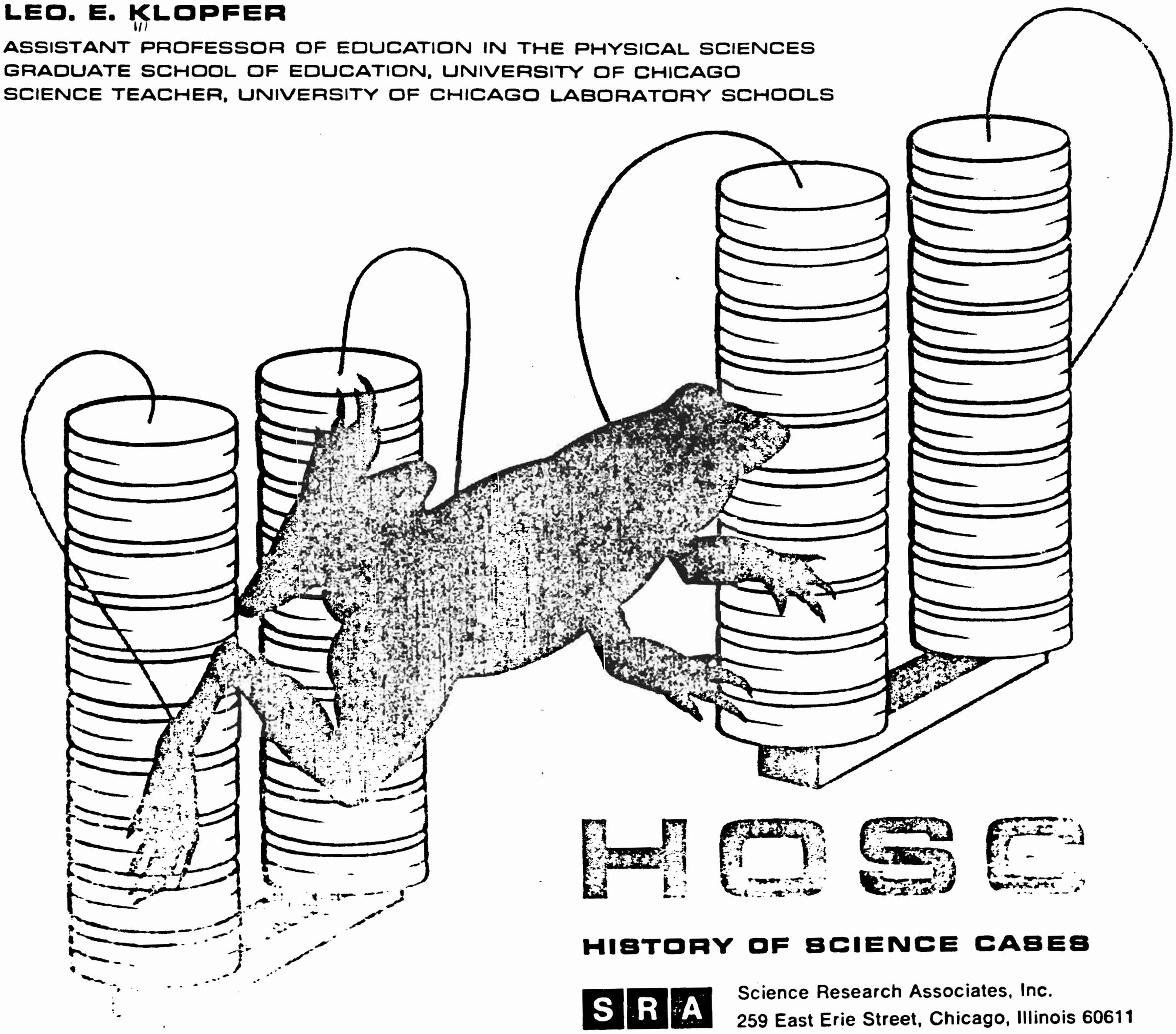
Dr. Ronald K. Gibbs
Wisconsin State University
Oshkosh, Wisconsin

TEACHER'S GUIDE

FROGS AND BATTERIES

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.
259 East Erie Street, Chicago, Illinois 60611

A Subsidiary of IBM

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ACKNOWLEDGMENTS

The HISTORY OF SCIENCE CASES were developed, beginning in 1956, at the Harvard Graduate School of Education. The two persons who, more than any others, inspired the development of these new instructional materials were Fletcher G. Watson, professor of education, and James B. Conant, the 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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The Teacher's Guide 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, Nancy Klabunde, Ulrich Klabunde, Eugene C. Lee, James W. Miller, Muriel B. Niles, Bernard O'Donnell, Susan G. Schacher, and John J. Seiler. The notes and comments for the Teacher's Guide accompanying *Frogs and Batteries* were compiled principally by Abraham and Roberta Flexer.

L.E.K.

TABLE OF CONTENTS

MATERIALS NEEDED FOR TEACHING FROGS AND BATTERIES

PRINTED MATERIALS FOR STUDENTS

Case booklet—1 copy per student (SRA Order Number 3-1216)
Student reference books—as available (see Reading Suggestions on the inside back cover of the case booklet)
Textbooks—any biology texts containing information on muscular contraction and the nervous system; any chemistry texts with a section on ionic reactions

SUGGESTED TEACHER REFERENCE BOOKS

(The books marked with an asterisk are frequently cited by authors' last names in the commentary of this guide.)

BEVERIDGE, W. I. B. *The Art of Scientific Investigation.* New York: Norton, 1957. (Also paperbound, Vintage V129; New York: Random House, 1960).

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

CONANT, JAMES B. *On Understanding Science.* New Haven, Conn.: Yale Univ. Press, 1947. (Also paperbound, Mentor MD68; New York: New American Library, 1951.)

*———. *Science and Common Sense.* New Haven, Conn.: Yale Univ. Press, 1951. (Also paperbound, Yale Paperbound Y32; Yale Univ. Press, 1960.)

*DIBNER, BERN. *Galvani-Volta.* Norwalk, Conn.: Burndy Library, 1952.

FULTON, J. F. *Muscular Contraction and the Reflex Control of Movement.* Baltimore: Williams & Wilkins, 1926.

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

HALL, A. RUPERT, and HALL, MARIE BOAS. *A Brief History of Science.* New York: New American Library, 1964. (Signet T2524.)

MARGENAU, HENRY; BERGAMINI, DAVID; and editors of *Life. The Scientist.* Life Science Library. New York: Time Inc., 1964.

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.

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

RUCH, T. C., and FULTON, J. F. *Medical Physiology and Biophysics.* Philadelphia: Saunders, 1961.

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

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

LABORATORY EQUIPMENT AND SUPPLIES

freshly killed frogs, dissecting apparatus, glass plates, saline solution	Experiments 2, 3, 4, 5
thin copper wire, iron wire, glass rods, metal rods, plastic rods, iron plates	various experiments and activities
filter paper	Experiment 6, Activities 2 and 3
copper disks, zinc disks	Experiment 6, Activity 3
Leyden jar, electroscope	Experiment 1
1.5-volt dry cell	Experiment 2
electrostatic machine (for example, a small Van de Graaff generator or an induction coil), ring stands, clamps	Experiment 3
string, paper strips, zinc strips	Experiment 4
adhesive tape	Experiment 5
flashlight bulbs	Experiment 6
pennies, dimes, galvanometers	Activity 2

(See also the notes on the experiments and additional activities in the commentary of this guide for further suggestions of materials you may wish to use.)

SUGGESTED SCHEDULE

The outline in this table may be useful if you wish to teach this HOSC unit in 10 lessons, with class periods between 40 and 50 minutes long and double periods for student laboratory work, plus one period for the unit test.

Lesson No.	Classwork	Assignments
		Read introduction to the case, page 3, and the account of Musschenbroek's experiment on page 4. Bring a silver spoon to class. Write answers to Questions 1 to 4.
1	Discuss purpose of the case. Quick experiment by students with spoon and aluminum foil. Class discussion of spoon experiment. **Demonstration:** Experiment 1, Leyden Jar. Discuss Questions 1 to 4.	Read the account of Whytt's work, through page 8. Read Experiment 2, Observations on Muscular Contraction. Write answers to Questions 5 to 8.
2	**Laboratory:** Experiment 2, Observations on Muscular Contraction, followed by discussion of results. Class discussion of Questions 5 to 8.	Read the account of Galvani's first experiment, through page 12. Read Experiment 3, Galvani's First Series of Experiments. Write answers to Questions 9 to 13.
3	**Demonstration:** Experiment 3, Galvani's First Series of Experiments. Discuss plate on page 16. Discuss Questions 9 to 13.	Read the account of Galvani's second experiment, through page 14. Write answers to Questions 14 to 17. Individual students assigned biographical reports, Activity 1, due at Lesson 10.
4	Review Galvani's experiments described on pages 12 and 14. Discuss "hypothesis" and "theory," focusing on Question 17. Discuss Questions 14 to 16.	Read the remainder of the account of Galvani's work, through page 18. Read Experiment 4, Galvani's Second Series of Experiments. Write answers to Questions 18 to 22.
5	**Laboratory:** Experiment 4, Galvani's Second Series of Experiments. Discuss results of experiment and Galvani's explanation of muscular contraction (page 18). Discuss Questions 18 to 22, giving special attention to Question 22.	Review material to date for a short quiz. Read the account of Volta's experiments and theory, through page 20.

