. This early man used fire because charcoal and charred remains of various materials have been found buried with his remains. He used tools and implements of bone and stone, over two thousand stone implements being present with the remains so far unearthed.

Piltdown Man or Dawn Man (Eoanthropus dawsoni).—Fragments of a female brain case and half of a lower jaw were found in a gravel pit in 1911 to 1913 by C. Dawson at Piltdown in southern England. This type is thought to have existed during the first interglacial age of the early Pleistocene epoch. His cranial capacity was about 1,300 c.c., which was larger than either Pithecanthropus or Sinanthropus. His brain was primitive and human with certain simian characteristics. The cranium was unusually thick (0.4 inch). The jaw and teeth were apelike in some respects and human in others. His forehead was apelike but without prominent supraorbital ridges. He was probably more manlike than Pithecanthropus or Sinanthropus. Crude flints deposited in the gravel with his remains indicate a primitive culture. He was burly and knew little about tools.

Heidelberg Man (Palaenthropus [Homo] heidelbergensis).—The lower jaw and teeth were found by Dr. O. Schoetensack near Heidelberg, Germany, in 1907. The Heidelberg man may have existed during the third interglacial age of the early Pleistocene epoch. His cranial capacity has not been accurately determined. The jaw was massive and primitive with the teeth large and human. The mouth region projected more than modern man but not as much as in the chimpanzee or gorilla. The forehead was low with prominent supraorbital ridges. From the remains, he evidently used flints and may have used rudimentary speech. His entire skeleton was massive, suggesting a powerful physique.

Neanderthal Man (Homo neanderthalensis).—The skull cap and parts of the skeleton were found in 1856 by Dr. Fuhlrott in the Neanderthal valley near Düsseldorf, Germany. This type is thought to have existed during the third interglacial and third glacial ages of the Pleistocene epoch. His cranial capacity was between 1,400 and 1,600 c.c. His higher mental faculties were not highly developed. The anterior region of his brain was not as highly developed or as large as in *Homo sapiens*. Neanderthal man had a low, broad forehead with massive supraorbital ridges. His eyes were large and round. His nose was broad. His knees were bent and his head was held forward when he stood or walked. His spinal column was slightly curved. All of this gave him a peculiar slouching attitude. His skeleton was not over 5 feet 4 inches tall; usually his average was less than 5 feet. His feet and hands were large and his legs were longer than his arms. He had a receding chin. More than fifty skeletons of this type of man have been found in England, Belgium, Germany, France, Spain, Italy, Palestine, Syria, Arabia, Iraq, Rhodesia, and China. This suggests a very wide distribution of this primitive race. From their remains it is thought that they lived at the entrance to caves rather than in them; that they used a language; that they used fire for warmth and cooking; that they were great hunters and ate the bone marrow of their captured animals; that they used implements of flint, bone, and unpolished stone; that they believed in a hereafter because they buried flint implements and foods with their dead. He probably clothed his hairy body in the skins of animals.

Cro-Magnon Man or Modern Man (Homo sapiens).—Five skeletons were found in the Cro-Magnon cave in Dordogne, France, in 1868. He is thought to have been present during the fourth glacial or ice age of the late Pleistocene epoch, even down to the recent epoch. His cranial capacity was from 1,400 to 1,500 c.c., which is equal to, if not greater than, that of the average European of today. The anterior part of the brain was large and well developed, being equal to, if not greater than, the average of today. The skull was large, long, and narrow. The forehead was high with moderate supraorbital ridges. The face was broad; the jaws, wide; the cheek bones, large; the eyes, large and far apart; the spinal column had four distinct curves. The male averaged 6 feet 2 inches in height, which suggests a strong, athletic race. The chin was well developed. In general, they were probably handsome people comparing quite well with existing races. They lived in caves and rock shelters. They hunted and fished by means of skillfully made harpoons and spears. Many implements and ornaments of bone have been found. They developed an art in which they carved and made drawings in oil. They developed primitive industries in which they used bone more extensively than flint. All in all, the Cro-Magnon man is a good ancestor of modern man from a physical as well as a mental standpoint. In the distant future, when man shall unearth the remains of some of us, what type of record will we have left, and for what will our civilization be noted?

QUESTIONS AND TOPICS

1. List the various types of fossils and records which ancient man has left and include the specific manner in which each has been preserved.
2. Give logical reasons why more records of ancient man have not been discovered.
3. Make a table of the more representative types of ancient man, including the outstanding characteristics of each.
4. Explain where and how records of ancient man are discovered. Are additional records being found at the present time? Where? (Read articles on present-day discoveries before answering these questions.)
5. What logical conclusions might you draw from a study of the sequence of records left by ancient man?
6. Explain how we might determine the type of life which ancient men led.
7. Where in the world have the records been found? What does this mean?
8. What important changes seem to have taken place in the structure of man as revealed by the remains available to date?
9. What type of records do you think we today will leave for future generations, and in the light of our present civilization what interpretations may be made of them?

SELECTED REFERENCES

Andrews: On the Trail of Ancient Man, G. P. Putnam's Sons.
Andrews: Meet Your Ancestors, Viking Press, Inc.
Coon: The Races of Europe, The Macmillan Co.
Gates: Human Ancestry, Harvard University Press.
Gregory: Our Face From Fish to Man, G. P. Putnam's Sons.
Hooton: Un From the Ape, The Macmillan Co.
Howells: Mankind So Far, Doubleday, Doran & Co., Inc.
Macgowan: Early Man in the New World, The Macmillan Co.
Moir: Antiquity of Man in East Anglia, Cambridge University Press.
Osborn: Men of the Old Stone Age, Charles Scribner's Sons.
Romer: Man and the Vertebrates, University of Chicago Press.
Schmucker: Man's Life on Earth, The Chautauqua Press.
Shimer: Evolution of Man, Ginn and Co.
Weidenreich: Apes, Giants and Man, University of Chicago Press.
Wilder: Pedigree of the Human Race, Henry Holt & Co., Inc.
Yerkes: Almost Human, London, Jonathan Cape, Ltd.
Yerkes and Yerkes: The Great Apes, Yale University Press.

Part 3

GENERAL AND APPLIED BIOLOGY

Chapter 29

GEOGRAPHIC DISTRIBUTION OF ANIMALS AND PLANTS—BIOGEOGRAPHY (ZOOGEOGRAPHY AND PHYTOGEOGRAPHY)

The scientific study of the distribution of living organisms in space is known as *biogeography*. If the study pertains to animals the science is called *zoogeography;* if it pertains to plants it is known as *phytogeography*. In general the study of the geographic distribution of living organisms deals with larger areas or regions such as a country or continent, while the ecologic study of those same organisms would be made in a more or less limited area, such as a field, pond, or river. Ecology is considered elsewhere in another chapter.

I. WHY STUDY GEOGRAPHIC DISTRIBUTION?

Zoogeography may profitably be studied for the following reasons: (1) To see that each species of animal is rather definitely restricted to certain regions of the world or to certain limited areas of a certain environment. The entire world has been divided into seven major geographic regions and each region has certain animals which are typical and representative for that region (Fig. 310). It is by a thorough study of geographic distribution that the various principles of zoogeography can be properly learned and interpreted. (2) To see, as a result of adaptation of a species of animals to a particular environment, that such a species is thus restricted by its resulting morphology and physiology to those parts of the world in which that particular type of environment exists. If animals change because of adaptations, they must then select an environment which will be satisfactory if they are to live successfully. All of this study attempts to ascertain and explain the various reasons for the particular distribution of various organisms. The effects of various environmental factors on the morphologic, physiologic, and developmental characters of animals also may be observed. Such a study of the interrelationships between organisms and their various environmental factors is known as the science of ecology. It will be observed also that a similar environment in two different and widely separated places does not necessarily contain similar animals. (3) To see that in the past the boundaries of sea and land have changed repeatedly, in some instances erecting natural barriers, in others providing favorable highways for dispersal. It will be seen also that two widely separated present-day types may have had a common ancestor in the past. The fossils of extinct North American camels were the ancestors of the present Old World camel and the llamas of South America.

II. TYPES OF GEOGRAPHIC DISTRIBUTION IN SPACE

There are two general types of geographic distribution of animals in space. The first is the lateral or longitudinal distribution throughout the various geographic regions of the world (Fig. 310). This type of

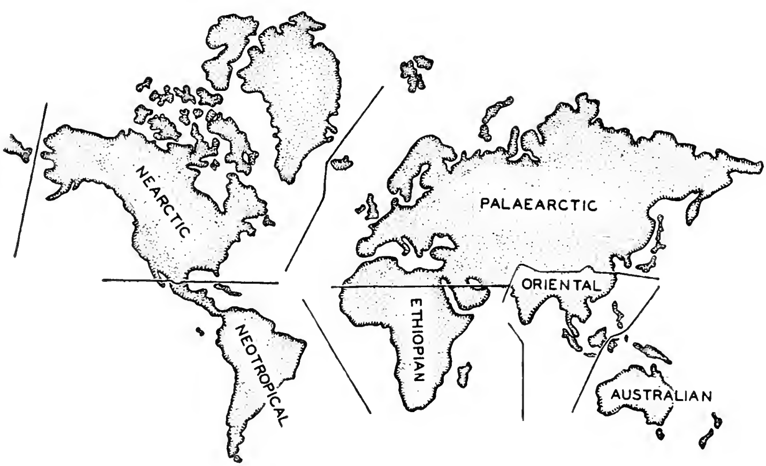


Fig. 310.—Geographic regions of the world.

distribution is limited to the spread of animals over the face of the earth in the various directions of the compass. The second is vertical distribution of animals throughout the various altitudes (Fig. 311). This type of distribution emphasizes the differences in animal distribution on mountains, in valleys, in caves, and in the various depths of the sea. Undoubtedly there are regions of animal distribution as we ascend from the lowest depths of the ocean to the top of the highest mountains.

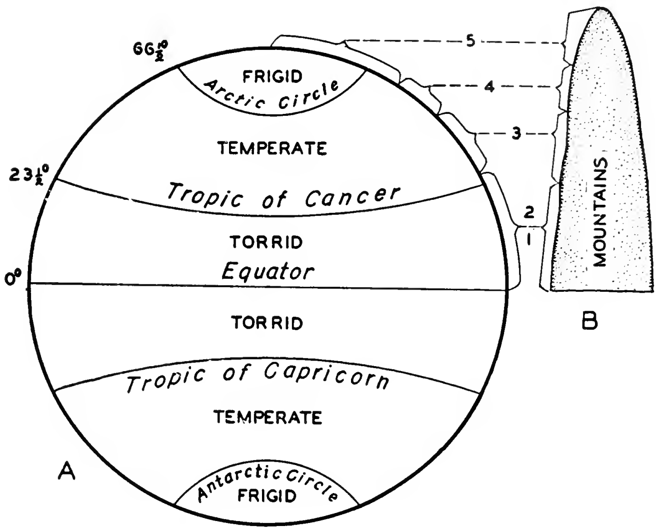


Fig. 311.—Diagram of the parallel distribution of organisms in longitude, *A*, and altitude, such as mountains, *B*, *1*, *2*, Tropical and subtropical organisms; *3*, deciduous trees; *4*, evergreen trees; *5*, limited varieties of such plants as mosses, lichens, etc.; a similar transition exists from the equator to the South Pole.

III. PRINCIPLES OF GEOGRAPHIC DISTRIBUTION

There are probably many principles of zoogeography, but the more important will be discussed only rather briefly in such a work as this. The *principle of dispersion* illustrates the fact that animals naturally tend to migrate or disperse from their birthplace. This is necessary because more offspring are usually produced than normally can be accommodated in that particular habitat. This so-called reproductive pressure tends to overpopulation. The latter leads to dispersal in an attempt to remedy these conditions. It is also known that offspring and parents cannot harmoniously occupy the same area because they all possess inherently the attitudes of survival of the fittest and the struggle for existence. Parents frequently destroy, or at least actively compete with, the offspring which they have produced.

The problem of overpopulation may be overcome in one of the following ways, or in a combination of several of them: (1) There can be a migration of a number of individuals from the overcrowded area. (2) There can be an extermination of a number of individuals by parents, brothers, sisters, or other species. (3) There can be a natural death for a sufficient number so that a balance again can be realized. (4) The problem of overpopulation may also be regulated by a reduction in the number of offspring produced. This is a factor which cannot easily be controlled, especially among the lower animals. (5) A different type of food can be utilized if the struggle should develop around this very important factor.

The *principle of definite habitats* shows that the home or habitat of a particular species is determined by such physical factors as the following: (1) The quantity and quality of foods. The herbivorous animals, such as deers, must be near suitable vegetation. The carnivorous animals, such as tigers and lions, must live near a source of suitable flesh foods. The omnivorous animals, such as man, can usually be more widely distributed, although they must also be distributed so as to get the proper types of both vegetable and animal foods. (2) The quantity and quality of water also affect the selection of a habitat by a particular species. A certain amount of water is essential for all animals because their bodies are made of 50 to 95 per cent water. Many forms in dry climates prevent excessive evaporation by some type of thick covering. Many species found under rocks are not always there in order to shun light but for moisture and protection. The depth, salinity, and hydrogen-ion concentration of the water also are important factors in influencing the selection of the proper habitat. (3) The quantity and quality of the air are also influential in determining the habitat selected by a certain species of animal. This is particularly true for terrestrial forms, although the availability of air in the water also affects the aquatic types. (4) The quantity and quality of light, including sunshine, is a factor which is influential in the distribution of many animals. Some types shun light for protection and for reduction of heat produced in their bodies. Others actually require certain amounts of light for their various normal metabolic activities. (5) The presence or absence of an optimum temperature may be a determinative influence in animal distribution. It is well known that animals will tend to seek the temperature for which they are particularly fitted. Many animals living in tropical regions pass the summer in a condition of *aestivation* or semitorpid condition of semiactivity. Certain animals living in colder climates pass the winter in various ways: (1) *Hibernation*, or a period of inactivity in some protected location. Such animals as frogs, turtles, snakes, the larvae and pupae of insects, hibernate. (2) Migration to warmer regions. Certain species of birds migrate from the arctic regions to the tropics. The golden plover (bird) illustrates such a migration. (3) Continued activity in their cold habitats. If animals remain in the cold habitats in winter, they frequently increase their fat layers as well as their coats of hair to help withstand the attacks of the cold. They may also change their diets to include foods which will produce greater amounts of heat. (4) Animals may die because of the extreme temperature. Many species naturally expect this and have carefully taken the precaution of depositing their eggs so that the developing offspring may take their places when more favorable temperatures return.

The *principle of barriers and highways* is one of the most important in animal dispersal. What may prove to be a barrier for one species may serve as a favorable highway for another. Some of the more common barriers are as follows: (1) There may be a lack of the proper quality and quantity of foods along the route of migration. (2) Water may be a barrier for terrestrial forms but may successfully be used by aquatic types. The size, depth, temperature, acidity, and pressure in bodies of water all may be important factors in dispersal of even aquatic animals. The aridity and humidity of terrestrial environments may act as highways or barriers, depending on the type of animal in question. Salt water may be a barrier for fresh-water forms, and fresh water likewise may be one for marine forms. Amphibia are rarely found in salt water. (3) The various kinds of land may serve as barriers or highways, depending on the type of land as well as the species of animal. For instance, tracts of land may act as barriers for aquatic forms; forests may act as barriers for open-country or prairie-inhabiting species; deserts and open country may act as such for forest-inhabiting types. Mountains with their characteristic temperatures, moisture, oxygen supply, and food supply may act as barriers to many types in their attempt to migrate over them. (4) The interference by other animals either through bodily struggles or competition for foods may influence the dispersal of certain kinds of organisms. (5) Winds, especially strong winds, tend to carry species of flying habits in the direction of the wind blow. This may result in their migration into more favorable or less favorable habitats as the case may be. (6) Temperature may prevent the dispersal of many animals, either by its direct effect on the migrant or by its effect on the vegetation upon which the migrant must depend for food and shelter. (7) The lack of adaptive ability of the animal may result in its inability to adapt itself quickly enough to new and changed environmental conditions. The result may be extermination or an attempt to continue its migration. This is an illustration of what is frequently known as a *biologic barrier.* Much of this adaptive ability is due to inherent, inherited properties of the protoplasm of each particular animal.

The following methods of dispersal are rather common in the animal world. (1) Driftwood may transport animals for great distances. William Beebe on his Arcturus voyage observed fifty-four species of marine fishes, worms, and crabs on one floating log. (2) Ships in their travels from port to port may transport various types of organisms. How many rats have had free transportation from one port to another can never be known. (3) Water and floods may mechanically transport organisms, drive them from their original habitats, or change the food supplies sufficiently that dispersal will be necessary. The presence of desirable water supplies for consumption during migration may determine the final and future habitation. (4) Aquatic animals may transport other animals on their bodies or within their bodies. The larvae of clams may be carried on the gills and fins of fishes. Many aquatic parasites are dispersed by aquatic organisms. (5) Terrestrial animals may transport other animals on the exterior or interior of their bodies. Birds may carry eggs, larvae, pupae, or adults of smaller animals, especially during migration. (6) Winds may direct the course of certain animals or may blow objects to which certain types are attached. (7) Glaciers may cause animal migrations by actually transporting them or by changing the temperature or food supply. (8) Man, either knowingly or unknowingly, aids in animal dispersal through the means of automobiles, airplanes, boats, and trains. A "horned toad" was transported from Texas to Springfield, Ohio, by a circus train, although after its arrival it found the rigors of the city too great. This was no fault of the method of migration. English sparrows were transported from the East to the West in returning empty grain cars. This method was successful for the rather friendly sparrow but would not have been used by the more timid bluejay which would hesitate to frequent the empty grain cars in the East.

The *principle of discontinuous distribution* is illustrated by the presence of the same species of animal in two widely separated regions, in which case it is usually concluded that the distribution of that species was once continuous between the present regions. For example, the tapirs today inhabit Central and South America, southern Asia, and the Malay archipelago only. In the Pliocene epoch of the past (Figs. 320 to 322), tapirs were distributed over nearly all of North America, Europe, and northern

Asia. Today they are extinct except in those regions mentioned above. There was a rather continuous distribution originally, but today they illustrate discontinuous distribution.

The *principle of vertical distribution* states that the organisms of higher elevations of mountains simulate those of the polar regions of the world. As we progress downward in altitude, the forms simulate those which would be found in travelling from the poles toward the equator. In general, the temperate zones not only extend laterally north and south of the equator but also vertically in parallel succession from the somewhat tropical conditions at sea level to the somewhat frigid conditions at the mountain peaks (Fig. 311).

IV. GEOGRAPHIC REGIONS OF THE WORLD

The world has been divided into seven regions (Fig. 310) each with its different characteristics and peculiar, yet typical, fauna and flora. Each of these seven regions will be briefly described.

1. **Nearctic Region** (Gr. *neo,* late or new; arctic).—This region includes North America down to the edge of the Mexican plateau, as well as Greenland. Great groups of mammals are characteristic of this region. Many types in this region are related to the Palaearctic region, although they differ in minor details. Animals which are peculiar to this region include the bluejays, rattlesnakes, raccoons, opossums, skunks, prairie dogs, water dogs (Cryptobranchus is found in the Mississippi RiverValley), and the musk ox. The latter, which is peculiar to North America, was until recently present in Siberia and originally lived in continental Europe and England. What a difference in the distribution of the musk ox in the past and present!

2. **Palaearctic Region** (Gr. *palae,* ancient; arctic).—This region includes Europe, Africa (north of the Tropic of Cancer), Asia (north of the Himalayas), and Japan. Many types of mammals of this region are closely related to those of the Nearctic region, differing in minor respects. Many trees and plants are common to both regions. These two regions are the most similar of all regions and are sometimes combined into one, known as the *Holarctic region* (Gr. *holo,* whole; arctic). Animals common to both Nearctic and Palaearctic regions include beavers, deers, hares, foxes, wildcats, and bears. Animals of the Palaearctic region include the nightingale, Megalobranchus (water dog of Japan which resembles our own water dog), and the camel and dromedary of central Asia and northern Africa.

3. **Neotropical Region** (Gr. *neo,* new or recent; tropical).—This region includes Central America, Mexico, South America, and the West Indies. The following types are present in this region: tapir,* sloth,† armadillo,† wild pig (peccary),* llama,* marmoset,† flat-nosed monkeys,† tree ant-eaters,† tree porcupine,† and many kinds of deer,* rats,* cats,* wolves,* and rabbits.*

4. **Ethiopian Region** (Gr. *aithiops,* black face).—This region includes Africa (south of the Sahara Desert), southern Arabia, and Madagascar and adjacent islands. The following animals are characteristic of this region, some of which are native only of this region: African elephant, hippopotamus, rhinoceros (several species), zebra, giraffe, antelopes (many species), lions, leopard, lemurs (found in Madagascar), gorilla, chimpanzee, baboon, and secretary bird.

5. **Oriental Region** (L. *orientalis,* eastern).—The region includes India (south of the Himalayas), southern China, the Philippines, Siam, Burma, Borneo, Java, and Sumatra. Animals of this region include the Indian elephant, rhinoceros, Indian tapir, tigers, jungle fowls (ancestors of domestic fowls), gibbons, orangutan (in Borneo and Sumatra), and the cobra.

6. **Australian Region.**—This region includes Australia, New Zealand, New Guinea, Tasmania, Papua, etc. This region has practically no higher mammals. It is the home of the marsupial animals (animals with pouches in which the young may be carried). It is still the home of the so-called Monotremes or lowest types of mammals, such as the duckbill. This region is one of the most peculiar in the world. Such animals as the following are characteristic: the lizardlike Rhyncocephalia of New Zealand, certain wingless birds of New Zealand, the Australian kangaroo with its closest relative the opossum in America, and certain characteristic birds, snakes, and lizards.

7. **Polynesian Region** (Gr. *poly,* many; islands).—This region includes the oceanic islands of the tropical Pacific, such as the Hawaiian Islands, Samoa, Society Islands, and Fiji Islands. This region is sometimes included with the Australian. The islands were formed in many instances by volcanic eruptions. Their shores are fringed with coral reefs. The vegetation is often large and herbaceous, such as the palm and banana trees. There are fewer types of living organisms than in the larger regions, and consequently there is less competition. There are no land mammals present except bats, and there are no amphibia on these islands.

---

*Types peculiar to South America now but have similar representatives in North America. The llama has its nearest relative, the camel, in the deserts of Asia.

†Types peculiarly South American with practically no forms in North America except the Canadian porcupine.

V. REGIONS OF GEOGRAPHIC DISTRIBUTION OF VEGETATION OF NORTH AMERICA

If a study were made of the geographic distribution of plants throughout the world, we would find that the world could be divided into geographic regions (just as for animals), each with its particular environmental characteristics and peculiar flora. However, it may be just as

Fig. 312.—Vegetation areas of North America (the boundaries of the various regions are given in a general way).

interesting and profitable to limit our study of phytogeography to North America. It will be observed (Fig. 312) that the North American continent can be divided into various vegetation areas (geographic regions). These areas are summarized in an accompanying table in which the general environmental characteristics and the plants typically present in each region are given. Observe that the environmental characteristics

Regions of Vegetation of North America (See Fig. 312)

	General characteristics	Plants typically present
A. *Tundras*	Fringes the northern limits of North America from Labrador to Alaska (north of latitude 55 to 60°) Long cold winters Limited moisture; light snowfall Air dry in winter Strong winds Short growing season because upper limits of soil thaw slightly and ground water is cold Soil temperature low	Certain mosses Certain lichens Certain grasses Certain sedges Certain herbs Certain low shrubs Certain dwarf willows
B. *Deserts*	Most of Arizona and Nevada; southern parts of New Mexico, California and Texas; peninsula of lower California and northern Mexico High evaporation of moisture from plants due to intense heat and low atmospheric moisture Intense and generous sunlight Small amount of rainfall Winds fairly strong	Sagebrush Cacti with small, spine-like leaves to protect and prevent excess evaporation Yucca trees Certain species of bunch grasses Few species of small herbs
C. *Grasslands*	Extends from central Texas to Manitoba and along foothills of the Rocky Mountains from New Mexico to Alberta Soil rich in humus overlying sand and clay Few trees probably because of limited soil moisture and excessive evaporation due to excessive heat Light annual rainfall	Various species of bunch grasses Various types of cacti Various kinds of shrubs
D. *Forests* (a) Northern evergreen	From Atlantic to the Pacific Oceans between the tundra on the north and the Great Lakes on the south; extends northwestward to Alaska	Cone-bearing trees as: Spruce Balsam fir White pine, red or Norway pine, jack pine Hemlock Arbor vitae Deciduous trees as: Balsam poplar Aspen White birch
(b) Southern evergreen	Southeastern U. S. from Texas to Florida and Virginia Many low, rolling sandy plains Many large swamps Also high coastal plains farther from the ocean	Long-leaf pine Short-leaf pine Water oaks Bald cypress Magnolia trees Gum trees

REGIONS OF VEGETATION OF NORTH AMERICA (SEE FIG. 312)—CONT'D

	GENERAL CHARACTERISTICS	PLANTS TYPICALLY PRESENT
(c) Deciduous forests	From central New York to Texas and Louisiana; from Wisconsin to Oklahoma	White oak; black oak Hickory trees Chestnut trees Walnut trees Maple trees Ash trees Birch trees Elm trees Certain cone-bearing trees as: Short-leaf pine White pine Hemlock
(d) Rocky Mountain forests	Along Rockies from southern Mexico to Columbia (except coasts of Mexico) These mountains present such variations in elevations and climates that a great variety of trees exists here No trees in altitudes higher than 10,000 feet, although there exist low vegetation which resembles that of the tundra	Western yellow pine Lodgepole pine Douglas fir Western hemlock Western larch
(e) Pacific Coast forests	Extend along the western slopes of the mountains from California to Alaska	
	(1) Canadian-Alaska region	Sitka spruce Douglas fir Western hemlock
	(2) Washington-Oregon region (mild winters and heavy rainfall; very luxuriant vegetation)	Sitka spruce Douglas fir Western hemlock Western white pine Dense undergrowth of ferns; shrubs; short, deciduous birches, maples, and poplars
	(3) California region	Coast redwoods Sequoia trees
(f) Tropical forests	Found in West Indies, Central America, coasts of Mexico, southern tip of Florida Jungles present in many places, and in certain regions they are so dense overhead that limited light results in diminished vegetation around the tall trees; upper parts of these tall trees filled with masses of ferns, mosses, lichens, tropical orchids, and lianas	Various palms Tropical orchids Lianas (woody, climbing vines) Mangrove swamps.

differ in tundras, deserts, grasslands, and forests. Naturally, we would expect to find different types of vegetation in each region. If the distribution of forests is studied in detail, it is apparent that different types of trees are distributed in various parts of the continent, depending upon the influential characteristics of the environment peculiar to each of these forest areas. Could we expect the same type of forest in the far north as we find in the tropics? Attempt to list the environmental characteristics of each vegetation area and then use them to explain the distribution of the types of vegetation peculiar to each of these regions. In doing so, you will begin to appreciate how Nature functions in limiting certain kinds of vegetation to specific areas.

VI. GENERAL FACTORS INFLUENCING THE DISTRIBUTION OF ORGANISMS

Only a few of the more common and important factors can be considered in such a brief discussion as this. (1) The connection of regions by the formation of bridges, such as the isthmus of Panama during the later Miocene epoch (7,000,000 years ago) (Fig. 320) permitted migrations of organisms in both directions. North and South America were not connected in the early Miocene epoch of the Cenozoic era as is shown by fossil records of the prevailing faunas in these regions. (2) Disconnection of regions by the formation of channels or straits, such as Bering Strait between Asia and North America, prevented migrations of certain animals. Fossil records in both regions show that migrations occurred in both directions across the former land bridge before the present strait was formed. (3) Glaciers may cause a lateral as well as a vertical migration because of changes in temperatures, food supplies, and places of protection. (4) The flora (plant population) of a region affects either directly or indirectly the animal population of that region as far as food, shelter, and protection are concerned. (5) The presence of belligerent, antagonistic species may influence the distribution of certain species of organisms. The first appearance of certain species in definite centers of dispersal may make it possible or impossible for later migrations. In this case, priority rights of possession are determinative factors. (6) When organisms are isolated from the main stock of species, divergence is promoted in proportion to the degree of isolation and the length of time isolated. This is in part accomplished by preventing new types from being eliminated by interbreeding with the old. Isolation is thus a factor in the process of descent with changes. According to Jordan, species are present in specific habitats because (a) they are prevented from migrating elsewhere because of barriers; (b) they have been unable to maintain themselves in other habitats and thus have had to move into this particular region because they were successful in doing so in this type of habitat; (c) they have been so changed in their new habitats that they now constitute a new species. The latter might explain certain origins of species in limited localities at least.

QUESTIONS AND TOPIC

1. Select ten animals from each of the seven regions of the world and give reasons why each animal is distributed as it is.
2. Select ten animals of your immediate community, telling why each is distributed as it is.
3. What biologic environmental factors have been and are the most influential in the distribution of the animals selected in the second question?
4. With somewhat similar conditions in Brazil and Africa, why does the former have the sloth, tapir, and New World monkeys, while the latter does not? Why does the latter have the elephant, chimpanzee, and gorilla, while the former does not?
5. Why are the marsupials the prevailing mammals of Australia?
6. In regions having similar environments, why do we often find an entirely different fauna of animals?
7. Why do we frequently find similar forms on the summits of two mountains which are a great distance apart, while the bases of these same mountains are inhabited by entirely different types?
8. On mountain tops, why are the types frequently similar to those which live in the polar regions of the world?
9. Why is the fauna of the British Isles similar to that of the adjacent continent?
10. Explain the relationship between long periods of isolation and the development of endemic species.
11. List the values derived from a study of biogeography. What are the relationships between biogeography and geography?
12. Discuss fully the importance of each of the principles of geographic distribution. Which are the most plausible? Why?
13. What does the parallel distribution of organisms in altitude and longitude suggest? Give several examples of each.
14. Give the general characteristics and boundaries of each of the seven regions into which the animal world is divided. What factors might prevent migration from one region to another?
15. How might a certain condition act as a barrier to one type of animal and at the same time act as a method of transportation to another type? Give several examples.

16. List animals which are rather generally distributed throughout our country. Describe the methods of dispersal of such animals as the European corn borer, Mexican bean beetle, the English sparrow, and other forms with which you are familiar.
17. What is the effect of quarantine on the dispersal of organisms?
18. What is the effect of better methods of transportation by man on the distribution of organisms?
19. List ten plants distributed in a certain area, and tell specifically why they are distributed there rather than elsewhere?
20. Give all the reasons you can for the particular distribution of such plants as the instructor may suggest.

SELECTED REFERENCES

Braun-Blanquet: Plant Sociology, McGraw-Hill Book Co., Inc.
Cain: Foundations of Plant Geography, Harper and Brothers.
Campbell: Outline of Plant Geography, The Macmillan Co.
Clements and Shelford: Bioecology, John Wiley & Sons, Inc.
Daubenmire: Plants and Environment, John Wiley & Sons, Inc.
Jones: Economic Geography, The Macmillan Co.
Oosting: Study of Plant Communities, W. H Freeman & Co.
Sears: Deserts on the March, University of Oklahoma Press.
Wallace: The Geographical Distribution of Animals, London, The Macmillan Co.
Weaver and Clements: Plant Ecology, McGraw-Hill Book Co., Inc.
Wulff: Historical Plant Geography, Chronica Botanica Co.

Chapter 30

ANIMALS AND PLANTS OF THE PAST AND THEIR RECORDS

I. RECORDS OF LIFE

A fossil may be defined as any trace, remains, or impression of a plant or animal of past geologic ages. The science which deals with fossil plants and animals is known as *paleontology* (Gr. *palaios,* ancient; *onto,* being; *logos,* a study). Paleontology may be divided into two sciences: the one dealing with fossil plants, known as *paleobotany* (Gr. *palaios,* ancient; *botane,* plant or pasture) and the other dealing with fossil animals, known as *paleozoology* (Gr. *palaios,* ancient; *zoon,* animal; *logos,* a study). Much of our present knowledge about ancient life has been gained by a very careful and accurate study of the records left by these ancient organisms in the various strata of the earth (Fig. 313). The rocks of the earth's surface are of two kinds according to their origin, sedimentary and igneous. The sedimentary rocks, such as limestone, sandstone, shales, etc., may contain fossils and are formed by the transportation and deposition of small rock particles or by the precipitation of materials from solutions or by the secretions by certain organisms, as in the case of limestones. Igneous rocks (L. *igneus,* fire), such as volcanic rocks formed by consolidation of molten lava of volcanoes, are produced as the result of heat and do not contain fossils. In the formation of sedimentary rocks the oldest naturally occur at the bottom of a series of strata and the youngest nearest the top. The most ancient fossils thus will be found in the oldest rocks, while the most recent fossils will occur in the youngest rocks.

II. NATURE AND KINDS OF FOSSILS

The following are ways in which animals and plants of the past (Figs. 313 to 319) have left their records: (1) by actual preservation of the original material of the organism intact, (2) by preservation of the skeletal structures practically unchanged, (3) by natural molds or incrustations, (4) by petrifaction, (5) by carbonization, and (6) by leaving trails and imprints (impressions).

Actual preservation of the original material of the organism intact may take place by freezing and preserving in ice or soil (Fig. 314). This is not a common method, but an excellent example is the frozen mammoth discovered in Siberia a few years ago. Even plants of the same period were refrigerated with the mammoth. The complete remains of organisms may be enclosed in rocks as illustrated by a leaf of a plant. The remains of animals and plants may be preserved more or less intact in tar, amber, or oil-impregnated soils (Fig. 316). Amber is a yellowish

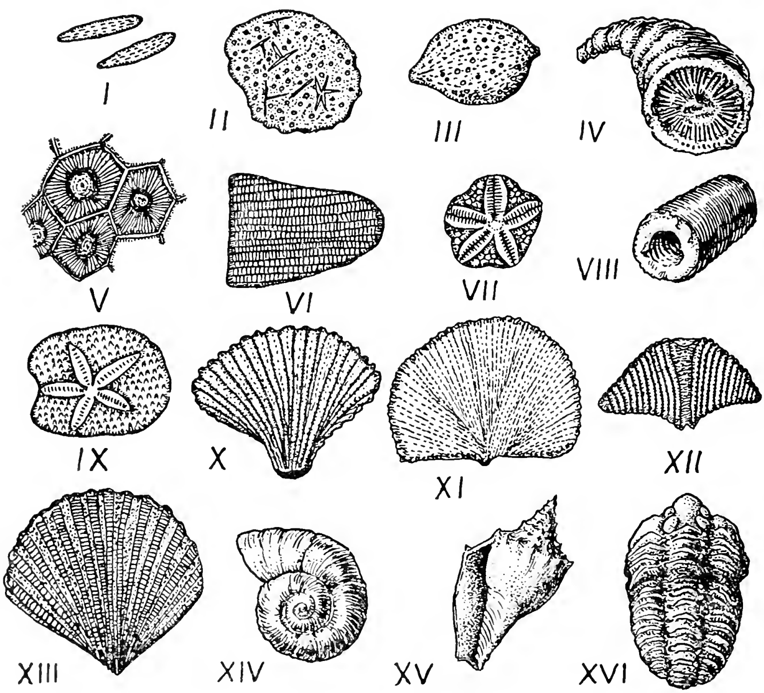


Fig. 313.—Fossils of invertebrate animals with the geologic period in which each type was found (see Figs. 320-322). *I,* Protozoa, Foraminifera (*Fusulina secalica*), Pennsylvanian epoch; *II,* Porifera, sponge (*Astraeospongia meniscus*), Silurian Period; *III,* Porifera "*Astylospongia*" (*Carpomanon stellatim-sulcatum*), Silurian Period; *IV,* Coelenterata, horn coral (*Zaphrentis prolifica*), Devonian Period; *V,* Coelenterata, coral (*Acervularia davidsoni*), Devonian Period; *VI,* Coelenterata, honeycomb coral (*Favorsites sp.*), Devonian Period; *VII,* Echinodermata, sea bud or Blastoid (*Pentremites sp.*), Mississippian epoch; *VIII,* Echinodermata, stem or stalk of a Crinoid, Mississippian epoch; *IX,* Echinodermata (*Epiaster whitii*), Cretaceous Period; *X,* Brachiopoda, Brachiopod (*Cyclothyris difformis*), Cretaceous Period; *XI,* Brachiopoda, Brachiopod (*Rafinesquina alternata*), Ordovician Period; *XII,* Brachiopoda, Brachiopod (*Spirifer pennatus*), Devonian Period; *XIII,* Mollusca, Pelecypod (*Glycimeris subovata*), Miocene epoch; *XIV,* Mollusca, Gastropod (*Bembexia sulcomarginata*), Devonian Period; *XV,* Mollusca, Gastropod (*Solutilites sayanus*), Eocene epoch; *XVI,* Arthropoda, Trilobite (*Calymene niagarense*), Silurian Period.

fossilized plant resin (pine tree) which was originally soft and captured the animal or plant intact. Later, the more volatile materials of the resin disappeared, leaving the hard amber with its imprisoned organism. Certain organisms may leave their remains more or less intact by being mired in quicksands or swamps.

When the *skeletal structure is preserved practically unchanged,* it remains almost in its original condition, except that it has lost most, if not all, of its organic material. In this method of fossilization, only the skeleton remains, while in the method described above, the skeleton and

Fig. 314.—Beresovka mammoth (*Elephas primigenius*) discovered frozen in the soil in Beresovka, Siberia, 800 miles west of Bering Strait and 60 miles north of the Arctic Circle. Clotted blood, unswallowed grass, as well as the entire specimen were quite well preserved by refrigeration. The specimen is shown as it appears in the Petrograd Museum. (From Lull: Organic Evolution. By permission of The Macmillan Company, publishers.)

all other structures as well are preserved. The author has found several skeletons of ancient mastodons, more or less well preserved, in soils of central and southwestern Ohio. In some instances the skeletal remains may have added such chemicals as carbonate of lime, which makes them more compact and heavier than the original. In other instances the skell-like skeletons of ancient animals have become more porous and somewhat lighter than they were originally.

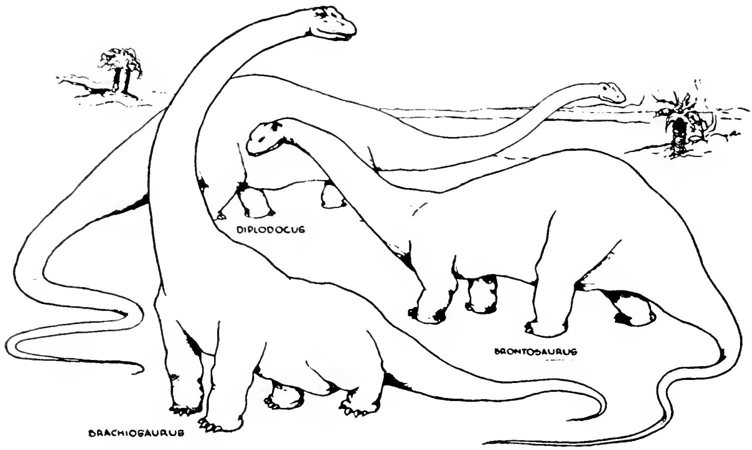


Fig. 315.—Three enormous dinosaurs (Gr. *deinos,* terrible; *sauros,* lizard), extinct reptiles of the past. *Diplodocus* was over eighty feet long and weighed forty tons; *Brontosaurus* was over sixty-five feet long; *Brachiosaurus* was about eighty feet long. (From Atwood: A Concise Comparative Anatomy, The C. V. Mosby Co.)

Fig. 316.—Pleistocene tar pool near Los Angeles, Calif., with entrapped animals. The elephant and wolves are caught while the saber-toothed tiger is about to suffer the same fate. (From Cleland: Physical and Historical Geology, published by the American Book Company.)

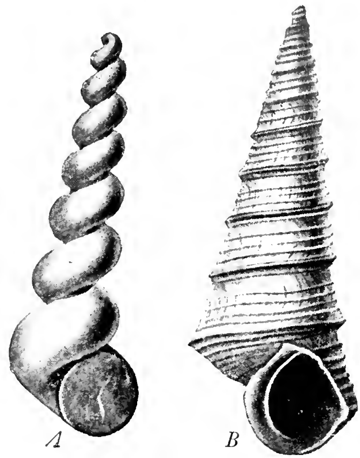


Fig. 317.—Specimens showing a natural mold, *A*, of the interior of an animal from which the shell has disappeared; *B*, the original shell of a similar specimen. (From Cleland: Physical and Historical Geology, published by the American Book Company.)

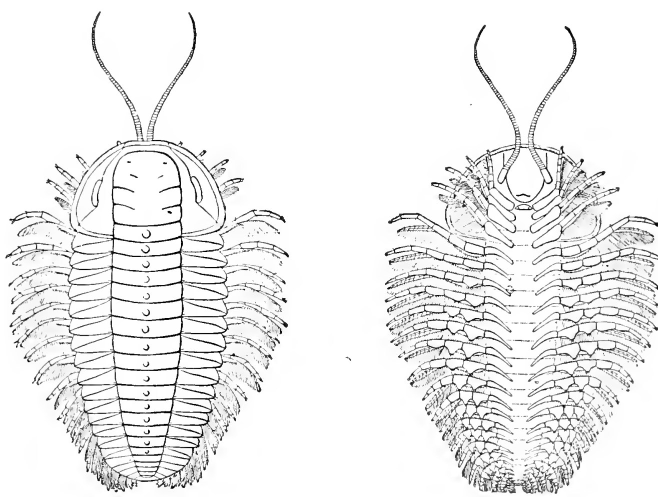


Fig. 318.—Trilobite, an extinct, fossil marine arthropod of the Ordovician period (see Figs. 320-322). Dorsal (left) and ventral views show the restored appendages. Trilobites (Gr. *tri,* three; *lobos,* lobes) had flattened, oval bodies composed of head, thorax, and abdomen; on the dorsal side the body is divided lengthwise by furrows into 3 lobes (one median and two lateral). They possess one pair of delicate antennae; their gills are attached to thoracic appendages; they have numerous, delicate, biramous appendages. (From Cleland: Physical and Historical Geology, published by the American Book Company.)

In natural *molds* or *incrustations* (Fig. 317) neither the minute structures nor the materials of the original organism are preserved but merely the general outlines of form and shape are recorded. Animals or plants may be enclosed by incrustations of calcium carbonate or silica which harden around the buried organism before it decays. The organic materials of the former organism eventually are removed by decay and a percolation of dissolving waters. The cavity which eventually remains retains the general form and shape of the original organism. In some

Fig. 319.—Passenger piegon (*Ectopistes migratorius*) which was once extremely abundant but is now extinct. (Copyright by General Biological Supply House, Inc., Chicago.)

instances the skeleton has disappeared entirely, leaving only the mold of it as a record. The shells of certain mollusks may have been covered with sediment while the soft parts decayed. The interior then may have been filled with the same sediment. Acidified waters then may have dissolved the limy shell, leaving only the molds of the exterior and interior. Sometimes the shell is removed, and the space left between the external and internal molds is filled with mineral matters carried in by percolating waters. In this manner the form of the original skeleton is preserved but not its natural structure.

In *petrifaction,* more or less of the original materials of the organism have undergone a certain amount of *mineralization.* In this case, the plant or animal materials have decayed in waters which contained large amounts of lime, silica, iron oxides, iron pyrites, or other dissolved substances. These chemicals replaced the original materials of the organism, sometimes faithfully retaining the original shape, size, and even minute details of structure of the former organism. Usually, the older the fossil in time, the greater the degree of mineralization. The harder parts of an organism are most frequently preserved. Shells, teeth, tusks, bones, and the harder, woody parts of plants are most frequently petrified by mineralization. We may find petrified wood which shows the minute structures just as they existed in the living trees but in which the walls of the cells are formed of the mineral silicon instead of the original cellulose. In this process, as each particle of cellulose disappeared, its place was accurately taken by a particle of silicon, thus retaining the minute details.

Carbonization of the original materials usually takes place in animals which possess chitinous skeletons. This also occurs in some plants. In this case, the organism loses oxygen and nitrogen, thus increasing the relative percentage of *carbon.* Even when plant materials are carbonized, they may afford valuable information regarding their original structure.

Trails and impressions (imprints) are the "fossils of living organisms," while other records are of dead organism. Many animals may leave their trails and imprints, but only vertebrate animals with feet can leave footprints. In all cases the records must be left in soft materials which later become hardened and preserved. Trails and imprints, although forming no part of the organism itself, nevertheless are considered as fossils. One of the most common of impressions is that made by a leaf in soft mud which later hardens and retains the impression. If the material in which the plant or animal impression is made turns to rock, the result is a fossil. This type of fossil usually does not give much information concerning the internal structures but much concerning the shape and form of the organism as a whole or of its parts.

III. CONDITIONS FOR FOSSIL FORMATION

In order for fossils to be properly formed, there must be a rather rapid burial of the original organism in a locality suitable for fossil formation. This burial usually is accomplished by water-borne sediment. Organisms with hard parts are more likely to fossilize than softer ones.

Hence, the simpler, softer organisms are rarely fossilized. This explains the absence of many fossils of the earliest plants. The organism must also remain intact a sufficient length of time to permit the fossilization process to take place. The original organism must be sufficiently heavy to settle to the bottom to be eventually covered rather than float on the water. Air must be excluded in order to prevent the oxidation of the organism as well as to prevent bacterial decay before the fossil is formed. During and after formation, the fossil must withstand such natural conditions as the elevation and sinking of the earth's strata, pressure and heat, the erosion processes within the strata, and the slow circulation of waters, especially acidulated waters, through the fossil. Because there are few places on land where materials are being extensively deposited, terrestrial plants and animals have little chance of becoming fossilized unless they are placed in water and eventually covered. The majority of land plants and animals after death will be quickly decomposed on the surface of the earth, thus leaving no extensive records. However, if covered with large quantities of volcanic ashes or lava, sand or dust, earth through landslides or earthquakes, or calcareous materials from calcareous springs, even terrestrial plants and animals may be fossilized to a limited extent. If the structures of an animal or plant are thin, fragile, easily broken, easily dissolved, and easily decayed, there may be little opportunity to form a fossil.

IV. SIGNIFICANCE OF FOSSILS

Fossils of certain types may indicate the boundaries and extent of former waters and lands. Fossils also may suggest the types of organisms of the past and their probable relationships with modern forms. The character of the fossils included in certain strata of the earth gives clues as to their geologic ages and when those particular sediments which formed these strata were laid down. Hence, certain animal and plant fossils are known as index fossils because through them it is possible to determine particular geologic ages and periods. Certain fossils also demonstrate that life has not existed without changes in the past because of the revelations of records of past animals and plants.

Fossils may give evidences of geographic distribution of organisms of the past and may show where land connections once existed but are no longer present. The Bering Strait between Asia and Alaska is about 35 miles wide and has a maximum depth of 200 feet. Studies of the fossils on these two continents show undoubtedly that they were once connected by land which sank beneath the water. It has been suggested that there is little land today which has not at some time been below the level of the sea, sometimes repeatedly. This explains why we may find fossils of former marine organisms even on high mountains today. Records of past animals and plants frequently suggest certain climatic conditions, such as moisture and temperature, which have existed at certain periods in the earth's history. Certain types of fossilized plants present in certain strata give us a good idea of the type of vegetation and necessary climatic conditions at the time when such plants were placed in these forming strata.

The study of fossil animals and plants is important because they often include the ancestors of modern species. In addition, the data secured from such fossils often explain relationships of present animals and plants. In some instances the ancient types serve to connect groups of organisms which today seem to have no direct connections. A study of fossil animals and plants also reveals that the race history (phylogeny) can be accurately traced. A study of the stratigraphic successions of fossil animals and plants gives much information in regard to the progressive developments of these animals and plants of the past, as well as suggests present and future progressive developmental tendencies. This study naturally would be much easier and more complete if unbroken and perfect records of fossil organisms could be procured. This is not possible so that these data must be interpreted accordingly.

Many interesting facts about ancient plants have been ascertained from a study of their fossil records in geologic rocks of the past. One reason for studying plant fossils is to secure a complete picture of the relationships between living organisms of today and their ancestors. The earliest known plants were very simply constructed. Age by age, more and more complex types appeared as shown by the study of the proper strata of the earth (Fig. 320). Before the Paleozoic era the only plants of which we find good records are the bacteria and blue-green algae. The most ancient land plants were the ancient spore plants from the Devonian period of the Paleozoic era. During the succeeding Carboniferous period there appeared large, complex, treelike ferns. The earliest seed plants (the seed ferns) occurred during the late Devonian and early Carboniferous periods. These primitive ferns belonged to the gymnosperms and became extinct in the Mesozoic era. Angiosperms are first found in the Cretaceous period of the Mesozoic era. They were dominant in this period and have retained this position ever since.

A knowledge of fossil plants is necessary for an understanding of the classification of plants. Formerly, the classification of plants was based on living forms, but as the knowledge of fossil plants increased, the clas-

Geologic Time Chart

Era	Period	Epoch	Duration in Years	Dominant Life
Cenozoic (Gr. *kainos*, recent; *zoe*, life)	Quaternary	Recent or Post-glacial	10,000	Man Mammals Birds Modern insects Flowering plants
		Glacial or Pleistocene (Gr. *pleistos*, most; *kainos*, recent)	1,000,000	
	Tertiary	Pliocene (Gr. *pleion*, more; *kainos*, recent)	6,000,000	
		Miocene (Gr. *meion*, less; *kainos*, recent)	12,000,000	
		Oligocene (Gr. *oligos*, little; *kainos*, recent)	16,000,000	
		Eocene (Gr. *eos*, dawn; *kainos*, recent)	20,000,000	
		Paleocene (Gr. *palaios*, ancient; *kainos*, recent)	5,000,000	
Mesozoic (Gr. *mesos*, middle; *zoe*, life)	Cretaceous (L. *creta*, chalk)		65,000,000	Reptiles
	Jurassic (fine developments in Jura mountains)		35,000,000	Angiosperms
	Triassic (threefold development in Germany)		35,000,000	
Paleozoic (Gr. *palaios*, ancient; *zoe*, life)	Permian (extensive in Perm, Russia)		25,000,000	Amphibia
	Carboniferous (carbon or coal-bearing rocks)	Upper or Pennsylvanian (well developed in Pennsylvania)	40,000,000	Seed ferns and giant spore plants
		Lower or Mississippian (well developed in Mississippi River Valley)	45,000,000	Gymnosperms
	Devonian (common at Devon, England)		50,000,000	Fishes Ancient spore plants
	Silurian (Silures, ancient tribe in Wales)		40,000,000	Algae
	Ordovician (Ordovici, ancient tribe in Wales)		85,000,000	Invertebrates
	Cambrian (Latin for Wales)		70,000,000	Algae
Proterozoic (Gr. *proteros*, early; *zoe*, life)	Upper Precambrian		550,000,000	Primitive multicellular organisms
Archeozoic (Gr. *arche*, beginning; zoe, life)	Lower Precambrian		650,000,000	Unicellular organisms, including bacteria

Fig. 320.—Divisions of geologic time with most important parts described. (Compare with Figs. 321 and 322.) (From various sources.)

sification was made more accurate and complete by incorporating the data contributed by paleobotany. Many large groups of plants of the past, although they have disappeared completely, have thrown much light on the relationships of living plants through their fossil records. Other large groups of plants which were originally dominant have diminished in numbers and importance until they are represented by a limited number of types today. However, they too have contributed to a more accurate classification of present-day plants.

A study of the fossil remains of ancient plants also reveals certain climatic conditions which prevailed at the time such plants existed. In other words, the presence of large numbers of plants at a certain period precludes a certain type of climate in order that such plants might fluorish. Such studies reveal luxuriant vegetation in regions which are at present more or less devoid of that type of plant. In general, the climate throughout a great part of geologic time is thought to have been much more uniform than at present. It is thought to have been quite mild, somewhat like present tropical climates, and with an abundance of moisture.

A study of paleontology also reveals certain geographic conditions of the past. Regions of the world now united originally may have been widely separated by barriers. Regions once connected are now widely separated. For example, mountains may have arisen or large land areas may have been submerged beneath the water. It is thought that much of the land area of today at some time in the past may have been below the surface of the sea. This is concluded by the type of fossils found in the earth's strata. Such natural phenomena as floods, glaciers, volcanic eruptions, and earthquakes have affected plant distribution in the past. A change in the quantity and quality of the atmosphere, water, food, or soil in the past undoubtedly influenced the distribution of plants. The greater and more extensive the changes in this connection, the greater the effects on plants. All of these factors have in the past been quite influential in determining plant growth and distribution.

A study of the fossil records of plants reveals that there has been a development from the simple to the complex and that the more complex flowering plants appear late in geologic history. In other words, throughout geologic time there has been a continued succession of plants. With each era and period, more complex and highly evolved plants become dominant, only to be superseded later by newer and more complicated groups. An accurate study of the plants of the past and present enables us to reconstruct much of the history of the plant world (Fig. 320).

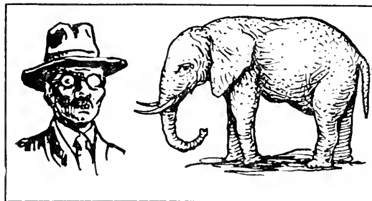
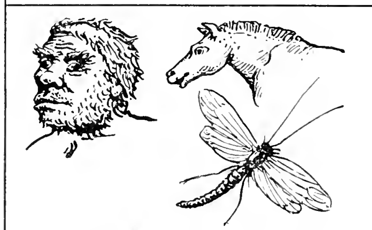
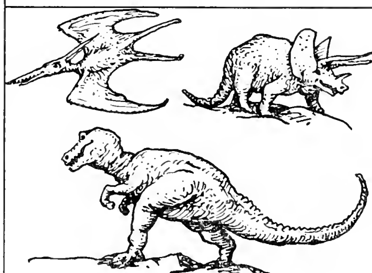
Era	Period	Epoch	Characteristics of the Times and Various Types	Representative Life
Cenozoic	Quaternary	Recent	Civilized man, modern mammals, modern birds, modern insects	
		Pleistocene	Periodic glaciation, elevation of continents Primitive man, modern mollusks, extinction of great mammals	
	Tertiary	Pliocene	Elevation of continents; development of Pre-man, rise of modern insects, decline of various mammals	
		Miocene	Maximum numbers of mammals	
		Oligocene	Rise of higher mammals	
		Eocene	Vanishing of primitive mammals	
		Paleocene	Rise of primitive mammals	
Mesozoic	Cretaceous		Climates quite mild; large deposits of chalk due to foraminifera (Protozoa); very specialized reptiles followed by extinction of giant reptiles; birdlike reptiles, toothed birds, bony fishes, rise of snakes, crocodiles, turtles, extinction of ammonites (Mollusca with coiled, chambered shells)	
	Jurassic		Giant reptiles (dinosaurs, ichthyosaurs, pterodactyls); rise of birds; clams and snails dominant; bony fishes, butterflies; decline of brachiopods; abundant ammonites (Mollusca with coiled, chambered shells)	
	Triassic		Rise of dinosaurs, primitive mammals, bony fishes; amphibia and mollusks	

Fig. 321.—Description of the periods and epochs of the Cenozoic and Mesozoic Eras of geologic time. Representatives of life during these times are shown at the right. (Not drawn to scale.) (Compare with Fig. 320.)

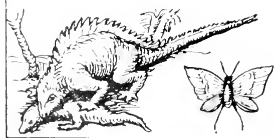
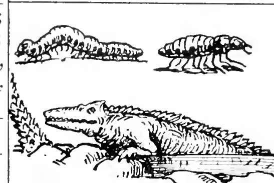
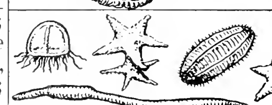
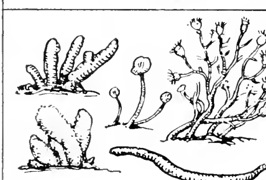
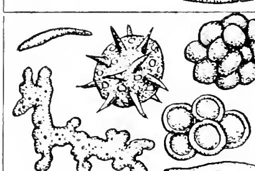
Era	Period	Epoch	Characteristics of the Times and Various Types	Representative Life
Paleozoic	Permian		Periodic glaciation; elevation of continents; several climatic changes; aridity pronounced Rise of land vertebrates and modern insects; rise of ammonites (Mollusca with coiled, chambered shells)	
	Carboniferous	Upper or Pennsylvanian	Coal-forming plants common; earliest reptiles, amphibia, fishes; mollusks, arthropods (crayfishes, beetles, cockroaches, centipedes, spiders), echinoderms	
		Lower or Mississippian	Coal-forming plants common Amphibia, fishes, mollusks, crinoids (coelenterates)	
	Devonian		Rise of amphibia, crabs, and snails; bony fishes, brachiopods; Mayflies; abundant mollusks; decline of trilobites	
	Silurian		Many parts of the world very arid; rise of air-breathing animals (as insects, scorpions, etc.) Abundant corals (coelenterates), armored fishes, mollusks, brachiopods, decline of trilobites	
	Ordovician		Rise of land plants, rise of fishes (cartilaginous and sharklike), rise of corals (coelenterates), brachiopods, trilobites	
	Cambrian		Only invertebrate animals present; segmented worms, mollusks; rise of brachiopods, echinoderms, jellyfishes, sponges, corals; abundant trilobites	
Proterozoic	Upper Precambrian		Rise of primitive, multicellular invertebrate animals; very few, imperfect fossils; traces of marine algae, bacteria, shelled-protozoa, coelenterates, segmented worms, sponges, and trilobites	
Archeozoic	Lower Precambrian		Rise of simple, primitive, unicellular types; large deposits of limestone, graphite, and iron ores of unicellular origin; no fossils remain, if any were ever formed	

Fig. 322.—Description of the periods and epochs of the Paleozoic, Proterozoic, and Archeozoic Eras of geologic time. Representatives of life during these times are shown at the right. (Not drawn to scale.) (Compare with Fig. 320.)

Fossils of certain characteristics are included in certain strata of the earth and give clues as to the geologic age of these strata. This is important in knowing when those particular sediments which formed these strata were laid down. Hence, certain plant and animal fossils are known as *index fossils* because through them it is possible to determine particular geologic eras and periods. Fossils also demonstrate that life has not existed without changes in the past because of the revelations of the records of past plants and animals.

V. GEOLOGIC TIME CHART

Because of the extensive studies of the strata of the earth, geologists have divided the earth's history into eras (Figs. 320 to 322). Each era has been divided into periods and the periods subdivided into epochs. Each of these eras, periods, and epochs has specific characteristics and definite ages and durations, as well as certain types of life which were dominant during that particular time. The most recent fossils are found in the upper strata, and the more ancient are successively arranged below, with the most ancient at the bottom. We find the fossil remains of plant and animal organisms distributed in this order in the strata of the earth.

The reader is probably wondering how the relative and actual lengths of the eras and periods have been calculated. This can be accomplished in two ways. The age can be approximated by the thickness of the sedimentary rocks formed during each period. It is known that a definite time is required to form a certain thickness of sedimentary rock of a certain type. From these data it can be estimated how long it would require a certain thickness to be formed. Another method of ascertaining the age of various strata is by the radioactive disintegration method. The radioactive elements, uranium and thorium, disintegrate spontaneously at constant, determined rates with the formation of lead. The age of a uranium mineral thus can be calculated from the proportions of uranium and the lead it contains. Determinations of the uranium-lead content of the oldest rocks suggest that the age of the earth is approximately 2,000,000,000 years. An accurate analysis of minerals reveals the fact that the Paleozoic era began over 500,000,000 years ago. Figures secured by this method correspond with similar figures secured by estimating the amount of time required for such sedimentary rocks to be formed. The characteristics of the various periods of the Cenozoic, Mesozoic, Paleozoic, Proterozoic, and Archeozoic eras, as well as dominant organisms of each era, are shown in Figs. 320 to 322.

QUESTIONS AND TOPICS

1. Give your own definition of a fossil.
2. Where have you found fossils, and what was their probable method of formation?
3. Of what importance in everyday life is a knowledge of animals and plants of the past and their records?
4. List several reasons why certain softer types of animals and plants have left no fossil records.
5. How are we able to estimate the age of the earth by a scientific study of the fossils in the successive strata of the earth?
6. Define index fossils and explain their values.
7. Do geologic records reveal a progressive change in life in the past? Give several specific examples from the animal and plant fields to prove or disprove this statement.
8. What conclusions do you draw from a careful study of the Geologic Time Charts? Upon what evidence do you base these conclusions?
9. If the older, earlier forms of life are found in the lower earth strata, and the more recent life in the upper strata, what effects might glaciers, earthquakes, and volcanic eruptions have on the proper interpretation of the data secured from areas so affected?
10. How have the various estimates of the age of the earth been made? How accurate are these estimates?
11. What is the estimated age of the earth from the Lower Precambrian Period down to the present?
12. What percentage of the total age of the earth represents the time which human beings have inhabited the earth?
13. As you remember specimens of petrified wood you may have seen, what were its characteristics? Do these characteristics conform to those described in the process of petrifaction?

SELECTED REFERENCES

Andrews: Ancient Plants and the World They Live In, Comstock Publishing Co., Inc.
Arnold: An Introduction to Paleobotany, McGraw-Hill Book Co., Inc.
Darrah: Textbook of Paleobotany, D. Appleton-Century Co., Inc.
Eames: Morphology of Vascular Plants, McGraw-Hill Book Co., Inc.
Huxley: Evolution, The Modern Synthesis, Harper & Brothers.
Lucas: Animals of the Past, New York, American Museum of Natural History (Handbook No. 4).
Lull: Organic Evolution, The Macmillan Co.
Raymond: Prehistoric Life, Harvard University Press.
Schuchert and Dunbar: Textbook of Geology (part 2), John Wiley & Sons, Inc.
Seward: Links With the Past in the Plant World, Cambridge University Press.
Smith: Cryptogamic Botany (vol. 2): Bryophytes and Pteridophytes, McGraw-Hill Book Co., Inc.
Thomas: Paleobotany and the Origin of Angiosperms, Botanical Rev. 2: 397-418, 1936.

Chapter 31

AN ECOLOGIC STUDY OF LIVING ORGANISMS—PLANTS AND ANIMALS

Ecology (e -kol′ o ji) (Gr. *oikos,* household; *logos,* discourse) is that part of biology which deals with the interrelationships between living organisms and their environment. Usually an ecologic study is made of a rather limited area, while a study of a larger area is usually considered as geographic distribution (biogeography). The term *bionomics* (bio-nom′ iks) (Gr. *bios,* life; *nomos,* law) is used in place of ecology at times. The factors which influence the interrelationships between living organisms and their environment are numerous and quite complex. Some of the most interesting and valuable results of a course in biology may be derived from a study of the ecologic relationships of living plants and animals. Consequently, the following outline for such a study is discussed in some detail so that the student may secure an idea of the complexity of such a study and procedures which might be followed in making it.

I. ECOLOGY OF LIVING ORGANISMS (PLANT AND ANIMALS)

Ecology may be defined as a scientific study of the interrelationships or interactions of living organisms and their environments. The ecology of an individual organism may be studied, or the ecology of a group of organisms of the same species may be included in such a study. On the other hand, a group of organisms (plant or animal) of two or more different species may be studied ecologically. Hence, the type of ecologic study which is made will be determined by the results we expect to secure.

In general, ecology concerns itself, more or less, with local or limited conditions, while biogeography deals with the wider faunal and floral relations and distributions. Biogeography, which is divided into phyto-geography (plant geography) and zoogeography (animal geography) will be considered in another chapter. Hence, we might study the

- A. Heredity
  1. The specific genes (factors) of the organism being studied.
  2. The inherited abilities and reactions of the organism.
  3. Mutations and the production of new types of organisms.
  4. Inheritance of specific structures by an organism.
  5. Rates of metabolism of the organism.
- B. Environment
  1. Physical factors
     - a. Temperature
     - b. Light
     - c. Wind
     - d. Gravity
     - e. Alternate recurrence of day and night
     - f. Physical makeup of the soil
     - g. Slope of soil as affecting the drainage and exposure to light and heat
     - h. Pressure
     - i. Currents of air and water
     - j. Presence or absence of natural barriers
     - k. Presence or absence of natural methods of dispersal
  2. Chemical factors
     - a. Quantity and quality (chemical composition) of the soil
     - b. Quantity and quality of water (moisture)
     - c. Quantity and quality of the atmosphere (oxygen, carbon dioxide, etc.)
     - d. Quantity and quality of usable foods
     - e. Ease and efficiency with which waste materials can be removed from around the organism
  3. Biologic factors
     - a. Competition between different kinds of animals (or plants) or even the same kinds of animals (or plants), for foods, light, moisture, space, etc.
     - b. Competition between sexes (animals)
     - c. Dependence of certain types of plants on insects for pollination
     - d. Mutual help, such as symbiosis, commensalism
     - e. Parasitism, saprophytism, predaciousness
     - f. Dissemination and destruction of plants and their seeds by animals
     - g. Plants contributing usable foods and oxygen
     - h. Plants detrimental to certain animals
     - i. Plants affording shelter, protection, and concealment for animals
  4. Human factors
     - a. Animal and plant quarantine regulations
     - b. Transportation of animals or plants by automobiles, trains, ships, airplanes, etc.
     - c. Usefulness and domestication of certain types of animals or plants not only influence their distribution, but also the distribution of other organisms around them
     - d. Detrimental animals and plants are destroyed at the hands of man which permits other types to take their place

ecology of a pool or square foot of soil and the biogeography (geographic distribution) of a continent or a certain country.

In making an ecologic study of a particular plant or animal (or groups of them), the specific heredity of the organisms involved, as well as all the environmental factors, must be taken into consideration. A brief, rather incomplete outline is given, which might be followed in such a study. When this outline is somewhat elaborated, the general problems of ecology, as well as the interdependence of hereditary and environmental factors, can be rather easily observed.

A. Heredity

1. The Specific Genes of the Organism Being Studied Ecologically.— Since hereditary genes (determiners) in the cells of an animal or plant determine to a great extent what the organism is going to be, its structures, its general abilities, its abilities to use certain foods, and its necessity to develop in a certain type of environment, it can be seen why heredity must be included in any study of the ecology of that particular organism. The genes of heredity also determine to a great extent the ability of a particular organism to develop variations by means of which it can attempt to fit into its environment, especially if the environment should vary from time to time. The inheritance of the ability to move around or be stationary also influences the ecology of any organism. These, as well as many other inherited factors, determine to a great extent the limits of distribution of a particular organism and consequently its ecologic relationships as well. When environments are changed from their normal, the organism living in them may attempt to vary itself sufficiently to continue living in the changed environment; it may, if possible, move to a more favorable environment, or it may die because it cannot accommodate itself to the changed conditions. Each living organism probably has an optimum environment in which it lives most successfully, although in many instances life can continue in changed environments, provided the changes are not too excessive. Animals and plants which do not possess the inherited abilities to vary sufficiently to meet changed environmental conditions have less opportunity of survival under such conditions.

Certain organisms, such as the common dandelion, are so constituted as to be able to live in a great variety of environments, in many types of soils, in the lowlands and on high elevations. Cranberry plants grow naturally in acid bogs and will not grow in neutral or alkaline soils.

Cacti grow best in arid soils and will not grow in poorly aerated, wet soils. Citrus fruits and palms of the tropics will not grow in habitats with freezing temperatures. Because of the hereditary factors in the grain of corn, a corn plant will be a corn plant, but the specific way in which it develops will be determined by many environmental factors which influence its growth. The common earthworm might be abundant in a moist soil well supplied with humus and organic food, while it might be very scarce, or entirely absent in a dry, sandy, abrasive soil with little or no available food.

2. The Inherited Abilities and Reactions of the Organism Being Studied.—All animals start their life by inheriting certain capacities to develop in a particular way. If the environment is not of the type to permit that development, the animal may move elsewhere, it may attempt to alter its environment, it may develop abnormally by remaining in such adverse environment, or it may be killed by such adverse environment. In some animals development must take place in a rather uniform environment in which conditions change very slightly. In other animals development must take place in an environment in which conditions are constantly changing in a very definite order. It is easily seen that one type of animal described above cannot well develop in the other environment and vice versa.

An example of inherited abilities and reactions which have influenced the ecologic relationships and distribution is that of the English sparrow. If this common bird had not possessed in many successive generations a tendency to be unafraid, its distribution today would be quite different than it is. Because of its inherited lack of timidity, the sparrow has had protection and a generous supply of foods most of the time. In fact, the sparrow has followed man and has taken advantage of all of its opportunities. Not being afraid, the sparrows are said to have entered the empty grain cars in the East and, after the doors of the cars were closed, have rather contentedly "hitch-hiked" their way to the West. Their inherited lack of temerity aided them no doubt in their distribution. Would one have expected such birds as blue jays, with entirely different inherited reactions, to have been transported easily and quickly across the continent? What happened to the West after the rapid influx of these birds from an ecologic standpoint? The inherited ability of sparrows to build their nests anywhere and from all kinds of materials also influences their ecology, while other birds require nesting sites and nesting materials of more specific qualities.

Each living plant has inherent tendencies to respond to certain stimuli in certain specific ways. For instance, a certain species of plant responds in a definite way to moisture, light, x-rays, cosmic rays, temperature, gravity, etc. These inherent abilities to react in a definite manner in no small measure determine how and where this species will be distributed and the characteristics which such species will possess.

3. **Mutations and New Types of Organism.**—Plants and animals which have been accustomed to a certain habitat may mutate rather abruptly and spontaneously. Such resulting mutants may be of such a variety that they will require an entirely different environment from that of their parents, so that the former will have to develop in the new habitats or be exterminated.

Natural crossing of plants, or animals, may result in offspring which are so different from their parents that the offspring may have to develop in a different kind of environment. In this case, as in the one mentioned above, an entirely new ecologic relationship may be instituted and consequently the distribution will be affected.

4. **The Inheritance of Specific Structures by Organisms Being Studied.**—Such inherited structures as the gills of a fish or a crayfish naturally limit their distribution to water, while the lungs of men, birds, rabbits, and turtles necessitate their living on land. The sucking type of mouth part of certain insects makes it necessary that they suck their nourishment from certain hosts, while the chewing type of mouth part of other insects determines their distribution on hosts of other types. Snails, in order to build their characteristic calcareous shells, cannot live in acid waters in which there is no lime. Certain insects, such as the common "walking stick" (order Orthoptera), because of their resemblance to a twig, are usually found in bushes where they are protected by their inherited morphology. These same insects distributed artificially on smooth surfaces are easily exposed and thus exterminated. Many moths and butterflies, because of their inherited structures and colorations, are found in certain environments because they are afforded protection there which they would not enjoy if they were distributed in an entirely different environment. Certain animals inherit definite color patterns by means of which they are partially hidden and protected by one type of environment. If moved to another type of environment, these same animals are easily detected and exterminated. These, as well as many other illustrations, show the importance of inherited structures which influence the ecologic relationships of the animals possessing them.

Certain plant seeds through inheritance are supplied with definite structures, by means of which they are disseminated. Claws, hooks, spirals, etc., may help such structures in being transported by animals, insects, birds, and the wind. The inheritance of certain structures for purposes of controlling the process of transpiration naturally will determine the distribution of such plants in various environments. The method of caring for transpiration on the part of cactus plants is such that they are able to exist in arid habitats, while plants which have not inherited such mechanisms cannot exist under such conditions. Hence, the distribution of these opposite types is somewhat predetermined.

The root systems of certain plants are such that they cannot possibly supply the necessary materials and provide the necessary anchorage and support in certain types of soils. In other words, certain types of roots make it necessary that such a plant be distributed in soils for which such roots are fitted.

Certain combinations of genes in plants sometimes result in a lack of development of chlorophyll. Naturally, such plants cannot long exist and the result is that the distribution is affected.

5. **The Rates of Metabolism of the Organism Being Studied Ecologically.**—Animals usually inherit certain rather definite, normal rates of metabolism. Certain factors of the environment are conducive to this normal rate, while other factors are not. To be successful, the animal must find that environment in which its particular rate of metabolism may be developed properly. If it cannot find such an environment, or because of an inherited lack of ability cannot locomote to better regions, it may die because of an abnormally induced rate of metabolism. This may prove to be a large factor in the ecologic relationship of that animal.

B. Environment

1. Physical Factors.—

(a) **Temperature:** Most animals have an optimum temperature at which their metabolic processes react best and at which they live most successfully. They also have a minimum and a maximum below and above which they will not live. Hence, animals will tend to select, as far as possible, those temperatures in which they can best exist. Freezing of water in which animals live affects them in the following ways: (1) some become hard and inactive during the frozen period; (2) others escape the freezing by burrowing deep in the mud; (3) others die under such conditions, but only after they have made the necessary provision to carry on the race by producing protected or resistant eggs. Such factors as these naturally affect the ecologic relationships of animals under these conditions. A covering of ice on a body of water not only affects the animals directly but also indirectly by altering the oxygen and food supply. This explains why many animals come to holes cut in the ice. Many fishes can be caught in this manner through holes in the ice.

It is a well-known fact that all types of plants cannot exist in the same temperature. Since temperatures vary in different environments, a plant must be placed in its required thermal environment or be killed because of this ill-adjustment.

(b) **Light:** Certain animal protoplasms are so constructed as to be unable to tolerate excess light, while others require large quantities to exist. In fact, some species seem to require the stimulation given by light in order to carry on many of their metabolic processes efficiently. Light naturally acts as an important factor in animal distribution directly. Indirectly, animals are affected by the presence of plants which require light for their existence. In other words, certain animals depend upon plants for food, protection, and oxygen. In turn, these plants depend upon the proper amount of light. Hence, animals are indirectly and directly influenced by the quantity and quality of light. Certain types of animals move around only in daylight (diurnal), while others do so only at night (nocturnal). In this case the presence or absence of light is a factor in the ecologic relationships of such animals.

Certain plants require a maximum of light, some require a medium amount, while still others require a minimum, or possibly none at all (such as mushrooms, bacteria). Plants will successfully locate themselves in the proper quantity and quality of light which suits their particular and specific requirements.

(c) **Wind:** The direction and velocity of the wind undoubtedly are very decided factors in the dispersal of certain animals. Very strong wind may also affect the water in which animals live so that it may be a factor in the distribution of such aquatic forms. The wind may affect them in various ways. It may cause injury to them directly. It may stir up the sediment in water so that animals may be influenced by it. The action of the wind also may influence the oxygen content of the air or of the water in which they live and thus be a factor in their distribution. Winds also may affect the temperature and moisture content of an environment and thus may directly influence animals or plant distribution upon which animals may be dependent. Very strong and constant winds may cause certain animals to change their habitats and seek a more quiet environment. Wind affects the ecologic relationships of plants in such ways as pollination (transfer of pollen from male part of the plant to the female part), in helping to disperse the seeds of many varieties, and in supplying movements of plants (can it be called exercise?) which may be necessary for the development of such plants. Winds might also aid in the distribution of oxygen, carbon dioxide, and obnoxious gases which in various ways might influence plant activities.

(d) **Gravity:** Unless land animals have special mechanisms by means of which they can counteract gravity, the heavier ones will be distributed at or near the surface. If animals move away from the surface, they do so in opposition to the force of gravity. Hence, the heavier animals are usually found at a lower level than the lighter ones. In water certain animals seem to be very little affected by gravity, for they are found at various depths. Other animals seem to live only near the surface, while others live on or near the bottom. Undoubtedly, other factors, besides gravity may influence these distributions of animals in various depths of the water. The force of gravity affects all plants either positively or negatively, sending stems and leaves upward and roots downward. Gravity in all probability affects aquatic organisms and somewhat determines their vertical distribution, depending on the specific gravity or density of the organisms in question.

(e) **Alternate Recurrence of Day and Night:** It is well known that the distribution of animals is quite different in daylight than at night. For instance, certain insects are to be observed only in the daytime (diurnal), while others are found more abundantly at night (nocturnal). There are many other factors besides the presence or absence of light which influence animal distributions as just described. The temperature is usually lower at night. This, in addition to more moisture at night, may cause certain animals to be seen at such times. This is particularly true for those types which have no special equipment to prevent the rapid evaporation of moisture from their surface. The stimulating effect of sunlight also may influence the distribution of certain types of animals.

(f) **Physical Make-Up of the Soil:** Some soils do not possess specific foods which are very essential to the growth of certain plants, because these foods are not in a form which these plants can utilize. Some kinds of soils are too hard for certain organisms and others are too loose or yielding for others. Certain animals require certain types of soil for food, burrowing, protection, etc. Plants requiring a specified amount of moisture may not be able to get it from one soil but are able to do so from some other soil. One plant requires a soil of a certain consistency to give it its necessary anchorage, while the requirements of another plant may be entirely different. The aeration of the soil is also determined to a great extent by its physical make-up. All of these and other similar factors help to determine the ecologic relationships.

(g) **The Slope of the Soil:** The slope of the soil and its exposure naturally determine the quantity and quality of light and heat. Some plants require a minimum of light and heat and hence would not find conditions ideal on a slope which is exposed to the hot sun of the afternoon. The opposite slope might be much more favorable for such plants. The slope of the soil also affects the drainage and this may also be an important factor in the distribution of certain kinds of plants. In all probability animal distributions are also affected by the environmental conditions of the slope of the soil. The slope may be conducive to erosion which may affect plant and animal distributions.

(h) **Pressure:** Pressure may be considered from the following standpoints: air, water, and soil. Naturally, the type of environment in which an animal lives will determine which of these pressures will influence its distribution. Air pressure is 15 pounds per square inch at sea level and decreases uniformly as one ascends from sea level to the higher regions. In high elevations the air pressure becomes too low to permit normal respiration in certain animals. This is a very salient factor in determining certain animal distributions.

Water pressure increases as one descends from the surface. Water pressure in the ocean is equal to the depth in feet multiplied by 0.434. Thus, at 200 feet depth, the water pressure per square inch is approximately 87 pounds. This pressure naturally determines the vertical distribution in deeper bodies of water because not all animals are so constructed as to withstand such enormous pressures. The rapidity of movement or the quietness of the waters also influences directly or indirectly the ecologic relationships of animals living in them. Soil pressures also vary according to the depth and physical construction of the soil. The pressure in soils is in some instances so great as to prevent the locomotion of certain types of animals through them. The porosity of the soil, its oxygen and moisture contents, and its food content are additional factors which might influence the distribution of living animals in it.

(i) **Currents of Water and Air:** Water and air currents in any one direction have a tendency to be a hindrance to locomotion of organisms, even for those equipped to swim or fly. Continuous strong winds have a tendency to move animals out of one area into another in the direction of the air currents. Strong water currents also have a similar effect. Water currents have a tendency to carry nonmotile types in the direction of the flow of water. Only those animals particularly constructed are able to counteract the water currents effectively. The "streamline" construction of many aquatic forms is beneficial to them for locomotion purposes and may be a great factor in their distribution.

(j) **Presence or Absence of Natural Barriers:** All types of living organisms have certain kinds of environments which are conducive to their dispersal. Any natural hindrances to dispersal are known as natural barriers. Something which may be a barrier to dispersal for one species may be a natural method of dispersal for another species. Water may be a natural method of dispersal for fishes, but it may prove to be a natural barrier for terrestrial forms unless the water is not too deep or extensive. Mountains may be natural barriers for certain types of animals, even if they are normally terrestrial forms. In this case, altitude, snow, ice, lack of proper vegetation for foods, shelter, home sites, etc., may be influential factors. Plants of certain types, when absent from certain regions, may serve as barriers to animal dispersal because those animals depend upon such vegetation for foods, shelter, home sites, etc. Earthquakes and volcanic activities may be barriers to the dispersal of certain types of animals and plants. Floods may be barriers to certain forms, while they may be used as methods of dispersal by others. Whether a certain condition serves as a means of dispersal or as a barrier depends upon the structural and physiologic properties of the particular organism in question. Heavy seeds, which cannot be easily carried by animals or the wind, may have difficulty in passing over a mountain or a large body of water. Lighter seeds may not be affected by these same barriers. The swiftly moving parts of a stream may be a barrier to the dispersal of the inhabitants of a quiet body of water because the environmental factors of the swift stream are different from those of the quiet area.

(k) **Presence or Absence of Natural Methods of Dispersal ("Highways"):** Most types of animals and plants have particular methods by means of which they are dispersed. The seeds of the dandelion are so constructed that they are easily carried by the wind. Sometimes when the most desirable method of dispersal is lacking, an alternative method may be used. If all usable types of dispersal are lacking, that particular animal or plant may be limited in its distribution. If certain types of vegetation depend upon moisture for dispersal, they may not be distributed during periods of extreme dryness. Certain types of seeds (burs, etc.) which depend upon animals for their distribution may have little or no distribution if animals are absent. The seeds of certain plants may be distributed widely through the feces of birds. If birds are absent, these plants must depend on alternative methods or not be dispersed at all.

2. **Chemical Factors.—**

(a) **Quantity and Quality of the Soil:** The quantity and quality of the soil affect not only animals living in the soil but also the aquatic forms living in the water which necessarily comes in contact with the soil. Certain soils, because of their high acidity, are not ideal for certain organisms, while alkaline or even neutral soils may be. Undoubtedly, the hydrogen-ion concentration (pH) of the soil is a vital factor in the ecology of many animals. The hydrogen-ion concentration of waters also is influential in determining their ecologic reactions. Certain chemical elements may either permit certain organisms to live in that particular soil or cause them to select other habitats, depending upon the quantity and quality of the chemical present. The quality and quantity of the soil also determine the kind of vegetation growing on it. Because certain types of vegetation are required as food, protection, and concealment by certain forms of animals, the characteristics of the soil may indirectly influence the ecology of the animals in that area. In addition to this, some plants supply moisture, oxygen, and homes for animals, and in this manner influence animal distribution.

Earthworms do not abound in sandy soils because such soils contain very little dead plant material to be used as food. The sand also irritates the worm as it burrows through it and tends to roll into the tunnels made by such worms, thus interfering with their movements and necessary oxygen supply. The moisture content of sandy soils also may be a factor in earthworm distribution in them. Other types of soils which possess a supply of available food, which are less irritable, and which retain the tunnels efficiently are more frequently used as habitats by earthworms.

Insects, turtles, and snakes deposit their eggs in soils of certain textures, temperatures, and moisture content. Decided variations from these desirable characteristics will influence the ecology of such animals. Some types of soils are unfit for making burrows and nests so that rabbits, gophers, skunks, and similar forms may distribute themselves where they may find habitats to their liking. Each plant requires an adequate amount of soil of the proper quality (chemical composition) to meet its specific requirements. In some instances the requirements are quite definite and specific. In such cases plants will not be found in soils which do not satisfy their peculiar needs. Cranberry plants will grow only in acid soils and not in alkaline. Certain weeds can be eliminated by merely altering the acid-base reaction of the soil. Dandelions evidently are not so specific in their requirements, for we find them growing in a great variety of soil environments.

(b) **Quantity and Quality of Water (Moisture):** All living organisms require water for various purposes, although the quantity which is sufficient for one type may be excessive for another. Protective substances and structures may prevent excessive evaporation and thus permit an organism to live in less than the normal requirement of moisture after it has once secured its normal supply. The presence in water of salts which are more or less ionized determines the acidity or alkalinity of that water. Some organisms apparently are not affected by the acid or base content (hydrogen-ion content), while others require an environment with a rather definite reaction. Hydrogen-ion concentration of 7 is known as neutral; that above 7, as alkaline; that below 7, as acid. When animals which normally live in a certain hydrogen-ion concentration are artificially transferred to an entirely different concentration, the animals may attempt to move out of the latter or they may be killed. Certain animals are constructed with hard, nonporous coverings, oils, or mucus in order to prevent excessive evaporation of moisture. In arid regions one would expect to find such characteristics in animals.

The transparency of the water permits the entrance of light which not only affects the animal directly but also affects the growth of plants upon which those animals depend for food, oxygen, and protection. The depth of the water, its suspended materials, and its rapidity are also factors in animal ecology. The pollution of waters with wastes and obnoxious materials is a decided factor in the ecology of certain animals, while the same conditions apparently do not affect others. Certain industrial wastes are responsible for the elimination of fishes, snails, clams, and crustacea from certain streams. This waste not only influences these types of animals but also the many other organisms which are associated with them. By eliminating large groups of organisms of certain types, the entire floral and faunal relationship of that area may be affected, and thus indirectly the ecology of many forms of life may be influenced. The elimination of one individual from a particular area may not have a great effect, but the wholesale removal of all members of a particular species may have far-reaching effects. In other words, there must be a reorganization of that area in order that life may continue efficiently and harmoniously.

Terrestrial and aquatic plants require water of a certain quantity and quality for their particular needs. Aquatic plants usually require much more than the average terrestrial type. The plants which grow in arid areas require much less moisture. It can be easily seen that an exchange of these various types of plants, as far as this type of environmental factor is concerned, may have detrimental results. Within certain limits the water conditions may be varied for a particular plant, but beyond that the plant will refuse to develop.

(c) **Oxygen, Carbon Dioxide, and Obnoxious Gases:** All living organisms require oxygen of a certain quantity. If this amount is insufficient for a certain animal, it may become extinct, or, if possible, may locomote to an area in which the oxygen supply is satisfactory. Oxygen is necessary for the oxidation of foods, and thus a sufficient quantity in an environment is an important factor in animal ecology. Carbon dioxide, if present in large quantities, is not conducive to animal life. The excess of this gas may be instrumental in the distribution of many types of animals, both terrestrial and aquatic. Obnoxious gases, either naturally or artificially produced, may result in a redistribution of organisms in that particular area. In fact, certain such gases are produced artificially to combat many undesirable animal types, such as insects, rats, moles, and gophers.

All green plants require a certain quantity of carbon dioxide to meet their needs for the process of photosynthesis. If the supply is insufficient, this very essential process cannot take place. If the oxygen supply is limited, a plant may be unable to oxidize its protoplasmic substances properly and thus be unable to liberate a sufficient amount of necessary energy to supply its particular demands. Obnoxious gases of various types may interfere with respiration, transpiration, and photosynthesis and thus indirectly be a very important factor in the ecology of the plants involved. Plants which do not possess chlorophyll (bacteria, mushrooms, etc.) quite naturally would require an entirely different atmosphere and consequently would be distributed accordingly.

(d) **Quantity and Quality of Usable Foods:** All animals require foods of animal or plant origin. Some types require specific foods of definite qualities. If such foods are lacking, the animal may die, or the lack may cause it to move, if possible, to a locality in which desirable foods are present. Other types of animals are not so specific in their food requirements and can exist on a great variety. The latter types of organisms are not so easily affected by the scarcity of any particular kind of food. Animals may be classified according to the types of foods utilized. Organisms depending upon animals for food are known as carnivorous (flesh-eating); those depending upon plants, as herbivorous (plant-eating); those which utilize both animal and plant foods, as omnivorous (all-eating). Animals of one of the above types may be compelled to change their habitat because of the quality and quantity of the particular foods they require in that community.

All living plants require foods of one type or another. In some instances their requirements are very specific and in others they are more general. If an area has a limited amount of food of a specific quality and plants require this kind of food in large quantities, it is quite evident that plant distribution will be affected accordingly. In some instances the foods present are in a form which is not usable. This fact also will be of importance in the determination of dispersal of plants.

(e) **Ease and Efficiency of Waste Elimination:** The ease with which detrimental wastes can be successfully removed from the environment of an animal no doubt affects its ecology. Since wastes, if allowed to accumulate, are detrimental to living protoplasm, it is necessary that the animal live in a habitat in which they can be quickly removed as they are formed. If a certain environment cannot accomplish this successfully for an animal, the animal will attempt to find a more favorable habitat. Thus, wastes may be a factor in animal ecology. The removal of wastes from a plant may be a minor factor in its ecology, but together with other minor factors may be quite influential. Under normal conditions, wastes are rather effectively removed from plants, but in case they are not they could be partially responsible for some of their peculiar behaviors.

3. **Biologic Factors.—**

(a) **Competition for Food, Light, Moisture, Space:** If too many animals with the same food requirements are present in an area with limited quantities of usable foods, there will be a struggle between them for that food. The result will be either the migration of certain of them in order to get suitable foods or the death of a certain number of the competitors. Since all animals require foods, it is easily seen that this struggle for them is one of the greatest ecologic factors in the animal kingdom. This migration in search of food may upset the natural balance of the new community in which the migrants locate.

Competition between plants of different species or even between plants of the same species rather closely resembles the struggle for existence in the animal world. Apparently nature sanctions this natural phenomenon in order to permit the fit to survive and exterminate the unfit. Such a struggle for foods, light, moisture, space, or position naturally will affect all of them in a minor or major way with its resulting ecologic effects.

(b) **Competition Between Sexes:** In the process of propagating the race, certain animals may travel long distances for the opposite sex. In other instances the competition of several members of one sex for a limited number of animals of the opposite sex may lead to dispersal or extermination. Since the urge to continue the individual as well as the race is a strong one, it can readily be seen that such a factor might be a very great one in determining the distribution of a particular species.

(c) **Dependence of Certain Plants on Insects for Pollination:** Certain plants require insects to carry pollen from the male reproductive organs to the female. In some instances a specific insect is required if extensive pollination is to occur. Bees are quite essential for this purpose in clovers. If bees are absent, the clover will bear a minimum of seed and hence will present an entirely different ecologic picture than if bees were present in sufficient numbers. Hives of bees are frequently to be seen in orchards and in clover fields for this purpose. Of course, such sources of nectar for making honey are also items not to be overlooked. Other plants do not depend upon insects for their pollination, so that the problem is quite different from the one presented above.

(d) **Distribution Affected by Mutual Help, Such as Symbiosis and Commensalism:** Sometimes organisms are distributed in certain areas because of the help which they give or receive from organisms of a different species. If this help were not available, there would be an entirely different distribution of the species in question. Symbiosis pertains to the rather intimate association of two different species of organisms with a mutual benefit to both. For instance, the termites ("white ants") are able to digest wood because they harbor in their digestive tracts certain flagellated protozoan animals which prepare the wood for absorption by the termites. In turn for their labors, the Protozoa are given protection by the termites. This mutual benefit results in a distribution of both the termites and their Protozoa in such a way that would not be possible if symbiosis did not exist. In a similar manner, certain green algae (plants) live symbiotically in the body of certain species of Hydra (animal). The green algae manufacture food through the process of photosynthesis in addition to giving oxygen to the Hydra. The latter gives protection and carbon dioxide to the algae. This symbiotic relationship between these two species of plant and animal causes a distribution of both of them that would not exist if symbiosis were not practiced. In the construction of the plants, known as lichens, the green, chlorophyll-bearing algae live symbiotically with the colorless fungi. In this case, two different species of plants live together so as to be mutually beneficial.

