HISTORY OF SCIENCE CASES

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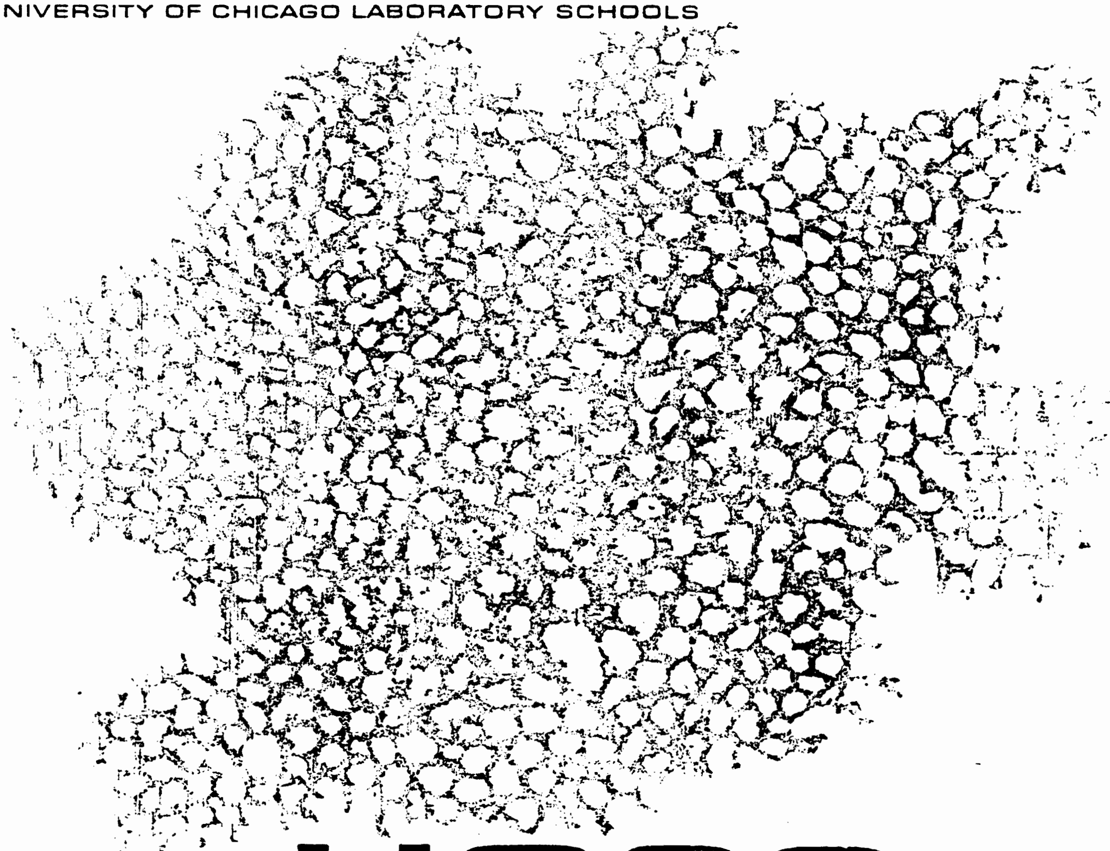
TEACHER'S GUIDE

THE CELLS OF LIFE

LEO. E. KLOPFER

ASSISTANT PROFESSOR OF EDUCATION IN THE PHYSICAL SCIENCES
GRADUATE SCHOOL OF EDUCATION, UNIVERSITY OF CHICAGO
SCIENCE TEACHER, UNIVERSITY OF CHICAGO LABORATORY SCHOOLS



HOSC

HISTORY OF SCIENCE CASES

SRA SCIENCE RESEARCH ASSOCIATES, INC.

ACKNOWLEDGMENTS

The HISTORY OF SCIENCE CASES were developed, beginning in 1956, at the Graduate School of Education, Harvard University. The two persons who, more than any others, provided the inspiration for the development of these new instructional materials were Fletcher G. Watson, professor of education, and James B. Conant, former president of Harvard, who pioneered the use of case histories in collegiate science teaching and edited the series of Harvard Case Histories in Experimental Science. Invaluable encouragement and assistance were also generously given by I. Bernard Cohen, professor of the history of science, Harvard; William W. Cooley, assistant professor of education, Harvard; Leonard K. Nash, professor of chemistry, Harvard; and Derek J. de Solla Price, professor of the history of science and medicine, Yale University.

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More than one hundred high school science teachers in twenty-six states participated in the experimental evaluation of the HISTORY OF SCIENCE CASES during the school year 1960–61. A report of the results of this study may be found in the **Journal of Research in Science Teaching,** Vol. 1, pages 35–47 (1963).

The Teacher's Guides accompanying the HISTORY OF SCIENCE CASES were prepared with the assistance of a group of teachers, including Maurice Belanger, Elba O. Carrier, Abraham Flexer, Roberta Flexer, Allan Furber, Eugene C. Lee, James W. Miller, Muriel B. Niles, Bernard O'Donnell, and John J. Seiler. The notes and comments for the Teacher's Guide to accompany **The Cells of Life** were compiled principally by Maurice Belanger and Eugene C. Lee.

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MATERIALS NEEDED FOR TEACHING "THE CELLS OF LIFE"

PRINTED MATERIALS FOR STUDENTS

Case booklet **The Cells of Life,** one copy per student in the class (SRA Reorder No. 3-1201).

Student reference books (see "Reading Suggestions" on the inside back cover of case booklet).

SUGGESTED TEACHER REFERENCE BOOKS

(The books marked with an asterisk are frequently cited in the commentary of this guide.)

BEVERIDGE, W. I. B. **The Art of Scientific Investigation.** New York: W. W. Norton, 1957.

*CALDER, RITCHIE. **Science in Our Lives.** (Signet P2124.) New York: New American Library, 1962.

*CONANT, JAMES B. **On Understanding Science.** (Mentor MD68.) New York: New American Library, 1951.

CONANT, JAMES B. **Science and Common Sense.** New Haven, Conn.: Yale University Press, 1951.

*GOLDSTEIN, PHILIP. **How to Do an Experiment.** New York: Harcourt, Brace, 1957.

HUGHES, ARTHUR. **A History of Cytology.** New York: Abelard-Schuman, 1959.

*MORHOLT, EVELYN, *et al.* **A Sourcebook for the Biological Sciences.** New York: Harcourt, Brace, 1958.

NASH, LEONARD K. **The Nature of the Natural Sciences.** Boston: Little, Brown, 1963.

*NORDENSKIÖLD, ERIK. **The History of Biology.** New York: Tudor, 1949.

SINGER, CHARLES. **A History of Biology.** 3d ed. New York: Abelard-Schuman, 1958.

*SWANSON, CARL P. **The Cell.** ("Foundations of Modern Biology Series.") Englewood Cliffs, N.J.: Prentice-Hall, 1960.

TAYLOR, GORDON R. **The Science of Life: A Picture History of Biology.** New York: McGraw-Hill, 1963.

*LABORATORY EQUIPMENT AND SUPPLIES	USED IN
Microscopes; slides; cover slips; iodine-staining solutions	A number of experiments
Slides of cork; piths from elder tree or one of the rushes	Experiment 1
Hay infusion; pond scum; water plant (elodea); sauerkraut juice; sour milk	Experiment 2
Plant specimens for observation of cells*	Experiment 3
Sodium chlorate; microprojector (optional)	Experiment 4
Animal specimens for observation of cells*	Experiment 5
Prepared slides of animal cartilage cells†*	Experiment 6
Small tin can; pane of glass; rotary can opener; tin snips	Activity 2

*See the notes on the experiments in the commentary of this guide for further suggestions of materials you may wish to use.

†Almost essential to make a key point in the case.

TO THE TEACHER

In the present-day world it is essential that our students, the citizens of tomorrow, attain a clear and realistic understanding of the nature of the scientific enterprise, of the aims and processes of science, and of the people who are scientists. The HISTORY OF SCIENCE CASES (HOSC) have been prepared to provide you, the science teacher, with a means of guiding your students toward a better understanding of science and scientists.

Understanding Through Case Studies

In the HOSC unit that you are about to teach, this understanding is developed through a critical study of the major events leading to the formulation of the cell theory. As your students look over the shoulders of scientists engaged in creating science, they will witness (and participate in) the struggle to make microscopic observations, the difficulties and dangers involved in interpreting observations, and the rectification of erroneous notions through further research. They will follow the chain of reasoning, often intricate, that connects the broad statement of a theory with hypotheses susceptible to experimental tests, and they will be able to see the variety of personal characteristics that different scientists possess.

Although students studying *The Cells of Life* case will find that it has a good deal of science content, they should be made aware from the beginning that the case is not primarily a vehicle for learning science subject matter. They certainly ought to learn some biology from it (see Sections A and B under "Objectives for This Unit," found on page 10 of this guide), but the primary purpose of the HOSC units—to teach *about* science and scientists—should remain permanently in the foreground. (The particular ideas concerning science and scientists that are illustrated in *The Cells of Life* are listed in Section C of the objectives.)

In the final analysis the goal of the HOSC units is a greater sensitivity on the part of students to the manner in which scientists work and think. If, through the study of one or more cases, students become more alert to certain ideas about science and scientists, they will then look for these and other ideas in their further science readings and in their everyday sources of information. The ultimate goal is that an understanding of science and of scientists will become a functional part of the lives of the students who study these cases. Such an understanding will prove useful to all students in the years to come. For tomorrow's world will require that all citizens—not scientists alone—have an understanding of science.

Materials and Teaching Procedures

Although there is a variety of ways of presenting this case to your class, the suggestions offered in this guide have been found particularly effective in practice. Of course, the instructor can make whatever adaptations and extensions he believes will improve instruction in his class.

Basic to this case is the narrative that appears on the even-numbered pages of the student case booklet. Implicit in this narrative—which tells the story of the early development of the cell theory—are important ideas about science and scientists. In studying the narrative, the students usually will be able to discover these important ideas through thoughtful consideration of the marginal comments and questions to the left of the narrative.

Some of the marginal comments lend themselves to individual and group assignments of supplementary reports based on suitable reference books. Marginal questions, in more detailed form, have been repeated on the page to the right of the narrative, and space has been provided there for students to write their answers. To assure consideration of the important points raised in these questions, it is good procedure to have students write out their answers as homework assignments. They should do so either directly in their case booklets or on separate sheets of paper. However, since the questions in the case booklet are not to be regarded as standard workbook questions, they should not be graded as workbook materials would be. Many of the questions do not have specific answers; and even when definite answers exist, they seldom are explicit in the text. Rather, the questions may be considered as starting points for the processes of discussion, of thinking through problems, of seeking out additional ideas and information, and of personal observation.

Some teachers may wish to give grades for day-to-day assignments of questions. This, of course, can be done. A check of a student's daily work, however, may better help the teacher evaluate the student's progress and his need for help in thinking, researching, and observing in new areas.

The experiments, which also appear on many right-hand pages of the case booklet, are an essential part of this HOSC unit. As many as possible of the suggested experiments, as well as other pertinent ones that the teacher may know of, should be carried out at appropriate points in this study of the case. The additional activities (pages 28–32) in the case booklet suggest appropriate extensions of certain points that are covered in the unit.

Together, the suggested experiments and activities are designed to provide students with an opportunity to develop a variety of abilities and skills. The instructor will need to determine from his own situation which experiments and activities are best carried out by all students and which are best done as special projects by some students only.

With due recognition of the controversy regarding the superiority of experiments over demonstrations, or vice versa, it does seem that for maximum success in achieving the objectives of this HOSC unit it is most important for students to get a feeling for the kinds of problems the scientists in the case were wrestling with. This is surely accomplished most effectively by having students "get their hands dirty" with experiments similar to the ones actually done by participants in the case. Ideally, every student should have a chance to carry out and observe for himself some of the experiments.

The Teacher and the Teacher's Guide

What is perhaps the single most important factor in the study of this HOSC unit is not found in the student case booklet. Instead, the opportunity to supply this factor, which is essential to success, has been reserved for the teacher. The objectives of HOSC can be effectively achieved only through the kinds of bringing out and bringing together that come in the framework of a well-led, intensive classroom discussion. In these daily discussions an important function of the instructor will be to set the stage in the period of history in which the case takes place and to supply some of the background facts and ideas that the students may lack.

In developing effective class discussions and, through them, the improved understanding of science and scientists that students can gain from this case, the instructor will find much help in the "Commentary and Teaching Suggestions" section of this guide. Presented there are general commentary related to the unit, answers and specific commentary related to questions from the student case booklet, notes on student activities and experiments, and references to sources of further background information.

While this guide can supply materials and ideas not otherwise quickly accessible and can give some suggestions for their use, in the long run it is the teacher himself who must make the major decisions as to how these materials can be most effectively used in his classroom to attain the goals of the HOSC units.

SUGGESTED SCHEDULE

The outline in this table will be useful if you wish to teach this HOSC unit in ten lessons, assuming class periods between 40 and 50 minutes long and double periods for student laboratory work, plus one more period for the unit test.

