

INVESTIGATING BIOLOGY

A Laboratory Manual for BIOLOGY



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ISBN 0-8053-1830-5

2 3 4 5 6 7 8 9 10—BA—97 96 95 94 93

The Benjamin/Cummings Publishing Company, Inc.
390 Bridge Parkway
Redwood City, California 94065

Preface

In science, as in life, learning and knowledge are distinct, and the study of things, and not of books, is the source of the latter.

THOMAS HENRY HUXLEY, BIOLOGIST AND EVOLUTIONIST (1825-1895)

Our knowledge of the biological world is based on the scientific enterprise of asking questions and testing hypotheses. An important aspect of learning biology is participating in the process of science and developing creative and critical reasoning skills. Our goal in writing this laboratory manual is to present a laboratory curriculum that encourages participation in the scientific process. We want students to experience the excitement of discovery and the satisfaction of solving problems and connecting concepts. For us, investigating biology is more than just doing experiments; it is an approach to teaching and learning.

These laboratory exercises are designed to encourage students to ask questions, to pose hypotheses, and to make predictions prior to initiating laboratory work. Students are required to synthesize results from observations and experiments and then draw conclusions from evidence. Finally, whenever possible, students apply their results to new problems and are encouraged to pursue open-ended investigations of their own design. Scientific writing is emphasized throughout the laboratory manual.

We are convinced that involving students in the process of science by investigating biological phenomena is the best way to teach. The organization of this laboratory manual complements this approach to teaching and learning.

Laboratory Exercises

The laboratory exercises are arranged by topic and in some cases build on information and techniques in previous exercises. The laboratory exercises incorporate a combination of traditional procedures and investigative processes for both experimental and observational exercises. There are basically three types of lab topics included in the manual:

1. Traditional exercises that have been reconstructed to involve students in the process of science. Typically, these traditional exercises have provided students with a procedure to follow and information on the correct results. We have reorganized these labs to include introductory information from which students develop hypotheses and then predict the results of their experiments. They collect their data and summarize it in tables and figures of their own construction. The students must then accept or reject their hypothesis, based on their results. Examples of these traditional laboratories include Lab Topic 2: Enzymes; Lab Topic 4: Diffusion and Osmosis; and Lab Topic 5: Photosynthesis.

2. Traditional laboratory exercises that have been reconstructed to incorporate unifying themes in biology to provide a framework for observations. These exercises have been the most challenging to write, to teach, and to do. We are convinced that observational exercises can be investigative if we provide the evolutionary themes of biology to assist students in summarizing and synthesizing their observations. Students can use their observations as evidence in support of these major concepts and apply their understanding to new problems. Examples of these laboratories include Lab Topic 3: Microscopes and Cells (Unity and Diversity of Life); Lab Topics 13 and 14: Plant Diversity (Adaptation to the Land Environment); and Lab Topics 19 to 21: Vertebrate Anatomy (Form and Function).

3. Open-ended investigations in which students generate their own hypotheses and design their own experiments. These exercises begin with an introduction and a simple experiment that demonstrates procedures. Then students are given suggestions for further investigation and a framework for performing these experiments. Examples of these open investigations include Lab Topic 18: Plant Growth; Lab Topic 24: Ecology II; and Lab Topic 25: Animal Behavior.

Scientific Communication— Writing and Speaking

Scientists must communicate their results in writing and in presentations to research groups and at meetings. Undergraduates need instruction in writing and an opportunity to practice these skills; however, critiquing hundreds of student research reports for each exercise would be overwhelming. Throughout this lab manual, teams of students are asked to organize and present their results to their peers during the discussion and summary sessions in the laboratory. Students are also required to write as part of each laboratory. They summarize and discuss their results and then apply information to new problems in the questions at the end of the laboratory.



We have also incorporated scientific writing into our lab manual in a stepwise fashion. Students must answer questions and summarize results within the context of the laboratory exercises. They also are asked to submit a Results section (Lab Topic 2), Discussion section (Lab Topic 4), Introduction and Bibliography or Literature Cited section (Lab Topic 5), Title Page and Methods and Materials section (Lab Topic 7), and at least one complete paper (Lab Topic 25). Instructions for writing a scientific paper are provided in Appendix A.