6	**Quiz:** 15 to 20 minutes. Discuss Volta's experiments and his theory of muscular contraction (page 22).	Read the account of the controversy and Aldini's experiment, through page 24. Read Experiment 5, Aldini's Experiment. Student volunteers to prepare demonstrations for Experiment 6, Voltaic Pile, as a project due at Lesson 8. Write answers to Questions 23 to 27.
7	Discuss Questions 23 to 27. **Demonstration** (by an able student): Experiment 5, Aldini's Experiment, followed by class discussion of its implications.	Read the account of Volta's battery and the resolution of the controversy, through the end of the case. Read Experiment 6, the Voltaic Pile, and Activities 2 and 3. Write answers to Questions 28 to 31.
8	Discuss Questions 28 to 31. **Demonstration:** Activity 2, An Eleven-Cent Battery. **Laboratory:** Activity 3, Volta's Experiments on Sensations, using the voltaic pile prepared in Experiment 6 by volunteers.	Write answers to Questions 32 to 35.
9	Discuss Questions 32 to 35, with special attention to Question 34.	Write answer to Question 36. Complete reports for Activity 1.
10	Biographical reports and discussion of Activity 1. Discuss the resolution of the controversy (Question 36). General review.	Study for unit test.
11	**Unit test:** Allow one period.	

TO THE TEACHER

It is essential that our students, soon to be citizens in a scientific age, 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 these understandings of science and scientists.

Understandings Developed

In the HOSC unit that you are about to teach, understandings of science are developed through a critical study of the controversy between Luigi Galvani and Alessandro Volta over the nature of the relation between electricity and muscular contraction. Your students will witness (and participate in) the attempts to design meaningful experiments and to interpret the results. They will see how ideas are revised as a result of new observations (or new interpretations of previous observations). They will realize that our description of the physical world changes, though the phenomena remain essentially the same. They will learn that a scientist's description of the world is influenced by his concepts and background. They will see some of the interactions between scientists, technicians, and the other members of society. Finally, they will see the variety of personal characteristics of scientists.

Although *Frogs and Batteries* contains a great deal of scientific information, it should be made clear from the beginning that the case is not primarily a vehicle for learning science subject matter. While students should learn some biology, chemistry, and physics from this case (see Sections A and B under "Objectives of the Unit," page 9 of this guide), the main purpose of this and all other HOSC units—to teach *about* science and scientists—should always be in the foreground. (The particular ideas concerning science and scientists that are illustrated in this case are listed on page 9–10.)

In the final analysis, the goal of the HOSC units is to develop in the students an awareness of the ways in which scientists work and think. It is hoped that, in studying these cases, students will acquire an understanding of science that will become a functional part of their lives.

Materials and Teaching Procedures

Although there are many ways of presenting this case, the methods suggested in this guide have been found particularly effective. Of course, the instructor is free to make whatever adaptations and extensions he believes best for his class.

The core of the case is the narrative that appears on the even-numbered pages of the student booklet. Implicit in this narrative of some late eighteenth century developments in biology and physics are important ideas about science and scientists. These ideas are emphasized by the comments and questions in the left-hand margin.

Some of the marginal comments may suggest individual or group reports based on suitable reference books. Marginal questions have been repeated in more detailed form on the odd-numbered pages, and space has been provided there for students to write their answers. You may want them to do this as homework assignments. However, many of the questions do not have definite answers; and even when definite answers exist, they are seldom explicitly stated in the text. Rather, the questions are intended as starting points, encouraging students to seek additional ideas and information and to explore problems themselves.

The suggested experiments that appear on many of the right-hand pages of the case booklet are an essential part of this HOSC unit. As many of these as possible, as well as other pertinent experiments known to the teacher, should be performed at appropriate points in the study of the case. The additional activities suggested on pages 30–31 are extensions of certain ideas covered in the unit.

Together, the suggested experiments and additional activities give students opportunities to develop a variety of abilities and skills. The instructor should decide which experiments and activities are best done as special projects by only a few students and which should be done by all members of the class.

It is most important for students to get a feeling for the kinds of problems the scientists in the case were wrestling with. This can be accomplished most effectively by having students perform experiments similar to those actually done by scientists in the case. Every student should have a chance to carry out and observe for himself at least a few of the experiments.

The Teacher and the Teacher's Guide

Class discussion—perhaps the most important factor in the study of this HOSC unit—cannot be included in the student booklet. The teacher must see that this essential factor is supplied. The objectives of the HOSC units can be achieved only through the kinds of exposition and synthesis that come about in well-led, intensive, daily classroom discussions. In these discussions the instructor should delineate the period of history in which the case takes place and supply some of the background information that the students may lack. It is important that the students recognize the intellectual framework within which eighteenth century scientists worked.

The "Commentary and Teaching Suggestions" section of this guide is useful in developing effective class discussion. This section includes a general commentary on the unit, answers and specific comments on questions in the student booklet, notes on student activities, and references to sources of further background information.

OBJECTIVES OF THE UNIT

Listed below are the objectives of *Frogs and Batteries*. These objectives can be divided into three somewhat overlapping categories: factual knowledge (the "A" objectives), subject-matter concepts (the "B" objectives), and ideas about the nature of science and the work of scientists (the "C" objectives).

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

1. Contribution of the Leyden jar, devised by Pieter van Musschenbroek, to electrical experimentation.
2. Work of Robert Whytt—his observations of contractions in muscles of freshly killed frogs when stimulated with a sharp object.
3. Work of Galvani—his accidental discovery of muscular contraction in prepared frog legs; his extensive follow-up investigation of the phenomenon.
4. Galvani's explanation of muscular contraction.
5. Work of Volta—his repetition of Galvani's experiments; his formulation of a rival theoretical explanation of muscular contraction; his invention of the bimetallic battery.
6. Volta's explanation of muscular contraction.
7. Giovanni Aldini's experiments without metals.
8. Resolution of the controversy over Galvani's and Volta's rival explanations of muscular contraction.
9. Three types of muscle tissues.
10. Structure of nerves.
11. Scientific applications of Volta's battery.

B. After studying this unit, students should understand the following concepts and principles (see note):

1. Muscular contractions are stimulated electrically.
2. Our senses can be stimulated electrically.
3. Nerves act as conductors of electric currents.

C. After studying this unit, students should understand the following ideas concerning science and scientists (see note):

1. Chance observations may lead to new experiments and new ideas, but they must meet a "prepared mind" and they must be followed up.
2. A scientist's observations and interpretations are influenced by his own hypotheses and by his background.
3. Ideas and experiments interact in scientific work. Imagination is needed to provide hypotheses and plan experiments to test them.
4. New observations may have a trigger effect: they often lead to a series of new hypotheses and new experiments and a revision of established concepts.
5. A controversy over rival theories is resolved, ideally, by an appeal to experimentation and observation. However, the outcome of a controversy can also be affected by the personalities and personal biases of the scientists involved and by the impact of dramatic demonstrations. Scientists sometimes ignore facts that do not fit into a proposed theory.
6. Scientists change experimental variables in order to isolate essential conditions.
7. Scientific societies facilitate scientific communication, support research, establish standards of terminology and measurement, set standards of excellence in research, and act as a professional "home" for scientists.
8. Science is a unified field of study, and its various branches are interrelated.

9. Instruments are used by scientists to extend the senses and make possible new experiments and observations. The introduction of a new instrument may open up vast new areas of investigation and bring about the development of many new ideas.
10. Science is different from applied science, or technology.
11. Science is an international activity.
12. Free communication is the lifeblood of science. Scientists communicate with one another through meetings, journals, books, and personal correspondence.
13. The general state of technology and of the entire culture often influences the development of science.
14. Scientists are people with special training and certain well-developed abilities. They vary widely in their personal characteristics.

NOTE: By "understand" we mean that a student should be able to do more than simply parrot a statement of an idea. He should be able to make an application of the principle or to seek out an example of it in a novel situation. The unit test at the end of this guide attempts to test for such understanding.

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 presentation of the total unit and major sections of the unit.
2. All questions from the student booklet, answers to the questions, and commentary and teaching suggestions related to specific questions.
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 last name. Titles and publishers are listed on page 4 of this guide.)
5. Sample questions for a mid-unit quiz and for a review lesson.

All numbered questions have been printed in boldface type—for example:

How could Galvani know about this experiment?

Paragraphs containing definite, factual answers to numbered questions from the student book are preceded by a check:

✓ None of the hypotheses mentioned in this experiment can be rejected by reasoning alone. . . .

When to Use the Unit

It is important for your students to have some experience with dissecting techniques before beginning the case; the frog dissections included here must be carried out rapidly. (If you are in a locality where dissections are not permitted, frequent reference to the plate on page 16 of the case will help to offset this disadvantage.) It is also recommended that the case be taken up in the science course prior to a study of the nervous system and the functions of the brain. However, this case may be used at almost any point in a science course, since little prior knowledge of biology is required of students.

The primary concern of this case is not the subject matter of biology, but rather the methods of science and the work of scientists. Introductory biology texts usually describe carefully the results of scientific investigations, but rarely give much consideration to *how* a theory arose, *who* the investigators were, or *what* obstacles had to be overcome. The historical background of our knowledge of muscular contraction and nerve physiology is usually treated very briefly, if at all, with only a few paragraphs on the results obtained by Galvani, Volta, and Aldini. *Frogs and Batteries* is intended to fill this gap.

This case is divided into seven brief sections, as follows:

Section One	Prologue and Musschenbroek
Section Two	Early Knowledge of Muscular Physiology; Whytt's Work
Section Three	Galvani's First Experiment
Section Four	Galvani's Second Experiment and His Theory
Section Five	Volta's Experiments and His Theory
Section Six	The Controversy and Aldini's Experiment
Section Seven	Volta's Battery and the Resolution of the Controversy

This division is reflected in the suggested schedule (pages 6–7) and in the commentary that follows.