LESSON	CLASSWORK	ASSIGNMENT
		Read introduction and beginning of story, from page 3 to middle of page 4, through ". . . middle of the seventeenth century." Write answers to Questions 1 and 2.
1	Discuss purposes of the case. Discuss importance of observations, their interaction with the observer's ideas, and the role of scientific societies in the advance of science (Question 2).	Read from middle of page 4 to end of page 8, through ". . . by doing Experiment 2.)" Write answers to Questions 3, 4, and 5. Read Experiments 1 and 2. Research and write biographies as indicated in Activity 1. In doing this, answer "What did this man accomplish in science and outside of science?"
2	**Laboratory:** Experiments 1 and 2, Hooke's Experiment and Leeuwenhoek's Animalcules. Discuss Hooke's observations and Question 6.	Read from top of page 10 to end of first paragraph on page 14, through ". . . more than Brown had." Write answers to Questions 6–10. Ask for volunteers to do Activity 2, Make Your Own Microscope, as a project.
3	Discuss questions in Hooke-Leeuwenhoek section (pages 4–10 of case booklet), with emphasis on communication among scientists (Questions 5 and 9), the extension of generalizations (Question 7), and the interplay between science and society (Question 10).	Read from second paragraph on page 14 to end of page 16, through ". . . and significant effect." Write answers to Questions 11–15.
4	**Demonstration or Laboratory:** Observations of Experiment 3, Brown's Discovery. **Demonstration:** Experiment 4, Crystallization. Discuss Schleiden's ideas on cells.	Read chapter on cells in regular biology textbook. Write answers to Questions 16–23.
5	Discuss questions in Brown-Schleiden section (pages 10–17 of case booklet), with emphasis on interactions between observations and the observer (Questions 15 and 19), use of mathematics in science (Question 18), scientific laws and scientific reasoning (Questions 20–22).	Review material covered to date. Read from top of page 18 through fourth paragraph on page 20, ending ". . . occurs in plant cells."
6	**Quiz:** 15–20 minutes (see page 21 of this guide). Discuss the main aims of science (Question 23). Outline Schwann's reasoning and arguments for his cell theory (pp. 20–22).	Study from second paragraph on page 20 through paragraph ending at top of page 26 with ". . . through this effort." Write answers to Questions 24–27.

LESSON	CLASSWORK	ASSIGNMENT
7	**Laboratory:** Experiments 5 and 6, Animal Cells and Cartilage Cells, with discussion of the implications of the observations for Schwann's hypotheses about cells.	Write answers to Questions 28–33.
8	Discuss questions in Schwann section (pages 18–25 of case booklet), emphasizing Schwann's arguments and the interplay of ideas and observations in establishing a scientific theory.	Read from last paragraph on page 24 to end of case. Write answers to Questions 34–37. Do Activity 3.
9	Discuss (1) Virchow's work; (2) self-correcting nature of science (Question 33); (3) open-endedness of science; (4) science vs. technology (Question 35); (5) how one gets to be a scientist (Activity 3).	Answer Question 38 and the review questions found on page 28 of this guide. Answer questions at end of Activity 1. For interested students: Search Flemming's paper in Activity 4, Division of the Cell and Nucleus, for illustrations of how scientists work and think.
10	Have students present biographical reports of Activity 1, Scientists and Nations, and give special reports on Activity 4, Division of the Cell and Nucleus. Discuss: (1) What kinds of people are scientists? (2) What factors influence the growth of science in a nation? Review of the case and the ideas that were developed (Question 38).	Study for unit test.
11	**Unit Test:** Allow one period.	

OBJECTIVES FOR THIS UNIT

A. After studying this unit, students should have basic factual knowledge about the following.

1) The work of Hooke on cells: his observation of cork under a microscope; his application of the name *cells* to the pores he saw there; his use of the idea of cells to explain the properties of cork and of piths.

2) In general, the contributions of microscopists in the century that followed Hooke's work, with particular emphasis on the work of Leeuwenhoek, who first described one-celled plants and animals.

3) The contributions of Robert Brown in this area: his discovery and naming of the nucleus in plant cells.

4) The contributions of Schleiden: his definition of a cell as including a nucleus and a cell wall; his investigation of plant cells to determine their origin; his proposal that new cells grow from the nucleus.

5) The contributions of Schwann: his extensive investigation of frog larvae cells and other animal cells; his demonstration that certain animal tissues have structures that correspond to plant cells, as Schleiden had defined plant cells; his proposal and testing of the theory that "cells are the basic unit of all life."

6) Those notions of Schleiden and Schwann that were incorrect and were subsequently corrected; particularly those corrected by Virchow's *"omnis cellula e cellula"* and by the knowledge that the cell wall is not a distinctive characteristic of all cells.

7) The structure of cells and the function of cell parts.

8) The phases of cell division (if Activity 4 is studied).

B. After studying this unit, students should understand the following concepts and principles (see note at bottom of Column 2).

1) The organism is an organization of cells.

2) Cells arise, grow, and develop through a distinctive life cycle.

3) Similarities and differences exist between plant cells and animal cells.

4) Cells come only from existing cells.

C. After studying this unit, students should understand the following ideas concerning science and scientists.

1) Instruments are used by scientists to extend the senses and to make possible new experiments and exploration of new ideas.

2) A successful scientific experimenter possesses skill in using certain techniques and is capable of making careful observations.

3) A scientist's observations and interpretations are influenced by his preconceptions and background.

4) A scientific theory is a broad generalized statement, or group of statements, that expresses a scientist's views about some portion of the natural universe. A theory serves to correlate and explain many phenomena within its scope and should be fruitful in stimulating new scientific research.

5) A chain of reasoning, often involving many assumptions, connects a theory with hypotheses that can actually be tested by experiment.

6) Diligence and patience can be productive of sound scientific works, even though the available instruments are relatively crude.

7) The choice of materials for study from the great variety available often influences what will be inferred from experiments and observations.

8) A proposed theory may be fruitful of new experimental activity, even though the theory is later found to be incorrect.

9) Free communication among scientists is the lifeblood of science. Scientists communicate with one another through meetings, journals, books, and personal correspondence.

10) Scientific societies are the professional organizations of scientists. Their main functions are to sponsor meetings, publish journals and books, establish high standards of performance, and provide a professional "home" for scientists.

11) Science is an international activity.

12) Scientists are human beings with certain well-developed abilities and some special training. They vary widely in their personal characteristics.

13) Science is different from applied science or technology.

Note: By "understand" we mean that the students should be able to do more than simply parrot back the statement of a principle, concept, or idea. They should understand it well enough to make an application of the principle or to seek out an example of the idea in a novel situation, such as they might face on the unit test for this case.

COMMENTARY AND TEACHING SUGGESTIONS

In this section of the Teacher's Guide, you will find the following instructional aids:

1. General commentary and suggestions related to the introduction and presentation to the class of the total unit and major sections of the unit.

2. All questions from the student booklet as well as answers and/or commentary and teaching suggestions specifically related to each question.

3. Notes on experiments and additional activities.

4. References to additional, related reading matter. (In the text these are referred to only by the author's name. Titles and publishers are included in the list on the inside front cover of this guide.)

5. Sample questions for use in a mid-unit quiz and in a review lesson.

In an effort to simplify reading, all numbered questions, questions within experiments and activities, and questions from quizzes have been printed in the typeface shown below:

What is the cell nucleus?

Definite and factual answers to numbered questions from the student book are printed in the typeface shown below:

Hooke thought that the cell wall was like that in a honeycomb.

Commentary and teaching suggestions—whether of a general nature or oriented toward a specific question—are printed in the same face as this paragraph. Also printed in this face are notes for experiments and activities and the reading references.

When to Use the Unit

Opinion will differ as to the best point at which this case may be taken up during a biology course. Actually there is considerable latitude in making this decision, since students need only a limited knowledge of biology in order to study the case profitably. The case could easily be used at some early phase in the course, when discussion centers on the properties of life, on microscope work, and, of course, on cell theory.

The case is also pertinent later in the course, after students have studied cells and have done some work with the microscope. As pointed out on page 6 of this guide, the primary interest of the case is not in the subject content of biology, but in the methods of science and the work of scientists. High school biology texts are usually highly descriptive in their chapters on cell theory and only rarely are concerned with *how* this theory arose, *who* the people evolving it were, or *what* obstacles they had to overcome. The dynamic background of the cell theory is usually treated very briefly in texts, with only a paragraph or two given to the contributions of Hooke, Brown, Schleiden, and Schwann. The approach to the cell theory in this unit, then, can be used with students who have already studied related materials in biology texts to reinforce their previous learning about cells and to reveal the cell theory in a new context.

Introducing the Unit

For the historical background in the biology of this case, you may wish to consult pages 389–405 of Nordenskiöld. A brief historical account of the cell theory is given on pages 3 to 5 of Swanson.

The unit opens with an exploration of certain aspects of seeing. In class, students may find it interesting to explore such questions as these: Do different people in the same situation see the same things? Does past experience play a part in determining what we see? Do we sometimes see what we want to see?

In a beginning class discussion of the case, particular emphasis might be given to the idea that we may not observe certain details unless our attention previously has been called to these or similar details and we have thus been prepared to see them. To start the unit with dramatic stress on this idea, the instructor can arrange to have a well-dressed girl come into the classroom and stand in front of the class to read a notice. After the girl has left the room, students will be asked to describe what she was wearing.

In this situation the girls in the class are apt to give more complete and accurate descriptions than the boys. Through discussion, students may try to discover what accounts for this and for any other noted variations in observational and descriptional skills. Do girls always observe things in greater detail? Do the results of this experiment imply that girls are generally more observant and therefore better suited to careers in science than boys?

From these topics, class discussion can move naturally to the problems of observing with a microscope and to the first question in the student booklet.

1. Have you ever had the problem of being unable to see something through a microscope because you

didn't know what to look for? Is there any connection between what we expect to see and what we can see? Explain.

Instead of presenting an answer to this question, the paragraphs that follow indicate some directions that the discussion might take and some general approaches to the discussion that should prove helpful. The problem of making careful and adequate observations will recur often and in many different contexts throughout this case. Other especially pertinent marginal questions on the theme of observations are 13, 15, 19, and 38. Further background reading on this subject is found in the chapter on observation on pages 28–32 of Goldstein.

If your students have had previous laboratory work with the microscope, you might wish to discuss some of the difficulties they had in obtaining good views of common objects under it. If students have not worked with the microscope, some of the following ideas will be useful in introducing and maintaining an interesting discussion.

A. High-magnification, close-up photographs of common objects can be shown. As each picture is shown, students can be asked to identify the object depicted. (Such photos are frequently printed in magazines and science books.)

B. "Hidden figure" pictures can be used to emphasize that we often do not see things unless we already know of their existence. Ask the class to look at the pictures, but do not mention the hidden figures. Then tell the class of the existence of the hidden figures and, perhaps, which particular figures are hidden in each picture. Let the group discuss why it is easier to see the figures after they know what to look for.

C. Historical examples of scientists seeing the significance of their observations may help students understand how important both seeing and understanding the significance of what is seen are to science. Some examples follow.

1) Newton's observation of the falling apple, leading to his formulation of the law of gravitation.

2) Galvani's observation of the twitching of dissected frog legs when an electrostatic machine was discharged nearby (see Conant, pages 74–77).

3) Pasteur's observation of the presence of microbes when wine was fermenting, leading him to associate living organisms with fermentation and, later, with disease.

4) Fleming's observation of the destruction of bacteria on Petri dishes when a penicillin mold, blown in through an open window, settled on them (see Calder, pages 91–95).

Some personal traits important to good scientific seeing are worthy of class discussion. Several examples of these are presented below.

A. *Open-mindedness*—the ability to interpret observations with a minimum of preconceptions.

B. *The ability to see by association*—the ability to see something new in terms of something old and more familiar. (An example of this kind of seeing is found in this case in Hooke's description of cork by comparing it with a honeycomb.)

C. *Intellectual honesty*—the willingness to see what is actually there rather than what one has been told is there. (Sometimes students will observe an object under a microscope and be reluctant to sketch what they actually see. Instead, in making their sketches, they would rather use as a model a picture or diagram of what they think they should see.)

Starting the Story—Pages 4-8

From the middle of page 4 through page 8, this case deals with the observations of the seventeenth century microscopists, particularly the work of Hooke. Emphasis in this section is on the interaction of observations with a scientist's ideas and the use of these ideas in the explanation of observed phenomena.

Experiments 1 and 2 belong to this section; Experiment 1, Hooke's Experiment, is especially valuable for the students themselves to try in the laboratory. Some students may also want to do Activity 2 as a project. You may wish to encourage this, especially if there is a shortage of microscopes. The essays suggested in Activity 1 can be assigned to individual students at this time, but it is probably best to postpone classroom discussion of this activity until the last section of the case.

The seventeenth century period of microscopics and microtechnology is rather fully treated on pages 158–66 of Nordenskiöld, although Hooke is not included in the account. This deficiency can be remedied by referring to E. N. da C. Andrade's excellent article on Hooke in *Lives in Science* (a Scientific American Book), pages 31–44.

Class assignments and discussions for this segment of the case can be centered on the questions and experiments listed below.

2. What are scientific societies? What purposes do they have? Do you know any present-day scientific societies?

Scientific societies and associations are professional organizations of scientists. They promote the progress of science through their various activities and functions. Scientific societies sponsor meetings, making possible formal and informal contacts among scientists; publish journals and books; stimulate and sometimes finance research; establish standards in terminology and physical measurements; help to publicize science and the work of scientists; and provide a focal point (a "home") for scientists.

Some scientific societies are sponsored by national governments (the French Academy of Science is an example). The vast majority, however, are organized by the scientists themselves. Generally such societies are voluntary associations of scientists working in a particular field. A few very large associations (for example, the American Association for the Advancement of Science) include scientists from many fields.