Commensalism literally means "eating at a common table," although, in a more general application, it means the association of two species of organisms, in which one species benefits and the other at least is not harmed. The sea anemone (Fig. 95) may attach itself to the shell of a crab, giving some protection to the crab in return for its food which the crab shares with it. The sea anemones are distributed by the crabs as the latter move from place to place. The various interrelationships of various living plants and animals are considered in more detail in other chapters.

(e) **Distribution Affected by Parasitism, Saprophytism, and Predaciousness:** These types of association of living organisms also influence the ecologic relationships of the organisms in question. Parasitism is the association of two organisms of different species in which the one, known as the parasite, lives at the expense of the other, known as the host. If the parasite lives within the host, it is known as an endoparasite, such as the liver fluke which lives in the body of a snail or sheep or the parasitic tapeworms or roundworms which live within the bodies of other animals. Various species of roundworms may be parasites within the bodies of plants. If the parasite lives externally on its host, it is known as an ectoparasite. Examples of ectoparasites are lice which live externally on the skins of dogs, cats, and men, the biting lice living on the surface of birds, plant lice (aphids) living on the surface of plants, certain fungi (plants) which cause "athlete's foot" living parasitically on the body of man. Some species of fungi live parasitically on or in the bodies of other plants. The disease of corn, called corn smut, is due to a parasitic fungus (class Basidiomycetes). The wheat rust is produced by a fungus parasite which also spends part of its life cycle on the common barberry (shrub). All of these illustrate the ways in which the ecologic relationships of these parasites and their hosts are influenced.

Saprophytes are those organisms which live on dead organic materials. Frequently, saprophytic plants or animals require rather specific types of dead materials for their existence so that their ecology is influenced.

Predaciousness, although somewhat similar to parasitism, differs in that the "host" is destroyed rather quickly, while in parasitism it may be destroyed only after a long period of time. Cats are predacious on mice and robins on earthworms. In each instance the distribution of each species is influenced by the presence of the other.

(f) **Dissemination and Destruction of Plants or Their Seeds by Animals:** Seeds or plants themselves may be widely distributed by insects and other animals by having the seeds carried in the digestive tract, on the external surfaces, or by mud on the feet. Many types of useful and detrimental plants and their seeds are destroyed by animals which eat them for food, use them for making nests, parasitize them, or in some other way interfere with their normal habits.

(g) **Plants Contributing Usable Foods and Oxygen:** The ecologic relationship between living plants and living animals is quite well known. It usually results in the green plant giving oxygen and food to animals, while the latter give carbon dioxide and waste materials which are useful to the plant.

(h) **Plants Detrimental to Certain Animals:** Certain types of plants may be detrimental to animals and in that way affect not only the distribution of the animals but also the distribution of the plants. Detrimental plants may be classed as either poisonous or predacious. The former may produce poisons which may affect animals and thus influence their distribution. The latter, or predacious plants (Fig. 330), actually capture and destroy animals. Examples of such predacious plants are Venus's-flytrap (*Dionaea muscipula*), the sundew (*Drosera sp.*), various pitcher plants (*Sarracenia sp., Nepenthes sp., Darlingtonia sp.*), and the bladderwort (*Utricularia sp.*). In Venus's-flytrap the two halves of each leaf blade have long stout teeth and three sensitive hairs.

When the latter are stimulated by an insect, the two halves of the leaf fold quickly together. The soft parts of the insect are actually digested by digestive juices secreted by the glandlike hairs on the leaf. In the sundews the flat leaf is covered with long, radiating, glandular hairs covered at their tips with a sticky secretion which contains a digestive enzyme capable of digesting insects lighting on the hairs. In the pitcher plants the leaves form urnlike pitchers which are partly filled with liquid in which the insects are captured and digested.

The bladderwort is a rootless, submerged water plant which bears numerous small bladderlike structures on its branches. Each bladder has one opening to the outside, closed by a valvelike trap opening inward. Small aquatic animals entering these traps are prevented from escaping and are used as food. In all these cases of predacious plants the ecologic distribution of the captured animals is affected.

(i) **Plants Affording Shelter, Protection, and Concealment for Animals:** Many animals live in certain places because they receive protection and shelter from particular plants. Without these plants they would be subjected to the ravages of nature and would be exterminated, or at least be distributed elsewhere. A little investigation will reveal many instances where animals are distributed in certain areas because of the presence of plants. Where do we find more animals, in a sandy area with limited vegetation or in an area with abundant plant life? List as many reasons as you possibly can for this phenomenon.

4. **Human Factors.—**

(a) **Animal and Plant Quarantine Regulations:** Quarantine regulations enforced by the government prevent, to a great extent, the importing of many varieties of animals and plants which otherwise would be brought to us from foreign countries in large numbers. Many of these types, if imported, would be very destructive of plants and other animals. In addition, these unwelcome immigrants would upset the natural balance or equilibrium of the present flora and fauna. This change in the equilibrium would necessarily affect the ecologic relationships of many other types of living organisms either directly or indirectly. In spite of this vigilance, many undesirable animals and plants are imported either secretly or knowingly. It is suggested that the organisms responsible for the destruction of large numbers of our elm trees (American elm disease) were brought in from Europe. If this parasite could have been prevented from entering, we could have saved many of our beautiful elm trees and by so doing could have saved large quantities of money. The destruction of large numbers of elms is not only a direct loss, but their absence also affects the ecologic relationships of other plants and animals which are present in the area in which they are destroyed. If there were no quarantine and everybody were permitted to import all types of vegetation, many detrimental, diseased, and parasitic plants as well as parasitized plants, would quickly make their appearance in this country. This would greatly add to our already enormous problems of economic botany.

(b) **Transportation of Animals and Plants by Automobiles, Trains, Ships, and Airplanes:** Only a little time need be spent on the highways or wharves to see how animals and plants are easily transported long distances by any of a number of methods. Not only are these truly methods of dispersal, but after animals or plants have been suddenly imported into new regions, their presence quite decidedly influences the former population to such an extent that an entirely new ecologic relationship will exist. These methods of dispersal are man's inventions and an animal or the seeds of plants may be quickly transported a great distance in a short time.

(c) **Usefulness and Domestication of Animals and Plants:** The very rapid changes in natural vegetation due to man's activities undoubtedly influence the distribution of numerous animals dependent on or associated with a vegetation of that type. The clearing of a land of its trees has a decided effect on the animal population of that area. The introduction of new species of wild or domesticated plants also directly or indirectly affects the animal distribution within that area. Man not only has taken domestic animals with him as he has gone over the earth's surface, but these animals also have taken their parasites with them. This has resulted in a necessary redistribution of the population into which the newcomers were taken. In general, it may be concluded that what may appear to be a small, insignificant factor may in the end prove to be a very influential one as far as ecology is concerned. The destruction of a few apparently useless animals may have a great effect in nature's balance, just as the introduction of a few apparently harmless varieties may cause an ecologic readjustment.

Domestication of useful plants has resulted in their being protected and cultivated, and hence their wide distribution has been ensured. The cultivation of domestic plants has a tendency to influence many wild types directly and indirectly. Many wild types are destroyed as weeds because they interfere with the normal development of domestic types. Many wild types influence the development of domestic types; an example is the destruction of corn plants by the European corn borer which may spend part of its life cycle in a great variety of weeds and other types of plants. Hence, the number of wild types which surround a field of corn and which harbor corn borers affects the domestic corn plants. The relationship between the barberry bushes and the rust of wheat is another example. A great variety of new types of plants have been "artificially" produced because they possess certain qualities which are beneficial for foods, shelter, fuel, or industry. The production and cultivation of many of these new species naturally affect the ecology of other plants in their vicinity.

(d) **Destruction of Detrimental Animals and Plants by Man:** This type of destruction not only affects the animals and plants being destroyed, but their absence affects many others indirectly by giving them more food, light, space, and moisture. The destruction of one kind of plant may cause animals which were dependent upon it to turn to some other type of plant and thus affect it. The destruction of certain plants may expose others to sunlight, heat, winds, etc., to which they were not accustomed. This will present a new ecologic factor for the remaining plants.

II. TYPICAL ENVIRONMENTS AND THEIR FAUNA AND FLORA

The following summary of a few typical environments and the types of organisms usually found in such environments will illustrate many points in the study of ecology. Environments for convenience will be divided as follows:

A. Water or aquatic
1. Rapid streams
2. Pools
3. Ponds
4. Lakes

B. Land or terrestrial
1. Open fields
2. Deserts
3. Tundras
4. Forests

Water or Aquatic

AQUATIC	CHARACTERISTICS OF ENVIRONMENT	TYPICAL ANIMALS PRESENT
Rapid streams	Rapid flow of water Usually a hard, firm, clean bottom Usually many loose rocks with crevices between them for protection Usually shallow, and hence plenty of light and oxygen from the surface Difficult for swimming animals Usually a minimum of vegetation	May fly larvae Stone fly larvae Caddis fly larvae Horsefly larvae Midge larvae Fishes, such as darters Snails (unless water is too acid)
Pools (more quiet part of streams)	Slow flow of water Usually a soft, yielding bottom of mud or sand useful for burrowing Crevices, if present, are soon filled with quickly settling silt Certain types of vegetation common	Dragon fly larvae Damsel fly larvae Midge larvae (blood worms) Clams Various types of common fishes, water snakes, and water turtles
Ponds	Slow flow of water Usually a soft, yielding bottom Certain types of vegetations which supply food, oxygen, etc., are quite common	Midge larvae Dragon fly larvae Damsel fly larvae Caddis fly larvae Crustacea Leeches Clams Water snails Fishes, water snakes, and water turtles
Lakes	Lakes are longer, wider, and deeper than ponds Wave action depends on many conditions Bottom may be sand, gravel, mud, loose rocks, or solid; these different types of bottoms influence the type of life to be found on each; constantly moving gravel or sand is not desirable for sessile animals; sand interferes with respiration of animals with gills; vegetation is limited because of sand movement and limited nourishment	The types of animals vary greatly, depending on the great variety of conditions encountered in such large bodies of water as lakes

Land or Terrestrial

TERRESTRIAL	CHARACTERISTICS OF ENVIRONMENT	TYPICAL ANIMALS PRESENT
Open fields	Temperatures usually severe in both summer and winter Wind action great Light intense Moisture evaporation high Very few places for protection except in the ground and in the limited vegetation	Beetles Grasshoppers Leafhoppers Certain types of spiders Certain types of snakes Certain types of mice Certain types of birds Toads Bees (if flowers are present)
Deserts	Temperatures severe in summer and winter Wind action great Light intense High evaporation of moisture due to intense heat and low atmospheric moisture Vegetation limited to sagebrush, cacti, yucca trees, bunch-grasses, etc.	Beetles Grasshoppers Leafhoppers Certain spiders Certain snakes Certain birds Horned toads
Tundras	Winter long and cold, only upper limits of soil thaw Air in winter is dry Often strong winds Relatively light snowfall Water of ground is cold Plant growth season short Vegetation consists of mosses, lichens, certain grasses, herbs, and shrubs	Very few animals can withstand the ravages of this polar and semi-polar area
Forests	Temperatures usually more moderate than surrounding areas Wind action reduced Protection from light, heat, wind, and moisture evaporation The type of forest will determine to a great extent the type of vegetation, and this in turn will greatly influence the distribution of animals	Bees Crickets Cockroaches Millipedes Centipedes Certain spiders Certain grasshoppers Katydids Tree toads Numerous birds, etc.

Ecology of a Portion of a Lake Shore

Station Number	Location of Station	Depth of Water	Temperature	General Characteristics	Attachment and Shelter	Food and Oxygen	Number and Types of Animals per Square Foot
A	Shoreline	6 in.	22° C.	Bottom of smooth, solid limestone Strong wave action; no crevices in the bottom	Strongly attached No shelter No plants for protection	Very little sediment to interfere with animal respiration No aquatic plants for food or to supply O_2 Shallowness permitted light and O_2 from surface	Midge larvae (50) Snails (Goniobasis) (4) Round worm (1) Caddis fly larva (1)
B	6 ft. from shoreline	18 in.	22° C.	Numerous, irregular rocks of various sizes Medium wave action; back wave action pronounced Many large crevices	Fairly strongly attached to all surfaces of rocks Algae (plant) very abundant	Slight sediment Great masses of green algae to supply food, O_2 and protection	Caddis fly larva (36) Midge larvae (27) Hydra (15) Snails Goniobasis) (9) Caddis fly pupae (6) May fly larva (1)
C	12 ft. from shoreline	36 in.	21° C.	Smooth, solid limestone bottom with occasional, free irregular rocks; surface wave action strong Few crevices	Fairly strong and uniform attachment Few plants	Slight sediment Few plants for food, O_2, or protection	Caddis fly larvae (35) Snails (Goniobasis) (8) Midge larvae (4) May fly larva (1)
D	Inland pool with connection with lake; 4 ft. inland from lake	6 in.	25° C.	Solid, smooth limestone bottom; no free rocks; no great disturbance by waves	Slight attachment Numerous plants (diatoms, desmids, algae)	No sediment Surface was covered with vegetation which was actively emitting O_2	Snails (Lymnea) (25) Midge larvae (4)

Fig. 323.—Summary of an ecologic study of a portion of a fresh water lake (see Fig. 324).

III. ECOLOGY OF A PORTION OF A LAKE SHORE

As an example of an ecologic study of a limited area, let us use a portion of a shore of a fresh-water lake. Four stations designated as A, B, C, and D are shown in Figs. 323 and 324. A thorough study of the environmental conditions and total numbers of animals found in each station (Fig. 323) will illustrate the problems of ecology. Note the differences in the environmental conditions and populations of Stations A, B, and C. Contrast these with Station D, which is a small, shallow pool located several feet from the lake but connected with it when wave action in the lake is particularly strong. A square foot of the bottom was studied carefully in each station. How can you account for such variations in the numbers and types of organisms in these stations? List as many factors as you can which you think might be responsible for such distributions.

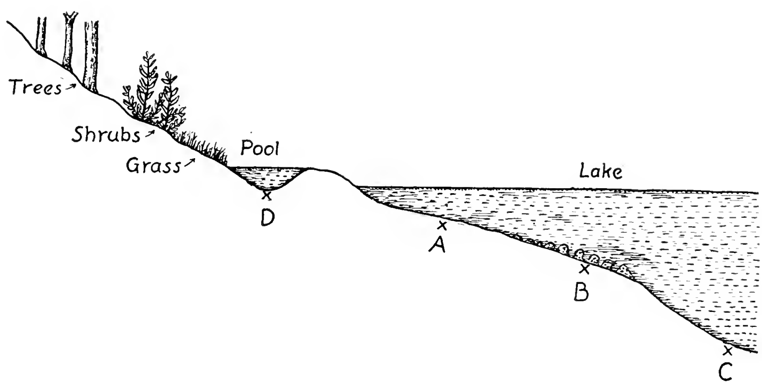


Fig. 324.—Diagram showing the location of Stations *A, B, C,* and *D* of an ecologic study of a fresh-water lake (see Fig. 323.)

A very good method of studying ecology is to select some desirable area, either land or water, and make a careful and detailed study of it yourself. You will also find quite a seasonal change in the animal and plant population of each area when studied at different times of the year.

IV. ECOLOGIC STUDY OF A PORTION OF YOUR CAMPUS

In order to understand the principles of ecology and the many factors involved in determining the distribution of living organisms, it is suggested that you study a small portion of your campus , following the outline given earlier in this chapter. You may study the ecologic relations of all the living plants and animals in a certain well-defined area, or you may attempt to ascertain the influence of all the factors (hereditary, chemical, physical, and human) on the distribution of one particular species. Be very accurate in your observations, records, and interpretations of your data.

QUESTIONS AND TOPICS

1. Select several different types of environments (upon consultation with the instructor) and make an ecologic study of the animals and plants in each area studied. Make use of the outline as presented in the chapter, adding or omitting as may be necessary for your particular problems. Record the data carefully after you have made the scientific observations. Make proper interpretations of your data and formulate conclusions which can be drawn logically from the data collected.
2. How can a knowledge of ecology be beneficial in the successful cultivation of vegetables and flowers? Give specific explanations.
3. How can a knowledge of ecology be beneficial in the proper care and operations of an out-of-door pool? Of an aquarium? Of a terrarium?
4. List some probable factors which might influence migrations of certain species of animals.
5. Study some maps which show the annual rainfall for the United States and interpret the distribution of certain types of plants in the light of this information.
6. Explain why cotton is primarily a southern crop. Give specific reasons.
7. Give reasons for the limitation of the cultivation of corn to certain regions of the United States. Do the same thing for wheat.
8. Secure data on the areas where citrus fruits are grown in the United States and attempt to explain why.
9. Explain how the distribution of certain types of plants might influence the distribution of certain types of animals and vice versa.
10. List all the benefits which might be derived from a scientific ecologic study of living organisms. How might you make practical applications of this information in the future?

SELECTED REFERENCES

Allee: Animal Aggregations, University of Chicago Press.
Allee: Social Life of Animals, W. W. Norton & Co., Inc.
Allee, Emerson, Park, Park, and Schmidt: Animal Ecology, W. B. Saunders Co.
Bates: The Nature of Natural History, Charles Scribner's Son.
Braun-Blanquet: Plant Sociology, McGraw-Hill Book Co., Inc.
Chapman: Animal Ecology: With Special Reference to Insects, McGraw-Hill Book Co., Inc.
Clements and Shelford: Bioecology, John Wiley & Sons, Inc.
Coker, Juday, Osburn, and Welch: Problems of Lake Biology, The Science Press.
Daubenmire: Plants and Environment, John Wiley & Sons, Inc.
Elton: Ecology of Animals, John Wiley & Sons, Inc.

Fasset: Manual of Aquatic Plants, McGraw-Hill Book Co., Inc.
Gates: Field Manual of Plant Ecology, McGraw-Hill Book Co., Inc.
King and Pessels: Working With Nature, Harper & Brothers.
McDougall: Plant Ecology, Lea & Febiger.
Morgan: Field Book of Ponds and Streams, G. P. Putnam's Sons.
Muenscher: Aquatic Plants, Comstock Publishing Co., Inc.
Needham and Needham: Guide to the Study of Fresh-Water Biology, Comstock Publishing Co., Inc.
Oosting: Plant Communities, W. H. Freeman & Co.
Pearse: Animal Ecology, McGraw-Hill Book Co., Inc.
Ward and Whipple: Fresh Water Biology, John Wiley & Sons, Inc.
Weaver and Clements: Plant Ecology, McGraw-Hill Book Co., Inc.
Welch: Limnology, McGraw-Hill Book Co., Inc.
ZoBell: Marine Microbiology, Chronica Botanica Co.

Chapter 32

UNITY AND INTERDEPENDENCE IN THE LIVING WORLD

I. UNITY IN THE LIVING WORLD

The term unity can be applied in a variety of ways in the animal and plant kingdoms. In such a brief space as can be devoted to this very important biologic principle, the following kinds of unity will be considered: (A) unity within each living organism, (B) similarity of structures and functions between closely related species of organisms, and, to a lesser degree, even in distantly related species, (C) unity and cooperation between various types of living organisms of similar or different species, (D) biologic communities (associations) and successions of plants and animals, and (E) dependence of all living animals and most plants on photosynthesis.

A. Unity Within Each Living Organism

1. **Unity Within the Individual Cell.**—One would easily surmise that there must be unity and harmony within the protoplasm of each living cell if that cell is to perform its various functions effectively and efficiently. When this unity ceases, the cell becomes abnormal, the degree of abnormality determining whether that cell will alter its structures and functions or whether it will eventually die. The foundation of unity and order, in the individual cell as well as in the living organism as a whole, is the "inherent ability of living protoplasm to transmit dynamic changes and impulses from one point to another within that protoplasm." This phenomenon results in all parts of a living organism knowing what is going on in other near-by or distant regions and acting accordingly. The living protoplasm also has the ability to "properly integrate and harmonize these various dynamic waves of excitation so that more or less complete harmony and cooperation results." It has been suggested that individual cells have certain regions ("poles") which are the controlling points for the activities of that particular cell.

Such a construction might well be called cell polarity. One of these so-called poles has a higher rate of metabolic activity than the remainder of the protoplasm and consequently assumes the necessary and desirable control of the cell as a whole.

2. **Unity Between the Various Cells of Each Tissue.**—We have suggested how unity and correlation might occur within an individual cell. This would be worth very little in a complex, multicellular organism if each cell did as it pleased. There must be unity and cooperation between the various cells of each tissue of a living organism if life processes are to be accomplished efficiently. The explanation suggested for the unity within a single cell might be extended and elaborated so that cooperation between various cells might be accomplished. Electrical phenomena, chemicals, and impulses of the nervous system probably integrate to a great extent the various cells of a tissue so that real harmony and cooperation exist. Electricity within cells and the electrical phenomena associated with nerve impulses suggest probable causes of integration. Various chemicals pass more or less freely from one cell to another, hence playing an important role in unity between cells. The chemical secretions in the ductless (endocrine) glands of higher animals will illustrate this process of coordination. (See discussion of ductless glands.) It has been demonstrated in certain cells that there are minute strands which extend from one cell to another, and evidently through such structures coordination might also be secured. All that has been said up to this point has dealt with the proper coordination of cells. There are times when certain cells, or certain parts of cells, must be subordinated, because all units cannot have the same degree of activity. This subordination of certain parts is just as important as the coordination process and is probably accomplished in much the same way.

3. **Unity Between the Various Tissues of Each Organ.**—An organ is an assemblage of different tissues, all of which work for a common purpose (perform a common function). Even though the various tissues of a certain organ are closely associated in the construction of that organ, there must be a specific integrating influence or force in order to make these various tissues function together as a unit. This is accomplished in much the same way as in individual cells and tissues, except on a larger scale.

4. **Unity Between the Various Organs of Each System.**—If each system of a living organism is to function normally and efficiently, there must be unity between the various organs which compose that particular system. The higher types of organisms with their greater numbers

of cells and their more numerous tissues and organs must necessarily have a more complicated nervous system than lower organisms in order to ensure the proper coordination. Chemical and physical factors probably play important roles in this respect. Could the digestive system of an organism function properly if all the organs of that system worked independently? How would one organ know what to do if it were not properly notified what is expected of it? Another evidence that all organs are closely related and associated is shown by the fact that effects of illness in one part of a system are frequently relayed to other parts of that system or even other systems so that the unity of the organism as a whole may be again regained. In other words. "sympathy" is expressed between the various units of a living organism. This is quite essential. In some instances when defects or abnormalities arise in a certain region, organs in some distant part of the animal may take on extra responsibilities until the defect is remedied. If the abnormality is not properly remedied, dissension may spread; overworked tissues cease to carry their double burdens and still greater consequences result. In other words, a living organism is as healthy as its weakest part.

5. **Unity Between the Various Systems of a Living Organism.**—From what has been said above, it is quite evident that every living organism must have the proper coordination and subordination of its various systems if efficiency is to result. A slight abnormality starting in a certain tissue, unless corrected, may spread to other tissues, to organs, and to systems, and eventually the organism as a whole may be affected. This may appear to be a mistake in construction on the part of Nature, but in reality it is a blessing in disguise, for without these consequences little might be attempted to care for minor disturbances. Consequently, it becomes highly desirable and essential to correct defects so that they do not spread.

B. Similarity of Structures and Functions Between Closely Related Species of Organisms

Students who are just beginning their study of biology will probably have some difficulty in realizing the great number of similarities between various apparently unrelated organisms. We have a great tendency to observe one or two differences when comparing two organisms and not to notice a greater number of similarities which are observed only after detailed study. As you study the structures, functions, and reactions of various types of living organisms, you will observe many more similarities than you at first surmised. These many similarities among living organisms reveal a certain close relationship, which in turn proves a certain degree of unity or uniformity among all living organisms. If a study of the entire animal or plant kingdom were to be made, and the similarities of the various species noted, one would have to conclude that there is a certain degree of unity in the animal and plant kingdoms.

C. Unity and Cooperation Between Various Types of Living Organisms

As we look about us in the living world and note the great struggles, animosities, battles, and antagonisms, it is difficult to realize that there are many, if any, instances in which there is real cooperation. However, a little investigation will reveal that this is true. In spite of all the struggles in the living world, none of them are so great as to disrupt life in any great region or cause any great catastrophes. After all, there must be, and is, more unity and harmony than discord among living organisms or they would quickly exterminate each other, which would result in ultimate and widespread ruin. In spite of the many hatreds and struggles throughout the living world, there are many attempts at cooperation, which in the final analysis seems to be a clue to a successful living and accomplishment. When will man with all his powers and abilities learn this one fact and place it into actual use? It is quite true that a certain amount of struggle and competition is necessary to bring out and develop the best in organisms, but these carried too far and made unnecessarily vicious tend to hinder development and progress and may ultimately lead to destruction. How does this link up with the condition of mankind over the world today? Is there not a great lesson to be learned from this great biologic principle in the conduct of human affairs?

When one studies the living organisms as a group, there is apparent a great degree of unity and cooperation not only between members of the same species, but also among members of different species. In fact, this spirit of cooperation exists not only between animals of different species but between various species of animals and a great variety of plants. Undoubtedly, there are many examples of the latter phenomenon, but none will better illustrate the point than the so-called cycles in Nature. The following typical cycles (Fig. 325) will be considered: nitrogen, carbon, and oxygen cycles.

1. **Nitrogen Cycle.**—Nitrogen is one of the essential elements of which living protoplasm is composed, being particularly essential in the con-

struction of proteins. Briefly stated, the following steps may be observed in a typical nitrogen cycle starting with the utilization of the free nitrogen of the atmosphere: (1) Free nitrogen of the atmosphere

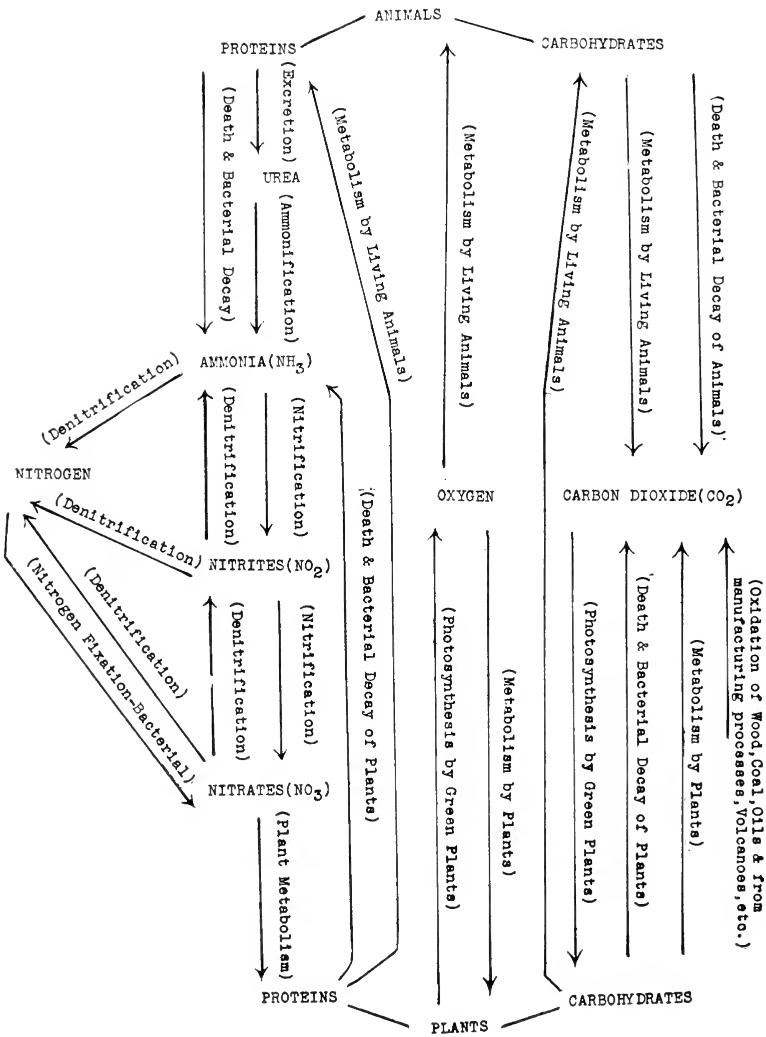


Fig. 325.—Nitrogen, oxygen, and carbon cycles in nature.

is utilized by certain species of bacteria *(Rhizobium sp.)* living symbiotically in the roots of leguminous plants (as clover, alfalfa, peas, etc.) to form nitrates (containing NO_3) which are usable by plants to build plant materials. Because of the irritating presence of these bacteria in the roots of such plants, the latter are stimulated to form enlarged nodules on their roots. The nitrogen-fixing organisms are in these nodules. (2) Free nitrogen is also changed to nitrates by other bacteria living in the soil (genus *Azotobacter* and genus *Clostridium*). (3) Other plants may secure their nitrates by bacterial decomposition of animal products (such as urea) and other nitrogenous materials. Certain bacteria (ammonifying bacteria) act on nitrogenous compounds changing them into ammonia (NH_3) through a process known as ammonification. (4) Other bacteria (*Nitrosomonas sp.* and *Nitrosococcus sp.*) oxidize the ammonia into nitrites (containing NO_2). (5) Still other types of bacteria *(Nitrobacter sp.)* oxidize the nitrites into nitrates. This whole process of transforming ammonia into nitrites and the latter into nitrates is called nitrification. The nitrates so formed are usable by plants. Thus, the two sources of nitrates for plants are: (a) the fixation of free nitrogen from the atmosphere and (b) the production of nitrates from ammonia by the process of nitrification.

When plants die, their complex nitrogenous compounds are reduced by bacterial action to ammonia, which can be used in the process of nitrification. When animals die, their complex nitrogenous compounds are also reduced by bacterial action to such simple compounds as urea, which can be converted into ammonia, to be used as a starting point in the nitrification process. Plants and animals both depend on these chemical compounds for their food materials, the animals depending upon the plants for at least part of their nitrogen supply from which to build proteins. As has been shown above, the roots of certain plants also contribute to the available supply of nitrates to be used by plants. Animals in turn use plant nitrates for their various needs.

There are still other types of bacteria which convert nitrates to nitrites, oxides of nitrogen, and free nitrogen—a reverse process which removes nitrogen from the soil. This process is known as denitrification.

2. **Carbon Cycle.**—Carbon is also an essential constituent of both plant and animal protoplasms. The stages in the carbon cycle may be briefly summarized. The carbon dioxide of the atmosphere comes from the respiration of animals, from the burning of wood, coal, oil, and gas, from various manufacturing processes, and from volcanoes (Fig. 325). Green plants which contain chlorophyll are able to combine the carbon dioxide with water in the presence of sunlight to form plant carbohydrates such as sugars, starches, and cellulose. This process is known as photosynthesis. Plants utilize the materials produced by photosyn-

thesis to manufacture more complicated plant proteins and fats. Animals use these carbon materials of plants with which to build even more complicated animal carbon compounds.

When plants and animals die, their carbon compounds are reduced into simpler carbon materials which can eventually be used again by living plants. Earthworms, certain insects, and such plants as bacteria and molds aid in restoring this carbon material to the soil where it can again be utilized.

3. **Oxygen Cycle.**—Oxygen is also an essential constituent of protoplasm (Fig. 325). It not only goes into the make-up of the protoplasm, but it is used in the process of oxidation, in which the oxygen combines with a substance so as to liberate the energy which originally held the units of the substance together. Oxygen is liberated and carbon dioxide is taken in by green plants during the active process of photosynthesis. Some of the oxygen is retained by the plant and used for building or oxidation purposes. Animals require oxygen for respiration. This oxygen oxidizes the foods of the animal with the release of energy and the formation of carbon dioxide which can be utilized again by chlorophyll-bearing plants. Hence, there is a mutual exchange and interdependence between animals and plants as far as oxygen is concerned. This exchange of oxygen and carbon dioxide also occurs between animals and plants in an aquarium, out-of-door pool, or any other body of water.

D. Biologic Communities (Associations) and Successions of Plants and Animals

Very few, if any, organisms live alone (Fig. 326). In many instances, groups of the same or different species are associated in a community in which there may be unity, disunity, helpfulness, interdependence, or destruction, depending on the many factors or conditions under which they are living. A certain association of organisms may live in harmony in one community with its particular environments, while the same association of organisms in another community might not live harmoniously because of certain environmental factors which differ from those in the first community. There is not one, all-important factor which is responsible for the distribution and successful living of animals and plants in any community. In making a scientific study of the reasons why certain organisms live as they do, we must take into account the heredity of those organisms, as well as such environmental influences as chemical, physical, and biologic factors in the surroundings. Even human factors may be quite influential as will be observed when these are considered in detail in another chapter. Frequently, we classify living organisms into different communities because of their habitats (where they live). Animals that live on land are *terrestrial* (Gr. *terra,* land); those that live in water are *aquatic* (L. *aqua,* water); and those that live in water and on land are *amphibious* (Gr. *amphi,* both; *bios,* life). Plants may be classed as water plants or *hydrophytes* (Gr. *hydro,* water; *phyton,* plant); land plants or *terraphytes;* desert plants or *xerophytes* (Gr. *xeros,* dry; *phyton,* plant); plants requiring moderate moisture are *mesophytes* (Gr. *mesos,* moderate or middle; *phyton,* plant). Living plants and animals may be divided into such communities as seashores, fresh waters, forests, grasslands, deserts, etc.

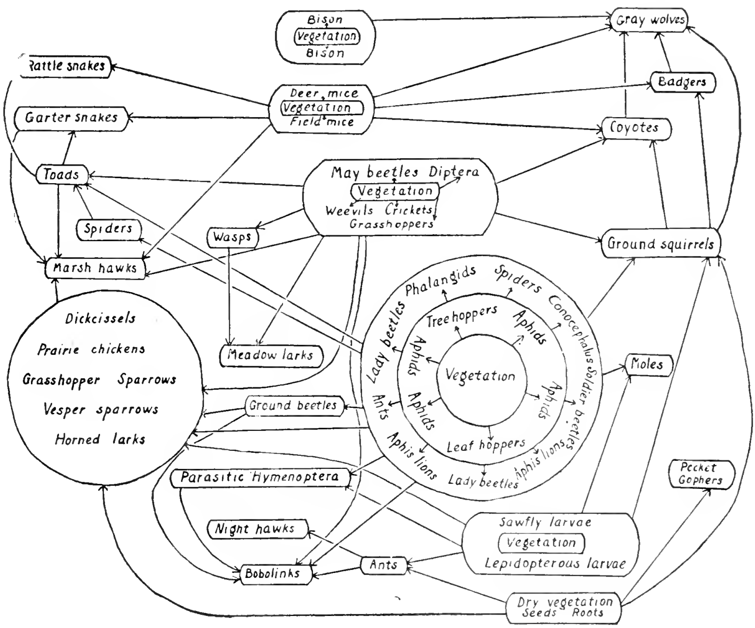


Fig. 326.—Balance in Nature as revealed by a diagram showing the food interrelationships in a hypothetical prairie community. All living things depend on other living things for various things, including food. The arrows point toward the organism which uses the other organism as a source of food. (Redrawn and modified from Shelford; from Potter: Textbook of Zoology, The C. V. Mosby Co.)

Animal and plant communities are never constant or static but are continually changing. These changes in individuals, or in the community as a whole, are the attempts on the part of living organisms to adjust themselves successfully to their changing, nonliving, and living environments. The introduction, naturally or artificially, of new species may require a complete readjustment in a certain community. In fact, these constant changes in the living world communities result in what is called a *succession of living organisms.* When environmental factors change sufficiently, the plants and animals which originally lived there may be destroyed and their places taken by other types. Such a sequence of plant and animal replacements is a *succession* which may occur naturally or be brought about, at least in part, by artificial means. For example, a fresh-water pond may have a certain type of animal and plant population. When this pond dries, the resulting changes in the environmental factors may result in a succession somewhat as follows: animals and plants which require a great amount of water will be gradually replaced by those whose water requirements are not so great; as the pond develops into a swamp, plants and animals typical of swamps will succeed; herbaceous plants will appear, to be followed by various types of shrubs, and eventually a succession of trees which will range from poplars to oaks and hickories to beech and maples. Even the appearance of these trees show a typical succession of species, each following the other as the proper environmental factors present themselves. The same phenomenon of succession is to be noticed in the replacement of plants and animals in an original forest community which was burned. As different plants succeed one another as environments change, so the animal population will also undergo a succession in that area. Certain types of animals requiring specific kinds of plants for protection and food cannot reappear in the burned area until the proper plants have reappeared in the plant succession. These and many other similar phenomena prove the unity and interdependence in the living world.

E. Dependence of All Living Animals and Most Plants on Photosynthesis

All plants and animals require foods of some type or another. Since animals and plants without chlorophyll cannot manufacture food, it is apparent that in the final analysis all life depends, directly or indirectly, upon the photosynthetic process for food. It is true that certain animals eat other animals, but somewhere in the continuous chain of food supply the animal was dependent upon plants for food. Even the plants without chlorophyll, such as fungi, bacteria, etc., must depend, directly or indirectly, upon the process of photosynthesis for their source of food. Bacteria may live on an animal which has eaten another animal, but probably the latter had consumed food which was manufactured by the process of photosynthesis. Photosynthesis not only supplies many of the foods but also materials used for shelters, clothing, fuels, etc. Refer to the detailed discussion of photosynthesis elsewhere in the text.

II. WEB OF LIFE AND BALANCE IN NATURE

All life in the world is so interdependent and closely related that it may be viewed as a web (Fig. 326) composed of various individuals and species of animals and plants which are more or less intimately associated together into a living unit. This web or unity of life may be constantly changing from time to time as far as the individuals who compose it are concerned, yet there seems to be more or less of a constancy in any given area. Probably no living organism lives unto itself alone, but each organism affects other living organisms and in turn is affected by one or more organisms. The more we study biologic phenomena, the more we realize and appreciate the interdependence of all living things. In any particular area of life, each organism contributes something, either large or small, to the total life of that area. In the web there may appear many struggles and antagonisms among the inhabitants, but in spite of them there actually exists a balance in Nature—all these struggles somehow counteract and balance each other so that the number of species in a given area remains about the same. If one group of organisms in a locality is eliminated, another group may take its place or the remaining organisms may expand sufficiently to fill the vacancy which was created.

All living organisms may be considered as links in a chain, all contributing their part so that the chain is an endless one. For example, certain bacteria of the soil change free nitrogen of the air into nitrates which help to build plant tissues. The latter are eaten by animals which may be consumed by other animals. Even if the latter die, their bodies are decomposed by other species of bacteria and molds, thus returning the ingredients to the soil where they are again available for future generations of plants.

III. PLANT AND ANIMAL MIGRATIONS (DISPERSAL)

Because of a lack of means of locomotion, most plants are not subject to the true migrations found in many animals such as birds, fishes, mammals, etc. However, plants do disperse by slow, gradual spreading by means of seeds, spores, or vegetative (propagative) units, such as parts of stems, roots, etc.

Animal migrations may take place (1) in order to meet the emergency of overpopulation in any particular area, (2) in order to ensure a better quantity and quality of food for themselves or their offspring, (3) in order to find more suitable environment in which to develop their offspring, or (4) in order to escape certain types of climate which are not highly satisfactory for their well-being.

The salmon (male and female adults) migrate from the ocean up the Yukon and Columbia rivers, possibly for distances up to two thousand miles. In the fresh water of these rivers, the adults spawn and then die. The young salmon migrate from these fresh waters to the salt water of the ocean where they mature and spend several years. Eventually, some of these adults again migrate up the rivers to spawn.

In the case of eels, the young are born in the salt water of the ocean and they migrate up fresh-water rivers, sometimes journeying over three thousand miles. After a few years, they return to salt water and breed, eventually dying, because adult eels do not return to fresh waters.

In the case of such mammals as fur-bearing seals, great herds of adult males and females migrate each spring to islands in the Bering Sea where they remain from about May 1 to September 1. During this time their young are produced. Great herds of the young seals migrate from these islands to other regions of the North, while other herds migrate long distances to cold regions of the South. Since seals are valuable because of their fur, they are protected by laws in many countries. The "bachelors" (three-year-olds) are caught for their fur.

We are familiar with the seasonal migrations of certain species of birds. A unique migration is illustrated by the Arctic tern which breeds in northern North America and migrates across the Atlantic Ocean to Europe, southward past Africa to the Antarctic, returning by a circuitous route to cross the Atlantic again to the northern habitat. The distance between their summer and winter habitats is over 10,000 miles, thus making a journey of over 20,000 miles each year.

QUESTIONS AND TOPICS

1. Attempt to give from your own observations as many illustrations as possible of (1) unity between various species of living organisms, (2) plant and animal antagonisms, resulting in a struggle for existence and a survival of the fittest, (3) plant and animal successions, and (4) Web of Life or Balance in Nature.
2. From your studies would you say that a living organism can live a life of complete isolation? Give reasons why you say so.

3. From your studies would you say that unity or disunity predominates in the living world? Think carefully before answering this question, and give specific reasons why you say so.
4. What happens when there is more disunity than unity?
5. Do you think that the phenomenon of interdependence in Nature is deliberate or a mere coincidence? Give reasons why you say so.
6. Does a study of the interdependence among lower forms of life throw any light upon the problems encountered in human conduct? Explain.
7. List several ways in which you might improve human conduct with specific suggestions for attaining that goal.
8. Explain the importance of the nitrogen, oxygen, and carbon cycles in Nature.
9. Discuss biologic communities (associations) and successions of plants and animals.
10. Explain the dependence of living animals and plants ultimately upon photosynthesis, either directly or indirectly.
11. Explain the causes and effects of animal migrations and plant dispersals. Explain in detail how certain animals have migrated or certain plants have dispersed. Be specific and include examples.
12. List all the reasons for migrations or dispersals that you can. Do these same reasons apply to human migrations? Explain.

SELECTED REFERENCES*

Gamow: The Birth and Death of the Sun, Viking Press, Inc.
Sanderson: Mystery of Migration, Saturday Evening Post, July 15, 1944.

*See also additional references in other chapters.

Chapter 33

PARASITISM AND PATHOGENESIS; SYMBIOSIS; COMMENSALISM; GREGARIOUSNESS AND COMMUNAL LIFE; PREDACIOUSNESS; INSECTIVOROUS PLANTS; EPIPHYTISM; SAPROPHYTISM

There are many kinds of biotic relationships in the living world, extending from the more or less dependence of living organisms on each other to the more or less independence, or even antagonism, in other organisms. These relationships may exist between different species of animals, different species of plants, or between animals and plants. The following brief descriptions of some of these relationships are representative:

I. PARASITISM AND PATHOGENESIS

In *parasitism* (par′ a sit izm) (Gr. *para*, beside; *sitos*, food) an organism known as the *parasite* lives on, or within, and at the expense of, another living organism known as the *host*. In this condition the host may not be killed immediately (contrast with predaciousness and insectivorous plants). When the parasite lives on the outside of the body of the host it is an *ectoparasite* (Gr. *ektos*, outside); when it lives within the body of the host, it is an *endoparasite* (Gr. *endo*, within). In parasitism the host is harmed while the parasite benefits.

When the effects of parasitism on the host result in discernible, abnormal characteristics (symptoms), we may consider the condition as disease-production, or *pathogenesis* (path o -jen′ e sis) (Gr. *pathos*, disease or suffering; *genesis*, origin). In some cases the distinction between parasitism and pathogenesis may be slight, but when actual, discernible disease-production results, we may consider it as pathogenesis and the parasite which causes the disease as a *pathogen*.

A. Plants Pathogenic for Animals

Bacteria (Fig. 34) may cause such diseases of man as typhoid fever, tuberculosis, leprosy, botulism (a type of food poisoning), undulant fever (brucellosis), boils, diphtheria, pneumonia, scarlet fever, gonorrhea, meningitis, whooping cough, tetanus (lock jaw), and many others. Bacteria produce diseases in many ways by the production of injurious substances which may tend to overcome the defenses of the body to infections or which may destroy tissues or impair their normal capacities to function properly. Certain bacteria produce a substance by which red blood corpuscles are broken down by the process of *hemolysis* (he -mol′ i sis) (Gr. *hiama,* blood; *lysis,* loosing). Certain bacteria (staphylococci, streptococci, pneumococci) produce substances known as *leucocidins* (lu ko-si′ din) (*leucocyte;* L. *caedere,* to kill) which destroy leucocytes (white blood corpuscles). Certain organisms (certain streptococci) dissolve blood clots. In certain staphylococcic infections *thrombi* (blood clots in vessels) are formed. Certain types of bacteria (including staphylococci, streptococci, pneumococci, and the rod-shaped, anaerobic bacteria associated with gas gangrene) produce a substance which affects the permeability of tissues so that materials will readily diffuse into surrounding tissues. Sometimes organisms block the blood vessels to produce damage either directly or indirectly. Bacteria may also influence disease production by the use of oxygen, and by the formation of acids, gases, and other detrimental products of metabolism. In some diseases the bacteria produce bacterial *toxins* ("poisons") which are water-soluble proteins and are extremely potent. Compared with some of them, the poison strychnine is rather mild.

Bacteria may produce in other animals such diseases as Bang's disease (contagious abortion or brucellosis) in cattle and other animals, tuberculosis in cattle, hogs, and other animals, tularemia ("rabbit fever") in rabbits and other similar animals, "lumpy jaw" in cattle, plague in rats and other animals, "black leg" in cattle, "limber neck" (botulism) in chickens, chicken cholera, glanders in horses, sheep, and goats, and anthrax ("wool sorter's disease") in sheep, horses, goats, etc.

Fungi may produce in man such diseases (Fig. 74) as actinomycosis, ringworm of various types, including "athlete's foot," aspergillosis (caused by certain species of *Aspergillus*), maduromycosis (madura foot), coccidioidomycosis (valley fever), etc.

Yeasts may cause such diseases in man as North American blastomycosis (Gilchrist's disease), moniliasis (thrush), European blastomycosis, etc.

Higher plants such as poison ivy, poison oak, deadly nightshade, locoweed, water hemlock, etc., are poisonous for man and other animals. The pollen of certain plants (ragweeds, grasses, roses, oaks, etc.) may produce allergies (Fig. 256) of various types and consequences in susceptible human beings.

B. Plants Pathogenic for Plants

Bacteria may cause such diseases in plants as wilt diseases of tomatoes, potatoes, melons, cucumbers, corn, etc., soft rot of carrot, cabbage, cucumber, celery, etc., bacterial blight of beans, fire blight of pears and apples, crown galls of apple, grape, raspberry, alfalfa, etc., bacterial blight of walnut, canker of citrus, and many others.

Higher *fungi* may cause such diseases in plants as rusts and smuts (Figs. 66 and 67) of such cereal grains as corn, wheat, barley, etc., downy mildew of grapes, chestnut blight, potato blight, Dutch elm disease, apple scab, bitter rot of apple, brown rot of peaches, peach-leaf curl, "damping off" disease of seedling plants, ergot of rye, barley, and wheat, black knot of cherry and plum, leaf spot of strawberry, black spot of roses, and many others. It should be noted that the disease of elms known as phloem necrosis is due to a virus and is not to be mistaken for the Dutch elm disease produced by a fungus.

Certain *flowering plants* such as dodder and mistletoe may parasitize other species of plants and produce damages which may often cause the death of the host.

C. Animals Pathogenic for Animals

Protozoa may produce such diseases in man as syphilis, amoebic dysentery, African sleeping sickness, various types of malarial fevers, tropical ulcers, kala-azar, and many others. Protozoa may cause diseases in other animals such as chicken septicemia, surra in horses and other animals, nagana in cattle, and many others.

Worms may cause such diseases in man as sheep liver fluke disease (*Fasciola hepatica*), Chinese liver fluke disease (*Clinorchis sinensis*), blood fluke diseases (*Schistosoma japonicum, S. mansoni, S. haematobium*), Oriental lung fluke disease (*Paragonimus westermani*), tapeworm diseases (*Taenia solium, T. saginata*), human ascaris disease (*Ascaris* *lumbricoides*), human pinworm disease (*Enterobius vermicularis*), hookworm diseases (*Necator americanus* and *Ancylostoma duodenale*), ground itch (*Ancylostoma braziliense*), elephantiasis (*Wuchereria [Filaria] bancrofti*), loa loa disease of the eye (*Loa loa*), *Trichinosis* or pork roundworm disease (*Trichinella spiralis*), human whipworm disease (*Trichuris trichiura*), and many others.

Worms may cause liver rot of sheep, cattle, and hogs *(Fasciola hepatica)*. Chinese liver flukes may be found in monkeys, cats, dogs, and snails (*Clinorchis sinensis*). Blood flukes may be found in monkeys, dogs, cats, pigs, cattle, and sheep *(Schistosoma sp.)* and lung flukes in dogs, cats, pigs, tigers, and snails (*Paragonimus*). Tapeworms may spend their immature stages in the pig, cattle, rabbit, mouse, lice, fleas, fish, sheep, monkeys, cat, dog, etc. "Gid" or "staggers" of sheep is caused by the immature stages of the tapeworm (*Multiceps*). Horse pinworm disease (*Oxyuris equi*) may be quite common. "Gapes" of birds is caused by the bird gapeworm (*Syngamus trachea*). The pork roundworm (*Trichinella*) may inhabit the pig, cat, dog, rat, etc.

The immature stages of certain mollusks, known as *glochidia* (glo-kid′ i a) (Gr. *glochis,* arrow-point; *idium,* diminutive), may attach themselves to the gills and fins of fish where they may cause diseased conditions. Lice and fleas may attack man, dogs, cats, rats, and many other animals, on which they may produce ill effects. Insects may parasitize other insects and even eventually destroy the host. An ichneumon wasp lays eggs in the cocoon of the tent caterpillar, the latter being affected by the developing larval stage of the ichneumon. The eggs of the tachina fly may develop into a larval stage in the army worm; insects of the hymenoptera type may parasitize boll worms, army worms, plant lice (aphids), etc.

D. Animals Pathogenic for Plants

Roundworms (nematodes) may attack the roots, stems, or leaves and produce nematode diseases in such plants as wheat, rye, cotton, tomato, clover, sugar beets, tobacco, peony, begonia, and many other higher plants; the immature stages of the Oriental intestinal fluke (*Fasciolopsis*) may be present in fresh-water plants; the immature stages of the Chinese liver fluke (*Clinorchis*) may be present in freshwater plants; the roundworm (*Heterodera [Caconema] radicicola*) may affect the potato, tomato, lettuce, trees, weeds, and many other plants.

Insects not only transmit plant diseases but as a result of their chewing, sucking, boring, and egg-laying activities are responsible for many serious consequences in the tissues of higher plants. Enlargements known as galls on leaves, stems, etc., are common examples. Bark lice, mealy bugs, various scale insects, etc., cause a great variety of serious diseases in plants.

The various causes and effects of the different diseases of plants and animals cannot be discussed in detail here, but the reader is referred to other sources for those in which there is a particular interest.

II. SYMBIOSIS

In some instances, in the living world there is more than mere living together in harmony, for there is more or less of a mutual helpfulness between certain living organisms. A condition in which two species of organisms (known as *symbionts*) live together with mutual benefit to both is known as *symbiosis* (sim bi -o′ sis) (Gr. *sym,* together; *bios,* life). In some cases this association is so complete that there is organic unity in which each type of organism contributes something to the other with which it is living. In the so-called green Hydra there live small green algae (plants) which photosynthesize food by combining water and carbon dioxide, the latter being given off by the Hydra. The foods and the by-product (oxygen) of photosynthesis may be used by the Hydra. In a group of plants known as *lichens* (li′ ken) (Gr. *leichen,* liverwort) (Fig. 327) there is a close relationship between the green, chlorophyll-bearing algae and the nonchlorophyll-bearing fungi of which lichens are composed. The algae supply foods for the fungi, while the latter give protection, supply water, etc.

Termites feed on cellulose of wood but are unable to digest it. Certain flagellated protozoa within their intestine render the cellulose digestible for both. These protozoa cannot exist outside the termite intestine. Certain types of ants protect certain species of aphids (plant lice) and in return use as food the sweet "honey milk" produced by the latter. The so-called green paramecium (*P. bursaria*) has within its endoplasm the unicellular, green alga (*Chlorella vulgaris*). The alga uses the wastes of the paramecium and gives food and oxygen in return. Certain sponges and green algae possess a relationship similar to that described above.

The Portuguese man-of-war, a coelenterate, possesses long tentacles among which live certain species of fish. The nematocysts of the tentacles protect the fish, and the latter share some of the foods which they capture with the Portuguese man-of-war.

The hermit crab may live in an empty mollusk shell upon which are placed various types of hydroid coelenterates. The stinging cells (nematocysts) of the latter protect the crab, while the sessile coelenterates are advantageously carried from place to place by the crab and secure some foods captured by the crab.

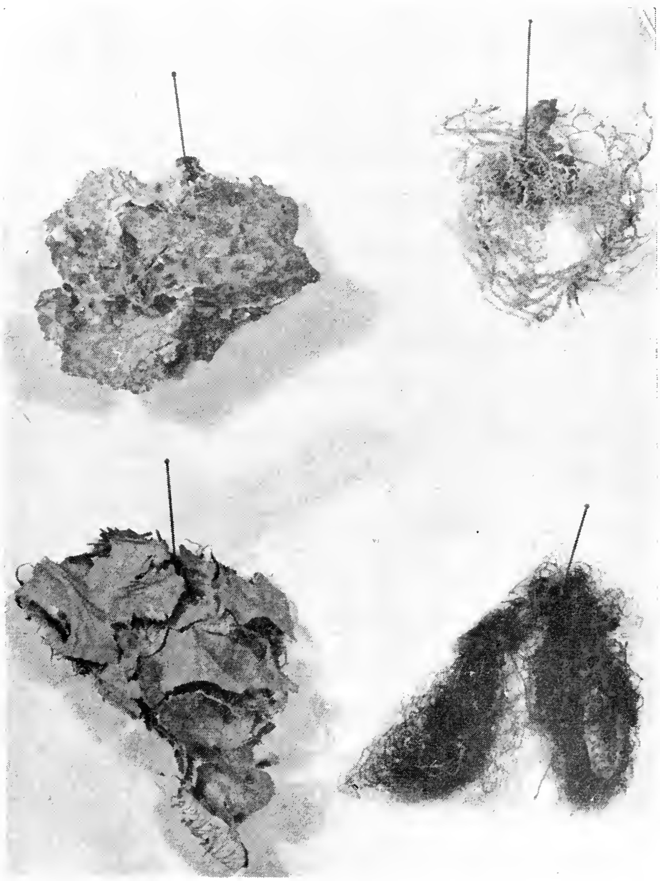


Fig. 327.—Types of lichens which are plants composed of algae (blue-green or green) and fungi (chiefly Ascomycetes, infrequently Basidiomycetes). The three principal types of lichens are (1) *foliose* (flat, often leaflike bodies), (2) *crustose* (hard, often granular crusts on bark or rocks), and (3) *fruticose* (branched structures which may be erect or hanging).

The so-called spider crab carries a species of sponge on its back which protects it through concealment and its disagreeable qualities. The sessile sponge is carried from place to place by the crab.

In certain higher plants, especially trees, a close relationship may exist between the mycelium of certain fungi and the roots. This association does not seem to harm the tree, and the mycelium may form an encircling mantle around the finer roots, causing them to enlarge and become much branched. This close association of fungus and roots is known specifically as *mycorrhiza* (mi ko -ri′ za) (Gr. *mykos,* fungus; *rhizos,* root), in which both plants derive mutual benefit; the fungi may prepare nitrogenous foods for the roots and receive food from the roots in return.

Certain types of nitrogen-fixing bacteria live in the small swellings (nodules) on the roots of leguminous plants such as clovers, alfalfa, beans, soybeans, etc. These specific bacteria take free nitrogen from the atmosphere and convert it into certain nitrogen compounds, which are changed by other bacteria eventually into usable nitrates. The nitrogen-fixing bacteria secure food and protection from the plant, while the latter profits from the foods formed by the bacteria. The nitrogen-fixing bacteria (Fig. 325) which are present in the root nodules of plants are referred to as *symbiotic nitrogen-fixing bacteria* to differentiate them from other bacteria which can accomplish a similar phenomenon, but the latter bacteria live free in the soils. The latter phenomenon is known as *nonsymbiotic nitrogen-fixation.*

III. COMMENSALISM

An association of members of two or more species of organisms in which one (*commensal*) is benefited but not injured while the other (*host*) is neither benefited nor injured, but both using the same supply of food, is known as *commensalism* (kom -en′ sal izm) (L. *com,* together; *mensa,* table, or food). In this type of association there is not quite the close relationship of organisms as found in symbiosis. A special type of tropical fish known as the shark sucker (*Remora*) attaches itself by means of a sucker to the body of sharks, turtles, whales, etc. Part of the food captured by the animal host is used by the *Remora.* In this case the host does not appear to receive any benefit from the association. Certain small birds, such as one of the grackles, may build nests near the nests of larger birds, such as a fish-eating osprey, thus securing protection. The so-called "rudder fish" secures shelter and protection from the stinging tentacles of large jellyfish but apparently gives nothing in return, but both may eat of the same food. Protozoa, yeasts, and fungi may live in the digestive tract of man and other animals, doing neither harm nor good but using some of the common food and receiving protection from the host.

IV. GREGARIOUSNESS AND COMMUNAL LIFE

In *gregariousness* (gre -ga′ ri us nes) (L. *grex*, flock) certain animals may associate with each other for protection, for securing foods, or possibly for reproduction purposes (which may be incidental in certain cases). The herding of herbaceous mammals, the flocking of birds, the schooling of fish are common examples. Dogs and wolves often hunt in packs, thereby attacking larger animals than they probably would if individuals did the hunting. The reasons for gregarious habits are not always known, and they are not always based on sex, because in certain schools of fish only one sex is present. In the latter case foods are possibly a controlling factor which brings about the association of the fish, and mass movements are the result of imitation of a so-called "leader." Herds of large mammals also display group or mass movements because of the leadership of one individual, usually a large or old male. The various social groups might be classified as (1) those in which there is division of labor among the various distinct castes, as in the bees, ants, termites, etc., (2) those groups of animals which react more or less as a unit, such as a family group of mammals, and (3) those which show a social toleration of similar individuals in a certain area, such as schools of fish, flocks of birds, etc.

Gregariousness may involve different species and may be due to the presence of certain desirable conditions for their existence such as shelter, food, moisture, nesting materials, etc. If organisms of the same species associate together, a communal society may result. In higher types of animals the gregarious habit may be the result of a desire for companionship or a feeling of safety in numbers. In the latter case alarms may be given by individuals, thereby giving warning to others of impending dangers.

Among lower animals the best examples of communal life are shown by the insects. Castes and well-developed divisions of labor are present in honeybees, social wasps, ants, and termites. Possibly associations might be considered as temporary groupings dependent upon environmental factors, while communal societies are held together and the conducts of the members influenced by the so-called social instincts. Possibly associations and societies have much in common, but they are also different because in the latter there is greater complexity and a variety of behaviors of the different members. Frequently in a group there is one leader, who is usually the strongest or most experienced. This one is followed by other members, and the leader may have acquired the position of leader through a process of destroying one or more less experienced or weaker adversaries. Much is unknown about the communal life of animals, and the reader is referred to additional references in this important field. After Charles Darwin proposed his doctrine of the survival of the fittest, it was maintained that all living animals and plants struggle for their existence. If this be true, then the success or failure of individuals or groups may be influenced to a greater or lesser extent by their inherent abilities of survival commensurate with the specific environmental factors present in the area in which they live. Cooperation between individuals is observed in the care of young by most mammals, the protection of wounded and sick by many higher animals, the protection of the herd by the male deer, the sharing of foods in such animals as apes and man, and the protection of members of a family against enemies, etc.

V. PREDACIOUSNESS

Predatism or predaciousness (pre-da′ shus nes) (L. *praeda,* prey or booty) is a condition in which one animal captures and preys on another living organism, usually using it for food. Predatism is characteristic of those animals which we term predatory which kill animals and devour them for food. These predatory habits may be exhibited by a great num-

Fig. 328.—Starfish attacking an oyster. Note the tube feet on the underside of the starfish arms. (Courtesy of The American Museum of Natural History.)

ber of animals whose methods of capturing and devouring their prey may vary greatly. *Amoeba, Paramecium,* and other protozoa may capture a variety of living organisms for food. *Hydra* and other coelenterates may devour aquatic organisms. The Portuguese man-of-war (Fig. 93)

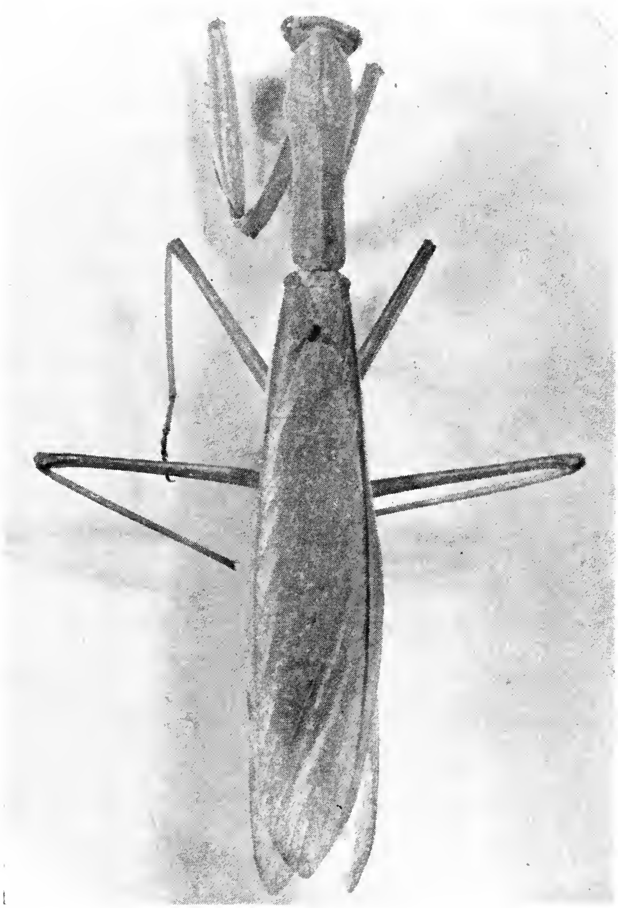


Fig. 329.—Praying mantis, a predacious insect of the order *Orthoptera.*

may prey on fish and crustaceans. Planarians may feed on mollusks, arthropods, etc.; squids capture fish; starfish capture oysters and other animals (Fig. 328); dragonflies (Fig. 205) may destroy flies and mosquitoes; certain insects (praying mantis [Fig. 329], ground beetles, ladybird beetles [Fig. 297] aphis lions, etc.) may destroy other insects, many of which may be detrimental. Fish may devour worms, crustaceans, insects, etc.; frogs may capture worms, insects; snakes may destroy frogs, birds, etc.; owls may kill rabbits, mice, etc.; chicken hawks may kill chickens, etc.; cats may destroy rats, mice, birds, etc. Harmful predacious mammals include wolves and cougars which kill sheep, cattle, horses, and big game; dogs and cats may be beneficial predators when they destroy harmful animals such as rats, mice, etc.

VI. INSECTIVOROUS PLANTS

The so-called insectivorous plants (in sek -tiv′ or us) (L. *insectus,* cut into or insect; *vorare,* to devour) possess special structures, usually modified leaves or parts of leaves, whereby they are able to trap and devour insects for part of their food (Fig. 330). The specialized structures secrete enzymes for the digestion of the insects, and the latter are absorbed

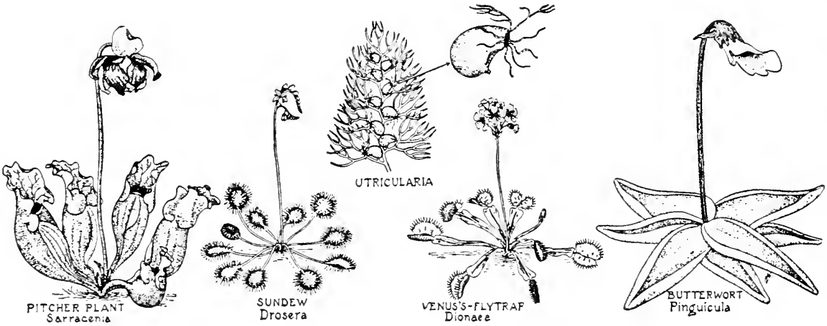


Fig. 330.—Insectivorous plants. In the pitcher plant the pitcherlike leaves are filled with water in which insects drown and are digested. In the sundew the leaves are supplied with sticky hairs for capturing insects. In the bladderwort *(Utricularia)* numerous "bladder traps" capture aquatic animals, and one is shown enlarged. In Venus's-flytrap the two halves of the leaves act like a spring-trap to capture insects. The sticky leaves of the perennial butterwort capture insects. (Copyright by General Biological Supply House, Inc., Chicago.)

by the plant. The so-called "pitcher plants" (*Sarracenia*) common in bogs possess a pitcherlike device which is filled with water and in which insects drown. Escape is prevented by inwardly directed spines and the digested insects are absorbed. In Venus's flytrap (*Dionaea*) the specialized leaves possess a row of "teeth" on the outer margin of each half of the leaf blade. On the upper surface, in the center of each half, are sensitive "hairs" which when stimulated by an insect cause the two halves to spring together to entrap the insect. Digestion by enzymes somewhat resembles that in the pitcher plant. In the common sundew (*Drosera*) the somewhat circular leaves are covered with long glandular hairs ("tentacles") which secrete a sticky substance to capture insects. The tentacles bend toward the center to form a trap in which the enzymes digest the insect. There are approximately two hundred species of chlorophyll-bearing, angiospermous plants which are insectivorous or carnivorous. They photosynthesize their foods but supplement with certain essential elements by the digestion of insects. If the correct ingredients are present in the soil, they need not ingest the animal foods. In the so-called bladderwort plants, present in ponds and lakes, there are tiny "bladder traps" on the submerged stems. Each bladder has a one-way trap door through which aquatic animals enter and in which they are digested. The leaves of Venus's flytrap and certain pitcher plants are able to digest such foods as hard-boiled egg, meat, etc.

VII. EPIPHYTISM

Epiphytes (ep′ i fite) (Gr. *epi,* upon; *phyton,* plant) are plants which use other plants, poles, trees, wires, etc., for support but do not derive nourishment from the other plant; hence they are not parasitic. Epiphytes are primarily *autotrophic* (o to -trof′ ik) (Gr. *auto,* self; *trephein,* to nourish) which means they photosynthesize their food and do not get it from plants on which they may happen to be attached. They secure carbon dioxide and water from the atmosphere and moisture and nutrients from debris in crevices in which they may be anchored. Ordinarily, epiphytes take no sustenance from the plant on which they are attached, but they may injure the plant by shading the leaves, by breaking limbs because of excessive weight, etc.

Certain algae may be epiphytes on other plants. The green alga *Protococcus* may grow epiphytically on the bark of trees. Certain brown algae and marine red algae may grow on other algae as epiphytes. Certain species of algae even grow among the hair of the three-toed sloth. Certain species of lichens, mosses, ferns, and tropical orchids and certain members of the pineapple family may be epiphytes. "Spanish moss" (*Tillandsia*) of the South is an epiphyte which is a rootless, flowering plant of the pineapple family and which hangs in great masses from trees, poles, and wires (Fig. 331). Often the growth is so enormous that the tree is killed, even though the "moss" is not parasitic. The flexible internal filaments of Spanish "moss" are being used for commercial purposes.

Fig. 331.—Spanish "Moss" (not a true moss), a flowering, epiphytic plant of the pineapple family which hangs in great masses from trees, poles, and wires in the South.

VIII. SAPROPHYTISM

A *saprophyte* (sap′ ro fite) (Gr. *sapros,* dead; *phyton,* plant) is an organism which secretes enzymes capable of utilizing (absorbing) as foods such dead organic materials as carbohydrates, proteins, etc. Saprophytism differs from other similar phenomena in that two living organisms are not involved but one living organism and a dead substance which may have been part of a living organism originally. The enzymatic actions bring about chemical changes in the dead, organic materials. When the latter involves carbohydrates and is usually associated with the production of gas, it is called *fermentation* (L. *fermentum,* ferment or yeast); when it involves proteins and is manifested by the production of foul odors, it is called *putrefaction* (L. *putrere,* rotten; *facio,* to make).

Plants without chlorophyll cannot photosynthesize foods so must absorb them from outside sources, which involves the presence of a certain amount of necessary moisture. Many bacteria absorb foods from dead, organic substances and are called saprophytic bacteria in contrast with parasitic or pathogenic bacteria. Slime molds may grow on decaying plant materials, rotting woods, and leaf molds; hence, they live saprophytically. Certain species of molds (fungi) may live on the dead organic materials of plants or animals or in humus-containing soils. Saprophytic fungi usually live wherever they encounter a suitable supply of organic matter, oxygen, water, and warmth. *Rhizopus nigricans* (Fig. 36) and similar molds are common saprophytes on moist bread, overripe fruits, foodstuffs, animal dung, etc. Yeasts may live in sugar solutions by utilizing an enzyme, zymase, which they secrete. Alcohol is formed in the process, with the liberation of carbon dioxide. The blue and green molds (*Penicillium* and *Aspergillus*) grow on fruits, foodstuffs, tobacco, leather, fabrics, nuts, and other organic materials in damp places. Mushrooms and related fungi live saprophytically in soils, on dead leaves, dung, dead wood, and bark and similar organic materials. Shelf fungi (bracket fungi) are common on dead wood, although parasitic species may kill living trees.

Saprophytism is not as common in higher plants as it is in lower, non-chlorophyll-bearing fungi. The Indian pipe (*Monotropa*) is a flowering plant that lacks chlorophyll which may obtain food from decaying leaf mold by the aid of fungi which inhabit its underground basal portion. In some instances it may be partially parasitic on the roots of living plants.

QUESTIONS AND TOPICS

1. Learn the correct pronunciation, derivation, and true meaning of each new term used in this chapter.
2. Add from your own experience any additional examples for each biotic phenomenon described in this chapter, being very careful to check so that it is placed in the proper category.
3. Discuss the probable origin of parasitism in the living world.
4. Give probable reasons why there are so many types of pathogenic organisms.
5. Discuss gregariousness and communal life, giving examples from your own observations.
6. What are the benefits of successful and efficient communal life?
7. What attributes are common to colonies of honeybees, ants, and human beings?
8. Discuss the uniqueness of predaciousness, insectivorous plants, and epiphytes.
9. Discuss plant and animal antagonisms, including the probable origin for such behavior and its consequences.
10. In the light of your present knowledge, discuss the human family, a colony of people, and possible communal life for entire countries and the world at large.

SELECTED REFERENCES*

Allee: The Social Life of Animals, W. W. Norton & Co., Inc.
Alverdes: Social Life in the Animal World, Harcourt, Brace and Co., Inc.
Chandler: Animal Parasites and Human Disease, John Wiley & Sons, Inc.
Conant et al.: Manual of Clinical Mycology, W. B. Saunders Co.
Darwin: Insectivorous Plants, London, John Murray.
Dodge: Medical Mycology, The C. V. Mosby Co.
Ewing: Manual of External Parasites, Charles C Thomas, Publisher.
Faust: Human Helminthology, Lea & Febiger.
Harshberger: Mycology and Plant Pathology, P. Blakiston's Son & Co.
Henrici and Ordal: The Biology of Bacteria (Microbiology), D. C. Heath & Co.
Lloyd: Carnivorous Plants, Chronica Botanica Co.
Sweetman: Parasitic and Predacious Insects, Comstock Publishing Co., Inc.
Wheeler: The Social Insects; Their Origin and Evolution, Harcourt, Brace and Co., Inc.

*Additional references in the chapter on Fungi, p. 184.

Chapter 34

HEREDITY—GENETICS

1. **Definitions and Methods of Studying Genetics.**—*Genetics* (je -net′ iks) (Gr. *genesis,* descent) is the science of *heredity* (L. *hereditas,* heirship) in which this branch of biology attempts to discover how hereditary materials are transmitted through succeeding generations of plants and animals and, as a consequence, how similarities and differences develop from these hereditary materials subject to the influences of various internal and external environmental conditions.

In general, genetics may be studied (1) by the *experimental crossing method* in which organisms of known genetic composition are crossed and the results interpreted, (2) by the *cytogenetic method* which is a study of those structures and functions of cells responsible for the transmission and development of hereditary traits, and (3) by the *pedigree method* whereby the differences and similarities of individuals in large populations are properly recorded and scientifically analyzed. Much valuable information regarding the inheritance of certain human traits has been secured by this method. Sometimes a combination of all three methods is used in an attempt to solve certain problems in genetics. In some instances, the hereditary mechanism is subjected to physical influences, such as x-rays, atomic radiations, etc., or chemicals, such as colchicine, and the results on the inheritance observed.

2. **Chromosomes, Polyploidy, and Mitosis.**—Chromosomes carry a linear series of genes or determiners by means of which hereditary materials are borne from parents to offspring and through which the expression of traits is controlled (Figs. 334 and 335). Chromosomes within the nucleus are always closely related and dependent upon the cytoplasm which surrounds the nucleus, either for their normal activities or for the normal and proper development and expression of their inherent hereditary factors. Chromosomes occur in even numbers (in pairs) in most organisms. Species which apparently are closely related may differ widely with respect to the number of their chromosomes, while species of unquestionably remote relationship may have an identical number of them in each of their cells (see accompanying table).

Chromosomes in Various Animals and Plants*

	Number of chromosomes per body or somatic cell
Animal	
Hydra fusca (phylum, Coelenterata)	12
Campanularia (phylum, Coelenterata)	20
Horse roundworm (Ascaris megalocephala) (Nemathelminthes)	4
Human roundworm (Ascaris lumbricoides) (Nemathelminthes)	48
Earthworm (Lumbricus sp.) (phylum, Annelida)	32
Leech (Nephelis sp.) (phylum, Annelida)	16
Snail (Helix sp.) (phylum, Mollusca)	48
Water flea (Cyclops sp.) (phylum, Arthropoda)	4
Brine shrimp (Artemia sp.) (phylum, Arthropoda)	168
Crayfish (Cambarus virulus) (phylum, Arthropoda)	200
Crayfish (Cambarus immunis) (phylum, Arthropoda)	208
Fruit fly (Drosophila sp.) (phylum, Arthropoda)	8
Cabbage butterfly (Pieris sp.) (phylum, Arthropoda)	30
Housefly (Musca sp.) (phylum, Arthropoda)	12
Mosquito (Anopheles sp.) (phylum, Arthropoda)	6
Cockroach (Periplaneta sp.) (phylum, Arthropoda)	34
Gypsy moth (Lymantria sp.) (phylum, Arthropoda)	62
Frog (Rana sp. (subphylum, Vertebrata)	26
Salamander (subphylum, Vertebrata)	24
Pigeon (Columba sp.) (subphylum, Vertebrata)	16
Opossum (Didelphys sp.) (subphylum, Vertebrata)	22
Hedgehog (subphylum, Vertebrata)	48
Armadillo (subphylum, Vertebrata)	60
Rabbit (Lepus sp.) (subphylum, Vertebrata)	44
Dog (Canis sp.) (subphylum, Vertebrata)	78
Horse (Equus sp.) (subphylum, Vertebrata)	60
Cat (Felis domesticus) (subphylum, Vertebrata)	38
House mouse (subphylum, Vertebrata)	40
Monkey (Rhesus macacus) (subphylum, Vertebrata)	48
Man (Homo sapiens) (subphylum, Vertebrata)	48
Plants	
Green alga (Spirogyra sp.) (phylum, Thallophyta)	24
Ascus or Sac fungus (Pyronema sp.) (phylum, Thallophyta)	24
Rockweed (Fucus sp.) (phylum, Thallophyta)	64
Peat moss (Sphagnum sp.) (phylum, Bryophyta)	40
Pine tree (Pinus sp.) (Gymnosperm)	24
Yew tree (Taxus sp.) (Gymnosperm)	16
Fir tree (Abies sp.) (Gymnosperm)	32
Pea (Pisum sp.) (Angiosperm)	14
Currant (Ribes sp.) (Angiosperm)	16
Chinese Primrose (Primula sinensis) (Angiosperm)	18
Tomato (Lycopersicum esculentum) (Angiosperm)	24
Black nightshade (Solanum nigrun) (Angiosperm)	72
Corn (Zea mays) (Angiosperm)	20
Sedge or shear grass (Carex aquatilis) (Angiosperm)	74
Onion (Allium cepa) (Angiosperm)	16
Lily (Lilium sp.) (Angiosperm)	24
Hawk's beard (Crepis virens) (Composite Family) (Angiosperm)	6

*For a list of chromosomes for approximately 1,000 species, see the Journal of Morphology 34: 1-67, 1920.

The evidence that inheritance is due to chromatin may be shown by the following facts: (1) Of all the parts of a cell, the chromatin is the most constant portion through all the changes of the cell. This suggests the chromatin as the probable carrier of hereditary factors. (2) The chromosome complex is maintained throughout the process of cell division (mitosis). At this time the mechanism for the transmission of hereditary factors from one cell to its daughter cells must be present

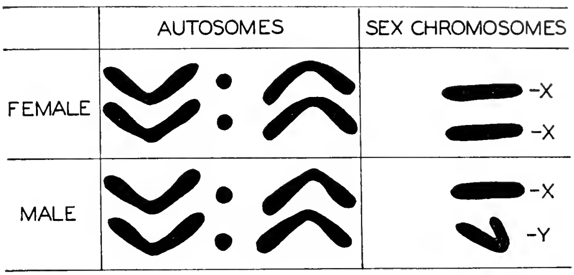


Fig. 332.—Chromosomes of the fruit fly *(Drosophila sp.)*, showing pairings, sizes, and shapes in the male and female (diagrammatic). In the female there are three pairs of autosomes and a pair of straight X chromosomes. In the male there are three pairs of autosomes and one straight X chromosome and a hook shaped Y chromosome.

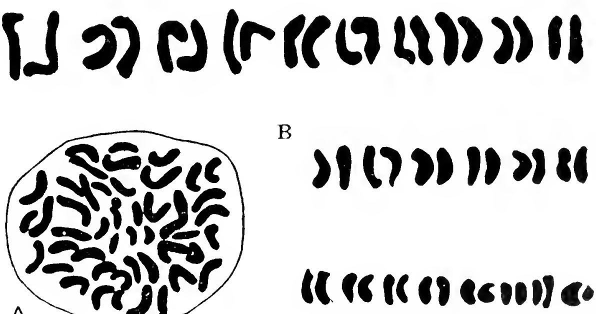


Fig. 333.—The chromosomes of man. *A*, Spermatogonium (of the male) during division, drawn so that the chromosomes do not overlap; *B*, the twenty-four pairs of chromosomes from a somatic (body) cell. (From Lindsey: A Textbook of Genetics. By permission of The Macmillan Company, publishers.)

and functional; otherwise there could be no such transfer. (3) There is a close correlation between abnormal inheritance and abnormal chromatin behavior. (4) There is a close relationship between chromosomes and the determination and development of sex, the latter being a hereditary character. The fact that the number of chromosomes is equal, or nearly so, in both sexes of most organisms ensures an equal opportunity of inheritance from each parent. It is worth noting that the cytoplasm of most sex cells is much greater in volume in the female sex cell. If heredity were fundamentally dependent upon the cytoplasm, there would not be the necessary equal opportunity suggested above. The role played by the chromosomes during the process of reduction-division, when sex cells are formed, also suggests their value in heredity. (5) The entire field of Mendelian heredity and its modern interpretations and modifications all tend to prove the chromosome theory of inheritance.

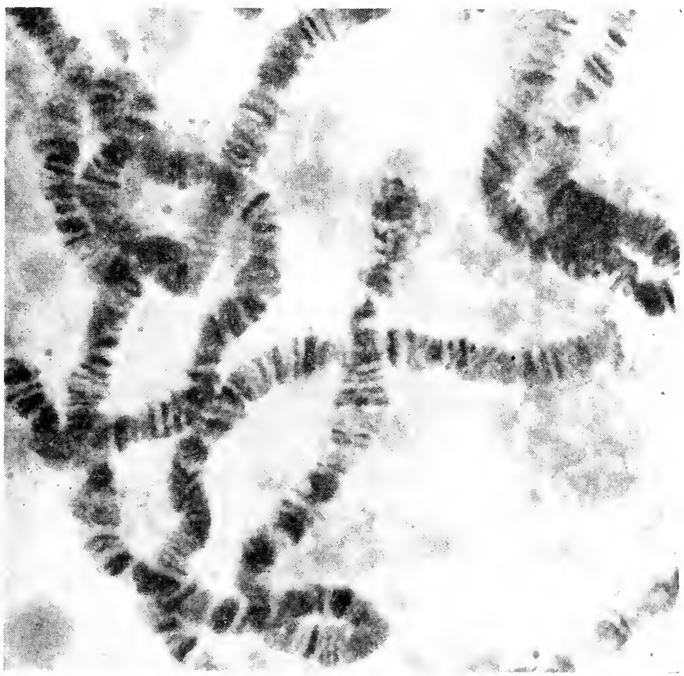


Fig. 334.—Giant chromosomes as photographed from the salivary gland of the fruit fly *(Drosophila melanogaster)*. (Copyright by General Biological Supply House, Inc., Chicago.)

Chromosome Polyploidy (Increase in the Number of Chromosomes): Under ordinary conditions, chromosomes do not change their normal number. However, in some instances, changes take place naturally or can be induced by artificial methods. One of the earliest examples of natural change in chromosomes was given by the Dutch botanist, Hugo de Vries (1895), in which he discovered the origin of a new species of primrose *(Oenothera gigas)* from the common primrose *(Oenothera Lamarckiana)*. The new species appeared suddenly and possessed a double number of chromosomes in the nuclei, and this double number of chromosomes remained constant afterward. De Vries had no explanation for this phenomenon, but in recent years it has been discovered that it may take place naturally or can be induced by certain chemicals, by such physical influences as x-rays, high or low temperatures, or centrifuging, or by removing the growing tip of a plant. The most striking results have been obtained by using a drug called *colchicine* (kol′ ki sin) which is an alkaloid poison ($C_{22}H_{25}O_6N$) extracted from the seeds of the plant called meadow saffron. Colchicine is almost a specific for inducing the doubling of chromosomes without cell division in plants. If a 1 per cent solution is applied to the growing buds or tips of plants, cells are formed with the double number of chromosomes. Frequently

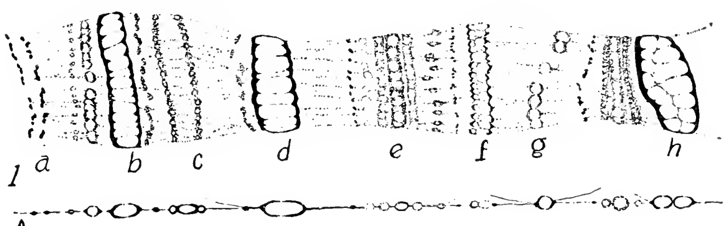


Fig. 335.—Chromosome from the salivary gland of the larva of a black fly *(Simulium sp.)*, an insect of the order *Diptera* (camera lucida drawing). The longitudinal threadlike bands are called chromonemata, consisting of a linear series of granules, the chromomeres, which have a specific arrangement of grouping. *A* is a semidiagrammatic representation of the types of chromomeres and the ways in which they are connected. At *a* in the main figure there are two rows of dotlike chromomeres associated in pairs. The band at *b* is composed of fifteen or sixteen vesiculated chromomeres closely packed together; *c-h* are other groupings of chromomeres along the chromonemata of the chromosome. (From Painter and Griffen: Chromosomes of Simulium, Genetics 22: 616, 1937.)

redoubling as many as three times takes place. The colchicine inhibits cell division while chromosome division continues as usual. This change is permanent because cells with doubled chromosome numbers continue to divide to form tissues, seeds, and embryos, all with double numbers of chromosomes.

The ease with which many plants may be artificially induced to double their chromosome number may explain the frequency of its occurrence in Nature. Müntzing concludes that more than half of the species of flowering plants, including many of our economically important plants, which have been studied have doubled or redoubled chromosomes. For example, different species of wheat with 14, 28, and 42 chromosomes are known; also chrysanthemum species with 18, 36, 54, 72, and 90 chromosomes. The regularity of these series of numbers (multiples of a lower number) suggests the origin of new species by doubling the chromosomes or by adding a single set such as found in a sperm or egg. Individuals with three or more single sets of chromosomes in their body cells are known as *polyploids,* and the condition is known as *polyploidy.*

In animals such series of chromosome numbers are encountered less frequently than in plants, and polyploidy has rarely been induced in animals by artificial methods. One explanation is that higher animals have their sexes separate, while most plants are monecious (hermaphroditic). If the sexes are separate, the doubling of chromosome numbers can occur only in case it takes place in males and females which subsequently cross. In addition, the doubling of chromosomes may lead to irregularity in the distribution of the sex chromosomes (X and Y chromosomes) which may cause sterility. In animals, new species probably originate by the slower method of gradual divergence by the accumulation of gene differences rather than by chromosome doubling.

Plants which have doubled numbers of chromosomes usually are larger, have thicker stems, thicker, broader leaves, darker green color, larger flowers and seeds; they develop more slowly, take longer to mature, and are often more hardy than the original plants. Many new plant types have been produced which are superior economically because of their doubled chromosomes. Tomatoes with doubled chromosomes have been produced; they contain about twice the usual quantity of vitamin C.

Chromosomes (Figs. 332-335) and their genes play important roles during the process of mitosis whereby the determiners for future traits are accurately duplicated during the division of cells. If genes were not accurately duplicated during mitosis, the resulting daughter cells might not possess their necessary hereditary materials from which future traits could be developed. Much valuable information regarding the internal structure of chromosomes has been secured by a study of the stained cells during mitosis.

During the so-called resting stage of a cell the chromatin is in the form of long thin, granular *threads* (chromatin strands) which eventually will shorten and thicken to become *chromosomes,* the number, size, and shape of which are specific for each species of plant or animal. During the prophase stage of mitosis each chromosome appears to possess a pair of thin, fiberlike (often coiled) *chromonemata* (kro mo -ne′-ma ta) (Gr. *chroma,* color; *nema,* thread) or *gene strings.* Each chromonema contains a specialized region known as the *centromere* (sen′-

tro mer) (Gr. *kentron,* center; *meros,* part) or *kinetochore*—the point for attachment to the spindle fiber when chromosomes migrate along the latter. As prophase progresses, the chromonemata thicken, uncoil, and acquire an accumulation of the *matrix* which surrounds them. The two threadlike chromonemata and their matrix in each prophase chromosome are called *chromatids.* In later prophase the two chromatids of each chromosome appear to be identical and lie next to each other. The two centromeres lie in close contact. After the chromosomes are arranged on the equator, the two chromatids of each chromosome repel each other, possibly through some electrical process between the two centromeres. This action results in the migration of the daughter chromosomes toward opposite poles. Attached to each chromonema in a linear series are numerous, beadlike granular *chromomeres* (kro′ mo mer) (Gr. *chroma,* color; *meros,* part) of various sizes and different distances apart. The chromomeres occur in different sizes and arrangements which are constant and characteristic for each chromosome. In other words, each chromosome has its unique arrangement of chromomeres of specific sizes which characterize it. It may have a series of large, small, or medium-sized chromomeres arranged along the chromonema, and this arrangement is specific for that particular chromosome. In studies of the giant chromosomes of the salivary glands of fly larvae of various species the chromosomes appear like a cylinder with larger numbers of characteristic *crossbands* or *disks.* Comparable to the differences in sizes of chromomeres and distances between them, these bands may be thin or thick, far apart or close together, all of this so characteristic and constant for each chromosome of a set that each band can be indentified and numbered. Are these bands the hereditary entities known as *genes* (Gr. *genos,* descent) or are these bands associated with genes? Evidence is inconclusive, although it is known that at least certain bands are associated with more than one gene.

3. **Chromosomal Aberrations.**—Normally the number of chromosomes in the somatic (body) cells of animals and the sporophyte generation of plants is double or *diploid* (2N), while it is single or *haploid* (N) in gametes, spores, and the gametophyte generation of plants, but there are exceptions. For example, the endosperm (stored food) of angiosperm seeds normally and regularly contains a triple *(triploid)* number (3N). In addition to the ploidy condition previously described, there are numerous chromosomal aberrations such as those which involve pieces of chromosomes, entire chromosomes, or entire sets of chromosomes (genomes).

In *chromosomal deficiency* a segment of a chromosome is missing, while in *chromosomal duplication* an extra segment is present. The duplicated segment may be inserted within a chromosome or it may be attached to the exterior. Because of chromosomal aberrations, the genes within the involved chromosome can produce disturbed genetic phenomena and ratios. In *inversion* a chromosome segment becomes inverted in position (changed end for end), and this may occur spontaneously and naturally or may be produced by various types of irradiations. If a portion of one chromosome is transferred to another position on the same chromosome or to another chromosome by a process that is not normal crossing over (to be discussed later), this aberration is called *translocation*. Commonly a segment of one chromosome may become exchanged for a segment of a nonhomologous chromosome (not one of the pair).

When aberrations of entire chromosomes are considered, there may be one or more entire chromosomes missing or one or more extra chromosomes present. In either case the genes involved may have effects of greater or lesser importance, depending on the type of involvement. These phenomena appear to originate from an irregular cell division so that two homologous chromosomes (members of a pair) become included in one daughter nucleus instead of one to each daughter nucleus. This abnormal behavior in which homologous chromosomes fail to separate normally is called *nondisjunction*. This phenomenon usually occurs at meiosis (maturation of germ cells) but may occur during mitosis. Many plants and some animals have been found which differ from the normal diploid set of chromosomes, some having only one set (haploid), while others possess three or more sets (polyploidy). All of these phenomena may have a corresponding effect on the traits which may develop.

4. **Genes and Genic Action.**—Genes are thought to be minute, invisible, molecules of highly specific giant nucleoproteins with enzymatic or catalytic properties capable of influencing structural, functional, and developmental processes in cells and consequently in organisms which are composed of these cells (Figs. 334 and 335).

They are thought to act as autocatalysts, because they generate or increase their own substance prior to each mitosis (cell division). In other words, each gene reproduces itself during mitosis, thus forming two genes which are identical. One of each pair of genes is placed in each new daughter cell. The characteristics of adult organisms are inherited from their parents through the medium of one or more specific genes for each trait in each of the gametes (sex cells). Each gene has a definite location in a particular chromosome. The various genes are arranged in a linear series within the chromosome. The position of a gene in the chromosome bears no relation to the location of the resulting characteristic developed in the body of the organism. For example, the genes for the determination of characteristics of the anterior end of an organism are not necessarily all located at one end of a chromosome, nor are all the genes for the traits of the posterior part of an organism located in the opposite end of the chromosome. They are, however, scattered promiscuously, yet specifically, throughout the chromosome.