For your own background reading, a good survey of the state of experimental biology and anatomy in Galvani's time is given on pages 234–263 of Nordenskiold. Your principal source of background information will probably be the excellent monograph by Dibner, which can easily be read in its entirety. The story of the case is also briefly reviewed, with some commentary, on pages 109–114 of Conant.

SECTION ONE

Prologue and Musschenbroek

Text: pages 3–4

Experiment in Prologue and Experiment 1

The case opens with a simple student experiment and a discussion of the possible explanations for the observed phenomenon. The experiment and the two explanations proposed are analogous to the problem that the students will see later in the case. For this reason, rather full discussion is desirable (see the comments below). You should, however, be careful not to commit yourself too strongly to either of the proposed explanations. Let the students argue the two points of view themselves. They should realize that agreement cannot be reached at this point by argument and reasoning alone.

1. Are we limiting the field too much when we say "the electricity comes from one of two sources"? Can you suggest any other possible sources for the electricity in our experiment? Can you reject these hypotheses of other possible sources by reasoning about them, or do you need to make additional observations?

✔ Yes, the field is too restricted for two reasons. First, the statement makes an *a priori* assumption that there are no more than two possible sources of the electricity—the body and the contact of the spoon and foil. Second, the statement excludes the possibility of a combination of the suggested sources as the real source. (See *b* below.)

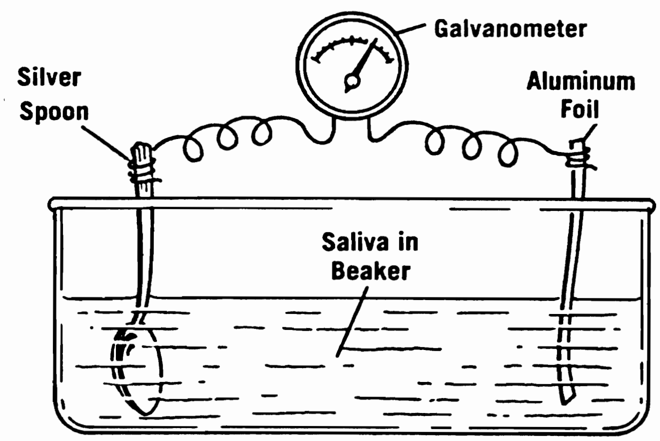
✔ Two other possible sources may be suggested: (*a*) the interaction between the tongue and one of the metals might produce the electricity while the second metal merely completes the circuit; (*b*) the chemical reaction between silver, aluminum, and the tongue (or the saliva) might be the source of the electricity.

✔ None of the hypotheses mentioned in this experiment can be rejected by reasoning alone. The proponents of each hypothesis could defend their case, but words alone cannot settle scientific disputes. The final evaluation must come from additional experimentation.

✔ An evaluation of the above two alternatives might include the following: (1) Bend the aluminum in such a way that it touches both top and bottom of the tongue, so that the circuit consists only of tongue and aluminum. Is the same sensation observed? Do the same with the silver spoon (a costly experiment perhaps). Repeat the experiment, substituting a wide variety of metals and nonmetals for aluminum and silver in turn. (2) If one had available a table of the electromotive series, the following reasoning could be applied:

$Al^{\circ} \rightarrow Al^{3} + 3e^{-}$	+1.67 volts
$3e^{-} + 3Ag^{+} \rightarrow 3Ag^{\circ}$	+0.80 volts
$3Ag^{+} + Al^{\circ} \rightarrow 3Ag^{\circ} + Al^{3}$	+2.47 volts

(Ag^{+} is generated by ionization of Ag° in mouth acids.) The same result could be observed in the experiment shown below:



Alternative *b*—that the source of the electricity is the interaction of the silver, aluminum, and saliva—is the currently accepted explanation for the phenomenon.

If your students do not raise this possibility, then you should not raise it either, since a background in chemistry is needed for a full discussion. However, if many of the students have been exposed to a formal chemistry course, then the topic of electrolytic cells can be profitably raised.

The interplay of reasoning and experimentation, one of the main themes of this case, should be emphasized here. This theme will be encountered several times.

2. For what reasons might a scientist write a letter to another scientist?

This is the first of three questions dealing with the means of communication between scientists. The principal intent of this group of questions is to show students that free and efficient communication is the lifeblood of science. We return to this theme in questions 15 and 23.

✓ Before the advent of the numerous regularly published scientific journals that are so familiar today, the writing of letters to other investigators was the principal means of exchanging scientific information. In the first half of the eighteenth century there were only two major scientific journals that appeared regularly, the *Philosophical Transactions of the Royal Society of London* and the *Journal des Savants* of the Académie des Sciences, at Paris, and publication of papers in these journals was generally delayed a year or two. Many of these papers were letters written by one scientist to another. An example that will be seen later in this case is the letter written to Sir Joseph Banks by Alessandro Volta, in which he reported the construction and operation of the first electric battery.

Even today many scientists maintain an active correspondence with their colleagues, although communication by telephone has supplemented, and to some extent supplanted, the writing of letters. In addition to the reasons that lead other people to exchange letters, scientists correspond to raise questions about each other's work, to describe new experiments, to discuss research proposals and grants, and to pass on information quickly without waiting for the publication of journal articles, which are sometimes delayed several months.

3. Can you guess why the name "Leyden jar" was chosen for this new piece of apparatus?

✓ The jar was developed at the University of Leyden by Musschenbroek and a group of his students and colleagues. It was named *bouteille de Leyden* (Leyden jar) by Jean-Antoine Nollet, a French popular experimenter, whose demonstrations made the jar widely known. He may have called it the Leyden jar to emphasize the contributions of the entire group at Leyden, or perhaps because *Musschenbroek* was too hard to pronounce and spell.

Actually the same discovery was made independently a year earlier by Ewald Georg von Kleist, dean of a cathedral in Pomerania. In Germany the jar was sometimes called a Kleist jar or Pomeranian jar, but Nollet's term has gained wide usage, perhaps because of Nollet's popular experiments, and perhaps because Musschenbroek's work was reported by Réaumur to the Académie des Sciences, while Kleist's remained little known. This question might lead to an interesting discussion of the matter of priorities and credits in scientific discoveries. Often the credit goes not to the first man to make a discovery, but to the man who is first to make his work known to other scientists. The work of a noted scientist will attract attention, while an experiment by an unknown Pomeranian parson may well be neglected. The personality, public-relations ability, and reputation of a scientist all help determine the influence his discoveries will exert on the scientific community. The means of communication used to report the discovery will also affect its influence.

4. What is the value of new apparatus in scientific work? Could science get along if new and improved apparatus were not developed? Explain.

The development and use of new apparatus is essential for scientific progress. New instruments increase the precision of measurements, extend the range of measurements, make observation of phenomena less difficult, and provide means for measuring things previously unmeasurable. Moreover, the introduction of a new instrument or technique often attracts many scientists to the exploration of areas previously neglected or unknown, as was the case with the Leyden jar and the voltaic pile. Other examples that readily come to mind are the microscope, the telescope, the pneumatic trough for collecting gases, the spectroscope, and the Wilson cloud chamber. The mere presence of a new piece of apparatus in the laboratory encourages scientists and their students to experiment with it. The description of a new piece of apparatus in a modern scientific journal is often followed several months later by a flood of articles from laboratories around the world reporting new experiments that were made possible by the new equipment.

While science could get along for a while without the development of new instruments, the limitations of existing apparatus would soon set a ceiling on scientific discovery. This is the chief reason why physicists, for example, continually build bigger and more powerful machines for investigating the interior of the atomic nucleus.

As a class discussion or a student project, it might be worthwhile to examine the effects on biological research and knowledge of the introduction and improvements of the microscope.

For further illustrations and discussion, see pages 81, 98–99, 216, 220–221, 241, and 285–286 of Conant.

EXPERIMENT 1
Leyden Jar

Simple Leyden jars similar to the one diagramed in the student booklet are available in most high school physics laboratories. A highly charged Leyden jar can produce a severe and dangerous shock. **STUDENTS SHOULD BE CAREFUL NOT TO TOUCH THE METAL PARTS OF THE JAR.** It should be discharged by connecting the outer coating to the knob, using a conductor held by an insulated handle.

The Leyden jar is a form or capacitor or condenser. Its action can be explained very simply, if somewhat imprecisely, by saying that the electrical current attempts to escape to the ground through the outer coating, but is unable to cross the insulating layer of glass, and is therefore stored inside the jar. A more sophisticated explanation will be found in most high school physics texts. In essence, the explanation is this: When a charge is placed on the inner foil, an opposite charge is induced on the outer foil. The opposite charges attract each other, but the potential difference is maintained, since the charges are unable to pass through the glass wall of the jar.

Capacitors made of two metal plates separated by air, oiled paper, paraffin, mica, or other nonconducting substances are widely used in various kinds of electronic circuits. The capacitors commonly used in radios are made of long strips of aluminum foil separated by oiled paper, rolled into tight cylinders and sealed in metal cans or dipped in wax.

The first atom smasher, built at Cambridge University in 1930, used a series of condensers that could be charged up to an electric potential of one million volts.

The Leyden jar was used by early electrical experimenters, both as a source of electrical discharges and as a convenient means of accumulating small electrical charges to produce a large potential. For example, Benjamin Franklin connected a Leyden jar to his famous kite, and was able to show that lightning charged up the jar. Other experimenters used the Leyden jar in a similar way to show that electric eels actually produce electrical charges.

If an electrophorus is available, it should be used during this experiment. The electrophorus was invented by Alessandro Volta and was widely used by early experimenters. It is perhaps more impressive than a Wimshurst machine or a Van de Graaff generator because of its very simplicity.