Today there are hundreds of scientific societies, large and small, throughout the world. One estimate cites more than nine hundred active scientific and technical societies in the United States alone. Some of the best-known of the world's scientific societies are:

Academy of Sciences of the U.S.S.R. (Russia)
Académie des Sciences (France)
Royal Society of London (England)
Deutsche Chemische Gesellschaft (Germany)
American Association for the Advancement of Science (U.S.)
American Chemical Society
American Institute of Physics
American Institute of Biological Sciences

For further discussion of the stimulating role played by scientific societies, see Conant, pages 71–72, and Calder, pages 7–16.

3. How does a scientist learn good techniques? Name two or more ways. Do good techniques come more easily to some people than to others? Do some people have a special scientific aptitude? Explain and defend your point of view.

Techniques your students have learned thus far in your biology course could be discussed here. Perhaps the class has had a laboratory experience in which some students were successful and others were not. Experiences in which success is dependent on student skill in the use of proper laboratory or computational techniques might be reviewed and discussed in the light of these questions. Particular emphasis might be given to techniques students have learned for using the microscope and for preparing temporary slides.

For a discussion of techniques see Goldstein, pages 92–93.

A scientist learns good techniques through his training. He learns them through observing the techniques of skilled people, through carefully following directions in books and manuals, through practicing good techniques. Beyond this, as a result of experience and thought, he learns a more inclusive technique—the careful planning of the sequence of operations and techniques that will be used in a specific situation.

Do good techniques come naturally? At present the answer to this question is not known. There is not yet sufficient evidence to enable us to decide whether a person who demonstrates skill in scientific techniques has learned them or whether there is an inborn, hereditary trait or aptitude for science. It is generally agreed that some people seem to "have a scientific bent," or "lean toward science," or "learn science easily," but such descriptive phrases do not provide conclusive evidence that these people have had a scientific aptitude from birth.

Moreover, to date there has been no real consensus regarding what traits constitute scientific aptitude, although much effort by psychologists and educational researchers is being devoted to this problem. Jobs in science are very diverse and require a variety of aptitudes. For example, a chemical experimenter would probably need great manual dexterity, but a theoretical physicist might not. It may be that workers in each branch of science, and even experimentalists and theoreticians within the same branch, must have different aptitudes and abilities.

4. What does Hooke mean by the mathematical expression "in proportion to"?

Hooke refers here to proportion in the sense of mathematical ratio. The mathematical relation of size of the pores to the size of the cell walls in cork is about the same as the size ratio of the pores in a honeycomb to their wax walls.

(Here is an example of careful observation and of the association of a new observation with something that is already known. You might question your students about the details that Hooke observed. This will be especially pertinent if they themselves have already made similar observations on cork, as suggested in Experiment 1.)

NOTES FOR EXPERIMENT 1: Hooke's Experiment

This experiment should give the student some understanding of how difficult it is to prepare materials properly for observation. For unless the cork can be sliced very thin, only a large, dark object will appear in the microscope. (You can relate this experience to

Question 3, which deals at length with the importance of good techniques.)

Not until it became possible to prepare thin slices of biological materials could much progress be made in the theory of cells. If you wish to discuss further the relation between technique and scientific progress, you may want to deal with developments in microscopy and in staining and preserving techniques that occurred after 1860. These will illustrate how technical improvements made possible the increased magnification and resolution in microscopes, and allowed scientists to examine a variety of tissues.

Do you see the cells that make the cork "not unlike a Honey-comb"?

Hooke, of course, did not see cells. Rather, he saw the cell walls of cork cells. The cork was long dead and the cells themselves had disintegrated. Students, too, see cell walls and not actual cells. Students need to realize that Hooke did not observe cells if we are defining the word *cell* in terms of modern cell theory. Even when we say that "Hooke saw the cell walls of cork cells," we are innocently bringing into our thinking three centuries of investigation. (This point is strongly related to Question 1.)

Do you get a better view than you did the first time? In the space below, explain why viewing did or did not improve.

Students should be able to see the preparation better when they use the drop of water. When added to the slide, the water acts as a lens by the principle of refraction.

Can you see any more under the high-power lens (which Hooke did not have)?

Students usually believe that they can see more with increased magnification (high power). You may wish to discuss this point, stressing that increased magnification is accompanied by decreased illumination as well as by problems of resolution.

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5. How does a scientist find out about the work of those who have gone before? Suggest at least five different ways.

This is the first of three questions concerned with the means of communication among scientists. Variations on this theme occur in Questions 9 and 16.

A scientist may learn about the work of his colleagues through (a) published books; (b) articles in journals; (c) courses, lectures, and seminars; (d) papers presented at meetings of scientific societies; (e) informal talks with people he sees at meetings; (f) personal correspondence with other scientists; (g) consultation with someone who is more familiar with a given field than he is.

6. You can account for these characteristics of cork as Hooke did. Use the idea that cork has cells containing air to explain why—

A. Cork is light compared with other woods. Hooke's own words (as given in "Micrographia"): "First, if I enquir'd why it was so exceeding light a body? my *Microscope* could presently inform me that here was the same reason evident that there is found for the lightness of froth . . .; namely, a very small quantity of a solid body, extended into exceedingly large dimensions."

B. Cork floats on water. ". . . our *Microscope* informs us that the substance of Cork is altogether fill'd with Air, and that that Air is perfectly enclosed in little Boxes or Cells distinct from one another."

C. Cork is compressible. "Our *Microscope* will easily inform us, that the whole mass consists of an infinite company of small Boxes . . . which is a substance of a springy nature, and that will suffer a considerable condensation . . . it seems very probable that those very films or sides of the pores, have in them a springing quality, as almost all other kind of Vegetable substances have, so as to help restore themselves to their former position . . ."

You may wish to stop a moment to call the attention of your students to what they are doing in answering this question. A number of observations (cork is light, floats, is compressible) are all explained by applying Hooke's generalization about the nature of cork. Thus we have here an example of the relation of a generalization to specific observable phenomena. These matters are still further pursued in the following part of Question 6.

Would you call what you have just done an example of applying a scientific theory? Back up your answer.

No, this is not an example of applying a scientific theory, because Hooke's idea is not a theory. His statement that cork is made up of pores is a generalization that is based directly on his observations and covers only a very narrow scope.

A scientific theory is a broad generalized statement of a scientist's views concerning some portion of the natural universe. It consists of a small number of postulates that often can be expressed in mathematical form. In the physical sciences today, the postulates of most of the major theories are stated as mathematical equations. In the field of biology, on the other hand, there are at present few theories that can be expressed in mathematical form. The cell theory, with which this case deals, is in this sense rather typical of theories in the biological sciences.

Whether or not a theory will be acceptable to scientists is determined by how well it performs. One criterion for the acceptability of a theory is that it should explain in abstract terms the observations and generalizations in the area it covers. This is sometimes called the explanatory function of the theory. Another criterion for acceptability, known as the correlative function of the theory, is how well it ties together in a consistent, rational manner the various phenomena and generalizations in its area. A third criterion for the acceptability of a theory, called its heuristic function, is whether or not it is fruitful of new hypotheses and new experiments. Testable hypotheses can be deduced from a scientific theory's postulates, in somewhat the same way theorems are deduced from postulates in geometry. (An illustration of this procedure is taken up later in the case, on pages 20 to 22.) An acceptable theory must lead to numerous problems for research investigation.

Though biology is relatively poor in broad general theories from whose postulates hypotheses can be deduced, it is rich in generalizations, sometimes called biological principles. An illustration of how such generalizations can be formulated and applied is provided by the work discussed here. Hooke observed three distinctive properties of cork. He also observed thin slices of cork under the microscope and reached the generalization that cork is made up of tiny air-filled pores. Applying this generalization, he found that it accounted for the three observed properties of cork. Thus generalizations do have an explanatory function in that they can be used to account for a number of observed phenomena.

Students frequently misuse the word *theory* in such statements as "That's just a theory!" or "That's so in theory, but not in practice." Since such phrases have become part of our common language, it may be difficult for you to teach the precise use of the term in science. The effort is worthwhile, however, since knowledge of what scientists consider a theory to be and what they expect from it are an important part of understanding science. Moreover, we shall be dealing with the formulation and functions of a major biological theory in this case and several related questions will be coming up. (See Questions 20, 24, 26, 27, 32, and 33.)

Note that the brief mention of the term *theory* on pages 31–33 of Calder is both inadequate and misleading. Conant, on pages 57–58, prefers not to use the word because of confusions connected with it. Instead he uses the term *conceptual scheme* throughout his book for what we are here calling a scientific theory.

7. Are Hooke's calculations correct? Check them to find out.

Hooke's calculations are correct. If there are 60 cells in 1/18 inch, then there are 60 × 18, or 1080, cells in a linear inch.

$(1080)^2 = 1{,}166{,}400$ cells in a square inch
$(1080)^3 = 1{,}259{,}712{,}000$ cells in a cubic inch

8. Piths are light and compressible. They float on water. Use Hooke's generalization to explain these characteristics of piths. By the way, what is Hooke's generalization now?

Hooke's generalization is now extended to the piths of a variety of plants. It might be stated in this way: The piths of some trees and vegetables have a similar microscopic structure, consisting of cells containing air. This extended generalization can be used to explain the properties of pith in much the same way that the properties of cork were explained in Question 6.

Students who have not become familiar with pith through work on Experiment 1 might examine elder pith at this point to observe its lightness, compressibility, and buoyancy. The structure of a variety of plant piths that the students have brought in could be examined microscopically in a lab session.

9. Why do scientists publish books and papers about their work? (This is a double-barreled question. As regards the advance of science the reasons are quite clear, but scientists also have personal reasons for publishing books and papers. Your answer should include both kinds of reasons.)

From their work on Question 5, students may have come to realize that communication is the life-blood of science. (See, too, pages 86–88 of Goldstein.) Further comment on this phase of the question is probably unnecessary. Students will be likely to find the scientist's personal reasons for publication are the subject matter for an interesting discussion.

Scientists' personal reasons for publishing include the following.

A. The publication of a paper describing his research assures a scientist credit for his discoveries and thus helps establish his professional reputation.

B. A scientist's ability to obtain grants to finance continued research is frequently dependent upon his publishing a paper every so often. At many universities where scientists work, publications are also a must for advancement and are even necessary in keeping a position.

C. There is a great deal of personal satisfaction in seeing an account of one's own work in print in a good journal. Being human, scientists enjoy adulation no less than anyone else.

D. Scientists have to eat. Publishing a book may sometimes be a profitable proposition.

NOTES FOR EXPERIMENT 2: Leeuwenhoek's Animalcules

If students have difficulty seeing protozoa because of their rapid movement, these movements can be slowed down by using a solution of clear gelatin. "Prepare a 2 to 3 percent solution of clear gelatin by dissolving in cold water and then heating gently until dissolved. Allow to cool at room temperature and add 1 drop of this to a slide along with 1 drop of culture containing the microorganism." (Evelyn Morholt, *et al.* A SOURCEBOOK FOR THE BIOLOGICAL SCIENCES, p. 314. New York: Harcourt, Brace & World, 1958.)

The variety of the shape of cells and microorganisms is illustrated on pages 13, 14, 16, and 17 of Swanson. For some interesting comments on cell size, see pages 18–23 of Swanson.

Nonpathogenic bacteria can be grown by standard procedures with an inoculation from sour milk. The bacteria are *Bacillus lactis*. Directions can be found on pages 118 and 119 of Morholt.

A number of comments can be made about Leeuwenhoek at this point in the unit. (The biographical account by Clifford Dobell, listed in the student case booklet, is excellent.) Leeuwenhoek studied Infusoria and Rotifera. He opposed the view that these arose from putrefaction and stated that they possessed reproductive structures and reproduced by means of them. His observations and descriptions show that he also examined *Hydra* and *Volvox*.

Leeuwenhoek's work demonstrates the importance of new instruments in the development of science. Not only did microscopes reveal a new world of life, but they brought about a questioning of ideas of spontaneous generation a long time before Pasteur.

10. Is a scientist's choice of problems to be investigated often influenced by events quite outside science, or are scientists working pretty much in an ivory tower that is quite isolated from the rest of society? Do you know any present-day examples to back up your opinion?

Science is not isolated from but is, to a large degree, the product of the prevailing culture in which it exists. Factors that determine how well, if indeed at all, science will flourish in a particular culture include:

A. The conduciveness of the general climate of opinion to scientific inquiry.

B. The maintenance of an adequate educational system to train competent scientific investigators.

C. The provision of sufficient financial backing for science personnel, materials, and institutions.

D. A relatively unrestrictive atmosphere in which scientists may pursue their creative work.

Since the degree to which these desiderata are met will vary from culture to culture and from time to time, the extent of scientific activity and achievements varies from one nation to another and throughout the history of one nation.

Present-day examples of the general culture's influence on science include:

A. The great amount of research in atomic physics and the space sciences in the United States due to government interest in these areas.

B. The present shortage of scientists in the United States caused by society's earlier apathy toward adequate education in the sciences.

C. The current emphasis in Japan (where research funds are relatively scarce) on such fields as theoretical physics and genetics—areas that require minimal equipment.

For further discussion of society's influence on scientific discovery, see pages 57–59 and 182–85 of Calder. Also see pages 69–70 and 109–10 of Conant. Note that this question can be tied in nicely with some of the questions raised in Activity 1.

Contributions of Brown and Schleiden to the Cell Theory—Pages 10-17

Beginning with the second paragraph on page 10 we finally get down to the main business of the case, the establishment of the cell theory. Pages 10 through 17 deal with the contributions of Brown and Schleiden. The emphasis here is on observation and description. Teachers may find it advisable to treat this section rather quickly, so that there will be more time for an adequate treatment of the following section, which is considerably more difficult.