Each zygote (fertilized egg) contains two genes for each hereditary character, one coming from each parent. This does not mean that the two are necessarily identical, although they may be. Thus, all body cells arising by mitosis from this zygote have duplicate genes for each specific hereditary character (Figs. 335, 350, and 351).

Genes recently have been photographed so that their form, at least, has been somewhat demonstrated. The size of certain genes is thought to approximate the size of a large organic molecule with a maximum dimension of about 40,000 millimicrons.*

A great majority of genes are stable and usually very resistant to environmental influences. X-rays and similar radiations are known causes of changes in genes. A few genes apparently are unstable, being changed frequently under ordinary conditions.

Over 1,000 genes have been determined so far in the chromosomes of the fruit fly (*Drosophila melanogaster*) (Fig. 332) and about 400 in corn. Undoubtedly, the twenty-four pairs of human chromosomes contain even greater numbers of genes. The total number of human hereditary characters has never been stated or even approximated.

The cells of an organism before maturation of the germ cells retain the duplicate set of chromosomes and genes. During maturation, those chromosomes which carry equivalent genes (hence, homologous chromosomes) unite temporarily in pairs. Later, during reduction division, one of each pair of chromosomes (and hence, one of each pair of genes) goes to each of the two new daughter cells. Therefore, each resulting gamete or sex cell has only a single set of chromosomes (and genes). Thus, when two sex cells are united during fertilization, the resulting cell (zygote) again has its duplicate supply, one of each pair having been contributed by each parent.

Since chromosomes are usually found in pairs in typical organisms (Figs. 332 and 333), genes must also be present in pairs. The pairs of

*1 millicrom is one-thousandth part of a micron, and a micron is one-thousandth part of a millimeter.

chromosomes and genes are known as homologues or *homologous chromosomes.* In each homologous chromosme there is a gene at a particular place or *locus* which affects a certain trait, although in some traits several genes may be required. Two genes at the same locus on homologous chromosomes but producing somewhat different effects on the individual are called *alleles* or *allelomorphs* (al -el′) (Gr. *allelon,* one another). For example, tall and dwarf traits in peas are due to alleles located at the same locus in homologous chromosomes. When one allele (gene) expresses itself to the exclusion of its "partner" allele, the former is called a *dominant gene* and the trait is known as a *dominant trait.* The allele whose effect is not visibly expressed is called a *recessive gene,* and the trait is known as a *recessive trait.* An organism having two identical genes at one locus is *homozygous* for that gene or is said to possess *homozygous genes.* When an organism possesses a dominant allele (gene) and a recessive allele (gene) at the same time, it is *heterozygous* for that gene or is said to possess *heterozygous genes.* For example, TT and tt are homozygous, while Tt is heterozygous (T represents tall; t represents dwarf pea plants).

It is known that genes in the nucleus of cells control cellular metabolism, the synthesis of various biochemical compounds, and the inheritance of certain traits. How do these genes act? How can the genes (contributed by both parents) in the fertilized egg determine the various structures and functions of the embryo and eventually the adult? As a matter of fact, the nucleus with its genes and the surrounding cytoplasm constitute a complex system or unit whose interactions are responsible for the phenomena suggested. It is not well known how these reactions function but it is theorized that the genes in the nucleus interact with certain specific substances also in the nucleus to form the products of *genic action.* The latter products may interact with other newly formed products in a sort of chain reaction so that numerous products may be formed in the nucleus. It is thought that eventually some of the original gene products as well as some of the newly formed gene products pass into the cytoplasm. In the latter, the various gene products may react still further with each other or with certain products of the cytoplasm. It is probable that some of the cytoplasmic products may diffuse back into the nucleus so that the entire process is one in which the great numbers of genes interact in a great variety of ways to lay the basis for cellular phenomena.

The fertilized egg by repeated mitoses develops into a multicellular embryo whose cells quite early show slight inequalities, some being slightly larger than the others. Internally the composition of the cytoplasm may differ in the two sides of the cells, and there may be more yolk granules in one side (lower) than in the other (upper). Hence, there are two types of cells (smaller, upper ones, and larger, lower ones) with the cytoplasm differing between the two poles of the cells. This is known as *differentiation of the cytoplasmic contents of cells,* and this phenomenon may lead to additional differentiations within cells and between certain adjacent cells. Hence, the identical genes in the nuclei of the various cells are surrounded by different cytoplasms as well as different gene-products and nongenic contents within the different nuclei. The organization and differentiation of an embryo depend upon genic actions in cells as well as the interactions between cells and between the various regions of the embryo and its surroundings.

How does genic action produce the traits or characteristics displayed by living organisms? A trait in a developing or fully developed organism may be any observable structure or function such as a biochemical property, a structure or function of a cell, tissue, or organ, a mental characteristic, etc. It is to be expected that no simple connection exists between genes and most observable, developed traits, but usually there may be several steps in sequence in the process. Most traits arise through complex interactions of numerous genes as well as interactions between genes and cytoplasmic influences, so that a single gene may often influence the development of more than one trait. The statement that a trait may depend on the interactions of several genes may seem to contradict the statement that a certain gene is responsible for a trait. A single gene, by being part of this network of developmental interactions, then may be indirectly responsible for the eventual development of a particular trait which is to say that a particular gene may not directly develop that trait but does so in an indirect manner. In other words, that particular trait might not have developed specifically as it did if that "one" gene had not been associated in the complex network of gene interactions. If "another" gene had been present instead of the "one," the resulting interactions might have been quite different and the trait developed might have also been quite different. The particular way in which genic and nongenic actions take place in a network of interactions might well be influenced by the presence of a single gene of a specific type.

5. **Mendel's Experiments and Laws.**—Gregor Mendel, a monk in Austria, in 1864 gave the first scientific interpretation of the heredity mechanism through his experimental crossings of pea plants in the gar-

den of his monastery. Mendel was not a professional geneticist but his training in mathematics directed him to record accurately the exact numbers of the thousands of individuals of the various types produced by his experimental crosses. His scientific interpretations of his recorded data led to his famous laws and ratios. His work laid the foundation for scientific, experimental crossing in genetics. Although his laws do not explain all types of inheritance, wherever his laws do apply they are as valid today as at the time of their discovery. He was fortunate in having selected organisms which possessed clear-cut, alternative traits, each controlled by a single pair of genes; otherwise he might not have made his discoveries. If he had not discovered these phenomena in heredity, they would ultimately have been formulated in 1900 by three other scientists: De Vries in Holland, Correns in Germany, and von Tschermak in Austria. However, Mendel died before his great contributions were accepted and understood. He had published his results, so the credit belongs to him—not to the three workers just mentioned. Their contribution, which is highly important in science, was that their work substantiated Mendel's earlier but unaccepted work.

From the many traits of peas, Mendel selected the following seven pairs of alternative ("different") characteristics:

	DOMINANT	RECESSIVE
Plant height	Tall	Dwarf
Form of ripe seeds	Round	Wrinkled
Color of stored endosperm	Yellow	Green
Color of seed coat	Gray-brown	White
Color of unripe pod	Green	Yellow
Form of ripe pod	Smooth	Constricted
Position of flowers	Axial	Terminal

By cross fertilization he experimentally crossed two pea plants, one of which had one of the traits and the other plant the alternative trait. The resulting *hybrids,* which resembled one or the other parent, were then crossed with each other. In the hybrid, Mendel recognized the trait which expressed itself as the *dominant*, while the one which was latent and did not express itself he called the *recessive*. When he crossed the hybrids, the dominant and recessive traits reappeared in a definite ratio of approximately 3 dominants to 1 recessive. This ratio based on outward appearance is called the *phenotype ratio*. The latter may be resolved into a *genotype ratio* which is based on different genetic compositions of the various individuals (refer to later consideration in this chapter).

From a scientific interpretation of the data, Mendel formulated the following principles known as *Mendel's Laws* or *Mendelism.*

(1) **Law of Unit Characters:** The inheritance of a pair of characters occurs as a *unit* and independently of any other pairs of characters.

(2) **Law of Segregation:** Each pair of genes for a character *segregate* (separate) during the formation and maturation (gametogenesis) of gametes, so that no gamete has more than one gene from each pair. Each pair of genes undergoes this assortment independently of every other pair.

(3) **Law of Dominance (Complete):** When a gene and its alternative gene are both present at the same time in an individual, the one which expresses itself is called the *dominant,* while the one which is latent and unexpressed is the *recessive.* An individual displaying a dominant character may do so because of the presence of two dominant genes (TT) and be *homozygous* or because of the presence of one dominant and one recessive gene (Tt) and be *heterozygous.* For a recessive character to be expressed the genes must be homozygous (tt). In this type of inheritance the dominant completely masks the recessive.

Common Illustrations of Dominance and Recessiveness

	DOMINANT	RECESSIVE
Cattle	Short legs	Long legs
Cattle	Hornlessness	Horns present
Guinea pigs	Short hair	Long hair
Guinea pigs	Rough (rosetted) coat	Smooth coat
Guinea pigs	Colored hair	White or albino hair
Horses	Gray hair	Other colors of hair
Horses	Trotting	Pacing
Rabbits	Short hair	Long hair
Rabbits	Black hair	White hair
Poultry	Extra toes	Normal number of toes
Poultry	Feathered shank	Bare shank
Poultry	Rose comb (as in Wyandottes)	Single comb (as in Leghorns)
Fruit fly	Red eyes	White eyes
Fruit fly	Ebony colored body	Gray colored body
Fruit fly	Long wing	Vestigial wing
Fruit fly	Straight hairs or spines	Forked hairs or spines
Peas	Tall plant	Short or dwarf plant
Peas	Smooth seed	Wrinkled seed
Peas	Green pod	Yellow pod
Peas	Colored flowers	White flowers
Peas	Flowers axial (arranged along axis or stem)	Flowers terminal (arranged in bunches at top of stem)
Peas	Yellow seed coat	Green seed coat
Barley	Beardlessness	Beardedness
Sunflower	Branched habit	Unbranched
Tomato	Tall vine	Dwarf or short vine
Summer squash	Disk-shaped squash	Sphereshaped squash

6. Monohybrid, Dihybrid, and Trihybrid Crosses.—Monohybrid crosses are those in which only one pair of differentiating characters are considered, dihybrid are those in which two pairs are considered, and trihybrid are those in which three pairs of different genes are involved.

By using the guinea pig and the following characters with their symbols, the different crosses suggested above may be illustrated.

B, black hair
b, white hair
R, rough hair
r, smooth hair
S, short hair
s, long hair

When the dominant (expressed by the capital letter) is present, it expresses itself, even though the opposite or recessive be present.

Monohybrid Cross (Guinea Pig)

Parents (P) — Black (BB) X White (bb)

Gametes produced — B, b

Offspring (F_1) — Black (Bb)

Gametes for both sperms and eggs — B, b

Offspring (F_2) shown by the Punnet square or checkerboard

Eggs \ Sperm	B	b
B	BB	Bb
b	Bb	bb

Thus we have produced 1 BB (black) 2 Bb (black) and 1 bb (white) or a ratio of 3 black to 1 white. This is a *phenotype ratio* of 3:1 for a monohybrid cross.

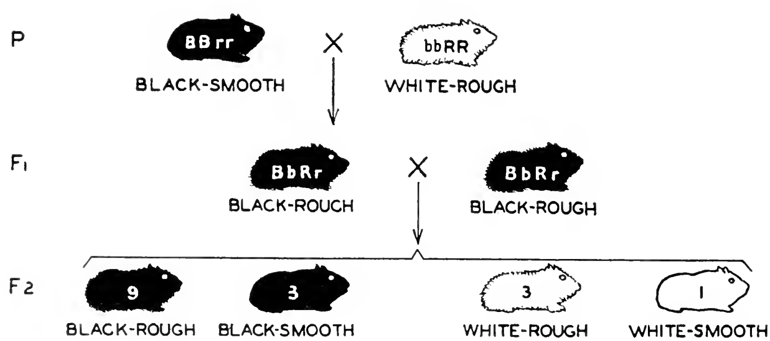


Fig. 336.—Dihybrid cross in guinea pigs when parents (*P*) are crossed. All of the F_1 generation are black-rough. When the latter are intercrossed, the F_2 generation is produced as shown. The genes for the *P* and F_1 generations are shown.

DIHYBRID CROSS (GUINEA PIG) (SEE FIG. 336)

Parents (P) — Black-smooth (BBrr) X White-rough (bbRR)

Gametes produced — Br ; bR

Offspring (F_1) — Black-rough (BbRr)

Gametes in equal numbers in both sperms and eggs — BR Br bR br

Offspring (F_2) (shown by the Punnet square)

Eggs \ Sperms	BR	Br	bR	br
BR	BR BR	Br BR	bR BR	br BR
Br	BR Br	Br Br	bR Br	br Br
bR	BR bR	Br bR	bR bR	br bR
br	BR br	Br br	bR br	br br

From the above squares there are the following:

9 black-rough
3 black-smooth
3 white-rough
1 white-smooth

This is the *phenotypic ratio* of 9-3-3-1 for a dihybrid cross in the F_2 generation, when the above parents are used.

TRIHYBRID CROSS (GUINEA PIG)

Parents (P) — Black-short-smooth (BBSSrr) X White-long-rough (bbssRR)

Gametes produced — BSr ; bsR

Offspring (F_1) — Black-short-rough (BbSsRr)

Gametes (equal numbers of each kind in both sperms and eggs) — BSR BSr BsR Bsr bSR bSr bsR bsr

Offspring (F_2) — By the Punnet square as in the monohybrid and dihybrid crosses there will be:

27 black-short-rough
9 black-short-smooth
9 black-long-rough
9 white-short-rough
3 black-long-smooth
3 white-short-smooth
3 white-short-smooth
3 white-long-rough
1 white-long-smooth

Thus a typical F_2 trihybrid, *phenotype ratio* is 27-9-9-9-3-3-3-1. By means of the Punnet square or checkerboard, it is apparent that all of the 27 which appear black-short-rough are not alike as far as their gene content is concerned. When we group together all those whose gene content is the same, we have the so-called *genotype ratio* (based on the gene content).

A very useful method in determining the number and different types of gametes (sex cells) produced by a particular organism is known as the bracket method. In the case of the trihybrid cross of guinea pigs considered above, the F_1 offspring, which is black-short-rough and with genes (BbSsRr), the gametes may be ascertained by the use of the bracket as shown in Fig. 337.

```
                              S { R--BSR
                       B {      { r--BSr
                              s { R--BsR
                                { r--Bsr
BbSsRr-------- {
(Parent genes)                S { R--bSR
                       b {      { r--bSr
                              s { R--bsR
                                { r--bsr
```

Fig. 337.—The so-called bracket method of determining the number and types of gametes (sex cells) produced by a parent containing the genes BbSsRr.

By using a plant, such as the pea, and the following characters with their symbols, the different crosses (monohybrid, dihybrid, trihybrid) may be illustrated:

T, tall plant
t, dwarf plant
R, round seed
r, wrinkled seed
Y, yellow seed
y, green seed

When the dominant (expressed by the capital letter) is present, it expresses itself even though the opposite or recessive is present.

Monohybrid Cross (Pea)

Parents (P)	Tall (TT) X Dwarf (tt)
Gametes produced	T ↓ ↓ t
Offspring (F_1)	↘ Tall (Tt) ↙
Gametes for both male and female	↙ T ↘ t
Offspring (F_2) shown by the Punnet square or checkerboard	Male gametes

Female		T	t
	T	TT	Tt
	t	Tt	tt

Thus we have produced 1 TT (tall), 2 Tt (tall), and 1 tt (dwarf), or a ratio of 3 tall to 1 dwarf. This is a phenotype ratio of 3:1 for a monohybrid cross.

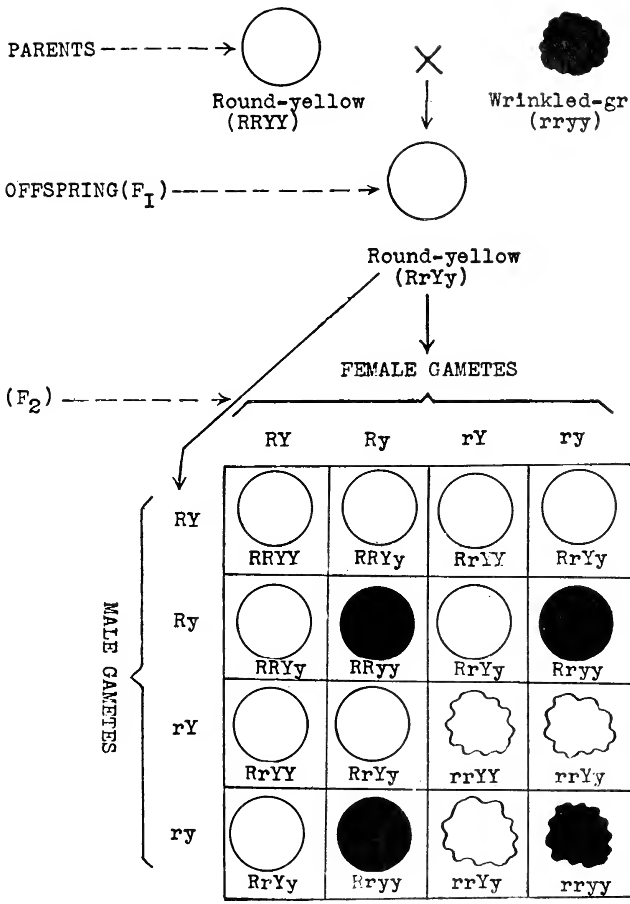


Fig. 338.—Dihybrid cross of peas showing gene content of each individual. The genes for the various members of each generation are shown. When two similar F_1 individuals are crossed, the results are shown in the checkerboard (F_2).

DIHYBRID CROSS (PEA) (SEE FIG. 338)

Parents (P)	Round-yellow (RRYY) X Wrinkled-green (rryy)
Gametes produced	RY ↓ ry
Offspring (F_1)	Round-yellow (RrYy)
Gametes for both male and female	RY Ry rY ry

Offspring (F_2) when (F_1) are intercrossed or self-pollinated (shown by the Punnet square)

Female gametes (columns); Male Gametes (rows)

	RY	Ry	rY	ry
RY	RY RY	Ry RY	rY RY	ry RY
Ry	RY Ry	Ry Ry	rY Ry	ry Ry
rY	RY rY	Ry rY	rY rY	ry rY
ry	RY ry	Ry ry	rY ry	ry ry

From the above squares it is seen that the following offspring are secured:

9 round-yellow
3 round-green
3 wrinkled-yellow
1 wrinkled-green

This is the *phenotype ratio* of 9-3-3-1 for a dihybrid cross in the F_2 generation.

TRIHYBRID CROSS (PEA)

Parents (P)	Tall-yellow-round (TTYYRR) X Dwarf-green-wrinkled (ttyyrr)
Gametes produced	TYR ↓ tyr
Offspring (F_1)	Tall-yellow-round (TtYyRr)

Gametes for both male and female TYR TYr TyR Tyr tYR tYr tyR tyr

Offspring (F_2) by the Punnet square as in the monohybrid and dihybrid crosses, there will be produced in the F_2 generation the following:

27 tall-yellow-round
9 tall-green-round
9 tall-yellow-wrinkled
9 dwarf-yellow-round
3 tall-green-wrinkled
3 dwarf-green-round
3 dwarf-yellow-wrinkled
1 dwarf-green-wrinkled

This is a typical F_2 trihybrid, *phenotype ratio* of 27-9-9-9-3-3-3-1 when such individuals as F_1 are used as parents.

7. **Incomplete Dominance.**—From studies just made it was noted that when opposite members of a pair of genes were present, one or the other

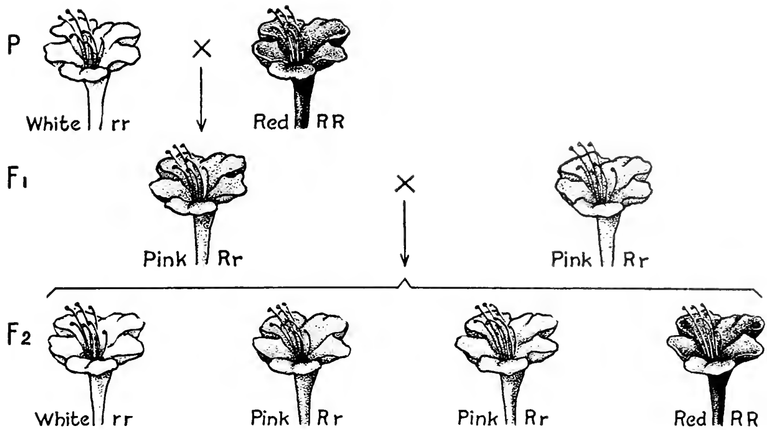


Fig. 339.—Incomplete dominance when a homozygous white-flowered four-o'clock *(Mirabilis jalapa)* is crossed with a homozygous red-flowered four-o'clock. The somatic condition is shown by the flower colors; the letters show the genes involved. When two pinks of the F_1 generation are crossed the results are shown in the F_2.

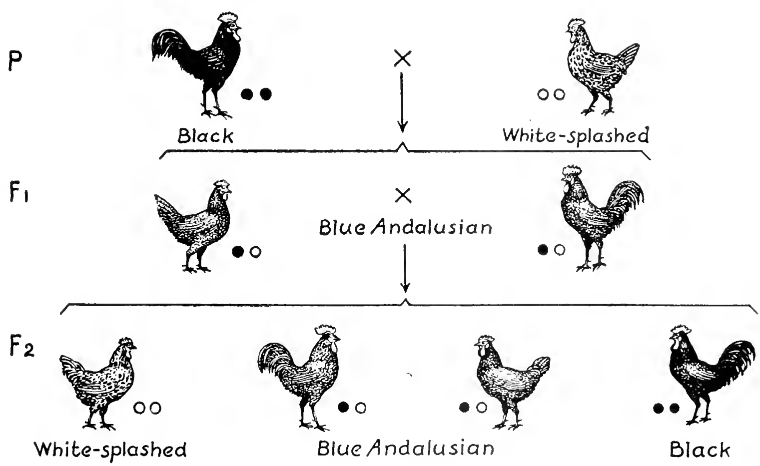


Fig. 340.—Incomplete dominance in blue Andalusian fowls. When a black fowl is crossed with white-splashed-with-blue, all the F_1 generation will be blue Andalusian. When the latter are interbred, there are produced one-fourth white-splashed-with-blue, one-half blue Andalusians, and one-fourth black in the F_2 generation. When the white-splashed-with-blue of the F_2 are interbred, only white-splashed-with-blue are produced. When the blue Andalusians of the F_2 are crossed, they produce offspring like those resulting from the F_1. When the black of the F_2 are crossed with each other, only blacks are produced. The black dots and circles show the factors involved in each individual.

completely dominated. In so-called *incomplete dominance* the F_1 does not resemble either parent exactly for the trait in question, neither gene of the pair completely dominating the other. An example is the four-o'clock flower (Fig. 339) in which homozygous white is crossed with homozygous red and the F_1 is pink. The genetic content and ratios are shown. Note that the phenotype ratio in the F_2 is identical with the genotype ratio. *Incomplete dominance*, with one pair of genes, is illustrated by the blue Andalusian fowl (Fig. 340). The F_1 shows incomplete dominance by being neither black nor white but an intermediate shade called "blue," which is always heterozygous. When two blue fowls are crossed, the offspring show a ratio of 1 white:2 blue:1 black. When a blue and black are crossed, the ratio is 1 black:1 blue; when a blue and a white are crossed, the ratio is 1 white:1 blue.

8. **Multiple Genes and Interaction of Genes.**—There are many traits which are determined by more than one pair of genes and the specific methods of inheritance vary, but the following may give a general idea of some of these genetic phenomena. When a quantitative character (one with various degrees of trait expression) is the result of several, duplicate, cumulative genes, such genes are known as *multiple genes* (multiple factors). The hair color in wild rabbits is the result of no less than thirteen pairs of different genes located in various chromosomes. Some of these genes are recessive, but a majority in this case are dominants.

Another example of *multiple genes* (more than one pair for a trait) is the production of skin color in which Negroes differ from whites in two pairs of genes. These two pairs of genes interact cumulatively and show *incomplete dominance*. Explanation: Negro, AABB; dark mulatto, AABb or AaBB; medium mulatto, AaBb, AAbb, or aaBB; light mulatto, Aabb or aaBb; white, aabb. Using these gene symbols, if a pure Negro (AABB) and a pure white (aabb) are crossed, the F_1 offspring are medium mulatto (AaBb). Another crossing may be shown as follows:

Parents	Medium mulatto (male) (AAbb)	X	Medium mulatto (female) (AaBb)
	↓		↙ ↓ ↓ ↘
Gametes	Ab		AB Ab aB ab
F_1	1 dark mulatto (AABb), 2 medium mulattoes (AAbb) (AaBb), 1 light mulatto (Aabb).		

When three pairs of cumulative genes interact and possess incomplete dominance, there result various degrees of trait expression. For example, Nilsson-Ehle found three pairs of genes in certain strains of red wheat. Deepest red is represented by $R_1R_1R_2R_2R_3R_3$ and white wheat by $r_1r_1r_2r_2r_3r_3$. The more genes represented by the capital letters in any individual, the darker the red. This may be shown by the following:

Parents	Deepest red wheat ($R_1R_1R_2R_2R_3R_3$)	X ↓	White wheat ($r_1r_1r_2r_2r_3r_3$)
F_1		Medium red wheat ($R_1r_1R_2r_2R_3r_3$)	

When two of the F_1 are crossed, the F_2 ratio is:

1 deepest red (6 red genes)
6 very deep red (5 red genes)
15 deep red (4 red genes)
20 medium red (3 red genes)
15 pale red (2 red genes)
6 very pale red (1 red gene)
1 white (no red genes)

When two dominant genes located in different pairs of chromosomes interact and supplement each other to produce an altogether new phenotype, such are called *supplementary genes.* In the combs of chickens, pea-comb is represented by at least one P and rr, rose-comb by pp and at least one R, single-comb by pprr, walnut-comb by at least one P and at least one R. The following cross shows a homozygous rose-comb crossed with a homozygous pea-comb with the genetic contents and ratios:

Parents	Rose-comb (pp RR) ↓	X	Pea-comb (PP rr) ↓
Gametes	pR ↘		Pr ↙
F_1		Walnut-comb PpRr	

When two walnut-combed chickens of the F_1 are crossed, the F_2 shows:

9 walnut-combed (at least one P and at least one R)
3 pea-combed (at least one P and rr)
3 rose-combed (pp and at least one R)
1 single-combed (pprr)

This shows not only a new type in the F_1, but, when intercrossed, a still different type, namely, single-comb (pprr), is produced.

When two dominant genes located in different pairs of chromosomes interact and complement each other (both present to produce a visible effect), such are called *complementary genes.* When two pure strains of white sweet peas are crossed, they produce only purple-flowered peas in the F_1. Purple flowers are represented by at least one C and at least one P. White flowers are represented by at least one C and pp, by cc and at least one P, and by ccpp. This may be shown as follows:

Parents	White-flowered pea (CCpp)	X ↓	White-flowered pea (ccPP)
F_1		Purple-flowered pea (CcPp)	

When the F_1 are crossed, the F_2 ratio is:

F_2
- 9 purple (at least one C and at least one P)
- 3 white (at least one C and pp)
- 3 white (cc and at least one P)
- 1 white (cc and pp)

This phenotype ratio is 9 purple:7 white.

9. **Lethel Genes.**—When lethal genes (le′ thal) (L. *letum,* death) are present they may kill the organism containing them or at least prevent the individual from attaining normal maturity (Fig. 341). Lethal genes are known in mice, fruit flies, human beings, in certain plants, etc. In

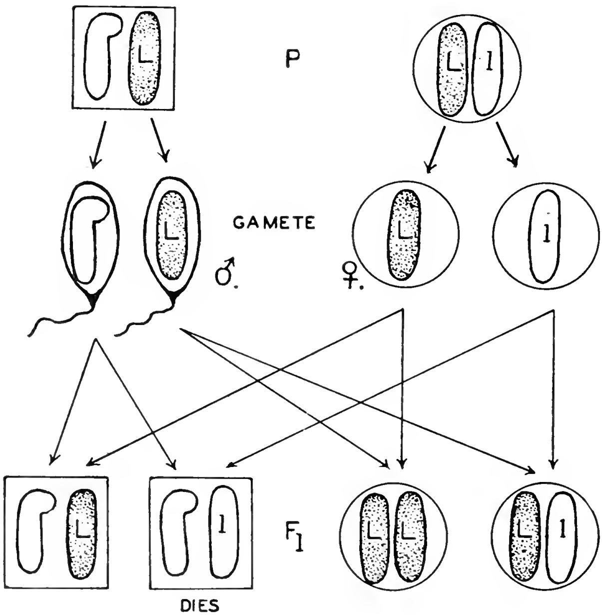


Fig. 341.—Inheritance of lethal, sex-linked factor in the fruit fly *(Drosophila sp.)* and its effect on the sex ratio. *l,* The lethal factor; *L,* its normal, nonlethal allele: *P,* parents (squares are males: circle are females); F_1, the first filial generation in which one-half of the males fail to develop, giving the sex ratio of two females to one male. Note that both parents (*P*) are normal but that the female carries the lethal factor which she later contributes to one-half of her sons, who consequently never develop.

plants, lethal genes may prevent the development of chlorophyll so the young plant is unable to photosynthesize food. Lethal genes may arise naturally, or they may be induced by irradiations by x-rays, radium, etc. About 80 per cent of all mutations induced by radiations are lethals. Possibly many of the lethal mutations may actually result from some type of chromosomal aberration, although some are true gene mutations. Some lethals have been discovered which are dominant, while others behave as recessives.

10. **Mutations.**—A mutation (mu -ta′ shun) (L. *mutare,* to change) is an inheritable trait which appears suddenly not as a result of environmental influences, but has originated spontaneously in the hereditary mechanism; hence, it may be transmitted to future offspring. Morgan, in 1910, discovered the sudden appearance of a white-eyed mutant in a stock of true-breeding red-eyed fruit fly, *Drosophila melanogaster.* When the white-eyed mutant was crossed with red-eyed flies, the white-eye trait was inherited as a recessive gene in the X chromosome. Hundreds of plants and animals have mutated with greater or lesser frequency. Mutations may affect any part of an animal or plant or any of their functions. They may occur periodically and frequently and be unobserved in Nature. The same mutation may arise simultaneously in different individuals. A mutation results in a new trait which is inheritable, and, if sufficiently extensive, may result in a new type or even a new species of that organism. Mutations may occur naturally, although some may be induced by irradiations such as x-rays, radium, etc. About 80 per cent of all induced mutations are lethal. In general, mutations are usually changes for the worse, although a few may be valuable. Some of our important plants and animals have arisen as mutants which possessed desirable traits. In the broad sense, changes in traits are the result of (1) actual, sudden change in a gene (gene mutation), (2) changes in the number of chromosomes or from chromosomal aberrations (anomozygous mutations), or (3) recombinations of previous genes in an entirely new arrangement for that particular organism (recombination). In a strict sense, the term mutation is reserved for those inheritable traits which arise abruptly from changes in a gene. If an organism mutates in a certain manner, it may now possess a trait which will benefit it in the future, or it may mutate in such a way as to possess undesirable traits which will interfere with its normal existence.

11. **Linkage and Crossing Over.**—Genes are considered to be associated with each other in a linear order within chromosomes. All the many genes in each chromosome tend to be inherited as a group and

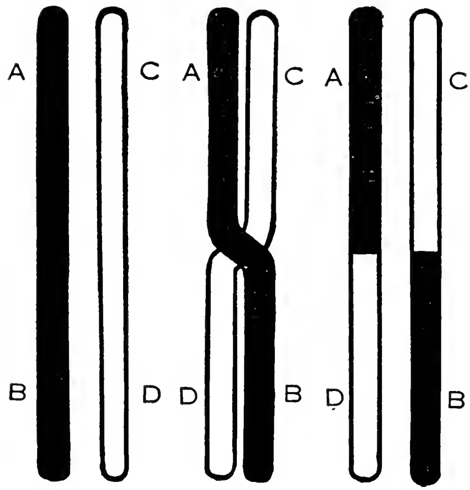


Fig. 342.—Diagram showing the crossing over of genes from one homologous chromosome to the other during synapsis. Observe the exchange of the genes *A-C* and *B-D*. Crossing over may occur at more than one point in much the same manner as shown. (From Potter: Textbook of Zoology, The C. V. Mosby Co.)

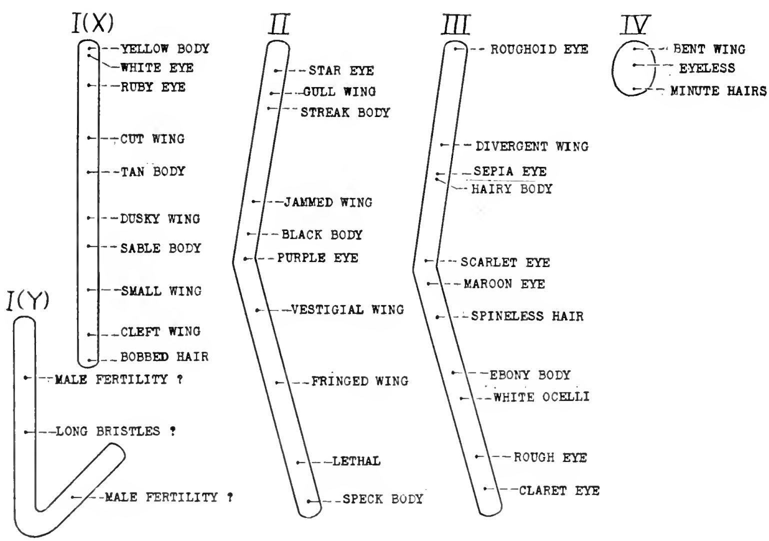


Fig. 343.—Chromosome map of the fruit fly *(Drosophila sp.)*, showing the locations (loci) of some of the genes in the autosomes *(II, III, IV)* and in the sex chromosomes (*I, X*) and (*I, Y*). The name applied to the gene is given to the right of its locus, and the distances between them are approximate.

are said to be *linked.* This linkage force keeps the genes in proper association. It is known that during meiosis (reduction divisions during gametogenesis) the homologous pairs of chromosomes separate as units, one of each pair passing to each gamete. Linkage between genes is usually not complete. During the process of *synapsis* (temporary fusion of homologous chromosomes), associated with gametogenesis (discussed later in this chapter), the homologous chromosomes often mutually exchange segments and their contained genes. This mutual exchange is

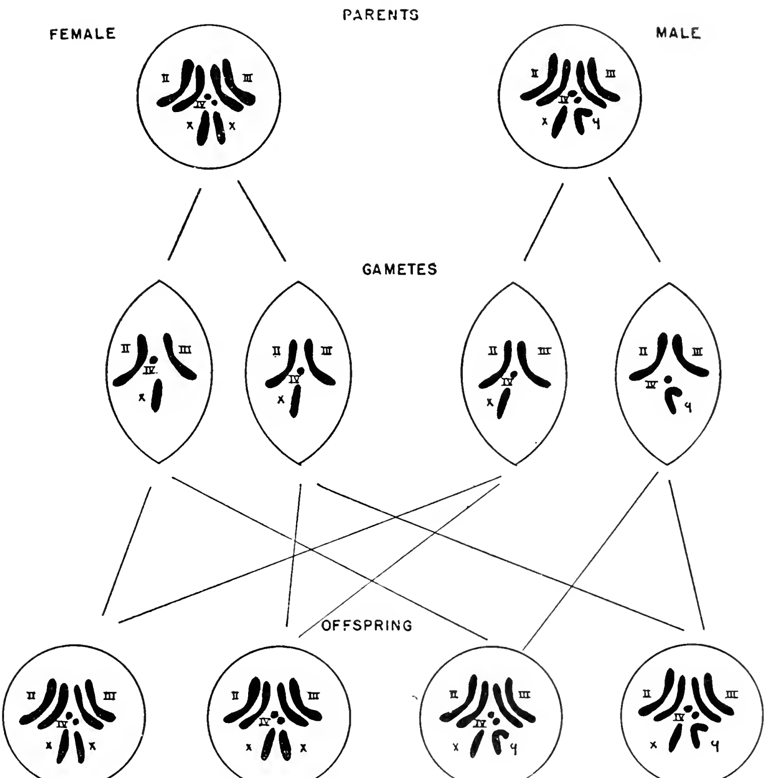


Fig. 344.—Inheritance of sex in the fruit fly *(Drosophila sp.)*, shown somewhat diagrammatically. Observe that in both male and female there are two pairs each of chromosomes known as *II, III, IV.* In the female there is an additional pair known as the X chromosomes. In the male there is an additional X chromosome and a Y chromosome. When gametes are produced, there is a separation of the members of each pair. When offspring are formed, the males have the three pairs of chromosomes in addition to an X and a Y chromosome, while the females have an additional pair of X chromosomes instead. Note the two kinds of male gametes. (From Parker and Clarke: Introduction to Animal Biology, The C. V. Mosby Co.)

called *crossing over* (Fig. 342). The controlling mechanism is unknown, but the greater the distance between the two loci and any two given genes, the greater the chance that crossing over will take place between them. Likewise, the smaller the distance between the loci of any two genes, the less the chance that crossing over will occur. New combinations of linked genes within the pair of chromosomes involved result from the crossing-over process.

From data secured from crossing-over experiments it is possible to locate approximately the genes (loci of genes) within the chromosome. Such an approximate location of genes is called a *chromosome map* (Fig. 343). The approximate locations of genes are determined experimentally by recording the percentage of crossing over between them. Let us take a theoretical example. If the experiments show that in a certain chromosome crossing over between its genes A and B occurs 8 per cent of the time, then these two genes are considered to be eight "units" of distance apart in that chromosome. If crossing over between genes B and C occurs 3 per cent of the time, they are three "units" apart. This could be interpreted as meaning that the sequence is A:::::::B::C. However, C might be between A and B. If the genes A and C cross over 5 per cent of the time, then the sequence is A::::C::B. In a similar manner other genes may be located within this chromosome.

Linkage and crossing over have been observed in many types of plants and animals, including human beings.

12. **Sex Determination and the Sex Ratio.**—From scientific cytologic studies of the fruit fly it has been found that each somatic cell contains three pairs of chromosomes known as *autosomes* and one pair of *sex chromosomes* (Fig. 344). The female has three pairs of autosomes and a pair of sex chromosomes called *X chromosomes,* while the male has three pairs of autosomes and one *X chromosome* and one *Y chromosome.* When female gametes (sex cells) are produced, each contains three autosomes and one X chromosome. When male gametes are produced, one type contains three autosomes and one X chromosome, while the other type contains three autosomes and one Y chromosome. Since the two types of male gametes are produced in equal numbers and each type is thought to have somewhat equal chances for fertilizing an egg, the ratio of male and female offspring is approximately 50:50.

It is known that somatic cells of human beings contain twenty-three pairs of autosomes and a pair of sex chromosomes as described for the fruit fly. The distribution of sex chromosomes in man is similar to that in the fruit fly.

The method of producing gametes and of fertilization, as well as the production of the sex of the offspring, is also similar. Sex is determined at the time of fertilization. If an egg is fertilized by an "X sperm," the zygote will develop into a female, while an egg fertilized by a "Y sperm" leads to an XY zygote which develops into a male. After fertilization, mitosis provides every cell of the developing embryo and the ultimate adult with the original chromosome constitution.

This explanation seems quite simple and sufficient, but it is only the basis for solving the problem of sex determination and its attendant phenomena. Many of these are too complicated to be considered in detail here, but the following may suggest some of the complications. A human XX zygote or XY zygote develops in a short time into an embryo which is structurally neither male nor female, or rather is both male and female, because the embryonic gonads consist of two parts—a characteristic ovary-like portion, and a characteristic testis-like part. Likewise, a pair of male and a pair of female internal sexual ducts are present in each early, "neutral" embryo. Even the embryonic parts which later develop into external genitalia of either sex are present. After this neutral stage has been reached, the specific genetic sex constitution of the embryo begins to differentiate visibly. In the embryo with XX cells the neutral embryonic gonads develop into ovaries, while the embryo with XY cells develops testes. Likewise, the proper types of internal sexual ducts and external genitalia are developed if things develop normally. It happens at times that parts of both male and female reproductive systems are present in certain adults who are known as *hermaphrodites* or *intersexes.*

In newborn children, sexual differentiation is not yet complete. *Secondary sexual traits* (differences apart from actual sex organs) develop during puberty and include differences in larynx and voice, differences in pelvic developments, breasts, hair growth, etc., which are influenced by specific hormones produced by the male and female sex organs.

13. **Sex-Linked Traits.**—Besides assisting in the determination of the sex, the sex chromosomes also possess genes for the determination of other traits, which, because of the location of the genes in the sex chromosome, are known as *sex-linked traits.* Two types of sex-linked inheritance are possible, depending upon whether the sex-linked genes are in the X chromosome or Y chromosome. Certain genes are known which are always associated with the Y chromosome, while others are associated with X chromosomes. Other genes have been found in males which cross over from the X to the Y chromosome, or vice versa. Very few

human traits show absolute Y linkage (do not appear in females and are not transmitted to them). An example is the so-called "porcupine man" trait (bristly, scaly skin) which appears in males only. Another possible Y-linked inheritance is a special type of web toe (web skin between second and third toes). It is known that a different web toe condition exists which is present in both males and females, with a preponderance

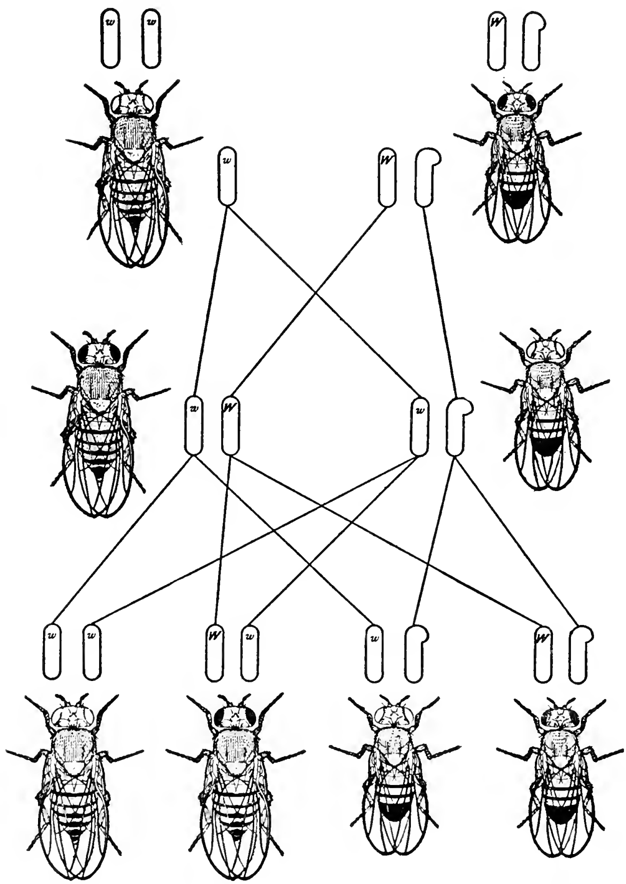


Fig. 345.—Sex-linked inheritance in the fruit fly *(Drosophila sp.)*. The red-eyed male (upper right) and the white-eyed female (upper left) are crossed to produce the male and female of the F_1 generation. The factor (*W*) for red eyes is carried in the X chromosome of the male, while the curved male Y chromosome does not carry an eye-color factor. The factor (*w*) for white eyes is carried in the X chromosome of the female. When members of the F_1 generation are crossed, the four kinds of the F_2 generation are produced (lower group). Note that a male has a larger tip of black on his abdomen than the female. Contrast these results with those in Fig. 346. (From Morgan: Evolution and Genetics, Princeton University Press.)

in the former, however. Sex linkage has been observed in fishes, poultry, silkworms, plants, fruit flies, man, etc.

In the fruit fly (Drosophilia) the gametes are heterozygous in the males and homozygous in the females. White eyes are sex-linked characters which are recessive to the normal red eyes.

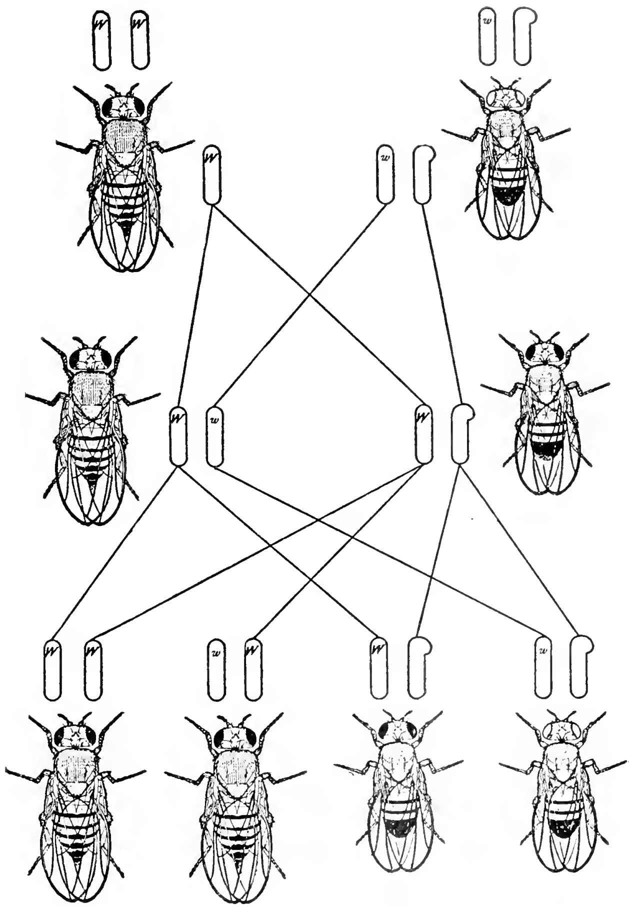


Fig. 346.—Sex-linked inheritance in the fruit fly *(Drosophila sp.)*. The white-eyed male (upper right) and the red-eyed female (upper left) are crossed to produce the male and female of the F_1 generation. The factor (*W*) for red eyes is carried in the X chromosomes of the female. The factor (*w*) for white eyes is carried in the X chromosome of the male. The curved male Y chromosome does not carry an eye-color factor. When the members of the F_1 generation are crossed, the members of the F_2 generation are produced, as shown in the lower line. Note that a male has a larger tip of black on his abdomen than the female. Contrast these results with those in Fig. 345. (From Morgan: Evolution and Genetics, Princeton University Press.)

When a white-eyed female is crossed with a red-eye male, the F_1 males are white eyed and the females are red eyed. In the F_2 generation one-half of the individuals of each sex are white eyed and one-half are red eyed (Fig. 345).

In the reciprocal cross in which a red-eyed female is crossed with a white-eyed male, all the offspring (both male and female) of the F_1 generation are red eyed. All the females of the F_2 generation are also red eyed. One-half of the males of the F_2 generation are red eyed, while the other half are white eyed. (Fig. 346.)

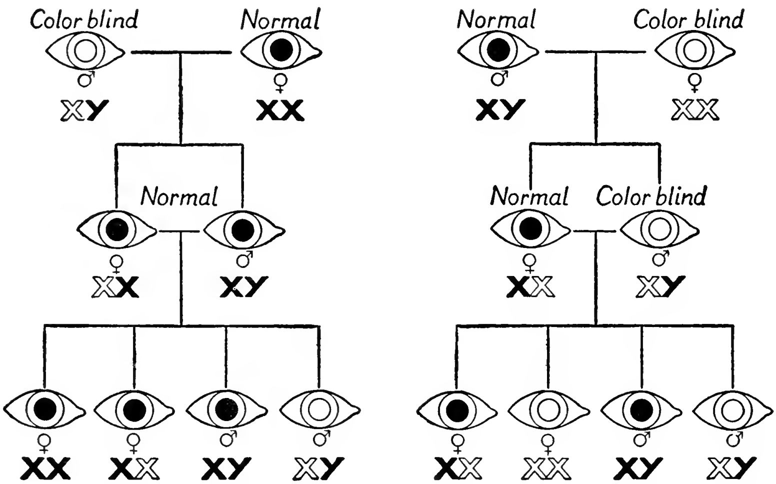


Fig. 347.—Inheritance of color blindness in man. On the left a color-blind man marries a normal woman. None of the children are color blind, but the defect is transmitted through the daughters to half of their sons. Color-blind persons and the chromosomes carrying the gene for color blindness are shown in white. On the right a normal man marries a color-blind woman, and all the sons are color blind, while the daughters are normal but carry a color-blind gene. In the second generation (on the right) from the type of mating shown in the diagram, half of the daughters and half of the sons will be color blind. Contrast the results of the two pedigrees and observe the effects of a sex-linked trait. (From Turner: Personal and Community Health, The C. V. Mosby Co.)

Human color blindness, or the inability to distinguish red from green, is usually transmitted from a color-blind mother to all of her sons but to none of her daughters. From a color-blind father it is transmitted through his daughters (who are normal as far as color blindness is concerned) to one-half of his grandsons (Fig. 347). When both parents are color blind, all the offspring are color blind. Another human sex-linked trait is hemophilia, a condition characterized by inability to form blood clots.

14. **Sex-Influenced Traits.**—Sex-influenced traits are sometimes called sex-modified or sex-controlled traits. Such traits are inherited by genes which are not present in the sex chromosomes (they are autosomal genes) but which are influenced or modified by the sex of the organism. These influences are due in part, at least, to the sex hormones of the male and female gonads and are responsible for differences in the expression of the traits in the two sexes, even though the genes may be the same in both.

Pattern baldness in human beings is sex influenced, being affected by the sex hormones. There are more bald males than females because only one gene for baldness is required in men, while two genes are required in women. For example, BB causes baldness in both men and women; bb causes no pattern baldness in either sex; however, Bb causes baldness in men but not in women. The same genes (Bb) produce different effects in the two sexes, depending upon the influence of the sex hormones.

The horns of certain types of sheep are phenotypically different in males than in females. The genes HH produce horns regardless of sex; hh is hornless in either sex; however, Hh produces horns in males, but the same genes produce a hornless female. Hence, Hh expresses itself differently in the two sexes, so is sex influenced. A similar condition exists in the production of mahogany spots and red spots in Ayrshire cattle.

15. **Inbreeding and Outbreeding.**—When closely related individuals are crossed, we call it *inbreeding*, and when unrelated strains or individuals are crossed, it is known as *outbreeding*. There seems to be much misinformation regarding these phenomena. It is commonly thought that inbreeding is harmful and leads to the production of undesirable abnormalities of various kinds. Inbreeding in itself may not be harmful, but it depends on what is inbred. If the parents have undesirable traits, inbreeding naturally will transmit them, and the chances that both parents may possess undesirable traits is greater because of their close hereditary relationship. Crossing less closely related individuals might prevent the expression of some of the undesirable traits.

On the other hand, commercial breeders use inbreeding constantly to improve and retain their strains of horses, cattle, dogs, chickens, wheat, fruits, etc., in which cases they capitalize on the good traits possessed by both parents even though they may be closely related. In fact, closely related individuals may be desirable parents providing they possess desirable traits (genes). If any stock of plant or animal has undesirable recessive traits, inbreeding may cause some of them to appear, while any stock of plant or animal having desirable traits will transmit them, or may even result in improvements. Many plants (beans, peas, wheat,

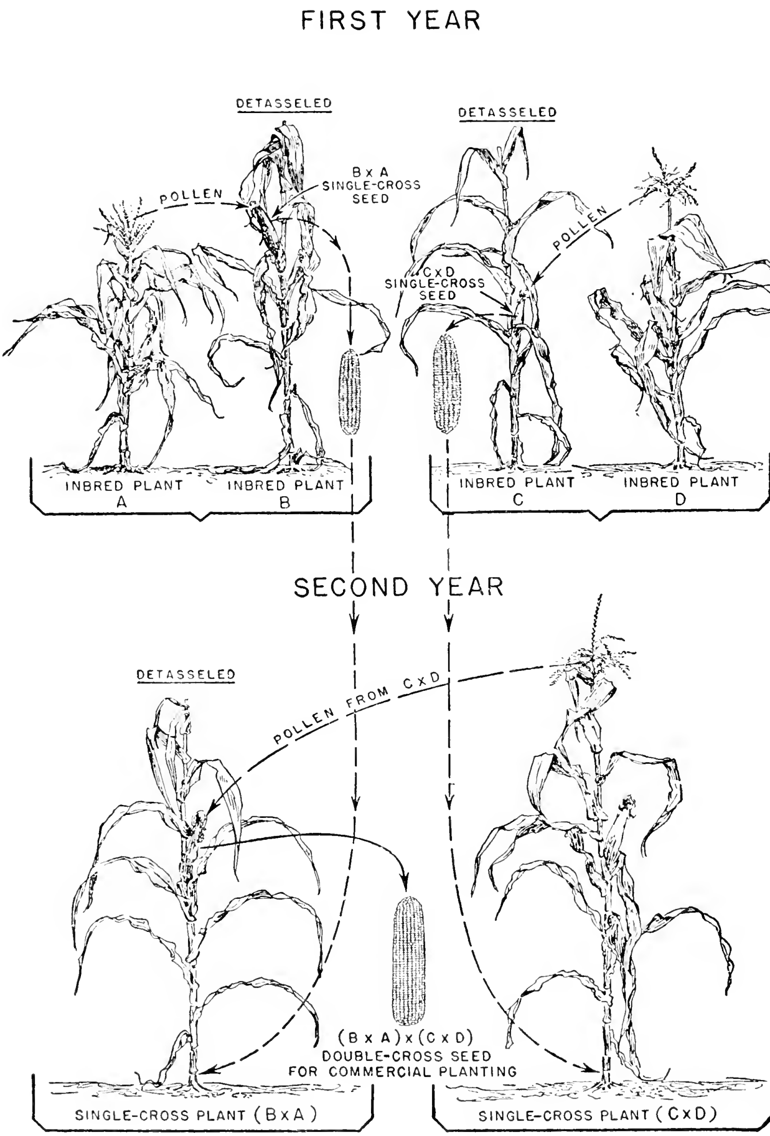


Fig. 348.—Diagram of the method of crossing inbred corn plants and the resulting single-cross to produce double-cross hybrid seed. The four plants, *A, B, C, D,* are inbred for several generations. Then strain *A* is crossed with strain *B* (*A* furnishes pollen and *B* is detasseled). Strains *C* and *D* are crossed similarly. Then the product of these two single-cross lines are crossed to produce the double-cross seed used in commercial plantings. (From Richey, F. D.: The What and How of Hybrid Corn, Farmers' Bulletin No. 1744, U. S. Department of Agriculture.)

oats, etc.) and some animals normally reproduce entirely or largely by self-fertilization, which is a type of inbreeding. On the other hand, such a plant as corn is normally cross fertilized. When a vigorous, desirable strain of corn is repeatedly inbred by self-fertilization, the quality, yield, and vigor decline for several generations. It is commonly known that inbreeding in certain human families results in highly undesirable consequences. If a human family has recessive genes for undesirable traits and if they are not expressed normally because of dominant genes, then inbreeding of closely related persons will tend to produce offspring who are homozygous for the undesirable recessive defects. Inbreeding in such a family is undesirable.

Outbreeding frequently results in offspring which are better than either parent, a phenomenon known as *hybrid vigor* or *heterosis.* This vigor may manifest itself in various ways in different animals and plants. In corn increased vigor may result in larger ears, greater number of grains per row, greater height of the plant, etc. Much of the corn grown in the United States is a special hybrid developed by crossing four different inbred strains of corn (Fig. 348). This will be considered in greater detail in a later part of this chapter. Hybrid vigor is a common phenomenon in many types of plants and animals. When a horse and donkey are crossed, the resulting hybrid mule is strong, sturdy, and more vigorous than either parent.

16. **Genetic Improvements of Plants and Animals.**—Many plants and animals have been produced as a result of some type or other of genetic improvement. Man has merely taken advantage of the natural genetic phenomena possessed by these organisms and has somewhat controlled and directed them so as to result in a better type. The number of genetically improved organisms is so extensive and the methods employed so varied that only a few examples can be given. Probably one of the more valuable and recent contributions is the production of hybrid corn; the method employed is given briefly.

Corn is normally cross-pollinated. When self-pollinated (selfed) for at least seven successive generations, the corn plants become progressively less productive and smaller. Eventually when two such self-pollinated corn plants are crossed, the resulting hybrid is more productive and larger than the ancestors. The procedure, in brief, is as follows: (a) Inbreeding (self-pollination) for at least seven successive generations in order to produce homozygous strains; (b) Two such homozygous strains which possess traits desired in commercial strains are then cross pollinated to produce the F_1 hybrids known as single-cross hybrids. However, such seeds are usually not sold because the yield is usually low and grains are of variable size; (c) Two single-cross hybrids, produced from different homozygous strains, are now crossed, producing double-cross hybrids, which produce higher yields of uniformly large seeds (Fig. 348).

Original Corn Plant Self-pollinated (inbred) for seven generations	Original Corn Plant Self-pollinated (inbred) for seven generations	Original Corn Plant Self-pollinated (inbred) for seven generations	Original Corn Plant Self-pollinated (inbred) for seven generations
Inbred Strain A	Inbred Strain B	Inbred Strain C	Inbred Strain D
(Furnishes Pollen) ↘	(Detasseled) ↙	(Detasseled) ↘	(Furnishes pollen) ↙

Single-Cross Hybrid (AXB) — (Detasseled) ↘

Single-Cross Hybrid (CXD) — (Furnishes pollen) ↙

Double-Cross Hybrid
(AXB) (CXD)
|
Seed for Commercial Planting (Fig. 348)

Other genetic improvements in plants include fiber length in cotton, sugar content of melons, yellow color of peaches, resistance to diseases in plants (wheat rust, corn blight, oats smut, tomato wilt, etc.), resistance of plants to pests (melon aphids, wheat Hessian fly, grape phylloxera, etc.), seedless grapes, improved tobacco plants, etc.

The genetic improvements in animals are extensive as shown by the development of poultry resistant to white diarrhea (*Salmonella pullorum*), resistance to abortion in rabbits, increased egg production by developing earlier maturity in fowls, the production of platinum (silver-blu) minks, hornless (polled) cattle, increased butterfat in milk, improved qualities in race horses, better meat qualities in turkeys, improvements in various breeds of dogs and cats, etc. (Fig. 349).

17. **Production and Maturation of Germ Cells.**—Since a great amount of the process of germ cell production, maturation, and fertilization deals with the various phases of inheritance, it is discussed in this chapter.

Weismann's theory of the continuity of germ plasm states that the germ plasm is transmitted from one generation to the next, or even many future generations, in a continuous and uninterrupted manner. The body cells (somatoplasm) arise from the germ plasm at the proper time and become specialized for their various bodily functions. Body cells thus can arise from germ plasm, but germ cells or germ plasm cannot arise

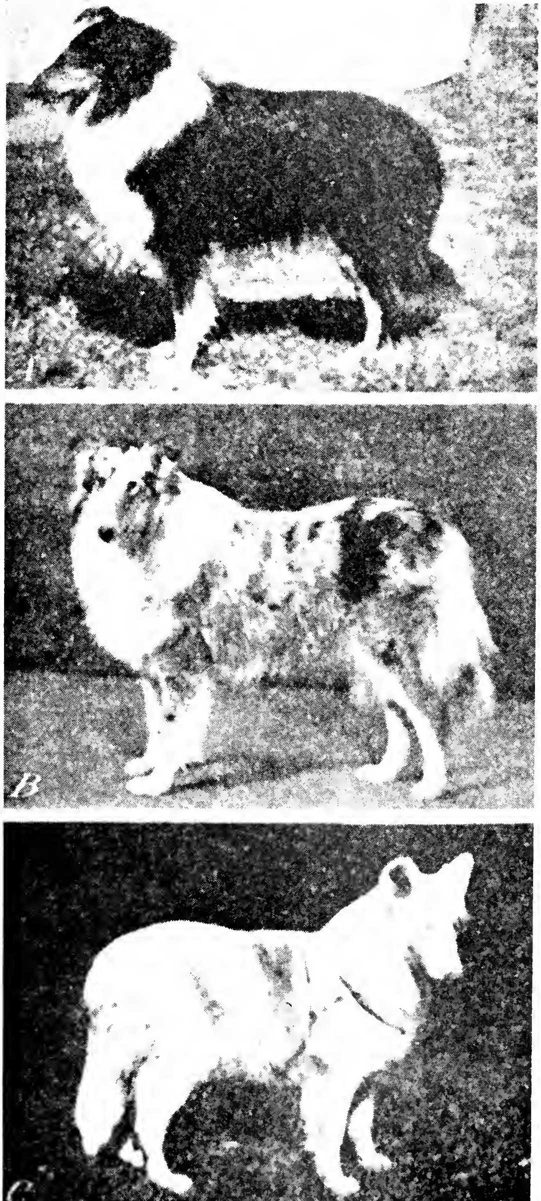


Fig. 349.—Inheritance in collie dogs. *A*, Normal tan and black collie with genes (vv); *B*, blue merle collie with genes (Vv); *C*, merle collie with defective hearing and eyesight and genes (VV). The homozygous (VV) merle spotted collies have defective sight and hearing, while in the heterozygous (Vv) condition some ill effects are shown. The latter usually have such pale blue eyes as to be wall-eyed, with a coat of intermediate blue merle. (After Mitchell. Reprinted from United States Department of Agriculture Yearbook, *Heredity in the Dog*.)

from body cells or somatoplasm. The continuity of type is thus maintained through a continuous lineage of germ plasm and germ cells from generation to generation (Fig. 350).

From the above statements, it is apparent that the germ plasm presents an unbroken descent from generation to generation. The history of this important process is known as the germ plasm cycle and may be divided into the following arbitrarily chosen periods or stages:

(a) The definite differentiation and segregation in the embryo of one or more *primordial germ cells,* which are the first cells set aside for the development of future sex cells (Fig. 351).

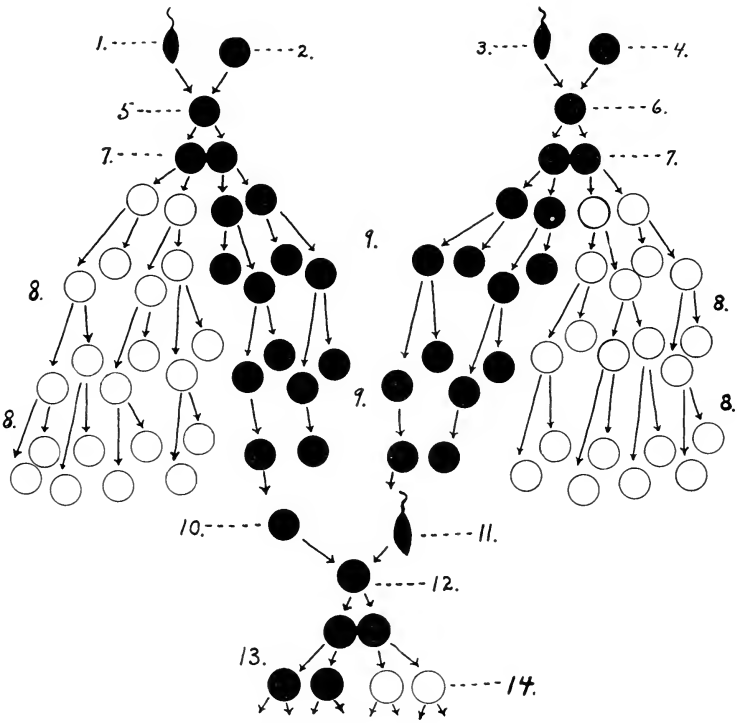


Fig. 350.—Continuity of germ plasm and the origin of somatoplasm. The germ plasm is represented by black and the somatoplasm by white. *1,* Sperm from mother's father; *2,* egg from mother's mother; *3,* sperm from father's father; *4,* egg from father's mother; *5,* zygote (fertilized egg) from which mother developed; *6,* zygote (fertilized egg) from which father developed; *7,* two cells arising from the zygote by cell division; *8,* numerous cell divisions of body cells (somatoplasm), which have arisen from the germ plasm originally; *9,* numerous cell divisions of the germ cells (germ plasm) which have arisen from previous germ plasm; *10,* egg produced by the mother; *11,* sperm produced by the father; *12,* zygote (fertilized egg) of the offspring from which two cells develop by cell division; *13,* germ cells (germ plasm) arising originally from the germ plasm of the zygote; *14,* body cells (somatoplasm) arising originally from the germ plasm of the zygote.

(b) A period of multiplication of the primordial germ cells, during which they increase in number.

(c) A period of rest, with no division or mitosis of the primordial germ cells, but a gathering into one or two groups to form the *primordia* or forerunners of the gonads (testes or ovaries).

(d) A second period of mitosis or multiplication which results in the formation of large numbers of *spermatogonia* (in male animals) and *oögonia* (in females). The stages in the embryologic development of man and the frog are given in an earlier chapter.

(e) Certain spermatogonia differentiate into nutritive or *Sertoli cells,* while other spermatogonia remain undifferentiated; in the female certain oögonia remain undifferentiated or germinal, while other oögonia differentiate into *nurse cells.*

(f) Then follows a period of growth without mitosis in which the spermatogonia and oögonia grow to form, respectively, the *primary spermatocytes* and *primary oöcytes.* In this stage the homologous chromosomes unite (appose) during the process of *synapsis* (union of homologous chromosomes), and crossing-over of chromatin materials (including genes) may take place.

(g) Next, there is a period of maturation in which the number of chromosomes is reduced to one-half the number ordinarily found in body cells or the soma cells of that particular species.. Cells with a reduced number of chromosomes are now called *secondary spermatocytes* and *secondary oöcytes.* In the formation of the secondary oöcyte there is an unequal division of the cell, producing one normal cell and a smaller, abortive, nonfunctional cell called the *polocyte* or polar body. Such a specialized type of two consecutive mitoses is called *meiosis* (reduction division) in which the sperm, or ovum, receives only a haploid (monoploid or simplex) number of chromosomes instead of the diploid (double) number usually present in cells.

(h) In the next stage the secondary spermatocytes produce a number of *spermatids,* which are the forerunners of the future male sex cells or sperm. The secondary oöcyte again divides by unequal division in this stage, producing a normal cell and a small polocyte. The polocyte of the previous stage has divided equally into two abortive, nonfunctional polocytes. We thus have three polocytes and one normal, functional egg arising from each of the original primary oöcytes.

(i) In the next step there is a transformation of spermatids into male *sperm.*

(j) The *egg* or *ovum* produced by the secondary oöcyte can now be *fertilized* by the *sperm.* In this process the hereditary factors or genes

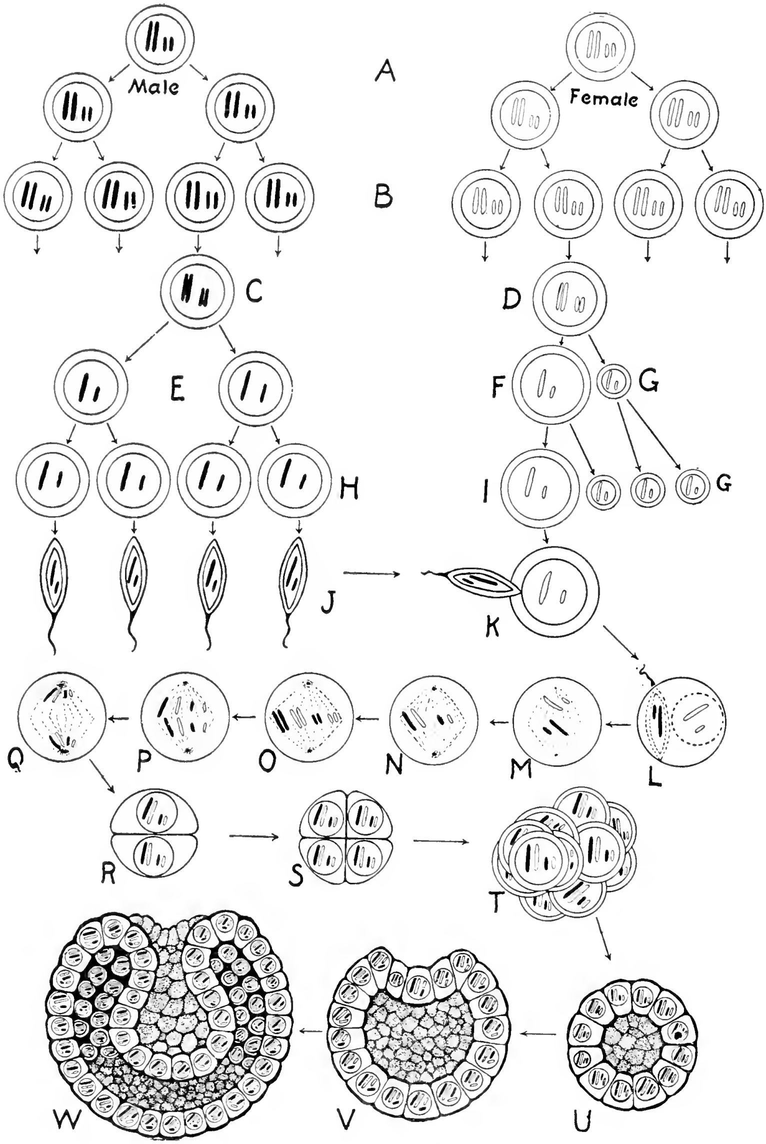


Fig. 351.—For legend, see opposite page.

carried in the chromosomes of the sperm are united or fused with the genes carried by the egg. In fact, fertilization is this fusion to a very great extent. It will be noted that each sex cell (sperm and egg) has contributed equal numbers of chromosomes to the resulting fertilized cell, known as the *zygote*. Thus each parent has an equal opportunity of contributing characteristics to the offspring, although this does not mean that each parent does contribute equally, merely the opportunity to do so. The number of chromosomes in the zygote is again normal.

(k) The zygote or the first cell of the new individual is really old material, but it is starting out on its journey primarily as an individual.

The zygote divides by mitosis, giving equal halves of each chromosome (also gene) to the two resulting cells. Hence, the inheritance of each of these two cells is the same as that of the previous cell, or zygote.

Mitosis of these two cells, as well as future cells, continues until there is a rather solid mass of similar cells (similar as far a hereditary factors). Such a mass of cells is known as the *morula stage*.

(l) The cells of the morula, after a certain length of time, arrange themselves in the form of a hollow sphere which is known as the *blastula stage*. The cells of this stage continue to divide by mitosis, thus increasing the size of the hollow structure. Naturally, this process cannot continue indefinitely, or we will have an animal which will be an enormous hollow ball, the wall of which will be only one cell in thickness.

(m) By a more rapid rate of cell division or mitosis at a certain point in the blastula, there is eventually an accumulation of cells at that point. These numerous cells usually push inwardly or invaginate, thus forming a structure which resembles a hollow ball, one side of which has been partly pushed in. Such an invaginated stage is known as the *gastrula stage*.

Fig. 351.—Germ plasm cycle. (The normal number of chromosomes in the body or somatic cells is considered to be four, or two pairs.) *A*, Primordial germ cells of both male and female; *B*, spermatogonia of male and oögonia of female; *C*, primary spermatocyte; *D*, primary oöcyte; *E*, secondary spermatocyte; *F*, secondary oöcyte; *G*, polar body or polocyte; *H*, spermatid; I, egg or ovum; *J*, sperm; *K*, entrance of the sperm into the egg during the fertilization process; *L*, zygote or first cell of the new individual in which the nuclear walls of both sperm and ovum disappear, and their contents tend to fuse; note the flagellum of the sperm left just outside the ovum wall; *M-R*, various stages in mitosis in which two cells are eventually formed, each with equal chromosomes; *S*, four-cell stage; *T*, morula or many-cell stage; *U*, blastula, or hollow-sphere stage (half-section); *V*, early gastrula stage (half-section view); *W*, later gastrula stage in which the three primary germ layers, the ectoderm, mesoderm, and entoderm, are shown; the mesoderm gives rise to primordial germ cells of the next generation.

The outer layer of cells of the gastrula is known as the *ectoderm layer;* the inner layer, the *entoderm layer;* and a middle layer, formed by both of the other layers, the *mesoderm layer.*

All these cells have received a portion of the original inherited materials which they will continue to pass on to future cells as they are formed. Thus, we see how an organism retains what it inherited at fertilization.

Various types of tissues arise from the three layers described above. Naturally, at some stage there will be set aside the first cell, or *primordial germ cell,* which will later develop into sex organs which in turn will produce sex cells. Thus, the cycle is completed. The reproductive organs arise from the mesoderm layer.

This cycle shows the continuity of life and the immortality of the germ plasm. The somatoplasm or body plasm which develops from the germ plasm is temporary and is mortal or dies.

18. **Inheritance or Noninheritance of Acquired Characters.**—Acquired characters are those responses or structural modifications acquired by an organism in its attempt to adjust itself to the various factors of the environment which surround it. Because most of the acquired characters affect only the body plasm (somatoplasm), it is considered that they are usually not inheritable, although some experimental evidence seems to point to the opposite view, at least in a few instances. Probably the correct conclusion is that most acquired characters are not inherited while a few may be. This does not mean that environment has no effect, because it is known that the development of even inherited characters of any individual organism depends upon the proper environment in which the inherited genes may develop properly. In other words, both nature and nurture are necessary for development.

19. **Human Inheritance.**—

Why Study Human Inheritance? A study of human heredity gives us an insight into the question of how and why we, as individuals, have come to be what we are and how and why we act as we do, through the interaction of various external and internal environmental factors and our inherited materials. We also may observe that human inheritance follows the same laws of heredity that pertain to other organisms. We may become familiar with the methods of race improvement; with the main applications of heredity and environment in our dealings with various sociologic, educational, and legal problems of our daily life. Through a knowledge of human heredity, we may have a more sympathetic understanding of human behavior, inheritances of diseases, and temperaments. Human inheritance is also considered in the chapter, Biology of Man.

Methods of Studying Human Inheritance: The following methods may be more or less successfully used in our study of human inheritance: (1) A study of genealogic records collected by families, public institutions, or scientific observers. (2) Selective mating which corresponds to experimental crossing in lower organisms. Certainly many defectives should never be permitted to pass these defects to their offspring. The latter will be personally handicapped and will in turn transmit them to their offspring. This is costly for human society at large. Undoubtedly, a wise selection of a prospective husband or wife can never be regretted from the standpoint of heredity. It is from studies of selected marriages that much of our information of human heredity has been secured. (3) Cytogenetic methods, in which a study of the cellular construction of the heredity mechanism of human beings is made, which should prove profitable. However, many obstacles prevent as much progress in this direction as might be desired.

Difficulties Encountered in Studying Human Heredity: The study of human heredity is quite difficult and complicated. This is true because: (1) The length of human life, especially the time required for individuals to reach maturity, is quite long, so that a single observer, at best, can see or study only three or four generations during his lifetime. This is a handicap because one of the necessities for the successful study of any heredity problem is the availability of a large number of successive generations. (2) Some individuals are reluctant to be studied. Frequently inaccuracies are recorded by observers because the persons who volunteer the information either willfully or unknowingly give the wrong information or impressions. (3) There is a lack of scientific and accurate records of human characters, if any record has been kept at all. Often, only the defects or particularly outstanding characters are listed or recorded. Certain individuals will give inaccurate information to "cover something up," or will give a type of information which will tend to make their family appear much better than it really is. Unless the observer can collect all his data personally, this is a severe handicap. (4) Many phases of human heredity are much more complicated than they are in lower organisms. With our present limited knowledge of heredity in general, we are unable to make great progress in the field of complicated human heredity. (5) The lack of definite description and definition of human traits, such as mentality, insanity, musical abilities, genius,

INHERITANCE OF HUMAN TRAITS

	DOMINANT	RECESSIVE
Hair	Dark	Blond
	Nonred	Red
	Curly (incomplete dominance)	Straight
	Abundant body hair	Little body hair
	Baldness (Sex influenced)	Normal
	White forelock	Normal
	"Dog-faced" (excess embryonic hair remains)	Normal
Skin and Teeth	Piebald (spotted pigmentation of skin and hair)	Normal
	Pigmented skin, hair, and eyes	Albinism
	Black (multiple factors; incomplete dominance)	White skin
	Dry scaly skin (ichthyosis)	Normal
	Freckles	Normal
	Absence of tooth enamel	Normal
	Normal	Absence of sweat glands
Eyes	Brown	Gray or blue
	Hazel or green	Gray or blue
	Pigmented eye color	Albino (nonpigmented)
	Cataract (congenital)	Normal
	Glaucoma	Normal
	Astigmatism	Normal
	Far sightedness	Normal
	Near sightedness	Normal
	Color blindness (sex-linked)	Normal
	Night blindness (congenital, defective twilight vision)	Normal
	Large eyes	Small eyes
	Long eyelashes	Short eyelashes
Ears and Nose	Free ear lobe	Attached
	Broad nostrils	Narrow nostrils
	High narrow bridge	Low broad bridge
	Curved nose ("Roman")	Straight nose
General	Short stature (multiple factors)	Tall
	Midget	Normal
	Dwarfism (short limbs)	Normal
	Polydactyly (more than five digits on hands and feet)	Normal
	Brachydactyly (short digits)	Normal
	Syndactyly (skin [web] between toes or fingers)	Normal
	"Lobster claw" (split hand or foot)	Normal
	High blood pressure (certain types)	Normal
	Anemia (certain inheritable types)	Normal
	Normal	Hemophilia (sex linked)
	Blood groups A, B (multiple factors)	Blood group O
	Blood groups (Rh factor) (multiple factors)	Normal
	Resistance to tuberculosis	Susceptibility
	Allergies (tendency)	Normal
	Diabetes mellitus	Normal

INHERITANCE OF HUMAN TRAITS—CONT'D

Nervous System	Normal	Schizophrenia (dementia praecox) (multiple genes)
	Normal	Juvenile idiocy (amaurotic) (nervous system degeneration)
	Maniac-depressive insanity (multiple genes)	Normal
	Normal	Microcephaly (small-headed idiot)
	Paralysis agitans (involuntary movement of hands, etc.)	Normal
	Huntington's chorea (involuntary twitching of head, arms, legs, etc.)	Normal
	Normal	Epilepsy (inheritable types) (multiple genes)
	Normal	Deaf-mutism
	Sick headache (migraine)	Normal

health, etc., has prevented our study of them in heredity. In other words, definite unit characters must be worked out so that we know their limits, variations, normalities, and abnormalities.

Human Pedigrees or Family Trees: Much of our information regarding human inheritance has been secured by the accurate collection of data and their proper evaluation and interpretation. A most desirable method of recording such data is in the form of a family tree or pedigree, several of which are shown in Figs. 352 to 356. In order for such a study to be of value, there must be a rather large number of individuals in the families, and there must be several generations. Every member of each family must be recorded accurately and none can be omitted, because if one is omitted it may be just the one who would throw most light upon the inheritance of that particular trait. The investigator must not guess in any case, since the guess may be wrong and consequently the final result inaccurate.

20. **Eugenics and the Future.**—Eugenics (u-jen′ iks) (Gr. *eu* well; *genos*, birth) attempts to improve the human race through scientific genetic measures. Race improvement may be brought about by attempting to prevent the hereditary transmission of undesirable traits or causing the transmission of desirable traits from generation to generation. Improvement of certain environmental conditions whereby that which is inherited may develop to the maximum of its inherent abilities may also prove beneficial, although this does not alter the genic composition of the individuals involved. No matter what the approach may be, there

is no substitute for good inheritance. The two parts to the solution of the problem of racial improvement are (1) the best possible inheritance (2) and the best possible environment in which specific inheritances can develop to their maximum.

The problems of preventing racial degeneration, let alone the question of racial improvements, are more numerous and extensive than can be treated here. With differences in birth rates between those with undesirable qualities and those classified as desirable, it becomes a major problem if we are even to maintain our present level of racial development.

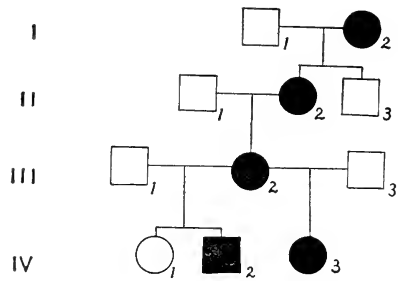


Fig. 352.—Pedigree of webbed toes (zygodactyly). Black symbols indicate persons possessing the trait. Squares represent males; circles, females. *I, II, III, IV* represent four generations. Note that Individual III_2 was married twice.

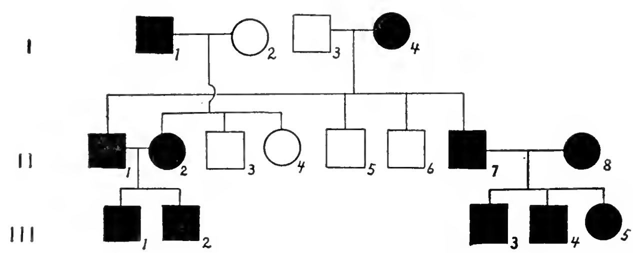


Fig. 353.—Pedigree of diabetes. Black symbols indicate persons having the trait. Squares represent male; circles, female. *I, II, III* represent three generations.

Some of the methods of eugenics which might be employed profitably are as follows: (1) An attempt to increase the number of offspring of parents who possess higher types of mental and physical traits. (2) The prevention of those with certain types of undesirable traits from propagating their kind by the rather simple process of sterilization. This is practiced to a greater or lesser extent in about thirty states and in many countries. An alternative to sterilization is complete segregation during

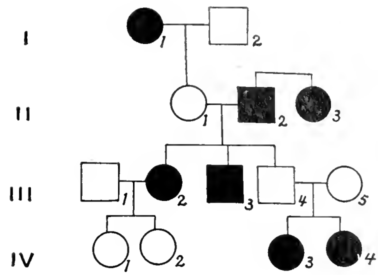


Fig. 354.—Pedigree of deafness (otosclerosis). Black symbols indicate persons having the trait. Squares represent males; circles, females. *I, II, III, IV* represent four generations.

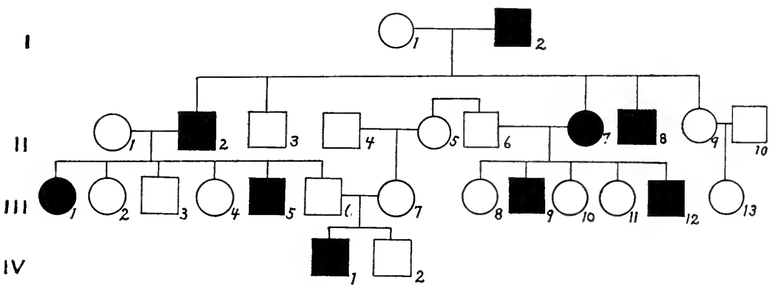


Fig. 355.—Pedigree of insanity (an inheritable type). Black symbols indicate persons having the trait. Squares represent males; circles, females. *I, II, III, IV* represent four generations.

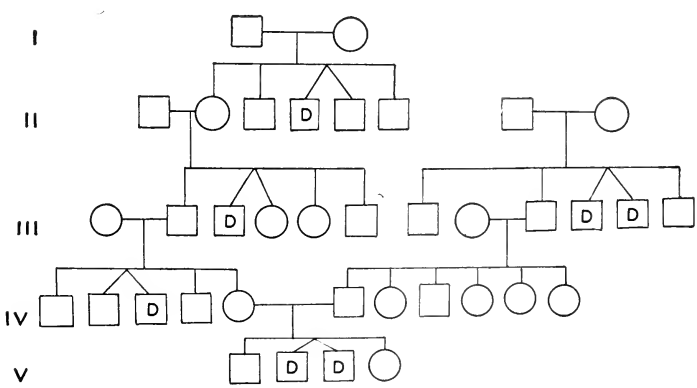


Fig. 356.—Pedigree of twinning. One or both twins died at birth in each case. Squares represent males; circles, females. *I, II, III, IV, V,* represent five generations. *D* represents death in infancy.

the period of procreation. Surveys show that sterilization is satisfactory to those sterilized and to society in general, and the cost is much less than the more expensive care and treatment of great numbers, either in or outside of institutions. (3) By methods of birth control, or the spacing of the birth of children and the regulation of their number commensurate with the abilities of the parents to care and train them properly. (4) By methods of contraception whereby fertilization may be prevented, although this method will probably be of least benefit to those groups who need it most—morons, imbeciles, idiots, etc. About 5 per cent of the people of the United States have an intelligence quotient (I.Q.) of 70 or less. It is up to the people of our country to decide what action is to be taken, but whatever action is taken should be in the light of scientific knowledge so that the results will be what are expected and desirable.

QUESTIONS AND TOPICS

1. Define genetics in your own words.
2. Discuss each of the methods used in the study of genetics. For what particular type of investigation is each method fitted?
3. Which method is best fitted for the study of human genetics? Discuss the reasons why certain methods cannot be used practically in human genetics.
4. Discuss reasons why the study of human genetics apparently has not reached the high level that has been attained in genetic studies of plants and lower animals.
5. What is the relationship between the study of genetics and a study of variations? What is the relationship between genetics and the general principles of evolution? How can genetics assist in solving problems in these two fields?
6. In what ways can hybridization of animals and plants be of practical value? List several specific examples to prove your points.
7. Discuss the properties of genes and genic action.
8. Discuss multiple genes and the interaction of genes, describing each type and giving an example of each.
9. Describe chromosomes, giving their outstanding characters. Do closely related animals or plants necessarily have identical or similar numbers of chromosomes? Give examples to prove your point.
10. Give all the evidence you can for believing that inheritance of detailed structures is due to chromatin rather than to other parts of the cell.
11. State and illustrate the laws of Mendelism.
12. Define (1) hybrid, (2) heterozygous, (3) homozygous, (4) dominant, (5) recessive, (6) phenotype ratio, (7) genotype ratio, (8) allele.
13. Explain what is meant by a monohybrid cross; by a dihybrid; by a trihybrid.
14. What is the value of the Punnet square or checkerboard in determining heredity?

15. Why do parents have duplicate genes for each specific character? From what source has each been received? Why, in the production of sex cells or gametes by parents, is it necessary to separate or segregate the allelomorphic genes? What happens when they are not segregated?
16. List reasons why it is desirable for each parent to contribute a gene for each character.
17. Do parents contribute equally to their offspring or do they merely have equal opportunity to contribute? Explain your statement.
18. Explain the difference between incomplete dominance and complete dominance.
19. Explain the phenomena of linkage and crossing-over. What are the results which follow each of these phenomena?
20. Contrast sex-linked and sex-influenced characters. Give several illustrations of each.
21. Discuss and give examples of the different types of chromosomal aberrations.
22. What are the chief causes of mutations? What are their chief characteristics? What benefits might be derived from mutations?
23. Explain how sex is determined. What has this to do with heredity?
24. Explain Weismann's theory of the continuity of germ plasm. Of what importance is this in heredity? Explain the origin of somatoplasm.
25. Explain all the more important stages in the production and maturation of germ cells. How does this affect heredity? Define meiosis and contrast with normal mitosis. Of what importance is synapsis in genetics?
26. List several human traits, telling which is dominant and which is recessive.
27. Problems in heredity:

Work the following problems in guinea pig inheritance using the following symbols: *B*, black hair; *b*, white hair; *R*, rough coat of hair; *r*, smooth coat of hair; *S*, short hair; *s*, long hair.

(a) Work out the entire monohybrid cross in the following by using the proper symbols. Carry through to the F_2 generation in each case: (1) Homozygous rough X homozygous rough; (2) homozygous rough X smooth; (3) heterozygous rough X heterozygous rough; (4) heterozygous rough X smooth.

(b) Work out the entire dihybrid cross through the F_2 generation using the correct symbols in the following: (1) Homozygous black-rough X homozygous black-rough; (2) homozygous black-rough X white-smooth; (3) heterozygous black-rough X heterozygous black-rough; (4) white-smooth X white-smooth.

(c) Work out the entire trihybrid cross through the F_2 generation using the correct symbols in: (1) BbRrSs X BbRrSs; (2) BBRRSS X bbrrss; (3) BbRRSs X bbRrSs; (4) bbrrSs X bbRrss; (5) bbrrss X bbrrss.

Work out the following problems in the inheritance in peas, using the following symbols: *T*, tall plant, *t*, dwarf plant; *Y*, yellow seed; *y*, green seed; *R*, round, smooth seed; *r*, wrinkled seed.

(a) Work the following monohybrid crosses as above: (1) Homozygous tall X dwarf; (2) heterozygous tall X heterozygous tall.

(b) Work out the following dihybrid crosses as above: (1) Homozygous tall-round X dwarf-wrinkled; (2) heterozygous tall-round X heterozygous tall-round; (3) homozygous tall-round X heterozygous tall-round.

SELECTED REFERENCES

Altenburg: Genetics, Henry Holt & Co., Inc.
Bauer, Fischer, and Lentz: Human Heredity, The Macmillan Co.
Beadle: Science in Progress, Yale University Press.
Beadle: The Genes of Men and Molds, Scient. Am. **179:** 30-38, 1948.
Beadle: Genes and the Chemistry of the Organism, Am. Scient. **34:** 31-53, 1946.
Burch and Pendell: Human Breeding and Survival, Penguin Books.
Burlingame: Heredity and Social Problems McGraw-Hill Book Co., Inc.
Colin: Elements of Genetics, P. Blakiston's Son & Co.
Dunn and Dobzhansky: Heredity, Race and Society, Penguin Books.
Fasten: Genetics and Eugenics, Ginn and Co.
Goldschmidt: Physiological Genetics, McGraw-Hill Book Co., Inc.
Hunt: Some Biological Aspects of War, Galton Publishing Co.
Holmes: The Eugenic Predicament, Harcourt, Brace and Co., Inc.
Holmes: Human Genetics and Its Social Import, McGraw-Hill Book Co., Inc.
Lindsey: Textbook of Genetics, The Macmillan Co.
Mohr: Heredity and Disease, W. W. Norton & Co., Inc.
Osborn: Preface to Eugenics, Harper & Brothers.
Popenoe and Johnson: Applied Eugenics, The Macmillan Co.
Rife: Dice of Destiny, Long's College Book Co.
Riley: Gentics and Cytogenetics, John Wiley & Sons, Inc.
Ruggles-Gates: Heredity in Man, The Macmillan Co.
Scheinfeld: You and Heredity, Frederick A. Stokes Co.
Shull: Heredity, McGraw-Hill Book Co., Inc.
Sinnott, Dunn, and Dobzhansky: Principles of Genetics, McGraw-Hill Book Co., Inc.
Snyder: Principles of Heredity, D. C. Heath & Co .
Stern: Principles of Human Genetics, W. H. Freeman & Co.
Waddington: Introduction to Modern Genetics, The Macmillan Co.
Walter: Genetics, The Macmillan Co.