The base of the electrophorus is made of a nonconductor, which acquires a negative charge when rubbed with fur. When the metal plate is placed on the base, it acquires a positive charge through induction while momentarily grounded. This positive charge can be transferred to a Leyden jar, and the plate recharged by repeating the process. Because the base is a nonconductor, little of its charge is lost during the process, which can be repeated many times without recharging the base.

SECTION TWO
Early Knowledge of Muscular Physiology
Whytt's Work
Text: pages 6–8
Experiment 2

This section provides background for the main story of the case. Here the early experiments with freshly killed animals are presented, and the work of Robert Whytt (pronounced *white*) is outlined. Experiment 2, which should be done as a laboratory exercise, will give your students some experience with muscular contraction resulting from pricking with a sharp object or from direct stimulation with electricity.

Further information about the work of Aristotle and Galen, which is cited in this section, can be found on pages 34–44 and 60–65 of Nordenskiold. For a discussion of the importance of Whytt's contribution to the development of physiology, see John F. Fulton (editor), *Selected Readings in the History of Physiology* (Charles C. Thomas, 1930), pages 79–81, 242–247.

5. What are three types of muscle tissue found in the bodies of animals? Which type is involved in the contraction of the leg muscles of a frog?

✔ The three major types of muscle tissue are (*a*) smooth or visceral (involuntary), (*b*) striated or skeletal (voluntary), and (*c*) heart or cardiac (involuntary). Striated muscle tissue is involved in the contraction of frog legs.

You may wish to have the students learn about the three types of muscle tissue at this point. A description of the structure and function of each type will be found in most biology textbooks. Either photomicrographs of the three types of muscle tissue or actual muscle preparations could be used here.

6. Is it usual today for scientists to work for universities, as Whytt did? Where do scientists work today?

✔ While many scientists today work for universities, many are also employed by industry or government. Relatively few scientists are self-employed.

There are several ways to treat this question. One approach is to stress the different satisfactions available from each of the three situations. Traditionally, basic research and teaching have been the main satisfactions of academic life. However, many university scientists find themselves either doing a considerable amount of applied research under contract or being so swamped by the daily requirements of teaching and publishing that they can do little research. Industry offers higher salaries than universities or government, but usually has limited research aims. Today, however, a number of companies are finding it profitable to encourage basic research (usually within the general realm of their company's production interests, but sometimes with a completely free hand) on the premise that the company will follow up new technological possibilities resulting from such basic research. Some government scientists work under the twin handicaps of low salaries and bureaucracy. For a very few scientists, government employment offers the prospect of influencing public policy in scientific research and education. To some extent the universities also offer scientists an opportunity to help shape the development of scientific education in public schools.

7. What are some of the possible explanations of muscular contraction? A full explanation should include suggestions about (a) exactly what it is that causes a muscle to contract when it is "pricked, torn, or otherwise stimulated" and (b) exactly what happens in the muscle to make it contract. What suggestions do you have?

This question gives your students an opportunity to stretch their scientific imagination. They may propose any number of explanations to account for muscular contraction. To illustrate an important facet of scientific research—the formulation and testing of explanations—you should set aside time during which the students can examine and evaluate one another's proposals. Perhaps they will be able to cite evidence to support or reject certain explanations; they should be urged to suggest experiments that might test their classmates' explanations.

The following explanations might be set forth at this point in the case to account for muscular contraction. The first emphasizes muscular factors, while the second stresses attractive forces.

1. Muscular contraction could occur because of the presence of thin strings running lengthwise within the muscle. These strings tighten and decrease in length when they are touched by some sharp object; as a result the muscle decreases in length (becomes contracted). Perhaps these "muscle strings" are broken when the muscle is pricked, and muscular material, moving to the site of damage to repair the broken string, causes the muscle to contract.

2. Perhaps there is some kind of attraction between the muscular material and the pricking tool. As the muscular material moves toward the pricking tool, the muscle appears to contract. The pricking tool may deposit "attractive material" in the muscle, toward which the muscular material is pulled. Possibly the active muscular material is located only at the ends of the muscle. When the muscle is pricked, the two attracted muscle ends would push toward the center, thereby contracting the muscle. This explanation is analogous to Ben Franklin's "one-fluid" idea of electricity, where attractive and repulsive forces resulted from excesses or deficiences of the electric fluid.

Students may well suggest other explanations of muscular contractions. The important objective at this stage is not to seek the "correct" explanation, but rather to encourage imaginative hypotheses and to help the students to realize that these hypotheses can be tested only by experimentation.

8. Whytt seems anxious here <u>not</u> to suggest a hypothesis about the cause of muscular contraction. Do you think he is being too cautious? By the way, what do we mean by "hypothesis" in science?

Your students will probably argue both sides of this question. Some will say that Whytt had an idea or two in mind to explain muscular contraction, and that he was being too cautious in not publishing his thoughts. Others in the class will favor the suggestion in the text that Whytt didn't think he understood this phenomenon well enough to put forth a hypothesis about its cause.

Certainly this question does not have one "correct answer." The amount of caution a scientist exercises when he publishes is largely a matter of personal preference. Many scientists are willing to put their wildest hypothetical ideas into print. These ideas are often revised or rejected by other scientists, but they may serve as stimuli for creative ideas by others. On the other hand, many scientists are reluctant to announce hypotheses they think are not entirely convincing. Whytt, apparently, was the cautious type. However, it would be inappropriate for us to consider him "too cautious" without further knowledge of his reasons.

This question, along with Questions 12, 16, 18, 19, 25, 26, and 30, is designed to shed light on the different personalities of scientists. Here and elsewhere we see that scientists cannot be stereotyped, but are different from one another like people in any group.

To answer the more general question: A hypothesis is merely a statement of a scientist's ideas about a certain phenomenon. Usually hypotheses are based on previous experience (observations) and on analysis (reasoning). Hypotheses are tested by using them to predict the outcome of experiments, then performing the experiments and comparing the results with the predictions. (Experiments here include the observations in sciences such as astronomy, where manipulative experiments are not possible.)

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

See pages 45–60, 69, 71, 91, and 265 of Conant.

EXPERIMENT 2
Observations on Muscular Contraction

General Suggestions for Preparation of the Frog
(These suggestions apply also for the preparation of Experiments 3, 4, and 5.)

The classical method of preparing a frog for dissection is by pithing. This is a delicate operation and presumably very painful for the frog if done ineptly. (Much practice is needed to become adept.) The following technique is easy and humane:

1. Refrigerate the frogs overnight in a moist chamber. The vegetable bin of a home refrigerator is quite adequate; pour in a few cups of tap water to prevent dessication. Refrigeration will make the frogs sluggish and easy to handle.
2. Grasp the frog around the body, keeping its legs extended so that it cannot jump. The frog may urinate copiously. Frog urine may be very caustic to the skin, and prolonged exposure often results in painful skin irritation. The hands should be protected by rubber gloves, or washed immediately after the completion of the dissection.
3. Obtain a pair of *sharp* household scissors. Using the lower blade of the scissors, force the mouth of the frog open and move the blade all the way back to the angle of the jaw.
4. Position the upper blade of the scissors well behind the eyes of the frog.
5. With one strong snip, sever the head of the frog from its body.
6. Grasping the decapitated frog securely, destroy the spinal cord by moving a probe around in the cavity of the spinal column. (Omit this step for the latter half of Experiment 3.)
7. Destroy the brain by moving a probe around in the brain case (reached through the opening in the base of the skull).
8. Continue the dissection as usual.

Keep the dissected frog moist at all times by applying a saline solution (8.5 gm NaCl per 1000 ml distilled water) with an eyedropper every five minutes or so.

Use the frogs as soon after dissection as possible.

Nerves and muscles are easily exhausted by repeated stimulation at the intensity used in these experiments. Allow the muscle preparations to recover by waiting at least four or five minutes after each set of three or four contractions. If this is done, the preparations will be responsive for a longer period.

Observations of Muscular Contraction

In the first part of this experiment the students have an opportunity to see for themselves the reaction of the frog's sensitive muscular tissues to various kinds of stimulation. In the second part the background is provided for the observation that so startled Galvani. Having seen that the frog's muscles contract when they are connected by a wire to a source of electricity, the students, it is hoped, will be as startled as Galvani was when in Experiment 3 they witness muscular contractions *without* any connecting wires.

Muscular Contraction Stimulated by Electricity

Directions for dissection of the gastrocnemius muscle of the frog are given in Morholt, page 131. This book presents an elegant method for carrying out this experiment, but the method is not really necessary to obtain the muscular contractions. It is sufficient simply to remove the frog's leg and expose the sciatic nerve. One electrode touching the nerve and the other electrode touching the muscle (through a slit in the skin) will yield good contractions.

Be sure that the ends of the electrodes are clean and free from oxide film. Cutting off the end of each wire just before use will ensure this. Do not maintain contact for too long, and wait several minutes after each series of three or four contractions.

SECTION THREE
Galvani's First Experiment

Text: pages 10–14
Experiment 3

This section brings us into the main story of the case. Your students have already seen (in Experiment 2) muscular contraction in frogs when there is an electrical connection between the frog and the source of electricity. In Experiment 3 they can appreciate the startling nature of Galvani's accidental discovery as they watch muscular contractions occur when an electrostatic machine discharges, even though there is no electrical connection between the frog and the machine. This experiment is probably best done as a demonstration.

In following the description of Galvani's experiments, your students should refer frequently to the plate reproduced on page 16 of the student booklet. This section is discussed on pages 11–15 of Dibner.