Integration of Other Sciences and Mathematics

Students often view biology as a separate and isolated body of knowledge. We have attempted to integrate biology, chemistry, some physics, and geology whenever possible. We provide opportunities for students to quantify observations, analyze and summarize results in tables and figures, and ultimately to use these data to construct arguments in support of their hypotheses.

Special Features

Applying Your Knowledge: As instructors, we want our students to be challenged to think and to develop critical thinking skills. Throughout this manual, students are asked to work logically through problems, critique results, and modify hypotheses. To further emphasize these skills, we have developed a section in each laboratory topic called "Applying Your Knowledge," where students are asked to apply their knowledge to other aspects of biology, to medicine, or to daily life.

Safety Considerations: Safety concerns are noted in the text by the use of icons for general safety  and for biohazards . Laboratory safety is also addressed in the Teaching Plans at the end of each lab topic in the Instructor's Edition.

Notes to Students: To assure student success, cautionary reminders and notes of special interest  are also highlighted in the text.

Appendices: Information needed in several laboratory topics is included in the appendices: scientific writing, using the chi-square statistic, and dissection terminology.

Color Insert: Color photographs are particularly helpful in the study of cells and organisms. Photos and illustrations in the color insert are cross-referenced to the text.

Preparation Guide: A detailed Preparation Guide accompanies the laboratory manual. It contains materials lists, instructions for preparing solutions and constructing materials, schedules for planning advance preparation, suggested vendors, and organization of materials in the lab.

Others: *Fish Farm*, an interactive computer software package, is available as a supplement for exploring the scientific method with students. In a section entitled Investigative Extensions, we suggest topics for additional discussion, library research, and independent investigation.

Instructional Support

Teaching biology using an investigative approach requires that instructors guide students in posing questions and hypotheses from which they can predict results for their experiments. We have included additional support for the instructor in the form of instructor's annotations in each lab topic. Annotations in the Instructor's Edition include simple suggestions, such as accepting hypotheses as long as they are testable, hints for success, and additional explanations appropriate for the instructor. Suggested answers to questions, typical results, and even explanatory figures are included. These annotations are intended to guide the instructor in responding to students, not to provide the right answers to every student question. We encourage instructors to become the guide to discovering rather than the repository of correct answers.

In the Teaching Plan for each lab topic we detail objectives, both for content and for development of skills in problem solving and scientific methodology. We list activities that correspond to specific objectives for

the laboratory so that instructors can integrate concept objectives with features of the laboratory topic. We suggest the order of the lab, estimate the time requirements for each portion of the lab, and provide options for organizing the activities for a two hour lab period. We provide hints on how to manage groups of students and involve them in investigations that might otherwise become passive learning experiences. The Teaching Plan originated from our objective to systematically develop more effective ways to engage students in the study of biology. Instructors should feel free to modify these plans to meet their specific needs.

Acknowledgments

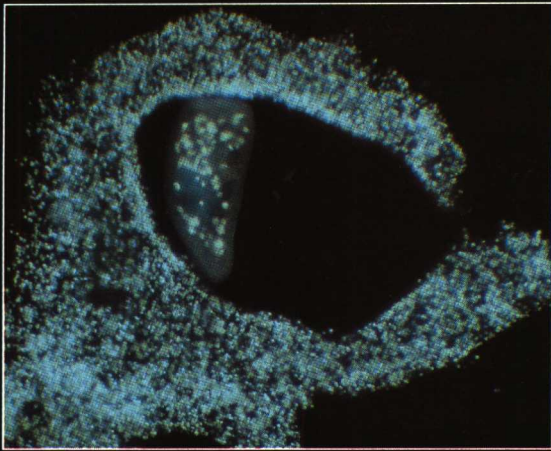
The development of our ideas, the realization of those ideas in laboratory exercises, and the preparation of this laboratory manual are the result of the effort of many colleagues over many years. We are especially indebted to all those laboratory educators who have shared their ideas, hints for success, and philosophies of teaching with us, especially our friends in the Association for Biology Laboratory Education (ABLE). We were fortunate to work with a creative, critical, and supportive editorial group at Benjamin Cummings. Our thanks to Edith Beard Brady, Lisa Donohoe, Korinna Sodic, Larry Olsen, Kelli West, Lynn Sanchez, and Elizabeth Williamson. John Norton contributed artwork, and Janet Greenblatt served as copyeditor. Many colleagues made particularly helpful or critical contributions to our efforts, including Steve Baker, William Brillhart, Joy Budensiek, Katie Dew Floyd, William Murdy, John Pilger, Homer Sharp, Richard Swanson, Theodosia Wade, Margaret Waterman, and David Westmoreland. We are indebted to our teaching assistants, particularly Leanne McGinnis, Jana Mock, Mary Rigger, and Gail Westmoreland, whose critical evaluation and insightful suggestions helped shape the exercises. We thank our students who, over the years, have provided the ultimate tests for these exercises and our ideas. Judith Gore provided expert assistance in preparing the manuscript, and Theodosia Wade helped develop the Preparation Guide. Special thanks to Jean Dickey, who served as a consultant, and to Arri Eisen, the author of Lab Topic 9: Molecular Biology. Finally, we thank our reviewers for sharing their words of encouragement and criticism, which were essential to the success of our work.