Chapter 35

VARIATIONS AND ADAPTATIONS IN ANIMALS AND PLANTS

Variations (L. *variare,* to change) are differences, both structural and functional, which exist between offspring of the same parents or in individuals of the same species. Variation also may be considered as the process of changing from one organic condition to another. The ability to vary is an inherent property of living organisms by means of which they attempt to live more or less successfully in their changing environment.

Adaptations (L. *ad,* to; *aptere,* to fit) are the result of structural or functional changes on the part of an organism whereby it attempts to adjust itself, directly or indirectly, to the influences of the environment in order to live more or less successfully. The powers of adaptation are the result of the inherent responsive ability (irritability) of living substance to stimuli. Since environment is changing constantly, a living organism must have a corresponding ability to change in order to attempt to adapt itself to these environmental changes.

IMPORTANCE OF VARIATIONS

Variations make it possible for individual organisms to differ from each other and thus express their individualities. Educational, cultural, or sociologic progress is due to the inherent abilities of living organisms to vary. Differences in variations are due to (1) a difference in the hereditary materials with which the organism starts its life, (2) the effects of different environmental factors, external and internal, upon these original hereditary materials, and (3) the interaction of the above factors.

Variations are of great importance in our studies of heredity. The causes, limitations, heritability, and effects of variations must be fully understood in order to draw correct conclusions in the study of heredity. It can be readily seen that ignorance of variations might lead to the conclusion that a particular character is being inherited when in reality it is merely a natural, normal variation. By taking advantage of variations, improvements in races of organisms can be made. New varieties are often the result of the proper selection and development of variations. A study of variations reveals that all life is constantly changing. As often stated, the most invariable thing in nature is variability. The successful plant or animal is the one which successfully can take advantage of its numerous variations.

CLASSIFICATION OF VARIATIONS

According to Their Heritability.—*Somatic modifications or acquired characters* are not thought to be inheritable, except in a few instances. Somatic modifications are structural and functional adjustments of the bodies (soma) of individuals to differences in environment, either during or after their embryologic development. Examples of somatic modifications are muscular changes, calloused hands, tanned skins, acquired information, and acquired injuries to animals and plants.

Combinations result from the combining of the hereditary characters of two different races or strains, with the production of nothing distinctly new but a mere combining of the old characters. Certain types of combinations are inheritable. For instance, the angora coat of a mother guinea pig might be combined with the black color of the father to produce a combination of angora and black in the offspring.

Mutations or hereditary variations are always inherently inheritable if they are to be classed as mutations. They are variations resulting from spontaneous chemical changes in the chromatin of the cells or an abnormal number of chromosomes or their contained genes. (For a more detailed discussion of mutations, see the chapter on Heredity.) An example of a mutation is the production of a fruit fly with a narrow, elongated eye (called bar eye) from a normal, oval-eyed form.

According to Their Nature.—*Morphologic or structural variations* (Fig. 357) are usually differences in size, shape, color, or number of structures.

Physiologic or functional variations are usually differences in such things as vitality, nutrition, productivity, or secretions. These variations are usually a necessary corollary of morphologic variation.

Psychologic variations are variable expressions of the nervous system or the inherent sensitivity of living protoplasm. Such things as responses, dispositions, and mental abilities are well-known variations in this field.

Ecologic variations result from a fixed relation to environment. Variations brought about by environment might be illustrated as follows: Members of the same species of an organism differ or vary when they live under entirely different environmental conditions. The same species of plant will appear quite differently when grown in high altitudes and when grown at sea level.

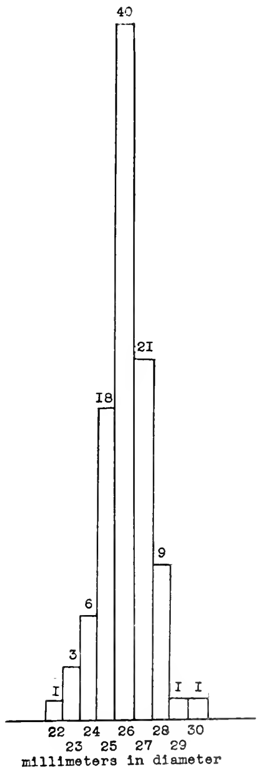


Fig. 357.—Diagram to show variations in snails. The diameters were measured of 100 land snail shells collected from an area with uniform environment. The diameters varied from 22 to 30 mm. The number of individuals of each diameter is represented by the upright blocks. Observe that these variations so plotted form a curve.

According to Gradations.—*Continuous variations or fluctuations* are common variations which occur in individuals with identical heredity; they grade one into another so as to make an unbroken, graded series from one extreme to the other. Examples of continuous variations are heights of human beings (Fig. 358), lengths of appendages, weights of individuals, sizes of leaves, heights of trees of the same species.

Discontinuous variations or mutations are the result of certain characteristics, appearing abruptly in an individual, which are so distinctly variable that they do not fit into the graded series of the main body. (Mutations are more fully considered in the chapter on Heredity.)

According to Their Direction.—*Orthogenetic or determinate variations* follow such a sequence that there is a straight development along specific and logical lines toward a definite goal. An example of this type is the ancestry of the horse (Figs. 359 and 360) in which the five-toed ancestor developed into the four-toed, then into the three-toed, and finally into the one-toed persent-day form.

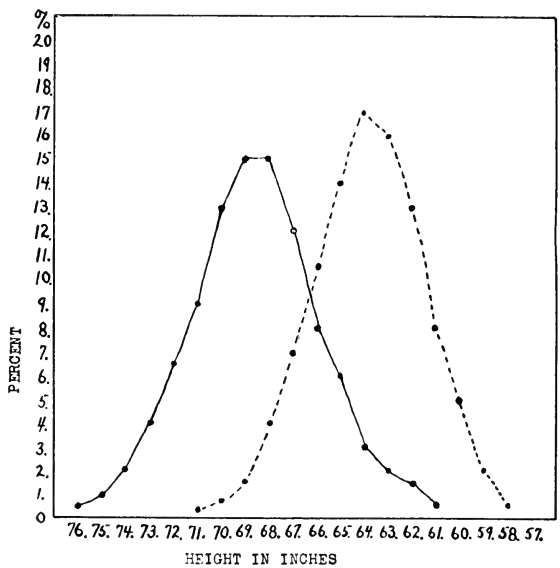


Fig. 358.—Distribution curves showing heights of college men and women including all ages; (——) represents the men; (----) represents the women.

Fortuitous or indeterminate variations fluctuate back and forth about a mean, apparently always within the same limits, generation after generation. For instance, the leaves of a tree may be larger one season than another and may continue to vary back and forth several generations, but they never fluctuate far from the mean size for leaves of a plant of that particular species. Such variations are caused by (1) recombinations

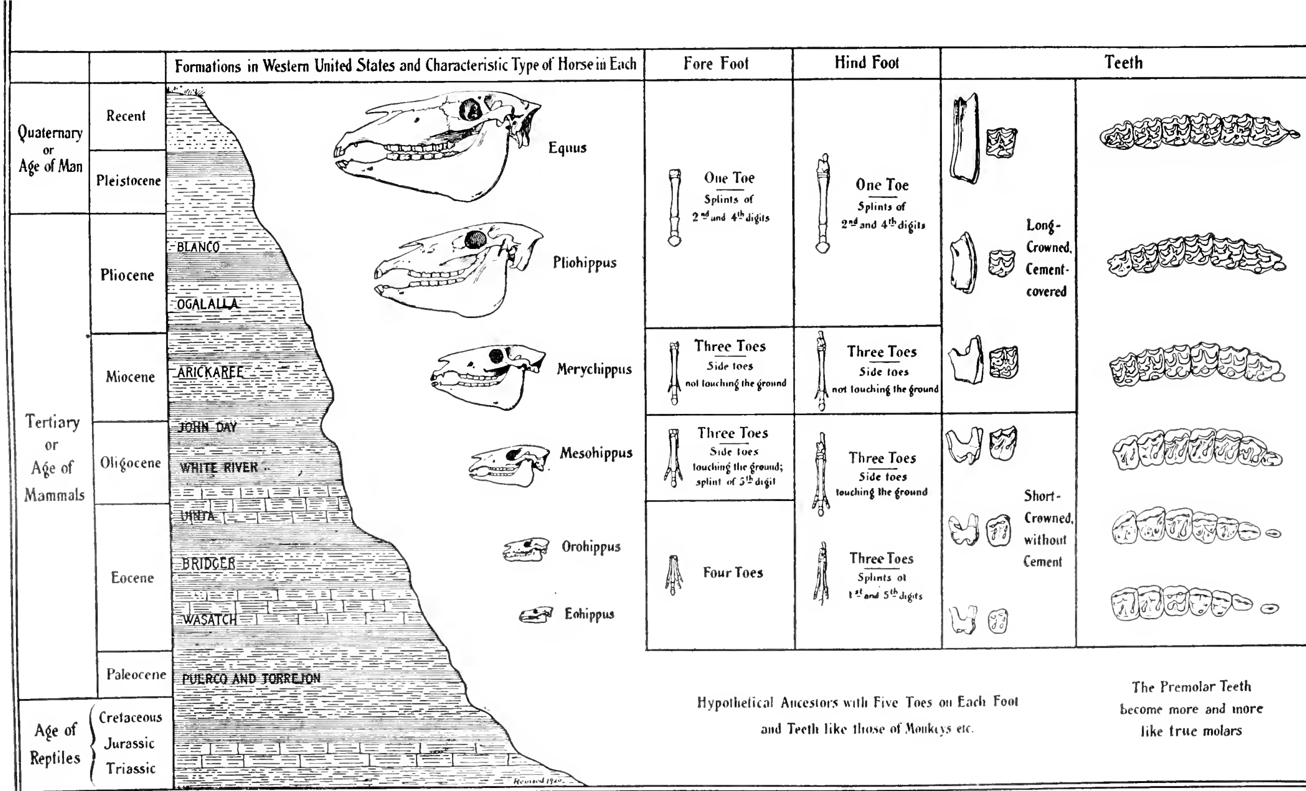


Fig. 359.—Evolution of the horse. Fossils of successive periods reveal marked and distinct difference in shape and size of the skull, in the bones of the feet, and in the structure and character of the teeth. (Compare with Figs. 320 and 360.) (Courtesy of the American Museum of Natural History.)

of one or more minor hereditary factors, (2) fluctuations in environment, or (3) the interaction of the above two causes.

According to Their Utility.—Variations may be such that they are *harmful, indifferent,* or *useful* to the organism possessing them. The utility is determined not only by the degree of variation but also by the type of environment in which the organism is asked to use that type of variation. What is useful in one environment might be harmful in another.

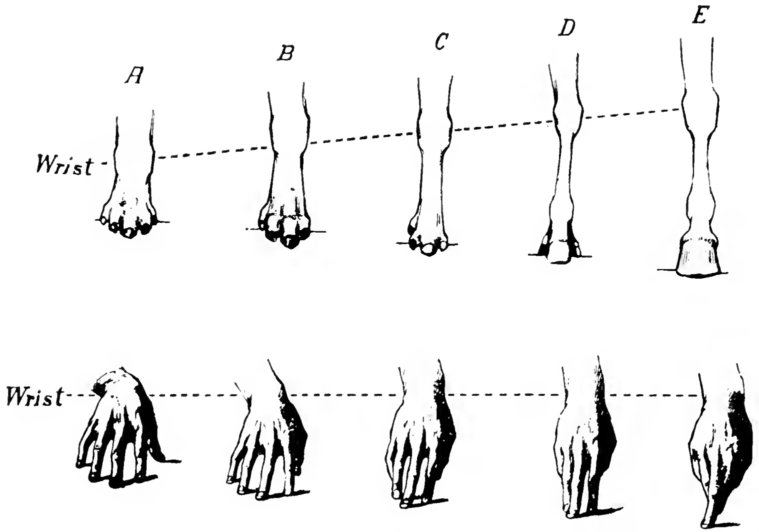


Fig. 360.—Comparative stages in the elevation of the horse's foot to the tip of the middle toe, as shown by the human hand. (Courtesy of The American Museum of Natural History.)

CAUSES OF VARIATIONS

The origins of variations are known as (1) germinal if they arise internally in the germ plasm, and (2) somatic if they arise in the somatoplasm (body plasm) due to external environmental causes, either during embryologic development or in adult life.

Charles Darwin considered variations as "axiomatic" or self-evident and thus needed no explanation. Lamarck regarded the causes of variations as being (1) intrinsic or physiologic, in which case the organism put forth an internal effort or response to successfully adapt itself to its particular surroundings or (2) extrinsic or external, in which the external environmental factors produced or caused the variations. In the above two cases, one cannot consider either one by itself, but in all probability the two working together would explain the causes of variations in a majority of cases. However, at one time the major or originating force might be external, while at another it might be internal. August Weismann believed that the causes of variations, at least the heritable ones, were inborn or intrinsic in the germ plasm. He suggested that sexual reproduction was for the purpose of mingling two strains of germ plasm, thereby doubling the possibilities of variations. Bateson suggested the futility of attempting to guess at the causes of variations, especially in the light of our present profound ignorance in this direction.

RESULTS OF VARIATIONS

Reflection will suggest many and varied results of variations. A few of the more important effects might be listed as follows: (1) Improvement of a race of animals and plants is possible by taking advantage of variations within them. (2) Through variations, individualities of organisms can be expressed. (3) With variations always present it is difficult to maintain pure lines or standard types. (4) The presence of variations provides for the diversification of species so that at least some of the individuals may be better fitted to cope with their environments, especially should the latter change, as they constantly are doing. Since environments are always varying, it is necessary that organisms vary also in order efficiently and harmoniously to fit into their environments. (5) Variations furnish valuable materials for the study of genetics. Without variations, the science of genetics would be much simpler and more easily understood. (6) Variations produce the "spice of life," for without them all organisms would produce such similarities that there would be few changes and all things always would be the same. (7) Education is based on variations. Without the possibility or ability of producing variations, attempts at education would be unnecessary and impossible. Through this process, the hereditary materials of an individual are subjected to the educational or environmental stimuli, thus bringing out and retaining such varieties of abilities as distinguish us one from another. Would it be desirable to have all individuals of equal ability, even though that ability might be high? Can two individuals really be equal?

ADAPTATIONS

Adaptations might be considered to be the result of those variations which are advantageous and enable an organism to live more successfully in its environment and in its struggle for existence (Fig. 361).

Adaptations may be internal (structure and activities of internal organs, tissues, etc.) or external (external phenomena), just as variations may be internal or external. The adaptive modifications in living organisms are apparently unlimited as we study the great variety of plants and animals. For example, the specific types of wings, legs, mouth parts, antennae, digestive tract, respiratory system, metamorphosis, etc., are among the most conspicuous adaptations of the numerous kinds of insects to fit them into various environments. Through adaptations, certain plants have become able to live in the arid regions of the desert

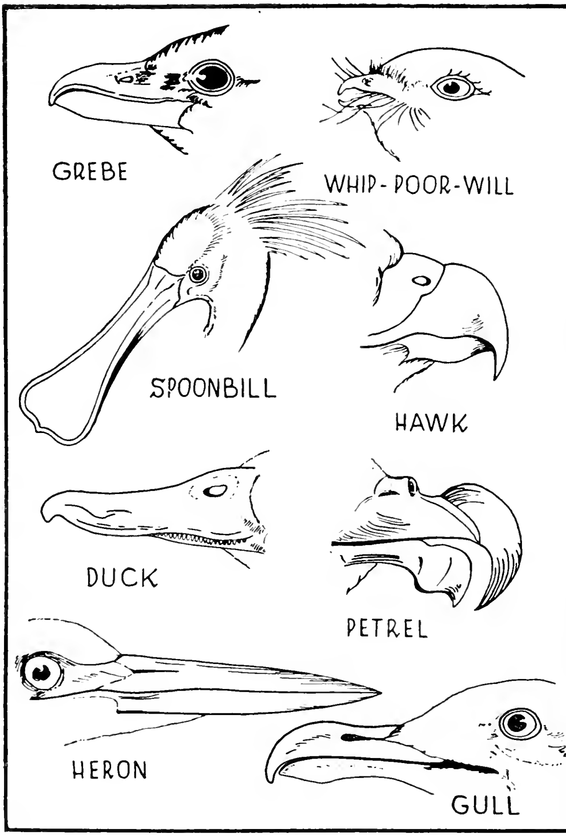


Fig. 361.—Adaptations of the bills of birds, showing variations in structure for different uses. The generalized bill of the Grebe is for eating seeds; spoonbill and duck, for straining mud; the heron, for catching fish; whippoorwill, for catching insects; hawk, for tearing flesh; petrel, for catching crustacea; gull, for devouring refuse. (From Atwood, A Concise Comparative Anatomy, The C. V. Mosby Co.)

(cacti) and some are able to live in swampy areas (cattails, etc.), while others are able to live in the frigid regions of the poles or on mountain tops (certain mosses, shrubby plants, etc.). An organism may be rendered unfit for a particular environment because of the presence of certain variations and their attendant adaptations, while that same organism with its same traits might fit perfectly into a different environment. Successful living depends upon the mutual fitting in of inherent abilities and the surrounding environment. An adaptation may be regarded as the result of developmental changes resulting from inheritable variations, with the retention of those which are advantageous. Undesirable variations may have resulted in the destruction of other organisms through the "struggle for existence" in the process of *natural selection*.

Motile organisms may be able to move into an environment which may prove to be more satisfactory for their particular abilities. The assumption is that the degree of adaptability to an environment or the ability to seek and find a more desirable environment commensurate with its abilities is an influential factor in the successful struggle for existence.

Adaptations may be *divergent* (L. *divergere,* to incline away) or *convergent* (L. *convergere,* to incline together). In *divergence (adaptive radiation),* species of living organisms that are somewhat closely related tend to radiate in various directions into different environments and become modified accordingly. From the standpoint of locomotion, the various species of mammals have become adapted to live on land (walking and jumping), in the ground (digging), in water (swimming), in trees (hanging), and in the air (flying). In *convergence (parallelism),* species of organisms belonging to different orders, families, etc., tend to become adapted to the same type of environment by means of similar modifications. For example, the wings of bats and flying squirrels are adapted for flying, the forelimbs of badgers and ant eaters for digging, the forelimbs of seals and porpoises for swimming, the limbs of sloths and gibbons for hanging, etc. In *convergent (parallel) evolution* there is a development of similar traits or features along similar lines among unrelated, or distantly related, groups of organisms. An example of convergent evolution among members of widely separated (distantly related) families of plants growing in similar environments is the development in desert-inhabiting cacti, spurge, live-for-ever, etc., of such similar characters as reduction or complete absence of leaves, formation of heavy layers of protective cutin, production of spines, and development of water storage tissues.

Some of the most striking adaptations in animals are the various colors and patterns which characterize certain species. Colors may be due to rough, reflecting, physical structures which scatter (*diffuse*) light into its various colored rays, or they may be due to the deflection of rays of light from the straight paths as they pass obliquely from one medium to another through the process of *refraction*. Hence, the physical structure of the bodies of insects, the scales of fish, the feathers of birds, etc., are responsible for many bright colors. Other colors in animals are due to chemical *pigments* which frequently are in special cells called *chromatophores* (kro′ ma to for) (Gr. *chroma*, color; *phoreo*, to bear). The latter contain pigments such as black, brown, yellow, orange, red, etc., which vary with the species and may even change size and shape in individual organisms, thereby altering the coloration (Fig. 209). In general, the coloration of an organism which blends with its environment renders it more or less inconspicuous in that particular habitat, while the same coloration in a different habitat may make it conspicuous. The colorations in animals may serve such natural purposes as protection (concealment) or aggression, warning or signaling, assisting in courtship and selection of mates, etc. Certain species seem to change colors rather quickly to more or less blend with the environment, as shown by the changing colors of certain fish, chameleons, etc. Others change colors with the seasons (seasonal coloration), thereby securing protection or being supplied with characters which conceal them for aggressive purposes. The weasel and ptarmigan (bird) change to white in the autumn and to dark colors in the spring.

Some organisms are so constructed as to resemble other organisms or even nonliving objects (*protective resemblance*), thereby being protected somewhat. The walking stick (an insect, order *Orthoptera*) structurally resembles a dead twig. The underside of the wings of the "deadleaf" butterfly (*Kallima*) of India resembles a dead leaf when folded at rest. The caterpillars of certain insects also resemble sticks. The viceroy butterfly (*Basilarchia*) greatly resembles the disagreeably tasting Monarch butterfly (*Danaus*) so the former may be somewhat immune from attack by birds. Such a phenomenon involving a model and mimic is called *mimicry*. Some animals may not use their colorations or special structures for protection but for aggression. This seems to be true for tigers, lions, tree frogs, praying mantes, etc., in which they may blend into their surroundings, thus permitting them to approach their prey more easily.

QUESTIONS AND TOPICS

1. Define variations and give examples you have observed.
2. List and discuss the values of variations in Nature. What would happen in the living world if nothing changed?
3. Classify variations in several different ways with examples of each type.
4. Discuss each of the various causes of variations.
5. Discuss the results of variations in the plant and animal worlds.
6. What do the various fossils of such animals as the horse found in successive periods in the earth's strata prove?
7. How might mutations explain the origin of certain new species or types of plants or animals?
8. Explain the statement that "mutations are the hope and the despair of plant and animal breeders."
9. Describe specifically how you might produce variations in certain plants and animals.
10. What is the relationship between variations of the inheritable type and descent with change (evolution)?
11. Define adaptations and give examples you have observed.
12. Contrast divergence (adaptive radiation) and convergence (parallelism), giving examples of each.
13. Discuss coloration as to causes and the uses to which it may be put, including examples of each type of coloration.
14. Explain protective resemblance, giving examples which you may have observed.
15. Explain seasonal coloration, including some examples you may have observed.

SELECTED REFERENCES

Allee: Animal Aggregations, University of Chicago Press.
Allee et al.: Principles of Animal Ecology, W. B. Saunders Co.
Child: Individuality in Organisms, University of Chicago Press.
Cott: Adaptive Coloration in Animals, Oxford University Press.
Daubenmire: Plants and Environment, John Wiley & Sons, Inc.
Oosting: The Study of Plant Communities, W. H. Freeman & Co.
Sears: Life and Environment, Columbia University Press.
Thayer: Concealing Coloration in the Animal Kingdom, The Macmillan Co.

Chapter 36

LIVING ORGANISMS—THEIR ORIGIN, CONTINUITY, DEVELOPMENT, AND DESCENT WITH CHANGE

I. ORIGIN OF LIFE

A. Abiogenesis (Spontaneous Generation)

A majority of scientists up to the seventeenth century believed in abiogenesis, which stated that living things, especially the lower types, arose spontaneously from nonliving substances. Such beliefs as the following were common: Field mice were thought to arise spontaneously from the mud of the Nile River. Aristotle (384-322 B.C.) believed that eels (fishes) arose spontaneously from nonliving materials. Kircher stated that he actually saw animals arise through the action of water on the stems of plants. Von Helmont (1577-1644), a Flemish physician, believed that house mice were generated from pieces of cheese placed in bundles of rags. Flies were thought to arise spontaneously from dirt, manure, and decaying meats. Anaximander (611-547 B.C.) thought that air imparted life to all living things.

Reasons Why Abiogenesis Was Believed.—Abiogenesis, or spontaneous generation of things, was believed because the complex life cycles of many of the animals and plants were not understood at that time. Many microscopic stages of certain living organisms were not seen or escaped methods of observation, because the microscope had not been sufficiently perfected to observe accurately. This lack of accurate knowledge formed a natural setting for such a theory as abiogenesis. Experimental methods of attacking such problems were not yet developed. Scientists attempted to prove by hearsay, supposition, or discussion rather than by experimental investigation. Rather than prove by exact evidence, they would attempt to prove by more or less logical reasoning.

Needham, in 1749, believed he had demonstrated the spontaneous origin of minute living organisms in infusions which he had boiled and sealed in flasks. By boiling he thought he had killed all living matter from which living organisms could arise later. The living organisms which later arose in his flasks probably arose from living materials which had not been killed by boiling.

B. Biogenesis (Life From Life)

Spallanzani (1729-1799) stated that Needham's results were inconclusive because they were obtained by insufficient sterilization of the infusions in the flasks. The chemists also entered the controversy by stating that free oxygen which is an essential material for life processes was excluded by Spallanzani in his experiments, thus preventing the possibility of spontaneous generation. To answer the latter point, various investigators during the first half of the last century showed that thoroughly sterilized infusions never developed living organisms even when sterile air was admitted. The air was sterilized by heating or by passage through acids in order to remove the suspended "dust particles" on which living substances were attached.

Francisco Redi (1626-1698), an Italian scientist, by a simple experiment of protecting decaying meat from contamination by flies, demonstrated that the maggots of these flies did not arise spontaneously from the meat, but that they developed from living eggs deposited by living flies. Redi's results definitely formulated the theory that "life must arise from living organisms" and cannot arise spontaneously from nonliving sources.

Louis Pasteur (1822-1895), by means of a special type of flask, convincingly proved that the source of life, which so rapidly appeared in infusions exposed to the air, was the air itself, or rather the life existing in the air. It was thus contended that much of the dust of the air was made up of microorganisms in a dormant condition ready to become actively alive when suitable environmental conditions, such as moisture, temperature, and food, were encountered. He stated that such organisms were the causes of certain chemical changes, fermentations, putrefactions, and certain diseases. Pasteur thus laid a rather accurate foundation for the germ theory of diseases and many chemical activities.

II. ORIGIN OF LIFE ON THE EARTH

Geologists and astronomers tell us that the condition of the earth at one time was such that life could not exist but that life was finally established hundreds of millions of years ago and has existed continuously since.

Theories for the Origin of Life on the Earth

1. **Cosmozoa Theory.**—This theory suggests that, because of the complexity of living matter and the establishment of biogenesis, life came to the earth from some other part of the universe. It was assumed that certain heavenly bodies of the universe have always been the abode of life and that life in a latent state was carried to the earth from them by small particles of those planets on which it existed at that time. This does not explain the real origin of life at its very beginning. This theory is based on two unproved assumptions: (1) that life exists or has existed elsewhere in the universe and (2) that life can be maintained during the interstellar voyage to the earth.

We have proof that certain present-day organisms under the influence of unfavorable environments can resist dryness, heat, cold, etc., although this does not prove that their remote ancestors may have had similar or greater properties of this type. These would be necessary to resist in transit such factors as the effects of light waves, extremely low temperatures, absence of water vapor in cosmic space, radiations, etc.

2. **Pflüger's Theory.**—Pflüger assumed that the earth was originally a superheated, incandescent mass from which arose a combination of carbon and nitrogen atoms to form *cyanogen* (CN). This union can occur only at high temperatures and takes up a large amount of energy in the form of heat which contributes energy to the organic protein compounds of which living substances (protoplasm) are composed.

3. **Moore's Theory.**—Moore suggests that life arose under suitable conditions from the inorganic elements of a cooling earth by a process of continuous complexification; that is, matter in general will tend to assume more and more complex forms in labile equilibrium. He suggests that the process of complexification is inherent in all matter and that, when a sufficiently complex stage is once reached in this evolutionary process, life invariably will be an attribute. Atoms, molecules, oxides, carbonates, colloids, and then living organisms arise as a result of these successive operations. This theory attempts to bridge the gap between nonliving and living substances.

4. **Allen's Theory.**—Allen suggests that at a time when the physical conditions of the earth were much as they are now some reactions as the following occurred: Energy coming from the sun was absorbed by the iron in damp earth or water and acted on certain raw materials in such a way as to dissociate and rearrange the atoms. This interaction between the nitrogen, carbon, hydrogen, oxygen, and sulfur resulted in

their accumulation in the water or damp earth. Later, still further actions followed because of the lability of the nitrogen compounds until poorly organized, diffuse substances were formed which still later changed into living protoplasm.

5. **Troland's Theory.**—At some moment in the earth's history a small quantity of a certain autocatalytic enzyme spontaneously appeared in the warm ocean waters. It then combined with a drop of rather inactive oily liquid, thereby increasing its rate of activity and size until the drop became split into smaller globules, giving rise to a substance having the power of continued and indefinite growth.

6. **Osborn's Theory.**—Osborn assumes that the air, water, and earth had all the necessary chemical elements and that they arranged themselves into water, nitrates, and carbon dioxide at a temperature between 6° and 89° C., long before sunlight could penetrate the various vapors of the atmosphere. He suggests that these materials so formed captured and transformed the electric energy of the chemical elements constituting living protoplasm and this property probably later developed only in the presence of heat energy from the sun or earth. First, there was a grouping of the several "life elements," and then by mutual attraction their arrangement in a state of colloidal suspension, with numerous actions and reactions, until an organic, living organism was formed which was distinct from the various other aggregations of the nonliving or inorganic matter previously brought together and held by forces of gravity.

7. **Transcendental Theory (Creation).**—This religious answer suggests that life was created by an agent working outside the realms of matter and science.

III. CONTINUITY OF LIFE

If, as we now believe, all life arises and has arisen from preexisting life (biogenesis), then the stream of life is continuous from the beginning of life to the present time (Figs. 350 and 351). The life of an individual organism is merely one link in the endless chain extending from the distant past to the future. After a study of the metamorphosis and life cycles of various animals and plants, we see that life transferred to the offspring by one or more parents is carried by that offspring through its various stages of development to maturity, when it in turn will pass life on to its offspring. This is possible because of the continuity of living substance between parents and their offspring (Chapter 34). Reproduction is for the purpose of continuing the life of a particular species after it is once started. The germ cell cycle is considered in Chapter 34. Two of the more important phases of the process (Fig. 351) are (1) the production of germ cells and (2) the maturation of the germ cells.

IV. DEVELOPMENT OF LIVING ORGANISMS

Development may be defined as the bringing to the fore what is already present but latent in an organism. The amount and type of development of a particular organism depend on (1) its particular inheritance and (2) the external and internal environmental factors which surround it and in which it must develop. All living organisms are affected by such factors as the quantity and quality of the food, amount of water available, quantity and quality of light, the improper elimination of their waste materials, their type of activity, the presence or absence of vitamins, enzymes, etc.

V. DESCENT OF ORGANISMS WITH CHANGE (EVOLUTION)

A. Evidences of Descent With Change

Evidences of descent with change have been secured from such sciences as (1) paleontology (science of fossil remains), (2) taxonomy (classification), (3) comparative embryology, (4) comparative anatomy, (5) comparative physiology, (6) biogeography (geographic distribution), and (7) genetics and variations.

1. **Evidences From Paleontology.**—Geologists can determine, in most cases with remarkable accuracy, the chronologic succession in time of the various strata composing the earth. The fossils of these various strata testify to the order of appearance and disappearance of various types of animals and plants on the earth, the more recent appearing nearer the surface.

Two examples of descent with change may be cited. (1) Birds seem to have evolved gradually from a reptilelike ancestor, because, in spite of superficial dissimilarities (such as the scaly-skinned, cold-blooded reptile and the feathered, warm-blooded bird), there are many fundamental structural and functional similarites not only between adult reptiles and birds but also between their embryonic stages. Fossil remains of a reptilelike bird *(Archaeopteryx)* show a connecting link between reptiles and birds as they are known today (Fig. 362). (2) The horse also has developed to its present status through a series of successive changes. These developmental changes through which the ancestors of our modern horse are believed to have gone are shown in the evolution of the horse (Figs. 359 and 360).

2. **Evidences From Taxonomy (Classification).**—A comparative study of the various species of animals and plants reveals a very great similarity; in fact, so great that it is difficult to decide where one species with

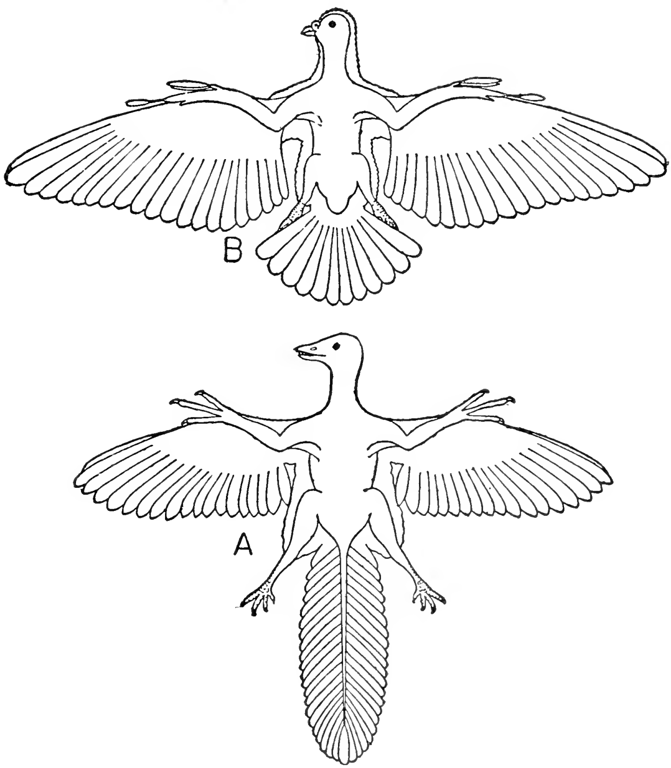


Fig. 362.—The *Archaeopteryx, A,* a reptilelike bird of the Upper Jurassic period compared with the pigeon *(Columba livia), B.* (From Lull: Organic Evolution. By permission of The Macmillan Company, publishers.)

its variations ends and another species with its variations begins. The intergrades (divergent individuals with a certain species) frequently are very similar functionally and structurally to those of a closely related species. When we attempt to classify similar types of organisms, we see clearly the close anatomic and physiologic relationships between many of them. What is the explanation for these similarities? Are living

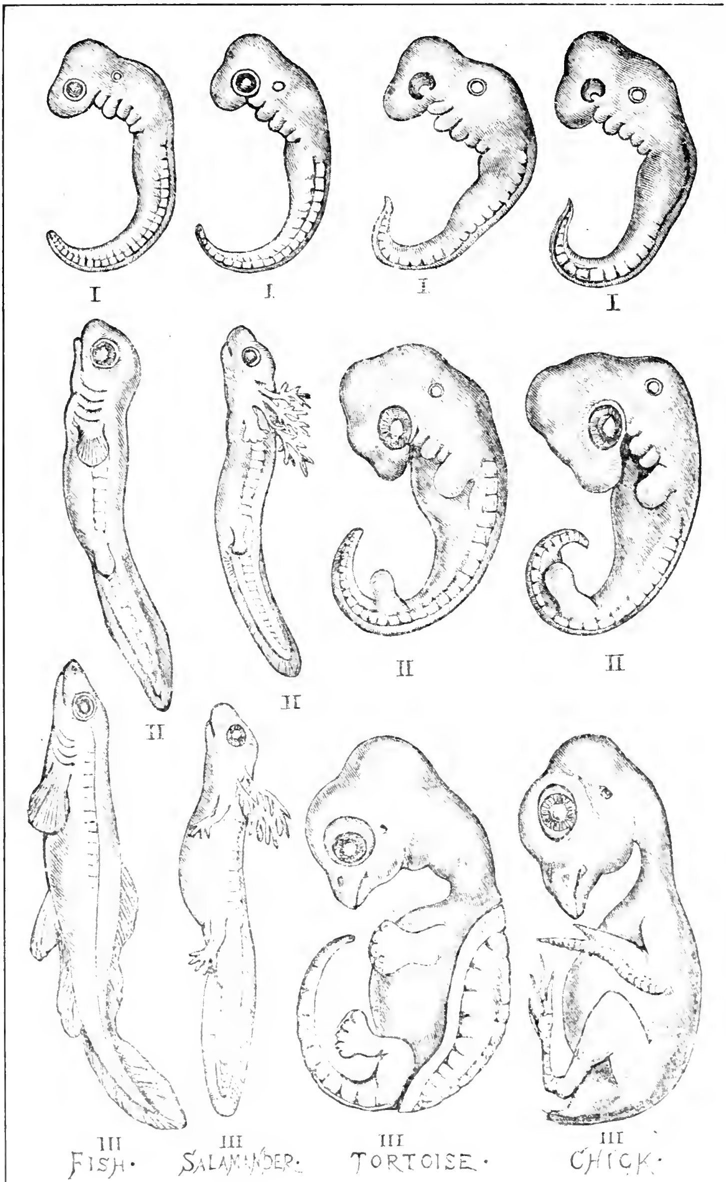
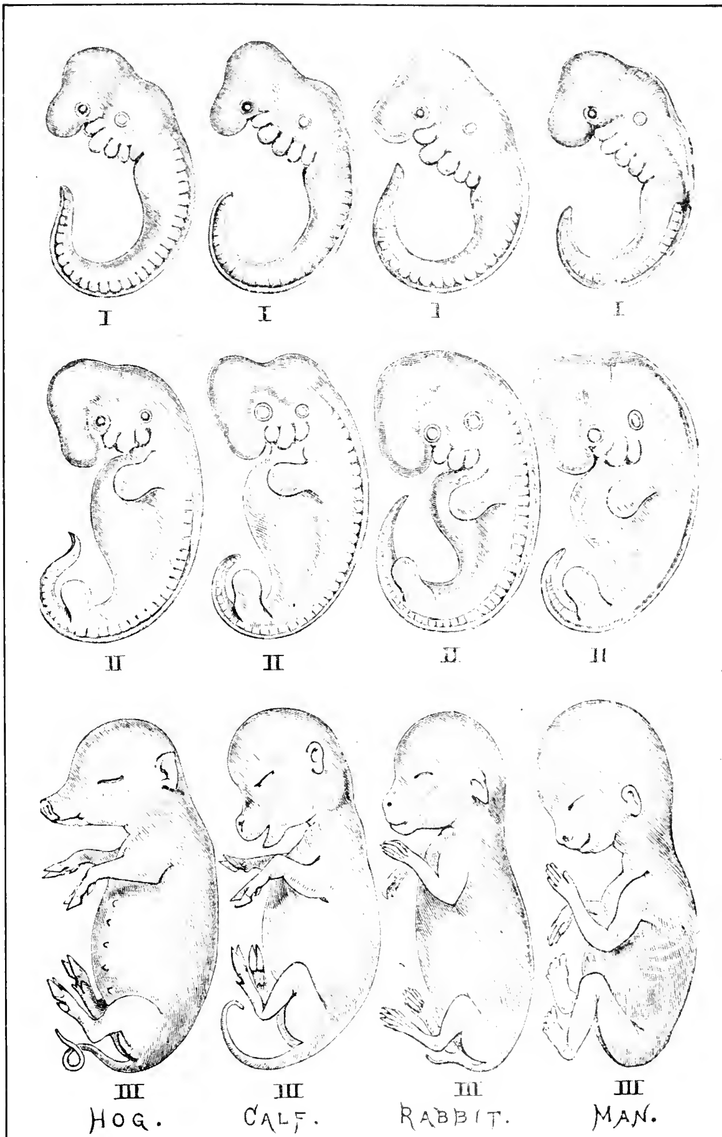


Fig. 363.—Parallelism in development of vertebrate animals. The upper row shows very similar stages of the eight different species of embryos; the middle row shows the different species becoming somewhat distinct; the lower row shows



still greater differentiation in the various species. Note the gill slits, metameres and external tails in the early stages of all types. (From Romanes: Darwin and After Darwin, published by the Open Court Publishing Company.)

things constantly changing? What things in your experience do not change? Does it decrease the glory and magnitude of Nature to have living things constantly evolving or changing according to definite, controllable laws? Would it increase our respect for the marvels and magnificence of Nature by having living things which would be static and unchanging? Could we make progress or educate ourselves if living protoplasm did not have the ability to change and evolve? What would

	AURICLES	VENTRICLES
Fishes	*One;* receives blood returning through veins from entire body	*One;* receives blood from auricle and pumps it through gills on its way to all parts of the body
Amphibia (frogs, toads, etc.)	*Two separate;* left receives blood from veins from lung; right receives blood from veins from all parts of body	*One;* receives blood from both auricles and pumps the mixture through arteries to all parts of the body
Reptiles (lower types; lizards, snakes, turtles)	*Two separate;* left receives blood from veins from lungs; right receives blood from veins from all parts of the body	*Two partially separated;* right receives blood from right auricle; left receives from left auricle; blood from the two auricles is mixed in the partially separated ventricles and pumped to all parts of the body
Reptiles (higher types; alligators, crocodiles, etc.)	*Two separate;* left receives blood from veins from lungs; right receives blood from veins from all parts of the body	*Two completely separated;* right receives blood from right auricle; left receives blood from left auricle
Birds (adults)	*Two separate;* left receives blood from veins from lungs; right receives blood from veins from all parts of the body	*Two completely separated;* right receives blood from right auricle; left from left auricle; left ventricle pumps blood to all parts of body; right ventricle, to lungs
Mammals (adults)	*Two separate;* left receives blood from veins from lungs; right receives blood from veins from all parts of the body	*Two completely separated;* right and left have same functions as in birds

Fig. 364.—Chambers of the hearts of vertebrates.

be the state of affairs if all things remained constant? Is it not logical and desirable to believe that all living things constantly change more or less and that such changes are controlled by certain natural laws? The answers to these questions will prove beneficial in laying the foundation for proper study of the descent of organisms with change.

3. **Evidences From Comparative Embryology.**—A comparative study of the embryologic stages through which animals pass reveals a wide-

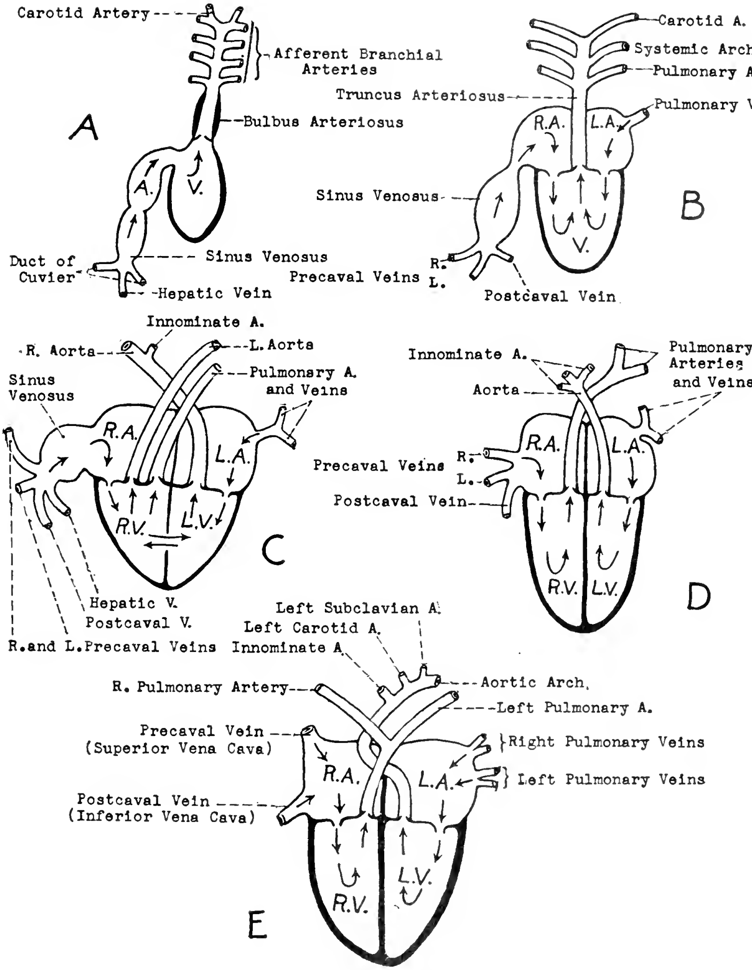


Fig. 365.—Hearts and blood vessels of vertebrates (somewhat diagrammatic). *A*, Fish (Pisces); *B*, frog (Amphibia); *C*, turtle (Reptilia); *D*, pigeon (Aves); *E*, man (Mammalia). Arrows show direction of blood flow. *A* (within heart) shows the auricle; *V* (within heart) shows the ventricle; *R*, right; *L*, left. *A* (outside heart) shows an artery; *V* (outside heart) shows a vein. The terms auricle and atrium (plural, atria) are sometimes used interchangeably.

spread general correspondence of the developmental stages in higher forms with the existing adult stages of lower forms. The history of the embryologic development of an individual frequently corresponds in a general and broad way to the history of the development of the race as a whole (Fig. 363). In other words, the *development of the individual recapitulates the ancestral descent of the race; ontogeny repeats phylogeny.* Read further in regard to ontogeny, phylogeny, and recapitulation (biogenetic) theory.

A study of the embryologic development of the heart of a bird or mammal shows that the various stages through which its development occurs really succeed each other in the same general way from the two-chambered to a four-chambered condition, as is shown when we pass from the lower vertebrates, such as the fishes, up through the amphibia, reptiles, and birds to mammals (Figs. 364 and 365).

A similar comparative study of the brains (Fig. 366), reproductive systems, skeletal systems, and digestive systems of these various vertebrates shows a similar condition in which the organs of the higher animals during their development pass through stages which correspond in general with the larval or adult condition of similar organs in the lower forms. Thus, the knowledge of the anatomy of an animal gives a broad and general idea as to its type of embryologic development.

These similarities of lower and higher types of organisms found by embryologic studies suggest a similar inheritance as a basis and probably an actual blood relationship between them. The only other alternative is that the same "blueprint" with slight modifications and alterations was used in the process of specially and individually creating each of the various species.

4. **Evidences From Comparative Anatomy.**—

a. **From Gross Comparative Anatomy:** A detailed comparative study of the anatomy of apparently different types of animals reveals a multitude of similarities which really overbalance the more visible dissimilarities which they possess. For instance, the differences possessed by the five classes of vertebrates are relatively slight when compared with the many basic and fundamental resemblances which they all possess to more or less degree.

The forelimbs of the frog, lizard, bird, horse, and man, for example, are constructed on the same general structural plan and arise in a similar way embryologically. They are thus said to be homologous struc-

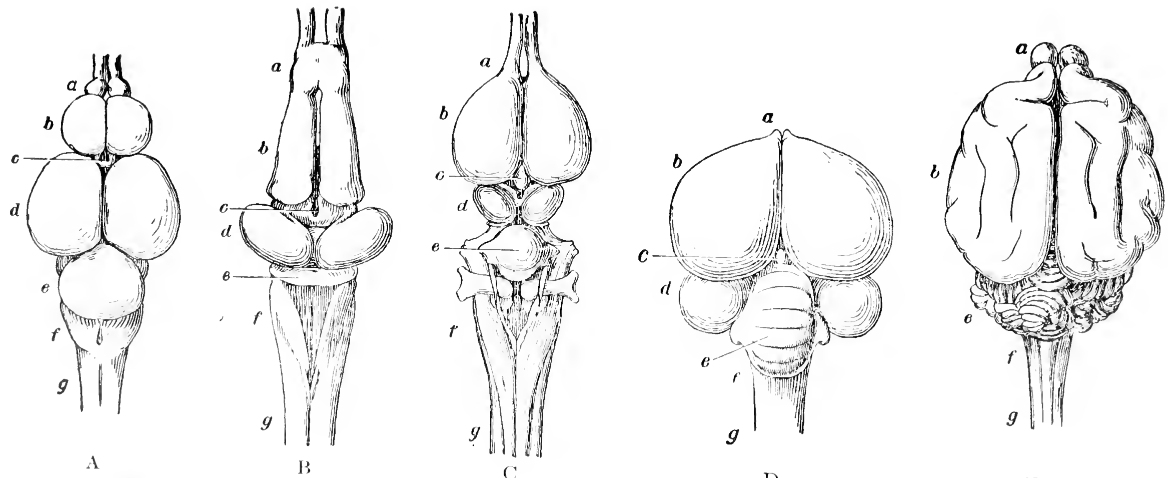


Fig. 366.—Brains of representative vertebrates (dorsal view). *A*, Bony fish (perch); *B*, amphibian (frog); *C*, reptile (alligator); *D*, bird (pigeon); *E*, mammal (cat); *a*, olfactory lobes; *b*, cerebral hemispheres; *c*, pineal body (endocrine gland); *d*, optic lobes; *e*, cerebellum; *f*, medulla; *g*, spinal cord. (From Woodruff; Foundations of Biology. By permission of The Macmillan Company, publishers.)

tures, and such differences or variations as exist are principally the result of the absence of some minor part or the transformation of a certain part, depending on disuse or specific use to which that part has been put. Nearly all the bones, muscles, nerves, and blood vessels are constructed and arranged in a homologous manner in the forelimbs of the entire group from the lower types or frogs to the higher types or man. The same thing is true for the hindlimbs, digestive systems, reproductive systems, and circulatory systems of this series.

b. **From Vestigial Structures:** Man has approximately one hundred useless or harmful structures which are also represented in lower types, in which case the same kind of structure may be very useful. What is the explanation of the presence of such useless or harmful structures in certain animals if they have not had their origin in some common ancestor? Why should they have been specifically placed in animals in which they are useless? Is it not logical to believe that they have evolved differently in different animals?

Illustrations of vestigial structures in man are quite numerous, but the following are most commonly cited as being representative: (1) The vermiform appendix is a remnant of an organ which is useful in certain herbivorous (plant-eating) animals. The appendix may have had a specific function in man many generations ago, although no specific function can be stated for it at present. (2) The third eyelid in the inner angle of the human eye corresponds to the nictitating membrane or lid which moves laterally across the eye in such lower animals as the frog, bird, and dog. (3) Muscles of the external ear are useless for man but are used by lower animals to turn the ear in the proper direction to acquire the sound waves more accurately. (4) The terminal vertebrae (coccyx) are of no value to man, but they are the foundation for the external tail in lower animals. It is interesting to note that the early embryos of man (Fig. 363) possess an external tail which is useless and which is discarded before the adult stages are reached. Only occasionally does the external tail persist in the adult man. (5) The lobe of the ear is of no practical benefit to man, although it may have had some function in the past. (6) The point of the ear, known as Darwin's point, on the edge of the upper roll or margin of the human ear, corresponds to the tip of the ear of animals who hold their ears upright. What is the value of this vestigial structure? Why should it have been placed there specifically if there is not some type of relationship?

Illustrations of vestigial structures in other animals are numerous as the following will illustrate: (1) The splint bones of the legs of the horse are remnants of original toes. (2) The poison glands of certain snakes are modified, specialized salivary glands which have evidently developed from the latter through the many stages of descent with change. (3) The gill slits of the embryos (Fig. 363) of higher vertebrates all disappear except one pair which develop as the Eustachian tubes connecting the pharynx and the middle ear. (4) The milk glands of mammals are merely modified and specialized sweat glands of the skin. In all probability the various stages of the descent with change brought about this modification. (5) Certain snakes bear small, useless hindlimbs which structurally resemble those of other animals in which they are useful.

5. **Evidences From Comparative Physiology.**—Since functions and structures are interdependent, one would expect to find fundamental physiologic similarities in organisms with structural similarities. The following examples will be sufficient to illustrate the point: (1) The bloods of closely related organisms are more nearly alike chemically and physiologically than the bloods of the more distantly related types. (2) The hormones of the excretions of closely related organisms are quite similar and in many instances interchangeable. The insulin of the pancreas of the sheep may be used for an insulin deficiency in man. (3) The crystal structures of bloods of similar organisms are more nearly alike than the crystalline structures in bloods of more dissimilar or unrelated organisms. In general, common properties persist in bloods of closely related types, and variations are greatest in distantly related forms.

6. **Evidences From Biogeography (Geographic Distribution).**—Certain organisms have been observed actually to undergo distinct and specific changes (descent with change) when placed in environments different from their relatives.

All the embryos produced by a single female aquatic snail were divided equally into two groups: one group was permitted to develop in the acid waters of a harbor and the other group in the alkaline waters of the open lake. Some time later, the developing offspring were compared. The results were so striking and significant that had the facts not been known, one would have stated that there was no relationship between the groups. Those developing in the acid waters had very thin, semitransparent shells; those in the alkaline water had large, heavy, crusty shells. Is this not suggestive of what happens in other living organisms all the time? May forms originally closely related develop along entirely different lines, depending on one or more differing environmental factors? Is this not illustrative of "descent with change"?

In fact, when similar animals or plants having identical inheritance are placed in widely different environments, the development is quite different and characteristic for each. Even human identical twins in whom the inheritance is considered as nearly identical as is possible, when placed in different environments develop into somewhat different types.

7. **Evidences From Heredity and Variations.**—The scientific study of heredity and variations has shown through indisputable facts and data that organisms are constantly changing. What is this so-called "descent with change" but an evolving which is fundamental and inherent in all life, regardless of where we may care to place the origin, the responsibility, and control of this evolving process?

If there were no change during descent, what would be the possibility for progress? Is it more remarkable to have created a world, the living contents of which are immutably constant and static, or to have one in which life has the abilities of constantly changing according to natural laws? Since our environmental factors are constantly changing, is it not necessary that our living organisms have the ability constantly to vary in order that they may keep step with the environment in which they are to live, develop, and struggle for their existence?

B. Theories of Descent With Change

1. **Lamarck's Theory of Acquired Characters (1809).**—Lamarck attempted to explain differences in individuals by suggesting that through disuse or use for specific purposes certain parts of an organism were under- or overdeveloped and that such differences were later inherited by future offspring. The first part is true—use and disuse modify structures and functions—but even today we have no conclusive evidence that such or similar modifications of the body or somatic cells are inheritable.

2. **Darwin's Theory of Natural Selection as a Factor in the Origin of Species (1859).**—Darwin observed that animals produce larger numbers of offspring than can naturally and normally exist in any given locality but that the total numbers of that particular species remain more or less constant or stationary.

Because of their morphologic and functional differences (or variations due to descent with change), there ensues between these offspring a "struggle for existence" and a consequent "survival of the fittest." This permits a "natural selection" of the best to survive, and thus the race as a whole is changed or benefited. If there were no natural selection or survival of the fittest through the various individual struggles for existence, there would be present many of the weaker types from which future populations might arise. In other words, the stronger win naturally in their struggle with the less fit. This is a factor in the explanation of the characteristics of a group of animals.

3. **Eimer's Theory of Orthogenesis** (1898).—The theory of orthogenesis (or definitely directed evolution) suggested that the evolution of organisms has followed a perfectly predetermined direction or pathway; that complex organisms arose through a series of directed and orderly sequences from simpler forms, much in the same way that a complex adult develops from the egg through a series of predetermined stages. This theory is on the border line of a vitalistic or supernatural interpretation of the directive physicochemical factors which cause evolution. According to this theory, certain types of variations are naturally destined to arise, and hence determine the course of evolution not merely at random but along a definite or straight line. This theory attempts to explain the origin of many characters which arise spontaneously without visible or apparent causes.

4. **De Vries' Theory of Mutations** (1901).—De Vries suggested that the production of sudden mutations results in the appearance of profound changes and differences between parents and offspring, thereby producing new species. Natural selection operates to eliminate or retain such organisms which have mutated. Undoubtedly some species have arisen through mutation, as shown by tailless dogs and cats, the short-legged breed of sheep (Ancon sheep) descended by mutation from a long-legged ram, the hornless Hereford cattle descended from a single calf born in Kansas in 1889.

5. **Weismann's Theories of the Continuity of Germ Plasm and the Noninheritance of Acquired Characters.**—One essential feature of Weismann's doctrine is that the germ plasm (germinal material) is continuous or forms a direct path from one generation to the next and is not derived from the soma or body plasm. Because of experimental evidence, he maintained that characters acquired by the body plasm were not inheritable. He suggested that only germinal variations which might arise as a result of new combinations in the germ cells (independent of environment) were inheritable. He recognized the almost limitless num-

ber of combinations possible when the germ cells of parents fuse during fertilization. This, together with natural selection, he held to be sufficient to determine which characters might arise and perish or persist and consequently be transmitted to future offspring.

6. **Theory of Hybridization.**—This theory attempts to explain how evolution might occur by the appearance of characters that are new by a combination of genes of organisms of the same species or more rarely of organisms of different species. Hybridization between animals of different species rarely occurs, although an example of such a new type is the infertile mule produced by crossing a horse and an ass.

QUESTIONS AND TOPICS

1. (1) Explain why abiogenesis was a common belief in the past. (2) Explain when and how abiogenesis was finally disproved.
2. Explain in detail each of the theories of the origin of life on the earth. Which one, if any, seems most plausible? Why do you say so?
3. Explain the phrase "continuity of life." How does this influence inheritance?
4. From your observations, do you believe organisms descend with change, or, in other words, evolve? Is there anything wrong in such belief? Why? To what source or sources must we look for the causes and control of such a phenomenon? Would it be desirable to have a static, unchanging world?
5. Discuss all the evidences from the seven biologic sciences which attempt to explain descent with change. Which, if any, contributes the most logical evidences?
6. What would you infer from observing the parallelism in the development of vertebrate animals?
7. (1) What does a comparative study of the hearts of vertebrates suggest to you? (2) What does a comparative study of vertebrate brains suggest?
8. Explain two of the great theories of descent with change.
9. What is the relation of genetics to the general principle of evolution?
10. Define Darwinism and Lamarckism. Do their theories necessarily hold true today? Why do you or do you not believe in Darwinism today?

SELECTED REFERENCES

Andrews: This Amazing Planet, G. P. Putnam's Sons.
Clark: The New Evolution, Zoogenesis, Williams & Wilkins Co.
Conklin: The Direction of Human Evolution, Charles Scribner's Sons.
Darwin: Origin of Species by Means of Natural Selection, London, John Murray.
Dobzhansky: Genetics and the Origin of Species, Columbia University Press.
Florkin: Biochemical Evolution, Academic Press, Inc.
Gamow: Biography of the Earth, Pelican Mentor Books.
Haldane: The Causes of Evolution, Longmans, Green & Co.
Hooton: Up From the Apes, The Macmillan Co.
Huxley: Evolution, the Modern Synthesis, Harpers & Brothers.
Lindsey: Evolution and Genetics, The Macmillan Co.
Lull: Organic Evolution, The Macmillan Co.

Mason: Creation By Evolution, The Macmillan Co.
Oparin: The Origin of Life, The Macmillan Co.
Osborn: From the Greeks to Darwin, The Macmillan Co.
Osborn: Men of the Old Stone Age, Charles Scribner's Sons.
Osborn: Origin and Evolution of Life Upon the Earth, Charles Scribner's Sons.
Parker: What Evolution Is, Harvard University Press.
Shimer: Evolution and Man, Ginn and Co.
Shull: Evolution, McGraw-Hill Book Co., Inc.
Simpson: Tempo and Mode in Evolution, Columbia University Press.
Waddington: How Animals Develop, W. W. Norton & Co., Inc.
Ward: Evolution for John Doe, Bobbs-Merrill Co.
Williams: The Human Frontier, Harcourt, Brace & Co., Inc.

Chapter 37

BIOCHEMICAL AND BIOPHYSICAL PHENOMENA

Many of the scientific explanations for various biologic phenomena come from a knowledge of chemistry and physics. In fact, a complete understanding of the structures and functions of plants and animals must be made from the chemical and physical standpoints. The progress in the fields of chemistry and physics and their contributions to biology have become so extensive that such sciences as biochemistry and biophysics are essential in the explanations of the phenomena of living organisms. Numerous biochemical and biophysical phenomena have been considered throughout the text, but it seems desirable to give additional explanations for some which have been described previously as well as to discuss others which have not been considered in great detail.

Chemical and Physical Properties of Living Protoplasm

These properties of living protoplasm have been considered previously, and in order to lay a proper background for considering other phenomena it is desirable that a review be made of them. The chemical construction of living protoplasm is influenced by the chemicals available from foods, but the actual composition of specific materials and their complex associations within it are determined by certain natural laws. Some of these laws must be understood in order to explain the structures and living process in plants and animals. A few of the more important are considered and possibly additional reading of selected references will be highly desirable in certain instances.

Atoms and Molecules

The universe is composed of two fundamental components called energy and matter. Under certain conditions these two may be interconverted. To the average person energy and matter may seem to be unrelated, but Einstein's equation suggests a close relationship: $E = mc^2$ (E = energy; m = mass; c = the velocity of light, which is constant). Usually we think of energy as the ability to produce a change or motion in matter (ability to perform work) and matter as anything which occupies space and has weight. Energy may take the form of heat, light, electricity, or motion. *Potential energy* is the ability to perform work because of the position (of atoms, molecules, or larger bodies), while *kinetic energy* is the energy of movement. A stationary ball at the top of an inclined plane has potential energy, but it displays kinetic energy as it rolls (motion) down the incline. Stored energy in foods is potential energy because of the position of atoms in the food molecules, but chemical digestion of the food results in changing the potential energy into heat, light, electricity, or energy of movement. According to the *law of the conservation of energy,* it cannot be created or destroyed but only transformed into another form. There are many examples of this law in the living and nonliving world.

All matter, whether it be solid, liquid, or gas, is composed of *atoms.* The properties of atoms and molecules are considered elsewhere and should be reviewed.

Electrolytic Dissociation

Electrolytes (e -lek′ tro lite) (Gr. *elektron,* amber or electricity; *lutos,* soluble) are substances which in solution are able to conduct electric currents, while those which do not are known as *nonelectrolytes.* For instance, sodium hydroxide (NaOH) in solution has positively charged Na ions and negatively charged OH ions. The Na atom acquires this positive charge because it loses an electron, while the OH atom acquires a negative charge because it gains an electron. Atoms charged in this way are called *ions.* Compounds which dissociate or ionize in such a manner are *electrolytes.* In general, inorganic compounds exhibit ionization to a greater extent than organic compounds. Acids, bases, and salts are good electrolytes, while alcohols and sugars are not. Ordinary salt (NaCl) dissociates or ionizes into a positively charged sodium ion (Na^+) and a negatively charged chlorine ion (Cl^-). The base, sodium hydroxide (NaOH), dissociates in water into a positive sodium ion (Na^+) and the negative hydroxyl ion (OH^-). The hydroxyl ions give the alkaline or basic properties to the solution. In water, hydrochloric acid (HCl) dissociates into positive hydrogen ions (H^+) and negative chlorine ions (Cl^-). The hydrogen ions give the acid properties to an acid. The numbers of hydrogen ions in a solution are an index of its acidity, and the hydrogen-ion concentration is expressed by the symbol pH. Distilled water has a pH of 7.0 or neutrality. Acids extend in pH from 0 to 7, while bases (alkalies) extend in the scale from 7 upward.

Protoplasm is a mixture of electrolytes. The acids, bases, and salts of the protoplasm are dissociated into ions. These substances confer charges on any surfaces on which they accumulate. Colloidal particles, each bearing a minute charge, may be changed as chemical reactions take place in the protoplasm or as ionizing substances are introduced from the outside. The effects on colloidal particles of the protoplasm by organic and inorganic substances brought to the protoplasm may explain the reasons for the invariable variations in all living protoplasm. The hydrogen ion acts as a catalyzer by hastening hydrolysis (double decomposition involving water) in the digestion of foods. The pH of human blood is slightly alkaline (about 7.4), which is of great importance in counteracting the acidity of other tissues. The body tissues, by constantly giving carbon dioxide to the blood, produce carbonic acid which causes only a very slight change in pH of the blood because of the buffer action of the carbonates, phosphates, and proteins in the blood. The carbonic acid also stimulates the respiratory centers of the nervous system to increase respiration to eliminate the excess carbon dioxide.

Permeability of Membranes and Osmotic Pressure

Permeability may be defined as the property of a membrane or partition that determines its penetrability. The permeability of a membrane depends on (1) the size of the pores of the membrane, (2) the size of the particles of the substance attempting to pass through that membrane, and (3) the solubility of the substance in the membrane. A membrane may be permeable to small molecules but impermeable to large molecules (Fig. 367). Another membrane may be permeable to ions but impermeable to even the smaller molecules. The boundary of cells consists of fatty substances and other aqueous materials which influence its solubility properties, which in turn, at least partially, determine its permeability. Living membranes, such as the plasma membrane of cells, which have a selective permeability are known as *semipermeable membranes.* Living membranes usually permit the passage of small molecules and certain ions, while larger molecules, like protein molecules, and colloidal particles are restrained. Different cells vary in the permeability of their boundaries. The cells of the lining of the lung allow certain gases to pass, while the cells of the intestine permit certain other substances to pass. Each has its specific type of permeability, and the plasma membrane of each individual cell plays an important role in regulating the activities of the protoplasm within that cell.

The force exerted by the pressure of moving molecules in a solution against a membrane is known as *osmotic pressure.* The passage of a substance through a semipermeable membrane is known as *osmosis.* The measurable force within living cells is considerable and usually keeps the cell membrane distended.

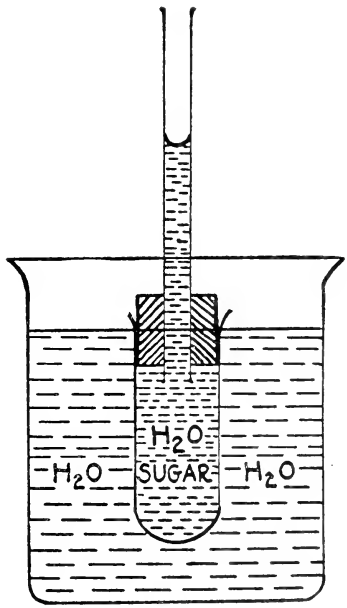


Fig. 367.—Demonstration of osmosis in which the test-tube shaped semipermeable membrane separates sugar solution and water. The pores of the membrane are of a size that permit the passage of water molecules but not sugar molecules. Hence, the passage of water is sufficient to cause it to rise in the upright tube. Water molecules pass in either direction, but they pass faster into the tube than out of it because of the greater concentration of water molecules on the outside. The liquid will rise in the upright tube until it reaches a level at which its hydrostatic pressure, due to its weight, is equal to the osmotic pressure produced by the sugar solution. (From Roe: Principles of Chemistry, The C. V. Mosby Co.)

A solution with greater concentration (less water) than the protoplasm, and which draws water from the protoplasm of the cell, is known as a *hypertonic solution.* In this case, water will pass out of the cell in an attempt to equalize the pressure. Under such circumstances (loss of water), animal cells will tend to shrink as a whole because of their delicate cell membrane, while the protoplasm of plant cells shrinks away from the rather rigid, resistant cell wall. Such shrinking of protoplasm from the cell wall or membrane during the loss of water is called *plasmolysis* (Gr. *plasma,* form; *lysis,* loose). A solution with less concentration (more water) than the protoplasm, and which places water into the protoplasm of the cell, is known as a *hypotonic solution.* In this case the addition of water to the protoplasm causes a condition known as *turgor* (L. *turgeo,* to swell). If carried to extreme, the cell may be destroyed. A solution which has the same concentration as the protoplasm and which neither withdraws nor adds water to the cell is known as an *isotonic solution.* In this case pressures are equal on both sides of the cell membrane and there is no shrinking or swelling. There can be no passage of materials to or from a cell under such conditions. It is quite clear that hypertonic and hypotonic solutions around a cell determine the passage of materials out of the cell and into the cell. The securing of foods and the elimination of wastes probably are accomplished in this way.

Diffusion and Conduction

Diffusion may be defined as the movement of two kinds of molecules in a solution, gas, or solid whereby the molecules of each kind tend to be uniformly distributed in all parts of the substance. Molecules always pass from a region of high concentration to a region of lower concentration. The molecules of a gas may diffuse through another gas or through a liquid. One liquid may diffuse through another. A solid may dissolve and then diffuse through a liquid. A crystal of copper sulfate in water will go into solution and then diffuse through the water until there is a uniform distribution of copper sulfate molecules. In this manner, by diffusion, the molecules of gases, liquids and solids taken in through the cell membranes are made available to the protoplasm of the entire cell.

The firmness or solidity of matter is determined by the distance which the molecules can travel without colliding with another molecule. In liquids the molecules are attracted and usually cannot escape from each other because of cohesive force. The application of heat overcomes this cohesion and the molecules escape in the vapor. Some liquids are very volatile and vaporize easily on contact with air. Gas molecules have no cohesion and can move freely throughout another gas.

Materials may be conducted from one cell to its neighbors, or they may be conducted great distances. In the latter case they may be rather quickly transported by the transporting system of the organism or by the slow process of passage from cell to cell. The phenomenon of conduction is very essential to ensure efficient distribution of materials to those regions where they are required or from those regions where they are not desired. Without molecular movements in the diffusion of substances from one part of a cell to another, the protoplasm would soon become lifeless.

Surface Tension

Surface tension may be defined as the greater tension or attraction between molecules on the surface of a liquid than between those beneath. All molecules of a substance exert an enormous attraction for each other. This property is called *cohesion.* In the deeper portions of a volume of liquid each molecule is attracted by adjacent molecules with equal force in all directions. However, on the surface of the liquid, the liquid molecules are attracted downward by the lower molecules of the liquid and attracted upward by the molecules of the gases of the air. The attraction of the liquid molecules for each other is greater than the attraction of the gas molecules for the liquid molecules. Hence, the attraction forces on the surface molecules of the liquid are unequal. Equilibrium is attained only when the surface is made as small as possible by reducing the number of liquid molecules on the surface. This produces a tendency for the surface to occupy the least amount of space. When a droplet of oil is immersed in water, the former will assume a spherical shape, and the boundary, known as the *interface,* between the oil and water is in a state of tension and therefore represents an equilibrium between forces. This tendency for surfaces to contract because of tension is known as *surface tension.* Naturally, surface tension differs widely among various materials.

Any substance which reduces surface tension has a tendency to accumulate at the surface. When ether is added to water, the ether molecules accumulate in greater numbers at the surface of the water than elsewhere in the water. The amount of potential energy at the surface of an ether-water mixture is much less than at the surface of pure water. If the area of the surface of a substance is reduced, there is a release of energy. Surface tension in living protoplasm is constantly being reduced by the presence of fats. In protoplasm the energy relation of the interfaces (boundaries) between the colloidal particles and their suspending medium is constantly changing. In the living process new compounds are constantly formed, and different sorts of molecules appear and disappear, so that the interfaces are also constantly changing. This constant change in surface tension at these interfaces is closely related with many of the phenomena of living protoplasm.

Energy

Energy may be defined as the ability to produce change or do work. Energy, which may be in the form of electromagnetic waves, is the unit of the universe because the various types of matter are thought to be merely different forms of energy. The power to do work or produce change is a property of living protoplasm. Energy, which is involved in all changes constantly taking place in living protoplasm, is ordinarily measured by the amount of work or change performed. A great variety of energies are known, the following being the more common: electrical, chemical, radiant, mechanical, and heat. Energies may be divided into potential and kinetic. *Potential energy* is the stored energy possessed by a substance because of its position or condition. Coal and wood before they are burned possess potential energy. Carbohydrates before they are digested also possess potential energy. *Kinetic energy* is action energy, or energy possessed by virtue of motion. Kinetic energy may become potential, and potential energy may become kinetic. Energy required to form a molecule of substance becomes inactive potential energy when stored in that molecule, but it is converted into active kinetic energy when the molecule is broken down. Energy cannot be created anew or decreased, but, when a quantity of a certain type disappears, an exactly equal quantity appears in some other forms.

All chemical reactions involve changes in energy distribution. Certain chemical reactions require some form of energy, usually heat, while others release energy in some form. When a sugar is built, energy is required; when it is catabolized, energy is released. The construction and catabolizing of other foods reveal a similar phenomenon. Both types of reactions, those which require and those which release energy, occur in living protoplasm. Much of the energy for heat production, muscular action, and similar activities is the result of oxidizing foods containing potential energies. Energy is used in joining chemical compounds together, and chemical energy is produced by the transformation of foods containing these chemical compounds. The living protoplasm of both animals and plants is composed of compounds so arranged as constantly to transform potential to kinetic or other energies. This constant transformation of energy requires a constant supply of potential energy in order to exhibit the continual changes and perform work. The ultimate source of the energy of our foods produced by green chlorophyll-bearing plants is the sun (see Radiant Energy). The energy value of a food is measured by a unit called a *calorie,* which is the amount of heat required to raise the temperature of 1 Gm. of water 1° C. One gram of fat produces about 9 calories of heat; 1 Gm. of carbohydrate, about 4 calories; 1 Gm. of protein, about 4 calories.

Radiant Energy

Radiant energy is the energy possessed by the sun's rays. When the electromagnetic waves of sunlight are passed through a prism, there is produced a *spectrum* (L. *spectrum,* vision) of various wave lengths and colors. These waves of different lengths (Fig. 368) are capable of different types of work and of producing a variety of phenomena. The longer, visible waves at the red end of the visible spectrum grade through the orange, yellow, green, and blue to the shorter, visible violet rays at

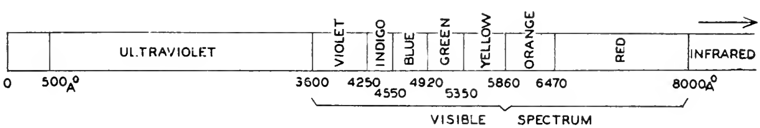


Fig. 368.—Diagram of a spectrum showing the divisions of the electromagnetic scale with the wave lengths of each band shown (approximately) in Ängström units (Å). One Ängström unit (Å) is one ten-billionth of a meter (0.000,000,-000,1). Roentgen rays extend from 2Å to 12Å; unexplored rays and x-rays from 12Å to 500Å; infra-red rays extend from 8,000Å to 3,100,000Å; unexplored rays, 31×10^5 to 160×10^5 Å; radio rays, from 160×10^6 to $120,000,000 \times 10^6$ Å.

the opposite end of the spectrum. At each end of the visible spectrum there are no visible wave lengths or colors, but rays continue indefinitely to become longer and longer beyond the red end, and shorter and shorter beyond the violet end. The waves at the red end are heat rays, as are those, known as *infrared rays,* just beyond the red. Those waves just beyond the violet end are the invisible, *ultraviolet waves.* Certain waves of the visible spectrum, as well as those of the violet end, show certain chemical activities (Fig. 368).

The chlorophyll of green plants in the presence of red, blue, and ultraviolet waves photosynthesizes carbohydrates from carbon dioxide and water. These waves of radiant energy split off the oxygen from the carbon dioxide molecule, this permitting the free carbon to unite with the water to form a carbohydrate. The free oxygen passes off into the atmosphere. The carbohydrate can be (1) oxidized for metabolic purposes, (2) stored for future use, and (3) combined with salts, especially those containing nitrogen, to form proteins. When sugars are stored, they are changed by enzymes through a process of dehydration (loss of water) to form starch. For example, glucose ($C_6H_{12}O_6$), a sugar, through the process of dehydration (loss of H_2O) is changed to starch ($C_6H_{10}O_5$)x, where x is a very large number. The chloroplasts containing the green chlorophyll are especially concentrated in the chlorenchyma cells of the palisade layer of plant leaves where a maximum of light is available (Fig. 60). Iron is not a constituent of chlorophyll, but it must be present in the presence of light in order for chlorophyll to be formed. The visible green color of chlorophyll is due to the absorption of certain light rays (Fig. 368) in the red, blue, and violet regions, with the transmission to our eyes of the remaining rays which give us the characteristic leaf-green color. The absorption of these specific rays by the chlorophyll explains the ability of green plants to manufacture foods. Certain lower plants as the blue-green, the brown, and the red algae, as well as such higher plants as the coleus and red cabbage, possess other pigments which may mask the chlorophyll, which is nevertheless present in them. These phenomena are considered in greater detail in other chapters.

Plant and Animal Colorations

The ability quickly to change color and shades in animals in response to external stimuli is usually confined to reptiles, amphibia, fishes, crustacea, and cephalopod Mollusca. Pigments are produced by cells known as *chromatophores*, which may function as single cells or as groups of cells (Fig. 209). In fishes the chromatophores are rather large and star shaped, and with a small central disk with repeatedly subdividing branches which radiate from the center. The four types of chromotophores which have been most extensively studied are: (1) *Melanophores* (Gr. *melan*, black; *phoros*, to bear), containing the black pigment melanin. The granules of melanin can be dispersed in cells by ether or dilute solutions of sodium chloride and can be aggregated by adrenalin or potassium chloride. (2) *Xanthophores* (Gr. *xanthos*, yellow; *phoros*, to bear) containing the yellow carotinoid pigment xanthophyll. The amount of xanthophyll in certain fishes, at least, depends upon the type of plant food. (3) *Erythrophores* (Gr. *erythros*, red; *phoros*, to bear), containing the red carotinoid pigment. (4) *Guanophores*, containing white crystals of guanin.

In each type of chromatophore an external stimulus causes a movement of the pigment within the cell. When a fish becomes paler, the melanin pigment granules move centripetally and concentrate in a small area in the center of the cell. When that fish becomes darker, the melanin pigments move centrifugally and fill the branches of each cell to increase the blackness of the skin. This transition from one shade to another may occur in a few minutes. The other chromatophores undergo similar phenomena. Stimuli which produce changes as described above usually include chemical, mechanical, thermal, or photic. In fishes the melanophores and xanthophores are controlled by the termination of different peripheral nerves of the autonomic nervous system so as to function independently. Hormones in the secretions from ductless glands of the fish supplement this nervous control. In amphibia the chromatophores (Fig. 209) are controlled by the secretions in the blood produced by the hypophysis (ductless gland). In reptiles the chromatophores are controlled directly by the nervous system supplemented by the secretion of the medulla of the adrenal gland (ductless gland). When a fish is placed on a yellow background, it assumes a quite different color from a similar fish placed on a gray background. The wave lengths of the light reflected from these backgrounds are influential factors in this behavior. This light-reflecting capacity of the surroundings, regardless of the degree of illumination, is the important factor. For example, a dull black surface placed in direct sunlight causes a fish to be black, while a white surface in diffuse light causes it to be pale. Recent research also suggests that fishes have a somewhat limited color vision. Many of the colors of plants and plant pigments are considered in detail in another chapter.

Coloration in plants and animals may be due not only to the absorption of certain waves of light by pigments or other substances, but also to the interference of light. A certain type of interference known as *refraction* (L. *re,* back; *frango,* to bend) is caused by the bending of rays of light as they come to our eyes with the result that a variety of colors is produced. Another type of interference known as *diffraction* (L. *dis,* apart; *frango,* to break or bend) is caused by the separation of light into parts which produces a variety of color sensations on our eyes. The metallic blue color of the tropical butterfly *(Morpho sp.)* is due to the interference of light. The bright colors on the neck of a hummingbird are due to interference, while those on the body are due to absorption of light. Colorations due primarily to absorption are those of certain moths and butterflies, the skin pigments of vertebrates, the feathers of many birds, and the hemoglobin of the red blood corpuscles.

Not all the functions of colorations in plants and animals are known. The complex color-producing mechanism of an animal renders that animal less conspicuous and less likely to be destroyed because of its *"protective coloration."* When pigments are located on or near the surface, they are usually protective for the sensitive tissues beneath by absorbing certain light waves. Pigments which line the visceral cavity or cover certain nerves of animals also may protect. Albinism (absence of pigment) causes an organism to be very sensitive to light. Human albinos, and even blonds, are more sensitive to light than darker-skinned persons. People in the tropics are heavily pigmented, naturally, or acquire protective pigments in the form of heavy tan. "Freckles" in the human skin are due to the increase in the pigments naturally present when stimulated by light. The interesting and complicated phenomena of the coloration of autumnal leaves have been considered in detail elsewhere.

Production and Use of Heat

When any kind of energy is released, there is an accompanying formation of more or less heat. In some instances this heat may be used to regulate chemical activities or control the body temperature, while in others the heat is a waste product which is no longer of use to the organism. In the formation of certain chemical compounds, there is often some heat produced. In some instances, such as the spontaneous combustion of hay, the amount of heat produced is sufficiently great to start a fire. In the destruction of chemical compounds, usually by oxidation, there is liberated a certain quantity of heat. For example, the oxidation of such foods as carbohydrates, fats, and proteins releases heat for use by the living organism.

A living organism which generates large quantities of heat through its activities is frequently not very efficient. In such cases much more heat is liberated than is required by that organism. A plant is much more efficient in this respect than animals generally are. Most of the heat acquired by plants is absorbed from the surroundings, and much of it is lost by transpiration. So-called cold-blooded animals attempt to maintain a body temperature somewhat similar to that of their environment, while warm-blooded animals generate and conserve their heat so as to maintain a rather constant temperature throughout life, regardless of the environment. Animals lose heat (1) by conducting it to other objects, (2) by radiating it, (3) by losing it through their feces and urine, (4) by the process of evaporation from the lungs and the sweat glands of the skin.

All energy eventually tends to be resolved into heat which cannot be resolved in turn into other energies. Consequently, the energy of the sun is constantly required to replace that which has become a useless waste. Animals to a limited extent, and green plants to a great extent, depend on the sun for this supply of heat. From these green plants this heat is transferred to animals. Kinetic energy usually produces heat. For example, a moving body encounters more or less friction and consequently causes a certain amount of heat to be produced. Potential energy may possess large quantities of latent heat which must be liberated in some manner or other before they are available.

Production and Reception of Sound

The vibration of some sounding body produces sound waves which are borne to, and interpreted by, a specialized organ, such as the ear of higher animals. The plants and lower animals do not produce sounds in the accepted sense, although they may be affected by sound waves in certain instances. In several higher animals sounds are produced and interpreted in some manner. Almost every insect which has sound receiving mechanisms also has sound producing (stridulating) organs. In the common locust there are two types of stridulation. When at rest, certain species draw the femoral joint of the hind leg across a specialized vein of the wing cover to produce sound. When flying, they produce a crackling sound by rubbing wings and wing covers together. Tympanic membranes connected by nerves to the nervous system are assumed to be auditory organs. The female mosquito produces a characteristic sound by vibrating her wings 512 times per second. In male mosquitoes the hairs on the antenna are auditory. The hairs are adjusted during flight so that the two plumelike antennae are stimulated equally by the wing sounds produced by the female, thus directing the male toward the female. In the cicada the male has a pair of large, ridged, parchmentlike drumheads on the first abdominal segment beneath the wings. The drumheads are vibrated by a pair of muscles. A pair of cavities within the body act as resonators for the sounds produced. The female cicada has no sound-producing or sound-receiving apparatus. In the katydid the stridulating organs consist of a rough file and a scraper on the wing covers. The sound-receiving apparatus consists of a series of tympanic chambers with membranous tympana. The latter pick up the sound vibrations (chirp) and transmit them to the nervous system. The chambers intensify the sounds. The honeybee produces its humming sound by moving its wings 190 times per second. The housefly produces its buzzing sound by completing 330 wing strokes per second. Many insects, especially those with heavy, chitinous exoskeletons, possess spines and hairs attached to nerves by means of which they recognize or "feel" sound vibrations.

In lower fishes the ear is primarily affected by stimuli produced by changes in the position of the fish. Hence, such fishes maintain a typical position with respect to their surroundings. Well-developed vocal cords and organs of hearing appear only in terrestrial vertebrates. Eardrums and vocal cords are not present in fishes. Amphibia (frogs, toads) have the simplest of vocal cords. It seems that the developments of sound-production and sound-reception mechanisms go together and that they are rather closely correlated. Male and female frogs *(Rana pipiens)* produce different kinds of croaking sounds by forcing air back and forth from the mouth cavity and lungs across their vocal cords. Frogs produce a "pain scream" when caught, a "grunting" sound when satisfied, an "alarm cry" to tell others to seek safety. In the ears of higher vertebrates (Fig. 250) the semicircular canals function as an organ of equilibrium, while the cochlea ("snail shell") receives sound waves and sends them over the auditory nerve to the brain. The human vocal apparatus and ears are described elsewhere.

Bioluminescence and Light

Bioluminescence may be defined as the phenomenon of light production by living organisms apart from incandescence (light with heat). Light may be defined as the form of radiant energy, the waves of which act on the eye so as to render visible the object from which the light comes. Light waves travel approximately 186,000 miles per second. Bioluminescent light is known as cold light because only 1 per cent is invisible heat rays. This is the most efficient light known. Luminous cells of plants and animals secrete granules containing *luciferin,* which glows in the presence of oxygen when activated by the enzyme *luciferase.* Luminescence is displayed by such animals as the firefly (beetle), the glowworm, certain squids and fishes, certain jellyfishes and shrimp, certain species of Protozoa, etc. In the firefly, photogenic organs containing localized masses of fatty substances produce a very efficient light by oxidizing the fatty substances. The photogenic organs are well supplied with oxygen by a copious supply of tracheal tubes. The greenish-yellow light has few nonluminous rays. Its emission appears to be controlled by the nervous system by regulating the oxygen supply. These photogenic organs are associated with sexual attraction, the female generally producing flashes of longer duration. In the luminous squids and fishes there are luminous organs, perfect lenses, and reflectors to reflect the glow. In the jellyfish (*Pelagia noctiluca*) the entire surface of the umbrella is covered with glowing granules. In the minute protozoan (*Noctiluca miliaris*) the luminous granules remain inside the cell. The shrimp emits the luminous granules into the water. Among the plants, certain putrefactive bacteria and special types of mushrooms emit a limited amount of luminescence. Luminous bacteria are frequently found on fish and ham, where they emit rather large quantities of light if the food and oxygen requirements are satisfactory.

Light affects animals in several ways. The protozoan, Euglena (Fig. 173), has a light-sensitive substance localized in a visible pink spot (stigma) near the reservoir. This mechanism directs the Euglena into the proper light for its metabolic activities. The earthworm has no eyes, yet it moves away from light. This is due to the presence of light-sensitive cells near the surface. The starfish locomotion is influenced by light. Protozoa, Planaria, clams, snails, and certain Crustacea are also influenced by it. The simple eyes of insects and spiders are influenced by light intensities. The compound eye of arthropods is constructed like a bundle of hollow tubes arranged in the form of a cone. The tubes are isolated from each other by black pigment, and together they produce an upright but reduced image of the object being viewed. The outer end of each tube contains a lens and a facet which is easily seen on the surface of the compound eye. The inner ends of these tubes possess light-sensitive materials connected with the nerves. These compound eyes also give the organism an interpretation of movement of objects. The eyes of vertebrates (Fig. 248) act somewhat like a camera. The lens focuses and forms an image on the retina. A black pigment inside the eyeball is present for the same reason as in a camera. The retina consists of enormous numbers of nerve cells, each with a chemical material which is temporarily changed by light. Each temporary image on the retina produces chemical changes in the nerve cells varying with the quantity of light on each cell. These chemical changes stimulate other nerve cells which send impulses over the optic nerve to the brain.

In plants, leaves arrange themselves to get a maximum of light. Sunlight supplies the energy for the chlorophyll of green plants to combine carbon dioxide and water to form carbohydrates through the process of photosynthesis. This process is described in detail in other parts of the book. Parts of plants react to light in different ways. Stems bend toward light, changing direction with the source of light. Roots bend away from light, while leaf stalks bend so that the leaves secure the necessary amount of light. This bending is due to the unequal amount of growth on opposite sides of the stem or root. Light, gravity, and contacts may influence this unequal growth. Possibly, all living protoplasm is affected by light to a greater or lesser extent, depending upon its degree of complexity.

Bioelectric Phenomena

Many recent experiments have tended to prove that a number of biologic phenomena are associated with electricity. When an acid colloid is separated from an alkaline colloid by a semipermeable, dielectric membrane or film, there is formed an electric cell within which an electric potential exists between the acid-positive nucleus and the alkaline-negative cytoplasm. The thin lipoid films surrounding the nucleus and cytoplasm offer definite resistance to positive hydrogen ions, while in death this resistance is lowered. The maintenance of the acid-alkali balance between the nucleus and cytoplasm of cells (the electric potential) is essential to life and furnishes the energy of the living processes. The reduction of it to equilibrium (zero) results in death. The vital potential in cells is due to oxidation, and this oxidation in turn is governed by the electric potential acting as a physical catalyst within the cell. Hence, we have the source and a controlling factor of the electrical phenomena associated with cells. Because of its high rate of oxidation, the comparatively acid nucleus supplies vital force in the form of electrical energy. Because of its higher electric potential (tension), the nucleus sends interrupted currents toward the cytoplasm, the currents following each other in rapid succession. As the electric potential of the nucleus increases, the current breaks through the nuclear membrane; the potential of the nucleus then falls and the current stops momentarily; oxidation immediately restores the potential in the nucleus with another discharge into the cytoplasm, which explains the interrupted currents passing from the positive nucleus to the negative cytoplasm as well as the accumulated charges on the surface of the membranes. The nuclear membrane and the plasma membrane are both lipoid films, semipermeable, exquisitely thin, and with high dielectric (nonconductive) capacities. The thinner this lipoid film, the higher the electric charge or capacity.

Water is an important catalyst and has an extremely high dielectric constant. Water holds an infinite variety of substances in solution and suspension in protoplasm. Many of these substances are easily ionized to initiate the electrical phenomena of living materials. Electrolytic solutions and colloids make up a bulk of protoplasm and are especially adapted to electrochemical processes. Carbohydrates are important sources of hydrogen ions which are released by oxidation. These hydrogen ions permeate all living matter and are of great significance in the electrical phenomena displayed by living protoplasm.

Just as the parts of the cell are positive and negative, so there are certain tissues and organs which are positive and negative. The so-called positive tissues are made of cells which possess greater oxidative capacities (hence, higher temperatures) and higher electrical potentials than the so-called negative tissues. The brain is a positive organ and the liver is considered as a negative according to recent experimental evidence. Consequently, the brain and liver may be considered as working together. The electric conductivity of the brain and liver varies in opposite directions. The removal of one quite naturally affects the other. The removal of the liver (negative pole) causes the brain (positive pole) to lose its potential and cease to function. When the circuit between the brain and liver is broken, the lipoid membranes, the interfacial surfaces between colloids, and the interfaces in proteins no longer receive electrical charges upon which their structures and functions depend. Coagulation and death result. Minor electric circuits, similar to that described above, carry on the activities of muscles, nerves, glands, and similar tissues. If a battery works continuously by keeping its circuit closed, its plates are polarized, which means that the difference in potential is diminished or disappears. Hence, the battery is exhausted. In a similar manner, continued use of cells and organs without a period of rest will lead to exhaustion and probable death. If the work period (passage of electric current) is short, as in a single heartbeat, the degree of polarization is quite small. The smaller the degree of polarization, the shorter the time required for depolarization through rest. Salivary glands, the stomach, and intestines have alternate periods of work (polarization) and rest (depolarization). The theory regarding the transmission of nerve impulses has been considered earlier in the text.