9. Is it usual for an instrument from physics to be used in biology? Can you give any other examples?

✔ Very usual. The physicist develops and makes use of apparatus to study physical phenomena. The biologist, in studying the effects of physical phenomena on biological systems, commonly makes use of the tools of the physicist. Among the instruments and techniques used by the biologist but developed by the physicist are microscopes of various kinds, X-ray photography, the ultracentrifuge, and radioactive tracer techniques.

The sharing of instruments and techniques is one of the many ways in which the various branches of science interact.

10. This experiment by Galvani is often called an accidental discovery. Was it? What role do accidental discoveries play in science? Are most scientific discoveries made accidentally?

✔ Popularizations of science sometimes give the impression that an accidental discovery is a lucky incident that might happen to almost anyone. Although the element of chance often plays an important role in scientific progress, it should not be confused with blind luck. The so-called accidental discoveries usually occur in the course of a planned investigation that the scientist is pursuing for some other purpose. If the scientist is prepared to seize upon the new or unexpected phenomenon that he has come upon by chance, he may well be led to a new discovery and even into an entirely new area of research.

The statement attributed to Pasteur is surely applicable: "Chance favors the prepared mind." The chance observation is only the beginning. To establish the full meaning of the accidental discovery, it must be recognized as a significant and unexplained observation and it must be followed up by carefully planned experiments.

Other examples of chance observations leading to important discoveries are Fleming's accidental observation of the antibiotic action of penicillin; Becquerel's accidental observation of the fogging of photographic plates, leading to the discovery of radioactivity; and Malus' accidental observation of the polarization of reflected light.

Some, but by no means most, scientific discoveries result from accidental observations. The vast majority of important scientific discoveries are the result of long and painstaking experimentation and analysis. For further discussion and examples, see pages 47–51 of Goldstein, pages 63 and 91–95 of Calder, and pages 108–122 of Conant. Also see R. Taton, *Reason and Chance in Scientific Discovery* (New York: Philosophical Library, 1957; or paperbound, Science Editions, 1962).

11. Where are the crural nerves located? Is there another name for them? On a diagram of the nervous system of the frog, locate the nerves to which Galvani refers.

This is a trick question—we've asked it this way to bring up an important point. Although there are crural nerves in the thigh of the frog, it is clear from Galvani's drawings (page 16 of the case) that he was referring to what we now call the sciatic nerves. We've used Galvani's term throughout the case to be consistent, but keep in mind and explain to the students that the scientists in the story are referring to the sciatic nerves.

✔ The sciatic nerves can be easily located on the diagram of the nervous system of the frog included in most biology textbooks. They are the pair of large, branched nerve bundles that extend downward from the lower end of the spinal cord. What are known today as the crural nerves are the small, arched branches leading from the sciatic nerves into the frog's thigh.

This question should be used to lead into a discussion of the importance to science of uniform terminology. It doesn't matter much *what* name is applied to something, but it does matter very much that scientists throughout the world understand the name in the same way. This is why a great deal of scientific literature is devoted to the routine task of careful definition. This is why a science student must devote a great deal of time to learning terms and their exact definitions. Clear communication between scientists is vital, and an international agreement on the exact meaning of words is essential to meaningful communication.

12. What attitudes is Galvani demonstrating? Do scientists generally have such attitudes? Do only scientists have them? How much or how often do scientists display these attitudes?

✓ Galvani has become curious, enthusiastic, and eager to study the nature of his accidental discovery. These reactions are often felt by scientists when they discover something new in the laboratory. Galvani wants to find out if the contraction of the frog legs observed when a spark is discharged is just a coincidence or if there is a definite causal relationship. He wants to investigate the nature of the relationship if there is one. (A scientist accepts the results of an experiment only if these results can be repeated by him and by other experimenters.) Galvani repeats the procedure with care and accuracy, eager to find an explanation for the phenomenon.

✓ Generally, scientists are careful, accurate, honest workers, since the nature of scientific investigation demands this of them. Galvani's reactions and attitudes, therefore, are typical of the scientist. Any professional career requires extensive training and often a high degree of intelligence, and professionals must be interested in what they're doing and must work to maintain high professional standards.

✓ While a scientist must exercise sound judgment if his work is to be accepted by his colleagues, he is under no such compulsion outside the laboratory. Away from his work he is just another citizen; he can be just as impatient in five-o'clock traffic as the next fellow, and just as rash and opinionated in nonscientific matters. We find that scientists are real people and that a halo does not come with the job.

13. What is meant by "changing the variables"? What three variables does Galvani change? What other variables might he have investigated?

✓ In an algebraic equation a variable is a symbol that may have many different numerical values. In a scientific experiment a variable is a condition that may be changed qualitatively or quantitatively. In any experiment there are a great number of variables. Normally the scientist makes a controlled change in one variable and observes the effects on other variables. If he changed more than one variable at a time, he would not be sure which change caused the observed effects. The scientist must use his intuition to formulate testable hypotheses to help him decide which variables to study.

✓ In this experiment Galvani chooses to vary (1) the pressure with which the scalpel is applied, (2) the time at which the scalpel is applied, and (3) the presence or absence of an electrical spark.

He chooses these variables because the hypotheses he has formulated lead him to believe that they might be important. He might also have studied the effects of changing such variables as the kind of metal in the scalpel, the distance from the electrical machine, the size of the spark, the kind of animal muscle, the time of day or season of the year, the relative humidity of the air, the age of the experimenter, the length of the scalpel, and so on. Some of these things might be totally unrelated to the effects observed, but others might change the results of the experiment. It would be impossible to test all possible variables, but a good experimenter like Galvani tries as many as he can. Eventually Galvani finds three variables that are definitely related to the contraction of the frog's leg. The frog's leg will contract if (1) a spark is produced nearby, (2) a metal conductor is touching the crural nerves of the prepared frog, and (3) the muscle of the frog's leg is connected with the ground by some conducting material. If any of these variables is changed, the result is changed. Other variables do not affect the results. By isolating the significant variables, Galvani has learned what factors are important. He must next attempt to produce an explanation that will show why these factors are important.

EXPERIMENT 3
Galvani's First Series of Experiments

In performing this experiment, we have had excellent results with a small Wimshurst machine that produced a maximum spark length of about one-half inch. Contractions began to be observed when the spark reached a length of about one-eighth inch.

You can use Galvani's dissection, as shown in the plate on page 16 of the student booklet, or the simple dissection suggested in Experiment 2. At the beginning of the experiment, the frog preparation should be placed within one foot of the spark gap. Use a small spark at first, and then increase the gap. The distance from the spark also can be increased. Keep the preparation moist with saline solution. To obtain contractions, the frog leg must be insulated (place the leg on a glass plate or a piece of waxed cardboard or paper) and the muscle itself must be grounded, either by a hand-held metal scalpel as in Galvani's original observation, or by a length of wire trailing on the ground as in his subsequent experiments.

The directions in the case (page 13) suggest several ways of changing the variables that might be significant. As many of these as possible should be tried, as well as others that your students suggest.

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14. Who was the American scientist who demonstrated that lightning and static electricity are identical? What was the experiment?

This question might serve to awaken the interest of some less able student who is familiar with this story. In *The Bright Design*, Katherine Shippen gives a very simple, easy-to-read account of Franklin, Galvani, and Volta. If this book is available, you may wish to assign it to some slower students.

✓ This well-known experiment was performed by Benjamin Franklin in 1750 at Philadelphia. It should be noted in passing that Franklin was known in Europe as a competent scientist long before he served the United States as a diplomat. For his work on the nature of electricity, Franklin was elected to membership in the Royal Society of London. Franklin's scientific reputation contributed to his success in his diplomatic missions for the new nation.

✓ In comparing the properties of static electricity with those of lightning, Franklin saw many similarities. He knew that static electricity was attracted to pointed objects, and wished to test such an attraction of lightning. The highest pointed object he could think of was a kite, and thus he performed his famous experiment—flying a silk kite on a silk string that had a key tied near the bottom. Franklin stood under a roof to keep the end of the string he was holding dry. When the exposed string became wet, it conducted the electricity down to the key. When Franklin brought his knuckles near the key, a spark jumped from the key to his hand. He was also able to charge a Leyden jar by connecting it to the key. Incidentally, Franklin was lucky—the next two men who tried this experiment were killed.

15. How could Galvani have known about this experiment? Suggest three possible ways.

This question, like Question 2, is intended to point out the means by which scientists communicate information and ideas. We shall return to the same theme in Questions 23 and 30.

✓ A scientist may learn about the work of his colleagues through (1) books, (2) articles in journals, (3) courses, lectures, and seminars, (4) papers presented at meetings of scientific societies, (5) informal talks with other scientists, (6) personal correspondence with other scientists.

✓ In this instance, Galvani probably learned of Franklin's experiment from a book, although we do not know definitely. An Italian translation of Franklin's book containing accounts of his electrical experiments was published in 1778.

For a discussion of communication between scientists, see pages 15–22 of Conant. For a fascinating discussion of the communication problems of modern science, see Derek J. de Solla Price's *Little Science, Big Science* (Columbia Univ. Press, 1963).

16. It is sometimes said that scientific work is impersonal, that when a scientist enters the laboratory he should leave his emotions outside. Do you think scientists really are unemotional in their work?

✓ Scientific work is disinterested and impersonal in that scientists must try to evaluate the significance of their observations without personal bias or prejudice. However, since scientists are men who are devoting their lives to finding the answers to certain questions, it is natural that they would strongly desire their experimental results to support their hypotheses. Scientists become excited when their experimental results back up their ideas, and sometimes are frustrated when they don't. Scientists obviously cannot avoid bringing their emotions into the laboratory. However, the scientist strives to be aware of these emotions, to acknowledge them, and to prevent them from coloring his interpretations of experimental results.