Experiments 3 and 4 and Activity 3 are pertinent to this section. Experiment 2 lends itself best to individual laboratory work and is quite essential for an understanding of Brown's accomplishment. If you have the equipment, Experiment 3, which deals with crystallization, can be effectively demonstrated by microprojection. Activity 3 can help your students appreciate Schleiden's contribution, but it is probably best not to spend time in discussing this activity here. Instead, the discussion may be postponed until the time when the biographies of Activity 1 are also taken up.

The historical background for this section is given on pages 389–94 and 436 of Nordenskiöld. Pages 27–30 of Swanson may also be helpful.

11. What do all the big words mean? Define: mode of fecundation; Orchideae; Asclepiadeae. (Note that Brown used the ending "-eae" for plant families, whereas today we usually use the ending "-aceae.")

Mode of fecundation: means of reproduction or proliferation.

Orchideae: a family of plants, the orchid family. This large plant family, second in size only to the Compositae family, comprises about 10,000 species and represents the highest point of development in the monocotyledons.

Asclepiadeae: another family of plants, the milkweed family. This family of dicotyledonous plants in the order Gentianales contains more than 1700 species, many of them particularly abundant in the tropics.

NOTES FOR EXPERIMENT 3: Brown's Discovery

Can you see the cells more clearly than before?

Students should be able to see the cells more clearly when iodine solution is added to the wet mount. Iodine can also be added to other slides of plant cells that students make and a comparison made of the cells with and without stain.

What is the importance of proper technique?

Proper techniques are important because they help make possible observations that can be used to answer questions about the natural world.

Simple techniques can be illustrated in this experiment. Discussion of the following problem in technique may prove illuminating. "You already have a drop of water on the tissue you are examining, and a cover slip is over the tissue. If you raise the cover slip and add a drop of iodine, you may get too much liquid on the slide and the mixture will then spill on the stage. How would you get just enough iodine on the tissue without removing the cover slip?" (Place a drop of iodine just to one side of the cover slip. On the opposite side, apply a piece of paper toweling or blotter. The liquid under the cover slip will be drawn off onto the tissue by capillary action, and the iodine will then be drawn under the cover slip.)

Although such demonstrations are simple, they can stimulate students to think about techniques and their roles in science. A recent example of new techniques and their successful application has been the one developed by Dr. John Enders which made it possible to grow viruses in test tubes. This technique enabled Dr. Jonas Salk to grow an attenuated virus in a test tube. He used the attenuated virus to develop a vaccine against polio.

In the second part of this exercise plants from an aquarium (for example, *Elodea*) or cells from citrus fruits could be examined.

Do all the plant cells you have examined have a cell wall?

In their sketches of the onion cells, students can draw cell walls and then cell membranes. Ask your students if they actually see a clear distinction between the cell wall and the cell membrane. Perhaps they only "see" the cell membrane because they know one should be there. Refer your students to Question 1 once more.

Using *Elodea* as a takeoff point, you may wish to pose the following problem to your students: "How could we gather evidence to determine whether there is a cell wall and also a cell membrane?" Again some technique is required. When a drop of strong salt solution is added to the slide, plasmolysis will result. There will then be a clear distinction between the cell wall and the cell membrane. (If your students have not studied osmosis before, we suggest that you do not teach the concept at this point.)

Actually, however, this is not very good evidence that there is a cell membrane, and students should not accept it as proof that such a thing does exist. Again, you could question your students on whether they believe there is a cell membrane simply because they have been told it is there.

Plasmolysis gives limited evidence only, but it is a bit better than what can be learned through simple observation of onion cells. The role of evidence will become crucial later in the case, during the discussion of Schleiden and Schwann.

Do they all have nuclei?

There will be considerable variation in the observations of plant cells. Some plants show a clear nucleus without stain. Some require staining. Some sections of tissue may not contain the nucleus, some nuclei may be hidden by chloroplasts, and so on. Your students should not have the idea that, on the basis of the evidence they have seen, they have demonstrated that all cells contain a nucleus.

What generalizations, if any, can you make on the basis of your observations?

As evidence is gathered, there comes a moment when one can make a generalization. But when is that moment? When is there enough evidence to justify a generalization? There is no clear answer. The amount and kind of evidence needed to justify a generalization fall in an area of decision where guidelines are fuzzy.

Sometimes it is many years before enough evidence is in to produce good generalizations. (Recall the nearly two hundred years between Hooke's work and the work of Schleiden and Schwann.) On the other hand, a generalization, or even a law, can be destroyed quite quickly. For example, several years ago scientists at Columbia University proposed some new theoretical ideas. A group of physicists took up these ideas, tested them, and within two weeks a basic law of physics—the principle of parity—was destroyed. For this work the participating scientists received a Nobel prize.

From his observations a student is justified in generalizing that plant cells seem to have a nucleus, a cell wall, and a membrane that can be separated from the cell wall.

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12. Where are the various parts of the flower that Brown refers to? On a diagram or model of a flower, locate epidermis, stamens, styles, floral envelope, stigma.

The intent of this question is not to have students memorize the names of the floral parts but, rather, to provide some orientation for Brown's description. To provide an answer to the question, refer to a diagram of the floral parts in any biology textbook.

13. Do you think Brown was a careful observer? In your opinion, was he born with this skill? What makes you answer as you do? Back up your opinion with facts.

From the brief sample of his writings, we can surmise that Brown **was** a careful observer. This impression was confirmed by his reputation in his lifetime and by some of his other work. For example, he was the first to report a clear-cut observation of the phenomenon now called Brownian movement.

It is the contention here that Brown was **not** born with his skill as an observer. Rather, he developed this valuable asset through many years of practice and effort. It may be that there are people of certain personality types who do have some sort of predisposition for becoming good observers, but so far there is no reliable evidence to support such a claim. (On this point, refer again to Question 3.)

It is perhaps worthwhile to point out here that, although Brown observed well, he really did not see the importance of his observation in this instance. (Recall some of our comments under Question 1.) Why was this so? Was it that Brown was primarily an acute observer and classifier of plants and therefore could not or would not take the intuitive leap that would point out the significance of his discovery of the plant nucleus? Were there personality differences between Brown and Schleiden, who did take this intuitive leap? Which course of action is it more "proper" for a scientist to take? (See the illuminating discussion and very appropriate illustrations for this discussion on pages 131–34 of Goldstein.) There is no pat answer to any of these questions, but your students should enjoy discussing them. (More on this theme will be presented under Question 15.)

14. In what ways are the monocotyledons and dicotyledons similar? How do they differ?

Monocotyledons and dicotyledons are similar in that both are plants that have their seeds enclosed by structures called ovaries. In addition, both belong to the angiosperm division of the spermatophytes.

The major differences between monocots and dicots are:

A. In monocots the veins in the leaves are parallel; in dicots they are netted.

B. In monocots the flower parts are in multiples of three; in dicots they are in multiples of four and five.

C. In monocots there is a single cotyledon per seed; in dicots there are two cotyledons per seed.

D. In monocots fibrovascular bundles are scattered in the stem; in dicots the vascular tissues of the stems are arranged in a circle surrounding the central pith. Cambium is usually present.

15. Explain the meaning of the awkward sentence, "Improved compound microscopes . . . helped Schleiden to see more and to 'see' more than Brown had." (Some of the remarks made on the previous pages should help you figure out the meaning.) Could you say the same thing in some other way?

Against the background of the remarks in the case and some of the comments in this guide, the meaning of this sentence should not be too obscure. It is certain that improved compound microscopes enabled Schleiden to make better observations, but good observations in themselves are not sufficient to bring about a significant scientific advance. (Witness the very interesting, yet largely unfruitful observations of Hooke, Leeuwenhoek, and Brown.) What is needed in addition is an insightful interpretation of the observations. It is to Schleiden's great credit that he was able to provide a meaningful interpretation of the plant cell nuclei that he observed.

The materials for observation are supplied by nature, though nature often needs a little prodding. (This is provided by the scientist's use of instruments.) But the interpretation of observations can come only from the scientist himself.

16. What kind of publication was this "Archiv"? List at least three different functions such publications serve.

The **Archiv** was a scientific journal in which experiments and ideas of workers in the scientific fields it served were published. Such publications provide one of the major channels of communication between scientists.

Communication between scientists is essential for the rapid progress of science. It often happens that scientists in different parts of the world are working on the same problem at the same time. If it were impossible for them to communicate and share their findings with each other, much duplication and wasted effort would occur. Moreover, through communication the work of one scientist may serve to complement and enhance the meaning of the work of another scientist thousands of miles away.

Scientific journals also serve as a forum for the discussion of new ideas and new interpretations of experimental and observational results. In addition, publication of the accounts of experiments in journals enables other workers to repeat these experiments, or variations of them, and to verify or modify the findings. Thus the exchange of scientific writings between members of the scientific community through journals also helps to keep the individual scientist honest.

Today the volume of journal articles being produced is so large that special abstracting journals also are being published. An abstracting journal contains brief accounts of recent articles from a particular field of science that have been published in many other journals in countries throughout the world.

17. What is important about the choice of material that Schleiden makes? (You may not be able to answer this question until you've read on for a few pages. But it's an important question, so be sure to come back to it.)

As indicated, your students probably will not be able to provide a satisfactory answer to this intriguing question until the subject has been further developed in the case. Accordingly, you should use your judgment as to when to discuss it in detail. Questions 34 and 37 are related to the same theme, but it is probably best to call attention to the two instances where choices of materials played an important role at the points in the case where they appear.

The choice of materials for study from the great variety available often influences what will be inferred from experiments and observations. If an atypical material is chosen, the inferences drawn from a study of this material may be vitiated by later investigations of typical materials of the same class. On the other hand, experiments with typical materials may be quite impossible with the means and instruments available at a particular time, so that an experimenter may be fortunate in choosing a material for study that has some property making it experimentally assailable but that, at the same time, is still representative of its class. Below are examples of choices that made a difference.

A. Schleiden chose to study reproductive cells in plants, but these cells have atypical growth mechanisms. Taking their growth mechanisms as typical helped him make an inference that was later shown to be incorrect. (This answers the above question.)

B. Schwann, as we shall see a little later on, chose to study cartilage tissue cells in tadpoles. These are also atypical in that they are among the few animal cells with distinctive cell walls. This turned out to be a fortunate choice, however, because it enabled him to apply one of Schleiden's criteria for the definition of a cell, even though this criterion was later found to be inappropriate.

C. Antoine Lavoisier selected mercuric oxide for his classic experiment on the role of oxygen in combustion. Mercuric oxide happens to be the only metallic oxide that, in the ordinary temperature range, can be decomposed into the free metal and oxygen and then be recombined into the oxide. In other respects mercuric oxide is not much different from other metallic oxides. Lavoisier's fortunate choice made it possible for him to provide an experimental demonstration of his new theory.

D. Gregor Mendel selected the sweet pea for his famous pioneer experiments in the inheritance of specific characteristics. This was a fortunate choice, as was his choice of the characteristics to be studied. The characteristics he chose happened to be completely dominant or recessive. Their pattern of inheritance in the sweet pea was uncomplicated. As a result of his choices, Mendel was able to come up with rather nice clean ratios.

18. Of what use are these numbers? In general, of what use are numbers and mathematics in science?

These numbers give us a rather precise idea of the relative sizes of the cytoblasts (nuclei). The sizes are expressed in terms of a definite standard of measurement, the centimeter, so that anyone who is interested can make a comparison of how large the cytoblasts are.

In general, numbers and mathematics provide a device for generalization from specific observations. The use of mathematics makes it possible to obtain agreement among observers from different cultures or with different languages and personalities. It is an enormously powerful tool, but has some built-in limitations. In using a mathematical model, whatever form it may take, there needs to be agreement about the size and nature of the units. Agreements about the size of units are arbitrarily set by an international commission, often after much wrangling. Secondly, once adopted, any mathematical model has self-momentum, and people may be misled into confusing it with the reality that it more or less accurately represents. For example, the curved universe of non-Euclidian geometry is only a mathematical model that seems to explain certain aspects of universal gravitation. It is not the physical universe!

19. How could Schleiden make all these observations? (His description sounds like something you might see on a motion picture film, but Schleiden certainly did not take movies of cell growth in 1838.) What techniques did he use? What part did Schleiden's imagination play in his description?

Schleiden probably used a series of arrested-development slides to make his observations (see Fig. 44 on page 77 of Swanson). This technique created problems in sequencing for quite a while. Today, by using live preparations and phase contrast microscopes, biologists are able to follow a sequence through its development. (Another problem that confronted Schleiden was the interpretation of raw data without any frame of reference. There was no substantiating evidence to tell him what the order of his still-life observations should be, nor were there guidelines telling him how to proceed.)

NOTES FOR EXPERIMENT 4: Crystallization

Crystals will begin to form as the solution cools. Why?

When 12 grams of sodium chlorate is placed in 10 milliliters of water, not all of the compound will dissolve. When the mixture is heated, more of the compound goes into solution. As the solution cools, the solubility is decreased and some of the sodium chlorate comes out of solution and forms crystals. The molecules that have been in solution form a regular pattern.

We do not expect that students will understand the complex forces involved in crystal formation. They should, however, have some idea that, as a crystal forms, molecules are added to the outside surface in some regular geometrical pattern.