In order to operate efficiently a bipolar organism through the maintenance of an optimum difference of electrical potential, the following are essential: (1) to have an abundant water supply, (2) to have an abundant oxygen supply, (3) to maintain the semipermeability of the lipoid membranes of the cells, (4) to maintain an optimum temperature,

(5) to ensure sufficiently long and frequent periods of rest for depolarization purposes, and (6) to maintain the integrity of the poles of the organism.

In the light of the discussion above, there would appear to be greater or lesser quantities of electricity in all animals. In the fishes of certain species there are modified muscle cells which are arranged in series to serve as electric organs. In such organs the electricity is produced, stored, and discharged into the surrounding water for offensive and defensive purposes. In these electric organs the positive pole of one cell is arranged against the negative pole of the next, so that the voltage produced is determined by the number of cells arranged in the series.

Burdon-Sanderson in 1882 and Waller in 1913 demonstrated that such motor plants as the sensitive plant and Venus's-fly trap display electric variations during their specific response to stimuli. These electric action currents are also known as "blaze" currents and are accompanied by a temporary increase in the permeability of the plasma membranes of the cells. Bosé in 1907 stated that electrical phenomena attend the activities of plants.

Enzymes

An enzyme (Gr. *enzymos,* ferment) may be defined as a complex, organic, catalytically active substance produced by living protoplasm, the action of which is independent of the life processes of the protoplasm. An enzyme is a chemical colloid, usually proteinlike, although the chemical formula has been determined for only a few of them. The numerous enzymes act as catalyzers (activators) in chemical reactions but apparently are not used up in the reactions. Enzymes play important roles in the life processes of all cells, including the bacteria as well as the cells of higher organisms. They were formerly called ferments which explains their being named enzymes. Enzymes are usually named by adding the suffix -ase to the name of the substance acted upon. For example, maltase acts on maltose, lactase on lactose, and protease on proteins. The total number of enzymes is as great as the number of different chemical substances that are acted upon. The substance acted on by an enzyme is called the substrate. The product formed by the action of the enzyme on the substrate is unstable because the enzyme is released unchanged, to be used over and over again. However, the amount of substrate which may be affected is not infinite as is true of a catalyst. By doubling the quantity of an enzyme, we reduce the time required for a reaction by approximately one-half, because each particle of enzyme repeats the same type of work over and over. Enzymes are specific in their action, each one causing a specific chemical change upon one substrate. Only a small quantity of an enzyme is required to produce a specific reaction. Many enzymes are produced in an inactive condition, known as pro-enzymes, which are changed into an active condition by such activators as acids, alkalis, or electrolytes. The number of different enzymes produced by the protoplasm of even one cell is probably quite large because the variety of reactions in such a cell is quite great. Enzymes are indispensable for all metabolic activities. Only a few of the more common enzymes with their functions will suffice to illustrate their general distribution. The various stages in the process of food digestion are dependent upon specific enzymes. The ripening and over-ripening of fruits are due to specific enzymes. Autolytic enzymes normally present in animal tissues sometimes cause the spoilage of meats in storage. Certain enzymes are responsible for specific effects in the preparation of foods, such as bread, butter, cheese, sauerkraut, etc. Industrially, enzymes are used in manufacturing alcohol, acetic acid, and lactic acid, etc. Enzymes in the liver change glucose into glycogen which is stored in the liver. Another enzyme changes unusable glycogen into usuable glucose again. The enzyme luciferase oxidizes luciferin, which is the photogenic material in certain animals, such as the firefly.

Plant and Animal Hormones, Including the Ductless (Endocrine) Gland Secretions

A hormone (Gr. *hormao,* to excite) is a chemical substance which increases activity, while a chalone (Gr. *chalinas,* to curb) diminishes or retards activity. Hormones differ from enzymes in that they take part in the reaction and are consequently used up. In this case they must be replaced. Hormones are produced in one part of the body and carried to other parts of the body where they produce specific structural or functional changes. Since these secretions do not travel in special ducts to their ultimate destination, they are known as ductless gland secretions. They are also known as endocrine secretions (Gr. *endon,* within; *krino,* separate). They are summarized in the chapter on Biology of Man.

The activities and characteristics of animal hormones have been known for some time, but only recently have data been secured for plant hormones. Growth hormones in plants are normally found in all rapidly growing regions of the tip of roots and stems from which they are transferred to the growing areas to promote cell elongation and possibly mitosis. When plants are stimulated by light coming from one direction, the growth hormones flow down the shaded side and decrease on the lighted side. Thus the growth is hastened on the shaded side and retarded on the lighted side. The light displaces the specific hormone toward the shaded side but does not enter into its formation. It is suggested that light changes the electrical potential, the shaded side being the positive side electrically. Since these growth hormones are acid, they would be displaced toward the positive (shaded) side. The respective growth of stems toward light and of roots away from light may be explained at least partially on this basis.

Certain hormones in plants conduct stimuli from one part of a plant to another. This is known as the hormone theory of conduction. These hormones are of great importance in the correlation phenomena in plants. Plant hormones might be defined as chemical substances naturally produced in minute quantities in certain regions of the plant and either stored or transported to other regions to regulate the growth, development, or reactions of that organism. The tropic responses of plants to light and gravity are definitely associated with specific hormones. Several different plant hormones have been isolated, such as auxin A, auxin B, and heteroauxin. These are considered in detail in another chapter. Another plant hormone, traumatin (Gr. *trauma,* wound), seems to initiate and influence healing of plant wounds. Plant hormones are transported (1) by diffusion, (2) by protoplasmic streaming, (3) by plant circulatory systems if they are present, and (4) by electrical phenomena by which they are moved toward a positively charged area because of changes in electrical potential within the plant. A plant hormone (indole-3-acetic acid) produces a tumorlike growth in certain plant tissues. In spite of the fact that plant hormones can be isolated from plants, we have no chemical test which provides a simple and efficient means of qualitative and quantitative detection of minute amounts of them in living plants. However, certain physiologic methods are now used to determine their concentration.

Many data have been collected in connection with hormones in higher animals. Hormonelike substances are present at the nerve endings of nerve fibers in vertebrates, where they may transfer impulses from nerve endings across synapses to responding tissues. Recent data associate hormones with the conduction of impulses in nerves. Recent experiments have demonstrated the presence of organic hormones in such invertebrate animals as insects, worms, crustaceans, cephalopods, etc. It is believed that invertebrates produce certain hormones, many of which resemble those of the vertebrate animals, whose functions approximate those of higher animals.

Vitamins

The definite chemical composition of certain vitamins is now fairly well established. Certain vitamins are rather unstable, especially when subjected to heat, oxygen, or light. Vitamins may be present in all living protoplasm in minute amounts, but in larger quantities they are

Fig. 369.—Effect of vitamin A on the growth of young white rats. These two rats, from the same litter, received the same food except that the one on the left had its allowance of vitamin A reduced. (Courtesy of Parke, Davis and Co.)

Fig. 370.—Xerophthalmia, an eye disease caused by a dietary deficiency of vitamin A. The eye becomes dry and a layer of horny tissue forms upon the cornea. (From Harris: Vitamins in Theory and Practice, 1935. Courtesy of the Cambridge University Press and The Macmillan Company.)

present principally in certain plants and plant products. Animals and animal products may have certain types in rather large amounts. The chief source of vitamins for animals is plants. Different plant and animal foods vary in the types and quantities of vitamins present, some being rich in certain vitamins and poor in others. Although their specific method of action is unknown, minute amounts of them probably act much like enzymes or catalyzers.

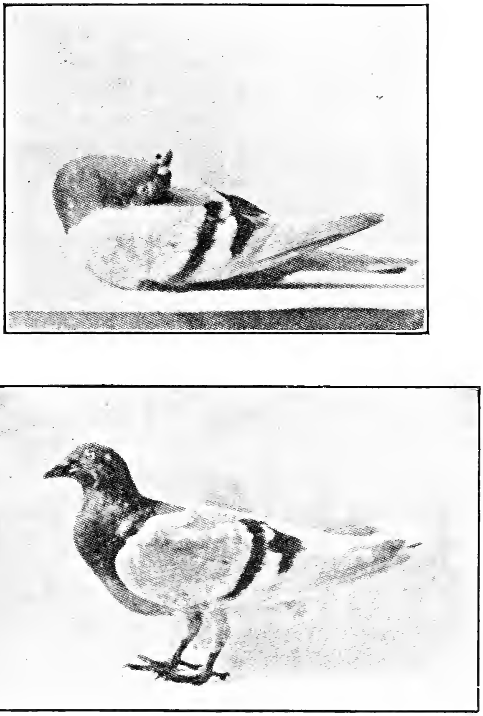


Fig. 371.—Polyneuritis, a dietary disease of animals due to vitamin B_1 deficiency. Above is a pigeon with a characteristic symptom, while below is the same pigeon a few hours after administration of vitamin B_1. The disease resulting from this dietary deficiency in man is called beriberi. (From Plimmer: Vitamins and the Choice of Food, Longmans, Green & Co.)

The first important experiments in search of vitamins were made by Lunin, in 1888, in Switzerland. He fed mice synthetic foodstuffs isolated, or prepared, in the laboratory by chemical methods. This diet contained proteins, fats, carbohydrates, and inorganic salts in the quantities which Lunin thought were present in milk. When fed on this diet, the mice died. However, when milk was added to the prepared diet, the animals lived. Lunin concluded that milk contained an unknown substance which must be present in a diet to maintain life.

In 1913, McCollum and Davis and Osborne and Mendel independently announced results of experiments showing that there is a substance in butterfat which promotes the growth and well-being of rats. Thus was discovered a fat-soluble dietary substance which is essential for satisfactory animal nutrition. The substance was first known as

Fig. 372.—Pellagra, which means "skin seizure," is a dietary disease of man caused by the deficiency of nicotinic acid (niacin) (of the vitamin B complex). Skin lesions are characteristic of pellagra, in addition to diarrhea, anemia, and lesions in the central nervous system producing mental confusion, dementia, and mania. (From Stitt: Diagnostics and Treatment of Tropical Diseases. Courtesy of P. Blakiston's Son & Co.)

"fat-soluble A" factor and is now called vitamin A (Fig. 369). A characteristic function of vitamin A is the maintenance of a normal condition of the eyes. A dietary deficiency of vitamin A produces a condition known as *night blindness* (inability to see well in dim light). Further deficiency of vitamin A results in a severe disease called *xerophthalmia* (Fig. 370) which will result in real blindness if the diet is not corrected.

A dietary deficiency of vitamin B_1 causes a loss of appetite, diminished digestive secretions, muscular atrophy, lesions in the central nervous system, and finally paralysis. This disease in man is called *beriberi,* and in other animals *polyneuritis* (Fig. 371).

A dietary deficiency of nicotinic acid (niacin) (of the vitamin B complex) causes *pellagra* ("skin seizure") in man, with characteristic skin lesions (Fig. 372), diarrhea, anemia, and lesions of the central nervous system which result in confusion, dementia, and mania. Pellagra is quite common in southern United States. A similar dietary disease called "black tongue" occurs in dogs. For a summary of the more common vitamins, consult the chapter on the Biology of Man.

Toxins, Split Proteins, Antibodies, and Hypersensitiveness (Allergies)

Real toxins are proteinlike substances of unknown chemical composition produced by the metabolic activities of the living protoplasm of certain bacteria. Split proteins are produced by the decomposition (probably enzymatic) of nonliving proteins or by the death and subsequent decomposition of any kind of bacterial cell. Real toxins stimulate the tissues of animal bodies to form specific chemical substances known as antibodies (antitoxins) which act specifically on the toxins in question. Split proteins do not excite the formation of antibodies, although they may institute a type of tolerance with no definite immunity. Toxins are specific in that they have a chemical affinity for certain cells or tissues on which they produce specific effects. Toxins are usually quite injurious. One-millionth of a cubic centimeter of botulism toxin kills a guinea pig weighing 250 grams in a rather short time. Such bacteria as diphtheria, tetanus, botulism, and gas gangrene organisms produce true toxins. Bacterial toxins prevent body cells from using foods in a normal manner, or they may destroy the cells because of the irritating effects of chemical constituents of the toxin. Toxins do not attack tissues as readily when the latter are well nourished, not overworked, and subjected to normal temperatures. A protein may be a perfectly good material, but, when split into smaller particles of proteins, the latter may become quite poisonous.

Antibodies are specific chemical substances produced by animal tissues when stimulated by specific proteins. For example, diphtheria antitoxins are produced by a horse when injected with diphtheria toxin. These diphtheria antitoxins when introduced into a patient act only on diphtheria toxins and not on any other type of toxin, even though it may be present. Antibodies may be formed in several places but especially in the bone marrow, lymph glands, and spleen. Antibodies do not act directly on bacterial cells. Certain white blood corpuscles, known as phagocytes (Gr. *phagein,* to eat), actually ingest bacteria and destroy them. This occurs when a sufficient amount of a substance known as an opsonin is present (Gr. *opsonin,* to prepare for). The chemical composition of opsonins is unknown. Various antibodies are also considered in the chapter on Biology of Man.

The phenomenon of hypersensitiveness (increased sensitiveness) is probably quite common in living organisms. Most, if not all, of these phenomena are hypersensitiveness on the part of animal protoplasms to protein materials. Their chemical compositions are not exactly known. The susceptibility of an individual to a certain protein material depends on the permeability of the cell membranes of his body to these protein materials. One person may have a type of cell membrane which prevents the entrance of a particular protein substance, while another individual may have cell membranes which permit their entrance. The former would be immune from attacks by that type of substance but might readily be attacked by a different protein material. It is well known that certain foreign proteins when taken into the body in certain states may create a characteristic reaction. These protein materials may be simple proteins which occur naturally, such as plant pollens, or they may be simple proteins which have been produced by the incomplete digestion of more complex proteins. Our reactions to eggs, milk, strawberries, and similar foods may be of the latter class. Several terms have been applied to such phenomena. Anaphylaxis is applied to acute conditions of hypersensitivity. Allergy (Fig. 256) is applied to the less fatal hypersensitive reactions in man.

QUESTIONS AND TOPICS

1. Discuss the specific interrelationships of biology, chemistry, and physics, including several examples in detail.
2. Define each of the terms listed in this chapter.
3. State the *law of the conservation of energy.*
4. Explain the roles of electrolytes in living protoplasm.
5. Discuss the permeability of membranes and osmotic pressure as they pertain in living protoplasm.

6. Contrast and give examples of each: hypertonic and hypotonic solutions, turgor and plasmolysis, potential and kinetic energy, melanophore, xanthophore, erythrophore, and guanophore, refraction and diffraction, luciferin and luciferase, hormone, vitamin, and enzyme, toxin and antitoxin, phagocytes and opsonins, anaphylaxis and allergy.
7. Explain the structure and functions of atoms as they pertain to certain phenomena in living organs, including specific examples to prove your points.
8. Review the physical and chemical properties of living protoplasm (discussed in earlier chapters).
9. Explain each of the various types of energy transformations encountered in living animals and plants.
10. Explain the electrical phenomena present in living organism, including the probable causes and effects of each.
11. Discuss the statement that "the ultimate source of energy of living organisms is the sun," including examples to prove your contentions.
12. Discuss the causes and effects of colorations in plants and animals, including examples of each type.
13. Discuss the production and the effects of light in the living world.
14. Outline an experiment whereby you would attempt to discover the way in which bioluminescence is produced by a particular living organism.
15. List as many specific enzymes as possible in plants and animals, including their origin, functions, etc.
16. Make a list of the vitamins, including sources, functions, etc., of each.
17. Discuss hormones in (1) plants, (2) invertebrate animals, and (3) vertebrate animals. (Read additional references.)

SELECTED REFERENCES

Avery: Hormones and Horticulture, McGraw-Hill Book Co., Inc.
Barrows: Biological Actions of Sex Hormones, Cambridge University Press.
Beutner: Physical Chemistry of Living Tissues and Life Processes, Williams & Wilkins Co.
Boysen-Jensen: Growth Hormones in Plants, McGraw-Hill Book Co., Inc.
Brown: Hormones in Crustaceans, Academic Press, Inc.
Cott: Adaptive Coloration in Animals, Oxford University Press.
Davson and Danielli: The Permeability of Natural Membranes, The Macmillan Co.
Eddy: Vitaminology, Williams & Wilkins Co.
Gaynor: Pocket Encyclopedia of Atomic Energy, Philosophical Library, Publishers.
Hanstrom: Hormones in Invertebrates, Oxford University Press.
Harrow: Textbook of Biochemistry, W. B. Saunders Co.
Harvey: Living Light, Princeton University Press.
Hoskins: The Tides of Life, the Endocrine Glands, W. W. Norton & Co., Inc.
Howard-Jones: Applied Biophysics, Chemical Publishing Co.
Lotka: Elements of Physical Biology, Williams & Wilkins Co.
Meyer and Anderson: Plant Physiology, D. Van Nostrand Co., Inc.
Mitchell: Textbook of Biochemistry, McGraw-Hill Book Co., Inc.
Scharrer: Hormones in Insects, Academic Press.
Schmidt and Allen: Fundamentals of Biochemistry, McGraw-Hill Book Co., Inc.
Selye: Textbook of Endocrinology, University of Montreal Press.
Sherman and Smith: The Vitamins, American Chemical Society.
Solomon: Why Smash Atoms? Harvard University Press.
Stuhlman: Introduction to Biophysics, John Wiley & Sons, Inc.
Turner: Endocrinology, W. B. Saunders Co.

Chapter 38

APPLIED BIOLOGY

After reading as far as this chapter, the reader undoubtedly will see for himself many of the numerous applications of biology in the various fields of endeavor. To cover this important topic properly would require much more space than can be devoted in one short chapter. It must suffice to point out only a few of the ways in which an application of biology has been made in the world about us. The majority of the applications will be left to the reader who with some reflection and investigation can easily add to the list. For more detailed discussions of certain phases of applications, the reader is directed to additional references, as well as such chapters as The Economic Importance of Animals and The Economic Importance of Plants.

I. BIOLOGY AND ITS RELATION TO AGRICULTURE AND HYDROPONICS

For many years man has utilized the animals and plants he has found in Nature, and in some instances he has improved and domesticated them so that they might better serve his needs. His earlier attempts in this connection were necessarily somewhat crude and unscientific. With the advent of scientific biology, he has made more successful progress, so that today the securing of most of our foods, fuels, clothing, shelter, furniture, and raw materials for many industries are in some way or another directly or indirectly influenced and made possible by what we have found through a study of biology.

Agriculture rests upon the knowledge of the structure, functions, inheritance, and development of domesticated plants and animals and of the great variety of environmental factors by which they are beneficially or detrimentally affected. Biology in no small measure has contributed to each of these phases and consequently has helped to make agriculture what it is today.

Biology, together with other sciences, has given practical and basic methods in many other fields. The improvement of the qualities of plants and animals by the proper selection of seeds and parents has made possible better offspring. The production of new kinds of animals and plants has been possible by crossing or hybridization which has been based upon the knowledge of heredity. The increase in the quantities of animals and plants has been made possible as the result of biologic investigation. Methods of controlling many parasites of plants and animals have been evolved by biologic investigation. Many improvements in the proper cultivation and care of soils have also had their biologic foundation and origin. Biology has also contributed in the prevention and treatment of many plant and animal diseases. Plant and animal foods have also been more perfectly preserved and more efficiently transported. Biology and chemistry have made it possible to use more completely and efficiently the by-products of animal and plant products which originally were wastefully discarded.

Hydroponics (hi dro -pon′ iks) (Gr. *hydor,* water; *ponos,* exertion) is a procedure in which plants are grown in solution cultures or sand cultures. The solutions used in hydroponics must have the essential elements required for the specific plants and in proper proportions. If, however, the nutrient requirements of plants are to be ascertained experimentally, the solutions may be made accordingly. Much of the information secured regarding the relative importance of various elements for plant growth has been secured through experiments with solution and sand cultures. Commercially, the process of hydroponics has been used successfully but on a large scale would be expensive and might not warrant the extra efforts and expense required. The elements which have been proved to have some physiologic importance in green plants include magnesium, nitrogen, sulfur, phosphorus, calcium, potassium, iron, boron, manganese, zinc, and copper. The importance of various amounts of these essential elements and the effects of their deficiencies are too extensive to be considered here. The reader is referred to texts on botany, plant physiology, etc. "Water farming" or aquiculture when performed experimentally has given much valuable information as to plant requirements. Biology has made many valuable contributions in fish propogation, oyster cultivation, etc.

II. BIOLOGY AND ITS RELATION TO FOODS, CLOTHING, FURNITURE, AND FUELS

Most of our foods, clothing, shelter, and fuels and much of our wealth are all directly or indirectly influenced in some way by the proper and effective application of a knowledge of biology. Most of our foods are either plant or animal in origin. We eat plants and animals, the latter depending on plants or other animals for their foods. The production, transportation, proper preparation, and efficient use of foods have all been materially affected by increased knowledge of biology. Through animal experimentation, the vitamin content and chemical composition of foods have been determined and their uses evaluated. More detailed information in this connection will be found in the chapters on economic importance of plants and animals.

Many of our articles of clothing originate directly or indirectly from plant or animal sources. The following typical examples will show the validity of such a statement: (1) true silk from the silkworm, (2) cotton from the cotton plant, (3) wool from the sheep and other animals, (4) linen from flax plants, (5) furs from rabbits, skunks, opossums, foxes, goats, muskrats, beavers, raccoons, (6) leather from prepared skins of the cow, horse, pig, alligator, and other animals; (7) straw from the stalks of wheat, rye, oats, and barley, (8) felt from the wool, fur, and hair of animals, and (9) rubber from the juice of the rubber tree.

Many of the materials for the construction of our furniture are of plant or animal origin: (1) wood from plants, (2) willow furniture from willow trees, (3) glue from the skins and hoofs of animals, (4) leather from the prepared skins of various animals, (5) excelsior from shredded wood, (6) paper from straw, bark, wood, and other fibers of plants, (7) shellac from the resinous materials secreted by certain scale insects, and (8) stains, varnish, and paint, at least in part, secured from various plant materials.

Unless we stop to reflect carefully and conscientiously, we do not realize how many of our fuels are closely related to plants which were formerly alive. The following brief suggestion in each instance will suffice. Coal is really formed from plant materials for the most part. Vegetation and stored solar energy, buried in the swamps of long ago, have undergone many changes so that coal of one kind or another has been formed. Wood is plant tissue which was once alive. It forms one of our most valuable fuels. Natural gas is the product of biologic decomposition of plant and animal remains of the past. This has probably taken place under great pressures within the deeper strata of the earth. Peat is one of the intermediate stages in the formation of coal and is utilized in localities where coal is not readily available. Petroleum is also formed by the decomposition of materials which to a great extent were of animal and plant origin. Gasoline is secured by refining petroleum. Paper is made from straw, bark, wood, and other fibrous plant materials. Coke is manufactured from certain kinds of coal by heating in the absence of oxygen. For a more complete consideration of this phase of resources, see chapter on the Economic Importance of Plants.

III. BIOLOGY AND ITS RELATION TO HUMAN WELFARE

A. Medicine and Health

In few fields have the contributions of biology been greater than in medicine and health. Courses in biology have given training for large numbers of premedical students who have had the qualifications later to enter the medical profession. Through animal experimentation, many of the fundamental and basic truths of behavior, health, diseases, and similar phenomena have been ascertained, with their subsequent application in the field of medicine and public health. An experimental study of animal reactions and behavior has suggested methods to be employed in attacking the problem of individual and group behavior in man.

Many of the medicines used today are of plant or animal origin. In addition, the efficiency and proper use of medicines have been determined largely through animal experimentation. Much of our knowledge of foods, their correct use, their composition, their preservation, their transportation, as well as diseases which they cause or transmit, are all dependent upon certain biologic facts. The parasites of plants, animals, and man have been studied in detail, and the information acquired has been used successfully in making our environment a better place in which to live. Many of the life cycles of parasites have been carefully studied and this knowledge applied to the elimination of many of them. Research in the fields of bacteriology and protozoology has contributed many facts which, when practically applied, have resulted in lower morbidity and mortality rates among living organisms. Heredity has made a great contribution in explaining how we have come to be what we are, how certain abnormalities arise, and how we may eliminate some of the undesirable traits by the proper application of the knowledge gained through the study of heredity.

Many of the improvements in our environment have been suggested and influenced by what we have learned by biologic investigations. The proper treatment of sewage, the purification of water, the inspection and refrigeration of foods, the rigid inspection of oysters and other shell foods for possible contaminations are only a few of the contributions in this direction. The studies of lower forms of the life have shown us the many frailties and shortcomings of the human race. This information in a measure may prepare us for what we see when we observe many of the behaviors and reactions of human beings. We come to appreciate that man cannot be expected to be perfect, and we are disappointed that he does not take full advantage of all his wonderful abilities and opportunities. Through our studies of biology we modify the attitudes and philosophies of our daily lives. Science has affected us not only in material ways but in mental and philosophic ways as well.

The science of endocrinology, by studying the ductless glands of certain animals, has pointed out the fundamental and basic principles to be followed in the effective application of this field in human beings. Much more in this field will have to be learned and a great amount of it will be accomplished by first experimenting on other animals. A detailed consideration of the endocrine glands is given in a summary in the chapter on Biology of Man. Our studies of disease-producing (pathogenic) bacteria, yeasts, molds, and Protozoa have given many methods of disease prevention, treatment, and cure. The extensive progress made in bacteriology in the last few years has made it possible to reduce the morbidity and mortality rates for many of our infectious diseases in this country. Much more remains to be done, and much is being done daily to alleviate the many human ailments and sufferings due to these microorganisms. What we as individuals owe in health and happiness to the hundreds who have scientifically investigated diseases in the past is beyond our imagination. Many of our human diseases are being successfully treated or prevented through the use of antibiotics which are the products of certain lower plants, particularly fungi. Additional antibiotics are being discovered, and improved methods of production and administration are recent contributions.

B. Biology and Wealth

Ordinarily, people do not associate biology and biologic products with the wealth of this country. A few data will illustrate very definitely the enormous contribution of biologic products to our national wealth. Over a ten-year period the corn grown in the United States averages over $1,500,000,000 annually. Over a similar ten-year period, the cotton was valued at about $1,000,000,000 annually, while the wheat was valued at about $635,000,000. Cotton is not grown in this country north of the thirty-seventh parallel. In 1926 the South cultivated 44,608,000 acres of cotton from which were produced 17,755,570 bales. From the cotton fibers of this yield were received $1,121,185,000, and from the cotton seed, $172,131,000. When a cotton planter takes 1,250 pounds of seed cotton to the ginnery, it is converted into one bale (500 pounds) of cotton lint or fiber and 750 pounds of cotton seed. The value of all meat-producing animals in the United States in 1928 was estimated to be approximately $3,000,000,000. The value of the wollen and worsted products in this country is slightly less than $1,000,000,000 each year. The fish industries are also extensive and their products are quite valuable. The salmon caught on our western coast are estimated to be worth about $50,000,000 annually, while the codfishes are valued at more than $30,000,000 per year. According to recent data, the total value of all farm properties in this country is over $57,000,000,000. If we add to the above list such products as rubber, lumber, hay, fruits, fuels, foods, clothing, and other products, the totals become enormous. In each of them biology plays a very important role in the cultivation, preparation, or use of them.

Biology makes a great contribution in the production of wealth, but it also makes an appreciable contribution to the methods of preventing unnecessary loss in many fields of human endeavor. Nearly the entire country is infested with rats which carry diseases causing untold damages. Rats destroy property valued at $200,000,000 each year. Metcalf and Flint estimate that the loss caused by insects in 1924 in the United States was over $1,500,000,000. The science of entomology through the study of insects has supplied us with information which, if efficiently applied, would materially reduce this enormous and unnecessary loss. Losses due to termites are increasing rapidly, and their extermination has been suggested by procedures which have come as the result of extensive experimentation in this field. Fisher estimates that the disease tuberculosis annually costs this country between $500,000,000 and $1,000,000,000 because of deaths, sickness, loss of work, inefficiency, maintenance of sanatoriums, hospitals, and similar projects. Much experimental work in connection with this one disease has resulted in a decided reduction of the loss due to its ravages. Most of our infectious diseases have been attacked by bacteriologists, and satisfactory progress has been made in many of them, so that today we can live longer and happier lives as the result of their many investigations. How much this field of bacteriology has contributed directly and indirectly to our wealth is beyond human computation.

C. Water Supplies and Sewage Disposal

Water is an important substance of all living organisms, and many of the activities necessary for their existence are dependent upon the proper quantity and quality of water. The chemical reactions of digestion, growth, and reproduction are dependent upon water, and the enzymes which aid in these processes act in aqueous solutions. Water is essential in the elimination of wastes, regulation of body temperatures, maintenance of proper consistency of blood, lymph, etc. Water is one of the best solvents for animals and plants as the following suggests: it dissolves soil particles and chemicals for plant use and it dissolves acids, alkalis, salts, gases and many other materials which have an endless variety of uses in the living organism.

The value of water has been recognized by peoples of all times because they have tended to settle where the supply has been of the proper quantity and quality. In the past the quantity and quality were not always the problem which they now are because of greater use of water and greater centers of population, together with increased industrialization. Today in many areas the "water problem" has become acute. Primitive peoples used water for drinking, for preparing food, and a small amount for washing and for their primitive handicrafts. As populations increased and urban industrialization developed, the amount of water required was greatly increased. Today, in some communities, we find water sanitation so inadequate that people actually consume their own sewage or that of the neighbor in order to get a sufficient supply. The per capita daily consumption of water in our cities is about 100 gallons, although it runs as high as 250 gallons in certain cities. European cities average only about 50 gallons, with a few using as much as 100 gallons daily. Such factors as the following influence the amount of water consumed: the cost of the water, the number and types of industries, the chemical and physical properties of the water, the amount used in cleaning streets, the number of fires which firemen must put out, whether the water is sold by meter or not, the number of leaky fixtures and pipes, the temperature and humidity of the climate, the amount used in watering lawns and gardens, etc.

Water comes to the earth in rain or snow; some is used by animals and plants and some evaporates, while the remainder collects on the surface of the earth or penetrates into the subsurface of the earth. Two sources of water are: surface (rivers, lakes, reservoirs, etc.) and subsurface or ground (wells, underground rivers and lakes, etc.). Waters may be classified as: (1) potable water, which is safe from the standpoint of health and is desirable from an odor, taste, or appearance standpoint, (2) polluted water, which contains substances not necessarily harmful but of such a character as to offend the senses of sight, taste, or smell (pollution usually refers to such physical characteristics as unpleasant tastes and odors, undesirable color, excessive turbidity, etc.), (3) contaminated waters, which contain substances harmful to health (pathogenic microorganisms, inorganic or organic poisons, etc.), and (4) pure waters, which are chemically and physically pure; such waters do not exist naturally but can be secured by distillation.

Waters may become polluted and contaminated by picking up all manner of materials in suspension and solution. They may acquire silt by passing through fertile lands; they may be hard by incorporating chemicals as they flow through limestone; they may have undesirable tastes and odors by contacting decaying plant and animal matters; they may be rendered undesirable by industrial wastes, wastes from oil wells, seepage from mines, domestic sewage, etc. From a sanitary standpoint, human excrements play the most important role in the contamination of water.

Waters may be purified by (1) filtration through sand filters, with or without previous coagulation induced by the use of chemicals which precipitate undesirable materials, (2) disinfection by the use of certain chemicals, usually chlorine, (3) some kind of water softening process, or (4) a combination of the above processes. The specific method used to purify is determined by the quality of the raw water and the quality of the water expected after treatment. If water contains little dissolved or suspended matter, chemical disinfection may be sufficient; if it is soft but contains suspended matter and microorganisms, filtration and chlorination may be necessary; if it contains such dissolved salts as those of calcium or magnesium, it may be necessary to soften it by one means or another.

Two types of sand filtrations are used for removing pollution from waters: (1) slow sand filtrations and (2) rapid sand filtrations. The former have been used extensively in Europe since 1830 but have not been satisfactory in the United States. Slow sand filters were made of concrete, covered about one acre each, and were filled with sand to a depth of one to four feet. Bacteria and other microorganisms are removed by mechanical filtration and also by their destruction in the gelatinous, zoogleal mass which covers the filter surface after it has operated for a few days. Criticisms of the slow sand filter include the following: (1) even if operated at full capacity the rate of purification is only two to three million gallons per acre; (2) it is not efficient if water contains large amounts of suspended materials because the surface soon becomes coated, thus interfering with the delivery of sufficient, desirable water; (3) it is expensive, especially if large quantities of water are required, because large areas of expensive land are required to build sufficient filters.

Rapid sand filters, introduced into the United States about 1890, are extensively used in modern water purification plants. The process, in brief, is as follows: (1) screen the raw water to keep out sticks, leaves, animals, etc.; (2) mix the water with flocculating chemicals, such as aluminum sulfate or iron sulfate, and allow the suspended floc to settle out in settling tanks; (3) pass the clarified supernatant water through rapid sand filter beds; (4) disinfect the water by means of chemicals, usually liquefied chlorine gas.

In recent times the contamination of water supplies by sewage has become a major problem because of increased centers of population and industrialization in cities, because of the increased demand for more water for homes and industries, and because of the greater difficulty in efficiently disposing of large quantities of sewage. Sewage may be considered as the used water supply to which have been added (1) human excrements (urine, feces), water used for bathing, washing, etc., (2) industrial wastes from laundries, creameries, breweries, chemical plants, slaughterhouses, tanneries, and many other similar industries, and (3) water from streets, sidewalks, etc.

Sewage may be disposed of (1) by dilution, (2) by irrigation, or (3) by stabilization of the sewage through bacterial actions. In the process of disposition by dilution the sewage is placed in a body of water sufficiently large to render the sewage more or less harmless. This old method is inexpensive, and if the body of water is large enough to dilute the sewage properly, and if the body of water is not to be used for other purposes, it is reasonably satisfactory. Sewage disposal by irrigation or by running raw sewage over land is not commonly used in the United States. The stabilization of sewage by the actions of various bacteria is based upon the fact that organic and inorganic substances in sewage are excellent foods for bacteria. When bacteria use these substances, they oxidize them more or less completely, forming new substances with less energy and lower molecular weights. When most of the energy of sewage is consumed, bacteria no longer grow rapidly and the sewage is stabilized. The specific method for the bacterial treatment of sewage depends upon many factors, such as the quality of the sewage, the quantity to be disposed, the nature of the body of water or soil into which the treated sewage is allowed to run, etc.

IV. DISEASES CAUSED OR TRANSMITTED BY ANIMALS*

A. Human Diseases

1. *Protozoan Diseases*

(a) Class *Sarcodina*	
(1) Amoebic dysentery (*Endamoeba histolytica*) (Fig. 264)	Transmitted by contaminated foods, water, flies; may cause ulcerations of the intestine, abscesses of liver, lungs, and brain; 10 per cent of world population infected, many being carriers.
(b) Class *Mastigophora* (Flagellates)	
(2) African sleeping sickness (Gambian) (*Trypanosoma gambiense*) (Fig. 263)	Transmitted by tsetse fly (*Glossina*); causes enlarged glands, emaciation, weakened limbs, coma, and eventually death; present in Africa, Europe, and tropics; from 1896-1906 over 500,000 died in Congo region
(3) African sleeping sickness (Rhodesian) (*T. rhodesiense*)	Similar to above; common in Africa
(4) Chaga's Disease (*T. cruzi*)	Common in South and Central America; carriers may be present in Southwestern United States; causes dangerous swellings in muscles, heart, and nervous system
(5) Kala-azar (*Leishmania donovani*)	Widely distributed in Asia; blood-inhabiting; attacks lining of blood vessels and certain white blood cells
(6) Oriental sore (*L. tropica*)	Present in Near and Far East; one attack of this cutaneous leishmaniasis immunizes against further attacks
(7) Cutaneous leishmaniasis (*L. braziliensis*)	Occurs in South and Central America; parasite resembles *L. tropica* morphologically.
(8) Flagellate diarrhea (*Giardia lamblia*)	May be the cause of a type of human diarrhea; present in 10 per cent of population
(c) Class *Sporozoa*	
(9) Tertian malaria (*Plasmodium vivax*) (Fig. 176)	Transmitted by female *Anopheles* mosquito (Fig. 303); parasites attack blood corpuscles; alternate periods of fevers and chills every 48 hours; more common type in temperate zone; less serious
(10) Quartan malaria (*P. malariae*) (Fig. 176)	As above except that attacks occur every 72 hours; not as common as other types
(11) Estivoautumnal or subtertian malaria (*P. falciparum*)	As above except for daily attacks, with more or less constant fever; more common in tropics; more serious type
(12) Diarrhea (*Isospora hominis*)	Burrows in the intestinal wall causing diarrhea; common in various regions of the Pacific in World War II
(d) Class *Infusoria* (Ciliates)	
(13) Diarrhea and ulcers (*Balantidium coli*) (Fig. 262)	Human beings may become infected by swallowing resistant cysts (from pig feces) which contaminate drinks and foods; in some persons the intestinal wall is ulcerated, producing diarrhea and often killing the host

*Other diseases are considered elsewhere in other chapters; the list given here is incomplete and descriptions are brief—merely to serve as a guide.

A. Human Diseases—Cont'd

2. *Human Diseases Caused By Worms*

(a) Flatworms (Platyhelminthes)

(1) Pork tapeworm (*Taenia solium*) (Fig. 182)	Transmitted by eating infested, improperly cooked pork; common wherever such pork is eaten
(2) Beef tapeworm (*T. saginata*)	Transmitted by eating infested, improperly cooked beef; common wherever such beef is eaten (Fig. 183)
(3) Chinese liver fluke (*Clinorchis sinensis*)	Lives in man in the Orient; transmitted by eating improperly cooked, parasitized fish (Fig. 373)

Fig. 373.—Chinese liver fluke (*Clinorchis sinensis*) photographed, showing the internal organs of an adult. Contrast with the sheep liver fluke (*Fasciola hepatica*). (Figs. 180, 181 and 374). (Copyright by General Biological Supply House, Inc., Chicago.)

(b) Roundworms (Nemathelminthes)

(4) Trichinosis or pork roundworm (*Trichinella spiralis*) (Fig. 100)	Transmitted by eating infested, improperly cooked pork; larvae may pass from human intestine into muscles and lymphatic system
(5) New world hookworm (*Necator americanus*) (Fig. 99)	Transmitted through skin from infested soils; parasites may be present in human blood, lungs, intestines, etc.; causes shiftlessness and anemia (loss of blood through intestine); common in South
(6) Elephantiasis (*Wuchereria* [*Filaria*] *bancrofti*) (Fig. 101)	Transmitted by night-flying (nocturnal) mosquitoes from blood in skin of patient to next person; in daytime the larval parasites (1/100 inch long) live in deeper human tissues (lungs, larger arteries, etc.); parasites enter human lymphatic system, obstructing the flow of lymph, causing typically enlarged limbs, etc.
(7) Human ascaris (*Ascaris lumbricoides*) (Fig. 184)	Eggs and larvae carried to human mouth by infested foods, water, or soil; the larvae in the human intestine migrate through the blood and lymphatic system to liver, lungs, and heart and eventually back to the intestine

A. Human Diseases—Cont'd	
3. *Human Diseases Caused by Arthropods*	
(a) "Chiggers" (*Trombicula irritans*) (Fig. 269)	The immature stages of this mite (class *Arachnoidea*) have 3 pairs of legs, while the adult has 4 pairs; mites are transmitted from the soil and vegetation to human skin where their claws cause irritation; they are reddish in color ("redbugs"), just visible to the naked eye, and suck blood with piercing-sucking mouth parts; adults do not attack man but attack insects
(b) Human lice (*Pediculus humanis*) and other species (Fig. 280)	Transmitted from person to person and by flies, bedding, clothing, etc.; there are several varieties of human lice each with its particular point of attack and structure; sucking blood and scratching by claws cause irritations; may transmit other diseases
B. Diseases of Animals Other Than Human	
1. *Protozoan Diseases*	
(a) Class *Mastigophora* (Flagellates)	
(1) Dourine of horses, etc. (*Trypanosoma equiperdum*) (see Fig. 266)	Transferred directly from host to host; usually a chronic disease of horses, dogs, rabbits, etc., of the United States, Canada, and parts of Europe in which paralysis results in death in a few months
(2) Nagana fever (*T. brucei*) (Fig. 266)	Transferred by tsetse fly (*Glossina*); causes fever in various African domestic mammals
(3) Surra disease (*T. evansi*)	Probably transmitted by tabanid flies; disease of horses, mules, cattle, and camels of India
(b) Class *Sporozoa*	
(4) Silkworm disease or pébrine (*Nosema bombysis*)	Transmitted by spores in the various stages of the life cycle of the silkworm; within the silkworm (*Bombyx mori*) the spores develop and invade all body tissues, eventually killing the host; this disease must not be confused with a bacterial disease of the silkworm
(5) Texas fever of cattle (*Babesia bigemina*) (Fig. 267)	Transmitted by cattle tick (*Boöphilus*); present in southern United States, parts of Europe, and Africa; characterized by destruction of red blood corpuscles, enlarged spleen, and affected liver; in acute stage the parasites usually appear as pairs of pear-shaped bodies in the blood corpuscles
2. *Diseases of Animals Caused by Worms*	
(a) Flatworms (Platyhelminthes)	
(1) Liver rot of sheep (*Fasciola hepatica*) (Figs. 180, 181, 374)	Transmitted by the snail (*Lymnaea*); not as common in this country as in Europe; very complicated life cycle which is described elsewhere in other chapters; also present in cattle, pigs, and occasionally in man
(2) Tapeworm of dogs, etc.	Transmitted from dogs and other carnivorous animals to pigs, sheep, and man; the larvae, known

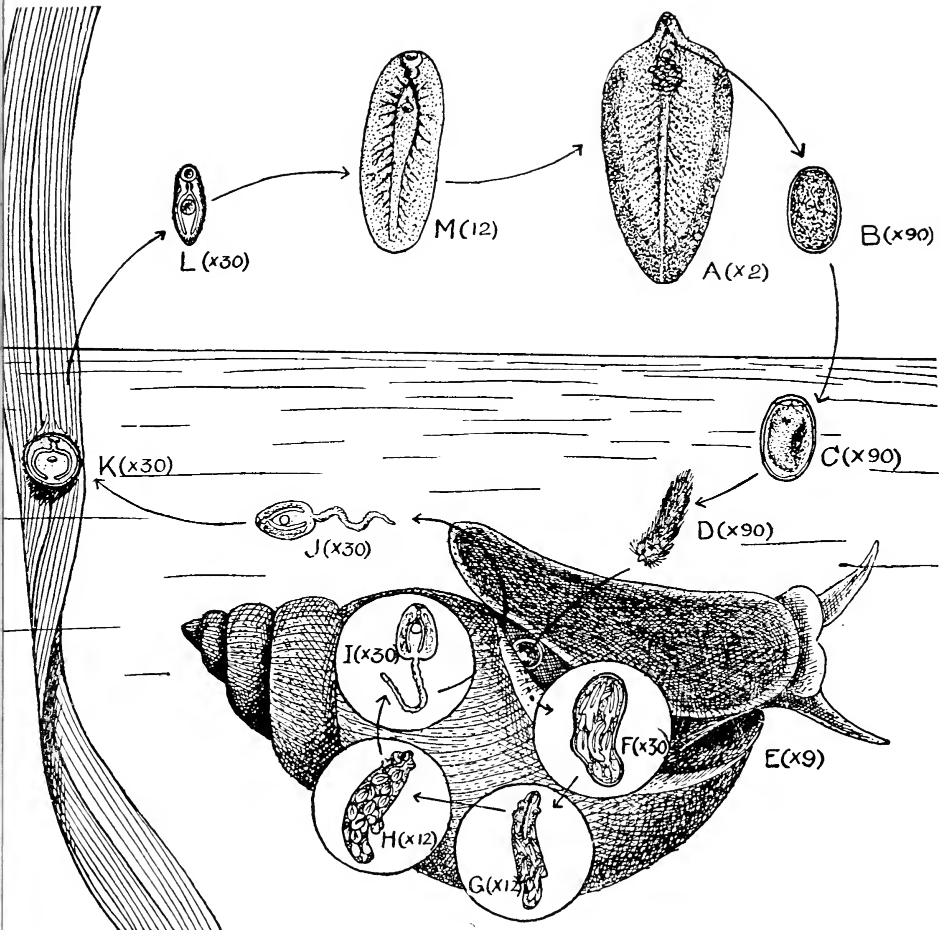


Fig. 374.—Life history of the sheep liver fluke (*Fasciola hepatica*). *A,* Adult in the sheep liver; *B,* egg passed from the body of the sheep; *C,* developing embryo in the water; *D,* ciliated embryo (miracidium) in the water and ready to enter the body of a snail; *E* and *F,* sporocyst containing rediae; *G,* redia containing daughter rediae; *H,* redia of the second generation containing cercaria; *I,* cercaria with tail; *J,* cercaria in water; *K,* cercaria encysted on grass; *L,* cercaria liberated from cyst after ingestion by sheep; *M,* young fluke in sheep liver. Enlargements of the various stages are indicated. (Reproduced by permission from Introduction to Human Parasitology, eighth edition, by A. C. Chandler, published by John Wiley & Sons, Inc., 1949.)

B. Diseases of Animals Other Than Human—Cont'd

(*Echinococcus granulosus*)	as hydatid cysts, may reach the size of a child's head and contain thousands of daughter cysts, each of which may give origin to a new worm; may be quite serious in severe cases; widespread in distribution; called hydatid disease in man
(3) "Staggers" or gid tapeworm of sheep (*Multiceps multiceps*) (Fig. 268)	The larva, known as a coenurus (se -nu′ rus) (Gr. *koinos,* common; *oura,* tail), contains several scoleces in each cyst, and, lodged in the brain of ruminant animals, causes "staggers" or "gid"; may be transmitted from dogs or other animals
(b) Roundworms (Nemathelminthes)	
(4) Roundworm of horses (*Strongylus vulgaris*) (compare Figs. 99 to 101)	Ingested larvae from feces of horses encyst in the colon or cecum of the horse where sucking of blood results in anemia; world-wide distribution, especially in warmer countries
(5) Dog ascarid (*Toxocara canis*)	Dogs become infected by swallowing eggs, especially young puppies; an acquired immunity results in the elimination of the worms in a few months; larvae migrate through the body of the dog much in the manner of *Ascaris* in man
(6) "Gapes" of poultry and game birds (*Syngamus trachea*)	Infestation occurs by ingesting larvae from feces or materials coughed up by infested birds; larvae travel through the esophagus, lungs, and trachea, where they attach and forms capsules, producing the characteristic "gapes"; abscesses may form; slender, red, adults in the trachea may produce eggs which develop into larvae; common in fowls and wild birds; may affect human beings in the tropics
(c) Segmented worms (Annelida)	
(7) Leeches (various species) (Fig. 114)	The fresh-water leech (*Macrobdella*) sucks blood from man, frogs, fish, and cattle; the horse leech (*Haemopis*) parasitizes horses, snails, worms, etc., and lives in mud near fresh-water; the medicinal leech (*Hirudo medicinalis*) sucks blood from many types of vertebrate animals; blood clotting is prevented by a special secretion; may suck blood up to three times its own weight and require several months to digest
3. *Diseases of Animals Caused by Mollusks*	
(a) "Blackheads" or black cysts of fish (larval stage or glochidium of mussels)	The eggs of mussels develop into bivalved, larval glochidia which are cast into the water where they clamp their jaws into the gills, fins, and body of fish; the fish forms a black cyst around the glochidium; eventually the cyst ruptures to liberate the developing larva and it begins its free-living existence as a young adult mussel
4. *Diseases of Animals Caused by Arthropods*	The diseases of animals and plants produced by members of the arthropod phylum and the diseases transmitted by members of this group are so numerous that the reader is referred to the chapter on the Economic Importance of Animals (phylum *Arthropoda*) or to textbooks of entomology

V. DISEASES PRODUCED BY PLANTS

No attempt can be made to discuss fully the diseases which are produced by plants. Approximately 200 diseases of animals and man are produced by bacteria, while many others are produced by pathogenic yeasts and molds. Approximately 200 diseases of plants may be caused by pathogenic bacteria. In general, the majority of infectious diseases of man in this country are caused by bacteria rather than by protozoa. This is true because climatic conditions prevent many of the protozoa from existing in this area. The bacterial diseases of animals are considered elsewhere, but if further information is desired, the reader is referred to the many textbooks in bacteriology. Besides the many bacterial diseases of living organisms, there are several produced by yeasts. Included in this group are thrush (parasitic stomatitis), a disease of the mouth, and blastomycetic dermatitis, which is an infection of the skin. Certain types of fungi produce such typical disorders as dermatomycoses of the skin; ringworm, a skin disease produced by at least two varieties of fungi; sporotrichosis, a disease of the skin characterized by multiple abscesses; "lumpy jaw" or "wooden tongue" of cattle; actinomycotic infections of man.

The problems of toxins, antibodies, split proteins, allergies, and hypersensitiveness are considered in more detail in other chapters. In addition to the large number of diseases of plants and animals produced by bacteria, yeasts, and fungi, there are certain higher plants, such as poison ivy, poison sumac, nightshade, and similar forms, which are harmful to man. Some of these must be taken internally to produce harm, while mere contact with others will produce characteristic disorders.

VI. DISEASES CAUSED BY VIRUSES

Viruses are also known as "inframicrobes," "ultramicroscopic or filtrable viruses," "microplasms," etc. A brief summary of some of the characteristics of viruses are as follows: (1) they are assumed to be *protein in nature,* because all other living things are, and because they can serve as antigens, and, according to present data, only proteins, or things combined with proteins, can stimulate the production of antibodies; (2) some, but by no means all, have been *crystallized* which differentiates some of them from other infective agents; (3) they are regarded by some investigators as *a form of life* in which one molecule, or aggregation of molecules, of the living protoplasm composes a unit just as a cell forms a unit of higher life, thus giving these chemical molecules the *ability to repro-*

duce themselves; (4) in their *resistance to chemical and physical agents,* they are intermediate between the resistant bacterial spores and the non-spore-bearing bacilli; (5) the *different viruses vary in size,* some being about 10 millimicrons and others as large as 200 millimicrons (a millimicron is one-thousandth of a micron, and a micron is one-millionth part of a meter); (6) viruses *cannot be grown in a strictly artificial culture medium,* but they must be grown parasitically in a cell for which they are more or less specific; (7) they are *invisible* when using an ordinary high-powered optical microscope employing ordinary visible light, because the smallest particle visible under these conditions is about 0.2 micron in diameter, but they can be photographed with an electron microscope; (8) they *pass through filters* of certain types and under certain conditions; (9) certain viruses *produce animal diseases,* such as smallpox, measles, etc., and *plant mosaic diseases,* which are *highly infectious;* (10) *immunity to virus diseases in animals* appears in general to be rather permanent, as smallpox, chicken pox, mumps, etc.; (11) pathogenic viruses usually *attack one set of tissues,* the two most characteristic tissues attacked being the skin (by dermotropic viruses) and the nervous system (by neurotropic viruses); (12) viruses also *tend to vary (mutate)* as a result of which some of them may change their disease-producing capacity; in fact, new virus diseases in plants are appearing continually; (13) according to one theory, viruses are nonliving chemical substances, possibly autocatalytic enzymes, or "wild genes," because they are protein, progagate themselves, etc.

The following are some of the more common diseases caused by pathogenic viruses:

Smallpox (variola)
Cowpox (vaccinia)
Chicken pox (varicella)
Mumps
Foot and mouth disease (cattle and man)
Common colds and influenza
Yellow fever
Dengue fever ("breakbone fever")
Pappataci fever (three-day fever)
Infantile paralysis (poliomyelitis)
Rabies (hydrophobia)
Epidemic encephalitis
Warts (various types; some infectious)
Trachoma ("granulated eyelids")
Hog cholera
Parrot fever (psittacosis)
Dog distemper
Herpes zoster (shingles)
Herpes labialis ("cold sores")
Herpes febrilis ("fever blisters")
Mosaic disease of plants (tomato, potato, tobacco)

QUESTIONS AND TOPICS

1. Describe the beginnings of agriculture in the distant past. What were the first attempts at plant cultivation and animal breeding?
2. Discuss the dependence of man upon the soil, both in the past and at the present time.

3. List the ways in which biology contributes to the advancement of agriculture.
4. List several ways in which biology may be of importance in hydroponics, including specific techniques used.
5. Explain the relationship between agriculture and the nitrogen, oxygen, and carbon cycles discussed in a previous chapter.
6. Give a brief résumé of animal diseases produced by bacteria. Of plant diseases produced by bacteria.
7. Give a short résumé of animal diseases produced by protozoa.
8. List all the ways in which biology may be directly or indirectly related to human affairs.
9. Explain the relationship between biology and (1) medicine, (2) dentistry, (3) pharmacy, (4) nursing, (5) industry, (6) forestry, (7) horticulture, (8) floriculture, (9) landscape gardening, (10) out-of-door pools, (11) fruit culture, (12) appreciation of nature, and (13) the formulation of a philosophy of living.
10. List the more common characteristics of viruses and some diseases supposedly caused by them.

SELECTED REFERENCES*

Burnet: Virus as an Organism, Harvard University Press.
Fernald and Kinsey: Edible Wild Plants of Eastern North America, Idlewild Press.
Hill: Economic Botany, McGraw-Hill Book Co., Inc.
Howard: The Insect Menace, D. Appleton-Century Co., Inc.
Muenscher: Poisonous Plants of the United States, The Macmillan Co.
Reese: Outlines of Economic Zoology, P. Blakiston's Son & Co.
Smith: Plant Viruses, John Wiley & Sons, Inc.

*Also see references on bacteria, yeasts, molds, protozoa, flatworms, roundworms, entomology, etc.

Chapter 39

CONSERVATION OF NATURAL RESOURCES

The constructive program to be followed in the conservation of our natural resources will be in great part biologic. There are many instances where there are shortages because of man's extravagance and shortsightedness. No matter how adept man becomes in producing substitutes artificially, there are instances where natural resources cannot be supplanted. Natural resources must also be conserved and restored from the standpoint of beauty and aesthetics. With greater leisure, man is going to have more time with which to enjoy Nature and the great out-of-doors. Proper conservation and provisions must be made to meet the ever-increasing demands in this direction. The biologic reclaiming of nonproductive lands also will be an important factor in supplying us with sufficient products for our various daily needs. One of the greatest of natural resources of a nation is the health of the individuals composing that nation. Biology in its various medical and health phases can make a great contribution toward our future physical and mental well-being.

Natural resources may be classified as (1) irreplaceable, or those which, once used or destroyed, cannot be replaced, such as coal, oil, natural gas, and minerals and (2) replaceable, or those which are used or destroyed but may be replaced if the proper conservation measures are employed (forests, soils, water, fishes, wild life). Greater and greater demands by homes, industries, wars, etc., have used great quantities of our irreplaceable natural resources so that the supply will be exhausted eventually. In some instances, substitutes may be found, but in most cases these will not be sufficient. Mineral resources in addition to those essential for industries are necessary for plant growth and the maintenance of health of all living things. Irreplaceable resources must be used carefully and conserved properly to ensure future needs. In most instances the replaceable resources will not replace themselves on their own initiative but will do so only when man institutes and follows certain conservation measures. In order better to understand the problems of conservation and the necessary remedial measures, the following resources are considered briefly.

Destruction and Conservation of Forests.—Unless forests are conserved, they will soon be unable to supply us with the necessities of life. In years past when a smaller population required less forest and the per capita supply was much greater, the problem was not so important. In addition to the extensive cutting of forests, they have been destroyed by the following: (1) *Fires* caused by lightning, careless campers, hunters and vacationists. Ninety per cent of the 200,000 forest fires in the United States each year are caused by man and the loss totals millions of dollars.

Fig. 375.—One careless act can burn a forest. Forest fires like this may travel at tremendous speeds and burn millions of small and large trees, destroy much wild life, and start soil erosion. About 200,000 forest fires occur annually in the United States, and most of them are started by careless smokers, hunters, campers, fishermen, trash burners, etc. "Let Each Person Help to Keep America Green" is a good slogan for everybody. (American Forest Products Industries, Inc.)

Forests may require over fifty years to be replaced and in the meantime erosion of the soil may have started. Fires may kill trees or merely injure them, destroy plants, leaves and soil, deprive birds of nesting sites, and deprive other animals of desirable protection; fires may injure trees or their young seedlings so that they are subject to destructive bacterial and fungal diseases. (2) *Improper cutting of trees,* which includes the cutting of small, immature trees; the destruction or injury of young trees during cutting operations; the nonreplacement of trees cut, by new, young trees. (3) *Animals,* which destroy young trees, seedlings, seeds; by using forests for grazing purposes, particularly if the forest is burned over for grazing purposes.

Forest conservation measures include: (1) Replanting burned-over areas. (2) Replanting forests which have been cut. (3) Removal of undesirable trees and vegetation to permit better growth of desirable varieties. (4) Prevention of forest tree diseases. (5) Providing basic protection for all forests, qualifying for cooperative Federal-state protection under the Clarke-McNary Act. (6) Education of careless hunters, campers, etc. If the following rules are followed faithfully, many forest fires can be prevented: (a) Hold and pinch all matches until they are cold; (b) crush out cigarette, cigar, and pipe ashes (use a rock or ash tray); (c) drown all camp fires, stir and drown again; (d) learn and obey laws about burning grass, brush, trash, etc.; (7) Building more fire lookout posts and patrol stations. (8) Discontinuance of practice of burning-over forests for grazing purposes. (9) Wiser and more economical use of timber. (10) Selection of better species of trees for particular areas so that better qualities can be raised in a shorter time.

Loss and Conservation of Soils.—Soils are lost by (1) wind erosion and (2) water erosion. Soils may be blown away because there is insufficient surface vegetation to hold the soil particles. In a similar manner, water currents may wash away great quantities of soil. It is estimated that forty tons of soil per acre are washed away from land with a 2 per cent slope during one rainy season. Recent dust storms have removed large amounts of soil for hundreds of miles, causing not only the loss of soil where it is needed, but placing it where it is not desired. The removal of trees, grasses, and other vegetation has resulted in water and wind erosion, with the loss of the water-retaining humus as well as minerals essential for plant growth. Soil washed into streams interferes with plant and animal life there in addition to filling up rivers, lakes, and ponds, thus rendering them useless. This silt will quickly fill a body of water behind a dam, so that the original purposes of the dam are defeated. Soil erosion also interferes with the water supply of cities, for much effort is required to remove these soil particles from the water supply. Many streams are polluted because of soil particles which interfere with the normal growth and development of plants and animals normally inhabiting them.

Soil conservation measures include (1) the reestablishment of the proper types of vegetation (trees, grasses, crops, etc.) to hold the soil particles, (2) the building of level spaces, known as terraces, on lands whose slope is great enough to permit erosion, (3) the correct type of contour plowing and the practice of strip cropping to reduce erosion to a minimum, (4) the establishment of permanent grasslands by planting the proper types of grasses in a soil supplied with the proper fertilizing ingredients to ensure growth, (5) the establishment of permanent woodlands where other crops are not feasible, (6) the building of dams across streams and gullies, and (7) the increase in fertility of the soil, either by natural or artificial methods, so as to promote greater plant growth. In brief, there should be no barren soils, but each soil should promote the type of vegetation for which it is best fitted.

Loss and Conservation of Water.—As we look at the ocean or a large lake we may wonder if it is necessary to conserve water. There may be about as much water now as there has ever been, but it is not located in the right places. Soils must contain a certain amount of water to ensure our water supplies and the proper plant growth. Any factors which permit the rapid loss of water from the soil must be corrected if we are to have sufficient supplies. Larger quantities of water are now being used in homes and industries than formerly and this has aggravated the problem still more. The greater use of water has reduced the "natural water level" of the soil and this, in turn, diminishes the amount of plant growth. Diminished plant growth results in greater loss of water, so that the cycle is complete.

Another important factor influencing the quantity and quality of available, usable water is the pollution of our water supplies with wastes from oil wells, coal mines, various industries, and sewage. Sometimes a sufficient supply may be available, but it is unsatisfactory for the purposes desired. Many streams have been altered so that their waters "run off" too quickly to permit their retention by the soils. Vegetation on their banks has been removed, thus permitting more water to enter the streams quickly. The presence of wastes, silt, etc., the lowering of the natural water level, the consequent changes in animal and plant foods, and the destruction of natural feeding and breeding areas are among the influential factors responsible for the diminished supply of fishes and other aquatic life in our waters.

Water conservation measures include (1) restoration of streams and other bodies of water to their natural conditions as far as possible, (2) prevention of unnecessary pollution of water by wastes, (3) wiser and more economical use of water, (4) replacement of the "vegetation blanket" (trees, grasses, crops, etc.) on the soils in order to retain a maximum of moisture, (5) the building of dams and dikes to conserve the supply until needed, (6) employment of the correct types of plowing and cultivating to retain a maximum of water in the soil, (7) reduction of evaporation by a covering of vegetation, and (8) institution of a system of flood preventions, thus alleviating the damages due to floods and also conserving water for future uses.

Loss and Conservation of Animal and Plant Wild Life.—Many wild animals and plants have been lost because of factors previously mentioned. Many species of wild flowers no longer exist because their natural habitats are no longer present. The removal of a forest results in a destruction of wild plant and animal life which normally lives there. Fishes, seals, deer, buffalo, birds, beavers, wild flowers will gradually diminish, and probably disappear eventually, unless conservation measures are promptly instituted. It must be remembered that all living things require more or less specific environments for their optimum growth and development. When these are interfered with or destroyed, the living organisms must perish if they are unable to adjust themselves to another type of environment. The loss of each type of wild life constitutes a unique problem in conservation, but the following general measures will illustrate: (1) regulation and control of fishing, hunting, collection of wild flowers, etc., (2) restoration of streams and other bodies of water to their natural conditions as far as possible, (3) restoration of forests, fields, and swamps so as to invite the growth of inhabitants normally found there, (4) prevention of pollution of bodies of water by industrial wastes, (5) prevention of destruction of plant and animal life by the fumes from certain industries, (6) the building of bird sanctuaries, providing nesting sites, proper foods, and protection, (7) protection of such animals as fishes, seals, deer, pheasants, buffaloes, etc., by proper hunting and fishing regulations, (8) the increase of state and national parks and preserves in which the animals and plants have a natural environment protected by laws, (9) prevention of the unnecessary destruction of wild life by the education of man as to the causes, results, and remedial measures, (10) education of the public that picking wild flowers, especially varieties which are scarce, will soon lead to their extinction because each flower picked is the prospective parent for future flowers, (11) increased support for the state and federal agencies for the conservation of natural resources, (12) prevention of devastating forest fires, and (13) the placing of big game in large forests where they are protected by law.

Loss and Conservation of Minerals and Fuels.—Mineral resources include deposits in the earth which in crude or manufactured form are of values in many phases of our personal and industrial life. They include (1) metals for building machinery, bridges, railroads, automobiles, airplanes, etc., (2) building materials such as stone, cement, clays, etc., (3) mineral fuels such as coal, petroleum, and natural gas, (4) fertilizers such as potash and phosphate, and (5) mineral products used in various chemical and industrial processes. Mineral deposits have required thousands of years to form and when once exhausted are not renewable. Our country has great supplies of certain mineral resources but only limited supplies of others, especially when the needs of our highly industrialized society are considered. Of the twenty-eight minerals of industrial importance, the United States possesses eleven in quantity sufficient for normal needs. We are partially dependent on other countries for eleven others, and wholely dependent for six (antimony, asbestos, chromite, nickel, nitrates, tin) of which we have no deposits of commercial value.

Mineral conservation measures include (1) more accurate data on the demands on and the supplies of essential minerals, (2) utilization of lower qualities of minerals ("marginal deposits") where possible, (3) production of substitute materials from less essential minerals where these are economically possible, (4) importation of certain scarce materials to prevent exhaustion of domestic supplies during war and peace, (5) utilization of more efficient methods of mining and processing essential minerals, (6) more economical use of finished products made from essential minerals and an efficient system of reclaiming certain minerals from worn-out or obsolete apparatus, and (7) more economical and efficient use of our natural, mineral fuels such as coal, gas, and petroleum.

Conservation of Human Resources.—The greatest of all resources are normal, healthy, and happy human beings. No nation can become, or remain, great if its inhabitants are physically unfit or socially and psychologically maladjusted. Other resources are unimportant if human beings cannot properly enjoy and utilize them. To maintain itself, a population must show more births than deaths over a period of time. From a money standpoint, one of the greatest assets is that of healthy, normal human beings. Of the total number of deaths in this country each year, few are due to natural senility, but a large proportion are due to causes which might be prevented if the proper conservation measures were followed. Many times as many persons suffer from various diseases as die from them; therefore, the efficiency and happiness of men could be greatly increased if the ravages of the various types of diseases and accidents were controlled.

Human resources conservation measures include (1) reduction of the rate of infant mortality, (2) control and prevention of communicable diseases, (3) guarantee of pure foods and water in sufficient quantities for the individual needs of each person, (4) proper elimination of sewage and industrial wastes, (5) proper growth and inspection of foods so that diseases may not be transmitted to man, (6) greater support to city, county, state, and federal health agencies which are doing much to educate and control the general public in regard to physical and mental health problems, (7) proper enforcement and acceptance of quarantine regulations, (8) the institution of a program of physical activity to develop and maintain a maximum of physical health for each person commensurate with his inherited abilities, (9) the elimination of infectious organisms, especially from crowded places, (10) the proper control of "carriers" of disease germs so that they are unable to transmit them to others, (11) better education of the public regarding the causes, transmission, prevention, treatment, and the effects of human diseases, (12) decrease in the occupational diseases through better working conditions and a reduction of the number of deaths and injuries due to various types of accidents, (13) better understanding of the dietary diseases due to deficiencies of certain essential nutrients, (14) more rigid enforcement of properly formulated pure food and drug laws, (15) more research in the fields of bacteriology, protozoology, immunology, and public health, and (16) the regulation of our individual lives so that we shall be able to develop and maintain the maximum of physical and mental health of which each of us is capable, considering the inherited materials with which each has started existence.

QUESTIONS AND TOPICS

1. Define natural resources and conservation of natural resources.
2. Discuss the causes for the necessity of conservation and specific measures to be used in the conservation of such natural resources as forests, soils, water, animal and plant wild life, minerals and fuels, human beings.
3. Discuss the statement that "the United States is the richest nation in the world," including such points on which we are strong or weak and how we might improve our status in specific instances.
4. Why and how has the necessity for conservation changed in the last fifty years?
5. Explain how the great industrialization of our country has affected the necessity for conservation.

6. Discuss the value of our twenty-eight National Parks and the many State Parks in view of our increased leisure time.
7. Discuss the justification of including human resources in the total program of conserving natural resources, including reasons why this problem has been changed as a result of our ways of living in recent years.
8. Discuss the benefits and detriments of industrialization, greater periods of leisure, concentration of populations in large cities (urbanization), increased mechanization of homes, industries, methods of transportation, etc.
9. Discuss the probable status of human society if and when we shall have exhausted many of the essential resources upon which we now seem so dependent. Include the contrasting status of our forefathers who lived under quite different conditions. Is it impossible for us to really exist if these conditions are prevalent again?

SELECTED REFERENCES

Bennett: Elements of Soil Conservation, McGraw-Hill Book Co., Inc.
Gustafson: Soils and Soil Management, McGraw-Hill Book Co., Inc.
Gustafson, Guise, Hamilton, and Ries: Conservation in the United States, Comstock Publishing Co., Inc.
Jacks and Whyte: Vanishing Lands, Doubleday, Doran & Co., Inc.
Osborn: Our Plundered Planet, Little, Brown & Co.
Peattie: Cargoes and Harvests, D. Appleton & Co.
Sears: Deserts on the March, University of Oklahoma Press.
Smith: Conservation of Our National Resources, John Wiley & Sons, Inc.
Trippensee: Wildlife management, McGraw-Hill Book Co., Inc.
Vogt: Road to Survival, Wm. Sloane Associates.

Chapter 40

BIOLOGISTS AND THEIR WORK

HISTORY AND DEVELOPMENT OF BIOLOGY

The history and development of biology have passed through several distinct periods. Agriculture, hunting, and husbandry of one kind or another had their origins with prehistoric man. From a practical standpoint, systems of medicine were in use at the very beginning of recorded history more than 5,000 years ago. When the Greek and Roman civilizations were at their height, the foundations for natural science and biology were laid. Particularly in Greece was the first systematic and scientific work accomplished. After the Greek and Roman periods, there was a decided decline during the Middle Ages, or so-called Dark Ages. As will be observed from our discussion, there was a renaissance in science which followed this long period of comparative inactivity. During the discouraging period of many years, the emphasis in scientific work was based on the "opinions" of a few so-called "authorities." Investigators made few attempts to prove things for themselves. The opinions of the authorities were accepted without question. In fact, it was on the border line of sacrilegiousness for an investigator to find out things for himself. To evaluate the scientific attempts of those times properly, we must judge and consider them in the light and spirit of that period of history rather than compare them too drastically with modern attempts. The following will give a few of the more important contributors to biologic development, the time during which they lived, their nationality, and their individual contributions. More detailed information will be found by reading the references given at the end of the chapter.

Thales (624-548 B.C.).—Theory that the ocean was the mother of all life.

Anaximander (611-547 B.C.).—Theory that all creatures originated from aquatic forms and were transformed into terrestrial forms.

Empedocles (495-435 B.C.).—Theory that living organisms were generated spontaneously from scattered materials by being attracted or repelled by love or hate.

Hippocrates (460-370 B.C.).—Greek "Father of medicine." Made a science of medicine.

Aristotle (384-322 B.C.).—Greek scientist and philosopher. "Father of natural history." Studied the development, anatomy, physiology, and classification of 500 animals. First used the inductive method of securing facts and then based conclusions or principles on these facts.

Theophrastus (370-287 B.C.).—Greek student of Aristotle. First scientifically studied plants. Founded the science of botany and wrote a *History of Plants.* Named 500 species of plants.

Pliny the Elder (A.D. 23-79).—Roman general, literary man, and scientist. Compiled thirty-seven volumes of half-true, half-false natural history data from his predecessors.

Dioscorides (A.D. 40).—Greek physician. Studied medicinal plants. Wrote *De Materia Medica.*

Galen (Claudius Galenus) (A.D. 130-200)—Roman. Greatest medical anatomist of antiquity. Gave a standard for anatomy which stood for fifteen centuries, without dissecting human bodies but by an analogy with other animals.

Andreas Vesalius (A.D. 1514-1564).—Belgian. "Father of modern dissective anatomy." Studied human anatomy by dissection. He personally dissected and did not permit the "barbers" to do this for his students. By the age of 28 years he had written the *Structure of the Human Body.*

Konrad von Gesner (A.D. 1516-1565).—Swiss. Most learned naturalist and zoologist of this period. Founded the first botanical garden and first zoological museum.

Francis Bacon (1561-1626).—English. Natural philosopher who broke away from the trammels of contemporary scholasticism and deduced his conclusions from facts.

William Harvey (1578-1657).—English. Founder of experimental physiology. Observed and demonstrated the circulation of the blood in 1621. Revived experimental methods in zoology after the so-called Dark Ages.

Francesco Redi (1628-1698).—Italian. Overthrew the theory of spontaneous generation of insects by discovering their eggs and larvae.

Marcello Malpighi (1628-1694).—Italian. Related anatomy and physiology to medicine. Studied tissues microscopically. Observed blood corpuscles and blood flow in capillaries. Started the study of microscopic insect anatomy, particularly that of the silkworm. Studied the anatomy of plants.

Antony van Leeuwenhoek (1632-1723).—Dutch. Philosopher natural historian, and student of microscopy. Studied many forms of microscopic plant and animal life. Discovered and described male germ cells. Sent over 400 papers and letters to the Royal Society in London and the French Academy of Sciences. Started the science of microbiology.

Jan Swammerdam (1637-1680).—Dutch. Great microscopic anatomist. Started the study of insect anatomy and life histories. Injected blood vessels.

Robert Hooke (1635-1703).—English, Made numerous studies with the compound microscope. Influenced the work of Grew in microscopy. Discovered and described cells as "little boxes."

Nehemiah Grew (1641-1712).—English. Studied microscopic anatomy and plant physiology. His book, *Anatomy of Vegetables,* started plant histology.

Bernard de Jussieu (1699-1777).—French. Laid the basis for our present system of plant classification. Wrote *Genera Plantarum.*

Carolus Linnaeus (1707-1778).—Swedish. Originated binomial nomenclature for naming organisms and a system of classification (taxonomy). He listed 4,437 different animals and plants. He originated uniform, latinized names and short descriptions which were more scientific and accurate than the common names which previously had been used.

J. Gottlieb Koelreuter (1733-1806).—German. Demonstrated sexes in plants. Produced a plant hybrid by crossing two species of tobacco.

Jean-Baptiste Lamarck (1744-1829).—French. Suggested the theory of the inheritance of acquired characteristics as an explanation of adaptations. He gave the first logical and complete theory of organic evolution.

Constantine S. Rafinesque (1784-1840).—French-German. He came to America in 1802. In 1815 he was professor of botany at Transylvania College, Ky. He made a classification of medical plants.

George Cuvier (1769-1832).—French. A zoologist who founded modern comparative anatomy. Founded the science of vertebrate paleontology (fossils). Originated the cataclysmic theory that there had been numerous creations, each of which had been completely destroyed and its place taken by newer forms.

Karl von Baer (1792-1876).—Russian. Originated modern comparative embryology.

Robert Brown (1773-1858).—Scotch. A physician who opened the field of plant physiology and genetics. Discovered the importance of plant cell nucleus.

Johannes Müller (1801-1858).—German. He founded modern comparative anatomy, combined the knowledge of physics, chemistry, and cytology (science of cells), and showed their proper relationships.

Matthias Schleiden (1804-1881).—German. A botanist who together with Schwann formulated the cell principle in 1839.

Theodor Schwann (1810-1882).—German. A zoologist who with Schleiden formulated the cell principle in 1839.

Louis Agassiz (1807-1873).—American. A great investigator and teacher in zoology. Studied the development of animals and paleontology. He was professor of zoology and geology at Harvard University and founded the Museum of Comparative Zoology there.

Charles Darwin (1809-1882).—English. Formulated the theory of natural selection (survival of fittest). Wrote *Origin of Species* in 1859.

Asa Gray (1810-1888).—American. First great botanist of America. Improved the system of plant classification.

Gregor Mendel (1822-1884).—Austrian monk and scientist. Used experimental method of studying heredity. Published Mendel's laws in 1865-1866.

Louis Pasteur (1822-1895).—French. Bacteriologist and chemist. "Father of modern bacteriology." Proved that microorganisms cause fermentation and decay. Proved relationship between bacteria and certain diseases.

Sir Francis Galton (1822-1911).—English. Formulated the laws of filial regression and ancestral inheritance in heredity.

Alfred Russel Wallace (1823-1913).—English. Shared with Darwin the credit for the theory of natural selection.

Thomas Henry Huxley (1825-1895).—English. Comparative anatomist and energetic defender of Darwin's theories.

Julius Sachs (1832-1897).—German. Proposed experimental methods for the study of photosynthesis, respiration, and transportation in plants.

August Weismann (1834-1914).—German. Distinguished between germ cells and somatic cells. Theory of continuity of germ plasm. Identified chromatin material of nuclei as bearers of heredity.

John Burroughs (1837-1921).—American. One of greatest of naturalists, having written many books on the lives and habits of living organisms.

Robert Koch (1843-1910).—German. Bacteriologist and physician. Devised the plate method for obtaining pure cultures of bacteria. Proved the relationship between bacteria and certain diseases (tuberculosis).

Carl Weigert (1845-1904).—German. Bacteriologist who first used aniline dyes to study microorganisms.

Luther Burbank (1849-1926).—American. Improved many types of domestic plants by crossing. Created several new varieties of plants.

HOW SCIENTISTS HAVE SOLVED PROBLEMS

There have always been and there always will be many problems of various kinds to be solved. In fact, the solution of one problem frequently creates other problems which require solution. Some of these problems may be personal and some may seem insignificant, while others may have far-reaching effects. The success of individuals, of groups, of nations depends upon the correct solution of the many problems which confront each. In order to become familiar with some of the problems and their solutions, it may be profitable to read some of the accounts of scientists in connection with the problems which they solved. The selection of the specific problems and their solutions may depend upon the availability of the literature in which they are described, the particular interests and qualifications of the students, and the specific reasons for making such a study. The way in which an article is written must be considered before it may be helpful, because sometimes the author does not always clearly state the detailed steps followed in the solution of his problem. The selection of specific references must be made with great care, or the beginner may not derive the desired benefits from their study. When reading a selected article, watch carefully for such steps as the following: (1) accurate and clear statement of the problem, (2) formulation of working hypotheses and methods of investigation, (3) accurate collection and recording of data and facts, and (4) scientific analysis and correct interpretation of data and facts, from which logical conclusions are drawn. As stated above, certain articles, as written, may not follow the steps suggested above, some steps being left out of the printed report, even though they may have been utilized by the scientist in his work. For purposes of brevity, some reports treat certain steps so briefly that they are not easily recognized. When you read the reference, do so very carefully, watching for the methods used in the solution of the problem under consideration. After you have reread the reference sufficiently, *write a report,* giving the contents under the proper headings or steps listed above.

QUESTIONS AND TOPICS

1. Describe the conditions under which the science of biology originated.
2. Why does the "father of natural history" deserve that designation? Considering the conditions under which he worked, how do you evaluate his work?
3. Discuss the reasons why biology as a science did not originate earlier and why progress was not more uniform and rapid.
4. Discuss several biologic theories proposed before the time of Christ.
5. Discuss the causes for the decline of biology after the so-called Greek period.
6. Discuss the reasons for the revival of science in the Middle Ages.
7. List the more important biologists of the past and include the contributions which each made to the progress of the science.
8. What were the effects on biology of the invention and perfection of the microscope? Be specific in your statements.
9. Why were the earlier biologists called natural philosophers? Is there still philosophy in biology today? Explain your answer and give proof.
10. Are there greater biologists today than in times past? Why do you say so? What makes a biologist great?
11. Was the lack of progress in biology of the past due primarily to a lack of scientific equipment? Why do you say so?
12. In what directions do you expect the greatest advances in biology in the future? Give reasons why you say so.
13. After you have read each of the assigned references which show how scientists have solved problems, record all materials under the four headings suggested in the chapter. Attempt to use the scientific method in the solution of as many of the problems which you encounter as possible. If certain problems do not seem to lend themselves to the use of the scientific method, is this due to the fault of the method or to a probable incorrect use of the method?
14. Memorize the steps to be followed in the scientific solution of a problem and use them in the solution of as many of the problems which you encounter as possible.
15. When you have solved a problem, attempt to apply the conclusions in other fields or problems as far as justifiable from the data at hand.

SELECTED REFERENCES*

Banting, Best, and Macleod: The Internal Secretion of the Pancreas, Am. J. Physiol. **59:** 479, 1922.

Bayliss and Starling: The Mechanism of Pancreatic Secretion, J. Physiol. **28:** 325-359, 1902.

Dobell: Antony van Leeuwenhoek and His "Little Animals," Harcourt, Brace and Co., Inc.

*Also see references to various chapters, especially Chapter I, and references supplied by the instructor.

Dubos: Louis Pasteur: Free Lance of Science, Little, Brown & Co.
Green: History of Botany, Oxford, Eng., Clarendon Press.
Hall: Source Book of Animal Biology, McGraw-Hill Book Co., Inc.
Howard: Luther Burbank: Victim of Hero Worship, Chronica Botanica Co.
Keynes: The Personality of William Harvey, Cambridge University Press.
Knobloch: Readings in Biological Science, Appleton-Century-Crofts, Inc.
Locy: Growth of Biology, Henry Holt & Co., Inc.
Locy: The Story of Biology, Garden City Publishing Co.
Loewi: Chemical Transmission of Nerve Impulses, Am. Scient. **33:** 159-174, 1945.
Nordenskiold: History of Biology, Tudor Publishing Co.
Olmstead: Charles-Edward Brown-Sequard, Johns Hopkins University Press.
Pavlov: Lectures on Conditioned Reflexes, International Publishing Co.
Peattie: Green Laurels (Great Naturalists), Simon & Schuster, Inc.
Radl: History of Biological Theories, Oxford University Press.
Reed: Short History of the Plant Sciences, Chronica Botanica Co.
Sarton: Guide to the History of Science, Chronica Botanica Co.
Sears: Charles Darwin, Charles Scribner's Sons.
Sedgwick, Tyler, and Bigelow: A Short History of Science, The Macmillan Co.
Snyder: Biology in the Making, McGraw-Hill Book Co., Inc.
Vallery-Radot: The Life of Pasteur, Garden City Publishing Co.
Zinsser: Rats, Lice and History, Little, Brown & Co.

Part 5

APPENDIX

I. IMPORTANT PREFIXES AND SUFFIXES USED IN BIOLOGY

The following list is by no means complete, but it will serve as a basis for additional types. It will prove very useful if memorized with an example of each type. The following abbreviations are used: *Gr.,* from the Greek; *L.,* from the Latin.

A

A- or **An-** (Gr., without or absent), *apoda,* without feet.
Ab- (L., away from or without), *aboral,* away from the mouth.
Ad- (L., toward, upon, or equal), *adrenal,* upon the kidney; *adductor,* drawing one part toward another.
-Ae (L.), plural ending of singular Latin nouns ending in *A*.
Aer- (Gr., air), *aerobe,* requiring free air.
Alb- (L., white), *albino,* without pigment.
Ambi- (L., both), *ambidextrous,* ability to use either hand.
Amphi- (Gr., on both sides), *amphibia,* living in water and on land.
Amyl- (L., starch), *amylase,* an enzyme changing starch to sugar.
Ana- (Gr., back or again), *anabolism,* building up process of metabolism.
Angio- (Gr., enclosed), *angiosperm,* protected or enclosed seeds.
Ante- (L., before in time or space), *antedorsal,* placed before the dorsal.
Anti- (Gr., opposed or opposite), *antitoxin,* opposed to or neutralizing a toxin.
Antr- (L., cavity), *antrum,* cavity in a bone.
Apo- (Gr., from or separate), *apodema,* extending from the body.
Aqua- (L., water), *aquatic,* living in water.
Arch- (Gr., early or chief), *archenteron,* early digestive tract or enteron; *archeozoic,* earliest life.
Areol- (L., space), *areolar,* containing minute spaces.
Arthr- (Gr., joint), *arthropoda,* jointed appendages or feet.
Asco- (Gr., sac or bag), *ascomycete,* sac-bearing fungi.
-Ase, suffix designating an enzyme *(zymase, protease).*
Aster- (Gr., star), *asteroidea,* a class of echinoderms resembling stars.
Auto- (Gr., self), *autosynthesis,* self building-up.

B

Bacter- (Gr., rod), *bacteria,* rod-shaped.
Basi- (Gr., base), *basidiospore,* spore formed at the base of a basidium.
Bi- (L., double), *bilateral,* similar on both sides.

Bio- (Gr., life), *biology,* science of life.
Blast- (Gr., bud or promotive), *blastoderm,* primitive germ layer.
Brachy- (Gr., short), *brachydactyly,* short digits.
Brevis (L., short), *adductor brevis,* a short adductor muscle.
Bryo- (Gr., moss), *bryophyte,* a plant of the phylum comprising the mosses.

C

Caec- (L., blind), *caecum,* blind pouch.
Calci- (L., lime), *calcareous,* containing lime.
Carp- (Gr., fruit), *pericarp,* around the fruit.
Cauda- (L., tail), *caudal,* tail.
Cav- (L., hollow), *vena cava,* hollow vein.
Ceno- (Gr., recent), *cenozoic,* recent life.
Centr- (L., centre), *centrosome,* center of activity during mitosis.
Cephalad (Gr., head), used adverbially, as toward the head or headward.
Chlor- (Gr., green), *chlorophyll,* green leaf.
Chond- (Gr., granular), *mitochondria,* small, granular parts of protoplasm.
Chondro- (Gr., cartilage), *chondrocranium,* part of the cranium developing from cartilage.
Chrom- (Gr., color), *chromatophore,* color-bearing.
Cili- (L., eyelash), *cilia,* hairlike.
Circum- (L., around), *circumesophageal,* around the esophagus.
Cloaca (L., sewer), *cloaca,* outlet for excretions.
Cnido- (Gr., nettle), *cnidoblast,* nettle cell of certain animals.
Coel- (Gr., hollow), *coelom,* hollow body cavity.
Coeno- (Gr., common), *coenosarc,* common tissue in certain animals.
Coleo- (Gr., sheathed), sheathed insects, such as beetles.
Com- (L., together), *commensalism,* living together.
Con- (L., cone), *conifer,* cone-bearing tree; or (L., with), *concretion,* grow together.
Cotyl- (Gr., cup-shaped), *cotyledon,* cup-shaped seed leaf.
Creta- (L., chalk), *cretaceous,* chalk period of geologic times.
Cyan- (Gr., blue), *cyanophyta,* blue-green algae.
Cyst (Gr., sac), *cyst,* a pouch or sac.
Cyt- (Gr., cell), *cytology,* branch of biology treating cell structure, function, etc.

D

De- (L., off), *degenerate,* to lose generative ability.
Dendr- (Gr., brush or tree), *dendrite,* treelike structure of nerve cell.
Derm- (Gr., skin), *dermis,* part of the skin.
Di- (Gr., twice), *diploblastic,* two germ layers; *dicotyledon,* two cotyledons.
Dis- (L., away), *distal,* away from.
Dors- (L., back), *dorsal,* pertaining to the back.
Dura- (L., tough), *dura mater,* tough outer covering of nervous system.

E

E- (L., without), *egestion,* to pass outside.
Ec- (Gr., house or environment), *ecology,* the habitats of an organism.

Ecto- (Gr., outside), *ectoderm,* the outer layer of cells.
En- (Gr., in, or within), *encyst,* to cover with a membranous cyst.
Endo- or **ento-** (Gr., within) *entoderm,* inner layer of cells.
Eo- (Gr., dawn, or early), *eocene,* early geologic period.
Epi- (Gr., upon), *epidermis,* upon the dermis.
Equus- (L., horse), *Equisetineae,* the class to which the horsetails belong.
Eu- (Gr., good or well), *eugenics,* being well born from a hereditary standpoint.
Ex- (Gr., external), *exoskeleton,* external skeleton.
Extra- (L., beyond), *extracellular,* beyond or outside the cell.

F

Fer- (L., to bear), *Porifera,* pore-bearing sponges.
Fil- (L., thread), *filiform,* threadlike.
Flex- (L., bend), *flexor muscles,* bend joints.
Form- (L., shape), *uniform,* all one shape.

G

Gam- (Gr., marriage), *gamete,* a reproductive cell.
Gastr- (Gr., stomach), *gastric,* pertaining to the stomach.
Gen- (Gr., to produce), *pathogenic,* to produce disease.
Geo- (Gr., earth), *geology,* science of the earth.
Gest- (Gr., to bear or hold), *ingest,* to take in.
Glea- (Gr., jelly), *mesoglea,* the middle jellylike layer in certain animals.
Glyc- (Gr., sweet or carbohydrate), *glycogen,* animal starch.
Gono- (Gr., seed, or to reproduce), *gonad,* an organ of reproduction.
Gymn- (Gr., naked), *gymnosperm,* seeds not covered when being formed.

H

Haem- (Gr., blood), *haemoglobin,* a substance in the blood.
Hemi- (Gr., half), *hemisphere,* one-half of a sphere.
Hepat- (Gr., liver), *hepatic,* pertaining to the liver.
Hetero- (Gr., other or different), *heterogeneous,* formed differently.
Hex- (Gr., six), *hexagonal,* six-sided.
Homo- (Gr., same), *homogeneous,* similar.
Hyal- (Gr., glass), *hyaline,* glasslike cartilage.
Hydr- (Gr., water), *dehydrate,* to remove water.
Hymen- (Gr., membrane), *hymenoptera,* membranous wings.
Hyper- (Gr., above), *hypersensitive,* especially sensitive.
Hypo- (Gr., under), *hypoglossal,* under the tongue.

I

In- (L., in, into, not, without), *invaginate,* to push in.
Infra- (L., below), *infraorbital,* below the orbit.
Inter- (L., between), *intercellular,* between cells.
Intr- (L., inside), *intracellular,* within a cell.
Is- (Gr., equal), *isotherm,* equal temperatures.

J

Juga- (L., join), *conjugate,* a process of reproduction in which two animals are joined.

K

Kata- (Gr., down or destroy), *catabolism,* tearing down or destroying.
Kine- (Gr., *kineo,* more), *kinetic,* kinetic energy is energy of movement.

L

Labi- (L., lip), *labium,* a lip.
Lac- (L., milk), *lactose,* milk sugar.
Later- (L., side), *lateral,* to the side.
Lemma- (Gr., covering), *neurilemma,* covering of a nerve.
Lepi- (Gr., scale), *lepidoptera,* insects with scale wings.
Lip- (Gr., fatty), *lipoid,* a fatty substance.
Log- (Gr., study), *zoology,* study of animals.
Luci- (L., light), *luciferin,* a light-producing material.
Lysis- (Gr., destroy), *bacteriolysis,* a bacteria-destroying substance.

M

Macro- (Gr., large), *macronucleus,* large nucleus.
Mal- (Gr., *mal,* bad), *malnutrition,* bad nutrition.
Mega- (Gr., larger), *megaspore,* larger spore.
Mens- (L., table), *commensalism,* eating at a common source of food.
Mere- (Gr., part), *micromere,* small part.
Meso- (Gr., middle), *mesoderm,* middle cellular layer.
Meta- (Gr., after), *metaphase,* the later phases of mitosis.
Micro- (Gr., small), *micronucleus,* small nucleus.
Milli- (Gr., thousand), *millipede,* an animal with a "thousand" legs.
Mio- (Gr., less), *miocene,* less recent period in history.
Mito- (Gr., thread), *mitosis,* cell division with formation of threadlike structures.
Mono- (Gr., one), *monograph,* something written about one subject.
Morph- (Gr., form), *morphology,* study of form.
Multi- (L., many), *multicolored,* many colors.
Muta- (L., to change), *mutation,* an abrupt hereditary change.
Myco- (Gr., fungus), *mycology,* a study of fungi.
Myxo- (Gr., slime), *myxomycophyta,* slime molds.

N

Nema- (Gr., thread), *nematocyst,* a threadlike structure of coelenterates.
Neo- (Gr., young, or recent), *neotropical,* a recent region in the tropics.
Nephro- (Gr., kidney), *nephridium,* a kidney.
Nuc- (L., kernel, or center), *nucleus,* in the center of a cell.