✓ From this we see that scientists have emotions just like other people, but that they must be especially careful to master their emotions while working as scientists. Different scientists do this with different degrees of success.

Regardless of how successful a scientist is in controlling personal bias, there is still another strong emotional factor in his work. The scientist does not view phenomena as coldly inanimate and uninteresting. To the scientist the universe is a continual source of fascination and challenge. The formulation and testing of a new hypothesis may be as creative and exciting an act as the composition of a poem or painting.

The important, if obvious, fact is that scientists are people. Studies have shown that most high school students picture scientists either as cold, inhuman automatons or as eccentrics. The important role played by the personalities of scientists in the development of new ideas is a major theme of this case.

SECTION FOUR
Galvani's Second Experiment and His Theory
Text: pages 12–18
Experiment 4

This is an important section and requires thorough treatment. It is the series of experiments presented here that convinced Galvani he had discovered animal electricity. (See the comments on Question 21 below.) Your description of the series of experiments on page 18 of the case should be so structured that your students will see clearly the importance of this turning point in the story. Experiment 4, Galvani's Second Series of Experiments, can be done by your students in the laboratory and will help them to see the rather inconclusive nature of the data on which Galvani based his decision. Or the experiment can be done as a demonstration with the students standing around the demonstration table. With either procedure, the relation between Galvani's explanation of muscular contraction (page 18 of the case) and Experiment 4 should be brought out and discussed thoroughly.

The biographical reports of Activity 1 should be assigned to individual students during this section.

This section of the case is paralleled by pages 16–18 of Dibner. Further comments on the way in which hypotheses evolve from experiments and observations are given on pages 47–60 and 110–114 of Conant, pages 30–35 of Calder, and pages 11–24 of Goldstein.

17. Would you call Galvani's idea a hypothesis?

✓ Galvani's idea that daily changes in atmospheric electricity could produce muscular contractions is clearly a hypothesis. It is, however, a rather restricted idea, not a hypothesis on the grand scale (see the comments for Question 8 on page 15 of this guide).

It might be well to spend a few moments at this point preparing for the subsequent development of the relation between experiments and hypotheses. Aspects of this theme, which is one of the important ideas of the case, are dealt with in Questions 20, 21, 27, and 36. At this point it should be sufficient to suggest that Galvani had an idea (hypothesis) which he thought explained certain observations (contraction of muscles under specific conditions). In order to find out if his idea was correct, he carried out an experiment.

18. Is patience a desirable characteristic of scientists? Why, or why not? Are all scientists patient?

✓ Patience is not only a desirable characteristic for scientists; it is a necessary one. Many kinds of research require the scientist to repeat an experiment many times, changing one or more variables each time. This is exemplified by the large number of experiments that Galvani performed. Such repetition is often tedious, and the scientist must have sufficient patience to carry him through the tedium. Moreover, some research—such as that in genetics—must be carried out over long time periods, which in itself demands considerable patience.

✓ To say that *all* scientists are patient is surely too sweeping a generalization. We can say that *most* scientists have a large measure of patience. Anyone who did not would probably not remain a scientist.

19. Is impatience a desirable characteristic of scientists? Why, or why not? Be sure to consider your answer to the preceding question when answering this one. Can a person be both patient and impatient? Are scientists generally impatient?

✓ Impatience of a certain kind is desirable in a scientist. He must have the impatience that will stimulate him to find answers to questions rather than sit back and let others find them. His impatience will force him to perform experiments and formulate hypotheses.

This kind of impatience, essentially a lack of complacency, is not incompatible with the patience needed to carry out experiments.

20. What effect does the observation of "no relation" have on Galvani's idea discussed in Question 17? Incidentally, what does Galvani mean by "no relation"?

This question continues the exploration of the relation between hypotheses and experiments begun in Question 17, and should be discussed at sufficient length to allow your students to understand clearly the reasoning involved.

✓ Galvani hypothesized that muscular contractions were caused by daily changes in atmospheric electricity. When he tested his hypothesis, he observed that muscular contractions did not seem to correspond with changes in atmospheric electricity. Changes in atmospheric electricity did not always produce contractions, and some contractions occurred when there was no change in atmospheric electricity. Therefore no cause-and-effect relation could be shown to exist between these two variables. Changes in one variable did not always correspond to changes in the other variable. They were independent occurrences: there was "no relation" between them.

21. What variables is Galvani testing when he goes indoors?

This is a clear example of a new, limited working hypothesis arising from observations.

✔ After Galvani eliminates the idea that changes in atmospheric electricity cause the contractions, he thinks the contractions may result from the discharge of electricity built up slowly in the animal from the atmosphere. This discharge, Galvani thinks, occurs when the brass and iron come into contact. To test this new hypothesis he eliminates the variable of atmospheric electricity. In the closed room there is no atmospheric electricity available to build up in the frog.

✔ When the contractions continue to occur, Galvani changes the location of his apparatus inside the room, the metals used, and the time of day. These are further examples of testing limited working hypotheses that have arisen from observations.

When Galvani changes from his original metals to poor conductors and nonconductors, he ceases to observe contractions.

This is the turning point in Galvani's research. At this point Galvani could hypothesize that two dissimilar metals must be present to cause contractions. Instead he hypothesizes merely that metal is necessary to complete a circuit for electricity originating in the animal.

Here we see a new theory arising from observations and experiments. Notice that at this crucial moment, the scientist must make a personal judgment as to which variables are important and which are not. Your students should realize that there are few guideposts to help the researcher, no fixed rules to follow, no magic formulas to use. Another researcher might have formulated a very different theory to explain the same series of experiments. See Questions 8, 25, 30, and 36 for other aspects of this personal aspect of science.

EXPERIMENT 4
Galvani's Second Series of Experiments

See the general suggestions for preparing the frog on page 15 of this guide.

For this experiment, it is absolutely essential that the wire and the plate be thoroughly cleaned. Clean the ends of the wire by flaming to red heat (cool before using) or by immersing briefly in dilute nitric or sulfuric acid (rinse well before using). Hard rubbing with a steel-wool pad will clean the plate.

Better results will be obtained if the frog is thoroughly bathed in saline solution (8.5 gm NaCl per 1000 ml distilled water) and the end of the wire placed in a small pool of solution on the plate.

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22. What is a theory? How is it different from a hypothesis? How are scientific theories used?

✔ A scientific theory is a broad, generalized statement of a scientist's view concerning some aspect of the universe. It consists of a small number of postulates or assumptions that can usually be expressed in mathematical form. In the physical sciences today, the postulates of most major theories are expressed as equations. A scientific theory evolves from repeated cycles of observation or experiment, analysis of results, and evaluation by the experimenter. By constructing theories of ever widening scope, the scientist attempts to approach the ultimate aim of science: a comprehensive description of the universe in terms of a few basic ideas.

✔ More important than the statement of a scientific theory, however, are the functions of a theory. One criterion for the usefulness of a theory is that it should explain the observations and generalizations in the area it covers. This is sometimes called the explanatory function of the theory. Another criterion for usefulness, 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 usefulness of a theory, called its heuristic function, is whether or not it suggests new hypotheses and experiments. Testable hypotheses can be deduced from the postulates of a scientific theory in much the same way that theorems can be deduced from postulates in geometry. A useful theory must lead to numerous problems for investigation. An extensive discussion of the nature and acceptance of theories will be found on pages 57–62 and 214–296 of Nash. A more traditional view, as well as a discussion of several opposing views, is given on pages 79–152 of *The Structure of Science*, by Ernest Nagel (Harcourt, Brace, 1961).

Scientists often use theories as a basis for formulating hypotheses. A hypothesis is a statement of the following sort: "According to our theory, if we do this, we shall observe that." If the observed results agree with those predicted by the hypothesis, confidence in the theory is strengthened. If the observed results do not agree with the prediction of the hypothesis, either the hypothesis or the theory must be reexamined. If the hypothesis was correctly drawn from the theory, then the theory must be modified to account for the observed results.

The essential difference between a theory and a hypothesis is that a theory is a proposed general explanation of a natural phenomenon based on observational data, while a hypothesis is a statement of a scientist's ideas about a certain phenomenon, which may be the predicted results of an experiment. (See the comments on Question 8.)

Since theories grow from human experience, they are human creations. Scientists do not claim that their theories define the ultimate reality of the universe. There are many examples of theories, once considered correct, that are now known to be inadequate. Examples include spontaneous generation of life (see pages 15–20 of Goldstein), the inheritance of acquired characteristics, bad air causing disease, and the idea that human sperm contains tiny, fully formed human beings. The very nature of scientific research—the continued reevaluation and retesting of hypotheses—ensures that as time goes on scientists will come closer and closer to a complete description of natural phenomena.

Students frequently use 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 common language, it may be difficult for you to teach the precise use of the word in science. The effort should be made, however, since an understanding of what scientists consider a theory to be and what they expect from it is an important part of understanding science.

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

PAUSE FOR A QUIZ

At about this point in the study of the case you may wish to give your students an informal fifteen- or twenty-minute written quiz. There might be two questions, one dealing with the biology subject matter of the case and the other with an idea about science or scientists that has been explored thus far. Following are two suggested questions:

1. a. According to Galvani, why do muscular contractions in prepared frog legs take place?
b. What contribution was made to Galvani's explanation by each of the following: Pieter van Musschenbroek, an "accidental discovery," and Benjamin Franklin?