Schleiden believed that the growth of cells was analogous to the growth of a crystal. According to Schleiden, the cell adds materials about the cytoblasts (see page 14 of this case) in the same manner as a crystal adds material to its outside surface. In crystallization the material that is added is the same as that of the parent crystal. In the demonstration using sodium chlorate, it is sodium chlorate that is added about the crystal. To account for the fact that the material that grew about the cytoblast was not all the same, but indeed varied greatly in different types of cells, Schleiden postulated that "somehow" the material that grows about the cytoblast is transformed.

Schwann, who accepted Schleiden's ideas on cell formation, thought he had found evidence in his observations of a crystal-forming structure surrounding the cartilage cells.

What shape and color do the crystals of sodium chlorate have?

Crystals of sodium chlorate are cubic. They are colorless.

Are you watching a living or a nonliving process? Explain.

Crystal growth is a nonliving process. The growth of cells is now known not to be analogous to crystallization. Crystallization is primarily a matter of the orderly addition of like molecules to the other portion of the crystal. In cells, by contrast, the mechanisms of growth and the duplication and cell division processes all involve complex chemical changes.

However, the line between crystal growth and living growth process no longer seems as sharply drawn as it once did. Today many viruses have been crystallized. The tobacco mosaic virus can be crystallized, then dissolved in a solution, and when this solution is spread on the leaves, it will reproduce as a virus. The entire field of the biology of the virus is extremely active, and the relation between viruses and other living things is open to question.

This area can be used to point out to your students that there are no clear answers and that there are no clean lines between living and nonliving things. The relation between crystallization and life processes is still a problem in the middle of the twentieth century.

20. What is a scientific law? How can laws in science be established? Do you think Schleiden established his "general law" of cell origin and growth on a firm basis?

A scientific law is a generalized statement concerning the relation between observed phenomena. Repeated, consistent observations of a relation between phenomena may lead to the statement of a scientific law by an investigator. Scientific laws are considered established if all subsequent observations are found to be in accord with the statement of the law.

As far as we can tell, Schleiden based his "general law" on the observations of only one kind of plant cells—the reproductive cells. Although he noted "many modifications of this development," he did not give sufficient weight to these modifications or consider that they might be evidence against the idea he was setting up. Thus we can hardly say that Schleiden established his "general law" on a firm base.

Pages 42–45 of Calder on scientific lawmaking are good reading, if you do not take seriously the discussion about a hypothesis being promoted to a theory. Also see the comments on generalizing under "Notes for Experiment 3" on page 18 of this guide.

21. What does Schleiden mean by "analogy requires it"? Is this a good argument? Why?

Schleiden was probably trying to rationalize observations that did not fit in with his "general law." He tossed aside other observations as inadequate because they were made under difficult circumstances. His argument was: If the general law is good, then these other observations are not correct, because they do not fit the general law. Unfortunately, as noted in the comment on the last question, this attitude resulted in a hasty establishment of a law that later turned out to be incorrect.

22. Is an incorrect idea of any value in science? How can an idea be shown to be incorrect?

Even if an idea is incorrect, it may still be fruitful in stimulating research that will in the long run correct errors or modify mistaken notions. Two examples are discussed in later pages of this case: (1) Schleiden and Schwann put great stress on the importance of the cell wall, but later research stimulated by their ideas has shown the cell contents to be far more important than the walls. (2) Schleiden's mistaken views on the way in which cells were formed were fruitful of much research activity that eventually showed him to have been in error.

There are two general ways in which scientific laws are shown to be incorrect. First, later investigators may demonstrate that there were errors in the observations or experiments from which the idea was developed. These could include inadequate procedure, inadequate controls, or the selection of atypical materials for study. Second, and more important, if a scientific idea is incorrect, it will predict some phenomena that cannot be found through experiments and observations, even when these are performed by competent investigators. When scientists fail repeatedly to observe predicted phenomena based on an idea, they will tend to lose confidence in the correctness of the idea. It must then be replaced with a new idea that is in accordance with the observations.

For a fine illustration of how one incorrect idea (that of spontaneous generation) was found to be incorrect because predicted phenomena did not occur, see pages 15–19 of Goldstein.

Pause for a Quiz

Before proceeding with the study of the rest of this case, you may wish to administer an informal fifteen- or twenty-minute quiz to your students. Two questions appropriate for use in such a quiz are given below. The first deals with the biology subject matter of the case; the second, with an idea about science and scientists.

1. Discuss Schleiden's concept of a cell. In doing so, try to answer the following questions.
   - A. According to Schleiden, what was a cell?
   - B. How was this definition of a "cell" influenced by the work of Hooke? by the work of Leeuwenhoek? by the work of Robert Brown?
   - C. Do scientists accept this definition today? Explain.
2. Suppose that a bright general science student said to you: "When two scientists make an observation through a microscope, they will surely see the same thing." Keeping in mind the story of "The Cells of Life," write out what you would say to this student.

The Key to the Case: Schwann's Establishment of the Cell Theory—Pages 18-24

Pages 18 through 24 make up the key section of this case. The concern here is with Schwann's arguments and with the observations that led to the formulation of his cell theory. It is not an easy section, for two reasons. First, Schwann's writing, although somewhat adapted for this case, is not always easy to follow. Second and perhaps more important, your students probably will not be familiar with the patterns of logically interwoven ideas and observations that are characteristic in the establishment of a scientific theory. It will be advisable to allow ample time for discussion of this section, so that Schwann's procedure of theory building can be made clear. The analysis on pages 20 to 22 of the case booklet and most of the marginal questions in the section are designed to assist in clarifying this procedure. It may also be helpful to put on the chalkboard the outline analyses of the arguments given under Questions 29 and 31 on pages 24 and 25 of this guide.

Just as this section is the key section of the case, Experiments 5 and 6 are probably the key experiments of the case. Through these experiments, students not only will be able to see the generality of the cell idea for themselves, but will more fully comprehend the force of Schwann's argument and also better understand the limitations of this argument. The observation of animal cartilage cells (Experiment 6) is particularly important here. If individual observations of these cells are not feasible, another possibility might be some form of microprojection.

For your own background reading, pages 12–18 of Swanson may be very helpful in this section. The brief account of Schwann's work on pages 394–96 of Nordenskiöld is also worthwhile.

23. Explain the comment: "Scientists gather a great deal of information, but that is not their main interest." What is the main interest of scientists?

The gathering of information is an important step in scientific work, but it is only a step toward the larger purpose of science. Unfortunately, many students tend to think of science merely as an accumulation of knowledge, a notion that is supported by vast amounts of information about the natural world that is gathered by scientists and stored in reference books and libraries. Yet, to place emphasis on this accumulation of information is to miss completely the dynamic quest for understanding nature that scientists constantly carry on.

The main interest of scientists is to attain a greater understanding of the phenomena of nature. They seek this understanding by structuring the knowledge about natural phenomena in such a way as to produce laws and theories. To the extent that they are successful in this effort, science may be said to "explain" natural phenomena. The scientific explanation of a particular phenomenon means that it can be included under a general and abstract law or principle that has been accepted (see Question 20). Laws and principles are, in turn, explained by reference to still more abstract, accepted theories or models (see Question 6). The aim of theoretical scientists is to formulate theories of great generality that encompass in a small number of abstract postulates a broad range of laws and principles.

Thus, coming back to the original question, the main interest of scientists is not merely the amassing of information but, rather, the seeking of an understanding of nature in terms of verified laws and theories.

For further discussion, see pages 34–37 of Conant.

24. How will Schwann prove his thesis? (This is a tough question, but it's an important one. To begin finding the answer, think about these questions: How do we prove a theorem in geometry? How do we prove an idea in science?)

The "proof" of a scientific idea is quite different from the proof of a geometric theorem. In geometry, we start with a group of statements (axioms or postulates) that are assumed always to be true or self-evident. From these postulates we generate other statements (theorems) which we show are logically consistent with the postulates. The demonstration of logical consistency is the proof of the theorem.

The proof of a scientific idea, on the other hand, can be obtained in the following way: From an idea which is generally rather abstract and not capable of being tested directly, we deduce certain hypotheses that can be tested by observation or experiment. If observations show that these hypotheses are correct, we can accept the hypotheses and will gradually gain confidence in the idea from which they were deduced. In this way, we may say that we have proved a scientific idea.

In the present instance Schwann is attempting to prove the hypothesis that all animal tissues, no matter how diverse, are made up of cells that are very similar to plant cells. He proposes to do this by enumeration—by listing a large number of examples that bear out his thesis. An inherent weakness of this type of proof is that the results are never completely certain. Even after a list of 1000 examples has been exhibited, one can never be sure that Example 1001 will not be an exception to the thesis. At best we can say that, as the list gets longer, the probability increases that the thesis is correct. Despite its deficiencies, it is this kind of testing of hypotheses that scientists most frequently use in establishing or proving their ideas.

NOTES FOR EXPERIMENT 5: Animal Cells

This experiment can give the student an opportunity to explore further the importance of laboratory techniques to meaningful observation. More important, your students will be able to participate in the formulation of hypotheses to account for their observations.

If you use the frog suggestion, you can also prepare tissues of muscles, brain, and other frog organs for temporary mounts. Directions for maceration of tissue will be found in pages 315–16 of Morholt.

An extension of this experiment might involve the use of the scales of live fish for observing the chromatophores in the cells. Mount a fish scale on a slide and add a drop of Ringer's solution. Draw off the Ringer's with a small piece of paper toweling, and add a drop of chloretone on the opposite side. After the students have examined the mount, again use toweling to draw off the chloretone. Then add a drop of adrenalin or potassium chloride to the same mount, and the chromatophores will contract. Ask students to explain their observations. (The chromatophores, which usually contract when stimulated by light, are the means by which frogs, fish, and some invertebrates are able to simulate various colorations. See pages 309–10 of Morholt.)

In what ways are animal cells and plant cells alike?

Both kinds of cells contain a number of structures in common—a nucleus, cell membrane, and cytoplasm. There are also a number of inclusions that are found in both plant and animal cells. Of course, these structures are similar but not identical.

How are they different?

The cells of plants contain a cell wall and a cell membrane, whereas most animal cells have only a cell membrane. Some plant cells contain chloroplasts, which are structures found in the cytoplasm of cells that carry on the process of photosynthesis. No animal cells, however, contain chloroplasts or other plastids. All animal cells contain a centrosome, which is located just outside the cell nucleus, but plant cells (except for some algae and some fungi) do not generally have a centrosome.

Students should realize that as a result of a hundred years of scientific activity in cytology, some major differences are now recognized between plant and animal cells. Still, some cells, such as *Euglena,* may present a classification problem. Depending on the nature of your biology course and the point in your course at which you use this case, you may or may not wish to call attention to more recent classification schemes which use the Protist kingdom as a third grouping. The above notes on differences between plant and animal cells are quite elementary. Again, depending on your class, you may wish to discuss more sophisticated differences in structural organization or chemical composition.

25. What does Schwann mean by "logically correct"? (As a hint, try this example: Almost all cars are similar in many characteristics. All have metal bodies, rubber tires, glass windows, steering wheels, and so on. Is it therefore logically correct to say that all cars are made of the same parts? Explain your answer.)

It is not the purpose of this question to create logicians. Rather, the purpose is merely to point out the role that logical thinking plays in scientific work. Most of your students, especially the boys, will recognize that there is "something wrong" with the possible conclusion, given in the example, that all cars are made of the same parts. But would they be equally critical of a similarly sloppy statement about a matter of science? A feeling for what is meant by "logically correct" can probably be obtained if the class tries, through discussion, to discover just what would be wrong with the suggested line of reasoning about cars.

To generalize about a whole class of objects (parts of all cars, all animal tissues) on the basis of a few isolated examples (metal body, rubber tires, and so on) or "certain individual tissues" is logically a poor procedure. Schwann informs us that he was being cautious in not generalizing unjustifiably on the basis of the limited data available to him at first.

26. What is a hypothesis in science?

A hypothesis is merely a statement of a scientist's ideas about a certain phenomenon. Hypotheses are usually based on previous experience (observations) and analysis (reasoning). One tests them by using them to predict the outcomes of experiments, then performing the experiments and comparing the results with the predictions. (Experiments are here understood broadly to include the predicted observations in sciences such as astronomy, where manipulative experiments are not always possible.)

A hypothesis may be concerned with a very restricted topic, such as one of the countless conjectures made every day in the science laboratory. On the other hand, it may be on the grand scale, as Conant says, and lead to a large number of predictions that can be tested by experiments. Some familiar examples of this type of hypothesis include Nicolaus Copernicus' idea of the solar system, Lavoisier's ideas of the nature of combustion, Niels Bohr's idea of the structure of the atom, Evangelista Torricelli's idea of the "sea of air," Schleiden's and Schwann's ideas on the cellular nature of all living things. These examples are grand hypotheses that were later generally accepted, but this is hardly the fate of most hypotheses that are proposed. For example, in **Science**, 122:815-21 (1955), William Stokes recounted twenty-nine hypotheses proposed at various times to explain the origin of continental glaciers. All of these hypotheses were eventually rejected.

For more on hypotheses, see pages 11–24 of Goldstein.

27. What is an assumption? Consider Assumption A and Assumption B in our analysis of Schwann's reasoning. Are they both correct? Is either one correct? If not, why not?

An assumption, as the term is used here, is an idea that is taken for granted as a part of an argument. It forms a link in the logical chain, but its correctness or incorrectness is not called into question by the argument itself. In reviewing someone's chain of reasoning, however, it is quite legitimate to ask whether the assumptions he used in arriving at his deductions are correct. If an assumption is incorrect, the argument in which it is used may, from a strict point of view, be considered unsound.