O

Octo- (L., eight), *octopus,* an animal with eight appendages.
Oedo- (Gr., swollen), *edema (oedema),* a swollen condition.
-Oid (Gr., like), *amoeboid,* like an amoeba.

Oligo- (Gr., few or little), *oligotrichous,* having few cilia.
Oo- (Gr., egg), *oogenesis,* producing an egg.
Or- (L., mouth), *oral,* pertaining to the mouth.
Ortho- (Gr., straight), *orthoptera,* insects with straight wings.
Os- (Gr., bone), *osseous,* pertaining to bone.
Ovi- (L., egg), *ovum,* an egg.

P

Palaio- (Gr., ancient), *paleontology,* study of ancient life.
Para- (Gr., beside), *parapodia,* appendages beside others.
Path- (Gr., disease), *pathogenic,* disease-producing.
Ped- (L., feet), *pedal,* pertaining to the feet.
Peri- (Gr., around), *peristome,* around an opening or mouth.
Phaeo- (Gr., dark or brown), *phaeophyta,* brown algae.
Phago- (Gr., to eat), *phagocyte,* a cell which eats or destroys.
Phor- (Gr., to bear), *sporophore,* to bear spores.
Photo- (Gr., light), *photosynthesis,* building by means of light.
Phil- (Gr., loving), *thermophil,* heat loving.
Phyco- (Gr., alga, or seaweed), *phycomycete,* an algalike fungus.
Phyll- (Gr., leaf), *mesophyll,* middle part of a leaf.
Phyto- (Gr., plant), *sporophyte,* spore-bearing plant.
Plasm- (Gr., formed), *ectoplasm,* formed outside.
Plast- (Gr., living), *chloroplast,* a green body in certain living plants.
Platy- (Gr., flat), *platyhelminthes,* flatworms.
Plio- (Gr., more), *pliocene,* more recent period.
Poly- (Gr., many), *polymorphous,* many forms.
Post- (L., after), *postnatal,* after birth.
Pous- (Gr., foot), *octopus,* an animal with eight feet.
Pre- (L., before), *prenatal,* before birth.
Pro- (Gr., before), *prostomium,* before the mouth.
Proto- (Gr., first or essential), *protoplasm,* an essential material.
Prox- (L., nearest), *proximal,* nearest.
Pseudo- (Gr., false), *pseudopodia,* false feet.
Ptero- (Gr., wing), *diptera,* two wings.

R

Re- (L., again, or back), *regenerate,* to form again.
Ren- (L., kidney), *renal,* pertaining to the kidney.
Rept- (L., creeping), *reptile,* creeping animals.
Retro- (L., backward), *retrolingual,* backward from the tongue.
Rhizo- (Gr., root), *rhizopoda,* rootlike appendage.
Rhodo- (Gr., red), *Rhodophyta,* red algae.
Roti- (L., wheel), *rotifer,* an animal with a wheel-like structure on its head.

S

Sarc- (Gr., flesh), *ectosarc,* outer flesh.
Schizo- (Gr., to divide), *Schizomycophyta,* fission fungi (bacteria).

Scler- (Gr., hard), *sclerotic,* hard.
Sect- (L., to cut), *dissect,* to cut.
Semi- (L., half), *semicircle,* half of a circle.
Sept- (L., wall), *septum,* a partition.
Set- (L., bristle), *seta,* a bristlelike structure.
Sinu- (L., hollow), *sinus,* a hollow cavity.
Soma- (Gr., body), *somatoplasm,* protoplasm of the body.
Spor- (Gr., seed), *spore,* a structure for reproductive purposes.
Stoma- (Gr., opening), *stoma,* an opening, such as is found in leaves.
Sub- (Gr., under), *submaxillary,* under the maxilla.
Super- (L., over or above), *superior,* higher, upper, above.
Supra- (L., above), *suprarenal,* above the kidney.
Sym- (Gr., together), *symbiosis,* living together.
Syn- (Gr., together), *synapsis,* fusing together.

T

Teleo- (Gr., complete, or end), *telophase,* the end stage of mitosis.
Terato- (Gr., wonder), *teratology,* a study of wonders.
Tetra- (Gr., four), *tetrapoda,* four feet.
Thec- (Gr., case), *spermatheca,* sperm case.
Thermo- (Gr., heat), *thermotropism,* reaction to heat.
Thigmo- (Gr., contact), *thigmotropism,* reaction to contact.
Tom- (Gr., to cut), *microtome,* an instrument to cut small sections.
Toxic- (Gr., poison), *toxin,* a bacterial poison.
Trans- (Gr., across), *transfer,* to carry across.
Tri- (Gr., three), *trilobed,* three lobes.
Tricho- (Gr., hair), *trichocyst,* a hairlike structure.
Trop- (Gr., react), *tropism,* reaction to stimuli.

U

Ultra- (L., beyond), *ultramicroscopic,* beyond the microscope.
Uni- (L., one), *unilateral,* on one side.
Ur- (Gr., tail), *anura,* without a tail.

V

Vas- (L., vessel), *vas deferens,* a vessel to transmit male sex cells.
Ventr- (Gr., belly), *ventral,* pertaining to the lower or belly side.
Vit- (L., life), *vital,* essential to life.
Vorti- (L., to turn), *vorticella,* an animal which turns as it moves.

Z

Zoo- (Gr., life or animal), *zoology,* study of animals.
Zyg- (Gr., to unite), *zygote,* the cell which results when male and female sex cells unite.
Zym- (Gr., a ferment), *zymase,* enzymes which act on a certain carbohydrate to produce carbon dioxide and water, or alcohol and carbon dioxide, etc.

II. GLOSSARY, BIOLOGIC PRINCIPLES, AND THEORIES

One of the most important contributions which the science of biology can make to the individual student is the imparting of a knowledge of the general principles and theories which underlie living organisms and their varied activities. Many of the detailed structures and functions of living organisms may be forgotten when the knowledge of the general principles will remain and continue to be a source of value and satisfaction. An attempt is made to summarize briefly the more important principles and theories. In some instances, clarity and completeness are sacrificed for the sake of necessary brevity. In cases where the consideration is insufficient, the reader is directed to the proper part of the text or to additional references.

The pronunciation, based on *Webster's New International Dictionary*, is given and the syllable to be emphasized is marked by ′. The derivations of the terms are included not only for a better understanding of the term, but to enable the student to use these derivations in an attempt to explain the meaning of other words with which he may not be familiar. Those derived from Greek are designated by *Gr.*, those from Latin by *L.*, those from Anglo-Saxon by *A.S.*, and those from French by *Fr.*

A

Abdomen (ab -do′ men) (L. *abdomen*, belly), the part of the animal, posterior to the thorax.

Abductor (ab -duk′ ter) (L. *ab*, away; *duco*, to lead), leading away from the center or median line (contrast with adductor).

Abiogenesis (ab i o -jen′ e sis) (Gr. *a*, not; *bios*, life; *genesis*, to create), the former theory that all living matter arose spontaneously from nonliving matter (same as spontaneous generation).

Aboral (ab -o′ ral) (L. *ab*, from; *os*, mouth), opposite the mouth.

Abortion (a -bor′ shun) (L. *abortare*, to miscarry), premature birth or incompletely formed structure.

Absorption (ab -sorp′ shun) (L. *ab*, away; *sorbere*, to suck or remove), the taking up of substances or their passage through the walls of cells or vessels.

Acclimation (ak li -ma′ shun) (L. *ad*, toward; *klimat*, region), the process of becoming accustomed or habituated to environmental conditions which are not native.

Accommodation (a kom o -da′ shun) (L. *ad*, to; *commodus*, fit), the ability of the eye to adjust to objects near and far.

Accretion (a -kre′ shun) (L. *accrescere*, to increase), increasing in size by adding deposits to the surface (contrast with intussusception).

Acetabulum (as e -tab′ u lum) (L. *acetabulum*, saucer-shaped), a cavity on each side of the pelvic bone into which the femur fits.

Achromatic figure (a kro -mat′ ik) (Gr. *a*, not; *chroma*, color), the nonstaining part of the nucleus.

Acoelomate (a -se′ lo mat) (Gr. *a*, without; *koilos*, hollow), without a hollow, true, body cavity or coelom.

Acquired characters, modifications of structures or functions acquired by the body plasm through the changes in environment or functions (contrast with mutation).

Acromegaly (ak ro -meg′ a li) (Gr. *akron,* point; *megas,* large), a disease in which the head, hands, and feet become enlarged, caused by overactivity of the pituitary gland.

Actinic rays (ak -tin′ ik) (Gr. *aktis,* beam or ray), the chemically active rays of light.

Adaptation (ad ap -ta′ shun) (L. *ad,* to; *aptus,* fit), the process of becoming fitted to an environment or the mutual fitness of an organism to its internal and external environments.

Adaptive radiation, the radiating or spreading in various directions of organisms arising from the same generalized stock and the assuming of different characters by them because of their adaptation to different kinds of environments encountered.

Adductor (a -duk′ ter) (L. *ad,* to; *duco,* to lead), leading toward the center or median line (contrast with abductor).

Adipose (ad′ i pos) (L. *adiposus,* fatty), pertaining to fat.

Adrenal (ad -re′ nal) (L. *ad,* near; *renes,* kidney), an endocrine (ductless) gland near the kidney (same as suprarenal).

Adrenalin (ad -ren′ a lin), a hormone secreted by the inner part or medulla of the adrenals.

Aerobe (a′ er ob) (Gr. *aer,* air; *bios,* life), requiring free oxygen for living (contrast with anaerobe).

Aestivation (estivation) (es ti -va′ shun) (L. *aestas,* summer), a semitorpid condition of certain animals in summer.

Afferent (af′ er ent) (L. *ad,* to; *ferro,* to bear), conveying toward a center.

Agglutination (a gloo ti -na′ shun) (L. *agglutinans,* gluing or clumping together), the collection of cells in a liquid into clumps due to specific substances known as agglutinins.

Agnostic (ag -nos′ tik) (Gr. *a,* not; *gnosco,* to know), no convictions on a subject.

Albinism (al′ bi nizm) (L. *albus,* white), the absence of normal pigments in the hair, skin, and eyes of animals or the absence of normal chlorophyll in plants which normally possess it.

Algae (al′ ji) (L. *alga,* seaweed), simple, green, chlorophyll-bearing plants.

Alimentary (al i -men′ ta ri) (L. *alimentum* food), pertaining to food and digestion.

Allantois (a -lan′ to is) (Gr. *allas,* sausage), an embryonic membrane of higher vertebrates for respiration.

Allelomorphs (alleles) (a -le′ lo morf) (Gr. *alleon,* of one another; *morphe,* form), genes similarly located in homologous chromosomes.

Allergy (al′ er ji) (Gr. *allos,* other; *ergon,* activity), a reaction to a foreign substance, especially protein.

Alternation of generations, *see* Metagenesis.

Alveolar (al -ve′ o lar) (L. *alveolus,* small cavity), small cavity; foamlike.

Ambulacral (am bu -la′ kral) (L. *ambulacrum,* covered way), regions in echinoderms in which are located the ambulacral tube feet for locomotion.

Amino acid (a -me′ no), organic acid containing the amino group (NH_2) and serving as building material for proteins.

Amitosis (am i -to′ sis) (Gr. *a,* without; *mitos,* thread), cells dividing directly without forming chromosomes, spindle, etc.

Amnion (am′ ni on) (Gr. *amnos,* lamb; the membrane around the embryo), thin membranous sac enclosing the embryos of reptiles, birds, and mammals.

Amoeboid (a -me′ boid) (Gr. *amoibe,* to change), resembling an Amoeba.

Amphiaster (am fi -as′ ter) (Gr. *amphi,* both; *aster,* star), the figure formed in dividing cells by the two asters and the spindle.

Amphibious (am -fib′ i us) (Gr. *amphi,* both; *bios,* life), living both in water and on land.

Amphiblastula (am fi -blas′ tu la), free-swimming larval stage of sponges.

Amphimixis (am fi -mik′ sis) (Gr. *amphi,* both; *mixis,* mingling), a union of nuclear materials from two different cells, as in fertilization.

Amphoteric (am fo -ter′ ik) (Gr. *amphi,* both), partaking of the nature of both, as proteins have both acid and basic properties.

Ampulla (am -pul′ a) (L. *ampulla,* flask), saclike structure of the ambulacral system of starfishes.

Amylase (am′ i las) (Gr. *amylon,* starch; *ase,* enzyme), starch-splitting enzyme.

Amylopsin (am i -lop′ sin) (Gr. *amylon,* starch), a starch-splitting enzyme of the pancreatic juice.

Anabolism (an ab′ o lizm) (Gr. *anabole,* to build), the building-up phase of metabolism.

Anaerobe (an -a′ er ob) (Gr. *an,* without; *aer,* air), living without free oxygen (contrast with aerobe).

Anal (a′ nal) (Gr., *anus,* anus), pertaining to the anus.

Analogy (analogous) (a -nal′ o gi) (Gr. *ana,* according to; *logos,* proportion), organs structurally different which perform similar functions, as wings of birds and butterflies.

Anaphase (an′ a faz) (Gr. *ana,* up; *phasis,* appear), stage in mitosis in which chromosomes move toward the poles of the cell.

Anaphylaxis (an a fi -lak′ sis), the reaction to foreign protein material which has a toxic effect and which may be due to increased sensitivity to the material because of previous contact with it.

Anastomose (a -nas′ to moz) (Gr. *anastomosis,* join), to join together into a network such as blood vessels.

Anatomy (a -nat′ o mi) (Gr. *ana,* up; *temno,* to cut), structure of organs, especially as revealed by dissection.

Angiosperm (an′ ji o spurm) (Gr. *angio,* covered; *sperm,* seed), plants with seeds enclosed by carpels (contrast with Gymnosperm).

Animal pole, that part of a cell in which the protoplasm has the highest rate of metabolism in contrast with the vegetal pole.

Anion (an′ i on) (Gr. *ana,* up; *ienai,* to go), a negatively charged particle or ion that travels to the positive anode during electrolysis.

Annelida (a -nel′ i da) (L. *annulus,* ring), with ringlike segments as in the earthworm.

Annual (an′ u al) (L. *annus,* year), plants which complete their life cycle and die within one year.

Annular ring, ringlike structure in stems of higher plants which show seasonal growth.

Antenna (an -ten′ a) (Gr. *ana,* up; *teino,* stretch), jointed sensitive organ on the head of insects, crustacea, etc.

Anterior (an -te′ ri or) (L. *anterior,* front), or head end.

Anteroposterior differentiation, body with front (head) and hinder (tail) ends.

Anther (an′ ther) (Gr. *anthos,* flower), pollen-producing part of a plant stamen.

Antheridia (an ther -id′ i a), the male sexual organs that produce sperm in certain flowerless plants.

Antheridiophore (an ther -id′ i o for) (Gr. antheridia; *phoreo,* to bear, antheridia-bearing structure.

Anthocyanin (an tho cy′ a nin) (Gr. *anthos,* flower; *kyanos,* blue), a coloring matter of certain higher plants which impart a red or blue color.

Anthozoa (an tho -zo′ a) (Gr. *anthos,* flower; *zoa,* animals), flowerlike coelenterate animals, including corals, sea anemone, etc.

Anthropoid (an′ thro poid) (Gr. *anthropos,* human), manlike organisms.

Anthropology (an thro -pol′ o ji) (Gr. *anthropos,* human; *logos,* science), the science of ancient man and his development.

Antibiotic (anti bi -ot′ ik) (Gr. *anti,* against; *bios,* life), antagonism of one organism toward another; a drug, chiefly from bacteria and true fungi.

Antibody (an′ ti bod i) (Gr. *anti,* against; A.S. *bodig,* body), a substance engendered in an organism by the presence of a foreign material, especially bacterial proteins; an antibody is specifically antagonistic to the antigen or substance under the influence of which it was formed.

Antigen (an′ ti jen) (Gr. *anti,* against; *gen,* to form), a substance causing the formation of an antibody.

Antimere (an′ ti mere) (Gr. *anti,* opposed; *meios,* part), one of the parts of a radially symmetrical animal, as the ray of a starfish.

Antitoxin (an ti -tok′ sin) (Gr. *anti,* against; *toxikon,* poison), a specific defensive substance in a body, either existing naturally or produced as a result of the presence of a specific toxin which it tends to neutralize.

Aorta (a -or′ ta) (Gr. *aorta,* raise), main artery arising from the heart.

Aortic arches, arteries arising from the ventral aorta and supplying the gill regions of vertebrate animals.

Apical (ap′ i kel) (L. *apex,* summit), apex, tip, or summit.

Apopyle (ap′ o pil) (Gr. *ap,* from; *pyle,* gate), an opening through which water passes from the flagellated canals of sponges.

Apospory (a -pos′ po ri) (Gr. *apo,* away; *sporos,* spore), the formation of a gametophyte plant directly from sporophyte tissue rather than from a spore.

Appendix (ap -pen′ dix) (L. *ad,* to; *pendere,* to hang), an outgrowth, such as the vermiform appendix of man.

Apterous (ap′ ter us) (Gr. *a,* without; *ptera,* wings), wingless.

Archegoniophore (ar ke -go′ ni o for) (Gr. *archegonos,* first of a race; *phoreo,* to bear), basal structure which bears the archegonium.

Archegonium (ar ke -go′ ni um) (Gr. *archegonos,* first of a race), female, multicellular sex organs in plants.

Archenteron (ar -ken′ ter on), (Gr. *archos,* beginning; *enteron,* intestine), the primitive digestive tract.

Archeology (ar ke -ol′ o ji) (Gr. *archos,* beginning; *logos,* science), a study of ancient peoples from their relics, equipments, etc.

Aristotle's lantern, the chewing apparatus of sea urchins.

Artery (ar′ ter i) (Gr. *arteria,* artery), vessel conducting blood away from the heart.

Arthropoda (ar -throp′ o da) (Gr. *arthron,* jointed; *pous,* appendage), phylum of animals with jointed appendages but without notochord or vertebral column.

Artificial parthenogenesis (par the no -jen′ e sis) (Gr. *parthenos,* virgin; *genesis,* orgin), the artificial activation of an egg to develop without fertilization by a male sperm.

Artificial selection, the development of certain traits by artificially crossing selected individuals.

Ascocarp (as′ ko karp) (Gr. *askos,* sac; *karpos,* fruit), a structure which produces saclike asci in sac fungi.

Ascomycetes (as ko mi -set′ ez) (Gr. *askus,* sac; *mycetes,* fungi), higher fungi whose spores are formed in saclike asci.

Ascospore (as′ ko spor) (Gr. *askus,* sac; *sporos,* spore), a spore contained in a saclike ascus.

Asexual (a -sek′ shu al) (Gr. *a,* without; *sexus,* sex), reproduction without sex cells.

Assimilation (as sim i -la′ shun) (L. *ad,* to; *similare,* to make like), conversion of digested food into living protoplasm.

Association areas, regions of the brain in which higher mental processes are presumably affected.

Aster (as′ ter) (Gr. *aster,* star), starlike figure of radiating lines about the centrosome during certain stages of animal cell mitosis.

Asymmetry (a -sim′ e tri) (Gr. *a,* not; *symmetria,* symmetry), without symmetry.

Atlas (at′ las) (Gr. *Atlas,* name of a god whose pillars upheld the heavens), the first or anterior vertebra of the neck.

Atom (at′ um) (Gr. *atomos,* indivisible), structural unit of a molecule which maintains its integrity in a chemical change; an atom enters into, and issues from, a chemical reaction unchanged except for a loss or gain of electrons.

Atomic theory, all matter is made of small units called atoms.

Atrophy (at′ ro fi) (Gr. *a,* not; *trophe,* nourishment), wasting away of an organ or a part of it (contrast with Hypertrophy).

Attraction sphere (L. *attractus,* draw to), structure which may aid in attracting chromosomes toward the cell poles during mitosis.

Auditory (o′ di to ri) (L. *audire,* to hear), pertaining to sound reception and interpretation.

Autogamy (o -tog′ a mi) (Gr. *autos,* self; *gamos,* marriage), nuclear reorganization and self-fertilization within the same individual (example, Paramecia).

Autolysis (o -tol′ i sis) (Gr. *autos,* self; *lysis,* destroying), self-digestion of a tissue or organ by enzymes formed by it.

Autonomic system (o to -nom′ ik) (Gr. *autos,* self; *nomos,* law), a system of nerves and ganglia regulating involuntary muscles, blood vessels, etc., and connected with the central nervous system by the cranial and spinal nerves.

Autosome (o′ to sum) (Gr. *autos,* self; *soma,* body), a regular chromosome as distinguished from a sex chromosome.

Autotomy (o -tot′ o mi) (Gr. *autos,* self; *tomos,* cut off), self-mutilation of an organism, as the loss of an appendage.

Autotrophism (o to-trof′ izm) (Gr. *autos,* self; *trophe,* nourishment), capable of self-nourishment by using chemical elements for food.

Autumnal coloration, colors produced in leaves by such pigments as anthocyanins, xanthophylls, carotenes, etc.

Auxin (ok′ sin) (Gr. *auxein,* to increase), plant hormone influencing growth.

Auxospore (ox′ o spor) (Gr. *auxe,* grow; *sporos,* spore), a reproductive cell in diatoms, usually resulting from the fusion of two diatoms.

Avoiding reaction, a somewhat fixed, protective behavior induced by adverse stimuli.

Axial gradient, an orderly arrangement of regions of different metabolic rates, with the most active at the apical end and a decrease in this metabolic rate as one goes toward the posterior end.

Axial skeleton (L. *axis,* axis), the main axis of the skeleton to which the appendages are attached.

Axis of polarity, an imaginary line extending from the anterior to the posterior end of an organism; the pole known as the animal pole is at the anterior end of the axis, while the pole with less activity, the vegetal, is at the posterior end of the axis.

Axis of symmetry, double metabolic gradients which run from the middorsal (midventral in invertebrates) region laterally and ventrally (dorsally in invertebrates).

Axon (ak′ son) (Gr. *axon,* axis), elongated process of a nerve cell for conducting impulses away from the cell body (contrast with dendrite).

Azygos (az′ i gus) (Gr. *a,* without; *zygon,* yoke or mate), an unpaired muscle, vessel or process such as the single azygos vein.

B

Backcross, a cross between an individual of the first filial generation (F_1) with one of the parental types.

Bacteria (bak -ter′ i a) (Gr. *baktron,* a stick), very small chlorophyll-less, single-celled fungous plants, a number of which produce diseases, decay, fermentation, and similar results, while others are beneficial.

Bacteriophage (bak -ter′ i o faj) (Gr. *baktron,* bacteria; *phagein,* to eat), living substance which destroys bacteria.

Barrier (bar′ i er) (Fr. *barriere,* bar), any physical, chemical, or biologic object which prevents natural migrations of organisms.

Basal metabolism, release of energy due to the oxidation of a definite quantity of food.

Basidiomycetes (ba sid i o mi -se′ tez) (Gr. *basidium,* base; *mycetes,* fungi), a fungus which produces spores on a paddle-shaped base called a basidium.

Basidiospore, a spore produced on a basidium.

Behaviorism, the reaction of animals to their environment.

Biceps (bi′ seps) (L. *bis,* two; *caput,* head), having two heads or origins, as biceps muscle of the arm.

Biennial (bi -en′ i al) (Gr. *bi,* two; *annus,* years), a plant which lasts two years (seasons), producing only leaves the first season and flowers and seeds the second.

Bilateral symmetry, arrangement of parts on opposite sides of a certain plane so that they are similar to each other.

Binary fission (bi′ na ri; fish′ un) (L. *bini,* two by two; *fissura,* to split), division into two equal parts.

Binomial nomenclature, the scientific method of naming organisms by two Latin or latinized words, the first the genus, the second the species.

Biochemistry, the chemical aspects of biologic phenomena.

Biogenesis (bi o -jen′ e sis) (Gr. *bios,* life; *genesis,* origin), the law that all life arises from preexisting living matter (contrast with Abiogenesis).

Biogenetic theory, each individual in its embryologic development (ontogeny) repeats or recapitulates, in modified or abbreviated form, the stages in the evolutionary development of that race (phylogeny). In other words, ontogeny repeats phylogeny.

Phylogenetic Stages	*Ontogenetic Stages*
(1) Single-celled animal	(1) Egg (single cell)
(2) Solid mass of cells	(2) Morula and blastula stage
(3) Two-layered animal	(3) Gastrula (two layers)
(4) Three-layered animal	(4) Three-layered embryo

Biogeography (bi o je -og′ ra fi) (Gr. *bios,* life; *geo,* earth; *graphein,* to write), geographic distributions of organisms in space (*see* Zoogeography and Phytogeography).

Biology (bi ol′ o ji) (Gr. *bios,* life; *logos,* science), study of living things.

Bioluminescence (bi o lu mi -nes′ ens) (L. *luminis,* light), light emission by living organisms not directly attributable to heat that produces incandescence.

Bionomics (bi o -nom′ iks) (Gr. *bios,* life; *nomos,* law), the relations of living organisms to their environments (*see* Ecology).

Biophysics (bi o -fiz′ iks) (Gr. *bios,* life; L. *physica,* natural), the physical aspects of biologic phenomena.

Biparental (bi pa -rent′ al) (Gr. *bi,* two), having a male and a female parent.

Biramous (bi -ra′ mus) (Gr. *bi,* two; *ramus,* branch), having two branches.

Bisexual (bi -sex′ shual) (Gr. *bi,* two; *sexus,* sex), possessing both male and female sex organs.

Bivalent chromosomes (bi -va′ lent; kro′ mo som) (Gr. *bi,* two; *valere,* to have power), two chromosomes, one from the male and the other from the female, united temporarily.

Bivium (biv′ i um) (Gr. *bi,* two; *via,* way), one side of an echinoderm having two rays.

Bladder worm (A.S. *blaedere,* bag), baglike stage of embryonic tapeworm.

Blastocoel (blas′ to sel) (Gr. *blastos,* bud; *koilos,* hollow), hollow segmentation cavity of the embryo.

Blastocyst (blastodermic vesicle) (blas′ to sist) (Gr. *blastos,* bud or young; *kystis,* sac), the hollow stage which follows the embryonic morula stage.

Blastoderm (blas′ to durm) (Gr. *blastos,* young; *derma,* skin), a cellular membrane formed by the division of the blastomeres.

Blastomere (blas′ to mer) (Gr. *blastos,* young; *meros,* part), any cell formed by mitosis of the egg.

Blastopore (blas′ to por) (Gr. *blastos,* young; *poros,* pore), the pore of the blastula stage.

Blastostyle (blas′ to stil) (Gr. *blastos,* young; *stylos,* pillar), the portion of a hydroid, such as Obelia, which forms medusa buds.

Blastula (blas′ tu la) (Gr. *blastos,* young), spherical, hollow mass of cells resulting from the divisions of the egg.

Blood corpuscle, one of a number of types of bodies in blood for performing certain functions.

Blood "islands," compact clusters of cells in the embryonic mesoderm for the future development of an embryonic circulatory system.

Botany (bot′ a ni) (Gr. *botania,* a plant), study of plants.

Bowman's capsule, the enlarged end of a kidney tubule in which is found a mass of thin-walled capillaries, known as a glomerulus.

Brachial (brak′ i al) (L. *brachius,* arm), pertaining to the arm.

Branchial (brang′ ki al) (Gr. *branchia,* gills), pertaining to gills.

Bronchus (brong′ kus) (Gr. *bronchos,* windpipe), tube leading from trachea to the lungs.

Brownian movement, the molecular movement of dispersed particles of a colloid, first described by Robert Brown.

Bryophyta (bri -of′ i ta) (Gr. *bryon,* moss; *phyta,* plants), phylum of plants including mosses and liverworts.

Buccal (buk′ al) (L. *bucca,* mouth), pertaining to the mouth.

Bud, an outgrowth which develops into a replica of the structure from which it has arisen.

C

Caecum (se′ kum) (L. *caecus,* blind), a blind pouch open at one end.

Calcareous (kal -kar′ e us) (L. *calx,* limy), limy composition.

Calciferous glands (kal -sif′ er us) (L. *calx,* limy; Gr. *ferro,* to bear), carrying lime, as in earthworms.

Callus (kal′ us) (L. *callus,* hard skin), tissue developed on wound surfaces of plant.

Calorie (kal′ o ri) (L. *calor,* heat), a unit of heat measurement, usually the amount of heat required to raise the temperature of 1 gram (1 c.c.) of water 1° C.

Calyptra (ka -lip′ tra) (Gr. *kalyptra,* covering), the archegonium of a moss or liverwort distended or modified with the growth of the sporophyte. In certain mosses it is carried to the top of the capsule to form a hood.

Calyx (ka′ liks) (Gr. *kylix,* husk or cup), the outer whorl of floral leaves known individually as sepals.

Cambium (kam′ bi um) (L. *cambiore,* change), the growing meristem tissue from which the secondary phloem and xylem arise in roots and stems; located between bark and wood.

Cambrian (from Cambria, Wales), earliest geologic period in which fossils are found abundantly.

Camouflage (ka′ moo flàzg) (F. *camoufler,* to disguise), concealment by colors or patterns to deceive.

Canaliculus (kan a -lik′ u lus) (L. *canaliculus,* little vessel), small channels in bone connecting the lacunae with one another or with the Haversian canals.

Capillary (kap′ i ler i) (L. *capillus,* hair), minute blood vessels whose walls are one cell thick and which connect arteries and veins.

Capillitium (cap il -esh′ i um) (L. *capillus,* hair), delicate network in the sporangia of slime molds (fungi).

Carbohydrate (kar bo -hi′ drat) (L. *carbo,* carbon; Gr. *hydro,* water), substances composed of carbon, hydrogen, and oxygen, with the latter two usually in the same ratio as in water (sugars, starch, etc.).

Carcinoma (kar sin -o′ mah) (*karkinos,* crab, cancer), a malignant growth, cancer.

Cardiac (kar′ di ak) (Gr. *kardia,* heart), pertaining to the heart.

Carnivorous (kar -niv′ o rus) (L. *carnis,* flesh; *vorare,* to devour), flesh eating.

Carotene (kar′ o teen) (Gr. *karoton,* carrot), a yellow-orange pigment of certain higher plants.

Carotinoid, carotene pigments.

Carpal (kar′ pal) (Gr. *karpos,* wrist), wristbone.

Carpel (kar′ pel) (Gr. *karpos,* fruit), a floral organ which bears and encloses the ovules.

Carpogonium (kar po -go′ ni um) (Gr. *karpos,* fruit; *gonos,* offspring), female sex structure of red algae.

Cartilage (kar′ ti -lazg) (L. *cartilago,* gristle), elastic, flexible connective tissue.

Caste (kast) (L. *castus,* pure), a distinct type or form among a group of organisms.

Castration (kas -tra′ shun) (L. *castrare,* to castrate), removal of gonads (sex organs) from animals or plants.

Catabolism (ka -tab′ o lizm) (Gr. *kata,* down; *bolle,* to throw), destructive phase of metabolism.

Cataclysmic theory (kat a -kliz′ mik) (L. *cataclysmos,* to inundate), the early theory that the stratification of the earth, the formation of mountains, etc., were the result of a series of vast, violent disturbances which destroyed all existing life, thus making necessary repeated, special creations to repopulate the earth.

Catalysis (ka -tal′ i sis) (Gr. *kata,* down; *lysein,* to loose), the initiation or acceleration of a chemical process by the presence of a substance (catalyst) which itself does not enter into the reaction.

Cation (kat′ i on) (Gr. *kata,* down; *ion,* going), a positively charged ion attracted to the negative cathode during electrolysis (contrast with Anion).

Caudal (ko′ dal) (L. *cauda,* tail), pertaining to the tail.

Cell (sel) (L. *cella,* small room), a small mass of protoplasm containing nuclear materials and enclosed by an outer covering.

Cell law, the law which states that all plants and animals are made of one or more cells.

Cell membrane, thin delicate membrane of a cell.

Cell wall, outer protective covering of certain cells.

Cellulose (sel′ u losz) (L. *cellula,* little cell), an organic substance in plant cell walls (a few animal cells such as the tunicates).

Cenozoic era (sen o -zo′ ik) (Gr. *kenos,* recent; life), the most recent geologic era which is characterized by mammals, birds, modern insects, etc.

Central nervous system, brain and spinal cord.

Centriole (sen′ tri ol) (L. *centrum,* center), small central granule of most centrosomes.

Centrosome (central body) (sen′ tro som) (L. *centrum,* center; *soma,* body), the body enclosing the centriole and located in the center of the aster during mitosis.

Centrosphere, see Centrosome.

Cephalic (se -fal′ ik) (Gr. *kephale,* head), pertaining to the head.

Cephalization (sef al i -za′ shun), development of larger head and brain in higher animals.

Cephalochordata (sef a lo kor -da′ ta) (Gr. *kephale,* head; *chorde,* chord), a subphylum of the phylum Chordata in which the notochord is confined to the temporary tail of the larva.

Cephalopoda (sef a -lop′ o da) (Gr. *kephale,* head; *pous,* foot), certain mollusks with muscular, sucker-bearing "arms" on the head region.

Cephalothorax (sef′ a lo -tho′ raks) (Gr. *kephale,* head; *thorax,* chest), head fused with the thorax.

Cercaria (ser -ka′ ri a) (Gr. *kerkos,* tail), tailed larva of a fluke.

Cerebellum (ser e -bel′ um) (L. dim. of *cerebrum,* brain), the part of a vertebrate brain dorsal and anterior to the medulla.

Cerebrum (ser′ e brum) (L. *cerebrum,* brain), anterior hemispheric part of a vertebrate brain.

Cervical (sur′ vi kal) (L. *cervix,* neck), pertaining to the neck.

Cestoda (ses -to′ da) (Gr. *kestos,* girdle), a tapeworm.

Chaeta (ke′ ta) (Gr. *chaite,* hair), spine or bristle.

Chalone (kal′ on) (Gr. *chalinos,* depress), a hormone which depresses activity.

Chelicera (ke lis′ er a) (Gr. *chele,* claw; *keras,* horn), the most anterior pair of appendages of the spider, scorpion, king crab.

Cheliped (ke′ li ped) (Gr. *chele,* claw; *pous,* foot), pincerlike appendage on the thorax of crayfish and allies.

Chemosynthesis, manufacture of foods by certain bacteria which use energy derived from chemical reactions such as the oxidation of ammonia, sulfur, etc.

Chemotaxis (chemotropism) (kem o -tax′ is; ke mot′ ro pizm) (Gr. *chemo,* chemical or juice; *taxis,* reaction) (Gr. *trophe,* turning), the simple response (either positive or negative) to chemical stimuli.

Chilopoda (ki -lop′ o da) (Gr. *cheilos,* lip; *pous,* foot), centipedes.

Chitin (ki′ tin) (Gr. *chiton,* covering), outer, horny covering of insects, crustacea, etc.

Chiton, a mollusk (class Amphineura) with a shell made of eight dorsal plates.

Chlamydospore (klam -id′ o spor) (Gr. *chlamys,* mantle), a thick-walled, resting spore in certain fungi.

Chloragogen cells (klo ra -gog′ en) (Gr. *kloros,* green; *ago,* lead) cells on the outer surface of the earthworm intestine.

Chlorophyta (klor -of′ i ta) (Gr. *chloros,* green; *phyta,* plants), green algae.

Chlorophyll (klo′ ro fil) (Gr. *kloros,* green; *phyllon,* leaf), the green pigment of many plants.

Chlorophyllogen (klo ro -fil′ o jen) (Gr. *kloros,* green; *phyllon,* leaf; *gen,* to form), the plant material from which chlorophyll is formed.

Chloroplast (Chloroplistid) (klo′ ro plast) (Gr. *kloros,* green; *plastos,* mouded), body containing chlorophyll.

Choanocyte (ko′ a no sit) (Gr. *choana,* funnel; *kytos,* cell) (*see Collar* cell).

Chondriosome (kon′ dri o som) (Gr. *chondros,* cartilage; *soma,* body), feebly refractive body in the protoplasm.

Chondroskeleton (kon dro -skel′ e tun) (Gr. *chondros,* cartilage), cartilaginous skeleton.

Chordata (kor -da′ ta) (L. *chorda,* string or chord), animals having a temporary or permanent dorsal skeletal notochord.

Chorion (ko′ ri on) (Gr. *chorion,* membrane), outer membrane enveloping the mammalian fetus and enclosing the amnion.

Choroid (ko′ roid) (Gr. *chorion,* membrane; *eidos,* form), a vascular layer between the retina and the sclerotic layer of the eye.

Chromatid (kro′ ma tid) (Gr. *chroma,* color), one of two threads and its matrix in a chromosome.

Chromatin (kro′ ma tin) (Gr. *chroma,* color), part of a nucleus which stains well.

Chromatophore (kro′ mat o for) (Gr. *chroma,* color; *phoreo,* to bear), a colored plastid or cell, as chloroplast.

Chromidia (kro -mid′ i a) (Gr. *chroma,* color), small particles of chromatin outside the nucleus.

Chromomere (kro′ mo mere) (Gr. *chroma,* color; *meros,* part), one of a linear series of chromatin bodies in a chromosome.

Chromonemata (kro mo -nem′ a ta) (Gr. *chroma,* color; *nema,* thread), threadlike structures within the chromosome.

Chromosome (kro′ mo som) (Gr. *chroma,* color; *soma,* body), deeply staining bodies formed in the cell nucleus during mitosis; they carry the materials of heredity.

Chrysophyta (cry -sof′ i ta) (Gr. *chrysos,* golden; *phyta,* plants), golden brown algae, yellow-green algae, and diatoms.

Chyme (kim) (Gr. *kymos,* juice), semiliquid partially digested food in the stomach.

Cilium (sil′ i um) (L. *cilium,* eyelash), hairlike, vibratile, cytoplasmic process on certain cells, as certain protozoa, etc.

Cirrus (sir′ us) (L. *cirrus,* a lock), hairlike structure on certain worms, insects, etc.

Cleavage (klev′ ij) (A.S. *cleofan,* to separate), division of the zygote into cells known as blastomeres.

Clitellum (kli -tel′ um) (L. *clitellae,* saddle), thickened area on certain annelids to assist in reproduction.

Cloaca (klo -a′ ka) (L. *cloaca,* sewer), common organ into which the intestine, kidneys, and sex organs discharge their products.

Clone (klone) (Gr. *klone,* twig), all the asexual offspring of an individual which are identical in regard to their gene content.

Cnidoblast (ni′ do blast) (Gr. *knide,* nettle; *blastos,* bud), sac-shaped stinging or nettle cell with a permanent, long barbed thread and poisonous fluid as in certain coelenterates.

Cnidocil (ni′ do sil) (Gr. *knide,* nettle; L. *cilium,* eyelash), small, triggerlike process for ejecting the thread from the cnidoblast.

Coccus (kok′ us) (Gr. *kokkus,* berry), spherical, unicellular organism.

Cochlea (kok′ le a) (Gr. *kochlias,* snail), spirally coiled part of the inner ear, containing receptors for hearing.

Cocoon (ko -koon′) (L. *concha,* shell), the enclosed stage of certain insects in which the pupa enters the cocoon and the adult emerges from it; egg case of spiders and earthworms.

Coelenterata (se lent er -a′ ta) (Gr. *koilos,* hollow; *enteron,* digestive tract), phylum of animals having a hollow digestive tract as Hydra, Obelia, etc.

Coelom (coelome) (se′ lum) (Gr. *koilos,* hollow), a hollow true body cavity containing organs.

Coelomization (se lom i -za′ shun), presence of a true body cavity (coelom) between the body wall and the digestive tract formed from mesoderm.

Cohesion (ko -he′ shun) (L. *cohaerere,* to stick), attraction whereby particles (molecules) of a body are united throughout a mass (attract each other).

Cold-blooded, body temperature varies with the environment.

Coleoptera (ko le -op′ tera) (Gr. *coleos,* sheath, *ptera,* wings), order of insects with hard, chitinous wings, such as beetles and weevils.

Collar cell (choanocyte), cells with a collarlike structure on the surface as in sponges.

Collembola (kol -em′ bo la) (Gr. *kolla,* glue; *embolon,* rod), wingless insects such as springtails.

Colloid (kol′ oid) (Gr. *kolla,* glue), a finely divided matter suspended or dispersed through some continuous medium.

Columnar (kol -lum′ nor) (L. *columnn,* column), column shaped.

Combination, an inherited variation due to the combining of genes from parents.

Combustion (L. *combustio,* burn), rapid oxidation of a chemical substance.

Commensalism (kom -men′ sal izm) (L. *com,* with; *mensa,* table), an association of members of two or more species (not truly parasitic) which live in, or on, or with each other, usually partaking of the same food.

Commissure (kom′ i shoor) (L. *commisura,* join together), a circle of nervous tissue to connect various regions as in earthworms, snails, insects, etc.

Companion cell, one which usually accompanies seive tubes in phloem tissues of plants.

Complementary factors, two or more dissimilar factors (genes) which interact and complement to produce a particular trait.

Compound, a substance made of two or more elements in chemical union.

Compound eye, one made of numerous units called ommatidia, as in certain arthropods.

Condyle (kon′ dil) (Gr. *kondylos,* knuckle), rounded process for articulation of a bone.

Congenital (kon -jen′ i tal) (L. *con,* together; *gigno,* to bear), present at birth.

Conidia (ko -nid′ i a) (Gr. *konis,* dust), small spores formed by constricting hyphae.

Conidiophore (ko -nid′ i o for) (Gr. *konis,* dust; *phoreo,* to bear), structure which bears conidiospores.

Conidiospore (conidium) (ko -nid′ i o spor) (Gr. *konis,* dust; *sporos,* spore), spore formed by constricting the tip of a hypha as in certain molds.

Conjugation (kon joo -ga′ shun) (L. *con,* together; *jugare,* to join), temporary union of two cells to exchange nuclear materials.

Connective tissues (kon -nek′ tiv) (L. *con,* together; *nectere,* to bind), similar cells for support and binding.

Conservation of energy, a law which states that the total energy content of the universe is constant, that none is created, none is lost, but merely transformed from one type to another (*see* Potential and Kinetic energy).

Continuity of germ plasm, germ plasm is continuous throughout all generations and is not produced anew each time a new individual is produced.

Continuous variations, those in which varieties are merely plus or minus deviations from the mode and which may be arranged serially in the form of a simple curve.

Contractile vacuole (kon -trak′ til; vak′ u ol) (L. *con,* together; *trahere,* to draw; L. *vaccus,* empty), a hollow structure which alternately contracts and expands, as in amoeba, paramecium, etc.

Conus arteriosus (ko′ nus; ar te ri -o′ sus) (Gr. *konus,* cone shaped), cone-shaped structure between the ventricle and arteries of certain animals.

Convergent adaptation, different organisms assuming similar forms because of their adaptations to the same environmental medium.

Coordination, the harmonious working together of the various parts of an individual or of various individuals.

Copulation (kop u -la′ shun) (L. *copulare,* to couple), sexual union.

Cork cambium, a ring of dividing cells, in woody plants, beneath the epidermis which originates parenchyma on the inside and cork on the outside.

Cornea (kor′ ne a) (L. *corneus,* horny), transparent part of the sclerotic coat of the eye that covers the iris and pupil.

Corolla (ko -rol′ a) (L. *corona,* crown), all the flower petals taken together.

Corpus luteum (kor′ pus lu′ te um) (L. *corpis,* body; *luteus,* yellow), a yellowish body developed from a Graafian follicle after extrusion of ovum.

Corpuscle (kor′ pus l) (L. *corpusculum,* little body), a small body, mass, or organ.

Cortex (kor′ tecks) (L. *corium,* covering or bark), the outer covering.

Cortin (kor′ tin) (L. *cortex,* covering), hormone from the cortex (covering) of the adrenal glands.

Cotyledon (kot i -le′ dun) (Gr. *kotyledon,* cup-shaped hollow), embryonic seed leaf, usually having stored food.

Cowper's gland, small gland associated with the prostate gland and urethra of male mammals.

Cranial nerves, those arising from the brain.

Cranium (kra′ ni um) (Gr. *cranios,* brain case), the brain case.

Creatinine (kre -at′ i nin) (Gr. *kreas,* flesh) nitrogenous substance in muscles, urine, etc.

Cretinism (kre′ tin izm) (L. *christianus,* human being), one who is physically and mentally deficient due to deficient thyroid gland.

Crinoid (kri′ noid) (Gr. *krinon,* lily; *eidos,* like), a lilylike animal of the phylum echinodermata.

Criss-cross inheritance, paternal traits transmitted to daughters and maternal traits to sons.

Cross fertilization, union of gametes (sex cells) produced by different individuals, either animals or plants.

Crossing over, rearrangement and crossing over of linked characters as a result of exchange of genes between homologous chromosomes during synapsis.

Crustacea (krus -ta′ she a) (L. *crustaceus,* shell or crust), a class of the phylum Arthropoda characterized by a chitinous exoskeleton.

Cutaneous (ku -ta′ ne us) (L. *cutis,* skin), pertaining to the skin.

Cuticle (ku′ tik l) (L. *cutis,* covering), transparent covering.

Cutin (ku′ tin) (L. *cutis,* skin) waxy substance covering leaves to make the cuticle impervious to water.

Cyanophyta (si an -of′ i ta) (Gr. *kyanos,* blue; *phyta,* plants), blue-green algae.

Cyclosis (si -klo′ sis) (Gr. *kyklosis,* circulate), circulating movement of protoplasm in a cell.

Cyst (sist) (Gr. *kystis,* sac), protective covering about an organism.

Cysticercus (sis ti -sur′ kus) (Gr. *kystis,* sac; *kerkos,* tail), larval bladderworm stage of certain tapeworms.

Cytogenic reproduction (si to -jen′ ik) (Gr. *kytos,* cell; *gen,* to form), reproduction affected by means of unicellular germ cells which grow and divide to form a multicellular organism (contrast with Somatogenic reproduction).

Cytology (si -tol′ o ji) (Gr. *kytos,* cell; *logos,* science), study of cells.

Cytolysin (si to -ly′ sin) (Gr. *kytos,* cell; *lysis,* destroy), substance which destroys cells.

Cytolytic, *see* Cytolysin.

Cytoplasm (si′ to plazm) (Gr. *kytos,* cell; *plasm,* liquid), the portion of the protoplasm outside the nucleus.

Cytoplasmic inclusions, nonliving materials in the cytoplasm.

Cytotoxin (si to -tok′ sin) (Gr. *kytos,* cell; *toxicon,* poison), substance having a specific toxic effect on cells of certain types.

D

Dactyl (dak′ til) (Gr. *daktylos,* finger), refers to finger.

Darwinism, theory of natural selection proposed by Charles Darwin; not synonymous with organic evolution.

Deciduous (de -sid′ u us) (L. *de,* away; *cadere,* to fall), falling off at end of a period of growth.

Dehydration (de hi -dra′ shun) (Gr. *de,* from; *hydros,* water), extraction or removal of water.

Deltoid (del′ toid) (L. *delta,* triangle), triangular, like the deltoid muscle.

Dendrite (dendron) (den′ drit) (Gr. *dendron,* tree), branched processes which carry impulses toward the nerve cell (neuron) (contrast with Axon).

Denitrifying (de -ni′ tri fy ing) (Gr. *de,* from; *nitrogen*), break down of nitrogenous substances.

"De novo," a Latin phrase denoting an origin from no known source or from no similar structure.

Dentine (den′ teen) (L. *dens,* tooth), inner part of tooth.

Dermis (derma) (der′ mis) (Gr. *derma,* skin), true skin underlying the epidermis (same as corium).

Determinate cleavage, early divisions of an egg in which each blastomere can be traced to some future tissue or organ and in which the original cells are arranged along the various axes of the organism.

Determiner, *see* Gene.

Dialysis (di -al′ a sis) (Gr. *di,* two; *lysis,* separating), separation of dissolved materials such as crystalloids from colloids by passage of former through a semipermeable membrane; diffusion of certain substances in solution through a membrane but not of other substances.

Diaphragm (di′ a fram) (Gr. *diaphragma,* partition), muscle separating thoracic and abdominal cavities.

Diastase (di′ a stas) (Gr. *dia,* through; *histanai,* to set), enzyme which converts starch into sugar.

Dichotomous (di -kot′ o mus) (Gr. *dicho,* two; *tome,* divide), repeated forking into two parts.

Diecious (di- e′ shus) (Gr. *di,* two; *oikos,* house), having male and female sex organs in separate individuals (contrast with Monecious).

Differentiation (specialization), process of becoming structurally or functionally unlike the original condition.

Diffraction (di -frak′ shun) (L. *diffractus,* break), deflection of light waves when passing through a narrow slit to form fringes of parallel light and dark-colored bands.

Diffusion (di -fu′ zhun) (L. *diffusia,* spread), passage of molecules of one substance among those of another from a region of greater concentration to one of less concentration.

Digestion (di -jes′ chun) (L. *digestio,* dissolve food), preparing food for absorption.

Dihybridization (di hy brid i -za′ shun) (Gr. *di,* two; *hybrida,* mongrel), producing an offspring from parents who differ with regard to two given characters.

Dimorphism (di -mor′ fizm) (Gr. *di,* two; *morphe,* form), two forms or types belonging to one species, as males and females of same species but differing from each other.

Diphyletic tree (dif i -let′ ik) (Gr. *diphy,* twofold), schematic, treelike representation of the supposed ancestral relations of various animals and plants.

Diploblastic (dip lo -blas′ tik) (Gr. *diplos,* two; *blastos,* germ), two germ layers (ectoderm and entoderm).

Diploid (dip′ loid) (Gr. *diplos,* two), double number of chromosomes found in the sporophyte generation of plants and body cells of animals as contrasted with single number in germ cells (contrast with Haploid).

Diplopoda (dip -lop′ o da) (Gr. *diploos,* double; *pous,* foot), millipedes.

Diptera (dip′ tura) (Gr. *di,* two; *ptera,* wings), insects with the two wings (one pair) as flies, mosquitoes, gnats, etc.

Direct cell division, *see* Amitosis.

Discontinuous distribution, two species occurring in two or more widely separated regions, suggesting that their distributions may at one time have been continuous. Tapirs exist only in Malay and tropical America.

Discontinuous variation, *see* Mutation.

Distal (dis′ tal) (L. *dis,* apart; *stare,* to stand), farthest from median line.

Divergence (adaptive radiation), somewhat closely related species radiate in various directions into different environments and become modified (vary) accordingly.

Division of labor, distribution of functions among cells, organs, or individuals.

Dizygotic (di zi -got′ ik) (Gr. *di,* two; *zygon,* yoke, pair), derived from two eggs as in certain types of twins (contrast with Monozygotic).

Dominance (dominant character), one of a pair of alternative characters which is always expressed when its gene is present and which appears to exclude the other (recessive) character.

Dorsal (dor′ sal) (L. *dorsum,* back), the back side of higher animals.

Dorsal aorta, chief artery arising from the heart to distribute blood to the body.

Dorsal horn (root), sensory root of a spinal nerve carrying impulses into the spinal cord; ventral root carries impulses from the cord.

Dorsoventral differentiation, body with definite dorsal (back) and ventral (belly) sides or regions.

Drosophila (dro -sof′ i la), the common fruit or banana fly; used extensively for heredity experiments.

Ductless glands, *see* Endocrine glands.

Duodenum (du o -de′ num) (L. *duodeni,* twelve), anterior part of small intestine, twelve fingerwidths long.

Duplicate factors, different factors (genes) having identical but not cumulative effects.

E

Ecdysis (ek′ di sis) (Gr. *ek,* out; *dyein,* to come), the losing or molting of an outer structure as in the crayfish, insects, etc.

Echinodermata (e kin o -dur′ ma ta) (Gr. *echinos,* spiny; *dermos,* covering), spiny-covered animals, such as starfishes, sea urchins, sand dollars, etc.

Ecology (e -kol′ o ji) (Gr. *oikos,* home; *logos,* study), scientific study of living organisms and their living and nonliving environments.

Ectoderm (ek′ to durm) (Gr. *ektos,* outside; *derma,* skin), outer layer of germ cells.

Ectoparasitism (ek to -par′ a sit -izm) (Gr. *ektos,* outside; *para,* beside; *sitos,* food), parasites attached externally to the host.

Ectoplasm (ectosarc) (ek′ to plazm) (Gr. *ektos,* outside; *plasma,* liquid), outer layer of cell cytoplasm.

Efferent (ef′ er ent) (L. *ex,* out; *ferro,* to carry), convey away from.

Egest (e -jest′) (L. *ex,* out; *gerere,* to carry) to throw out, usually indigestible material.

Egg (ovum), the mature female sex cell of a plant or animal.

Elater (el′ a ter) (Gr. *elater,* driver), a springlike organ of various plants to disperse spores.

Electrolyte (e -lek′ tro lit) (Electric; Gr. *lytos,* dissolved), a substance, such as salts, acids, and bases, which in solution dissociates into electrically charged ions.

Electrolytic dissociation, breaking up of the molecules of electrolytes (acids, bases, salts) into electrically charged positive and negative ions capable of conducting an electric current.

Electron (e -lek′ tron) (Gr. *elektron,* gleaming, sun), smallest part, or unit, of negative electricity (*see* Nuclear electrons and Extranuclear electrons).

Element (el′ e ment) (L. *elementum,* unit), a substance whose atoms are all the same; over ninety elements are known.

Elemental theory, the entire individual is explained as a result of the summation of the activities and characteristics of its ultimate parts (contrast with Organismal theory).

Elytra (el′ i tra) (Gr. *elytron,* sheath), sheathlike wings of beetles.

Embryo (em′ bri o) (Gr. *embryon,* embryo), early stages of development of an organism.

Embryology (em bri -ol′ o ji) (Gr. *embryon,* embryo: *logos,* study), study of early development of organisms.

Embryonic disc (embryonic shield), a cellular partition separating the amniotic and yolk sac cavities of certain embryos from which the embryo proper will form.

Embryophyta (em bri -of′ i ta) (Gr. *embryon,* embryo: *phyta,* plants), plants producing a multicellular embryo.

Emulsion (e -mul′ shun) (L. *emulgere,* to milk out), mixture of two liquids or semisolids, neither of which is soluble in the other, with the result that one is in the form of droplets suspended in the other.

Emulsoid, a suspension of the nature of an emulsion but with the dispersed phase more finely divided. Cream is a system of fat droplets suspended in water.

Encystment (en -sist′ ment) (Gr. *en,* in; *kystis,* sac), surrounded by a protective coat.

Endocardium (en do kar′ di um) (Gr. *endon,* within: *kardium,* heart), inner lining of the heart.

Endocrine (ductless) glands (en′ do krin) (Gr. *endon,* within: *krinein,* to separate), ductless glands which produce internal secretions from materials brought to them by blood and whose secretions are carried from them by the blood.

Endoderm, *see* Entoderm.

Endometrium (en do -me′ tri um) (Gr. *endon,* within: *metra,* womb), a heavy, mucous glandular layer of the uterus during pregnancy.

Endoparasite (en do -par′ a sit) (Gr. *endon,* within: *para,* beside: *sitos,* food), an internal parasite (lives within body of its host).

Endoplasm (en′ do plazm) (Gr. *endon,* within: *plasma,* liquid), inner cytoplasm of a cell.

Endopodite (en -dop′ o dit) (Gr. *endon,* within; *pous,* appendage), inner of two branches of a biramous appendage of a crustacean.

Endoskeleton, internal skeleton.

Endosperm (en′ do spurm) (Gr. *endon,* within: *sperma,* seed), nutritive substances within the seed coats but not a part of the embryo proper.

Endosteum (en -dos′ te um) (Gr. *endon,* within; *osteon,* bone), internal lining of a bone.

Endothelium (en -do -the′ li um) (Gr. *endon,* within; *thele,* nipple), cells arising from mesoderm and lining blood vessels and lymph spaces.

Enteric (en -ter′ ik) (Gr. *enteron,* intestine), pertaining to digestion or digestive tract.

Entoderm (en′ to durm) (Gr. *entos,* within; *derma,* skin), inner germ layer (contrast with ectoderm).

Entomology (en to -mol′ o ji) (Gr. *entomon,* insect: *logos,* study), science dealing with insects.

Entoparasite, *see* Endoparasite.

Enzyme (en′ zim) (Gr. *en,* in; *zyme,* leaven), a ferment or organic catalyst secreted to bring about or hasten a reaction but which is not consumed in the process.

Epicotyl (ep′ i kotl) (Gr. *epi,* upon; *kotyle,* cotyledon), portion of the embryo axis above the attachment of the cotyledons to form the young stem.

Epidermis (ep i -dur′ mis) (Gr. *epi,* upon; *derma,* skin), outer layer of skin.

Epigenesis (ep i -jen′ e sis) (Gr. *epi,* upon; *genesis,* origin), doctrine that development proceeds from a relatively simple germinal substance, with complexity arising through the interaction of the protoplasm and the environment (contrast with Preformation).

Epiglottis (ep i -glot′ is) (Gr. *epi,* upon; *glotta,* tongue), covering of the glottis during swallowing.

Epimysium (ep i -miz′ i um) (Gr. *epi,* upon; *mys,* muscle), covering of a muscle.

Epinephrine (adrenalin) (ep i -nef′ rin) (Gr. *epi,* upon; *nephros,* kidney), hormone of the inner medulla of the adrenals, which are located on the kidneys.

Epiphyte (ep′ i fite) (Gr. *epi,* upon; *phyton,* plant), a plant which is physically supported by another plant or from poles, wires, etc.

Epithelium (ep i -the′ li um) (Gr. *epi,* upon; *thele,* teat or nipple), membranes lining or covering a surface, including secreting glands.

Equatorial plate, middle or equator of the spindle during mitosis.

Erepsin (e -rep′ sin) (L. *eripere,* to set free), protein-splitting enzyme of the intestine.

Erythroblast (e -rith′ ro blast) (Gr. *erythros,* red; *blastos,* originate), cell from which red blood cells (erythrocytes) develop.

Erythrocyte (e -rith′ ro sit) (Gr. *erythros,* red; *kytos,* cell), red blood corpuscle.

Esophagus, *see* Oesophagus.

Estivation, *see* Aestivation.

Ethnology (eth -nol′ o ji) (Gr. *ethnos,* nation; *logos,* study), study of the characteristics, distribution, and relationships of human races.

Eugenics (u -jen′ iks) (Gr. *eugenes,* well born), science of race improvement through heredity.

Eumycophyta (u mi -kof′ i ta) (Gr. *eu,* true; *mykos,* fungus; *phyta,* plants), true fungi, as Phycomycetes, Ascomycetes, and Basidiomycetes.

Eustachian tube (u -sta′ shun) (Eustachio, an Italian anatomist), tube connecting pharynx and middle ear.

Evagination (e -vaj i -na′ shun) (L. *evageri,* to go forth), outgrowing of a layer of cells from a cavity.

Evolution (ev o -lu′ shun) (L. *evolvo,* to unroll), theory that all living organisms have undergone, and do undergo, gradual changes through successive generations; that all living organisms are constantly changing (evolving).

Excretion (eks -kre′ shun) (Gr. *ex,* out; *cernere,* to separate), elimination of wastes.

Excurrent (eks -kur′ ent) (Gr. *ex,* out; *currens,* to run), conducting away from a cavity or organ.

Exhalant (eks -hal′ ant) (Gr. *ex,* out; *halare,* to breathe), to conduct outward from the interior.

Exopodite (eks -op′ o dit) (Gr. *ex,* out; *pous,* appendage), outer of two branches of a biramous appendage of a crustacean.

Exoskeleton (ek so -skel′ e ton) (Gr. *exo,* outside), outer skeleton.

Expiration (ek spi -ra′ shun) (Gr. *ex,* out; *spirare,* to breathe), emitting air from lungs.

Extensor (eks -ten′ ser) (Gr. *ex,* out; *tendere,* to stretch), muscle to extend a limb or part.

External receptor, sense organ on surface of an organism to receive stimulation.

External respiration, exchange of gases between blood and the outside through lungs, skin, or gills.

Extra-embryonic coelom, one of the coeloms of the early embryo.

Extranuclear electrons, those outside the nucleus of the atom.

Eye spot, pigmented, light-sensitive area, as the stigma of Euglena.

F

F_1, F_2, F_3, etc., abbreviations for the first, second, third filial generations in heredity.

Factor, *see* Gene.

Facultative (fak′ ul ta tiv) (L. *facultas,* faculty), the ability to change certain methods of living to suit conditions.

Fallopian tube (fa -lo′ pi an) (From Fallopius, a physician who died in 1562), the oviduct in mammals.

Family (fam′ i li) (L. *familia,* household), organisms of one group of an order.

Fascia (fash′ i a) (L. *fascia,* band), bandlike covering of connective tissue.

Fat (A.S. *faett, fat*), adipose tissue, cells of which are filled with oil.

Fatty acid, one of a group of organic acids, such as acetic, butyric, oleic, stearic, etc., which contains only one COOH (carboxyl) group.

Fauna (fo′ na) (L. *Faunus,* god of the woods), animal life characteristic of a given area.

Feces (fe′ sez) (L. *faeces,* dregs), wastes or excrements.

Femur (fe′ mer) (L. *femur,* thigh), thigh bone or the third segment of an insect leg from the proximal (near) end.

Fermentation (fur men -ta′ shun) (L. *fermentum,* ferment or leaven), change in an organic substance caused by a ferment, as souring of milk.

Fertilization (fur til i -za′ shun) (L. *ferre,* to produce), union of sperm and egg in sexual reproduction.

Fetus (**foetus**) (fe′ tus) (L. *fetus,* offspring), the later embryo of a vertebrate (after third month in human being).

Fibril (fi′ bril) (L. *fibrilla,* small fiber), small, fibrous structure.

Fibrin (fi′ brin) (L. *fibra,* band), an insoluble material in blood after clotting.

Fibrinogen (fi -brin′ o jen) (L. *fibra,* thread; *gignesthai,* to form), a constituent of blood that aids in fibrin formation.

Fibula (fib′ u la) (L. *fibula,* buckle), outer, smaller bone of lower leg.

Filial (fil′ i al) (L. *filia,* daughter; *filius,* son), one or more successive generations after the parents.

Filial regression law, superior parents tend to have superior offspring but who on the average are less superior than the parents; inferior parents tend to have offspring who are also inferior, but less so than themselves.

Fission (fish' un) (L. *fissus,* cleave), asexual division into two or more parts.

Flagellum (plural, flagella) (fla -jel' um) (L. *flagellum,* whip), whiplike process for locomotion.

Flame cell, an excretory cell with a bunch of cilia by means of which wastes are expelled to the outside; the action of the cilia somewhat resembles a flickering flame.

Flatworm, a member of the phylum Platyhelminthes.

Flavone (flavonol) (fla' von) (L. *flavus,* yellow), yellow pigment of certain higher plants.

Flexor (flek' ser) (L. *flexus,* bend), muscle to bend a joint.

Flora (flo' ra) (L. *flos,* flower), plants characteristic of a region or period (contrast with Fauna).

Fluctuations, somatic variations which result from differences in environment or functions and which are not inherited.

Fluke, a parasitic flatworm (phylum Platyhelminthes).

Fontanelle (fon ta -nel') (Fr. *fontanelle,* little fountain), space between bones of the cranium, covered with a membrane, through which blood flow pulsations show.

Foramen (fo -ra' men) (L. *foramen,* opening), an opening in a structure.

Foreign protein, one not common to an organism.

Fossil (fos' il) (L. *fossilis,* dug up), preserved record of ancient organism.

Fossilization, formation of records of ancient organism.

Fragmentation, reproduction by isolating a part of an organism to form a new individual.

Fraternal twins, those produced by fertilization of two different eggs which usually have different hereditary traits. Sometimes called nonidentical or dizygotic twins.

Frond (frond) (L. *frond,* leafy branch), fern leaf.

Fructose (fruk' toz) (L. *fructus,* fruit), fruit sugar.

Fucoxanthin (fuk o -zan' thin) (L. *fucus,* seaweed; *xanthos,* yellow), yellowish-brown pigment of brown algae.

Fundus (fun' dus) (L. *fundus,* base), base of an organ.

Fungus (fun' gus) (L. *fungus,* mushroom), lower chlorophyll-less plants.

G

Gall bladder, sac near the liver in which bile is stored.

Galvanotropism (gal va -not' ro prizm) (after the Italian, Galvani), response of living organisms to electric currents.

Gametangium (ga me -tan' ji um) (Gr. *gamos,* gametes; *angios,* vessel), a gamete-producing structure.

Gamete (gam' et) (Gr. *gamos,* marriage), mature male or female sex cell.

Gametogenesis (gam e to -jen' e sis) (gamete; *genesis,* origin) production and maturation of gametes (sex cells).

Gametophyte (ga -me' to fit) (*gamos,* marriage; *phyton,* plant), plant producing gametes (sex cells).

Ganglion (plural, Ganglia) (gang' li on) (Gr. *ganglion,* enlargement), an enlargement of a nerve which contains nerve cells and acts as a center of influence.

Gastric (gas′ trik) (Gr. *gaster,* stomach), pertaining to the stomach or to digestion.

Gastrovascular (gas tro -vas′ ku lar) (Gr. *gaster,* stomach; L. *vasculum,* vessel or circulation) digestive-circulatory cavity as in Hydra.

Gastrulation (gas troo -la′ shun) (Gr. *gaster,* digestive), the formation of the gastrula stage in embryonic development by an invagination (infolding) process whereby the future digestive tract will be formed.

Gel (jel) (L. *gelare,* to stiffen), state of a colloidal system in which the external phase is more solid than the internal phase (jellylike colloid).

Gelation (jel -a′ shun) (L. *gelare,* to stiffen), the phenomenon of forming a gel.

Gemma (gem′ a) (L. *gemma,* bud), small, green, asexual reproductive bodies found in such plants as the Marchantia (Liverwort).

Gemmule (gem′ ul) (L. *gemma,* bud), asexual reproductive body of several cells found in certain sponges.

Gene (jen) (Gr. *gen,* to form), factor (determiner) in a chromosome which influences the development of a hereditary trait.

Genetics (je -net′ iks) (Gr. *genesis* origin), science of trait transmission from parents or other ancestors to offspring.

Genital (jen′ i tal) (L. *gignere,* to beget), pertaining to reproduction.

Genotype (jen′ o tip) (Gr. *genos,* race; *typos,* model), hereditary constitution of an organism or a group of organisms based upon gene content (contrast with Phenotype).

Genus (je′ nus) (Gr. *genos,* race), somewhat similar organisms having one or more species which are structurally or phylogenetically related.

Geographic distribution (biogeography), distribution of plants and animals in different geographic areas.

Geotropism (je -ot′ ro pizm) (Gr. *ge,* earth; *trope,* turning), reaction of organisms to gravity.

Germ cell, male or female reproductive cell.

Germinal continuity (jurm′ i nal) (Gr. *germen,* offspring), the unbroken, continuous stream of germ plasm from one generation to another.

Germinal variation, variation arising in a germ cell.

Germ layer, two or three embryonic cellular layers from which future adult tissues and organs arise.

Germ plasm, material basis of inheritance found in germ cells (sex cells) and transmitted by them to the cells of the offspring.

Germ theory of disease, certain types of diseases are caused by microorganisms.

Gestation (jes -ta′ shun) (L. *gestatio,* to bear), carrying of young (normally in the uterus) from conception to delivery (birth).

Gill, filamentous or platelike structure with blood vessels for respiration in water.

Gill book, specialized, booklike organ of respiration in certain Arachnida.

Gill slits, paired openings in vertebrates connecting the pharynx with the exterior and permitting the exit of water (same as pharyngeal cleft).

Gizzard (giz′ ard) (Fr. *giser,* gizzard), muscular grinding organ for digestion.

Gland (L. *glans,* nut), a cell or group of cells for secretion.

Glochidium (glo -kid′ i um) (Gr. *glochis,* arrow point), bivalved larva of mollusks which live parasitically, on a fish for a time.

Glomerulus (glo -mer′ u lus) (L. *glomero,* ball), ball-like mass of capillaries at enlarged end of the kidney tubule of higher vertebrates (same as Malpighian body).

Glottis (glot′ is) (Gr. *glotta,* tongue), slitlike opening in the pharynx leading to windpipe (trachea).

Glucose (glu′ kos) (Gr. *glykys*), grape sugar.

Glycogen (gli′ ko jen) (Gr. *glykys,* sweet), a starchlike carbohydrate stored in the liver and other tissues and in certain algae and fungi.

Goiter (goi′ ter) (L. *guttur,* throat), pathologic enlargement of the thyroid gland.

Golgi bodies (gol′ je) (after Golgi, Italian physician), special bodies in cytoplasm of certain cells.

Gonad (gon′ ad) (Gr. *gonos,* reproduction), a male or female sexual reproductive organ.

Gonidia (go -nid′ i a) (Gr. *gone,* seed), asexual nonmotile reproductive cells.

Gonophore (gon′ o for) (Gr. *gonos,* seed; phoreo, to bear), gonad-bearing structure.

Graafian follicle (graf′ i an; fol′ i kl) (after de Graaf, Dutch physician; L. *follis,* bag), small cavity in the ovary, especially of mammals, in which egg develops.

Grafting, transplanting an organ or tissue from one plant or animal to another.

Grana (gran′ a) (L. *granum,* small grain), small particles of chlorophyll in chloroplasts.

Green gland, excretory organ of a crayfish.

Growth hormone, specific chemical substances in plants and animals (especially higher animals) which influence, regulate, or control growth or other activities.

Guanin (gwa′ nin) (*huano,* dung), a white substance found in guano (excrement of sea birds) and other animal substances.

Guard cell, specialized cell of the epidermis of leaves to regulate the size of the stomata of leaves.

Gullet, *see* Oesophagus.

Gustatory (gus′ ta to ri) (L. *gustare,* to taste), sense of taste.

Guttation (gu ta′ shun) (L. *gutta,* drop), exudation of water drops from plants (especially leaves) due to internal pressure.

Gymnosperm (gym′ no spurm) (Gr. *gymnos,* naked, exposed; *sperm,* seed), a plant whose seeds are not enclosed by carpels (contrast with Angiosperm).

Gynandromorph (ji -nan′ dro morf) (Gr. *gyne,* woman; *aner,* man; *morphe,* form), an abnormal individual who has male characteristics in one part of its body and female characteristics in another.

H

Habitat (hab′ i tat) (L. *habito,* to dwell), usual or natural dwelling place.

Halteres (hal -te′ rez) (Gr. *halter,* weight used in jumping), pair of capitate bodies used as balancers during flight of insects in the order Diptera. They represent the rudimentary posterior wings of these insects.

Haploid (hap′ loid) (Gr. *haplos,* single; *eidos,* form), single or reduced number of chromosomes in mature germ cells (gametes), or the gametophyte generation of plants, in contrast to the diploid number in body cells.

Haversian canal (ha -vur′ shan) (after Havers, an English physician of the Seventeenth Century), small canals in bone to conduct blood, etc.

Heliotropism (he li -ot′ ro pizm) (Gr. *helios,* sun; *trope,* to turn), response to light.

Helminthology (hel min -thol′ o ji) (Gr. *helmins,* worm; *logos,* study), study of worms.

Hemiptera (he -mip′ tur a) (Gr. *hemi,* half; *ptera,* wings), order of insects whose front wings have their basal region hardened, while the tips are membranous, as in true bugs.

Hemocoel (he′ mo sel) (Gr. *haima,* blood; *koilos,* hollow), special portion of the coelom for blood circulation.

Hemoglobin (he mo -glo′ bin) (Gr. *haima,* blood; L. *globus,* globe), reddish, oxygen-carrying substance of red blood corpuscles.

Hemophilia (he mo -fil′ i a) (Gr. *haima,* blood; *philos,* loving), a disease, usually hereditary, with a tendency to excessive bleeding, even from slight wounds.

Hemorrhage (hem′ o rij) (Gr. *haima,* blood; *rhegnymi,* break), loss of blood from broken blood vessel.

Hepatic (he -pat′ ik) (Gr. *hepar,* liver), pertaining to the liver.

Hepatic portal system, the double blood supply of the liver of vertebrates.

Herbaceous (hur -ba′ shus) (L. *herbaceous,* grassy), plants without woody tissues.

Herbivorous (hur -biv′ o rus) (L. *herba,* plant; *vorare,* to devour), plant-eating organisms (contrast with Carnivorous).

Heredity (he -red′ i ti) (L. *hereditas,* heir), transmission of physical and mental traits from parent or other ancestor to offspring (*see* Genetics).

Hermaphrodite (hur -maf′ ro dit) (Gr. *Hermes* and *Aphrodite*), having both male and female reproductive organs in one individual (same as Monecious; (contrast with Diecious).

Heterauxin (het er -ox′ in) (Gr. *hetero,* different; *auximos,* promote growth), a special hormone which affects plant growth.

Heterocyst (het′ ero sist) (Gr. *heteros,* different; *kystis,* sac), clear cell in certain algae which separate the filament into hormogonia.

Heterogamy (anisogamy) (het er -og′ a mi) (Gr. *heteros,* other; *gamos,* marriage), union of unlike gametes (sex cells) (contrast with Isogamy).

Heteronomous segmentation (het er -on′ o mus) (Gr. *heteros,* different), dissimilar segmentation or metamerism, such as in crayfish, etc. (contrast with Homonomous).

Heterosis (het er -o′ sis) (Gr. *heteros,* other), increased vigor due to crossing or hybridization.

Heterospory (het er -os′ po ri) (Gr. *heteros,* different; *spora,* spores), production of unlike spores (contrast with Homospory).

Heterotrophic (het er o -trof′ ik) (Gr. *heteros,* different; *trophe,* food), organisms, unable to manufacture their food; hence they are parasites or saprophytes (contrast with Autotrophic).

Heterozygote (het er o -zi′ got) (Gr. *heteros,* unlike; *zygon,* yoke), formed by union of gametes that are unlike in their gene content (contrast with Homozygote).

Hibernate (hi′ ber nat) (L. *hiberna,* winter), torpor or dormancy of certain organisms due to cold.

Histogenesis (his to -jen' e sis) (Gr. *histos,* web, tissue; *gen,* to form), tissue formation and development.

Histology (his -tol' o ji) (Gr. *histos,* web, tissue; *logos,* study), study of tissues and cells.

Holophytic (hol o -fit' ik) (Gr. *holos,* whole; *phyton,* plant), plants that manufacture their own food (contrast with Holozoic).

Holozoic (hol o -zo' ik) (Gr. *holos,* whole; *zoon,* animal), securing nourishment, as in animals, by ingesting and digesting organic materials (contrast with Holophytic).

Homologous chromosomes (ho -mol' o gus) (Gr. *homos,* same; *logos,* speech), a pair of chromosomes, one from each parent, that have relatively similar structure and gene values.

Homologous genes, genes similarly located in homologous chromosomes, contributing to the same expression or a different expression of a trait.

Homology (ho -mol' o ji) (Gr. *homos,* same; *logos,* study), parts or organs which are similar structurally and which have originated embryologically in a similar way: for example, the forelegs of a dog and frog show homology.

Homonomous segmentation (ho -mon' o mus) (Gr. *homos,* similar), similar segments (metameres) as in the earthworm (contrast with Heteronomous).

Homoptera (ho -mop' tur a) (Gr. *homos,* same; *ptera,* wings), order of insects whose wings are similar and membranous throughout (contrast with Hemiptera).

Homospory (ho -mos' po ri) (Gr. *homo,* same; *spora,* spore), production of like spores (contrast with Heterospory).

Homozygote (ho mo -zi' got) (Gr. *homo,* same; *zygon,* yoke), union of gametes that are alike in their gene content (contrast with Heterozygote).

Hormogonia (hor mo -go' ni a) (Gr. *hormos,* chain; *gonos,* offspring), portions of algal filaments able to form new individuals.

Hormone (hor' mon) (Gr. *hormaein,* to excite), a chemical substance secreted by one organ and producing a specific effect in another.

Host (L. *hostis,* stranger), an organism in or on which a parasite lives.

Humerus (hu' mer us) (L. *humerus,* shoulder), upper arm bone.

Hyaline (hi' al in) (L. *hyalos,* glass), clear or transparent as hyaline cartilage.

Hybrid (hi' brid) (L. *hybrida,* mongrel), a crossbred animal or plant; the offspring of two parents who differ in at least one trait.

Hydrogen-ion concentration (pH), the index of acidity due to the number of positive hydrogen ions concentrated in a solution.

Hydroid (hi' droid) (Gr. *hydra,* water; *eidos,* like), resembling Hydra.,

Hydrolysis (hi -drol' i sis) (Gr. *hydor,* water; *lysis,* destroy), destruction of a chemical substance by the addition of the elements of water.

Hydroponics (hi dro -pon' iks) (Gr. *hydro,* water; *ponus,* exertion), growth of plants in liquid culture media (soilless cultivation).

Hydrostatic (hi -dro -stat' ik) (Gr. *hydor,* water; L. *statique,* weigh), regulating the specific gravity of an organism in relation to that of water, as the air bladder of certain fish.

Hydrotropism (hi -drot' ro pizm) (Gr. *hydor,* water; *trope,* turning), response of organisms to water.

Hydroxyl (hi -drox' il), the radical OH.

Hymenoptera (hi men -op' tur a) (Gr. *hymen,* membrane; *ptera,* wings), order of insects with membranous wings as bees, wasps, etc.

Hyoid (hi' oid) (Gr. *hyoides,* Y-shaped), bone or cartilage at base of tongue.

Hypersensitiveness (Gr. *hyper,* above), excessive sensitiveness to certain foreign materials, especially proteins, because of peculiar permeability of membranes.

Hypertonic (hi per -ton' ik) (Gr. *hyper,* above; tension), possessing greater osmotic pressure than some related substance (contrast with Hypotonic).

Hypertrophy (hi -per' tro fi) (Gr. *hyper,* above; *trophe,* growth), excessive growth or development (contrast with Atrophy).

Hypha (hi' fa) (pleural, hyphae) (Gr. *hyphe,* web), a threadlike element of the mycelium of a fungus.

Hypnosis (hip -no' sis) (Gr. *hypnos,* sleep), type of artificially produced sleep in which there are certain unusual activities, with the diminution or suspension of others.

Hypocotyl (hi po -kot' il) (Gr. *hypo,* below; *kotyle,* cotyledon), portion of the embryo axis below the attachment of cotyledons and forming the primary root of the seedling.

Hypodermis (hi po -dur' mis) (Gr. *hypo,* below; *derma,* skin), cellular layer lying below, and secreting, the cuticle of arthropods, annelids, and other invertebrates.

Hypostome (hi' po stom) (Gr. *hypo,* under; *stoma,* mouth), around or under the mouth.

Hypotonic (hi po -ton' ik) (Gr. *hypo,* below; tension), possessing lesser osmotic pressure than some other related substance (contrast with Hypertonic).

I

Identical twins, those produced by the division of a single, fertilized egg and resulting in two separate individuals with identical hereditary traits. (Same as monozygous twins; contrast with Dizygotic or nonidentical twins.)

Ileum (il' e um) (L. *ileum,* groin), posterior or lower part of small intestine.

Ilium (il' i um) (L. *ilium,* flank), dorsal part of hip or pelvic bone.

Immunity (i -mu' ni ti) (L. *im,* not; *munia,* obligation), ability of an organism to resist disease.

Inbreeding, mating or crossing closely related types of animals or plants.

Incisor (in -size' er) (L. *incisis,* cut), adapted for cutting.

Incomplete dominance, neither of two genic factors completely dominating the other.

Indeterminate cleavage, segmentation of the egg in such a way that the prospective fate of the individual cells is not easily traced, and consequently there is very little specialization of the cells or blastomeres (contrast with Determinate).

Indirect cell division, *see* Mitosis.

Individuality, in a living organism, consists of complex living protoplasm, somewhat limited in size, which possesses definite form, structure, chemico-physical activities, and a certain degree of order, correlation, and subordination in order to bring about a unity of the whole.

Incus (ing′ kus) (L. *incus,* anvil), middle or anvil bone of the ear of certain vertebrates.

Indusium (in du′ si um) (L. *indusium,* cover), membranous cover of a fern sorus.

Infection (in -fek′ shun) (L. *in,* in; *facere,* to make), invasion of tissues by pathogenic organisms with a resulting pathologic condition.

Infundibulum (in fun -dib′ u lum) (L. *infundere,* pour into), funnel-like outgrowth from the ventral part of the diencephalon of the brain (*see* Pituitary gland).

Infusoria (in fu -sor′ i a) (L. *infusus,* crowded in), class of Protozoa very common in hay infusions, on plants in water, etc.

Ingest (in -jest′) (L. *ingestus,* take in) take in food.

Inhalant (in -hal′ ant) (L. *in,* in; *halere,* breathe), to draw in or inspire.

Inheritance, transmission of traits from one generation to another.

Inhibitor (in -hib′ i ter) (L. *in,* in; *habeo,* to have), restrain or check.

Inner cell mass, the inner group of cells of the embryonic morula in contrast to the outer layer or trophectoderm (trophoderm).

Innominate (in -nom′ i nat) (L. *in,* not; *nomen,* name), nameless.

Inorganic (in or -gan′ ik) (L. *in,* not; organic), not organic but pertaining to nonliving.

Insecta (in -sek′ ta) (L. *insectus,* cut into), class of Arthropoda to which insects belong.

Insectivorous (in sek -tiv′ or us) (L. *insectus,* insect; *voro,* to eat), insect eating.

Insertion (in -sur′ shun) (L. *insertus,* join), place of attachment, as the more movable end of a muscle (contrast with Origin).

Instinct (in′ stingkt) (L. *instinguere,* to incite), subconscious fixed reflex act due to a definite arrangement of an inherited pattern of nerve cells and tissues.

Insulin (in′ su lin) (L. *insula,* island), hormone secreted by the islands of Langerhans of the pancreas.

Integument (in -teg′ u ment) (L. *integumentum,* covering), covering or investing layer.

Intercellular (in ter -sel′ u lar) (L. *inter,* between; *cellula,* cells), between cells.

Internal receptor, sense organ within the body.

Internal respiration, passage of oxygen from the blood into the protoplasm of tissue cells (contrast with External respiration).

Internal secretion, *see* Hormone or Endocrine.

Internode (in′ ter node) (L. *inter,* between; *nodus,* knot), space between two joints.

Intestine (in -tes′ tine) (L. *intestinus,* internal), part of the digestive tract beyond the stomach.

Intracellular (in tra -sel′ u ler) (L. *intra,* within; *cellula,* cells), within cells (contrast with Intercellular).

Intussusception (in tus su -sep′ shun) (L. *intus,* within; *suscipere,* take up), growth by adding new materials within the living protoplasm (contrast with Accretion).

Invaginate (in -vaj′ i nat) (L. *in,* in; *vagina,* sheath), to fold in, as in the gastrula.

Invertebrate (in -vur′ te brat) (L. *in,* not; *vertebratus,* vertebra), lower animals without vertebrae or notochord (contrast with Vertebrate).

Ionization, breaking up of solute molecules into electrically charged ions in the process of solution.

Ions (i′ ons) (Gr. *ion,* going), electrically charged particles into which molceules may be split when in water.

Iris (i′ ris) (L. *iris,* rainbow), colored part of eye.

Irritability (ir i ta -bil′ i ti) (L. *irrito,* excite), ability to receive and respond to external or internal stimuli.

Ischium (is′ ki um) (Gr. *ischion,* hip), posterior and dorsal bone of the pelvic girdle.

Islands of Langerhans, areas in the pancreas which secrete the hormone insulin.

Isogametes (i so ga -mete′) (Gr. *isos,* equal; gamete), similar gametes (sex cells).

Isogamy (i -sog′ a mi), union of similar gametes (contrast with Heterogamy).

Isolation (is o la′ shun) (L. *isolato,* island), to keep away from; in heredity the prevention of interbreeding between certain organisms.

Isotonic solution (i so -ton′ ik) (Gr. *isos,* equal; *tonikos,* tension), one with osmotic pressure equal to that of protoplasm.

J

Jejunum (je -joo′ num) (L. *jejunus,* empty), middle or second part of the small intestine between the duodenum and ileum.

Jellyfish, group of jellylike coelenterates.

Jugular (jug′ u lar) (L. *jugulum,* collarbone), pertaining to the neck, as jugular vein in neck.

K

Kappa particle, a "killer" particle in a paramecium.

Karyokinesis (kar i o ki -ne′ sis) (Gr. *karyon,* nut; *kinein,* to move), *see* Mitosis.

Karyolymph (kar′ i o limf) (Gr. *karyon,* nut or nucleus; L. *lympha,* liquid), liquid ground substance of the cell nucleus.

Karyosome (kar′ i o som) (Gr. *karyon,* nut or nucleus; *soma,* body), nucleus-like body in the cell nucleus as opposed to the nucleolus (plasmosome).

Keratin (ker′ a tin) (Gr. *keras,* horny), insoluble substance, similar to chitin, forming the basis for horns, hoofs, etc.

Kinetic energy (ki -net′ ik) (Gr. *kineo,* move), possessed by virtue of motion such as falling water, winds, etc. (contrast with Potential energy).

Krause's membrane, transverse membranes within striated, voluntary muscle.

L

Labial (la′ bi al) (L. *labium,* lip), pertaining to lip.

Labium (la′ bi um) (L. *labium,* lip), lower lip of insects.

Labrum (la′ brum) (L. *labrum,* lip), upper or anterior lip of insects, etc.

Lactase (lak′ tase) (L. *lac,* milk; *ase,* enzyme), enzyme that changes lactose (milk sugar) into dextrose and galactose.

Lacteals (lak′ te al) (L. *lacteus,* milky), lymphatic vessels of small intestine to convey the milky chyle from the intestine through the mesenteric glands to the thoracic duct.

Lacuna (la -ku′ na) (L. *lacuna,* cavity), cavity in which cells are located, as in bone, cartilage, etc.

Lamarckism (la -mark' izm), Lamarck's theory that acquired characters are inherited.

Lamella (la -mel' a) (L. *lamella,* small plate), structure made by small plates, as lamella of bone or layers of a cell wall.

Lanugo (la -nu' go) (L. *lanugo,* down), downy covering of fetus shed early in life.

Larva (lar' va) (L. *larva,* mask), active, immature stage of development (contrast with Pupa).

Larynx (lar' inks) (Gr. *larynx,* larynx), enlarged anterior end of trachea (windpipe) which contains the vocal folds; present in vertebrates except birds.

Legume (leg' yum) (L. *lego,* to gather), family of plants in which the seed vessel is two-valved and having a linear arrangement of seeds, as beans, alfalfa, peas.

Lepidoptera (lep i -dop' ter a) (Gr. *lepis,* scale; *ptera,* wings), order of insects with scaly wings as moths, butterflies, etc.

Lethal factor (le' thal) (L. *letum,* death), genetic factor that brings premature death to the individual.

Leucocyte (lu' ko sit) (Gr. *leukos,* white; *kytos,* cell), colorless blood corpuscle.

Leucoplast (id) (lu' ko plast) (Gr. *leukos,* white; *plastos,* formed), colorless plastid.

Levator (le -va' ter) (L. *lavare,* to rise), a muscle to elevate a structure.

Lichen (li' ken) (Gr. *leichen,* lick), flat plant composed of a chlorophyll-bearing alga and a fungus living together symbiotically.

Life cycle, various stages of development to maturity.

Ligament (lig' a ment) (L. *ligare,* to bind), band of connective tissue to bind one bone to another or a support for an organ.

Lignin (lig' nin) (L. *lignum,* wood), chemical substance related to cellulose, constituting the essential part of woody tissue.

Linin (li' nin) (L. *linum,* thread), fine threadlike structure associated with the chromatin of the nucleus.

Linkage, inheritance of traits in groups because their genes are near each other (linked) in the same chromosome.

Lipase (li' pase) (Gr. *lipos,* fat), a fat-splitting enzyme.

Lipoid (li' poid), of fatty nature.

Locomotion (lo ko -mo' shun) (L. *locos,* place; *motus,* move), moving from one place to another.

Lumbar (lum' ber) (L. *lumbus,* loin), pertaining to the loins (posterior to ribs).

Lumen (lu' men) (L. *lumen,* cavity), space within an organ or tube.

Lycopsida (lai -kop' si da) (Gr. *lykos,* wolf; *opsis,* appearance), subphylum to which the club mosses belong.

Lymph (limf) (L. *lympha,* liquid), the blood plasma and white blood corpuscles which have passed from the circulatory vessels and which surround tissues and cells.

Lysin (li' sin) (Gr. *lysis,* destroy), substance which destroys cells or tissues.

M

Macrogamete (mak ro ga met') Gr. *makros,* large; *gamos,* gamete), large female gamete (sex cell) produced by an organism exhibiting heterogamy.

Macromere (mak′ ro mere) (Gr. *makros,* large; *meros,* part), large cells produced by embryonic cleavage in certain organisms.

Macronucleus (mak ro nu′ kle us) (Gr. *makros,* large; L. *nucleus,* nucleus), the larger nutritive nucleus of certain protozoa as distinguished from the smaller reproductive micronucleus.

Macrophyll (mak′ ro fil) (Gr. *makros,* large; *phyllon,* leaf), large leaf (same as Megaphyllous).

Macroscopic (mak ro -skop′ ik) (Gr. *makros,* large; *skopein,* to see), visible to the naked eye.

Macrospore (mak′ ro spor) (Gr. *makros,* large; *spora,* spore), the larger spore of a heterosporous plant.

Madreporite (mad′ re po rit) (L. *mater,* mother; Gr. *poros,* porous), porous plate leading to the water—vascular system of a starfish.

Malaria (ma -la′ ri a) (L. *mal,* bad; *aria,* air), fever produced by Protozoa (class Sporozoa), formerly thought due to "bad" air.

Malpighian (mal -pig′ i an) (after Malpighi, of Pisa), malpighian corpuscle is a body in a vertebrate kidney (*see* Bowman's capsule).

Mammal (mam′ al) (L. *mamma,* breast), vertebrates having milk-giving breasts.

Mandible (man′ di bl) (L. *mandere,* to chew), chewing jaw.

Mantle (man′ tl) (L. *mantellum,* cloak), sheetlike tissue in clams, oysters, snails to secrete shell.

Marsupial (mar -sup′ i al) (L. *marsupium,* pouch), mammals that carry young in an abdominal pouch as opossum, kangaroo, etc.

Mastax (mas′ taks) (Gr. *mastax,* mouth), crushing apparatus in rotifers.

Matrix (ma′ triks) (L. *mater,* mother), noncellular material in which cells are embedded, as in cartilage, bone, etc.

Maturation (mat u -ra′ shun) (L. *maturus,* mature), maturing of sperm or eggs.

Maxilla (maks -il′ a) (L. *maxilla,* jaw), a jaw, especially the upper in higher animals.