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Pseudopodium

Cell membrane

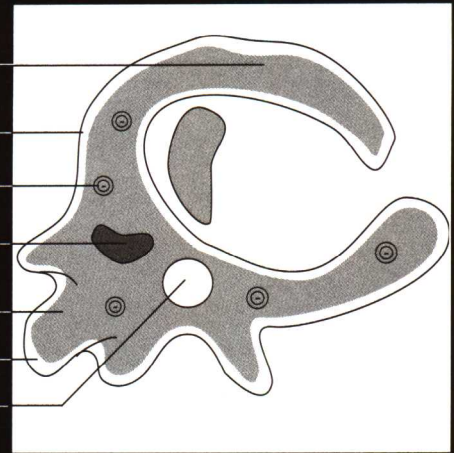
Food vacuole

Nucleus

Endoplasm

Ectoplasm

Contractile vacuole



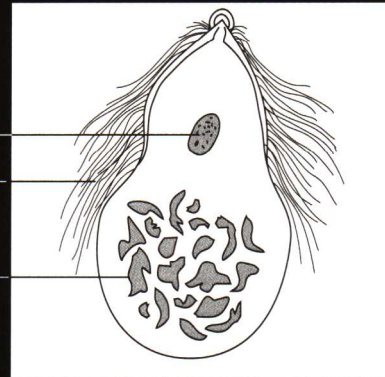
1. *Amoeba* ingests prey by engulfing them in a pseudopodium (Lab Topic 3).



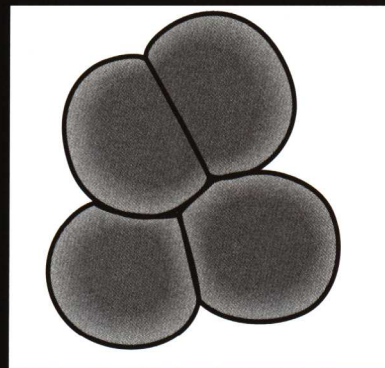
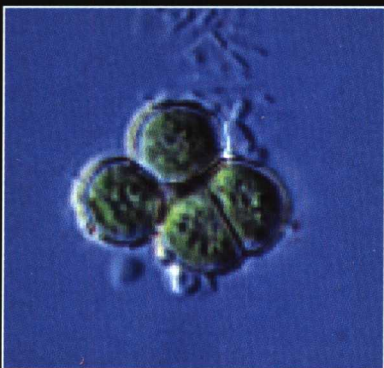
Nucleus

Flagella

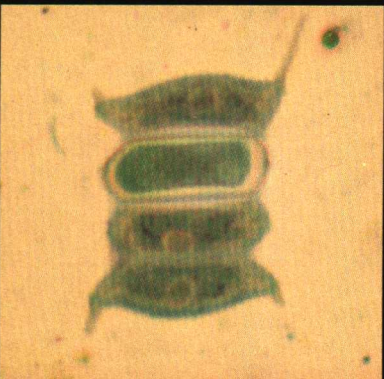
Wood particles



2. *Trichonympha* inhabits termite intestines (Lab Topic 3).



3. *Protococcus*, a green alga that forms loose aggregates on tree bark (Lab Topic 3).