Assumptions may be made consciously, as Schwann's Assumption B seems to have been, or unconsciously, as Schwann's Assumption A probably was. Virtually every chain of reasoning in science involves some assumptions—conscious or unconscious, or both. An evaluation of Schwann's two assumptions follows.

ASSUMPTION A. In Schwann's day there was no reason to doubt that all life could be included in the two categories—plant and animal. Today, however, we know of groups of organisms that have characteristics typical of plants as well as animals. We know of others with characteristics that are not normally found in either plants or animals. Interestingly enough, it is to just such organisms that the cell theory does not seem to apply. (For further discussion of this point, see pages 5-7 of Swanson.) Nevertheless we must concede that Assumption A, as far as Schwann could know, was quite correct.

ASSUMPTION B. As we shall see later in this case, the characteristics of structure and growth by which Schleiden and Schwann defined cells were shown by subsequent investigations to be inadequate (for Part 1 of Assumption B) or totally incorrect (for Part 2 of Assumption B). Perhaps the most fascinating aspect of this case is the realization that Schwann succeeded in establishing the cell theory, perhaps the most important theory in biology, while using an incorrect assumption. Surely, however, this does not deter us from recognizing the genius of Schwann's accomplishment in establishing the theory. He brilliantly employed what he considered to be the best ideas available at the time—Schleiden's definition of cells. Yet the fact remains that Assumption B is incorrect.

28. What is a notochord? Do you have one, or did you lose it?

The notochord is a rod of cartilage, similar to the spinal cord in vertebrates. It is found running longitudinally along the dorsal side of the lower chordates. The notochord is always found in the early embryological stages of vertebrates, including man, but it disappears in the later stages before birth.

NOTES FOR EXPERIMENT 6: Cartilage Cells

The importance of Schwann's being able to see the cell wall was that it enabled him to satisfy one of his assumed criteria for the definition of a cell. Cartilage cells nicely filled his need.

There are no special notes for this experiment, since it involves the straightforward observation of prepared slide materials. If good slides are obtained, students should have little difficulty distinguishing the cell walls of the cartilage cells with a magnification of about $\times 180$. Very good results can be obtained by using some slides containing cross sections and longitudinal sections of notochordal tissue of salamander larvae. (These are available through Carolina Biological Supply House, Elon College, N.C., stock number H668.)

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29. How did Schwann "prove" his first hypothesis? Describe his method of testing Hypothesis I and give examples of the materials he used.

Schwann proved his first hypothesis by the method of enumeration discussed in Question 24. Hypothesis I calls for "a sufficient number" of animal tissues to have nuclei and cell walls, and this leads to a series of limited working hypotheses, each of which can be tested by observation. The following analysis illustrates Schwann's procedure.

HYPOTHESIS I: If a sufficient number of the elementary parts of animal tissues have nuclei and cell walls, then animal tissues are composed of cells.

Limited Working Hypothesis I-1: The elementary parts of the notochord in tadpoles have nuclei and cell walls. *Test by observation.*

Limited Working Hypothesis I-2: The elementary parts of the dorsal cord in fishes have nuclei and cells walls. *Test by observation.*

Limited Working Hypothesis I-3: The elementary parts of the cartilage corpuscles have nuclei and cells walls. *Test by observation.*

Limited Working Hypothesis I-n: The elementary parts of __________ have nuclei and cell walls.* *Test by observation.*

When Schwann found that his observations confirmed a satisfactory "sufficient number" of these limited working hypotheses, he accepted Hypothesis I. We might say that he had proved his first hypothesis in this way. (Recall, however, the limitations of this procedure mentioned in the comments for Question 24.)

30. Compare Schwann's description of various animal cells with Schleiden's account of plant cells on pages 14 and 16. Does Schwann see something similar to what Schleiden saw?

Though Schwann's description is much briefer than Schleiden's, it is clear that he believed he was observing a sequence of events in the branchial cartilages of frog larvae quite similar to what Schleiden had reported seeing in plant cells. Even if there were no record of the fateful meeting between Schwann and Schleiden, this paragraph would provide ample evidence that Schwann was thoroughly familiar with Schleiden's work.

You may wish to raise again the question of how Schwann was able to make the observations he described. No trace remains in his description of the vast number of arrested-development slides he must have made or of the many problems he must have encountered in sequencing them. It all sounds like a nice, clean, straightforward job of observation, without complexities, headaches, or frustrations. How often reports of scientific research come to us with virtually all the scaffolding essential in the formulation of the work diligently hidden away!

31. How does Schwann test his second hypothesis? Compare his way of testing Hypothesis II with his way of testing Hypothesis I. Are there differences?

Schwann tests his second hypothesis in much the same way that he tested his first hypothesis (see Question 29 above). There is, however, one difference. The second hypothesis is so stated that any one observation showing the growth of cells in animal tissue in the manner described by Schleiden would be sufficient to confirm it. Schwann may have reasoned somewhat as follows: The analogy between animal cells and plant cells is actually established on the basis of similarity in structure (see Hypothesis I). Thus, to test the second hypothesis, all that is needed is a demonstration that the process of growth in any animal tissue is similar to the growth process Schleiden described for plant cells. Schwann may have been influenced by the difficulties involved in demonstrating the growth sequence of cells using only arrested-development slides. Nevertheless he did provide several examples to support his second hypothesis, as is shown in the following analysis.

HYPOTHESIS II: If the elementary parts of any animal tissue grow in the same manner that Schleiden described for plant cells, then the tissue is composed of cells.

Limited Working Hypotheses II-1: The elementary parts of notochord tissues grow as Schleiden described. *Test by observation.*

Limited Working Hypothesis II-2: The elementary parts in blood grow as Schleiden described. *Test by observation.*

Limited Working Hypothesis II-n: The elementary parts of __________ tissue grow as Schleiden described.* *Test by observation.*

The larger the number of these limited working hypotheses that were confirmed by observation, the more confidence Schwann could place in the correctness of his second hypothesis.

32. Do you think Schwann proved his point satisfactorily? Did he really show that "cells are the basic unit of all life"? What more, if anything, could he have done?

Schwann did everything that he could reasonably be expected to do in establishing his cell theory. The hypotheses he deduced from his theory were confirmed by a large number of careful observations, which is the kind of proof that is acceptable for establishing any scientific theory. Perhaps he could have continued to seek additional examples to confirm his hypotheses, and this search might eventually have led him to a realization of the misapprehensions in Schleiden's definition of the cell and to destruction of the whole fabric of Schwann's argument. But this is certainly too much to expect, since it took cytologists several decades to convince themselves of the inadequacies of Schleiden's ideas.

Did Schwann really show that "cells are the basic unit of all life"? The answer to this question is both yes and no. Schwann certainly demonstrated this idea to

*In this paragraph the "n" stands for "any number of succeeding working hypotheses" and the blank space may be filled in with the name of whatever material one is working with.

his own satisfaction and to the satisfaction of his contemporaries. It was quite generally accepted and turned out to be very fruitful in directing further biological research. On the other hand, the purist would say that all Schwann demonstrated was that his two hypotheses were confirmed by his observations, as far as he went. Since the assumptions that served to connect Schwann's two hypotheses with his theory are inadequate or incorrect, there is a break in the logical chain (see Question 27). Thus the confirmation of the hypotheses cannot be taken as confirmation of the theory itself (see page 20 of the case booklet). From our present point of view, Assumption B has been replaced by a better definition of the cell (the cell is the minimum organization of matter that is alive), and both plant and animal tissues have been found by a multitude of observations to be in accord with the new definition. However, uncertainties about Assumption A still leave us with some doubts about whether or not cells **are** the basic unit of **all** life.

33. It often happens in science that earlier ideas are replaced. What other examples do you know of? Since scientific ideas may have to be revised at some future time, does this mean that they are not very dependable? Defend your answer.

It is a general characteristic of scientific ideas that they are tentative and subject to change as our understanding of nature changes. Conant says, "Almost by definition . . . science moves ahead." If we were ever to arrive at the stage where scientific ideas would no longer change, where all the phenomena of nature would have been explained by concise theoretical formulations, then there would be no more science.

A few examples of once-prominent scientific ideas that have been replaced are: (1) the earth is the center of the universe; (2) atoms are indivisible, hard spheres; (3) diseases result from an imbalance of the four humors of the body; (4) living things can arise from nonliving things (spontaneous generation); (5) plant and animal species are immutable; (6) heat is a material substance.

The dependability of a scientific idea is determined partly by how well the idea has been established through successful testing of working hypotheses. If we inject disease germs into an animal, we can be quite confident that the animal will contract the disease, since the germ theory of disease has been well established through many confirming observations. The reliability of a scientific law may also be related to the area in which it is applied. Newton's laws of motion are very dependable for calculating the impact of a bullet, for computing tide tables, and for determining the orbit of a satellite, but they are not dependable for describing the motion of an electron. The size and speed of electrons are outside the range to which Newton's laws apply. Similarly, the cell theory is quite dependable for understanding the growth of a chick embryo, but it is of little help in describing the behavior of viruses. Chick embryos consist of cells; viruses do not. These are two examples of ideas that are quite dependable so long as they are used only within the limited areas to which they apply.

For further discussion of the progressive nature of science, see pages 35–37 of Conant.

The Closing Section: Errors Corrected —Pages 24-26

Pages 24 (last paragraph) and 26 are the wind-up sections of the case and, after the struggle with the preceding section, should go quite easily. The main point of this section is the self-correcting nature of science. Although Schleiden and Schwann had passed on two erroneous notions with their cell theory, the efforts of later investigators, whom they helped stimulate, served to correct the errors. The story is told in much greater detail than we tell it in the case on pages 396–405 in Nordenskiöld.

Since the story of the case near its end is quite straightforward and there are no experiments directly connected with it, we have suggested that the biographical reports in Activities 1 and 3 be taken up in this section. The discussion of these reports will serve to highlight three additional themes that should be aired through the study of this case: (1) the kinds of people who are scientists; (2) the ways in which a person gets to be a scientist; (3) the factors affecting the welfare of science in any nation.

A further chapter in the story of scientists' understanding of cells and nuclear division can be provided your students through the reading of Flemming's paper in Activity 4. This activity extends the case in two ways: (1) in terms of the biology subject matter and (2) as a further exercise in getting students to ferret out from their science reading ideas about the nature of the scientist's work.

34. How can a scientist know whether he has selected a typical material for study? Is there any way to be certain, or must he take a chance? What may happen if the material he studies and observes is not typical?

The theme was discussed in some detail in the comments for Question 17. It is raised again here because the selection of materials for study is one of the knottiest problems connected with scientific research.

In the last analysis, there is probably no way in which a scientist can be sure in advance whether or not he has selected a typical material for study. Only after he has some knowledge about the particular material he has selected can he check it with other materials of the same class to determine how typical it is. In a sense, then, a scientist must take a chance on the typicalness of the first material he selects for study in his efforts to establish a new law or theory.

If the chosen material happens to be atypical, the inferences the scientist draws from his observations may be incorrect (as was the case with Schleiden). As has been pointed out, however, incorrect ideas can stimulate worthwhile research activities that in the long run will correct or modify mistaken ideas. This process of self-correction is another general characteristic of science.

35. Are scientists concerned with health problems? What kinds of scientists are particularly concerned? What kinds are not?

In common usage, any one of a multitude of persons performing a multitude of activities might be called a scientist. In this unit the term is used to designate a person whose main concern is the orderly structuring of knowledge concerning nature (see Question 28). Though aware of the possibilities of its practical exploitation, scientists by and large consider scientific knowledge an end in itself, a "value." By contrast, persons whose main concern is the practical application of scientific knowledge are "applied scientists" or "technologists."

Not all scientists are concerned with health problems. Applied scientists in the area of medicine and public health—for instance, practicing physicians—are immediately concerned. Many botanists, zoologists, cytologists, embryologists, biochemists, and other experimentalists and theorists who are working on developing new knowledge may be concerned only indirectly with health problems, if at all. Moreover, large groups of scientists—for instance, most physicists, astronomers, and geologists—are not even remotely concerned with health problems, except as they pertain to their personal health and the health of their families.

36. What might have been some reasons for the delay in learning about the details of the process of cell division?

The delay in learning about the details of the process of cell division was principally due to the lack of instruments and techniques equal to the task. The details of cell division are difficult to observe, and it was not until late in the nineteenth century that the necessary tools were made available. Scientists in the late nineteenth century were better prepared to ferret out the details of cell division because of improvements in (1) lenses used in the construction of microscopes, (2) the procedures for fixing a material for observation, and (3) the application of specific chemical stains. In addition, they were aided by the introduction of the microtome for preparing very thin sections.

See the description of staining techniques in Flemming's paper of 1879 (Activity 4) and in pages 404–5 of Nordenskiöld.

37. How did the selection of cartilaginous tissue help Schwann?

Schwann selected for study one of the few animal cells that have a distinctive cell wall. As a result, he was able to apply to animal tissue one of the criteria (all cells have a cell wall) that Schleiden used in defining plant cells. Despite the fact that Schleiden and Schwann were wrong about its being a basic part of the living cell, this instance of a cell wall's existence in animal tissue helped to establish the cell theory. (See related comments under Questions 27 and 34.)

38. What does a scientist "see" through his instruments? (This question refers to the same problem that was mentioned in Questions 1 and 15. Now that we are near the end of this case, can you discuss the problem more fully?)