Maxilliped (maks -il′ i ped) (L. *maxilla,* jaw; *pes,* foot), an appendage modified to serve as a masticatory organ and foot; the three pairs of appendages of a crayfish thorax just posterior to the maxillae.

Mechanism (mechanistic view), theory (in contrast to Vitalism) that states that life can be explained in terms of natural transformations of energy and matter without the introduction of any immaterial or extranatural "vital forces."

Medulla (me -dul′ la) (L. *medulla,* marrow), inner portion of an organ as the medulla of the kidney. Medulla oblongata is the posterior part of the brain.

Medullary plate, groove, and tube, three successive stages in the embryologic development of the central nervous system of vertebrates.

Medullary ray, pith ray that separates the vascular bundles in certain higher plants.

Medullary sheath, covering of a medullated nerve fiber.

Medusa (me -du′ sa) (Gr. *medousa,* one who rules), free-swimming hybroid (jellyfish).

Megagametophyte (meg a ga -me′ to fite) (Gr. *megas,* large; *gamos,* gametes; *phyton,* plant), female gametophyte resulting from the development of a megaspore and producing female gametes (eggs).

Megasporangium (meg a spo -ran′ ji um) (Gr. *mega,* large), a sporangium that bears megaspores which develop into megagametophytes.

Megaspore (meg′ a spor) (Gr. *mega,* large; *spora,* spore), a large spore produced in a megasporangium.

Megasporophyll (meg a -spor′ o fil), sporophyll which produces megaspores.

Meiosis (mi -o′ sis) (Gr. *meiosis,* to make less) the preparation and maturation (reduction division) of a sex cell for fertilization in which the chromosome number is reduced one-half.

Melanin (mel′ a nin) (Gr. *melas,* black), blackish pigment.

Melanophore (mel′ an o for) (Gr. *melas,* black; *phoreo,* to bear), chromatophore that contains blackish pigment.

Mendelism (Mendel's laws), characters are inherited as units independently of each other; genes separate (segregate) from one another and later recombine in various ways in the germ cells; characters are in pairs (opposites), one of which is dominant over the other or recessive one. These laws were formulated by Gregor Mendel.

Meninges (me -nin′ jez) (Gr. *meninx,* membrane), three membranous coverings of the brain and spinal cord, outer dura mater, arachnoid, and inner pia mater.

Meristem (mer′ i stem) (Gr. *merizein,* to divide), undifferentiated tissue of growing plants composed of cells actively dividing.

Mesencephalon (midbrain) (mes en sef′ a lon) (Gr. *mesos,* middle; *kephale,* head), third region of vertebrate brain.

Mesenchyme (mes′ eng kime) (Gr. *mesos,* middle; *enchyma,* infusion), middle, cellular layer of embryos which forms connective tissues, blood vessels, heart, etc.

Mesentery (mes′ en ter i) (Gr. *mesos,* middle; *enteron,* intestine), membrane to invest and suspend internal organs such as the intestine.

Mesoderm (mes′ o durm) (Gr. *mesos,* middle; *derma,* skin), middle germ layer of cells which give rise to certain tissues and organs.

Mesogloea (mes o- gle′ a) (Gr. *mesos,* middle; *gloios,* glue), noncellular gelatinous substance between ectoderm and entoderm of sponges and coelenterates.

Mesonephros (mes o -nef′ ros) (Gr. *mesos,* middle, *nephros,* kidney), vertebrate kidney of animals from lamprey to amphibia inclusive.

Mesophyll (mes′ o fil) (Gr. *mesos,* middle; *phyllon,* leaf), plant leaf tissues between upper and lower epidermis.

Mesophyte (mes′ o fit) (Gr. *mesos,* middle; *phyton,* plant), plant requiring only medium moisture.

Mesothelium (mes o -the′ li um) (Gr. *mesos,* middle; *thelium,* lining), lining of the peritoneal cavity.

Mesothorax (mes o -thor′ aks) (Gr. *mesos,* middle; *thorax,* chest) middle of three thoracic segments of insects.

Metabolism (me -tab′ o lizm) (Gr. *metabole,* change), sum of constructive (anabolism) and destructive (catabolism) phases of protoplasm.

Metagenesis (met a -jen′ e sis) (Gr. *meta,* over; *genesis,* origin), the alternation of asexual and sexual generations in the life cycle of such animals as Obelia and of several higher plants.

Metamere (met′ a mere) (Gr. *meta,* over [repeat]; *meros,* part), series of similar parts (segments) of a body.

Metamerism (me -tam′ er izm), displaying metameres.

Metamorphosis (met a -mor′ fo sis) (Gr. *metamorphosis,* to transform), rather abrupt change from one stage of embryonic development to another, as from larval stage to pupa in insects.

Metaphase (met′ a faz) (Gr. *meta,* between; *phasis,* to appear), a period in mitosis between the prophase and anaphase stages.

Metaphysics (met a -fiz′ iks) (Gr. *meta,* beyond; physics), aspects of science that transcend the physical world.

Metaplasm (met′ a plazm) (Gr. *meta,* beyond; *plassein,* to mold), nonliving materials in living protoplasm.

Metathorax (met a -tho′ raks) (Gr. *meta,* after; *thorax,* chest), posterior part of insect thorax.

Metazoa (met a -zo′ a) (Gr. *meta,* later; *zoa,* animals), higher, multicellular animals (contrast with unicellular Protozoa).

Microgamete (mi kro ga -met′) (Gr. *mikros,* small; gamete), smaller of two gametes formed by heterogamous organism.

Microgametophyte (mik ro ga -me′ to fite) (Gr. *mikros,* small; *gamos,* gamete; *phyton,* plant), male gametophyte resulting from the development of a microspore.

Micron (mi′ kron) (Gr. *mikros,* small), one-thousandth part of a millimeter; or one twenty-five thousandth of an inch.

Micronucleus (mi kro -nu′ kle us) (Gr. *mikros,* small; nucleus), smaller reproductive nucleus of certain Protozoa in contrast to the larger nutritive macronucleus.

Microorganism (mi kro -or′ gan izm) (Gr. *mikros,* small), microscopic organism as a bacterium, protozoan, etc.

Micropyle (mi′ kro pile) (Gr. *mikros,* small; *pyle,* gate), small opening.

Microspore (mi′ kro spor) (Gr. *mikros,* small; *spora,* spore), minute spore which grows into a male gametophyte; in seed plants it is the young pollen grain.

Microsporophyll (mi kro -spo′ ro fil) (Gr. *mikros,* small; *spora,* spore; *phyllon,* leaf), a sporophyll-bearing microsporangium (sporophyll which bears microspores).

Migration (mi -gra′ shun) (L. *migro,* move), moving from one region to another.

Mimicry (mim′ ik ri) (L. *mimikos,* imitate), resemblance for protective purposes.

Miracidium (mi ra -sid′ i um) (Gr. *meikakion,* young), ciliated larval stage of a fluke.

Mitochondria (mit o -kon′ dri a) (Gr. *mitos,* thread; *chondros,* grit or grain), somewhat regularly shaped bodies in cytoplasm.

Mitosis (mi -to′ sis) (Gr. *mitos,* thread), indirect cell division characterized by nuclear division with the formation of chromosomes, spindle, etc.

Modification, noninheritable variation in the somatoplasm due to environmental causes.

Modifying factor, a gene which modifies others to bring about a changed trait.

Mold (A.S. *molde*, earthy), saprophytic fungi.

Molecule (mol′ e kul) (L. *moles,* mass), an aggregate of two or more atoms combined chemically.

Mollusca (mol -lus′ ka) (L. *mollis*, soft), soft-bodied animals such as clams, snails, etc.

Molt (L. *muture*, to change), shedding of an outer covering.

Monecious (mo -ne′ shus) (Gr. *monos*, one; *oikos*, household), both male and female reproductive organs in the same individual (same as hermaphroditic; contrast with Diecious).

Monohybrid (mon o -hi′ brid) (Gr. *monos*, single; L. *hybrida,* mongrel), offspring from parents who differ in one trait.

Monozygotic (mon o zi -got′ ik) (Gr. *monos,* one; *zeugon*, yoke), two or more offspring formed from one zygote (fertilized egg).

Morphogenesis (mor fo -jen′ e sis) (Gr. *morphe*, form; *genesis*, origin), origin and development of form and structure in an organism.

Morphology (mor -fol′ o ji) (Gr. *morphe,* form; *logos*, study), dealing with form and structure of animals and plants.

Morula (mor′ u la) (L. *morum*, berry), mass of cells, called blastomeres, formed by cleavage of the egg in early development of many animals.

Motor fibers (L. *moveo*, move), nerve fibers whose impulses cause movement (in muscles).

Mucous membrane (mu′ kus) (L. *mucus,* slime), lining of alimentary tract and respiratory system.

Multiple factors, two or more pairs of genes which have a similar or cumulative effect.

Mutation (mu -ta′ shun) (L. *mutare,* change) an abrupt inheritable germinal variation.

Mutual symbionts (sim′ bi onts) (Gr. *sym,* with; *bios*, life), living together for mutual benefit.

Mycelium (mi -se′ li um) (Gr. *mykes,* mushroom), mass of filamentous hyphae of all true fungi.

Myoblast (mi′ o blast) (Gr. *myo*, muscle; *blastos*, bud), muscle-developing cell.

Myogenic theory (mi o -jen′ ik) (Gr. *myo*, muscle; *gene*, origin), theory that the rhythmic heartbeat is due to innate properties of heart muscles rather than nerve impulses.

Myoneme (mi′ o nem) (Gr. *myo*, muscle; *nema*, thread), contractile fiber of certain protozoa.

Myosin (mi′ o sin) (Gr. *myo*, muscle), protein of muscle.

Myotome (mi′ o tom) (Gr. *myo*, muscle; *tome*, cut), muscle segments of the body wall of embryonic higher chordates and of adult lower chordates.

Myxomycophyta (mix o my -kof′ i ta) (Gr. *myxos*, slime; *mykos,* fungus, *phyta*, plants), the phylum of plants including slime molds.

Myxamoeba (miks a -me′ ba) (Gr. *myxa,* slime; *amoeba*, change), swarm cell of slime mold.

N

Nacreous (na′ kre us) (L. *nacre*, mother-of-pearl), pearly.

Nares (na′ res) (L. *nare*), nostrils.

Natural selection, Darwin's theory that the fittest individuals survive through natural processes of struggle.

Negative tropism (tro′ pizm) (Gr. *trope,* turning), tendency to move away from a stimulus.

Nemathelminthes (ne math el -min′ thez) (Gr. *nema,* round; *helmins,* worm), roundworms.

Nematocyst (nem′ a to sist) (Gr. *nema,* thread; *kystis,* sac), permanent, stinging thread thrust from a saclike cell as in Hydra.

Nematode (nem′ a tod), class of roundworms.

Neoplasm (ne′ o plazm) (Gr. *neos,* new; *plasma,* formation), newly added tissue, generally pathologic.

Neoteny (pedogenesis) (ne -ot′ o ni) (Gr. *neos,* new; *teinein,* to stretch), retention of larval traits throughout life, even being sexually mature in this larval condition.

Nephritic (ne -frit′ ik) (Gr. *nephros,* kidney), pertaining to the kidney.

Nephridium (ne -frid′ i um) (Gr. *nephros,* kidney), tubular excretory organ of lower animals as earthworms.

Nephrostome (nef′ ro stom) (Gr. *nephros,* kidney; *stoma,* opening), ciliated opening of inner end of a nephridium.

Nerve (L. *nervus,* sinew), group of nerve fibers, end to end and side by side, held together by special connective tissue called neuroglia.

Neural groove, tube, *see* Medullary groove, etc.

Neurilemma (nu ri -lem′ a) (Gr. *neuron,* nerve; *lemma,* covering), membranous covering of nerve.

Neuroblast (nu′ ro blast) (Gr. *neuron,* nerve; *blastos,* origin), cell which embryologically gives rise to nerve cells.

Neuroglia (nu -rog′ li a) (Gr. *neuron,* nerve; *glia,* glue), special tissue to bind and support nerve cells and fibers.

Neuromuscular, combining nervous and muscular functions.

Neuron (nu′ ron) (Gr. *neuron,* nerve), unit of the nervous system composed of dendrite, cyton, and axon.

Nissl's granules (Nis′ l) (after Nissl), present in nerve cell cytoplasm and associated with its activity.

Nitrification (ni tri fi -ka′ shun), preparation of nitrogenous materials for use by organisms.

Nitrifying bacteria, those capable of changing ammonia into nitrites or nitrites into usable nitrates.

Nitrogen-fixing bacteria, those capable of combining free nitrogen of the air with oxygen, either in the nodules of the roots of leguminous plants (such as clovers, peas, alfalfa, etc.) or by other species of bacteria that live freely in the soil.

Nodes of Ranvier (ran -vya′), places on a nerve fiber where the membranous covering (medullary sheath) is interrupted.

Nomenclature (no′ men kla-tur) (Gr. *nomen,* name), system of naming objects or organisms.

Nondisjunction (non dis jungk′ shun), failure of homologous chromosomes to separate after synapsis, both going to one cell.

Nonelectrolyte (non e -lek′ tro lite), a substance such as sugar or alcohol which, in solution, cannot be ionized and hence cannot conduct electric currents.

Notochord (no′ to kord) (Gr. *notos,* back; *chorde,* string), rodlike structure in the dorsal (back) side which is the forerunner of backbone.

Nucellus (nu -sel′ us) (L. *nux,* nut), the megasporangium of an ovule, locatec inside the integument and enclosing the megagametophyte.

Nuclear electron, one within the nucleus of the atom.

Uucleolus (nu -klé o lus) (L. dim. of nucleus), the somewhat spherical body within the nucleus, probably of regulatory function (same as Plasmosome).

Nucleoplasm (nu′ kle o plazm) (L. *nux,* nucleus; Gr. *plasma,* liquid), liquid part of the nucleus.

Nucleus (nu′ kle us) (L. *nucleus,* kernel), specialized, central, organized structure in most cells.

Nymph (nimf) (Gr. *nymphe,* bride), specific stage in metamorphosis of such insects as the grasshopper.

O

Obligate (ob′ li gate) (L. *ob,* about; *ligo,* bind), unable to change life habits to suit varying conditions.

Occipital (ok -sip′ i tal) (L. *occiput,* back of head), base of skull.

Ocellus (plural ocelli) (o -sel′ us) (L. *oculus,* eye), simple eye.

Octopus (ok′ to pus) (Gr. *okta,* eight; *pous,* feet), a mollusk with eight feet (arms).

Oculomotor (ok u lo -mo′ ter) (L. *oculus,* eye; *movere,* to move), moving the eye.

Oesophagus (esophagus) (e -sof′ a gus) (Gr. *oise,* bear; *phagein,* to eat), tube from pharynx to stomach.

Olfactory (ol -fak′ to ri) (L. *olere* odor; *facere,* to make) pertaining to odors.

Ommatidium (om a -tid′ i um) (Gr. *omma,* eye), unit of which compound eyes are made, as in crayfish, certain insects.

"Omnis cellula a cellula," Virchow's dictum that all cells arise from cells.

Omnivorous (om -niv′ o rus) (L. *omnis,* all; *vorare,* to eat), eating both plant and animal tissues.

Ontogeny (on -toj′ e ni) (Gr. *on,* being; *genes,* born), developmental life history of an individual, including embryology, metamorphosis, and adolescence, as distinguished from phylogeny (evolution of a race or group).

Oöcyte (o′ o sit) (Gr. *oön,* egg; *kytos,* cell), female egg before maturation.

Oogamy (o -og′ a mi) (Gr. *oon,* egg; *gamos,* marriage), union of nonmotile egg and male gamete.

Oögenesis (o o -jen′ e sis) (Gr.*oön,* egg; *genesis,* origin), formation of an egg and its preparation for fertilization and development.

Oögonium (o o -go′ ni um) (Gr. *oön,* egg; *gonos,* offspring), primordial egg cell before maturation; the one-celled female sex structure in certain thallophytes and produces one or more eggs.

Operculum (o -pur′ ku lum) (L. *operculum,* cover or lid), lidlike covering.

Opsonin (op′ so nin) (Gr. *opsonein,* to cater), substance in the blood which aids phagocytes to destroy bacteria.

Optic (op′ tik) (Gr. *optikos,* sight), pertaining to sight or the eye.

Order (or′ der) (L. *ordo,* order), methodical arrangement; group of closely allied organisms all belonging to the same class.

Organ (or′ gan) (Gr. *organon,* an implement), a group of different tissues all performing a common function.

Organelle (or gan -el′), a special part of a single cell serving a specific function.

Organicism (or -gan′ i sizm), a theory stressing the importance of the organization of the entire living thing rather than the importance of the parts of which that thing is composed.

Organism (or′ gan izm) (Gr. *organon,* implement), an independent living being.

Organismal theory, a theory that an organism is a unit with its unity consisting of centralized control of one dominant region over all subordinate regions (contrast with Elemental theory).

Organogeny (or gan -og′ a ni), formation and development of organs.

Orientation (o ri en -ta′ shun) (L. *orient,* rise), change in location or position by organs or their parts due to environmental influences; may also be applied to an entire organism.

Orthogenesis (or tho -jen′ e sis) (Gr. *orthos,* straight; *genesis,* descent), development or evolution in a definite direction.

Orthoptera (or -thop′ ter a) (Gr. *orthos,* straight; *ptera,* wings), order of insects, such as grasshopper, whose wings meet in a straight line down the back.

Osculum (os′ ku lum) (L. *osculum,* little mouth), an excurrent opening as in a sponge.

Osmosis (os -mo′ sis) (Gr. *osmos,* pushing), diffusion of substances through a semipermeable membrane.

Osmotic pressure, pressure exerted by substances in solution due to molecular activity.

Osseous (os′ e us) (L. *os,* bone), pertaining to bone.

Osteology (os te -ol′ o ji), study of bones.

Ostium (os′ ti um) (L. *ostium,* little opening), mouthlike opening.

Otolith (o′ to lith) (Gr. *ous,* ear; *lithos,* stone), a limy particle in the auditory organ of certain animals.

Outbreeding, crossing of unrelated or distantly related individuals.

Ovary (o′ va ri) (L. *ovarium,* ovary), female reproductive organ in which the egg cells develop; the enlarged, basal part of a pistil (female) within which seeds develop.

Oviduct (o′ vi dukt) (L. *ovum,* egg; *ducere,* to lead), tube to carry eggs from ovary (to exterior).

Oviparous (o -vip′ a rus) (L. *ovum,* egg; *parere,* bring forth), producing eggs that hatch after being excluded from the body.

Ovipositor (o vi -poz′ i ter) (L. *ovum,* egg; *ponere,* to place), specialized tip of abdomen in certain insects for depositing eggs.

Ovoviviparous (o vo vi -vip′ a rus) (Gr. *ovum,* egg; F. *vivipare,* produce), forming eggs, with a well-developed covering, which develop within the body of the parent.

Ovulation (o vu -la′ shun) (L. *ovum,* egg), discharging mature eggs from the ovary.

Ovule (ov′ ule) (L. *ovum,* egg), structure consisting of a female gametophyte, nucellus, and integuments, which, after fertilization, develops into a seed.

Oxidation (ox i -da′ shun) (Gr. *oxys,* acid), combining oxygen with a substance.

Oxyhemoglobin (ok si he mo -glo′ bin) (Gr. *oxys,* acid; *haema,* blood; L. *globus,* globe), temporary union of oxygen with the hemoglobin of the blood.

P

Paedogenesis (pedogenesis) (pe do -jen′ e sis) (Gr. *pais,* child; *genesis,* origin), reproduction by a larval or embryonic stage rather than by an adult.

Paleobotany (pa le o -bot′ a ni) (Gr. *palaios,* old; *botane,* plants), science of ancient plants.

Paleontology (pa le on -tol′ o ji) (Gr. *palaios,* old; *logos,* study), science of plant and animal life of the past geologic periods.

Paleozoology (pa le o zo ol′ o ji) (Gr. *palaios,* old; *zoa,* animals; *logos,* study), study of ancient animals.

Palisade layer (pal′ i sade) (L. *palus,* stake), columnar cells with chloroplasts in the mesophyll tissues of leaves, just below the upper epidermis.

Pancreas (pan′ kre as) (Gr. *pan,* all; *kreas,* flesh), an accessory digestive gland.

Pangenesis (pan -jen′ e sis) (Gr. *pan,* all; *genesis,* origin), Darwin's theory that all body cells give rise to minute particles called pangenes which migrate to the germ cells and impress their traits upon them (theory not accepted today).

Parallelism (*see* Convergent adaptations or Variations).

Paramecin, a "killer" particle in a paramecium.

Paramylum (par -am′ i lum) (Gr. *para,* beside; *amylon,* starch), starchlike substance in certain protozoa.

Paraphyses (pa -raf′ i sez) (Gr. *para,* beside; *physis,* growth), sterile, hairlike structures associated with sex structures in certain algae, fungi, mosses, etc.

Parapodium (par a -po′ di um) (Gr. *para,* beside; *pous,* foot), paired processes on the body segments of the sandworm (nereis) of the phylum annelida.

Parasite (par′ a site) (Gr. *para,* beside; *sitos,* food), a plant or animal living in or on another living organism; living at its expense.

Parathyroid (par a -thi′ roid) (Gr. *para,* beside), four small endocrine glands adjacent to the thyroid.

Parenchyma (pa -reng′ ki ma) (Gr. *para,* beside; *en,* in; *chein,* to pour), spongy mesodermal tissues of lower animals or fundamental plant tissues as opposed to more highly differentiated plant tissues.

Parotid (pa -rot′ id) (Gr. *para,* beside; *otos,* ear), salivary gland located below the ear.

Parthenogenesis (par the no -jen′ e sis) (Gr. *parthenos,* virgin; *genesis,* origin), development of an egg without fertilization by a male sperm.

Pasteurization (pas ter i -za′ shun) (after Pasteur), killing certain organisms by heating a liquid to 142°-145° F. for thirty minutes (212° F. is boiling).

Patella (pa -tel′ a) (L. *patena,* pan), kneecap.

Pathogenic (path o -jen′ ik) (Gr. *pathos,* suffering; *genesis,* origin), disease-producing.

Pathology (pa thol′ o ji) (Gr. *pathos,* suffering or disease; *logos,* science), study of diseased or abnormal conditions.

Pecten (pek′ ten) (L. *pecten,* comb), comblike structure in certain insects.

Pectoral (pek′ to ral) (L. *pectus,* breast), pertaining to chest or breast.

Pedal (ped′ al) (L. *pes,* foot), pertaining to the foot.

Pedicelaria (ped i se -la′ ri a) (L. *pediculus,* small foot), small, pincerlike structures on the surface of certain echinoderms such as the starfish.

Pedogenesis, *see* Paedogenesis.

Pellicle (pel′ i kl) (L. *pellicula,* small skin), thin layer as on certain cells.

Pelvis (pel′ vis) (L. *pelvis,* basin), arrangement of bones to support abdominal organs and for attachment of lower (hind) limbs.

Penis (pe′ nis) (L. *penis,* penis), male organ of copulation.

Pentadactyl (pen ta -dak′ til) (Gr. *penta,* five; *daktylos,* finger), five fingers or digits.

Pepsin (pep′ sin) (Gr. *pepsis,* digest), protein-digesting enzyme of the stomach.

Perennial (per -en′ i al) (L. *per,* through; *annus,* year), plant living more than two years (contrast with Annual and Biennial).

Perianth (per′ i anth) (Gr. *peri,* around; *anthos,* flower), all the petals and sepals of a flower taken collectively.

Pericardium (per i -kar′ di um) (Gr. *peri,* around; *kardia,* heart), serous membane which encloses the heart.

Pericycle (per′ i si kl) (Gr. *peri,* around; *kyklos,* circle), circle of plant tissue of stems and roots between the cortex and stele.

Perimysium (peri -mizh′ i um) (Gr. *peri,* around; *mys,* muscle), covering or binding muscle.

Periosteum (peri -os′ te um) (Gr. *peri,* around; *os,* bone), membranous connective tissue that covers bones.

Peripheral nervous system, that part of the nervous system composed of cranial and spinal nerves (contrast with Central nervous system).

Peristalsis (per i -stal′ sis) (Gr. *peri,* around; *stallein,* to arrange), wavelike constriction passing along a tube, due to muscular contraction, as in esophagus, intestine, etc.

Peritoneum (per i to -ne′ um) (Gr. *peri,* around; *teinein,* to stretch), membrane which lines the coelom of vertebrates and covers the viscera of the coelom.

Permeable membrane, one which permits substances to pass.

Perspiration (per spi -ra′ shun) (L. *per,* through; *spiro,* to breathe), watery excretion of perspiratory glands of skin.

Petal (pet′ al) (Gr. *petalon,* leaf), one of the inner whorl of a flower, usually colored; all petals taken collectively form the corolla.

Petiole (pet′ i ol) (L. *petiolus,* little stalk), slender support for the blade of a foliage leaf.

Petrifaction (pet ri -fak′ shun) (L. *petra,* rock), method of fossil formation in which mineral matter takes the place of the original organic or living matter during the disintegration of the organism.

Peyer's patches (after Swiss anatomist, Peyer), oval patches of lymphoid tissue of the small intestine attacked by typhoid germs in man.

Phaeophyta (fe -of′ i ta) (Gr. *phaeo,* brown; *phyta,* plants), brown algae.

Phagocyte (fag′ o site) (Gr. *phagein,* eat; *kytos,* cell), type of leucocyte which engulfs foreign materials.

Phagocytosis (fag o si -to′ sis), destruction of foreign materials by action of phagocytes (white blood corpuscles).

Pharyngeal cleft, *see* Gill slit.

Pharynx (far′ inks) (Gr. *pharynx,* pharynx), tube connecting mouth to esophagus on the one hand and to the larynx on the other.

Phenotype (fe′ no tipe) (Gr. *phaino,* show; *typos,* impression), a type or kind determined on the basis of visible traits as distinguished from genotype (based on gene content).

Phloem (flo′ em) (Gr. *phloios,* bark), food-conducting tissue of plants; phloem and xylem together form a vascular bundle.

Photosynthesis (fo to -sin′ the sis) (Gr. *phos,* light; *synthesis,* to build), production of carbohydrates from water and carbon dioxide by means of chlorophyll in presence of light (to supply energy).

Phototaxis (fo to -tax′ is) (Gr. *phos,* light; *taxis,* response), response to light.

Phototropism (fo -tot′ ro pizm), *see* Phototaxis.

Phrenic (fren′ ik) (Gr. *phren,* diaphragm), pertaining to the diaphragm.

Phycocyanin (fy co -si′ a nin) (Gr. *phycos,* seaweed or alga; *kyanos,* blue), blue pigment of the blue-green algae.

Phycoerythrin (fy co e -ryth′ rin) (Gr. *phycos,* alga; *erythros,* red), red pigment of red algae.

Phycomycetes (fi co mi -se′ tez) (Gr. *phycos,* alga; *mycetes,* fungi), filamentous (algalike) fungi.

Phylogeny (fi loj′ e ni) (Gr. *phylon,* race; *gen,* descent), ancestral history of a race or group as contrasted with ontogeny.

Phylum (fi′ lum) (Gr. *phylon,* tribe), one of the main groups into which the animal and plant kingdoms are divided (plural, phyla).

Physiology (fiz i -ol′ o ji) (Gr. *phusis,* nature; *logos,* study), study of functions.

Phytogeography (fi to ge -og′ ra fi) (Gr. *phytos,* plant), geographic distribution of plants; same as Plant geography.

Phytopathology (fi to pa thol′ o ji) (Gr. *phyto,* plant; *pathos,* diseased), study of diseased or abnormal plants.

Pia mater (pi′ a; ma′ ter), inner of three coverings of brain and spinal cord.

Pigmentation of plants, various colors of plants produced by such specific pigments as chlorophyll, xanthophyll, carotene, anthocyanins, and flavones of higher plants and phycoerythrin, phycocyanin, fucoxanthin in algae, etc.

Pineal (pin′ e al) (L. *pinea,* cone), small endocrine gland between the two cerebral hemispheres.

Pisces (pis′ es) (L. *piscis,* fish), class of vertebrates to which fishes belong.

Pistil (pis′ til) (L. *pistilum,* a pestle), the ovule-producing part of a flower, consisting of one or more carpels.

Pith (A.S. *pitha,* pith), soft, spongy tissue in the center of the stems of certain plants.

Pituitary (pi -tu′ i ta ri) (L. *pituita,* phlegm), small, oval endocrine gland attached to the infundibulum of the brain whose two lobes have entirely different hormones.

Placenta (pla -sen′ ta) (Gr. *plakous,* flat cake), flat vascular organ which aids in nourishing the fetus in the uterus; or attachment of plant seeds.

Plankton (plangk′ ton) (Gr. *planktos,* wandering), animal and plant life floating in the water.

Plant geography, *see* Phytogeography.

Plasma (plaz′ ma) (Gr. *plasma,* liquid), liquid part of the blood, lymph, or milk.

Plasmagene (plaz′ ma jen) (Gr. *plasma,* form; *genos,* descent), a gene within the cytoplasm in contrast to a nuclear gene; sometimes called a cytogene.

Plasma membrane, living semipermeable membrane covering the cytosome of certain cells (*see* Cell membrane).

Plasmodesma (plaz mo -dez′ ma) (Gr. *plasma,* something formed; *desma,* bond), protoplasmic connection between cells (plural, plasmodesmata).

Plasmolysis (plaz -mol′ i sis) (Gr. *plasma,* liquid; *lysis,* loosening), shrinking of the cytoplasm in a living cell due to loss of water.

Plasmodium (plaz -mo′ di um) (Gr. *plasma,* formed), naked, protoplasmic mass, as in slime mold.

Plasmosome (plaz′ mo som) (Gr. *plasma,* liquid; *soma,* body), body known as the nucleolus within the liquid of the nucleus.

Plastid (plas′ tid) (Gr. *plastes,* to form), specialized protein body in a cell concerned with producing a certain substance.

Platyhelminthes (plat i hel -min′ thez) (Gr. *platus,* flat; *helmins,* worm), flatworms.

Plecoptera (ple -kop′ ter a) (Gr. *plekos,* folded; *ptera,* wings), order of insects to which the stone flies belong.

Pleura (ploor′ a) (Gr. *pleura,* rib or side), membranous lining of thoracic cavity of mammals and covering the lungs in the cavity.

Plexus (plek′ sus) (L. *plexus,* interwoven), network of nerves or blood vessels.

Plumule (ploo′ mul) (L. *pluma,* feather), primary bud of an embryo seed plant.

Poison (poy′ sin) (L. *poto,* to drink), substance harmful to an organism.

Polar body, *see* Polocyte.

Polarity (po -lar′ i ti) (Gr. *polos,* pivot), having two opposite poles with different physiologic values. In an egg, there is usually a formative animal pole and a nutritive vegetal pole.

Polar transportation, movement of plant hormones in young tissues in a basipetal direction.

Polarized growth, development of younger plant tissues in length rather than another direction due to specific plant hormones and certain environmental conditions.

Polian vesicle (after the Italian, Poli), bulblike organ of the water vascular system of certain echinoderms.

Pollen (pol′ en) (L. *pollen,* fine flour), dustlike grains of material produced by the male anthers of flowers.

Pollen tube, formed by a pollen grain and transports sperm to the eggs in ovules. A pollen grain and its mature tube are the male microgametophyte.

Pollination (pol i -na′ shun), application of male pollen to the female stigma, or ovule, of a plant.

Polocyte (po′ lo site) (Gr. *polos,* pole; *kytos,* cell), small cell separated from the egg during maturation; function unknown; also called polar body.

Polygamy (po -lig′ a mi) (Gr. *poly,* many; *gamos,* marriage), more than one mate at one time.

Polymorphism (poly -mor′ fizm) (Gr. *poly,* many; *morphe,* form), more than two types or castes of individuals in a colony or community which belong to the same species and are derived from the same parents. The various castes of honeybees, ants, termites, etc., are typical.

Polyp (pol′ ip) (Gr. *poly,* many), sessile phase of the life history of certain coelenterates.

Porifera (po -rif′ er a) (Gr. *poros,* pore; *ferro,* to bear), pore-bearing sponges.

Portal vein (port′ al) (L. *porta,* gate), blood vessel carrying blood to the liver from spleen, pancreas, digestive tract, etc.

Postcaval vein (post -ka′ val) (L. *post,* after; *cavus,* hollow), inferior (posterior) vena cava carrying blood to the heart from posterior parts of the body.

Posterior (pos -te′ ri or) (L. *posterior,* following), behind or opposite anterior (head).

Potential energy (po -ten′ shal) (L. *potens,* be able), stored energy possessed by virtue of position or stresses, such as the stored energies of food, coal, wood, etc. (contrast with Kinetic energy).

Precaval vein (pre -ka′ val) (L. *prae,* before; *cavus,* hollow), anterior (superior) vena cava carrying blood to the heart from the anterior parts of the body.

Precipitin (pre -sip′ i tin) (L. *praecipitare,* precipitate), specific antibody developed in response to stimulation by a foreign protein and characterized by causing a precipitation.

Predaceous (pre -da′ shus) (L. *Praeda,* prey), outright killing of an animal, such as owls killing (preying on) mice, etc.

Preformation (pre for -ma′ shun) (L. *prae,* before), old theory that adults are preformed (represented in miniature) in the germ cell (contrast with Epigenesis).

Premaxilla (pre max -il′ a) (L. *prae,* before; maxilla), in front of the maxilla or upper jaw.

Prenatal (pre -na′ tal) (L. *prae,* before; *natalis,* birth), before birth.

Primates (pri′ mate) (L. *primus,* first), highest animals such as man, apes, monkeys.

Primordial germ cell (pri -mor′ di al) (L. *primordium,* origin), first cell set aside in the embryo for future development of sex organs.

Proboscis (pro -bos′ is) (Gr. *proboskis,* trunk), trunklike process.

Progestin (pro -gest′ in), hormone of the corpus luteum (yellow body) of the ovary.

Proglottid (pro -glot′ id) (Gr. *pro,* for; *glotta,* tongue), one of the sections or individuals of the chain making up a cestode worm such as tapeworm.

Pronephros (pro -nef′ ros) (Gr. *pro,* before; *nephros,* kidney), first kidney structure to develop in a vertebrate.

Prophase (pro′ faz) (Gr. *pro,* before; *phasis,* to appear), preparatory stage of mitosis preceding the metaphase.

Prophylaxis (pro fy -lacks′ is) (Gr. *pro,* before; *phylasso,* guard), preventive measures in connection with diseases.

Prosopyle (pros′ o pile) (Gr. *proso,* forward; *pyle,* gate), pores leading into flagellated chambers from the incurrent canals in certain sponges.

Prostate (pros′ tat) (Gr. *pro,* before; *stare,* stand), an accessory male reproductive gland near the urethra.

Prostomium (pro -stom′ i um) (L. *pro,* before; *stoma,* mouth), portion of head before the mouth.

Protective resemblance, protection of an organism due to the resemblance of it, or some part of it, to its environment. This resemblance may be due to structure, color, pattern, etc.

Protein (pro′ te in) (Gr. *protos,* first), compound of carbon, hydrogen, oxygen, and nitrogen, and frequently traces of phosphorus or sulfur.

Prothallus (pro -thal′ us) (Gr. *pro,* before; *thallos,* young part), the reduced prethallus gametophyte of ferns and their allies.

Prothorax (pro -thor′ aks) (*pro,* before; *thorax,* chest), anterior segment of insect thorax which bears first pair of legs.

Protista (pro -tis′ ta) (Gr. *protistos,* first), single-celled plants and animals.

Proton (pro′ton) (Gr. *protos,* first), part of a nucleus of the atom, and with a positive charge of electricity.

Protonema (pro to -ne′ ma) (Gr. *proto,* first; *nema,* thread), first threadlike growth from a spore in mosses.

Protoplasm (pro′ to plazm) (Gr. *protos,* first; *plasma,* liquid), substance of which all living organisms are composed.

Protopodite (pro -top′ o dite) (Gr. *protos,* first; *pous,* foot), basal (proximal) segment of a typical crustacean appendage to which endopodite and exopodite are attached.

Protozoan (pro to -zo′ an) (Gr. *protos,* first; *zoa,* animals), simple, unicellular animals.

Proventriculus (pro ven -trik′ u lus) (Gr. *pro,* before; *ventriculus,* small stomach), first part of a stomach in such animals as insects, birds, etc.

Proximal (prox′ i mal) (L. proximus, near), nearest the main axis; opposed to distal.

Pseudopodium (plural, pseudopodia) (su do -po′ di um) (L. *pseudo,* false; *pous,* feet), temporary protrusion of protoplasm from a cell, especially certain protozoa like ameba, and serving for various functions but particularly locomotion.

Psychical (si′ kik al) (Gr. *psyche,* soul), pertaining to the mind.

Psychology (si -kol′ o ji) (Gr. *psyche,* mind; *logos,* study), study of the mind, etc.

Pteropsida (ter -op′ si da) (Gr. *pteris,* fern; *opsis,* appearance), a subphylum to which ferns, conifers, and flowering plants belong.

Ptomaine (to′ mane) (Gr. *ptoma,* dead body), an organic base or alkaloid formed by the action of putrefactive bacteria on nitrogenous matter. Some ptomaines are poisonous but most are harmless.

Ptyalin (ty′ a lin) (Gr. *ptyalon,* spittle), salivary enzyme changing starch to sugar.

Pubis (pu′ bis) (L. *pubes,* adult), anterior part of the hip (pelvic) girdle.

Pulmonary (pul′ mon a ri) (L. *pulmo,* lung), pertaining to the lung.

Pulsating vacuole, same as Contractile vacuole.

Punnet square, a checkerboard-like diagram for determining the results of a cross in heredity.

Pupa (pu′ pa) (L. *pupa,* baby), the quiet stage in the development of certain insects occurring between the larval and adult stages; known as a cocoon in moths and chrysalis in butterflies.

Pure line, a group of individuals arising from homozygous parents and having identical genes.

Pylorus (pi -lo′ rus) (Gr. *pylorus,* gate), opening between stomach and small intestine.

Pyrenoid (pi -re′ noid) (Gr. *pyren,* fruit stone; *eidos,* resembling), plastid or center for forming starch.

Q

Quadruped (quard′ ru ped) (L. *quattuor,* four; *pes,* feet), four-footed animal.

Quard′ ruplet, one of four offspring born at the same time.

Quaternary (qua′ ter na ri), the last of the great fossil-bearing rocks (Pleistocene).

Queen, the reproductive female in colonies of social insects.

R

Radial canal (L. *radius,* ray), canal radiating from a center as in starfish.

Radial symmetry, arrangement of similar parts around a central point like the spokes of a wheel.

Radicle (rad′ i cl) (Gr. *radix,* root), primary root of seedlings.

Radioactivity, a condition in which there is a partial disintegration of atoms, with the shooting out from the atomic nucleus of alpha particles, electrons, x-rays, etc.

Radioulna, fused radius and ulna bones of frog forearm.

Radius (ra′ di us) (L. *radius,* rotate), rotating bone of forearm.

Radula (rad′ u la) (L. *radere,* to scrape), scraping organ for mastication in certain Mollusca as snails.

Recapitulation theory (re ka pit u -la′ shun) (Gr. *re,* again; *caput,* head), the life history of an individual repeats (recapitulates) in an abbreviated manner the ancestral history of that race as a whole (*see* Biogenetic theory).

Receptor (re -sep′ ter) (L. *receptor,* receiver), receiving sensory cell or organ.

Recessive characters, those traits which are not expressed, even though their genes are present together with the gene for the opposite, allelomorphic dominant.

Rectum (rek′ tum) (L. *rectus,* straight), posterior part of intestine.

Red blood corpuscle, oxygen-carrying cell.

Redia (re′ di a) (after Italian naturalist, Redi), the second type of larva found in life cycle of flukes.

Reduction division, the division of chromosomes of maturing gametes in which the normal, diploid, somatic number of chromosomes is reduced to the haploid, single number.

Reflex action (L. *re,* back; *flectere,* to return), automatic, involuntary response of nervous and motor mechanisms to stimuli.

Refraction (re -frakt′ shun) (L. *re,* back; *frango,* break), deflection of light waves when passing obliquely from one medium to another with different refractive indices.

Regeneration (re gen er -a′ shun) (L. *re,* again; *generare,* to beget), ability to replace a lost part or develop a new individual from a lost part.

Renal (re′ nal) (L. *renes,* kidney), pertaining to kidney.

Renal portal system (L. *renes,* kidney; *porta,* gate), blood vessels (veins) carrying impure blood from the posterior part of the body to the kidneys. Oxygenated blood is carried to the kidneys by renal arteries. Fishes, amphibia, and reptiles have this double blood supply for the kidneys, while this system is vestigial in birds and absent in mammals.

Rennin (ren′ nin) (A.S. *rennan,* run), milk-coagulating enzyme.

Reproduction (re pro -duk′ shun) (L. *re,* again; *pro,* forth; *duco,* to lead), production of offspring.

Reptile (rep′ til) (L. *repere,* to crawl), a class of vertebrates which ordinarily crawl, as snakes, turtles, lizards, etc.

Respiration (res pi -ra′ shun) (L. *re,* again; *spiro,* to breathe), exchange of oxygen (entering) and carbon dioxide (leaving) in an organism.

Response, reaction to a stimulus, external or internal.

Resting cell, one not dividing by mitosis.

Reticular (re -tik′ u lar) (L. *reticulum,* net), network of fibrils.

Reticular theory, that protoplasm is physically constructed of networks of fibrils.

Retina (ret′ i na) (L. *rete,* net), light-sensitive membrane of the eye to receive images.

Reversion (re -ver′ shun) (L. *re,* back; *verto,* to turn), return to an ancestral type or condition.

Rhabdite (rab′ dite) (Gr. *rhabdos,* rod), rodlike structure in epidermis of certain flatworms, probably for protection.

Rheotropism (re -ot′ ro pizm) (Gr. *rhein,* flow; *trope,* respond), response to water currents.

Rhizoid (ri′ zoid) (Gr. *rhiza,* root; *eidos,* like), slender, rootlike filaments in certain lower plants which function as roots.

Rhizome (ri′ zom) (Gr. *rhiza,* root), underground stem which has the appearance of a root.

Rhodophyta (ro -dof′ i ta) (Gr. *rhodon,* red; *phyta,* plants), red algae.

Rodent (ro′ dent) (L. *rodere,* to gnaw), gnawing animal such as rat.

Root cap, the extreme, protective tip of a root.

Root hair, fine hairlike extension of the epidermis of plant roots for absorption.

Rotifer (rot′ i fer) (L. *rota,* wheel; *ferro,* to bear), small, multicellular, aquatic animal with wheel-like organ of rotating cilia on the anterior end.

Rudimentary (roo di -men′ ta ri) (L. *rudis,* immature), not fully developed.

Ruminant (roo′ mi nant) (L. *rumen,* throat), animal which chews its cud, as a cow.

S

Saliva (sa -li′ va) (L. *saliva,* spittle), secretion of salivary glands.

Saprophyte (sap′ ro fite) (Gr. *sapros,* rotten; *phyton,* plant), an organism living on dead or decaying organic matter, particularly of plants.

Sarcolemma (sar ko -lem′ ma) (Gr. *sarx,* flesh or muscle; *lemma,* covering), covering of a striated voluntary muscle cell.

Sarcoplasm (sar′ co plazm) (Gr. *sarx,* muscle; *plasma,* liquid), the cytoplasm of muscle cells exclusive of sarcostyles (fibrils).

Sarcostyles (sar′ ko stile) (Gr. *sarx,* muscle; *stylos,* rod), fibrils in the cytoplasm of voluntary, striated muscle cells.

Scapula (skap′ u la) (L. *scapula,* shoulder blade), shoulder blade or dorsal part of pectoral girdle.

Schizomycophyta (skiz o my -kof′ i ta) (Gr. *schizo,* fission; *mykos,* fungus; *phyta,* plants), fission fungi or bacteria.

Sclerenchyma (skler -engk′ i ma) (Gr. *scler,* hard; *engchyma,* poured in), plant tissues whose cell walls are thickened for protection and support.

Sclerotic (skle -rot′ ik) (Gr. *skleros,* hard), tough, outer coat of eyeball.

Scolex (sko′ leks) (Gr. *skolex,* worm), enlarged anterior end of tapeworm.

Sebum (L. *sebum,* tallow), fatty secretion of the sebaceous glands of the skin.

Secondary sexual characters, structural, functional, or behavioral differences between two sexes other than those pertaining to the different sex organs themselves.

Secretin (se -kre′ tin) (L. *secratio,* secrete), intestinal hormone which activates the pancreas.

Secretion (se kre′ shun) (L. *secretus,* to separate), producing a substance by the action of a gland or cell.

Sedentary (sed′ en te ri) (L. *sedere,* to sit), temporarily attached and not entirely free moving.

Segmentation (seg men -ta′ shun), *see* Metamerism.

Segmentation cavity, hollow, central cavity (blastocoele) formed during early cleavage of embryo.

Segregation law, passage of one member of each pair of allelomorphic genes to different germ cells during maturation.

Selective absorption, absorption of certain substances and not others.

Self-fertilization, fertilization (fusion) of an egg by a sperm from the same individual.

Semicircular canals (L. *semi,* half; *circulus,* circle), ear canals of vertebrates devoted to sense of equilibrium.

Seminal receptacle (sem′ i nal) (L. *semen,* seed fluid; *recipere,* to receive), organ for storing sperm from opposite sex until needed for fertilization.

Seminal vesicle (sem′ i nal) (L. *semen,* seed fluid; *vesica,* bladder), saclike organ for storing sperm during spermatogenesis, as in earthworm.

Seminiferous tubule (sem i -nif′ er us) (L. *semen,* seed fluid; *ferro,* to carry; *tubules,* small tube), tube to conduct seminal fluid of male.

Semipermeable, permitting passage of certain molecules but not others.

Sepal (se′ pal) (L. *separ,* covering), one of the outer whorl of floral leaves which taken as a group are known as the calyx.

Septum (plural septa) (sep′ tum) (L. *septum,* partition), partition separating two cavities.

Serial homology (ho -mol′ o ji) (Gr. *homo,* similar; *logos,* study), presence of structures of similar origin and form on different segments of the same animal.

Serous (se′ rus) (L. *serum,* watery), clear, watery fluid.

Sertoli cells (ser -to′ le), modified, supporting or nurse cells for forming sperm in the testes.

Sessile (ses′ il) (L. *sedere,* to sit), permanently attached and never free moving.

Seta (plural setae) (se′ ta) (L. *seta,* bristle), bristlelike structure.

Sex chromosomes, odd chromosomes (X and Y chromosomes) distinguished from the regular chromosomes which aid in sex determination.

Sex-limited characters (sex-influenced), those traits influenced or modified by the presence of a particular sex organ (and its secretion), such as beard and voice of the male due to hormones from the male testes.

Sex-linked characters, those traits whose genes are located in the sex chromosome.

Sexual dimorphism (di -mor′ fizm) (Gr. *di,* two; *morphe,* form), two forms or types of a plant or animal due to their sex.

Sieve tube, elongated, fused, conducting cells of plant phloem which have perforated sieve plates at their ends.

Sigmoid (sig′ moid) (Greek letter, *sigma; eidos,* resemble), curved like the Greek letter sigma.

Sinus venosus (si′ nus ve -no′ sus) (L. *sinus,* cavity; *vena,* vein), thin-walled chamber in certain hearts into which main veins empty.

Smooth muscle, one whose cells are not striated.

Sol, a state of a colloidal system in which the external phase is more liquid than the internal phase (contrast with Gel).

Solation (so -la′ shun), phenomenon of forming a sol.

Soma (so′ ma) (Gr. *soma,* body), entire body, exclusive of reproductive cells.

Somatogenic reproduction (so mat o -jen′ ik) (Gr. *soma,* body; *genesis,* origin), reproduction by division of a multicellular body by fission, budding, etc. (contrast with Cytogenic reproduction).

Somatoplasm (so -mat′ o plazm) (Gr. *soma,* body; *plasma,* liquid), protoplasm of the body (somatic) cells.

Somite (so′ mite), segment or metamere of an organism.

Sorus (sor′ us) (Gr. *sorus,* heap), a heap of sporangia as on fern leaves.

Special creation, doctrine that each species of organism is specially created.

Species (spe′ shes) (L. *species,* particular kind), individuals so similar that they might appear to have originated from the same parents.

Sperm, *see* Spermatozoa.

Spermatheca (sperm a -thek′ a) (Gr. *sperma,* sperm; *theke,* case), saclike structure of certain invertebrates for storing sperm.

Spermatia (spur -ma′ she a) (Gr. *sperma,* seed), cells in rust fungi, produced in spermagonia; also the male gamete of red algae.

Spermatid (sperm a -tid′) (Gr. *sperma,* sperm), male cell arising by division from a secondary spermatocyte and which later gives rise to a sperm.

Spermatocyte (sper -mat′ o site) (Gr. *sperm,* sperm; *kytos,* cell), male germ cell (arising from the spermatogonium) before it is mature.

Spermatogenesis (sper mat o -jen′ e sis) (Gr. *sperm,* sperm; *genesis,* origin), formation of mature sperm.

Spermatogonium (spur mat o -gon′ i um) (Gr. *gonos,* offspring), primordial male cell giving rise to the spermatocyte; flask-shaped structure in rust fungi, producing spermatia.

Spermatozoa (spur ma to -zo′ a) (Gr. *sperma,* sperm; *zoa,* animal), male sex cells (sperm).

Sphenopsida (sfen -op′ si da) (Gr. *sphen,* wedge; *opsis,* appearance), subphylum including horsetails.

Sphincter (sfingk′ ter) (Gr. *sphinggein,* to bind tightly), circular muscle to close an opening, as the stomach, bladder, anus, etc.

Spinal canal, canal in the spinal column containing the spinal cord.

Spinal column, bony structure enclosing spinal cord.

Spindle (A.S. *spinnan,* to spin), fibrous structure of nucleus associated with chromosomes during mitosis.

Spiracle (spir′ a kl) (L. *spiraculum*, air hole), external opening of respiratory system of insects.

Splanchnic (splangk′ nik) (Gr. *splanchnon*, entrail), pertaining to internal, visceral organs.

Spleen (Gr. *splen*, spleen), ductless, vascular organ near the stomach.

Spongin (spun′ jin) (Gr. *spongos*, sponge), horny material allied to silk, forming skeletal fibers of certain sponges, especially commercial types.

Spongy tissue, plant mesophyll tissue with cells loosely arranged, with many intercellular (air) spaces, and located beneath the lower leaf epidermis.

Spontaneous generation, *see* Abiogenesis.

Sporangium (spor -an′ jium), structure containing spores.

Spore (Gr. *sporos*, seed or spore), cell with resistant covering and for reproductive purposes; one or several may be produced at one time, depending on the species.

Spore mother cell, a cell which by cell divisions produces usually four spores.

Sporophyll (spor′ o fil) (Gr. *spora*, spore; *pyllon*, leaf), a leaf that bears sporangia.

Sporophyte (spor′ o fite) (Gr. *spora*, spore; *phyta*, plant), spore-bearing (asexual) generation in plants exhibiting alteration of generations.

Sport, a mutant.

Squamous (skwa′ mus) (L. *squama*, scale), flat, scalelike.

Stamen (sta′ men) (L. *sta*, stand), pollen-bearing structure of a flower.

Statocyst (stat′ o sist) (Gr. *statos*, stationary; *kystos*, sac), organ of equilibrium as in medusae.

Steapsin (ste -ap′ sin) (Gr. *stear*, tallow; *pepsis*, digest), a pancreatic enzyme able to change fat to fatty acid and glycerin.

Stele (ste′ le) (Gr. *stele*, post), central cylinder of united vascular bundles in the root and stem of dicotyledonous seed plants.

Sterigma (Gr. *sterigma*, support), a stalk for bearing a basidiospore.

Sterile (ster′ il) (L. *sterilis*, barren), infertile, free from all types of organisms.

Sternum (stur′ num) (L. *sternum*, breast bone), breast bone.

Stigma (stig′ ma) (L. *stigma*, a mark), upper part of pistil to receive pollen; or same as eyespot.

Stimulus (stim′ u lus) (L. *stimulare*, to incite), condition or substance which induces a response.

Stoma (plural, stomata) (stom′ a) (Gr. *stoma*, mouth), small opening as in leaves.

Striated (stri′ a ted) (L. *stria*, channel), marked by small channels, usually parallel.

Strobilus (strob′ i lus) (Gr. *strobilos*, twisted), cone-shaped group of sporophylls in horsetails, conifers, etc.

Style (sti′ l) (Gr. *stylos*, pillar), stalk to support the stigma.

Subclavian (sub -kla′ vi an) (L. *sub*, under; *clavis*, clavicle or collar bone), under the collar bone.

Subcutaneous (sub ku -ta′ ne us) (L. *sub*, under; *cutis*, skin), beneath the outer skin.

Supplemental factors, genes which modify and supplement the ability of other genes.

Suprarenal (supra -re′ nal) (L. *supra*, above; *ren*, kidney), an endocrine (ductless) gland above each kidney (also called adrenal).

Surface tension, greater tension (attraction) of the surface molecules of liquids for each other than the attraction of molecules beneath the surface.

Suspension, particles not dissolved but suspended in a fluid.

Suture (su′ tur) (L. *suo,* to sew), junction of two bones, usually an irregular, serrated line.

Swimmerets, paired, branched appendages beneath the crayfish abdomen and just posterior to the walking legs.

Symbiosis (sim bi -o′ sis) (Gr. *syn,* together; *bios,* living), two different species of organisms associated for mutual benefit.

Symmetry (sim′ e tri) (Gr. *syn,* together; *meton,* measure), having similar parts or regularity of form.

Sympathetic nervous system, *see* Autonomic system.

Synapse (sin′ aps) (Gr. *syn,* together; *hapto,* unite), space between axon brush of one nerve cell and dendrite of next nerve cell.

Synapsis (si -nap′ sis) (Gr. *synapsis,* union), temporary conjunction of the pairs of homologous chromosomes (from male and female parent) previous to the maturation of germ cells.

Syncytium (sin -sit′ i um) (Gr. *syn,* together; *kytos,* cell), undivided mass of protoplasm with several nuclei, as in certain muscles, fungi, etc.

Synergid (si -nur′ gid) (Gr. *synergos,* working together), two small cells near the egg at the micropyle end of the embryo sac in an ovule.

Syngamy (sin′ ga mi) (Gr. *syn,* together; *gamos,* marriage), union of male and female gametes (sex cells) to form a zygote.

T

Tactile (tack′ til) (L. *tangere,* touch), concerning stimulation by contact.

Taenia (te′ ni a) (L. *taenia,* ribbon), tapeworm.

Tarsus (tar′ sus) (Gr. *tarsos,* flat), ankle bone or the terminal segment of insect leg.

Taxis (tack′ sis) (Gr. *taxis,* arrangement), tropismal response involving movement of the organism as a whole.

Taxonomy (taks -on′ o mi) (Gr. *taxis,* arrangement; *nomos,* law), scientific classification of organisms.

Telegony (te -leg′ o ni) (Gr. *telos,* end; *gonio,* generation), the unproved theory that mating of a female with a certain male will affect the future offspring of that female even when she is mated to a different type of male.

Teleology (tel e -ol′ o ji) (Gr. *telos,* end; *logos,* study), philosophical study of the final purposes and causes of things which imply the existence of a design in Nature.

Telophase (tel′ o faz) (Gr. *telos,* end; *phais,* appear), final stage in mitosis when daughter cells are formed.

Tendon (ten′ don) (L. *tendo,* stretch), connective tissue to connect muscle to bone.

Tentacle (ten′ ta kl) (L. *tento,* touch), flexible appendage for movement, grasping, etc.

Terrestrial (ter -res′ tri al) (Gr. *terra,* earth), pertaining to land.

Test (L. *testa,* shell), hard, outer shell of such animals as sea urchins.

Testis (tes′ tis) (L. *testis,* testis), male gonad for forming sperm.

Thalamencephalon (thal a men -sef′ a lon) (Gr. *thalamos,* receptacle; *engkephalon,* in brain), part of vertebrate brain derived from the embryonic forebrain.

Thallophyta (thal -of' i ta) (Gr. *thallos,* young shoot or branch; *phyta,* plant), simple, thallus plants without true leaves, stems, or roots.

Thallus (thal' us) (L. *thallos,* a shoot), simple, undifferentiated plant.

Thermotaxis (thur mo -tack' sis) (Gr. *therme,* heat; *taxis,* response), reaction to heat or cold.

Thermotropism (thur -mot' ro pizm) (Gr. *therme,* heat; *trope,* turn), *see* Thermotaxis.

Thigmotaxis (thig mo -tack' sis) (Gr. *thigema,* touch; *taxis,* arrangement), motile response to contact or touch.

Thigmotropism (thig -mot' ro pizm) (Gr. *thigema,* touch; *trope,* turn), response to contact.

Thoracic (tho -ras' ik) (Gr. *thorax,* chest), pertaining to thorax (chest).

Threshold (thresh' old) (A.S. *therscold,* starting point), minimum amount of a stimulus to get response.

Thrombin (thromb' in) (Gr. *thrombos,* clot), substance to aid blood clot formation.

Thymus (thy' mus) (Gr. *thymos,* thymus), ductless gland in the pharyngeal region of vertebrates.

Thyroid (thy' roid) (Gr. *thureos,* shield; *eidos,* resemble), ductless gland in the neck of vertebrates which regulates metabolism, growth, etc.

Thyroxin (thy -rok' sin), hormone produced by the thyroid.

Thysanura (thi sa -nu' ra) (Gr. *thysanos,* fringe; *oura,* tail), order of wingless insects such as bristletails.

Tibia (tib' ia) (L. *tibia,* pipe), larger, inner bone of the lower leg of vertebrates. The part between the femur and tarsus of an insect leg.

Tissue (tish' u) (Fr. *tissu,* woven), group, of similar cells performing a specific function.

Toxin (tok' sin) (Gr. *toxicon,* poison), chemical substance of bacterial origin which stimulates animal protoplasm to produce a specific antitoxin (against toxin).

Trachea (tra' ke a) (Gr. *tracheia,* windpipe), tube to carry air.

Tracheal tube (tra' ke al) (Gr. *tracheia,* tube), rather long tube of the plant xylem composed of several hollow cells fused end to end.

Tracheid (tra' ke -id), single, hollow, enlongated plant cell with pitted walls (in the xylem) to conduct materials.

Tracheole (tra' ke ol), small tracheal tube.

Tracheophyta (tre ke -of' i ta) (Gr. *tracheia,* tube; *phyta,* plants), subphylum of plants possessing vascular tissues.

Transformism (trans -form' izm) (L. *trans,* over; *forma,* form), the doctrine that species may change to form new species, as opposed to special creation or fixism.

Translocation (trans lo -ka' shun) (L. *trans,* beyond; *locus,* place), transfer of soluble materials through the sieve tubes of the phloem of vascular plants; the exchange of parts of chromosomes.

Transmutation (trans mu -ta' shun) (L. *trans,* over; *mutare,* change), ability of genes to change their position, as in translocation from one chromosome to a nonhomologous one.

Transpiration (trans pi -ra' shun) (L. *trans,* through; *spiro,* breathe), loss of water from plants, especially from leaves.

Trial-and-error, theory that living organisms find their way to favorable environments by continually avoiding less favorable ones.

Trichinella (tri ki -nel′ la) (Gr. *thrix,* hair), small roundworm, sometimes parasitic in pork, causing trichinosis in man.

Trichocyst (trik′ o sist) (Gr. *thrix,* thread; *kystos,* bag), organelle producing hair-like fibers for offensive and defensive purposes in such animals as paramecium.

Tricuspid (tri -kus′ pid) (L. *tres,* three; *cuspis,* point), three-pointed.

Trihybrid (tri -hy′ brid) (L. *tres,* three; *hybridos,* mongrel), offspring of parents who differ with regard to three different traits.

Trilobite (tri′ lo bite) (L. *tres,* three; *lobos,* lobes), type of extinct crustacean with a trilobed body.

Triploblastic (trip lo -blas′ tik) (Gr. *triplax,* triple; *blastos,* bud), three primary germ layers (ectoderm, mesoderm, entoderm) from which all organs and tissues arise.

Trochanter (tro -kan′ ter) (Gr. *trochanter,* run), second segment of an insect's leg.

Trophectoderm (Trophoderm) (trof -ek′ to durm) (Gr. *trophe,* food; *ecto,* external, *derma,* skin or layer), outer layer of cells of the embryonic morula which later supplies nourishment (contrast with Inner cell mass).

Trophozoite (trof o -zo′ ite) (Gr. *trephein,* nourish; *zoon,* animal), sporozoan during its growth stage.

Tropism (tro′ pizm) (Gr. *trope,* turn), automatic response of living organism to a stimulus.

Trypsin (trip′ sin) (Gr. *truein,* rub down; *pepsis,* digest), protein-splitting enzyme of the pancreas.

Tube foot (L. *tuba,* pipe), tubular organ of certain echinoderms (as starfish) for locomotion, etc.

Turgor (tur′ gor) (L. *turgere,* to swell), pressure within a cell because of absorption of water.

Twinning, production of two individuals at the same time.

Tympanum (tim′ pan um) (L. *tympanum,* drum), eardrum.

Typhlosole (tif′ lo sole) (Gr. *typhlos,* blind; *solen,* channel), median, dorsal furrow of earthworm intestine to increase absorption.

U

Ulna (ul′ na) (L. *ulna,* elbow), bone which together with the radius forms the forearm.

Umbilical cord (um -bil′ i kl) (L. *umbilicus,* navel), cord composed of blood vessels and connective tissues to connect fetus with the mother.

Umbilicus (im -bil′ i kus) (L. *umbilicus,* navel), scar on the abdomen where the umbilical cord was attached.

Uniformitarianism (uni form i -ta′ ri an izm) (L. *unus,* one; *forma,* form), doctrine that past geologic processes were similar to those of the present (contrast with Catastrophism).

Unit character, trait which is inherited independently and more or less as a unit.

Unity of an organism, constant integration of various structural and physiologic components of an organism so that it will be a unit, structurally and functionally.

Urea (u -re′ a) (Gr. *ouron,* urine), nitrogenous waste material of animal metabolism.

Ureter (u -re′ ter) (Gr. *oureter,* ureter), tube carrying urine from kidneys to bladder or to cloaca.

Urethra (u -re′ thra) (Gr. *ourethra,* urethra), tube carrying urine for bladder to outside.

Uriniferous tubules (u ri -nif′ er us), unit of urinary system of higher animals consisting of coiled tubes and a capsule.

Urogenital (urinogenital) (u ro -gen′ i tal) (Gr. *oura,* urine; *gignesthai,* to produce), the organs of both urinary and reproductive systems taken collectively.

Uropod (u′ ro pod) (Gr. *oura,* tail; *pous,* appendage), modified swimmeret on either side of the last abdominal segment of a crayfish.

Urostyle (u′ ro stile) (Gr. *oura,* tail; *style,* pillar), last rodlike bone of frog spinal column.

Uterus (u′ ter us) (L. *uterus,* belly, womb), enlarged part of oviduct; in female mammals an organ for containing and nourishing the developing young before birth.

V

Vaccine (vak′ seen) (L. *uacca,* cow), the virus of cowpox administered to build immunity against smallpox. The term is more generally applied, although incorrectly, to many types of so-called "shots."

Vacuole (vak′ u ole)' (L. *vaccum,* empty), space for receiving something.

Vagina (va -ji′ na) (L. *vagina,* sheath), in female mammals a tube leading from the uterus to the exterior.

Variation (var i -a′ shun) (L. *variare,* change), differences shown by individuals of the same species, etc.

Vas deferens (plural, vasa deferentia) (vaz; def′ er ens) (L. *vasa,* vessel; *de,* down; *fero,* to bear), tube to carry sperm to the exterior.

Vasa efferentia (vaza: ef er -en′ sha) (L. *vasa,* vessel; *ex,* out; *ferro,* to bear), tubes carrying sperm from testes to the vasa deferentia.

Vascular (vas′ ku lar) (L. *vasculum,* little vessel), pertaining to vessels, usually blood vessels.

Vascular bundle, structure composed of vessels (xylem and phloem) for conducting liquids in higher plants.

Vasomotor nerves (vas o -mot′ er) (L. *vasa,* vessel; *movere,* to move), nerves controlling the caliber of the arteries by the contraction and expansion of muscles in their walls.

Vegetal pole (veg′ e tal) (L. *vegetare,* enliven), pole of a cell where the rate of metabolism is lower than that at the animal pole.

Vegetative reproduction, asexual reproduction by such methods as grafting, cuttings, fragmentation, etc.

Vein (L. *vena,* vein), vessel carrying blood toward the heart; vascular bundle of a leaf.

Ventral (ven′ tral) (L. *venter,* belly), lower or belly side.

Ventricle (ven′ tri kal) (L. *ventriculus,* little belly), lower heavier chamber of the heart from which blood is pumped out.

Vermiform appendix (ver′ mi form) (L. *vermis,* worm; *forma,* form), slender appendage of the large intestine where it joins the small intestine.

Vertebrate (vur′ te brate) (L. *vertebratus,* backbone), animal having a vertebral column.

Vestigial (ves -tij′ i al) (L. *vestigium,* trace), rudimentary part of an organism no longer functionally useful.

Villus (plural villi) (vil′ us) (L. *villus,* hair), minute projection of small intestine to increase absorption.

Virus (vi′ rus) (L. *virus,* poison), living ultramicroscopic, virulent cause of certain plant or animal diseases.

Viscera (vis′ er a) (L. *viscera,* internal organs), organs within a body cavity.

Viscosity (vis -cos′ i ti) (L. *viscosus,* viscous), tendency of certain liquids not to flow easily due to internal friction (adherence of liquid particles to each other).

Vitalism (vi′ tal izm) (L. *vita,* life), the doctrine which attributes at least some of the living phenomena to an interplay of nonmaterial forces other than those prevailing in the lifeless world (contrast with Mechanistic view).

Vitamin (vi′ ta min) (L. *vita,* life; *amin,* a chemical radicle, NH_2), substance which is essential for the proper metabolism and regulation of body processes; they were named vitamins because they were thought originally to contain an amine radicle, which is incorrect.

Viviparous (vi -vip′ a rus) (L. *vivus,* alive; *parere,* to bear), development of the embryo within the mother's body and the subsequent birth of a living young organism.

Vomer (vo′ mer) (L. *vomer,* ploughshare), bony partition in the nose.

W

Warm-blooded, animals whose blood retains a rather constant temperature regardless of external temperatures, as birds and mammals (contrast with Cold-blooded).

White blood corpuscle, colorless blood cell: also called leucocyte.

Wolffian duct (after German anatomist, Wolff), the forerunner of the male vas deferens in vertebrates.

Working hypothesis (hi -poth′ e sis) (Gr. *hypo,* under; *tithemi,* place or consideration), a basic assumption to guide the study of a problem or subject and to be proved or disproved by the data accumulated.

X

Xanthophyll (zan′ tho fil) (Gr. *xanthos,* yellow; *phyllon,* leaf), yellow-orange pigment of certain higher plants, especially leaves.

X chromosome, a chromosome associated with sex of many organisms.

Xerophyte (ze′ ro fite) (Gr. *zeros,* dry; *phyton,* plant), plant adapted to dry conditions.

Xylem (zi′ lem) (Gr. *xylem,* wood), woody, water-conducting portion of a fibrovascular bundle.

Y

Y chromosome, a special chromosome associated with the sex of the organism. In human beings this chromosome is present only in males.

Yeast (A.S. *gist,* ferment), unicellular, chlorophyll-less plants capable of fermentation; some are pathogenic.

Yolk (yok) (*yolke,* yellow), stored food in the egg cytoplasm.

Z

Zone of tissue differentiation, the point in young plant roots and stems where adult tissues are being formed.

Zoogeography (zo o je -og′ ra fi) (Gr. *zoon,* animal; *ge,* earth; *graphein,* to write), geographic distribution of animals in space.

Zoology (zo -ol′ o ji) (Gr. *zoon,* animal; *logos,* study), study of animals.

Zoosporangia (zo o spor -an′ ji a) (Gr. *zoon,* animal; *sporos,* spore; *anggeion,* vessel), a structure in which motile zoospores develop.

Zoospore (zo′ o spor), motile spore.

Zygospore (zy′ go spor) (Gr. *zygotos,* united), spore formed by the union of two gametes (male and female sex cells).

Zygote (zy′ got) (Gr. *zygotos,* united), fertilized egg cell after fusion with male gamete.

Zymase (zy′ mas) (Gr. *zym,* leaven; *ase,* enzyme or ferment), enzyme (in presence of oxygen) which converts glucose and other carbohydrates into carbon dioxide and water or (in absence of oxygen) into alcohol and carbon dioxide or into lactic acid.

Zymogen (zy′ mo jen) (Gr. *zym,* ferment; *gen,* to form), forerunner of an enzyme (pre-enzyme); a substance which is produced and later becomes an enzyme when it is activated by another substance (probably another enzyme).

Zymosis (zy -mo′ sis), any form of fermentation, especially morbific (L. *morbus,* disease; *facto,* to make).

III. NEW AND OLD SYSTEMS OF CLASSIFYING PLANTS CONTRASTED*

NEW	OLD
Kingdom Plantae	Kingdom Plantae
I. Subkingdom Thallophyta (plants not forming embryos)	1. Phylum Thallophyta
	A. Subphylum Algae (simple plants with chlorophyll)
1. Phylum Cyanophyta (blue-green algae)	(1) Class Myxophxyceae (Cyanophyceae) (blue-green algae)
2. Phylum Chlorophyta (green algae)	(2) Class Chlorophyceae (green algae)
3. Phylum Chrysophyta (yellow-green, golden-brown algae and diatoms)	(3) Class Bacillariophyceae (Diatomaceae) (diatoms)
4. Phylum Phaeophyta (brown algae)	(4) Class Phaeophyceae (brown algae)
5. Phylum Rhodophyta (red algae)	(5) Class Rhodophyceae (red algae)
	B. Subphylum Fungi (simple plants without chlorophyll)
6. Phylum Schizomycophyta (bacteria)	(1) Class Schizomycetes (bacteria)
7. Phylum Myxomycophyta (slime molds)	(2) Class Myxomycetes (slime molds)
8. Phylum Eumycophyta (true, higher fungi)	
(1) Class Phycomycetes (algalike fungi)	(3) Class Phycomycetes (algalike fungi)
(2) Class Ascomycetes (ascus [sac] fungi)	(4) Class Ascomycetes (ascus [sac] fungi)
(3) Class Basidiomycetes (basidium [club] fungi)	(5) Class Basidiomycetes (basidium [club] fungi)
II. Subkingdom Embryophyta (plants forming embryos)	
9. Phylum Bryophyta (Atracheata) (plants without vascular [conducting] tissues)	2. Phylum Bryophyta (liverworts and mosses)
(1) Class Musci (mosses)	(1) Class Musci (mosses)
(2) Class Hepaticae (liverworts)	(2) Class Hepaticae (liverworts)
10. Phylum Tracheophyta (Tracheata) (plants with vascular tissues)	3. Phylum Pteridophyta (club "mosses," horsetails, ferns)
A. Subphylum Lycopsida	
(1) Class Lycopodineae (club "mosses")	(1) Class Lycopodineae (club "mosses")
B. Subphylum Sphenopsida	
(1) Class Equisetineae (horsetails)	(2) Class Equisetineae (horsetails)

(*Continued on next page*)

*The newer classification is based more or less on the natural relationships of plants. The complete classification is not given here but only those parts which deal with plants being studied. When contrasted with the older, traditional method, both methods may be helpful in reading additional references. More detailed discussions of the newer method are given elsewhere in the book.

NEW	OLD
C. Subphylum Pteropsida	
(1) Class Filicineae (ferns)	(3) Class Filicineae (ferns)
	4. Phylum Spermatophyta (flowering plants)
(2) Class Gymnospermae (plants with exposed, naked seeds) (conifers and their allies)	(1) Class Gymnospermae (plants with naked, exposed seeds (conifers and their allies)
(3) Class Angiospermae (plants with seeds enclosed by carpels) (flowering plants)	(2) Class Angiospermae (plants with seeds enclosed by carpels) (flowering plants)
(a) Subclass Dicotyledoneae (two embryonic seed leaves) (beans, sunflowers, etc.)	(a) Subclass Dicotyledoneae (two embryonic seed leaves) (beans, sunflowers, etc.)
(b) Subclass Monocotyledoneae (one embryonic seed leaf) (corn, grasses, etc.)	(b) Subclass Monocotyledoneae (one embryonic seed leaf) (corn, grasses, etc.)

INDEX

A

Abbé, 31
Abdomen, 318, 319, 329, 340, 393, 394*
Aberration, 679, 680
Abiogenesis, 732
Absorption, 82, 226, 227, 353, 430
Acclimation, 813
Accretion, 95, 101
Acetabulum, 423,* 425
Acetylcholine, 503
Achilles tendon, 426*
Achromatic figure, 64
Aciculum, 307*
Acid, 84, 87, 88, 169, 232, 429, 476
Acontia, 291*
Acoustic, 495
Acquired characteristics, 712, 722, 746, 747
ACTH (pituitary hormone), 510
Actinomycosis, 659
Actinopoda, 274
Adaptation, 96, 101, 721-731, 723*-728*
Adaptive radiation, 729
Adductor muscle, 312,* 313,* 426*
Adipose (*see* Tissues)
Adrenal gland, 507,* 508, 511
Adrenalin, 511 (*see also* Endocrine glands)
Aeciospore, 129, 167, 182, 182*
Aedes (*see* Mosquito)
Aerobe, 122, 170
Aestivation, 594
African fever, 660
Agaricus (Psalliota) (*see* Mushroom)
Agassiz, 803
Agglutination, 519, 524
Agranulocyte, 484-486
Agriculture, 775, 776
Air bladder, 331, 332*
  cavity, 141,* 147,* 188, 211, 215, 224, 226, 411
  sac, 396,* 397, 403,* 405, 490,* 492
  sinus, 469*
Albumin, 89, 311, 312*
Alcohol, 252
Aleurone, 210
Algae, 109-119, 150-166, 249, 250
  blue-green, 109, 110, 113,* 151-155, 249
  brown, 109, 110, 116, 118,* 153, 154, 160-162, 249
  desmids, 115,* 116, 153-159
  diatoms, 116, 117,* 153, 154, 159, 160, 249
  economic importance, 249, 250
  green, 109, 110, 114-116, 115,* 153-159
  red, 109, 110, 118, 119,* 153, 154, 162-165, 163*
  yellow-green, 109, 110, 116, 117,* 153, 154, 159, 160
Algalike fungi (Phycomycetes, 109 (*see also* Mold)
Allantois, 451,* 453
Allele (Allelomorph), 525, 682, 694*
Alligator, 338*
Allium (onion) (*see* Mitosis)
Alternation of generations (*see* Metagenesis)
Alveolar, 74, 75,* 464*
Alveoli, 434, 490,* 492
Amboceptor, 520
Ambulacral, 300,* 301,* 302,* 303, 304,* 305*
Ambystoma (*see* Salamander)
Amino, 88, 429, 476
Ammonia, 651
Amnion, 451,* 452, 453, 455*
Amoeba, 274, 275,* 344-349, 345*-348*
Amoebic dysentery, 533,* 784
Amoebocyte, 283*
Amphiaster (achromatic figure), 64
Amphibia, 331, 333*-335,* 421-441, 653 (*see also* Frog)
Amphineura, 309, 309*
Amphioxus, 328,* 329
Amphoteric, 89
Ampulla, 301,* 302,* 304
Amylopsin, 429, 476
Anabena, 113,* 154, 155
Anabolism, 93, 101

*Asterisk following reference indicates page with illustration. Also refer to Glossary in the Appendix for definitions, principles, theories, and additional references.

Anaerobe, 122, 170
Analogy, 576, 578
Anaphase (mitosis), 62, 63,* 65, 66,* 67
Anaphylaxis, 520, 773
Anatomy, 24
  and physiology of higher animals, 458-529
    of plants, 219-248
Anaximander, 732, 800
Ancylostoma, 295, 661
Andalusian fowl, 691*
Anemia, 484, 525
Angiospermae, 110-112, 143-148, 206-218
Anguillula (*see* Vinegar eel)
Animal, cellular organization, 46-55
  classified, 272-343
  economic importance, 530-575
  kingdom, 272-343
  number of species, 273
  of past and records, 605-619
  pole, 445,* 452
  wildlife, 797
Animals and plants contrasted, 104-107
Animate organization, 99-103
Anion, 83
Annelida, 304-309, 307*-309*, 384-392, 540, 541, 788
Annual ring, 214, 221, 222
Annulus, 139,* 196, 198
Anodonta (*see* Clam)
Anomalies, 582
Anopheles (*see* Mosquito)
Anoplura (lice) (*see* Insects)
Ant, 571,* 572 (*see also* Insects)
  lion (*see* Insects)
Antenna, 318, 319, 321*-324,* 394,* 398, 403 * 405, 410,* 411,* 414-418
Antennule, 320,* 321*
Anther, 144,* 146,* 208, 210, 212, 217, 223,* 225, 225*
Antheridiophore, 189
Antheridium, 119, 129, 131,* 132*-134,* 136, 137,* 138, 138,* 154, 161, 162, 163,* 164, 165, 174,* 175, 186-189, 191-197, 202
Antherozoid, 132,* 136,* 197, 204
Anthocyanin (*see* Pigments)
Anthozoa, 290, 291,* 292*
Antiaggressin, 520
Antibiotic, 175, 250
Antibody, 519, 772
Antigen, 519
Antimere, 286, 299
Antipodal cell, 206, 207
Antitoxin, 519, 773
Anus, 295, 296,* 298, 299, 301,* 302, 307,* 309,* 311*-315,* 321,* 327, 327,* 328,* 332,* 350,* 381, 396*
Anvil, 466, 498,* 505
Aorta, 311,* 313,* 315,* 332,* 340,* 396, 396,* 403,* 477, 478*-480,* 482, 741*
Aperture, 310*
Aphid (plant louse), 559, 561* (*see also* Insects)
Aphis lion (*see* Insects)
Apis (*see* Honeybee)
Apopyle (*see* Sponges)
Apothecium, 176
Appendages, 577*
Appendicularian, 327
Applied biology, 775-791
Arachnoid, 503
Arachnoidea, 319, 326,* 544, 545*
Arbacia (*see* Sea urchin)
Archaeopteryx, 736, 737*
Archegoniophore, 189
Archegonium, 129, 131*-134,* 136, 136,* 137,* 138, 138,* 140,* 186-189, 191-197, 202-204, 206
Archenteron, 447
Archeozoic era, 614, 617
Archinellida, 306
Aristotle, 732, 801
Aristotle's lantern, 303*
Arm, 301,* 302-304, 307,* 315*
Artery, 430,* 432, 470,* 477-489, 740,* 741*
Arthropoda, 314-325, 393-408, 543-572
Ascaris (roundworm), 295, 298, 379-382, 380,* 538, 660, 785, 788
Ascaroidea, 295
Ascidian, 327, 328*
Ascocarp, 177
Ascomycetes, 109, 125, 167, 175-177 (*see also* Yeast; Aspergillus, Penicillium; etc.)
Ascospore, 125*-127,* 167, 176, 177
Ascus, 125,* 126
Asexual reproduction (*see* various organisms)
Aspergillus, 126,* 127, 129, 175, 176, 250, 251*
Assimilation, 94, 345, 353
Association (animal and plant), 646, 652
Aster (*see* Mitosis)
Asterias (starfish), 301, 301*
Asteroidea, 301
Astral ray (aster), 63,* 64, 64,* 65
Asymmetry (*see* Symmetry)
Athlete's foot, 659

Atlas, 423, 423*
Atom, 77, 78, 79,* 80, 81,* 82, 83, 83,* 750
Atomic energy (*see* Atom)
number, 78, 79*
theory (*see* Atom)
Atracheata, 109
Atrium, 328,* 477, 478*-481,* 490,* 741* (*see also* Auricle)
Atrophy, 817
Attachment fiber, 65
Auditory, 394,* 398, 405, 424, 495, 505
Aurelia, 290, 290*
Auricle, 311*-313,* 331-340, 332,* 340,* 370,* 371,* 372, 401,* 403, 430, 430,* 470,* 740*
Australian region, 598
Autocatalysis, 92, 94, 680
Autogamy, 817
Autolysis, 817
Autosome, 675,* 698
Autosynthesis, 92, 93, 101
Autotomy, 299, 304, 443, 576, 578
Autotrophic, 168, 669
Autumnal coloration (*see* Pigments)
Auxin A and B, 240, 583, 768
Auxospore, 154, 160
Aves (*see* Birds)
Avoiding reaction, 352,* 355, 359
Axial, filament, 359
gradient, 372, 373, 537
skeleton, 423
Axiate organization, 373, 537
Axis, 372, 373, 537
Axon 47, 54, 54,* 501
brush, 54*
Azotobacter, 651

B

Babesia, 534, 534,* 786
Back cross, 818
Bacon, Francis, 801
Bacteria, 109, 120-122, 121,* 167-172, 250-256, 650, 659
and nitrogen fixation, 650,* 651, 664
pathogenic, 120, 122, 168, 171, 255, 659, 660
Bacteriolysin, 520
Baer, Karl von, 803
Baeyer, 231
Balance in Nature, 653,* 655
Balanoglossus, 326,* 327
Balantidium, 530, 532*
Baldness, 703
Band, dark and light, 52*
Barb, 406
Bark (*see* Tissues, plant)
lice (*see* Insects)
Barnacle, 318, 323,* 544
Barrier, 595, 629
Basal granule (*see* Paramecium)
metabolism, 93
Basement membrane, 393
Basidiomycete, 109, 128,* 129, 167, 177-183 (*see also* Mushroom, etc.)
Basidiospore, 128,* 129, 167, 178,* 179-181, 182*
Basidium, 128,* 129, 167, 178,* 179-181, 182*
Basket star, 303
Bast fiber, 214
Bat, 340
Bausch, 31
Bean, garden or kidney, 143, 144,* 211-213
Beche-de-mer (trepang), 540
Bedbug, 558* (*see also* Insects)
Bee, 319, 398-408
glue, 405
Beetles, 319, 563-565, 563,* 564* (*see also* Insects)
Behavior (*see* specific organisms and nervous equipments)
Benthon, 112, 151
Beriberi, 474, 770*
Beroë, 291, 292,* 293
Beverages from plants, 264-266
Bile, 427,* 428, 429
Bilirubin, 493
Bills of birds, 728*
Binomial nomenclature, 819
Biochemical phenomena, 750-774
Bioelectric phenomena, 764 (*see also* Electricity)
Biogenesis, 733, 735
Biogenetic, 442, 742
Biogeography, 24, 591, 736, 745
Biologists and their work, 800-806
Biology, 17
applied, 775-791
defined, 17
history of, 800-806
how to study, 19
of higher plants, 219-248
of man, 458-529
subdivisions of, 24, 25
Bioluminescence 762
Bionomics, 620
Biophysical phenomena, 750-774
Biotic, 658
Birds, 339, 339,* 340, 340,* 574, 728*
Bivium, 302*
Black tongue, 772
Blackhead, 788
Bladder, 377
air, 331, 332*

Bladder—Cont'd
  float, 289*
  gall, 427,* 428, 429, 470,* 471*
  swim, 331, 332*
  urinary, 298, 299,* 427,* 435, 439,* 440, 492, 493,* 494, 514
Bladderworm, 379
Bladderwort, 636
Blade, 210, 223, 224
Blastocoele, 445,* 446, 452
Blastocyst (blastodermic vesicle), 451,* 452
Blastomere, 452
Blastomyces, 252
Blastopore, 445,* 446
Blastostyle, 285*
Blastula, 285,* 445,* 446, 451,* 710,* 711
Blight, 129, 177
Blood, 50,* 51, 396
  clotting of, 486-487
  corpuscles, red, 50,* 51, 484, 485
    white, 50,* 51, 484-486
  groups, 489, 524-526
  "islands," 455
  plasma, 51, 396, 405, 486
  platelets, 51, 485, 486
  vessels, 741*
Blue-green algae (*see* Algae)
Blue mold (*see* Mold; Penicillium; etc.)
Body cavity (*see* Coelom)
Bog moss, 133, 134*
Bonannus, 29
Bone, 49, 50,* 51,* 462,* 465-467, 495
  tissues (*see* Tissues, animal)
Book lice (*see* Insects)
  lung, 319, 325*
Botany, 24, 249-271
Bouton, 402*
Bowman's capsule, 435, 493,* 494
Bracket fungus, 129, 179
  method, 688*
Bract, 216
Brain and cranial nerves, 54, 299, 311,* 321,* 332,* 333, 340, 370,* 371, 376, 385,* 391, 396,* 405
Brains of vertebrates, 435-438, 436,* 437,* 495,* 502-506, 743*
Branchia, 302,* 328,* 331
Branchiostoma, 329
Bread mold (Rhizopus) (*see* Mold, black bread)
  yeast (*see* Mold, yeast)
Breast bone (*see* Sternum)
Breathing, 489
Bridges of protoplasm, 357 (*see also* Plasmodesma)
Brittle star, 300,* 303
Bronchi (bronchus), 490,* 492
Brown algae (*see* Algae)
Brown, Robert, 31, 803
Brownian movement, 77, 100
Bryophyta, 109, 130-133, 131*-134,* 185-190, 256
Buccal mass, 312*
  pouch, 384, 388*
Buds and budding, 125,* 127, 133,* 145,* 167, 176, 286,* 290, 377
Bugs (true) (Hemiptera) (*see* Insects)
Bulbus arteriosus, 741*
Burbank, Luther, 804
Burroughs, John, 804
Bursa, 296*
Bursaria, 530, 531*
Busch, 35
Buttercup (Ranunculus), 223,* 224
Butterfly, 319, 410,* 413* (*see also* insects)
Butterwort, 668*
Button of mushroom, 128*

C

Caconema, 539, 661
Caddice fly (*see* Insects)
Caeca (cecum), 301,* 302,* 332,* 340,* 471*
  gastric, 394, 396*
  hepatic, 301*
  pyloric, 302*
  rectal, 403*
Calcarea, 281, 281,* 282*
Calcareous, 280, 281, 299, 303-314
Calcium carbonate, 280, 281, 299, 386
Callus, 580
Calorie, 87, 235, 757
Calyptra, 187
Calyx, 144,* 145,* 208, 212, 224
Cambarus (*see* Crayfish)
Cambium, 59, 141,* 143, 145,* 207, 214, 221, 222, 223*
Camera lucida, 30, 31
Canal, 350,* 354
  auditory, 498,* 505
  Bidder's, 440, 440*
  circular, 302*
  circumoral, 302*
  connecting, 282,* 301,* 302*
  excurrent, 282,* 284*
  incurrent, 282,* 284*
  lateral, 302*
  radial, 282,* 284,* 288,* 301,* 302*
  ring, 288,* 302,* 306*
  semicircular, 498,* 505
  stone, 302*

Canaliculi, 49, 50,* 51*
Cancer, 583
Cane sugar (sucrose), 87, 92
Capillary, 389, 431, 483, 492
Capillitium, 123,* 172
Capsule, 139*, 187-190, 196, 198
Carapace, 322*
Carbohydrate, 85-87, 228-248
Carbon, 79*
assimilation, 229
cycle, 650,* 651
dioxide, 150, 228-237, 390, 489-493, 632
fixation, 229
Carbonization, 605, 611
Carcinoma, 583
Cardiac cycle, 478, 479
muscle (*see* Tissues, animal)
stomach, 426, 427*
Carnivora, 105
Carotene (carotin), 116 (*see also* Pigments)
Carpel, 140,* 143, 206, 208, 223,* 225, 225*
Carpellate, 140,* 203, 204
Carpogonium, 154, 163,* 164, 165
Carpospore, 119, 154, 163,* 164, 165
Cartilage (*see* Tissues, animal)
Catabolism, 93, 101
Cataclysmic, 821
Catalyst, 91, 94, 101, 680
Cation, 83
Cell, 37-45, 40,* 42,* 100, 104, 646
antheridial, 202
bast, 145,* 214
companion, 56, 57,* 60, 147,* 192, 209-214, 224
division (*see* Mitosis)
guard, 56, 57,* 58,* 145,* 210, 211, 215, 224, 226
membrane, 40,* 63,* 65, 66*
plate, 60, 65, 67
pole, 66,* 67, 646
principle, 37-45
prothalial, 194, 202, 204
sap, 39, 40,* 43
sheath, 147,* 151, 157
tube, 202, 204
wall, 39, 40,* 59, 66,* 67, 104
wood, 59, 207, 214
Cellulose, 56, 59, 87, 104, 115, 155, 169, 170, 261, 327, 360
Cenozoic era, 614, 616
Centipede, 318, 324,* 543, 544
Central nervous system, 502
Centriole, 40,* 62
Centromere, 678
Centrosome, 41, 62, 63,* 70
Centrosphere, 40,* 41, 62, 63*
Cephalin, 486, 487
Cephalochordata, 328,* 329
Cephalodiscus, 327
Cephalopoda, 311, 315,* 316*
Cephalothorax, 318, 319
Cercaria, 375,* 377, 787*
Cerci, 414
Cerebellum, 54, 340,* 495,* 496,* 502, 503*
Cerebrum, 54, 308,* 312,* 313,* 314, 325,* 371, 371,* 388,* 502, 503
Cestoda (*see* Tapeworm)
Chaetopoda, 307,* 308
Chalone, 822
Chameleon, 338,* 340
Checkerboard, 686-690
Chelicera, 325*
Cheliped, 320,* 321*
Chemosynthesis, 168
Chemotropism (chemotaxis), 243, 352*
Chevalier, 31
Chiasma, 496*
"Chigger" (harvest mite), 545,* 786
Chilopoda, 318, 324,* 544
Chinch bug, 558* (*see also* Insects)
Chinese fluke, 785*
Chitin, 314-325, 393, 394, 400
Chiton, 309,* 542
Chlamydomonas, 116
Chlamydospore, 129, 167, 180, 180*
Chlorenchyma (*see* Tissues, plant)
Chlorogogen, 386, 387,* 390
Chlorophyll, 105, 112, 114, 116, 118, 130, 150-166, 185-190, 191-198, 200-218, 224-245, 360
Chlorophyllogen, 822
Chlorophyta, 109, 114, 115,* 153, 156*
Chloroplast (chloroplastid), 40,* 43, 56, 57,* 113,* 115, 115,* 130, 134,* 147,* 153, 155, 156, 156,* 159, 187, 188, 210-215, 228, 229, 230,* 236, 359, 360, 362
Choanocyte, 283,* 284*
Cholecystokinin, 512
Cholinesterase, 502
Chondriosome, 40,* 41
Chondrus (Irish "moss"), 119, 119,* 249
Chordata, 325-343, 572-574
Chorion, 451,* 453, 455,* 823
Choroid, 497,* 505, 823
Chromatic (*see* Mitosis)
Chromatid, 66,* 67, 679
Chromatin, 40,* 44, 62, 63,* 64, 65, 66,* 70, 151, 152, 154, 344
knot (karyosome), 40*
strands, 66, 66,* 67, 678