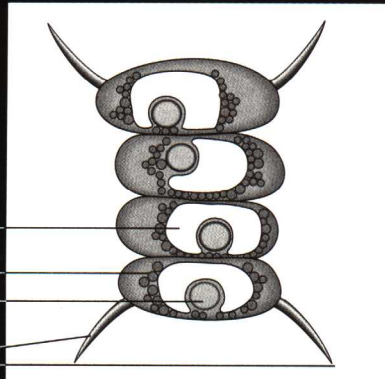


Vacuole

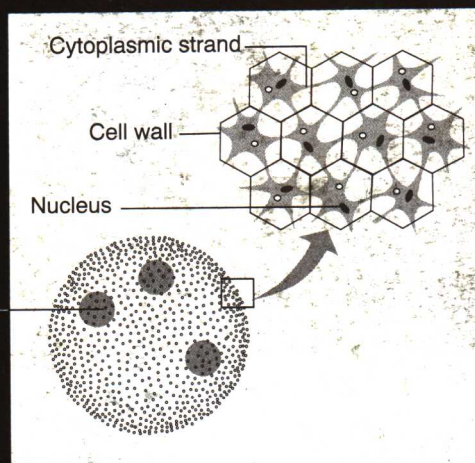
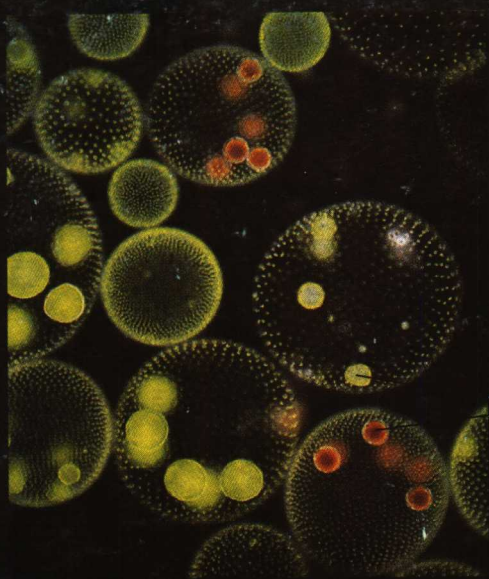
Chloroplast

Nucleus

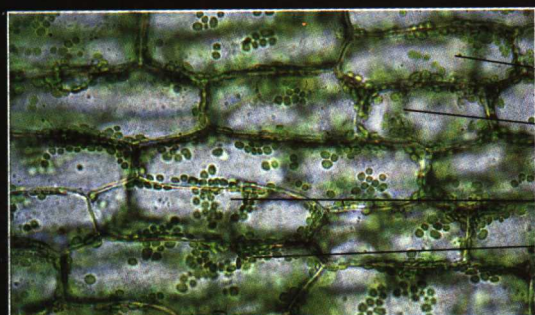
Spines



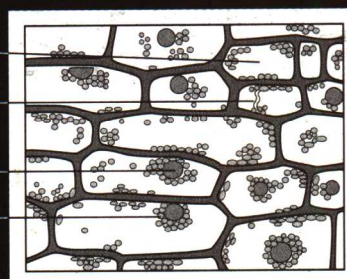
4. *Scenedesmus*, an aquatic alga that occurs in simple colonies of four cells connected by an outer cell wall (Lab Topic 3).



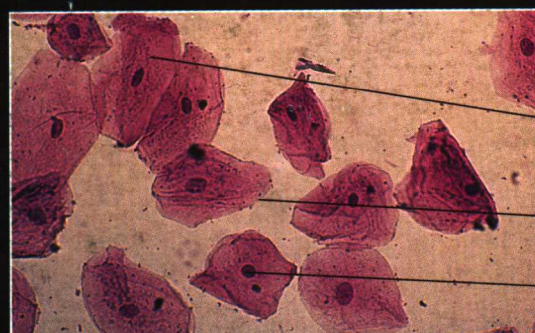
5. **Volvox**. Individual cells in this complex colony are connected by cytoplasmic strands to form a sphere. Red and green daughter colonies are specialized for reproduction (Lab Topic 3).