2. What is meant by "changing the variables"? How is this idea used in a scientific investigation?

SECTION FIVE
Volta's Experiments and His Theory
Text: pages 20–22

This is a short section, but it is just as important as the preceding one. Since your students have already been over similar ground in Section Three, this section will probably be covered somewhat more rapidly. There is no experiment for this section. If there were to be one, it would be the same as Experiment 4. This is the essential point of the section. Volta brought a different background and a different orientation to his investigation. He observed the *same phenomena* as Galvani but came up with a completely *different explanation* of muscular contraction.

The two rival explanations of muscular contraction should be compared. There is little doubt that each investigator was satisfied with his own explanation, although each was aware of the other's explanation. (As we shall see later, further research has shown that neither was wholly correct.) Galvani's explanation seems to retain a certain aura of the mystique that is found in many biological explanations of the eighteenth century. Volta's explanation reflects a much clearer grasp of electrical phenomena; however, his concept of the production of electricity is still immature and inadequate. You might also wish to point out that the construction of an electric battery is an almost inevitable logical deduction from the first three points in Volta's explanation.

Pages 19–20 and 24–28 of Dibner provide background information for this section. Also see pages 109–114 of Conant.

23. What kind of publication was the Proceedings of the Bologna Academy of Arts and Sciences? What functions do such publications perform?

✔ The *Proceedings* of the Bologna Academy of Arts and Sciences was a journal in which the ideas and recent experiments of scientists and scholars in and around the University of Bologna were published. Such publications form one of the major channels of communication between scientists and scholars.

✔ Communication between investigators is essential to 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 these scientists to share their findings with each other, much duplication and wasted effort would result. Moreover, 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 new ideas and new interpretations of experiments and observations. In addition, publication of the accounts of experiments in journals enables other workers to repeat the experiments, or variations of them, and to verify or modify the findings. This distribution of scientific writings to all members of the scientific community helps to keep individual scientists honest as well as informed.

Today the volume of journal articles being produced is so large that special journals of abstracts are also published. A journal of abstracts contains brief accounts of recent articles in a particular field of science that have been published in other journals around the world. Even the journals of abstracts cannot reduce the mass of articles sufficiently to enable a man to keep up with all the work being done in his field. Nearly 100,000 scientific journals had been founded by 1950, and at the present rate of growth this number would reach 1,000,000 by the year 2000. Many scientists are searching for ways to use high-speed computers to store and retrieve information as needed.

24. Why is this called a revolutionary age? What was happening in the Western world at about this time (the 1790s)? Do you think that events outside science have any effect on the kinds of problems scientists investigate? Or are scientists so isolated from the rest of society that there is little effect? Can you give any examples to support your opinion?

✔ The decade of the 1790s is often called a revolutionary age because the political, social, and philosophical systems of the Western world were undergoing rapid, drastic changes. The American Revolution had recently ended; the French Revolution was in progress; Napoleon was rising to power (he annexed northern Italy in 1796, founding the Cisalpine Republic to which Bologna was to belong); and the idea of social democracy (Jean Jacques Rousseau) was developing. As a result of these attacks on established social, philosophical, and political institutions, men were receptive to new ideas. They were more likely to question old answers and to seek newer and more satisfactory ones.

Events outside science influence in two broad ways the kinds of problems scientists will study. First, the technological demands of a society encourage scientific research in certain areas. For example, in America today a great deal of money is being spent to encourage scientific research in basic plant nutrition and soil sciences. This is being done in the hope that a fuller understanding will lead to improvements in agricultural techniques that will help overcome widespread food shortages. Second, events outside science influence scientific research in a negative way. It often happens that in a given community a great deal of sentiment is aroused against such scientific pursuits as dissection of corpses and experimentation with live animals. In this way the pressures of society can restrict scientific investigation.

For further discussion of the interrelation of science and society, see pages 57–59 and 173–189 of Calder and pages 296–311 of Conant.

25. Why do scientists repeat experiments? Does the fact that experiments can be repeated help to keep scientists honest in reporting their results? Aren't scientists naturally honest?

✔ Most scientists are cautious workers and try to avoid drawing conclusions from just a few observations. However, even the most skillful scientist can make errors in judgment or technique. For these reasons, an experiment might be repeated many times before the scientist is satisfied that the results obtained are consistently reproducible. Furthermore, by such repetition the influence of significant variables that might otherwise have been overlooked (for example, barometric pressure, relative humidity, effects of the particular instruments used, time of day) may be detected.

✔ The case suggests another reason for repeating experiments. Quite often a scientist will repeat the experiments of some other scientist and, because of a difference in training or the use of improved techniques, will see something that the other scientist had overlooked. In this case Volta noticed the effect of dissimilar metals and thus considered Galvani's explanation of muscle contractions inadequate.

✔ Another aspect of the repetition of experiments is brought out by the last part of the question. The knowledge that his experiments can be repeated is a potent factor in keeping a scientist honest. Scientists are only human and may grow careless in their work, or may be tempted to distort the reports of their results in order to gain support for a favorite theory or hypothesis. The knowledge that his experiments can, and almost certainly will, be repeated by someone else helps to encourage the scientist to be particularly careful and honest in performing and reporting his experiments.

26. Do all scientists have as "profound an intelligence" as Volta said Galvani had? Just how intelligent are scientists, in general?

✓ Scientists are generally more intelligent than the average man in the street. Nearly all scientists have earned college degrees, and most have completed several years of postgraduate studies. Any group made up of men who have survived higher education is certain to consist largely of men with higher-than-average intelligence. However, scientists differ in intelligence just like members of any other professional group. While most scientists have more than average intelligence, very few are geniuses. It is interesting to note that a group of psychologists, attempting to determine the IQs of great scientists of the past on the basis of their biographies and writings, assigned the highest IQ to Johann Wolfgang von Goethe, a man better known for his accomplishments in literature than for his scientific work. Details of this and other studies are given in Anne Roe's fascinating book *The Making of a Scientist* (Dodd, Mead, 1952). The results of this study of a group of leading contemporary scientists would make an interesting report for one of the better students of your class. The author emphasizes the wide variety of personalities and intelligences to be found among even the best of scientists. Her book is short, easy to read, and interesting. See also *The Scientist*, by Henry Margenau, David Bergamini, and the editors of *Life*, a volume in the Life Science Library (New York: Time Inc., 1964), pp. 32–34.

27. What variables did Volta change? How can a scientist identify the significant variables in an experiment? Can different explanations result from changing different variables? How?

✓ You will recall our definition of a variable in our notes on Question 13: "a condition that may be changed qualitatively or quantitatively." Volta changed the number of points at which the frog leg preparation was touched in eliciting a contraction (only the nerve, only the muscle in two places, the nerve and the muscle, and so on).

✓ In order to answer the question "How can a scientist identify the significant variables?" we must first specify what we mean by a "significant variable." We can consider a variable significant if by changing *only* that variable, one can significantly alter the results of a particular experiment. This definition makes the answer to the question obvious. A scientist systematically alters each of the variables that his hypothesis suggests may be significant. If changing these variables causes no change in the outcome of the experiment, he reexamines his hypothesis.

✓ It is indeed possible for different explanations to result from changing different variables. Many scientific theories have been discarded when further research showed that variables originally neglected were significant. In this case we see Volta discovering the significance of several variables Galvani had overlooked. Since Galvani's theory does not predict that these variables will be significant, his theory must be altered or replaced with another theory that accounts for these occurrences.

For further discussion, see Question 21.

SECTION SIX
The Controversy and Aldini's Experiment

Text: pages 22–24
Experiment 5

This is a very short section and should be covered rapidly. A fascinating aspect of this section is the manner in which scientists seem to choose up sides in support of one view or the other in the controversy. This is characteristic of most scientific controversies. Presumably the supporters of each view are motivated solely by the convincing nature of the evidence on that side, but we can never be sure that this is so. After all, scientists are human, and they may be subjected to the subtle pressures of persuasion by their colleagues or the "team spirit" of the institutions to which they belong. In some controversies, even the philosophical, political, or religious beliefs of the scientists may influence their attitude. Famous examples include the effects of religious beliefs on scientific attitudes toward the heliocentric solar system, the possibility of a vacuum, and the evolutionary development of man. In the recent controversy over the significance of radioactive fallout, political views seem to play a large part in the attitudes of scientists. Students may wish to discuss such instances, and then look for similar influences on the participants in this controversy.

Experiment 5, Aldini's Experiment, is probably best done as a demonstration, preferably by an able student. You will want to point out that the positive result of this experiment is consistent with Galvani's theoretical explanation of muscular contraction, but not with Volta's. For Volta's explanation to triumph, it was necessary to ignore Aldini's experiment, to sweep it under the rug, so to speak.

This section is paralleled on pages 20–24 and 28–30 of Dibner. A fuller account of Aldini's experiment is given on pages 50–51 of Dibner.

28. Why would an experiment to obtain contractions without using metals be important? How does it challenge Volta's theoretical explanation?

✔ Volta had proposed an explanation for muscular contraction in which the electricity produced by the combination of two dissimilar metals *caused* the contraction. Any experiment in which a muscle could be made to contract without any metals present would show that Volta's explanation was inadequate. Such an experiment would also provide support for the proponents of animal electricity.

This would be a good time to review the discussions of Questions 13, 17, and 22.

29. Can you identify the parts of a nerve? What is the function of each part?

✔ The principal parts of a vertebrate peripheral nerve are identified in the diagram on page 41.

✔ Their functions are as follows:

Dendrites receive impulses from other neurons.

Nucleus is the site of the control of most of the cell's activities.

Cytoplasm is the site of most of the cell's activities.

Node of Ranvier. Function unclear; may help speed up nerve impulses.