Obviously this is a discussion question, and students should be encouraged to write two or three paragraphs to answer it. They should now be able to give a somewhat better answer than was possible for them in their response to Question 1. Since major portions of the first two sections of the case were focused on this question, no attempt is made here to give a complete answer. However, the following brief summary may be of value in guiding class discussion.

What a scientist "sees" through his instruments is a result of more than the sensory impression that light makes on his optic nerves. Every scientist brings to his observations some background of ideas that may or may not be correct. His ideas may cause him to concentrate on certain aspects of the optical field, and it is more than likely that he will find what he is looking for. It is quite impossible to make an observation without some expectation of what will be found. However, the danger remains that if preconceptions are too firmly fixed, the scientist may be blinded to certain stimuli that are actually present in his visual field. (Witness Schleiden, for example, when he deliberately overlooked "many modifications of this development" in the growth of cells. See Question 20.) What a scientist "sees" through his instruments is actually an intricate matrix of visual stimuli interwoven with his own ideas.

Questions for Review

The questions given here are suggestive of the kinds of questions that may be useful in reviewing the biology subject matter and the ideas about science and scientists developed in the case. For your own background prior to review, a rereading of "Objectives for this Unit" (page 10) as well as pertinent sections of the commentary would be appropriate.

1. Name the parts of a cell and the functions of each.
2. What contribution did each of the following make to our understanding of cells?
   (A) Seventeenth century Dutch lens makers
   (B) Robert Hooke
   (C) Anton van Leeuwenhoek
   (D) Robert Brown
   (E) Matthias Jakob Schleiden
   (F) Theodor Schwann
   (G) Rudolf Virchow
   (H) Rise of the German dye industry in the nineteenth century
3. How are animal cells like plant cells? How are they different?
4. Consider the experiment in which we take a piece of stale bread (which contains no living organisms), moisten it, and place it in an airtight glass jar. After the jar has stood for a day or two in a warm, dark place, colonies of bacteria (which are living plants) are seen growing on the bread. Surely this is an example of living things arising from nonliving matter. Or is it? Explain.
5. What is meant by "The organism is an organization of cells"?
6. Why do you think a man becomes a scientist?
7. What is meant by "theory" in science? How are theories proved?
8. What do you think goes on at a scientific meeting? How is a convention of scientists like a convention of plumbers?
9. What effect do you think the invention of the printing press may have had on the progress of science? Explain.
10. What is important about the choice of a material for an investigation?
11. Comment on the following statement: "The engineers who design and launch our ballistic missiles are making an important contribution to the advance of science in America."
12. Complex computers can do the jobs previously performed by some workers. In what ways would it be difficult for computers to replace scientists?

The questions on the unit test for *The Cells of Life* are divided about equally between the biology subject matter and certain ideas concerning science and scientists found in the case. You should *not* imply to your students that the questions above will be on the unit test.

Notes for Additional Activities
—Pages 28-32

The appropriate times at which the following activities may be used to greatest advantage during the study of this case have already been indicated in the commentary presented earlier in this guide.

NOTES FOR ACTIVITY 1: Scientists and Nations

The intent of this activity is to help drive home several points. First, it is designed to combat the notion that advances in science result solely from the efforts of a relatively small number of great men. For every scientist whose name finds its way into elementary textbooks, there are hundreds of equally hardworking, dedicated men (and, more recently, women) who have made their contributions. Consider the countless number of experiments, the multitude of papers and reports, the many proposals and counterproposals that are invested in the development of any major scientific idea. All this activity must be carried out by scores of people who bring their minds and skills to bear on some part of the problem.

Second, the activity is designed to emphasize that scientists are highly individual human beings. It is often possible to find a number of interesting contrasts by looking at the lives and activities of different scientists. Some scientists are gregarious, others are recluses; some scientists have many interests outside science, others appear to be concerned with little else; some scientists attain considerable distinction in their time, others go almost unrecognized; some scientists are very generous, others are downright stingy; some scientists are mild and even-tempered, others are fiery and uncompromising; most scientists marry and have families, but a few remain bachelors.

In making their reports on the lives of the scientists listed under this activity in the student case booklet, students can look into such matters. The best sources of information are biographies and biographical dictionaries. The next-best source is an encyclopedia. Since encyclopedias may be the only major reference works available in some school libraries, you will find below the names of those scientists mentioned in the case booklet for whom there is an article in the *Encyclopaedia Britannica,* 1960.

England—Nehemiah Grew, Robert Hooke

France—Félix Dujardin

Germany—Christian Gottfried Ehrenberg, Friedrich Gustav Jacob Henle, Hugo von Mohl, Johannes P. Müller, Karl von Nägeli, Lorenz Oken, Theodor Schwann, Karl Theodore Ernst von Siebold, Rudolf Virchow

Holland—Anton van Leeuwenhoek

Italy—Marcello Malpighi

Scotland—Robert Brown

Switzerland—Rudolf Albert von Kölliker

Regarding those scientists for whom there is no article in the *Britannica,* you may wish to emphasize again the idea that science is made by both the famous and the not so famous.

The third idea to be emphasized by this activity is science's international scope. Since the phenomena of the natural world with which science deals are accessible to all, the people of all nations possess the potential for making contributions to science. This being true, if science is to progress at an optimum rate, free communication between the scientists of various countries is necessary. The scientific disciplines foster such communication through international conferences and by emphasizing knowledge of foreign languages in schools preparing scientists. Governments can foster or impede the flow of scientific information by the kinds of regulations they make in this regard.

Although science is international and people from all nations have the potential for contributing to science, the fact remains that, at any one point in history, some nations are more productive in their scientific work than others. This points to the final area emphasized in this activity—the factors operating in a particular country at a given time that are likely to produce a large number of scientists.

The number of scientists a particular nation will produce at a certain time and the areas in which these scientists will work are largely reflections of the country's educational system, the national attitude toward science, the country's technological needs for research in a given area, and the availability of funds for training scientists and for the support of scientific research.

The important role played by the educational system in producing scientists is quite clear. If the nation is to produce many scientists, it must provide a universally available, up-to-date educational system that will train and prepare potential scientists for their careers.

The national attitude toward science—that is, public opinion—also plays a key role in determining the number and quality of scientists produced at a certain time. Public opinion may either stimulate or retard the training of scientists and the progress of science. The country where public opinion toward science is favorable—where funds are provided for good education, where scientists and science have some prestige, where scientists can secure funds for research—will produce and have available as many scientists as it needs. A nation where the public is unwilling to provide an adequate education system, where the public regards scientists as unnecessary, mysterious, even sinister, and where the public does not provide funds for research will find itself desperately short of scientists.

The technological demands of a culture also have an effect on the rate at which scientists are produced within the culture. Farsighted industrial leaders may make funds available for the training of scientists and for the support of "pure" scientific research in certain areas. (Such areas are usually those in which scientific research may lead, in the not-too-distant future, to the solution of practical problems.) Largely because of technological need, the governments of some countries (for example, the United States, England, France, and the U.S.S.R.) make available funds for the training of scientists and the support of scientific research.

In today's world, where every aspect of our lives is affected by science, it is important for citizens to be aware of the factors conducive to scientific advance.

NOTES FOR ACTIVITY 2: Make Your Own Microscope

The directions given for this activity in the student case booklet are self-explanatory. If directions are carefully followed, the student should achieve excellent results.

NOTES FOR ACTIVITY 3: Matthias Jakob Schleiden

This activity deals with variations in career patterns and personality traits among scientists and with the past and present educational patterns of scientists.

In his lifetime Schleiden was the suicidal lawyer, then the eminent scientist, and finally the wanderer. Certainly this is not the usual scientific career. But what is the usual scientific career? There have been, and are, as many career patterns as there have been, and are, scientists. For every general type of scientific career pattern one might attempt to outline, examples can be found in history where the pattern was not followed. For instance, although the general tendency is to consider that a scientific career requires long training, there are some examples of amateurs making significant contributions in science. Moreover, many scientists in the past—Aristotle, Bacon, Galileo, and Newton are all examples—devoted much energy to nonscientific work. From the seventeenth century to the present, however, there has been an increase in emphasis on the word *scientist* as a career or job title—the name of a profession by which one earns a living.

The careers of individual scientists vary in many ways: how they enter science, the training they receive, the kinds of activities and roles they are involved in as a part of their work.

Scientists also vary greatly in personality. At present there is no evidence that any special kind of disposition is a requirement for science. Jobs are highly diverse and they accommodate a wide range of personalities. It may be that scientists who are primarily experimentalists have quite different personal characteristics from scientists who are primarily theoreticians. At any rate, it is unrealistic to envision a specific "scientific personality," since scientists, like members of any professional group, differ widely in their personality characteristics. (Note that characteristics of personality are quite distinct from any special abilities and skills that scientists may develop. For related discussion on this, see the previous comments in this guide for Questions 3 and 13.)

Since two major tasks of scientific work are the development of new ways of thinking about what is observed and new techniques for observing, it is possible to specify that a definite creative effort is demanded of scientists. The personal characteristics that are associated with creativity also appear, of course, among people working in other fields where creativity is demanded. These characteristics include above-average intelligence, imagination, perseverance, dedication to work, and curiosity.

The last point in the activity—the relation between the kind of education suitable for scientists of the past and that suitable for modern scientists—has been presented in terms of whether a modern scientist might be successful with the kind of training that Schleiden had in the last century.

Certainly Schleiden did not lack for university degrees. He was prepared as a lawyer and held the degrees of doctor of philosophy and doctor of medicine. Still, two aspects of his educational preparation might work against him in the modern world of science.

In the first place, the content of the courses studied in preparing for his doctor's degrees did not include many things taught today. In the second place, while there are people even today who turn to science after trying some other line of work, the great majority of scientists have entered directly into a scientific career.

The reason for this, as has been mentioned, is that scientific work today demands a long period of training, starting with the selection of a definite pattern of studies as early as high school. If a person does not receive this training in his high school and college courses, he usually cannot switch over into preparation for a career in science unless he is willing to take the time to make up the courses that he has missed. Virtually all successful scientists today have prepared for scientific careers throughout high school, college, and postgraduate work. It is therefore unlikely that Schleiden, having started out in an education and a career area far removed from science, would eventually become a successful scientist today.

NOTES FOR ACTIVITY 4: Division of the Cell and Nucleus

No further explanation of this activity is necessary. Correctness of students' marking of the article can be established through class discussion.

It may be of interest to your students that the small drawings that appear in this activity are copies of sketches Flemming made in 1879. These sketches are quite different from the diagrammatic drawings of nuclear division usually found in textbooks, and they are also quite different from modern microphotographs of the same process. (See, for example, page 49 of Swanson.) What *does* a scientist see through his instruments?

NOTES ON UNIT TEST

Permission to reproduce the test printed on pages 33–37 may be obtained by writing to

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Science Research Associates, Inc.
259 East Erie Street
Chicago, Illinois 60611

When the test is reproduced, adequate space should be provided for students to write their answers.

You will find below information about the different parts of this test and the ways in which these parts are related to the "Objectives for This Unit" printed earlier in this guide.

PART I

This part mostly consists of recall items. The primary emphasis is on testing for knowledge of factual information presented in the case or studied in connection with the case, such as the "A" objectives listed on page 10. Some ideas from the "C" objectives listed on the same page may also creep in. Any student who has been paying attention should find these items easy to answer.

PART II

This is an attempt to test for some of the "B" objectives on page 10, though, again, some of the "C" objectives may be included. Principles and concepts presented in the case appear in a novel situation. Students must have some understanding of the principles and concepts, not merely the ability to recall them, in order to analyze and interpret the new situation. The majority of the items will probably be difficult for many students to answer, unless the class has had extensive practice in scientific reasoning.

PART III

This part tests for understanding of ideas concerning scientists and scientific work (the "C" objectives on page 10). Some of the true-false items of Section A involve simple recall of statements of ideas discussed in connection with the case; others call for making some rather careful discriminations. Most of the true-false items should be easy for students to answer correctly. The rewriting of false statements into correct ones will be more difficult, but it is important that this be done, since incorrect ideas should not be permitted to stand. Section B attempts to measure the students' achievements in one of the long-range aims of studying the HOSC units: a greater sensitivity to the nature of the scientific enterprise as evidenced by students' ability to recognize fundamental ideas about science when reading unfamiliar materials (see page 6 of this guide). Practice in recognizing such basic ideas has been provided in Activity 4, and this technique is exemplified by the marginal comments and questions throughout the case. Nevertheless, the task of inducing general ideas from specific illustrations is not likely to be an easy one for many students. A great help in accomplishing the task successfully is given by the general statements under A of this part of the test. These statements indicate the ideas to be sought in the selection. Students will find that the example at the beginning of Part III is also helpful.

PART IV (OPTIONAL)

Section A is an extension of the testing offered in Part III-B, but it is more open-ended, since the ideas to be sought are not specified. Actually, this is a better indicator of a student's individual sensitivity to the nature of the scientific enterprise than is III-B; however, the dual task of recognizing an illustration and generating a statement of the general idea is more difficult. The grading of the performance is more difficult, because it involves numerous separate judgments.

In Section B the student has an opportunity to demonstrate how well he comprehends a key argument of the case and understands the process of deducing testable hypotheses from the statement of a theory. Some recall is involved, since the question deals with a specific example from the case. (Use of an unfamiliar example would make this an extremely difficult question.) Grading will be a problem with this question, as it is whenever an essay answer is required.