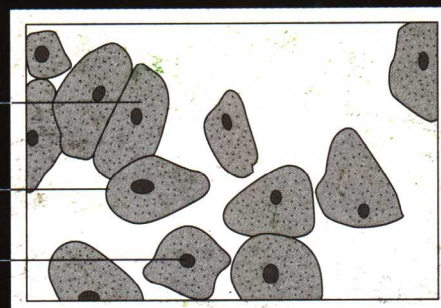
Vacuole
Cytoplasmic strands
Nucleus
Chloroplast



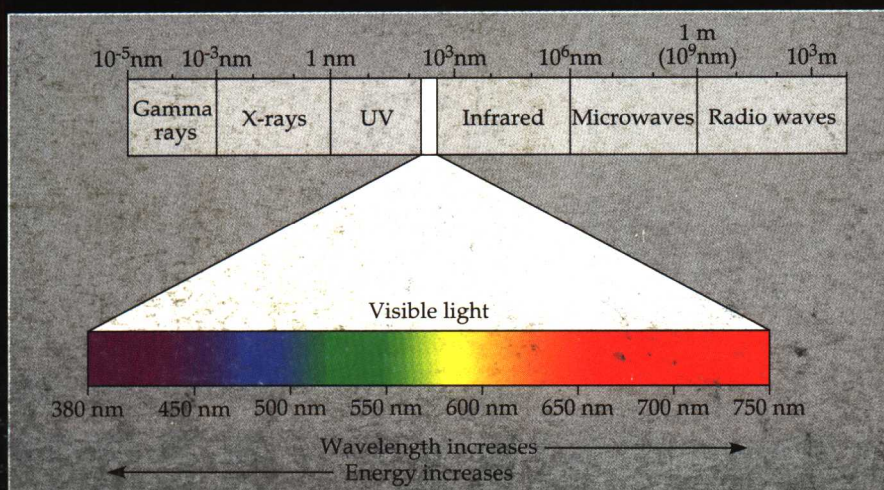
6. **Elodea**, an aquatic plant with a three-dimensional cell shape and a large central vacuole (Lab Topic 3).



Cytoplasm
Cell membrane
Nucleus



7. **Human epithelial cells**--thin, flat cells that line the cheek (Lab Topic 3).



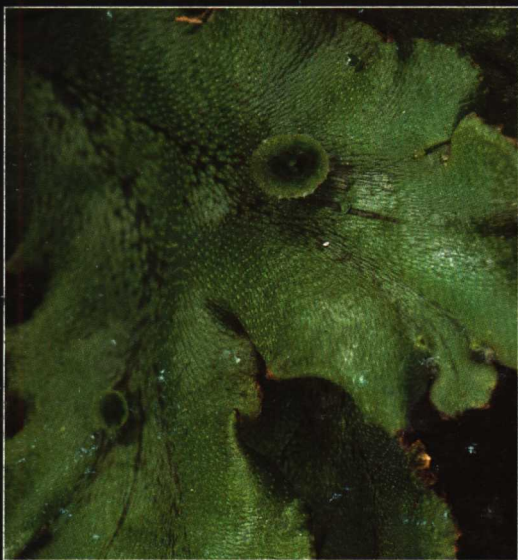
8. **The electromagnetic spectrum** (Lab Topic 5).



9. *Brassica rapa*, shown here growing in a quad, completes its breeding cycle in 35 days (Lab Topic 7).



10. *Talinum*, a succulent commonly found in shallow soils on rock outcrops (Lab Topic 11).



11. Liverworts. Gemmae cups on the surface of this bryophyte function in asexual reproduction (Lab Topic 13).



12. Whisk fern, a dichotomously branched psilopsid found in subtropical and tropical habitats (Lab Topic 13).



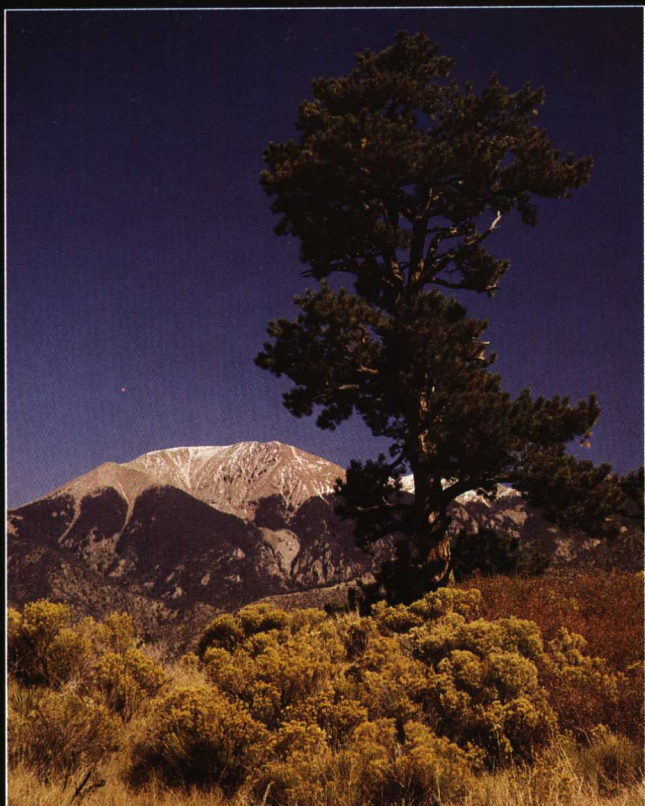
13a. *Lycopodium*. On this club moss, sporangia are seen at the end of the leafy stem, forming strobili (Lab Topic 13).