Chromatophore, 274, 276,* 358,* 359, 532,* 730, 758
Chromomere, 679
Chromonemata, 44, 679
Chromoplast, 43, 161
Chromosomes, 44, 63,* 64, 65, 66,* 67, 673-683, 675*-677,* 696,* 698, 710*
  aberration, 679, 680
  map, 696,* 698
  number in animals and plants, 674
Chrysalis, 413*
Chrysophyta, 109, 116, 117,* 153, 249
Cicada, 319, 561* (*see also* Insects)
Cilia, 277, 278,* 279,* 304, 349-357, 350,* 368, 369,* 370
Ciliary body, 497*
Ciliata, 277, 278,* 297, 299
Cinclide, 291*
Circulation, 477-489 (*see also* specific organisms)
Cirri, 307,* 328*
Clam, 311, 312,* 313*
  worm (sandworm) (Nereis), 307,* 308, 541
Classification of animals, 272-343
  of insects, 409-420
  of plants, 108-148, 865, 866
Claw, 394, 401,* 402
Cleavage, 444, 451,* 452
Clefts, 325-343, 328*
Cleistothecia, 177
Clinorchis, 661, 785*
Clitellum, 384, 389,* 391
Cloaca, 299,* 306,* 340,* 427,* 428, 440*
Clostridium, 121,* 651
Clothes and biology, 776
  moth, 567* (*see also* Insects)
Club moss, 110, 134, 135,* 191-194, 256
Cnidoblast, 287*
Coat, seed, 208, 210
Coccidia, 534
Cochlea, 495, 498,* 505
Cockroach (*see* Insects)
Cocoon, 373, 391, 392, 407
Coelenterata, 285,* 286-290, 536
Coelom (body cavity), 299, 302, 302,* 306-309, 314, 325-343, 327,* 384, 387,* 388, 390, 435, 449*
  extraembryonic, 451,* 453
Coenurus, 538,* 788
Cohesion, 824
Colchicine, 677
Cold-blooded animal, 331-333
Coleoptera (beetles), 563-565, 563,* 564* (*see also* Insects)
Coleoptile, 211
Coleorhiza, 211
Collar, 283,* 327, 327*
Collaterals, 54
Collembola (*see* Insects, orders of)
Collenchyma (*see* Tissues, plant)
Collies, heredity, 707*
Colloid, 74, 75, 75,* 78
Colon, 470,* 471,* 475, 477
Colony, 152, 154, 155, 159, 169, 171, 274, 298, 360, 363, 399
Coloration, 421, 423, 758, 760 (*see also* Pigments)
Colorblindness, 702*
Colors (dyes) from plants, 263
Columella, 124*
Comb, 400,* 401,* 402
Combinations in heredity, 722
Comb-jelly, 292, 292*
Commensalism 634, 658, 664
Commissure, 391
Communal, 646, 652, 658
Companion cell (*see* Cell)
Comparative anatomy, 736, 742
  embryology, 736, 740
  physiology, 736, 745
Complement, 520
Complementary gene, 693
Composite flower, 145,* 213
Compound, 84
Conceptacle, 162
Conduction, 227, 494, 500-502, 754 (*see also* circulation in specific organisms)
  of nerve impulses, 498-502, 498*
Condyle, 333, 340, 424
Cone, 135, 135,* 136, 138, 193-195, 200-205
Conidiospore, 122, 126,* 127, 129, 167, 172, 175, 177, 180
Conifer (Coniferales), 110, 138, 200-203, 257
Conjugation, 124,* 125, 157, 158,* 159, 173, 277,* 355, 355,* 356*
Conjunctiva, 497*
Connecting strands of protoplasm, 41, 42,* 357
Connective tissues (*see* Tissues)
Conservation and biology, 18, 792-799
  of energy, 751
  of fishes, 797
  of forests, 793, 793*
  of human resources, 797, 798
  of minerals, 794
  of soils, 794
  of water, 795
  of wild life, 796

Continuity of germ plasm, 523, 747
of organisms, 732-749
physiologic, 363
Continuous variation, 723
Contractility, 47, 498
Control group, 22
Conus arteriosus, 332,* 430, 430*
Convolution, 503
Coordination, 494-513
Copepod, 317,* 543
Copulation, 372, 389,* 391, 392, 406
Coral, 249, 290, 292,* 536
Cord, spinal (*see* Nervous system)
Corium, 459, 460*
Cork, 141,* 261 (*see also* Tissues, plant)
Corn, borer, 568*
hybrid, 704*
Indian (maize), 146,* 209-211
Cornea, 397, 497,* 505
Corolla, 145,* 224
Corpus luteum, 509, 512, 516
Corpuscles (*see* Tissues, blood)
Correlation, 239 (*see also* specific organisms)
Corrodentia (*see* Insects)
Cortex, 141,* 145,* 214, 216, 220, 223,* 354,* 503
Cortin, 511
Cotyledon, 110, 140,* 144,* 148, 194, 202, 204, 207-213
Coxa, 394, 400, 401*
Crab, 318, 319, 323,* 544, 547
horseshoe (king), 319, 325*
Crane fly (*see* Insects)
Craniata, 329
Cranium, 329-343, 423, 462*
Crayfish, 318, 320,*-322,* 543
appendages, 577*
Cretin, 508,* 511
Cricket (*see* Insects)
Crinoidea, 304, 307*
Cristispira (in mollusca), 535
Crocodile, 340
Cro-Magnon man, 589
Crop, 308,* 312,* 385,* 386, 394, 396* 404
Cross, heredity, 686, 695, 696,* 698
sex-influenced, 703
sex-linked, 699-702, 700*-702*
Crossing over of genes, 695, 697
Crustacea, 317,* 318-324, 543
Crystalloid, 75
Ctenophora, 291-293, 292,* 537
Cuff, 30
Culex (mosquito), 411,* 569*
Cup fungus, 127,* 129
Cuticle, 141,* 145,* 147,* 295, 296,* 298, 358,* 373, 379, 381, 387,* 393, 459
Cutin, 39, 56, 214, 215, 226
Cuttlefish (sepia), 311, 542
Cuvier, George, 802
Cyanophyta, 109, 113, 113,* 151-155, 249
Cycadales (sago palm), 142,* 203, 204
Cycas, 142,* 203, 204
Cycle, carbon, 650,* 651
estrous, 516
nitrogen, 649, 650*
oxygen, 650,* 652
Cyclops, 317,* 318
Cyclosis, 346, 353, 359, 360, 366
Cyclostomata (*see* Lamprey)
Cyst, 296,* 297, 358,* 360, 377, 377,* 379, 787
Cysticercus, 379
Cytogene (*see* Plasma gene)
Cytogenetic, 673
Cytology, 24
Cytolymph (*see* Cell sap)
Cytopharynx, 278,* 351, 358
Cytoplasm, 39, 40,* 47, 54, 62, 63,* 66,* 70, 156,* 344-367
Cytoplasmic gene, 357
granule, 40*
strand, 40,* 118, 153, 157, 162, 164
Cytosome, 39, 350, 358, 359

D

Daddy longlegs, 319, 326,* 547
Damsel fly (*see* Insects)
Daphnia, 324,* 543
Dark and light bands (striated muscle), 467, 468
field, 32, 33
Dart sac, 311,* 312*
Darwin, Charles, 803
Data, 23
Deafness, heredity, 717*
Defense of body, 518, 519
Demospongia, 281
Dendrite, 47, 54, 54,* 501
Denitrification, 649, 650*
"De novo," 826
Dentalium, 314, 316*
Dentine, 464*
Dermis, 421, 422,* 459, 460*
Descent with change (evolution), 24, 94, 732-749
Desmid, 115,* 116, 154, 159
Determinate variation, 724
Development, 101, 732-749 (*see also* Embryology)
Devilfish (octopus), 316,* 542
Diabetes, heredity, 716*
Dialysis, 827
Diaphragm, 340, 470*
Diarrhea, 784

Diastase, 476
Diastole, 478
Diatom, 116, 117,* 154, 159, 160, 249
Diatomaceous earth, 160, 250
Dicotyledoneae, 110, 143-148, 207, 211, 213
Diecious, 164, 186, 189, 200, 202, 203, 295, 382
Differentiation, 46, 94, 95, 241, 242, 683
Diffraction, 759
Diffusion, 39, 80, 100, 730, 754
Digestion, 344, 352, 369, 388, 472-477 (*see also* specific organisms)
Digit, 333, 425
Dihybrid cross, 686-690, 686,* 689*
Dimorphism, 381
Dinosaur, 608*
Dioscorides, 801
Diphyllobothrium, 537
Diploid, 162, 206, 207, 357, 679, 680, 709
Diploplastic, 280, 286
Diplopoda, 318, 324,* 544
Disaccharide, 87
Discontinuous variation (mutation), 724
Diseases caused by animals, 660, 661, 784-789
by fungi, 252-254, 253,* 659, 660
by plants, 659, 789
by viruses, 789-790
human, 516-522, 659, 784-786
Disk, 189, 216, 286,* 291,* 297, 302, 303, 699
Dispersal, 76, 78, 593, 655, 656
Distomum (*see* Liver fluke)
Distribution, 591-604, 593*
Divergence, 729, 827
Diverticulum, 308,* 328,* 369, 371*
Division of labor, 828
Dizygotic, 828
Dobson fly, 562* (*see also* Insects)
Domestication, 638
Dominance, 682-692
Dominant and recessive traits, 682-692
Dorsal horn, 55*
Dourine in horses, 786
Dragonfly (*see* Insects)
Drone, 399, 399*
Drosophila (*see* Fruitfly)
Drugs, 269
Duct of Cuvier, 741*
of Wirsung, 477
Ductless glands (endocrine), 495,* 506-513, 507*
Dugesia (*see* Planaria)
Dujardin, 31, 37
Duodenum, 340,* 426, 427,* 429, 470,* 473, 509, 512
Dura mater, 503
Dyes, 263
Dynamic, 100
Dysentery, 784

E

Ear, 146,* 439, 495, 498,* 505
Early man and records, 585-590, 587*
Earthworm, 309, 384-392, 385,* 540
Earwig, 562* (*see also* Insects)
Eberthella typhosa, 121,* 255
Ecdysis, 393, 398
Echinococcus, 537, 788
Echinodermata, 299-304, 300,* 540
regeneration of, 98, 98*
Echinoidea, 303, 303,* 305*
Ecology, 24, 620-645, 723
Economic botany, 249-271
beverages, 264-266
coloring (dyes), 263
cork, 261
fibers, 260
flavoring substances, 266
foods, 264
fuels, 258, 259
gums and resins, 262, 268
medicines and poisons, 267-270
oils, 259, 267
savory substances, 267
zoology, 530-575
insects (*see* Insects)
Ectoderm, 280, 286, 286,* 287, 288,* 291,* 292, 293, 295, 299, 306, 309, 314, 325, 368, 373, 445,* 449,* 454
Ectoparasite, 653
Ectoplasm (ectosarc), 39, 40,* 345,* 349
Efferent nerve, 494, 497
vessel, 322*
Egg (ovum), 134,* 136, 136,* 140,* 143, 154, 161, 162, 163,* 164, 174,* 175, 188, 189, 194-197, 201-203, 361,* 363, 396,* 398, 406, 410
sac, 225,* 317,* 389,* 391*
Ejaculatory duct, 380,* 382, 398, 406, 513
Elasmobranchii, 329, 331
Elater, 136, 137,* 189, 195
Electricity, 77, 353,* 647, 746-766
Electrocardiogram, 479
Electrolyte, 84, 751
Electron, 79,* 81, 81,* 83*
microscope, 32, 34,* 35
Elements, 78, 79,* 80, 85
Elephantiasis, 297, 297,* 298, 539, 661, 785
Elodea, 40*

Elytra, 829 (*see also* Beetles)
Embolus, 487
Embryo, 129, 130, 134, 137,* 138, 143, 147,* 185-198, 200-205, 206-218, 296,* 382, 442-457
Embryology, 24 (*see also* specific organisms)
of animals, 442-457
of frog, 444-450, 445*-457*
of man, 450-456
of vertebrates, 442-457
of whitefish, 64*
Embryonic disk (embryonic shield), 451,* 453
seed leaf, 207
Embryophyta, 109-112, 129-149, 185-198, 200-205, 206-218
Empedocles, 801
Emulsoid, 78
Enamel, 464*
End organ, 495
Endamoeba, 274, 532, 533,* 784
Endocardium, 478
Endocrine glands, 495,* 506-513, 507,* 767-772
hormones, 506-513, 507,* 767-772
Endocyst, 277*
Endoderm (*see* Entoderm)
Endodermis, 141,* 145,* 216, 220
Endometrium, 452, 514
Endoparasite (entoparasite), 658
Endoplasm, 39, 40,* 344, 345,* 349, 354*
Endopodite, 320*
Endoskeleton, 423
Endosome, 358
Endosperm, 143, 147,* 202, 204, 206-208, 210
Endospore, 121,* 122, 167, 172
Endostyle, 328*
Energy, 79, 86, 87, 101, 105, 215, 229, 751, 756, 759
Enterobius, 539, 661
Enterokinase, 476
Enteron, 286, 287,* 445*
Enteropneusta, 327
Entoderm, 280, 286, 286,* 288,* 291,* 292, 293, 295, 299, 306, 309, 314, 325, 368, 373, 445,* 449,* 454
Entomology (*see* Insects)
Environment, 621, 625-645
Enzymes, 91, 94, 101, 122, 171, 232, 236, 344, 353, 360, 428-430, 443, 668, 766
digestive, 344, 353, 360, 388, 476
Eohippus (*see* Horse)
Ephyra, 290*
Epicotyl, 147,* 202, 204, 213
Epidermis, 141,* 145,* 147,* 368, 380,* 384, 459, 460* (*see also* Tissues, epidermal)
Epididymis, 513, 514, 514*
Epigenesis, 830
Epiglottis, 469,* 492
Epimysium, 52,* 53
Epinephrine (*see* Endocrine glands)
Epipharynx, 410
Epiphysis, 509, 512
Epiphyte, 113, 114, 151, 152, 658, 669, 670*
Epithelium, 283,* 284* (*see also* Tissues, epithelial)
Equatorial plate, 63,* 65, 66,* 70
Equilibrium, 439, 496, 505
Equisetineae (horsetail), 110, 135, 194-195
Equisetum, 110, 137, 137,* 194, 195
Eras, 613-618
Ergosterol (*see* Vitamins)
Ergot, 252
Erythrocyte (*see* Blood)
Esophagus, 296,* 299, 306,* 315,* 321,* 327,* 328,* 332,* 374,* 376, 381, 385,* 386, 394, 396,* 427,* 469,* 471,* 473
Estrin (*see* Endocrine glands)
Ethiopian region, 598
Eugenics, 526, 527, 715-718
Euglena, 274, 276,* 357-360, 358*
Eumycophyta, 109, 124-129, 124*-128,* 173-184
Eustachian, 427,* 439, 469,* 498,* 505
Evagination, 830
Evergreen, 200-204
Evolution (progressive development), 24, 94, 729, 732-749
Excretion, 106 (*see also* specific organisms)
Excretory pore, 369, 370, 376, 380,* 381
Excurrent canal (*see* Sponges)
Exopodite, 320*
Exoskeleton, 314, 393, 400 (*see also* specific organisms)
Experimental cross, 673
method, 22
Extraembryonic coelom, 831
Eye, 307,* 310,* 311,* 312,* 321,* 325,* 332,* 371, 421, 456,* 497, 497,* 505
brush, 401*
compound, 393, 394,* 403,* 406, 410,* 411,* 412*
muscle, 438
simple (ocellus), 393, 394,* 396, 397, 403*
spot (stigma), 156, 293, 301,* 308, 359, 370-372, 370*

F

Facet, 397
Factor (*see* Gene)
"Factor B," 232
Facultative, 831
Fallopian, 452, 514, 515*
Family chart (family tree), 715 (*see also* Heredity)
Fasciola hepatica, 373-377, 537, 660, 661, 786, 787* (*see also* Liver fluke)
Fat body, 332,* 439, 441
Fatigue, 499
Fats, 85, 87, 153, 160, 161
Fauna, 639
Feather, 340
 star, 304, 307*
Female gamete (*see* Sex cell)
Femur, 394, 394,* 400, 401,* 423,* 425, 462,* 466
Fenestra cochlea (rotunda), 505
 vestibuli (ovalis) 505
Fermentation, 671, 831
Fern, 110-112, 137, 138, 138,* 139,* 191, 195-198, 196,* 256, 257
Fertilization, 143, 201-204, 207, 355-357, 382, 710*
Fetus (*see* Embryology of man)
Fever (*see* Malaria; Texas; Typhoid; etc.)
Fibers, 65, 498,* 505
 from plants, 260
Fibrillae, 40,* 47, 53
Fibrillar (filar) theory, 74, 75*
Fibrin, 486, 487
Fibrinogen, 486, 487
Fibrous tissue (*see* Tissues)
Filament, 208, 210, 223,* 225*
Filaria, 295, 539
Filarioidea, 295
Filicineae (ferns), 110, 137, 138,* 139*
Fin, 315,* 328, 331, 331,* 332*
Fish, 330,* 331, 573
 moth, 550, 551*
Fission, 114, 122, 152, 154, 167, 171, 373 (*see also* Reproduction)
 binary, 348,* 349, 354, 355, 356,* 358*
Flagella, 114, 115, 118, 121,* 122, 123,* 124, 153, 155, 156, 156,* 157, 159, 161, 162, 171, 173, 186, 189, 274, 276,* 283,* 286,* 311,* 312,* 357-360, 358,* 361,* 362*
"Flagellated body," 365*
Flame cell, 299, 369,* 370
Flatworm, 368-374, 660, 786 (*see also* Planaria; Flukes; Tapeworm; etc.)
Flavone (flavonol) (*see* Pigments)
Flavoring materials from plants, 266
Fleas, 570,* 571 (*see also* Insects)
Flies, 568* (*see also* Insects)
Flora, 639
Floret, 145,* 213
Flower, 143-148, 145,* 146,* 206-218, 223,* 224, 225, 225*
Fluctuations, 723
Flukes, 294 (*see also* Liver flukes; Trematoda; etc.)
Flytrap, 636
Follicle, 461, 509, 515
Food, 472-477, 633
 and biology, 264, 776
 manufactured by plants, 227-239
Foot, 132,* 134,* 137,* 189, 190, 193, 194, 197, 298, 299,* 309, 309,* 310, 310,* 311, 311,* 312,* 316*
Foraminifera, 531* (*see also* Protozoa)
Forebrain, 445*
Formaldehyde, 232
Fortuitous variation, 724
Fossils, 605-619, 606*-609,* 725,* 726,* 736
Four-o'clock flower, 691*
Fragmentation, 115, 131, 154, 155, 157, 161, 162, 185, 188, 189
Frog, 333, 333,* 421-441, 422*-440,* 573
 circulation, 430-434
 coordination and sensory equipment, 435-441
 excretion, 435
 ingestion and digestion, 425-430
 integument and skeleton, 421-425
 motion and locomotion, 425
 reproduction and life cycle, 440-441
 respiration, 434-435
Frond, 137, 138,* 139,* 195, 198
Fruit, 212
 fly, 675,* 676,* 691,* 700,* 701*
Fucoxanthin (*see* Pigment)
Fucus (rockweed), 118, 118,* 154, 161, 162
Fuels from plants, 776
Fungi, 109-112, 119-129, 167-184
 economic importance, 250-256
 kinds, algalike, 109, 124,* 125, 167
  ascus (sac), 109, 125, 125,* 167, 175
  bacteria (*see* Bacteria)
  basidium, 109, 128,* 129, 167, 178-183, 178*
  bracket, 129, 179
  cup, 127,* 129, 176
  fission, 120-122, 121,* 167-172

Fungi, kinds—Cont'd
slime, 122-124, 123,* 167
yeast, 176 (*see also* Yeast)
pathogenic, 252-254, 253,* 659, 660
Funiculus, 212, 225*
Furniture and biology, 776

G

Gapes (gapeworm), 539, 540, 661
Galen, 801
Galls, 546,* 547
Galton, Francis, 803
Galvanotropism, 353*
Gametangia, 112, 130, 150, 158, 185, 191
Gamete, 124,* 130, 156, 157, 159, 160, 164, 174, 174,* 178,* 277,* 361,* 363
Gametocyte, 277,* 365,* 366
Gametophyte, 117, 130, 131*-133,* 136, 137, 137,* 143, 160, 161, 164, 185-190, 191-198, 200-205, 225
Ganglion, 54, 55,* 308,* 312,* 313,* 325,* 328,* 386,* 391, 403*
Gastric caeca, 394, 396*
gland (*see* Glands)
filament, 290*
Gastrin, 512
Gastrocoel, 284*
Gastropoda, 310
Gastrovascular cavity, 286, 287,* 288,* 289, 291,* 293, 369, 370
Gastrula, 445,* 446, 451,* 710,* 711
Gel (gelation), 76, 833
Gemma, 131,* 185, 187, 189
Gemmule, 284*
Generations, alternation of (*see* metagenesis)
Generative cell, 202, 225*
Genes (determiner, factor), 92-94, 357, 443, 622, 678-683, 693, 694
Genetics (heredity), 24, 102, 673-720, 736
Genic action, 680-683, 692-695
Genital opening, 296,* 310,* 311,* 312,* 371,* 373, 376, 378,* 380,* 382,* 396, 398
Genome, 679
Genotype, 684-690
Geographic distribution, 591-604, 736, 745
regions of world, 592,* 597-602
Geologic time table, 614-618
Geotropism, 243
Germ cell, 706-712
primordial, 708-712, 708,* 710*
layers, 445,* 451,* 454
Germ—Cont'd
plasm, 708-712, 708,* 747
tube, 181
Gesner, 801
Gestation, 453
Giardia (diarrhea), 532
Gid, 537, 538,* 661, 788
Gill, 178,* 179, 309,* 311, 313,* 315,* 322,* 328,* 331, 434, 447, 448*
arch, 331, 332,* 445, 445*
cover (operculum), 447
filament, 310
plate, 307,* 313,* 331
slits, 325-343, 326,* 328,* 329, 449,* 738*
Girdle, pectoral, 423, 424, 465, 466
pelvic, 423, 425, 465, 466
Gizzard, 385,* 386, 394
Glands (*see also* Endocrine)
adrenal, 439,* 440*
accessory, 311,* 398, 406
albumin, 311*
calciferous, 385,* 386
cement, 298, 396*
Cowper's, 513, 514, 514*
gastric, 299,* 473, 476
green, 320,* 321*
intestinal, 476
mammary, 340
mucous, 311,* 312,* 421, 422*
oil, 340,* 461
pedal, 298, 299*
poison, 325,* 404,* 406, 421, 422*
prostate, 513, 514, 514*
rectal, 403*
salivary, 312,* 394, 396,* 403,* 471,* 473, 476, 498
shell, 374,* 378*
silk, 325,*
sweat, 460,* 460, 463, 464
yolk, 371,* 373, 378*
Glass, 536
Glenoid fossa, 425
Gleocapsa, 113,* 152, 154
Glochidium of mussels, 541, 661, 788
Glomerulus, 493,* 494
Glottis, 427,* 435
Glucide, 85-87
Glucose, 86, 87, 92
Glycerine (glycerol), 87, 429, 476
Glycogen, 86, 87, 114, 152, 153, 428-430
Gnat (*see* Insects)
Goiter, 511
Golgi apparatus (body), 40*, 41, 47
Gonad (testis or ovary), 288,* 291,* 295,* 302,* 306,* 313,* 316,* 322*

Gonidia, 122, 167, 172
Gonionemus, 288,* 289
Graafian follicle, 450, 515
Grana, 229, 230*
Grantia (scypha, sponge), 279, 281, 281*-284*
Granular theory, 74, 75*
Granules, 47, 349, 353*-355*
Granulocyte, 484-486
Grasshopper, 319, 393-398, 412* (*see also* Insects)
Graves' disease (*see* Endocrine glands)
Gravity, 627
Gray, Asa, 803
Gray matter, 55,* 503, 505
Green algae (*see* Algae)
Gregarious, 658, 665
Grew, Nehemiah, 29, 802
Ground pine, 192, 257
Growth, 70, 94, 95, 101, 105
Guanin, 758
Guard cell, 56, 57,* 58,* 145*
Guinea pig heredity, 686, 686,* 687, 688
Gullet, 290, 291,* 350,* 358, 358*
Gums from plants, 262, 268
Gymnospermae, 110-112, 138, 200-205
  economic importance, 257
Gynandromorph, 834

H

Habitat, 318, 319, 594
Hair, 211, 340, 391, 459-461, 460*
Halters, 409
Hammer bone, 466, 498,* 505
Haploid, 162, 357, 679, 680, 709
Harvestman, 326,* 547
Harvey, William, 801
Haustoria, 177
Haversian canal, 49, 50,* 51*
Head, 308,* 310, 311, 318, 319, 329 393, 394*
Health and biology, 778
Heart, 314, 315,* 321,* 322,* 325,* 326,* 385,* 388, 390, 395, 396,* 403,* 405, 430, 430,* 477-481, 478*-481,* 491*
  chambers of vertebrates, 331-340, 740,* 741*
  urchin, 303
Heat, 87, 231, 760, 761
Helianthus (*see* Sunflower)
Helix, 311,* 312,* 542 (*see also* Snail)
Hellbender (*see* Salamander)
Hellgrammite, 562,* 563
Hematin, 237, 263
Hemichordata, 326,* 327, 327*
Hemocoel, 314, 393, 396, 400, 405
Hemoglobin, 390, 434, 484
Hemolysis, 659
Hemophilia, 702 (*see also* Heredity)
Hemopyrrole, 237
Henle's loop, 493*
Heparin, 487
Hepatic, 301*
Hepaticae, 109, 130, 131, 131,* 132,* 186 (*see also* Liverwort)
Herbaceous, 207
Herbivorous, 105, 835
Heredity (genetics), 24, 102, 621-625, 673-720, 722, 746
  blood groups, 489, 524-526
  chromosomes (*see* Chromosomes)
  definition, 673
  genes (*see* Gene)
  human, 522-526, 712-719
  Mendelian, 683-685
  methods of study, 673
Hermaphroditism, 292, 309, 312,* 372, 376, 391, 699
Heteroauxin, 240, 768
Heterocyst, 118,* 154, 155
Heterodera, 539, 661
Heterogamous, 115, 118, 125, 154, 155, 161, 162, 167
Heteronomous, 835
Heterosis, 705
Heterospory, 142, 143, 192, 200, 203, 206
Heterotrophic, 119, 167, 168
Heterozygous, 682, 685
Hexactinellida, 281
Hexagonal area, 349, 353,* 354*
Hibernation, 594
Highways, 595, 629
Hillier, 35
Hilum, 144,* 212
Hindbrain, 743*
Hippocrates, 801
Hirudinea (leeches), 308,* 309
Hirudo (leech), 306, 308,* 309, 541, 788
Histology, 24
Histomonas, 534
History of biology, 800-806
Holdfast, 116, 151, 160, 161, 304, 307*
Holoblastic, 444
Holophytic nutrition, 359
Holothurioidea, 303, 306*
Holozoic nutrition, 836
Homo sapiens, 589 (*see also* Man)
Homologous chromosomes, 682
Homology, 576, 577,* 578*

Homonomous, 836
Homospory, 136, 192-196
Homozygous, 682, 685
Honeybee, 398-408, 399*-404,* 571
Hooke, Robert, 28, 37, 802
Hooks, 377, 377,* 379, 400, 538*
Hookworm, 295, 296,* 298, 539, 785
Hoppers (*see* Insects)
Hormogonia, 113,* 154, 836
Hormones, animal, 506, 510-513, 767-772
  plant, 239-242, 767-772
Horse, origin and development, 725,* 726*
Horsetail (scouring rush), 100-112, 137, 137,* 191, 194, 195, 256
Host, 664
How science solves problems, 804, 805
  to study, 19
Human muscles, 467-472, 467,* 468*
  resources, 797
Huxley, 803
Hybrid vigor, 705
Hybridization, 684
  of corn, 704,* 705, 706
Hydatid (tapeworm larvae), 537, 788
Hydra, 286, 286,* 287, 289
Hydranth, 285*
Hydrogen, 79,* 81,* 83,* 169
Hydrogen-ion concentration, 631, 751, 836
Hydroid, 289, 290
Hydrolysis, 92
Hydrophyte, 206, 653
Hydroponics, 775, 776
Hydrorhiza, 285*
Hydrostatic, 836
Hydrotropism, 243
Hydroxyl, 751, 836
Hydrozoa, 285,* 289, 289*
Hymenium, 127,* 128,* 176
Hymenoptera, 398-408 (*see also* Insects)
Hyoid bone, 423, 424, 466, 469*
Hypersensitiveness, 520, 772, 773
Hypertonic, 753
Hypertrophy, 837
Hypha, 124, 124,* 126, 126,* 127,* 167, 173-176, 179
Hypocotyl, 144,* 147,* 202, 204, 210, 213
Hypodermis, 837
Hypopharynx, 410, 411*
Hypophysin (*see* Endocrine glands)
Hypophysis, 495,* 496,* 507
Hypostome, 286*
Hypotheses, 22
Hypotonic, 754

I

Ichneumon, 572* (*see also* Insects; Hymenoptera)
Ileum, 427,* 470,* 471, 475*
Ilium bone, 423, 425
Immunity, 518-522
Impressions (imprints), 605, 611
Improvement by heredity, 704,* 705, 706
Impulse in nerve, 498-502, 489*
Inanimate things, 99-103
Inbreeding, 703, 705, 706
Incomplete dominance, 690-692 (*see also* Heredity)
Incrustation, 610
Incus bone, 466, 498,* 505
Indeterminate variations, 724
Indian pipe, 671
Indirect cell division (mitosis), 62-72
Individuality, 97
Indusium, 198
Industrial plants, 257-271
Infusoria, 276, 278*-280,* 349, 354, 531,* 532,* 534 (*see also* Protozoa)
Ingestion, 344 (*see also* specific organisms)
Ink, 315,* 542, 547
Inner cell mass, 451,* 452
Innominate vein, 488,* 490,* 741*
Inorganic salts, 89
Insanity, heredity of, 717*
Insectivorous plants, 658, 668, 668*
Insects, 319, 393-408 (*see also* Grasshopper; Honeybee; etc.)
  classification and identification, 409-420
  economic importance, 550-572
  metamorphosis, 410, 414-418
  mouth parts, 409, 410,* 411,* 414-418
  orders of:
    Anoplura (lice), 415, 553
    Aptera (Collembola; Thysanura), 414, 450
    Coleoptera (beetles), 417, 563
    Collembola, 414, 550
    Corrodentia, 416, 557
    Dermaptera, 417, 561
    Diptera, 418, 568
    Ephemerida (Ephemeroptera), 414, 550
    Hemiptera, 416, 557
    Homoptera, 416, 558
    Hymenoptera, 418, 571
    Isoptera, 415, 555
    Lepidoptera, 418, 565
    Mallophaga, 415, 551
    Mecoptera, 417, 565

Insects, orders of—Cont'd
Neuroptera, 417, 563
Odonata, 414, 550
Orthoptera, 415, 554
Plecoptera, 415, 551
Siphonaptera, 418, 571
Thysanoptera, 416, 557
Thysanura, 414, 550
Trichoptera, 417, 565
Instar, 413*
Instinct, 665
Insulin, 511 (*see also* Endocrine glands)
Integument, 140,* 202, 203, 225,* 344, 349, 368, 384, 459-465 (*see also* specific organisms)
Intersex, 699
Interzonal fiber, 65
Intestine, 296,* 299,* 306,* 311*-313,* 321,* 322,* 327,* 328,* 332,* 369-380, 384, 396,* 473, 507*
Intussusception, 95, 101, 838
Invaginate, 838
Ions, 77, 83, 89, 751
Iris, 497,* 498,* 505
Iron, 169
Irritability, 96, 101
Ischium bone, 423,* 425
Isogamous, 115, 116, 118, 125, 154-157, 160, 161, 167
Isotonic, 754
Isotope, 82

J

Jacket layer, 129, 130, 132,* 164, 165, 185
Janssen, 27
Jaw, 298, 331, 423, 424
Jejunum, 411,* 475
Jellyfish, 289, 290, 290*
Joints, 465, 466
Juices, digestive, 430 (*see also* specific organisms; Digestion)
Jussieu, Bernard, 802

K

Kappa particle, 357
Karyokinesis (*see* Mitosis)
Karyolymph, 44
Karyosome, 40,* 44
Katabolism (*see* Catabolism)
Katydid (*see* Insects)
Keel of flower, 144,* 212
Kelp (Laminaria), 116, 118, 118,* 160, 161
Keratin, 459, 460*
Kidney, 311,* 312,* 316,* 340,* 435, 439, 440, 492, 493, 493*
Killer (in paramecia), 357
Kinesthetic, 496
Kinetic energy, 79, 105
Kinetochore, 679
Knoll, 35
Koch, Robert, 804
Koelreuter, 802

L

Labium, 313,* 395,* 409, 410,* 411*
Labrum, 395,* 404, 409
Lac, 559*
Lacewing (*see* Insects)
Lacteal, 481,* 488*
Lacuna, 49, 50,* 51*
Lamarck, 802
Lamella, 39, 49, 50*
Lamellibranchiata, 311
Lamina, 223
Laminaria (kelp), 118, 118,* 154, 161
Lamprey, 328,* 331, 573
Lancet (*see* Amphioxus)
Langerhans, islands of, 508, 511
Larva, 399,* 407, 413,* 419, 447
Larynx, 434, 469,* 490,* 491
Lateral line, 331,* 331
Leaves, 133-148, 191-198, 200-204, 206-218, 223, 223,* 224
absorption by, 226, 227
parts, 206-218
transpiration by, 226, 227
Leech, 306, 308,* 309, 541, 788
Leeuwenhoek, 27, 274, 802
Leguminous plants, 144,* 211, 212
Lens, 398, 456,* 497,* 505
Lethal gene or factor, 694
Leucocidin, 659
Leucocyte, 390, 396, 434, 484-486 (*see also* Tissue, blood)
Leucopenia, 486
Leucoplast (leucoplastid), 43
Leucosin, 116, 153, 159
Leucosolenia (sponge), 282*-284*
Lice, 786
bark, 556,* 557
biting bird, 551, 553*
book, 556,* 557
dog, hog, rat, 553, 554*
human, 553, 554*
Lichen, 113, 114, 116, 151, 152, 155, 662, 663*
Life cycle (*see* reproduction of specific organisms)
from life, 733
Ligament, 47, 49
Light, 233, 234, 626, 633, 762
Lignin, 39, 59, 209, 261
Ligule, 193

Limulus (horseshoe crab), 325,* 547
Linin, 40,* 44
Linkage in heredity, 695, 697
Linnaeus, 802
Lipid (fats), 87, 476
Liver, 311*-315*, 321,* 328,* 427,* 429, 470,* 471,* 479, 493, 512, 513
  fluke, 293, 294, 373-377, 374,* 375,* 538, 785, 785,* 787*
  rot (*see* Liver fluke)
Liverwort (Marchantia), thalloid, 109-112, 130, 131, 131,* 132,* 188-190
  Porella (leafy), 131, 132,* 189
Living and nonliving contrasted, 99-103
  animals and plants contrasted, 104, 107
Lizard, 336,* 340
Lobster, 318, 543
Locomotion, 106 (*see also* specific organisms)
Locus of genes, 696,* 698
Locust (*see* Insects and Grasshopper)
Loligo (squid), 315*
Luciferase, 762
Luciferin, 762
Lumbricus, 384-392 (*see also* Earthworm)
Lung, 311,* 331, 333, 340, 434, 470,* 489-493, 490*
  book, 319, 325*
Lycogala (slime mold), 123,* 124, 173
Lycopodineae, 110, 134, 136,* 191-193
Lycopodium, 135, 135,* 192, 193
Lycopsida, 110, 134, 135,* 191, 192
Lymnea (snail), 310,* 376, 538, 786
Lymph, 51, 390, 425, 487-489, 488*
Lymphatics, 481,* 488*
Lymphocyte (*see* Tissues, blood)

M

Macrogamete (megagamete), 840
Macromere, 444
Macronucleus, 279,* 349, 350,* 356*
Madreporite, 302, 302,* 303, 304, 306*
Magnesium, 79*
Maize (*see* Corn, Indian)
Malaria, 275, 276, 363-367, 364,* 532, 784
Malleus bone, 466, 498,* 505
Malpighi, Marcello, 29, 801
Malpighian layer, 421, 422,* 435, 459, 494
  tubule, 325,* 394, 396,* 397, 403,* 405
Maltose (malt sugar), 92, 429, 476
Mammalia (mammals), 340, 341,* 574
Mammoth, 606*
Man, 340
  biology of, 458-529
  blood groups, 489
  chromosomes (*see* Chromosomes)
  circulation, 477-489
  coordination and sensory equipment, 494-506
  diseases, 516-522
  ductless glands, 506-513 (*see also* Endocrine glands)
  early, and records, 585-590, 587*
  embryology, 450-456
  excretion, 492-494
  ingestion and digestion, 472-477
  inheritance, 522-526
  integument and skeleton, 459-465
  motion and locomotion, 467-472
  race improvement, 526-527
  reproduction and life cycle, 513-516
  respiration, 489-492
Mandible, 320,* 321,* 331, 393-404, 395,* 409, 411,* 424, 462,* 466, 469*
Mantle, 309, 310, 310,* 311, 312,* 313,* 328*
Marchantia, 188-190 (*see also* Liverwort)
Marl, 152
Marrow of bone (*see* Tissues, bone)
Marton, 35
Mastax, 298, 299*
Mastigophora, 274, 276,* 358, 358,* 361,* 531*-534* (*see also* Protozoa)
Matrix, 49, 50,* 51, 67, 360
Matter, 73, 78
Maturation of germ cells, 706-712
Maxilla, 331,* 395,* 409, 411,* 423,* 424
Maxilliped, 320,* 321*
May fly (*see* Insects)
Mechanistic view, 841
Medicine and biology, 778
Medicines from plants, 267
Medium, 76, 78
Medulla, 54, 340,* 496,* 502, 504
Medullary fold, 447
  plate, 447
  ray, 141,* 221
  sheath, 54, 54*
Medullated nerve, 54
Medusa (medusoid), 285,* 289, 290*
Megagamete, 842
Megagametophyte, 136,* 137,* 140,* 142, 143, 194, 200-203, 206, 225*
Megaphyll, 137

Megasporangia, 136,* 140,* 193, 200-203, 225
Megaspore, 136,* 140,* 142, 143, 193, 194, 200-203, 206, 225
Megasporophyll, 138, 140,* 142, 193, 200-203, 206, 225*
Meiosis (reduction division), 187, 357, 697, 709
Meissner's corpuscle, 495
Melanin, 422,* 758 (*see also* Pigments)
Melanoplus (*see* Grasshopper)
Membrane, cell, 39, 40,* 393
  nictitating, 438
  permeability of, 39
  plasma, 39, 40*, 156*
  sieve, 282*
  undulating, 279*
Mendel, Gregor, 683-685, 803
Mendel's laws, 683-685
Meninges, 503
Menstruation, 516
Merle collies, 707*
Merozoite, 365,* 366
Mesenchyme, 46, 280, 284,* 295, 309, 381, 449,* 454
Mesentery, 289, 290, 291,* 306, 488*
Mesoderm, 292, 293, 295, 299, 306, 309, 314, 325, 368, 373, 445,* 449,* 451, 453
Mesoglea (mesogloea), 280, 286, 286,* 287,* 288*
Mesonephros, 842
Mesophile, 122, 170
Mesophyte, 653
Mesothelium, 842
Mesozoic era, 614, 616
Metabolism, 92, 101, 625
Metacarpal, 423, 425, 462,* 466
Metagenesis, 117, 130-149, 154, 160, 164, 185-198, 285,* 286
Metamere and metamerism, 314-340, 738*
Metamorphosis (*see also* Reproduction)
  of frog, 448*
  of insects, 410, 414-418
    complete, 413,* 418
    gradual, 411, 412*
    incomplete, 411, 412*
    none (ametamorphosis), 410, 411*
Metaphase (mitosis), 62, 63,* 65, 66, 67
Metaplasmic granule, 40,* 43
Metaplast, 44
Metastasis, 583
Metatarsus (metatarsal), 400, 401,* 423,* 425,* 462,* 466
Metridium (*see* Sea anemone)
Microgamete, 843
Microgametophyte, 142, 143, 194, 201-204, 206, 225*
Micromere, 444
Micronucleus, 279,* 349, 350,* 356*
Microphyll, 135
Micropyle, 140,* 142, 144,* 201-203, 213, 225,* 406
Microscope, 27-36, 28,* 30,* 32*-34*
Microsome, 349, 354*
Microsporangium, 136,* 140,* 193, 201-203
Microspore, 136,* 140,* 142, 143, 193, 194, 200-204, 206, 225
Microsporophyll, 140,* 142, 193, 201-203, 225*
Midbrain, 54, 445,* 456,* 502, 503
Migration, 655, 656
Mildew, 127, 129, 177
Millipede, 318, 324,* 543, 544
Mimicry, 730
Mimosa (*see* Sensitive plant)
Mineral salts, 89
Mineralization, 611
Miracidium, 375,* 376, 787* (*see also* Liver fluke)
Mites, 319, 326,* 543, 544, 545,* 554*
Mitochondria, 40,* 41
Mitosis, 62-72, 63,* 64,* 66,* 68,* 69,* 349, 673, 680
Mixture, 85
Mohl, von, 37
Mold, black bread (Rhizopus), 124,* 125, 173
  blue (Aspergillus), 125-129, 126,* 175
  blue (Penicillium), 125-129, 126,* 167, 175
  bracket fungus, 128,* 129
  cup fungus, 127,* 176
  mushroom, 128,* 129,* 177-179, 178* (*see also* Basidiomycete)
  slime, 122-124, 123,* 172
  water (Saprolegnia), 125, 173, 174*
  yeast, 125,* 176
Molecule, 77-79, 79,* 81,* 83,* 750
Molgula, 328*
Mollusca, 309-314, 309*-316,* 541, 542
Molting, 944
Monecious, 175, 186, 200, 202, 309, 372, 376, 391
Monilia (*see* Yeast)
Monkey, 340
Monocotyledoneae, 110, 143-148, 207, 209, 222
Monocotyledons and dicotyledons contrasted, 143, 207
Monocystis, 275, 277,* 534
Monohybrid cross, 686, 688
Monosaccharide, 87

Monozygotic, 844
Morphogenesis, 241, 242, 442-456, 576, 580
Morula, 444, 451,* 452, 710,* 711
Mosquito, 364,* 366, 569* (*see also* Insects)
mouth parts, 411,* 569*
Moss, club, 110, 112, 134, 135, 135,* 191-194, 256
Irish, 119,* 249
peat (bog), 133, 134,* 187
Polytrichum, 133, 133,* 186
Sphagnum, 133, 134,* 187
Mother cell, 202, 203
Mother-of-pearl, 541
Moths, 319, 549, 567,* 568* (*see also* Insects)
Motor root, 844
Moult, 393
Mouth, 278,* 286,* 288,* 290,* 293-297, 296,* 299,* 300,* 304, 305,* 309, 310,* 312*-316,* 321,* 326,* 327, 332,* 350,* 358,* 368-374
parts, 394-404, 409, 410,* 411,* 414-418
Mucus, 293, 368, 387*
Mud puppy, 335*
Müller, Johannes, 803
Mulatto, 692
Multiceps, 537, 538,* 661, 788
Musci (moss), 109, 132, 133,* 134,* 186
Muscle, 312,* 425, 426,* 467-472, 467,* 468,* 497,* 498-499, 505 (*see also* Tissues, muscular)
spindle, 505
Mushroom (Psalliota [Agaricus]), 128,* 129, 177-179, 178*
Mussel (Anodonta, Lampsillis), 311
Mutation, 93, 624, 695, 722, 724 (*see also* Heredity)
Mycelium, 124,* 125, 126, 127,* 173, 178*
Mycorrhiza, 664
Myelin, 54
Myocardium, 478
Myofibril, 53
Myogenic theory, 844
Myoneme, 279,* 359
Myotome, 328*
Myriapoda, 318
Myxamoeba, 124, 167, 172
Myxedema, 511
Myxomycophyta (slime mold), 109, 122-124, 123,* 167, 172-173
Myxophyta, 114, 151

N

Nacre, 541
Naiad, 411, 412*
Nails, 459, 461
Nares, 332,* 427,* 434, 439
Nasal (*see* Nostril)
Natural selection, 844
Nautilus, 311
Nearctic region, 597
Necator (hookworm), 295, 296,* 539
Nectar and nectary, 208, 223,* 404, 547, 785
Necturus, 335*
Needham, 732
Negro, inheritance, 692
Nemalion, 119, 154, 163,* 164
Nemathelminthes, 295-298, 374-382, 538, 539
Nematocyst, 286, 286,* 287*-291*
Nematoda, 295, 298
Neoplasm, 583, 845
Neoteny, 845
Neotropical region, 598
Nephridia, 318, 375,* 385,* 386, 387,* 390
Nephridiopore, 390
Nephrostome, 390, 435
Nereis (sandworm), 307,* 308
Nerve cells, 54, 55*
cord, 54, 55,* 308,* 314, 321,* 322,* 325-343, 327,* 329, 370,* 371,* 378,* 387,* 391, 397
cranial, 54, 438, 496,* 502-504
ending, 437
fiber, 459, 498*
impulse, 498-502, 498*
motor, 844
olfactory (*see* Olfactory)
optic, 497,* 498,* 505
peripheral, 54, 435
radial, 302*
ring, 296,* 308,* 376, 381
sensory, 502, 503
spinal, 54, 55,* 502
Nervous equipment (*see also* specific organisms)
system (*see also* specific organisms)
autonomic, 502, 506
central, 54, 435, 502
enteric, 502, 506
parasympathetic, 502, 506
peripheral, 54, 435
sympathetic, 54, 397, 435, 437, 502, 506
Neural arch, 424
groove, 445,* 446, 449,* 455
plate, 449*
spine, 424
tube, 447, 449*

Neurilemma, 54, 54*
Neurofibril, 47, 459, 498,* 505
Neuroglia, 845
Neurohumor, 501
Neuromotor apparatus, 352*
Neuron (nerve cell), 47, 54, 54,* 501
Neutron, 79,* 80, 81,* 83*
Newt, 333,* 334*
Nictitating membrane, 438
Nissl granule, 47, 54*
Nitrogen, 79,* 650, 651
  fixation, 169, 650, 651, 664
Noctiluca, 763
Node of Ranvier, 54, 54,* 845
Nodus, 412*
Nondisjunction, 680 (*see also* Heredity)
Nonelectrolyte, 751, 845
Nonmedullated (*see* Nerve)
Nosema, 534
Nostoc, 113,* 154
Nostril, 328,* 331, 331,* 332,* 421, 424, 434
Notochord, 325-343, 326,* 327,* 328,* 329, 332,* 447, 449*
Nucellus, 201-203, 225
Nuclear framework, 40,* 43-44
  membrane, 40,* 43, 62, 63,* 65-67
  sap, 44
Nucleolus, 40,* 44, 62, 66*
Nucleolymph, 43-44
Nucleoplasm, 40,* 44
Nucleus, 40,* 43-44, 62, 65, 66,* 70, 143, 153-156, 156,* 157-162
  of the atom, 79,* 80, 81,* 83*
Nuda, 293
Nurse cell, 709
Nutrition, autotrophic, 120, 168
  chemosynthesis, 120
  heterotrophic, 119, 120, 167, 168
  holophytic, 359
  holozoic, 836
  parasitic, 120
  photosynthetic (*see* Photosynthesis)
  saprophytic, 120, 123, 125
Nymph, 398, 411, 412,* 419

O

Obelia, 285,* 289
Obligate, 846
Ocellus, 393, 394,* 398, 406
Octopus, 311, 316,* 542
Oestrone (*see* Endocrine glands)
Ogliole, 536
Oil, 153, 159
  from plants, 259, 267
Olfactory equipment, 311,* 398, 405, 424, 439, 447, 505 (*see also* specific organisms)
Oligochaeta, 308
Ommatidia, 397
Omnivorous, 846
Onion root, 68,* 69,* 71 (*see also* Mitosis)
Ontogeny, 442, 742
Onychophora, 318, 324*
Oocyst, 365,* 367
Oocyte, 709, 710*
Oogamy, 115, 118, 119, 130, 154, 155, 161, 187
Oogenesis, 709, 710*
Oogonia, 161, 162, 174,* 175, 709, 710*
Ookinete, 365,* 366
Opalina, 534, 534*
Operculum, 303
Opsonin, 520
Optic chiasma, 496*
  lobe (*see* Brain)
  nerve, 497, 497*
Oral groove, 350, 350*
Orbit, 79*, 81, 81,* 83,* 427, 438*
Organ, 55, 60, 647
Organelle, 274 (*see also* Protozoa)
Organicism, 847
Organisms, continuity of, and descent with change (evolution), 732-749
Organization, 97, 100
Oriental region, 598
Orientation, 847
Origin of life, 732-735
Orthogenesis theory, 847
Orthogenetic variation, 724
Orthoptera, 393-398
Oscillatoria, 113,* 152, 154
Osculum, 281,* 284*
Osmosis, 38, 752, 753, 753*
Osmotic pressure, 226, 752, 753, 753*
Ossicle, 302*
Ostium, 282,* 284,* 291,* 321,* 324,* 425,* 395, 514
Otolith, 496
Outbreeding, 703
Ovary, 143, 144,* 145,* 146,* 207-217, 223,* 225, 225,* 286,* 292, 296,* 299,* 321,* 328,* 332,* 371-383, 389,* 439,* 440, 450, 507,* 509, 512, 514, 515*
Oviduct, 299,* 311,* 312,* 320,* 321,* 332,* 371-378, 389,* 391, 396,* 398, 406, 427,* 439,* 514
Oviparous, 847
Ovipositor, 394,* 398
Ovotestis, 311,* 312*
Ovoviparous, 847

Ovule, 140,* 142, 143, 200-204, 206, 208, 216, 225, 225*
Ovum (egg), 133,* 143, 201-203, 286,* 389,* 450,* 514, 515, 708,* 709, 710*
Oxygen, 79,* 81,* 83,* 228, 489-493, 632
Oxyhemoglobin, 434, 484
Oxytocin (*see* Endocrine glands)
Oxyuris, 661
Oyster, 311

P

Paedogenesis (pedogenesis), 848
Palaearctic region, 597
Palate, 469*
Paleobotany, 605
Paleontology, 24, 605, 736
Paleozoic era, 614, 617
Paleozoology, 605
Palisade tissue, 145,* 195 (*see also* Tissues, plant)
Palm, 142,* 143, 203, 204, 261
Palp, 307,* 313,* 395,* 404,* 410, 410*
Pancreas, 340,* 427,* 428, 429, 471,* 476, 477, 507,* 508, 511
Pangenesis, 848
Papilla, 302,* 381, 421, 448, 459, 460,* 494
Parallelism, 593,* 729, 738*
Paramecin, 357
Paramecium, 278,* 279, 349-357, 350*-356*
Paramylum, 359
Paraphyses, 127,* 162, 176, 186
Parapodium, 306, 307,* 308
Parasite, 129, 133, 151, 152, 168, 177, 179, 183, 197, 201, 293, 297, 635, 658 (*see also* Bacteria; Fungi; etc.)
Parathormone, 507*
Parathyroid, 507,* 508, 511 (*see also* Ductless glands)
Parenchyma, 130, 141,* 145,* 220, 293, 373 (*see also* Tissues, plant)
Parthenogenesis, 162, 168, 298, 301, 361,* 363
Parthenogonidia, 363
Passenger pigeon, 610*
Pasteur, Louis, 733, 803
Pathogenic, bacteria, 120, 122, 168, 171, 255, 659, 660
  molds (fungi), 659, 660
  protozoa, 274, 660
  viruses, 789, 790
  yeasts, 660
Pathology, 24, 848
Peat moss, 133, 134,* 189, 258
Pébrine (silkworm disease), 535, 786
Pecten, 401,* 403
Pedicellaria, 302,* 304
Pedigree, 673, 715, 716,* 717*
Pedipalp, 325*
Pedogenesis, 848
Peduncle, 216
Pelecypoda, 311, 312*
Pellagra, 474, 771,* 772
Pellicle, 276,* 278,* 349, 350,* 353,* 354,* 358*
Peltate, 203
Pelvic, 462,* 466
Pen, 290, 315*
Penial seta, 380,* 382
Penicillin, 250, 251*
Penicillium, 126,* 127, 129, 175, 250, 251,* 671
Penis, 311,* 312,* 315,* 371,* 372, 374*
Pentamerous, 301, 303
Pepsin, 429, 476
Peptone, 476
Perch, 330*-332,* 331
Perennial, 200, 214
Perianth, 208, 224
Pericardium, 309, 311,* 313,* 324,* 325,* 395, 478
Pericarp, 210
Pericycle, 145,* 214, 220 (*see also* Tissues, plant)
Peridinium, 530
Periosteum, 849
Peripatus, 318, 324*
Peristome, 187, 307*
Perithecia, 177
Peritoneum, 47, 302,* 387*
Permeability, 743, 752, 753*
Petal, 144,* 208, 212, 217, 223,* 224, 225,* 305*
Petiole, 195, 215, 223
Petrifaction, 605, 611
Peziza (cup fungus), 127,* 129, 176
Phaeophyta (brown algae), 109, 116, 118,* 153, 160-162, 249
Phagocyte, 485, 518, 773 (*see also* Tissues, blood)
Phalanges, 423,* 425, 462,* 466
Pharynx, 276,* 279,* 296,* 308,* 311,* 325-343, 328,* 368-380, 385,* 396,* 469,* 471,* 491
Phaseolus, 144,* 211-213 (*see also* Bean)
Phases, 76
Phenotype, 684-690
Phloem, 133, 141,* 147* (*see also* Tissues, plant)
Phosphorescent, 530

Photosynthesis, 105, 112, 130, 150-166, 168, 169, 186, 210, 211, 359, 360, 363
Phototropism, 243, 347,* 348, 359
Phycocyanin, 114, 118, 151-154
Phycoerythrin, 118
Phycomycete (algalike fungi), 109, 124,* 125, 167, 173-175, 174*
Phylogeny, 442, 742
Physiology, 24 (*see also* specific organisms)
Phytogeography, 591
Phytomastigina, 274
Phytopathology, 850
Pia mater, 503
Pieris (cabbage butterfly), 413*
Pigeon (*see* Birds; Aves)
Pigment, 153, 156,* 243-247, 421, 732
  anthocyanin, 206, 208, 245, 246
  carotene (carotin), 115, 153, 155, 159, 208, 228, 229, 244, 245
  chlorophyll (*see* Chlorophyll)
  chromatophores, 758, 759
  erythrophore, 758, 759
  flavone (flavonon), 245, 246
  fucoxanthin, 116, 153, 160, 161, 244
  guanophore, 758, 759
  melanin (melanophore), 422,* 758, 759
  phycocyanin, 114, 118, 151, 152, 162, 244
  phycoerythrin, 118, 153, 162, 164, 244
  plant, 115-118, 227-247
  xanthophyll, 115, 153, 228, 229, 244, 245, 758, 759
Pileus, 179
Pine tree (Pinus), 138-143, 140,* 141,* 201-203
Pineal gland, 495,* 507,* 509, 512
Pinna, 138,* 195, 203
Pinnule, 138,* 304, 307*
Pinworm, 539
Pisces, 330,*-332,* 331 (*see also* Fish)
Pistil, 143, 146,* 208-216, 223,* 225, 225*
Pitcher plant, 636, 668*
Pith of plants, 145,* 147* (*see also* Tissues, plant)
Pitocin (*see* Endocrine glands)
Pitressin (*see* Endocrine glands)
Pituitary, 507,* 507, 510
Pituitrin (*see* Endocrine glands)
Placenta, 340, 453, 455,* 509, 512
Planaria (Dugesia), 293, 368-373, 369*-371,* 537
Plankton, 112, 151
Plant, anatomy and physiology, 219-248
Plant—Cont'd
  breeding (*see also* Heredity)
  cellular organization, 55-61
  coloration, 758-760
  classification, 865, 866
  ecology (*see* Ecology)
  economic importance, 249-271
  fossils, 605-619
  geography, 591
  hormones, 239-242, 768
  lice (aphids) (*see* Insects)
  number of species, 110
  quarantine, 637
  tropism, 242, 243
  wild life, 796
Planula, 285,* 290*
Plasma, 390, 396, 405, 486 (*see also* Tissues, blood)
  gene, 357
Plasmodesma (Plasmodesmata), 41, 42*
Plasmodium, 123, 123,* 124, 167, 172, 275, 276, 363-367, 532, 784
Plasmolysis, 105, 754
Plasmosome, 40,* 44 (*see also* Nucleolus)
Plast (plastid), 43, 114-116, 118, 130, 153, 159, 160, 162, 164
Plate, calcareous, 309, 310
  genital, 304*
  horny, 333
Platelet, 485, 486 (*see also* Tissues, blood)
Platyhelminthes, 293-295, 537, 538
Pleura, 492
Pleurococcus (*see* Protococcus)
Pliny the Elder, 801
Plumule, 144,* 210, 211, 213
Pod, 144*
Poisons, 404,* 406
  from plants, 267-270
Polar body (polocyte), 452, 516, 709, 710*
  nucleus, 206, 225*
  transportation, 240
Polarity, 241, 242, 499
Pole, 445,* 452
Polian vesicle, 306*
Pollen, 405, 407, 634
  basket, 401,* 403
  brush, 401,* 402
  comb, 401,* 404
  grain, 140,* 142, 143, 146,* 201-204, 206-213, 225, 225*
  spur, 401,* 402
  tube, 140,* 143, 201-204, 206-212, 225*
Polocyte (*see* Polar body)
Polychaeta, 308
Polygordius, 308

Polymorphism, 851
Polynesian region, 598
Polyneuritis, 474, 770,* 772
Polyp, 289,* 290
Polyploidy, 673, 676-680
Polypodium (fern), 138, 139,* 198
Polysaccharide, 87
Polysiphonia, 119, 119,* 154, 164 (*see also* Algae, red)
Polytrichum, 133, 133,* 186 (*see also* Moss)
Pond scum, 157
Pons, 54, 495,* 496,* 502, 504
Porella, 131, 132,* 189 (*see also* Liverwort, Porella)
Porifera (sponges), 279-286, 535, 536
Porkworm, 539
Porocyte, 283*
Portuguese man-of-war, 289, 289*
Postcaval vein, 315,* 480, 741*
Potential energy, 105
Pounce, 542
Praying mantis, 554, 667*
Prebus, 35
Precipitin, 520
Predacious (predatism), 635, 636, 658, 666, 667*
Preformation, 842
Prenatal, 852
Primary germ layers, 445,* 451-454
Primordial germ cells, 708-712, 708,* 710*
Principle, barriers, 595
  cell, 37-45
  definite habitats, 594
  discontinuous distribution, 596
  dispersion, 593
  hibernation, 594
  highways, 595
  longitudinal distribution, 591-604
  migration, 591-604
  vertical distribution, 597
Proboscis, 326,* 327,* 369, 375,* 410*
Proctodeum, 447 (*see also* Embryology)
Progesterone (*see* Endocrine glands)
Progestin, 452
Proglottid, 293, 377, 377*
Prophase (mitosis), 62, 63,* 66*
Prophylaxis, 520
Propolis, 405
Prosecretin (*see* Endocrine glands)
Prosopyle, 282,* 284*
Prostate, 513, 514, 514*
Prostomium, 307,* 384, 385,* 388*
Protective resemblance, 730, 760
Protein, 85, 88, 92, 476
Proterozoic era, 614, 617
Prothallus, 137,* 138, 138*, 188, 192, 193, 197
Prothrombin, 486, 487
Protococcus (pleurococcus) (green Alga), 115,* 116, 154, 157
Proton, 79,* 80, 81, 81,* 83*
Protonema, 134,* 187, 188
Protoplasm, 37-45, 73-103
  chemical properties, 84-92, 750
  physical properties, 93-103, 750
Protoplasmic strands, 41, 42,* 362,* 363
Protoplast, 44, 123,* 160
Protopodite, 320*
Protozoa, 274-279, 275*-280,* 344-367, 530-535, 660
Protractor muscle, 312*
Proventriculus, 394
Psalliota (Agaricus) (*see* Mushroom)
Pseudopodia, 123, 172, 173, 188, 274, 275,* 286,* 344, 345, 345,* 346*
Pseudospora, 535
Psychology, 853
Psychrophile, 122, 170
Pteridium (Pteris), 138, 138,* 195-198 (*see also* Fern)
Pteropsida, 110, 137, 138, 138,* 191, 195, 200-205, 206-213
Ptyalin, 476
Puccinia, 181-183, 182*
Pulmonary, 311,* 312,* 480,* 741*
Pulvillus, 394, 401,* 402
Punnet square, 686-690
Pupa, 399,* 407, 413,* 419
Pupil, 438, 497, 505
Pure line in heredity, 853
Putrefaction, 671
Pycniospore, 129, 167, 181, 182, 182*
Pyloric, 302,* 321,* 332,* 426, 427,* 473
Pyrenoid, 115, 115,* 117, 118, 153, 155, 156, 156,* 157, 162, 276,* 358,* 359

Q

Quarantine, 637
Queen, 399, 399,* 406

R

Race improvement, 526-527
Radial symmetry (*see* Symmetry)
Radicle, 210-213
Radioactive, 82
Radiolaria (*see* Protozoa)
Rafinesque, 802
Rana (*see* Frog)
Ranunculus (*see* Buttercup)
Ranvier, node of (*see* Nerve)
Raphe, 213

Rays, 141,* 301, 301,* 303, 307,* 328,* 331
 medullary, 222
 sting, 329*
Reaction, 348, 352,* 355,* 359
Recapitulation, 442, 854
Receptacle, 161, 208, 216, 224, 225*
Recessive, 682, 684
Records of ancient life, 605-619
Rectal gland (*see* Glands)
Recti muscles, 497,* 498,* 505
Rectum, 308,* 313,* 315,* 327,* 380,* 381, 394, 396,* 403,* 404, 471,* 477
Red blood corpuscle (*see* Tissues, blood)
Redi, Francesco, 733, 801
Redia, 375,* 377, 787*
Reduction division, 607, 709, 854
Reef, 536
Reflex, 503, 505
Refraction, 730, 759
Regeneration, 98, 98,* 293, 299, 304, 372, 373, 576, 579
Renal, 483, 493, 494
Rennin, 476
Reproduction, 96, 102 (*see also* specific organisms)
Reptilia (reptiles), 333, 336*-338,* 573
Reservoir, 276,* 358,* 358, 359
Resin, 262, 263
 canal, 141*
Respiration, 100, 239, 306,* 310,* 318, 319, 489-492 (*see also* specific organisms)
Respiratory tree, 74, 75,* 306*
Resting stage (*see* Mitosis)
Reticular theory, 74, 75*
Retina, 438, 456,* 497, 497,* 505
Retractor muscle, 312,* 313,* 384
Reversion in heredity, 855
Rh factor, 525
Rhabdite, 293, 368
Rhabdom, 398
Rhabdopleura, 327, 327*
Rheita, 29
Rheotropism, 855
Rhizobium, 650
Rhizoid, 125, 126,* 130, 131,* 132,* 133, 134,* 136, 137,* 138,* 173, 186-189, 193-198
Rhizome, 135, 137,* 138,* 139,* 192-198, 197*
Rhizoplast, 359
Rhizopoda, 274 (*see also* Protozoa)
Rhizopus (black bread mold), 124,* 125, 173, 671
Rhodophyta (red algae), 109, 118, 119,* 153, 162-165, 163,* 249
Rhomaelia (*see* Grasshopper)
Ribs, 462,* 466
Richards, 34
Rickets, 475
Riddell, 31
Ringworm (*see* Athlete's foot)
Rockweed (Fucus), 118, 118,* 161
Rods and cones, 497
Root, 133-148, 137,* 140,* 144,* 147,* 191-198, 200-205, 206-218, 219-222
 absorption by, 226
 cap, 215, 219
 dorsal, 55*
 hairs, 145,* 210, 216, 219, 226
 pressure, 227
 regions of growth, 219-222
 tissues (*see* Tissues, plant)
 ventral, 55*
Rotifer, 297, 298, 299,* 539, 540
Roundworm, 379-382, 661, 788 (*see also* Ascaris; Hookworm; Trichinella, etc.)
Royal jelly, 407
Rubber, 262
Ruska, 35
Rusts, 129, 181, 182*

S

Sac, embryo, 206
Saccharomycetes (*see* Yeast)
Sacculus, 496
Sachs, Julius, 803
Salamander, 333, 334*
Salivary gland, 311,* 312,* 498
Sand dollar, 303, 305*
Sandworm (Nereis), 307,* 308, 541
Saprolegnia (water mold), 125, 173, 174*
Saprophyte, 113, 120, 123, 151, 168, 172, 173, 176, 177, 635, 658, 671
Sarcodina, 274, 275,* 343,* 531,* 533* (*see also* Protozoa)
Sarcolemma, 52,* 53
Savory substances from plants, 267
Sawfish, 329*
Sawfly (*see* Insects)
Scale, 331
 insects, 558, 560*
Scallop, 311
Scaphopoda, 311, 316*
Schistosoma, 660, 661
Schizogony, 367
Schizomycophyta (bacteria), 109, 120-122, 121,* 167-172, 250-256

Schizont, 365,* 366
Schleiden, 31, 37, 803
Schultze, 38
Schwann, 31, 37, 803
Scientific method, 17, 20-24, 804, 805
Sclera, 497,* 505
Sclerenchyma, 141,* 197* (*see also* Tissues, plant)
Scleroblast, 283*
Scolex, 293, 377, 377,* 379, 538*
Scorpion fly, 319, 326*
Scouring rush, 110, 137, 137,* 256 (*see also* Horsetail)
Scrotum, 514*
Scurvy, 475
Scypha (Grantia), 279-281, 281,* 284* (*see also* Sponge)
Scyphistoma, 290*
Scyphozoa, 289, 290*
Sea anemone, 290, 291*
cucumber, 304, 306*
fan, 290
lily, 304
pen, 290
squirt, 328*
urchin, 303, 303,* 304*
walnut, 293
weed (*see* Algae)
Sebaceous gland (*see* Glands; Skin)
Secondary sexual traits (*see* Heredity)
Secretin (*see* Endocrine glands)
Sedentary, 856
Seed, 138, 140,* 142, 143, 144,* 146,* 200-218, 225*
coat, 210, 213
leaf, 194
Segmentation, 304, 307,* 309, 314, 325
Segregation law, 685
Selaginella, 135, 136,* 193
Semen, 514
Seminal receptacle, 311,* 312,* 371,* 372, 373, 385,* 389,* 391, 398
vesicle, 296,* 371,* 372, 380,* 382, 385,* 389,* 391, 406, 513, 514*
Sensitive plant, 106
Sensitivity of protoplasm, 357
Sensory equipment, 494-506 (*see also* specific organisms)
Sepal, 144,* 208, 212, 223*-225*
Septa, 173, 179, 308, 384, 385,* 386, 387*
Serpent star, 303
Sertoli cell, 709
Serum, 478
Sesamoid bone, 466
Sessile, 106, 116
Seta, 132,* 134,* 189, 304-308, 307,* 380,* 384, 387*
Sewage, 781-783
Sex cell, 162 (*see also* Reproduction)
chromosome, 675,* 694,* 697,* 698
determination, 697,* 698
-influenced traits, 703
-linked traits, 699-703, 700*-703*
ratio, 698
Sexual dimorphism, 857
Sharks, 329,* 331, 573
Shelf fungus, 128,* 129, 179, 671
Shell, 79,* 81, 81,* 83,* 309, 310, 311, 313,* 316,* 377, 377,* 406
Shellac, 559*
Shipworm, 311, 314,* 542
Shrimp, 318, 322, 324,* 543
Sieve membrane, 282*
tube, 145,* 147,* 192, 220, 224
Sigmoid, 471,* 477
Silicon, 159, 160, 194, 280, 281
Silk, 146,* 567*
Silkworm, 565, 567,* 786
Silverfish, 550, 551,* (*see also* Insects)
Sinus, 314, 322,* 395, 479,* 480
venosus, 332,* 431, 431,* 741*
Siphon, 164, 312,* 313,* 315,* 328*
Siphonoglyphe, 291*
Skate, 331
Skeleton, 329-343, 423-425, 423,* 465-467, 462* (*see also* specific organisms)
Skin, 421, 422,* 437, 459-465, 460,* 493, 504, 518
Skipper (*see* Insects)
Skull, 587*
Sleeping sickness, 660, 784
Slime mold (Myxomycophyta), 109, 122-124, 123,* 172, 173, 252
Slug (snail), 310, 542
Smut, 129, 179, 180*
Snail, 310, 310,* 311,* 312,* 542
variations in, 723*
Snake, 337,* 340
Snow flea, 411,* 550
Society, human, 585-590
Soils, 794
Sol, 76
Solation, 857
Somatic modifications, 722
Somatoplasm, 708-712, 708*
Somite, 304, 307,* 385*
Sorus, 137, 139,* 182,* 192, 196, 196,* 198
Sound production and reception, 393, 435, 761, 762
Sowbug, 317,* 318, 544
Spallanzani, 733
"Spanish moss," 669, 670*

Spectrum, 757, 757*
Spemann, 581
Spencer, 31
Sperm, 119, 133,* 136, 136,* 137,* 138,* 138, 143, 154, 161-164, 163,* 186, 189, 194, 195, 201-204, 286,* 320, 361,* 363, 365,* 372, 374,* 391, 398, 406, 450,* 514, 708*
  mother cell, 277*
  nucleus, 206
Spermatheca, 325,* 391, 398, 406
Spermatid, 709, 710*
Spermatium, 163*
Spermatocyte, 709, 710*
Spermatogenesis, 708-710
Spermatogonia, 514, 675,* 709, 710*
Spermatozoa (*see* Sperm)
Spermogonium, 181
Sphagnum (moss), 133, 134,* 187, 256
Sphenopsida, 110, 135, 191, 194
Spicule, 281,* 282*
Spider, 319, 325,* 326,* 543, 544, 544,* 547
Spinal cord, 54, 55,* 328,* 332,* 340,* 436,* 437, 449,* 462,* 466, 496,* 502, 505
  nerves, 54, 55,* 436,* 437, 502
Spindle, 63,* 64, 65, 66,* 67
  cell, 434
  muscle, 505
Spine, 300,* 303, 303,* 304
Spinneret, 325*
Spiracle, 394,* 396,* 397, 403,* 448
Spirogyra (green alga), 115,* 116, 154, 157, 158*
Spittle insect (*see* Insects)
Splanchnic layer, 858
Spleen, 332,* 427,* 507*
Split protein, 772
Sponges, 279-286, 281*-284,* 535, 536 (*see also* Scypha; Leucosolenia; etc.)
Spongilla (sponge), 284,* 286
Spongin, 280, 281
Spongocoel, 284*
Spontaneous generation, 732
Sporangiophore, 112, 119, 124,* 125, 136, 173
Sporangium, 112, 119, 123,* 124,* 125, 130, 131,* 133,* 135, 135,* 136, 136,* 137, 150, 154, 165, 172, 173, 187-190, 192-195
Spore, 112, 119-129, 172, 186-190, 192
  mother cell, 132,* 187, 197
  swarm, 156, 174
Sporocyst, 275, 277,* 375,* 376, 787*
Sporogony, 367
Sporophore, 126,* 128,* 179, 192-195
Sporophyll, 135, 135,* 136,* 138, 192, 196, 200-204
Sporophyte, 117, 128,* 130, 131,* 132,* 133-135, 136,* 137, 138, 138,* 140,* 143, 161, 164, 191-198, 200-204, 206, 207
Sporozoa, 275, 363-367, 534* (*see also* Protozoa)
Sporozoite, 277,* 365,* 366, 367
Sporulation (*see* Spore)
Springtail, 411,* 550, 551* (*see also* Insects)
Squalus (*see* Sharks)
Squid, 311, 315,* 542
Staggers, 537, 661, 788 (*see also* Multiceps)
Stalk, 190, 198, 223
Stamen, 144,* 208-216, 223,* 224, 225*
Staminate, 140,* 202-204
Standard (of a flower), 212
Stapes bone, 466, 498,* 505
Starch, 115, 118, 153, 155, 162, 204
Starfish, 300*-302,* 301, 540, 666
Statocyst, 288*
Statocyte, 284*
Steapsin, 429, 476
Stele, 145,* 214, 216, 220
Stem, 133-148, 191-198, 200-205, 206-218, 222, 223, 223*
  dicotyledonous, 143
  monocotyledonous, 143
Stemonitis (slime mold), 123,* 173
Stentor (*see* Protozoa)
Sterigma (sterigmata), 128,* 178,* 179
Sternum, 424, 462,* 466
Stigma, 143, 145,* 207-217, 223,* 225, 225,* 276,* 358,* 359, 361,* 363, 763
Stimulus, 100, 106, 348, 494
Sting, 404,* 406
Stipe, 161
Stirrup bone, 466, 498,* 505
Stolon, 173
Stoma (stomata), 56, 57,* 58,* 133, 141,* 145,* 147,* 189, 191, 192, 210, 211, 215, 224, 226
Stomach, 299, 301,* 306,* 308,* 311*-315,* 327,* 328,* 332,* 396,* 470,* 471,* 473, 507,* 509, 512
Stomodeum, 290, 447
Stone cell (sclerenchyma) (*see* Tissues, plant)
  fly (*see* Insects)
  lily, 304

Strands of cytoplasm, 153, 157, 162, 164, 362,* 363
Stratum compactum, 422, 422*
corneum, 421, 422,* 459, 460*
granulosum, 459, 460*
lucidum, 459, 460*
mucosum, 459, 460,* 461
spongiosum, 421, 422*
Striation, 381, 384
Strobila and strobilization, 290,* 377
Strobilus, 135, 135,* 136, 136,* 137,* 192-195
Strongyloidea, 295, 788
Struggle for existence, 747
Style, 143, 144*-146,* 207-217, 223,* 225, 225*
Subclavian, 741*
Suberin, 39, 59
Substrate, 91, 131
Successions of organisms, 646, 652, 654
Succus entericus, 476
Suckers, 293, 308,* 309, 311, 315,* 375,* 376-379, 538*
Sucrose (cane sugar), 87, 92, 472-477
Suctoria, 279
Sugar, 87, 92, 472-477
Sulcus (sulci), 503
Sulfur, 79*
Sundew, 636, 668*
Sunflower (Helianthus), 145,* 213-217
Supplementary genes, 693
Suprarenal (adrenal), 508, 511
Surface tension, 755
Survey of animal kingdom, 272-343
of plant kingdom, 108-149
Suspensor, 193, 194, 202, 204
Suture, 466
Swammerdam, 29, 802
Swarm spore, 123, 123,* 156, 167, 172, 174
Swimmeret, 320,* 321*
Syconoid (sycon) (*see* Sponges)
Symbiosis, 151, 155, 169, 535, 634, 658, 662
Symmetry, asymmetry, 309, 310
bilateral, 292, 293, 298-304, 309-314, 325-343, 368, 372
biradial, 292
radial, 279, 286, 292, 299
Sympathin, 502
Synapse, 54, 501, 502
Synapsis, 696,* 697, 709
Syncytium, 53
Synergid cell, 206, 859
Syngamus, 539, 540, 661, 788
Syngamy, 859
Synura, 530, 532*
Systems, 60, 647, 648
of classification of plants, 865, 866

T

Tactile, 303, 398, 405, 460, 460,* 495
Tadpole, 447, 448*
Taenia (*see* Tapeworm)
Tails, 738*
Tapeworm, 293, 294, 377-379, 377,* 378,* 537, 538,* 660, 785, 786
Tar pool, 608*
Tarantula, 547 (*see also* Spider)
Tarsal (tarsus), 394, 394,* 400, 401,* 425, 462,* 466
Tassel, 146,* 210
Taste, 398, 406, 440, 472-477, 495, 505
Taxonomy, 24, 736, 737, 865, 866 (*see also* Classification)
Teeth, human, 461-464, 463,* 464,* 473
palatine (maxillary), 427*
vomerine, 424, 425, 427*
Telegony, 859
Teliospore, 129, 167, 181, 182*
Telophase (mitosis), 62, 63,* 65, 66,* 67
Telson, 320,* 321*
Tendon, 49, 53, 426*
Tentacle, 278,* 286-293, 286,* 288,* 289,* 291,* 304, 306,* 307,* 310,* 311, 311,* 312,* 327*
Tentaculata, 293
Tentaculocyst, 290*
Teredo, 314,* 542
Termite, 556* (*see also* Insects)
Terraphyte, 653
Terrestrial, 653
Test, 303,* 304*
Testes (testis), 286,* 292, 296,* 328,* 371,* 372, 374,* 378,* 380,* 382, 389,* 391, 398, 440, 440,* 507,* 509, 512, 513, 514*
Testosterone (*see* Endocrine glands)
Tethelin (*see* Endocrine glands)
Tetraspore, 119, 154, 165
Texas fever of cattle, 534,* 786
Thales, 800
Thallophyta, 109-112, 150-166, 167-184
Thallus, 131,* 188, 189
Theelin (*see* Endocrine glands)
Theophrastus, 801
Theories, acquired characteristics, 746, 747
Allen's, 734
atomic (*see* Atom)
axial gradient, 372, 373
biogenetic, 442, 742
cell (*see* Cell)
cosmozoa, 734

Theories—Cont'd
Creation, 735
Darwin's, 726, 746
demonic, 517
de Vries', 747
Eimer's, 747
gene (*see* Genes)
germ, 518
plasm, 706
humoral, 518
hybridization, 748
Lamarck's, 746
membrane (nerve), 498,* 498-502
Moore's, 734
mutation, 747 (*see also* Mutation)
natural selection, 729, 746
organicism, 847
organismal, 847
orthogenesis, 847
Osborn's, 735
parallelism, 738*
Pflüger's, 734
pythogenic, 518
recapitulation, 442
species specificity, 88
"struggle for existence," 729, 747
surface tension, 345
"survival of fittest," 747
transcendental (Creation), 735
Troland's, 735
viscosity, 345
Weismann's, 706, 747
Thermophile, 122, 170
Thermotropism, 243, 348
Thigmotropism, 243, 346,* 348*
Thorax (thoracic), 318, 319, 329, 340, 490*
Thrips, 557* (*see also* Insects)
Thrombin, 486, 487
Thromboplastin, 486, 487
Thrombus, 487, 659
Thumps, 539
Thymus, 507,* 509, 512
Thyroid, 507, 507,* 511
Thyroxin, 511 (*see also* Endocrine glands)
Thysanura (*see* Insects, orders of)
Tibia, 394, 394,* 400, 401,* 423,* 425, 462,* 466
Ticks, 543
Tiedemann's body, 302*
Time chart, 614-618
Tissues, 46-61, 647
adipose, 49, 50*
animal, 46-55, 48,* 50,* 51,* 52,* 54*
areolar, 49, 50*
bast, 214
blood and lymph, 50, 51*
Tissues—Cont'd
bone (osseous), 49, 50,* 51*
cambium, 59, 141,* 143, 145,* 207, 214, 221, 222
cartilage, 49, 50*
chlorenchyma, 56, 229
collenchyma, 55, 56
companion cells, 56, 57,* 60, 192, 209, 214, 216, 224
conducting, 57,* 59, 207-216
connective, 46, 49, 50*
cork (plant), 55, 56, 57,* 59
cortex (cortical), 214, 220, 222
endodermis, 197,* 216, 220, 223*
epidermal (epidermis), 55, 56, 57,* 58,* 195, 197,* 209-216, 220-222, 223,* 224,* 368, 421, 422,* 459, 460*
epithelial, 46, 48, 48,* 283,* 284,* 459-461
fibrous, 49, 50*
germinal, 48, 48*
goblet, 48
mechanical (plant), 57,* 59, 220, 223
medullary (rays), 59, 60, 221
meristematic (growth), 55, 56, 57,* 207, 214, 215
mesophyll, 224-229
muscular, 47, 52,* 53*
nervous, 47, 54, 54,* 55*
neuroepithelium, 47
palisade, 215, 224
parenchyma, 55, 56, 57,* 59, 60, 185, 197,* 209, 214, 216, 220-223, 223*
pericycle, 197,* 214, 216, 220
phloem, 56, 57,* 60, 191-198, 197,* 209-216, 220-222, 223*
pith, 213, 214
plant, 55, 56, 57,* 58,* 59, 60
plasma, 51
rays, 214
reproductive, 48, 48*
reticular, 49, 50*
sclereid, 55, 57,* 59
sclerenchyma, 55, 57,* 59, 197,* 209
sieve plate, 57,* 60, 209, 214
spongy, 206-218, 224
stele, 214, 216
tracheal tube (vessel), 56, 57,* 59, 207-216
tracheid, 56, 57,* 59, 207-216, 220, 224
tube, 56, 57,* 60, 192, 209-216, 220, 224
vascular bundle, 191-198, 197,* 200-205, 222, 223*
white fibrous, 49, 50*

Tissues—Cont'd
xylem, 56, 57,* 59, 191-198, 197,* 207-216, 220, 223*
yellow elastic fibrous, 49, 50*
Toad, 333, 333,* 336,* 340, 573
Tolles, 31
Tongue, 469,* 473
Tooth shell, 314, 316*
Toxin, 659, 772
Tracers, 82
Trachea, 318, 319, 325,* 396,* 397, 397,* 403,* 407, 434, 469,* 470,* 490,* 492
Tracheophyta, 110, 133-148, 191-198, 200-205, 206-213
Trails, 605, 611
Transformation, 860
Translocation, 680, 860
Transmutation, 860
Transpiration, 226, 227
Transportation, 240, 638
Traumatin, 240, 768
Travertine, 114, 152
Tree of life, 104
respiratory, 306*
Trematoda, 293, 294, 373, 537
Trepang, 540
Trial-and-error theory, 861
Trichinella, 295, 296,* 297, 298, 539, 661, 785
Trichinelloidea, 297
Trichinosis, 295-299, 539, 661, 785
Trichocyst, 278,* 349, 350,* 353,* 354*
Trichogyne, 163,* 164, 165
Trihybrid cross in heredity, 686-690
Trilobite, 609*
Triploblastic, 292, 293, 295, 299, 306, 309, 314, 325-343, 368, 373
Triploid, 207, 679
Trochanter, 394, 400, 401*
Trochelminthes (Rotifers), 297-299, 299*
Trochophore, 308
Trophectoderm (trophoderm), 451,* 452, 453
Trophozoite, 277,* 365,* 366
Tropisms, 242, 243, 861
Truncus arteriosus, 430, 430,* 741*
Trypanosome, 275, 532, 533,* 534, 534*
Trypsin, 429, 476
Tsetse fly, 534*
Tube cell, 202
foot, 299, 300*-304,* 304
nucleus, 207, 225*
Tubercle, 304*
Tumor, 180,* 583
Tundra, 599,* 600
Tunic, 327, 328*
Tunicata, 327
Turbatrix (*see* Vinegar eel)
Turbellaria, 293, 369*
Turgor, 754, 861
Turtle, 337,* 340 (*see also* Reptilia)
Twinning in heredity, 717*
Two-, four-, eight-cell stages of embryos, 444, 451*
Tympanic, 398, 421, 438
Tyndall's cone, 77
Typhlosole, 386, 386,* 387*
Typhoid, 255

U

Ulothrix, 115,* 116, 154, 157
Ultraviolet, 32, 33
Umbilical, 451, 453, 455*
Umbo, 312*
Uniformitarianism, 961
Unit character, 685
Unity in living organisms, 646-657
Uranium, 82
Urea, 493
Uredospore, 129, 167, 181, 182, 182*
Ureter, 311,* 332,* 340,* 427,* 439,* 440,* 492, 493,* 494, 514,* 515*
Urethra, 493,* 513, 514*
Uriniferous tubule (*see* Kidney)
Urochordata, 327, 328*
Uroglena, 530, 531*
Uropod, 320,* 321*
Urostyle, 423,* 424
Used spindle (mitosis), 65
Ustilago, 180*
Uterus, 296,* 374,* 377,* 378,* 380,* 382, 440, 452, 455,* 514
Utricle, 496
Utricularia, 668*

V

Vacuole, 40,* 43, 160, 162
contractile, 156, 156,* 276,* 278,* 279,* 345,* 346, 350,* 354, 355, 358,* 359, 360, 362*
food, 279,* 344, 345,* 350,* 351, 352, 369
Vagina, 311,* 312,* 374,* 378,* 380,* 382, 398, 406, 514, 515*
Valve, 159, 311, 395, 405, 477, 480*
Variations, 93, 721-731, 723*-728,* 736, 746
Vas deferens (vasa deferentia), 311,* 312,* 371,* 372, 378,* 380,* 382, 389,* 391, 398, 406, 513, 514, 514*

Vasa efferentia, 371,* 440, 513
Vascular bundle, 133-148, 145,* 147,* 191-198 (*see also* Tissues)
Vegetal pole, 445,* 452
Vegetation areas of North America, 599-602, 599*
Veins, 311,* 312,* 400
  of frog, 430, 431,* 433
  of leaves, 145,* 147,* 210-215, 224
  of man, 470,* 477-489, 740,* 741*
Velum, 288,* 289, 310,* 328,* 400, 401*
Vena cava, 431, 478*-481,* 480-489, 488,* 493,* 741*
Venter, 186, 187, 197, 202
Ventral horn, 55*
Ventricle, 311,* 312,* 331-340, 332,* 340,* 430, 430,* 431, 456,* 470,* 477, 478*-480,* 495,* 503, 504, 740*
Venus's flower basket (sponge), 281
Venus's-flytrap (plant), 106, 636, 668*
Vermiform appendix, 863
Vertebral column, 329-343, 423, 423,* 424, 449*
Vertebrata (vertebrates), 329-343, 340,* 421-441
Vertebrate brains, 743*
  embryos, 738*
  heart chambers, 331-340, 740,* 741*
Vesalius, 801
Vesicle, 306,* 452
Vestibule, 505
Vestigial structure, 516, 744
Vigor, hybrid, 705
Villus (villi), 451,* 453, 475
Vinegar eel (Turbatrix), 295, 296,* 298, 539
Viosterol (*see* Vitamins)
Virus, 789-790
Visceral, 311*
Vision, 398 (*see also* Eye)
Vitalism, 863
Vitamins, 90, 169, 176, 474, 475, 486, 487, 769-772, 769*-771*
Vitelline, 455
Vitreous body, 497,* 505
Viviparous, 863
Vocal fold (vocal cord), 469,* 492
  sac, 427*
Volutin, 160
Volvox, 274, 360-363, 361,* 362,* 535
Vomerine, 424
von Mohl, 37
Vorticella, 278,* 279 (*see also* Protozoa)
de Vries, 676, 684

W

Walking stick, 554, 730 (*see also* Insects)
Wallace, 803
Warm blooded, 340-343
Wasps, 319 (*see also* Insects)
Waste elimination, 100, 106, 390, 435, 492-494, 633 (*see also* specific organisms)
Water, 90, 226, 228, 235, 492-494, 629-633
  "bloom," 114, 152, 249
  farming, 776
  flea, 318, 324*
  mold, 173, 174* (see also Saprolegnia)
  molecule of, 83*
  silk, 157
  storage, 187, 188
  supply, 781-783
  vascular system, 302*
Wax, 404
Wealth and biology, 779
Web of life, 655
  toe, heredity, 716*
Weevil (*see* Insects)
Weigert, 804
Weismann, 706, 803
Welfare and biology, 778
  and heredity, 693
Wheat rust (Puccinia), 129, 181-183, 182*
Wheel organ, 298
Whelk, 310
White "ant" (termite) (*see* Insects)
  corpuscle (leucocyte) (*see* Tissues, blood)
  matter, 55,* 503, 505
Whitefish embryo, 64*
Whorl, 194
Why study biology, 17
Willstätter, 233 (*see also* Photosynthesis)
Wilson, 29
Windpipe, 434
Wings, 140,* 144,* 202, 203, 212, 318, 340, 393, 400, 414-418
Wollaston, 30
Wood, 145,* 201-203, 207, 214, 220, 258, 261
Wooden tongue of cattle, 789
Worker honeybee, 399, 399* (*see also* Honeybee)
Working hypothesis, 22
Wormian bone, 466
Wuchereria (filaria), 297, 297,* 298, 785

X

X chromosome, 187, 697,* 698 (*see also* Heredity)
Xanthophyll, 863 (*see also* Pigments)
Xerophthalmia, 474, 769,* 772
Xerophyte, 653, 963
Xylem, 133, 141,* 145,* 147* (*see also* Tissues)

Y

Y chromosome, 187, 697,* 698 (*see also* Heredity)
Yeast, 125,* 127, 129, 176, 252-254
  pathogenic, 252-254, 253,* 660
Yolk granule, 375,* 445*
  gland, 371,* 373, 374,* 378
  plug, 445,* 456
  sac, 451,* 452, 455, 455*

Z

Zamia, 142,* 203, 204
Zea mays, 146,* 209-211 (*see also* Corn)
Zein of corn, 89
Zernike, 34
Zona pellucida, 452
Zoogeography, 591
Zooglea, 170
Zooid, 289*
Zoology, 864
Zoomastigina, 275 (*see also* Protozoa)
Zoosporangium, 125, 154, 157, 161, 174, 174*
Zoospore, 115, 116, 118, 125, 154-157, 159, 161, 167, 174, 174*
Zygapophysis, 424
Zygodactyly, 716*
Zygospore, 124,* 125, 158,* 173, 175, 361,* 363
Zygote, 119, 124, 124,* 125, 130, 136,* 138, 143, 150, 157, 158,* 159, 161-164, 173, 175, 185-189, 193-195, 202, 204, 207, 277,* 285,* 361,* 363, 366, 444, 708,* 710,* 711
Zymase, 671, 864
Zymogen, 864
Zymosis, 864