UNIT TEST

PART I

A. Match each of the definitions given in 1 to 5 below with a name taken from the list at the right. Write the letter of the name in front of the definition.

____________ **1.** structure found in most plants, but rarely in animals
____________ **2.** structure found below the dorsal nerve cord of chordate embryos
____________ **3.** thin, living layer on the outside of plant and animal cells
____________ **4.** the unit of structure of living things
____________ **5.** living portion of a cell which lies outside the nucleus

a. cell
b. cell membrane
c. cell wall
d. cytoblast
e. cytoplasm
f. notochord
g. nucleolus
h. nucleus
i. spinal cord
j. tissue

B. The principal participants in "The Cells of Life" were Robert Brown, Robert Hooke, Anton van Leeuwenhoek, Matthias Schleiden, Theodor Schwann, and Rudolf Virchow. In front of each of the accomplishments listed below, write the **last** name of the man who was responsible for it. For any item in the list that was **common knowledge** to the men in the case, print the letters **C.K.**

____________ **6.** Stated that cells grow up around the cell nucleus.
____________ **7.** Discovered and named the nucleus in plants.
____________ **8.** Discovered that proper techniques are important for making good observations.
____________ **9.** Observed that some animal cells have a cell wall.
____________**10.** Stated that cells arise from previously existing cells.
____________**11.** Observed that living things grow and develop.
____________**12.** Discovered that some animals and plants consist of only a single cell.

PART II

This part consists of sentences to be completed and questions to be answered. For each item, choose the **one best** response on the basis of the information given and your understanding of biological ideas and scientific reasoning. Circle the letter of the response you choose.

Two biology students, Bill and Mary, were examining some water they had obtained from a swamp. They noticed several pale-green, spherical objects, about 5 mm in diameter, moving around in the water. Bill asked, "Do you think those are plants or animals, Mary?"

1. What is the best answer Mary could give?
   A. They are either plants or animals.
   B. They are plants, because they have a green color.
   C. They are animals, because they can move by themselves.
   D. They may not be living organisms.

Bill managed to capture one of the elusive spheres and place it on a microscope slide. Mary observed it carefully under the microscope for quite a while. She finally made out a network of tiny fibrils connecting many small greenish cells on the surface of the sphere.

2. "Now," Mary said correctly, "I'm sure this is
   A. a living organism."
   B. a plant."
   C. a fiber cell."
   D. an animal."

3. Mary's interpretation at this point was most likely based on the idea that
   A. omnis cellula e cellula.
   B. plant cells contain a green substance (chlorophyll).
   C. an organism is an organization of cells.
   D. plant and animal cells are similar in many ways.

4. Mary next suggested that they try to stain the cells and observe them under a microscope with greater resolving power. Bill agreed. The best reason for Bill's agreement to this procedure is that
   A. biologists usually use very high-power microscopes in their research.
   B. proper techniques and instruments make better seeing possible.
   C. proper staining techniques are essential for observing microscopic preparations.
   D. cells cannot be seen unless microscopes that have great resolving power are used.

5. With further observation, Bill and Mary learned that every cell on the surface of the sphere had two whiplash flagella, with which the organism could move itself. They also observed a single nucleus in every cell. Bill and Mary now interpreted the information they had. The best interpretation they can make from their information is that
   A. the organism is an animal.
   B. the organism is a plant.
   C. the organism is an animal or a plant.
   D. the organism is a flagellum.

6. To reach the best interpretation given in question 5, which one of the following statements would one have to assume to be correct?
   A. All animals can move under their own power.
   B. Omnis cellula e cellula.
   C. Flagella are whiplike structures of one-celled organisms.
   D. All life consists of plants and animals.
   E. All plant cells contain a nucleus.
   F. All animal cells contain a nucleus.

7. Bill now noticed that every cell on the surface of the organism was surrounded by a rigid cell wall. "That settles it," he said gleefully. "Now I know what this creature is, Mary."

Bill's interpretation and his correct reason for it was probably that this organism was
   A. a plant, because only plant cells are surrounded by a cell wall.
   B. an animal, because only animal cells are surrounded by a cell wall.
   C. a plant, because most plant cells have nuclei and cell walls.
   D. an animal, because most animal cells have nuclei and cell walls.

8. Mary smiled, because she knew that Bill was sometimes not very cautious in his reasoning. "Your interpretation is too hasty, Bill," she said, and then made the four statements below to back up her argument. Three of Mary's statements are correct. Which one is **NOT** correct?

- **A.** Some plant cells have no nucleus.
- **B.** Some animal cells have a cell wall.
- **C.** Some living things are neither plants nor animals.
- **D.** Some animals have a greenish color.

PART III

A. Several statements about scientists and scientific work are made below. Decide whether each statement is generally true or generally false. If the statement is true, print **T** in Column A to the right of the statement. If a statement is false, print **F** in Column A and write out a true statement **about the same idea.** A sample has been worked out for you below. (Do not write in Column B until you have read the directions for Section B.)

	Column A	Column B Par. No.
Sample. The principal aim of science is to provide people with better things for better living.	F	
The principal aim of science is to attain understanding of the phenomena of the natural world.		______
1. A scientific theory consists of statements of a scientist's ideas about some part of the natural world.	______	______
2. Important contributions to biological science have been made chiefly by scientists in England, Germany, and the United States.	______	______
3. The kinds of instruments that are available to scientists play only a minor part in the progress of scientific research.	______	______
4. The general state of the culture outside of science has little or no effect on the development of science.	______	______
5. Scientific investigations often begin with an observation of something that is not understood.	______	______
6. A scientific hypothesis expresses a scientist's ideas about a certain phenomenon.	______	______
7. When a scientist succeeds in establishing a theory through very careful experiments and observations, the theory is not likely to be changed later.	______	______
8. A scientific law is a generalized statement of observed empirical relationships.	______	______

B. The selection below contains illustrations of numerous ideas about scientists and scientific work like those discussed in the case "The Cells of Life." You may not fully understand some of the facts presented in the selection, but that is not important. What you should be able to recognize are illustrations of many of the true statements from Section A above—both true statements that were given and true statements that you wrote.

Read the selection through carefully. When you find an illustration for one of the ideas in Section A, write the number of the paragraph in which the illustration appears on the proper line in Column B above. For example, the idea expressed in the true restatement of the sample is illustrated by the underlined portion in paragraph 1 of the selection; hence, the numeral 1 should be written in Column B.

Not all the true statements from Section A are illustrated in the selection. For those ideas for which you find no illustration, mark an **X** on the proper line in Column B.

THE NUCLEOLUS IN THE CELL

by Manuel Elkay

1 The nucleolus presents many unanswered questions to biologists who are trying to understand the complex processes that occur in the living cell. A nucleolus (or often several nucleoli) is found inside the nucleus of most cells. Nucleoli are usually roundish and usually stand out quite dark and sharp in the dye-stained nuclei of resting cells, since the nucleolus takes on dye more readily than other parts of the nucleus. Remarkably, however, the nucleolus generally disappears during the phases of cell division and reappears later.

2 The first recorded observation of the nucleolus in the nucleus of an animal cell was made by the Italian biologist Felice Fontana in 1781, when he turned his microscope on the slime from the skin of an eel. Fifty years later, Rudolf Wagner in Germany recognized a "Keimfleck" (germ spot) in the nuclei of the egg cells of various animals and suggested that this dark spot (the nucleolus) could serve as a distinctive feature for identifying nuclei. M. J. Schleiden soon reported the first observations of nucleoli in the nuclei of plant cells, and he put forth the idea that the nucleus grows from the nucleolus. This idea was taken up by Theodor Schwann, who applied Schleiden's notions of cell growth in plants to animal cells as well. Schwann's work of 1838–39 established the cell theory, but the role that the nucleolus actually plays in the cell remained obscure.

3 The disappearance of the nucleolus during cell division was a particularly vexing problem for cell biologists in the last two decades of the nineteenth century. Eduard Strasburger, professor of botany at Bonn, hypothesized that the nucleolus was the storehouse of kinoplasmic material. Strasburger's hypothesis fitted in with his theory of kinoplasm. Strasburger's theory assumed that the protoplasm of the cell consisted of two distinct substances, a specially active **kinoplasm** and a less active **trophoplasm.** The trophoplasm was assumed to be involved mainly in cell nutrition, while the kinoplasm was thought to bring about the building-up and movement phenomena of the cell. More kinoplasm was assumed to be necessary during cell division—a time when these phenomena are more pronounced. Thus, if the nucleolus stored kinoplasm, this material would be released during cell division, and the nucleolus would become smaller or vanish entirely. When cell division was completed, the demand for kinoplasm would be reduced, and this material again would accumulate in its storehouse, the nucleolus, which would then grow larger.

4 Strasburger's theory accounted for the observations already made of changes in the nucleolus. Careful experiments also showed that some parts of the protoplasm easily took on certain kinds of stains while other parts did not, suggesting that there are different substances present in protoplasm. Thus Strasburger's kinoplasm theory had good experimental support.

5 Despite the attractiveness of Strasburger's theory, other investigators proposed various different functions for the nucleolus in the economy of the cell. One hypothesis held that the nucleolus is an energy reservoir for the nucleus. Other hypotheses suggested that the nucleolus serves as a source of nutritional material for the cell in general or for the nucleus in particular. Still another hypothesis viewed the nucleolus as a place for temporary storage of waste products from the metabolism of the nucleus and cytoplasm. Subsequent investigations did not satisfactorily confirm any of these hypotheses. At the same time the investigators also learned that Strasburger's hypothesis of the nucleolus as a storehouse of kinoplasmic material could not be accepted. In fact, Strasburger's whole theory of kinoplasm and trophoplasm was found to be an inadequate description for the organization of protoplasm in the cell.

6 In recent years, research on the function of the nucleolus has been carried out by, among others, Torbjörn O. Caspersson in Sweden, Jean Bracket in Belgium, and J. L. Sirlin at the University of Edinburgh, Scotland. New insights into all the questions concerning the structures of cell components and their functions have been gained in the last two decades through the application of powerful biochemical techniques and electron microscopy to the study of cells. In the 1940s biologists learned that the nucleolus is composed chiefly of ribonucleic acid (RNA) and it is thought that the nucleolus is involved in the synthesis of proteins in the cell. Just how the nucleolus functions in protein synthesis, however, is a question still open to speculation today.

PART IV

A. In the selection "The Nucleolus in the Cell," there are a number of illustrations of ideas about scientists and scientific work that were not included in the true statements of Part III-A. Reread the selection to see if you can spot them.

Write out a concise statement of any new ideas (like those discussed in the case "The Cells of Life") for which you find an illustration in the selection. Give the number of the paragraph in which the illustration appears.

B. Give a statement of the theory that Theodor Schwann was trying to establish in "The Cells of Life."

Since a scientific theory cannot be tested directly, how did Schwann establish this theory? Be specific in your answer, and include Schwann's reasoning, his assumptions, and his observations.

KEY FOR UNIT TEST 1

PART I 1 point for each correct answer

Section A.
1. c
2. f
3. b
4. a
5. e

Section B.
6. Schleiden
7. Brown
8. C.K.
9. Schwann
10. Virchow
11. C.K.
12. Van Leeuwenhoek

PART II 2 points for each correct answer — these are expensive items in terms of the reading and analysis required

1. D
2. A
3. C
4. B
5. C
6. D
7. C
8. A

PART III 1 point for each correct T-F identification; 1 point for each correct rewrite of a false statement; 1 point for each correct paragraph reference

Section A.	Section B.
1. T	Par. 3 (sentences 3 and 4) is the best illustration; also par. 2 (sentence 3) and par. 6 (sentence 3)
2. F Important contributions to biological science have been made by scientists in many countries.	Par. 2 and 6
3. F The kinds of instruments that are available to scientists play an important part in the progress of scientific research.	Par. 6 (sentence 2)
4. F The general state of the culture outside of science often influences the development of science.	X
5. T	Par. 3 (sentences 1 and 2) is the best illustration; also par. 5 (sentence 5)
6. T	Par. 5 (sentences 2, 3, and 4); par. 3 (sentence 2); par. 2 (sentences 3 and 4)
7. F Even though a scientist succeeds in establishing a theory through careful experiments and observations, the theory is very likely to be changed later.	Par. 5 (last sentence)
8. T	X

PART IV (Optional)

A. 2 points for each correct idea ferreted out and referred to a paragraph

Some of the ideas illustrated in the selection and not cited in Part III-A are listed below. Students may find others that can be counted as correct if they are referred to an appropriate phrase in the selection.

Every scientist builds on the work of his predecessors. (Illustrated best in par. 2.)

Objects to be observed are easier to find when the investigator knows what to look for and has a distinctive way of identifying them. (Illustrated in par. 2, sentences 2 and 3.)

A chain of reasoning connects a scientific theory with hypotheses that can be tested by experiments and observations. (Illustrated in par. 3.)

Different hypotheses may be proposed by scientists to account for the same set of phenomena. (Illustrated in par. 5.)

B. 7 points

The theory Schwann was trying to establish is:

"Cells are the basic units of all life."

One point may be given for a correct statement of the theory and up to 6 points for the essay answer, in which the student is asked to demonstrate how well he understands one of the key arguments of the case. (See pages 20–22 of the case booklet and pages 24–25 of this guide.) A good answer may be given 5 or 6 points; fair, 3 or 4 points; poor, 1 or 2 points.

POINTS SUMMARY:

PART I — 12
II — 16
III — 20
48

PART IV: variable; likely maximum — 15