13b. *Selaginella*. This club moss is a living member of the division Lycophyta (Lab Topic 13).



14. Horsetails. *Equisetum* is seen here with a cluster of sporangia, or strobili, on the tip of one stem (Lab Topic 13).



▲ **15. Coniferophyta.** Conifers are among the largest and oldest organisms on Earth (Lab Topic 14).



▲ **17a. Ginkgophyta.** These pollution-resistant plants are native to Asia (Lab Topic 14).

17c. Ginkgophyta. Ginkgo leaves with male strobili (Lab Topic 14). ▶



▲ **16. Cycadophyta.** Cycads are gymnosperms that produce seeds without fruits (Lab Topic 14).



▲ **17b. Ginkgophyta.** Ginkgo leaves with ovules (Lab Topic 14).

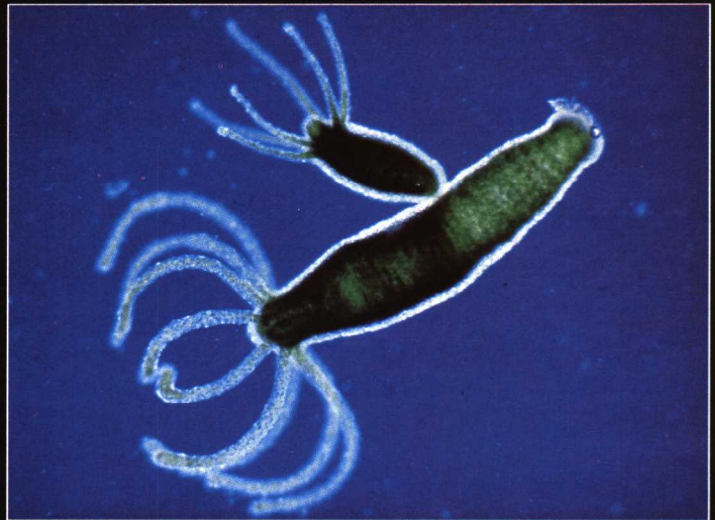




▲ **18. Gnetophyta.** Mormon tea occurs in the deserts of North and Central America (Lab Topic 14).



▲ **19. Sponge.** Needlelike spicules of calcium carbonate protrude from the osculum and surface of the sponge body (Lab Topic 15).



▲ **20. Hydra.** This freshwater Cnidarian reproduces by budding (Lab Topic 15).



▲ **21. Dugesia,** a freshwater planarian with two pigmented eyespots between the two auricles on its anterior end (Lab Topic 15).



22. **Nereis**. This segmented clamworm is an annelid that bears fleshy appendages called parapodia (Lab Topic 15).



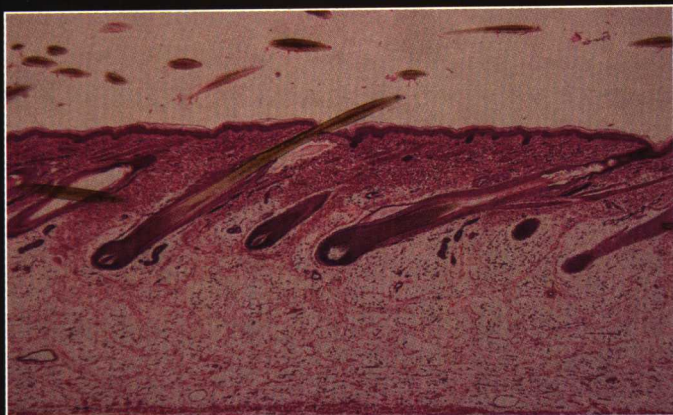
23. **A Pacific clam**. The muscular foot, used for locomotion, protrudes between the valves (Lab Topic 16).



24. **Cambarus**. The freshwater crayfish is a member of the phylum Arthropoda (Lab Topic 16).



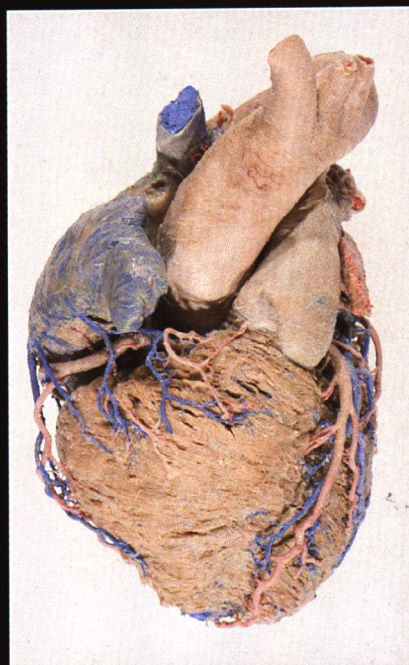
25. **Branchiostoma**. The lancelet is a small Chordate that lives in coastal waters (Lab Topic 16).



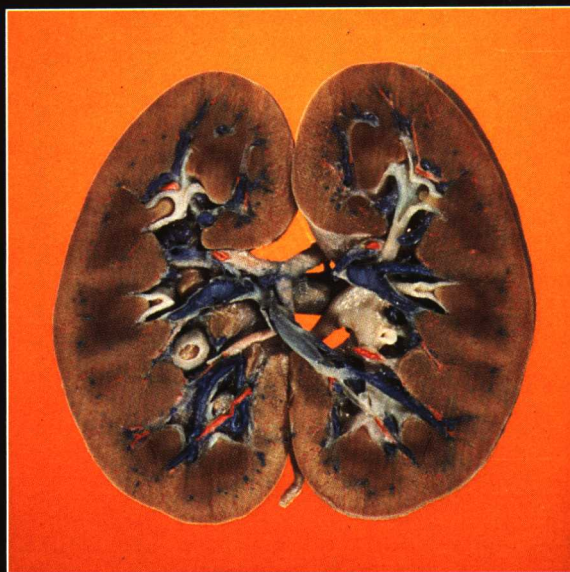
26. **Pig skin**, showing hair follicles, epidermis, dermis, and underlying loose connective tissue (Lab Topic 19).



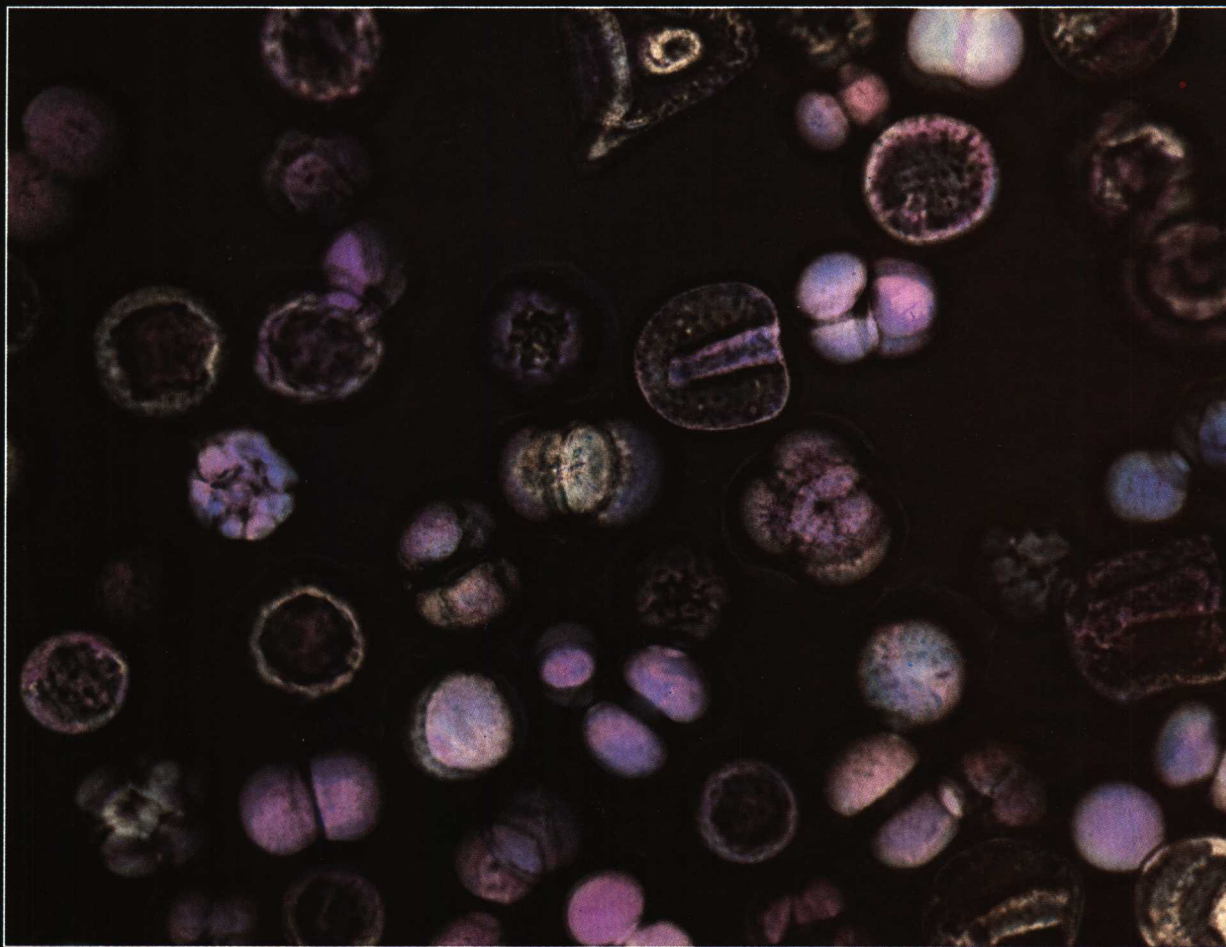
28. **Arteries** (red) and **bronchi** (clear) in a resin cast of lung tissue (Lab Topic 20).



27. **Vertebrate heart**. Lateral view, showing the aortic arch to the left of the pulmonary trunk (Lab Topic 20).



29. **Vertebrate kidney**, frontal section, showing the renal cortex and medulla (Lab Topic 21).



30. **Echinoderm embryos.** Photomicrographs of various developmental stages (Lab Topic 22).



31. **Zebra fish**, newly hatched embryo, 2.5 days past fertilization (Lab Topic 22).



32. ***Betta splendens***. The male Siamese fighting fish displays agonistic behavior (Lab Topic 25).

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Lab Topic 4: Exercise 4.1, Experiment B adapted from Helms, D.R., and S.B. Miller, *Principles of Biology: A Laboratory Manual for Biology 110*. Apex, NC: Contemporary Publishing, 1978. Lab Topic 7: Procedures for Fast Plants adapted from *Wisconsin Fast Plants Manual*. Burlington, NC: Carolina Biological Supply Company, 1989. Lab Topic 8: First published as Morgan, J.G., and V. Finnerty, "Inheritance of Aldehyde Oxidase in *Drosophila melanogaster* in Tested Studies for Laboratory Teaching." *Proceedings of the 12th Workshop/Conference for Biology Laboratory Education (ABLE)*, ed Corey Goldman. Lab Topic 9: Written by Dr. Arri Eisen, Assistant Professor of Biology, Emory University, Atlanta, GA. Lab Topic 10: Modified in part from an exercise in the lab manual by Jon Glase, used in the General Biology Program, Cornell University, Ithaca, NY, and presented at the 1986 meetings of the Association of Biology Laboratory Education (ABLE). Lab Topic 11: Problems 2a,b,c from Ayala, F.J., *Population and Evolutionary Genetics: A Primer*. Menlo Park, CA: Benjamin/Cummings, 1982, 55-56, questions 1, 2, 3; Applying Your Knowledge question is from question 4. Lab Topic 22: Exercise 22.3, Development in the Zebra Fish, is based on an exercise by John Pilger, Professor of Biology, Agnes Scott College, Atlanta, and a workshop presented by Robert R. Cohen, Professor of Biology, Metropolitan State College, Denver, at a meeting of the American Society of Zoologists. Lab Topic 24: Written to correspond with Odum, E.C., H.T. Odum, and N.S. Peterson, *Environmental Decision Making: A Project BioQUEST Simulation*. The Academic Software Developmental Group, Computer Science Center, University of Maryland.