Axon conducts nervous impulse from cell body to end brush (may be up to 10 feet long in whale, elephant, and giraffe).

Myelin sheath is a fatty sheath that acts as an insulating cover.

End brush stimulates the muscle by secretion of hormones.

Neurilemma is a protective membrane surrounding the myelin sheath.

EXPERIMENT 5
Aldini's Experiment

See the general suggestions for preparing the frog on page 15 of this guide.

The reaction obtained by Giovanni Aldini was a vigorous contraction of the muscle. He presented this as evidence supporting the existence of animal electricity, since there was no external source for the current. The presently accepted explanation for the contraction was provided in the next century by Leopoldo Nobili, who said it was the result of the stimulation of the nerve by the *injury current* of the cut muscle.

In this experiment Aldini recognizes the need for proper experimental technique. One of the requirements for a valid scientific experiment is adequate technical control over the circumstances and materials involved. Failure to exercise sufficient care in the manipulation of the experimental material amounts to a failure to control the variables.

SECTION SEVEN
Volta's Battery and the Resolution of the Controversy

Text: pages 24–28
Experiment 6
Activities 1, 2, and 3

In this final section of the case, emphasis should be placed on the dramatic nature of Volta's invention of his battery and his experiments with sensation, and on the retrospective evaluation of the two rival explanations of muscular contraction (page 28 of the case). This is also a good place for you to point out the distinction between science and applied science (see Question 34).

Activity 2, An Eleven-Cent Battery, can be done as a quick demonstration. Activity 3, Volta's Experiments on Sensation, using the voltaic pile previously constructed as a student project (Experiment 6), should be done by as many students as possible. Time should also be set aside in this section to hear some of the biographical reports prepared for Activity 1 and to discuss the questions at the end of that activity.

For more details on Volta's battery and his experiments on sensation, see pages 30–34 and 42–49 of Dibner. You will find information about two nineteenth century electrophysiologists, Hermann Helmholtz and Emil du Bois-Reymond, on pages 409–413 of Nordenskiold.

30. Do you detect any differences in personality between Galvani and Volta from their styles of writing? If so, what differences?

✔ It would be difficult to discern personality differences purely on the basis of the few excerpts from the writings of Galvani and Volta given in this case. Extensive study of their writings, however, shows that Volta was more analytical in considering the principles underlying the phenomena he observed, while

Galvani's approach was more observational. Volta made his assertions boldly (". . . it has not, I say, been ascertained . . .") and with more definite statements (". . . and was thus enabled to make several discoveries which had escaped Galvani"). From this we might conclude that Volta was the more outgoing and confident man. Galvani, who was just as curious and interested in the phenomena, was a more timorous person and did not state his scientific findings as aggressively.

The personalities of scientists can often influence the course of scientific research and progress. Other instances of such influences have been indicated in Questions 12, 18, 19, 21, 25, and 27, and will be discussed again in Questions 34 and 36.

31. Are ideas or instruments more important in science? Explain your answer.

✓ Ideas and instruments are of equal importance in experimental science. We have already discussed the importance of instruments to scientific advances (see Question 4). Just as new instruments sometimes lead to the development of new ideas, so a scientist's idea about a phenomenon often leads him to develop a new instrument or technique to test his idea. For example, the idea that beams of electrons would act like beams of light led to the development of the electron microscope. Other examples:

Idea	*Technique or Instrument*
Proteins and other large molecules often carry a net plus or minus charge, depending on the *p*H of the medium.	Electrophoresis
Most substances are soluble to different extents in different solvents.	Purification by countercurrent distribution and by chromatography
Various fabrics are colored to different degrees by different dyes. Why not stain parts of a cell with different stains?	Differential staining

Instruments or techniques that led to new ideas include the following:

Instrument or technique	*Idea*
Radioactive isotopes, borrowed by biologists from physicists and used as tracers.	New information and ideas concerning circulation, photosynthesis, biochemistry, and so on.
Electron microscope	New insight into cell structure.
Warburg respirometer	More information about the biochemistry of respiration and fermentation.

Thus ideas lead to the development of new instruments, and the use of new instruments leads to new ideas. Both are important to scientific progress.

Refer to Questions 4 and 35 for further discussion of instrumentation in science.

32. What kind of organization is the Royal Society? What do the Royal Society and similar organizations do? Give at least five functions of these organizations.

✓ In 1960 the Royal Society celebrated its tercentenary, dating from the founding meeting on 28 November 1660, at Gresham College in the City of London. Among the twelve founders were Sir Christopher Wren the architect, Robert Boyle the chemist, two astronomers, and several men of public affairs. Henry Oldenburg was appointed secretary, stimulator of communication, and mediator of scientific and personal quarrels. Robert Hooke became curator, with responsibility for producing experiments for the weekly meetings. There had been a group meeting weekly in London since 1645 for "philosophical inquiries," moving to Oxford after the outbreak of the Civil War. The Royal Society itself was formed in the year of the restoration of Charles II. It received his endorsement at once, and a royal charter was granted to the society in 1662.

Election as a fellow of the society, giving the privilege of using the title F.R.S. after one's name, has always been the greatest scientific honor in Great Britain. Currently 25 new fellows are elected from Great Britain each year, and only four foreign members. Of the total of 66 foreign members of the society today, nearly half are Nobel laureates. The total membership is about 600.

In its first century, and especially under the presidency of Sir Isaac Newton, the Royal Society was the source of most scientific research in England. In the nineteenth century it lost some of its vigor, and the Lunar Society of Birmingham and the British Association assumed parts of the society's former role and prestige. In the last hundred years the Royal Society has recouped its primacy, although its role is much different. Fellows enter only after they have done substantial research in universities or in industry. Although not a government body, the Royal Society does allocate substantial government funds for research, and is responsible for drawing up research priorities and standards for fund recipients. The governing council of the society is advised by more than fifty committees, subcommittees, and panels, and in turn acts as primary adviser to the government on matters of international science.

In many of its functions the modern Royal Society is similar to our National Academy of Sciences. It played a leading role in guiding British participation in the International Geophysical Year and in follow-up programs. Through its three hundred years it has provided stimulus and support to the greatest British scientists: Boyle, Hooke, Newton, Dalton, Faraday, Darwin, J. J. Thompson, and Rutherford.

✓ The Royal Society and other scientific societies and associations perform many valuable functions, including publication of journals and books, sponsoring of meetings and congresses (providing personal contact between scientists), providing funds for research, establishing standards for terminology and measurement, acting as a professional focal point or "home" for scientists, and setting standards for scientific research.

For further discussion of the stimulating role played by scientific societies, see pages 14–22 of Conant and pages 7–16 of Calder.

33. Can you suggest any other arrangements of three materials to make various types of batteries?

✓ A few examples:

1. Volta's famous "crown of cups," consisting of connected silver and zinc plates in cups of weak acid or brine (see page 35 of Dibner).

2. The Daniell cell, a zinc electrode immersed in a solution of zinc ions and a copper electrode in a solution of bivalent copper ions, with the two solutions separated by gravity or by a porous cup.

3. The dry cell, a rod of carbon surrounded by a paste of zinc chloride and ammonium chloride, which in turn is surrounded by a zinc cup.

34. How is applied science different from science? Give three examples of results from each.

✓ In common usage the words *science* and *scientist* cover a multitude of activities. We prefer to think of a scientist as a person whose main concern is the orderly structuring of knowledge about nature. Though not unmindful of the possibilities of its practical exploitation, scientists by and large consider scientific knowledge an end in itself. By contrast, people whose main concern is the practical application of scientific knowledge we prefer to call applied scientists or technologists. This group includes, among many others, engineers, practicing physicians, nutritionists, and opticians.

While science and applied science may appear to be quite similar, they are fundamentally very different. We can best illustrate this difference by considering the activities of people concerned with these two pursuits.

✓ The applied scientist or technologist is interested in learning how to do a specific job or thing. The technologist makes use of the theories and principles that have been developed by the scientist, but today he does not usually develop these principles or theories himself. Technologists attack such problems as these: How can I make a stronger plastic? What is the best way to prepare frozen foods? What is the cheapest way to produce this paint? How can I land a man on Mars? How can I build a more efficient source of electrical power?

✓ The scientist is interested in understanding the whys and wherefores of the physical universe. His work is directed toward discovering the basic principles that govern the operation of the universe. Pure scientists are interested in such questions as these: What is the structure of the atom? What is a gene? How does a cell grow? How is it that a single cell can give rise to billions of genetically identical cells, many of which appear and act quite differently? Why do the various chemical elements have the properties they have? Is the universe expanding? What causes electrical currents?

For a discussion of the relation between applied and pure science, see pages 60–62 and 296–328 of Conant. Also see comments on Question 24 above.

35. What were some of the scientific uses of the voltaic pile? (Do <u>not</u> give examples from applied science or technology.)

See pages 37–40 of Dibner.

✓ Among the scientific uses of the voltaic pile were the decomposition of chemical compounds into elements by electrolysis, the study of the effects of heat and light produced by an electric current, the study of continuous electric arcs or spark gaps, the study of the electrical nature of chemical solutions, and the study of the effects of electric stimulation on organisms. Many theories about the electrical nature of atomic and molecular forces and attractions were developed as a result of studies conducted with the voltaic pile, and during the nineteenth century the idea was generally accepted that chemical processes were basically electrical, rather than gravitational as had been thought by eighteenth century scientists.

EXPERIMENT 6
Voltaic Pile

The arrangement of the pile of disks is clearly shown in the illustration on page 26 of the student booklet ("A" in the illustration stands for *argentum*, silver, but we are using the cheaper metal copper). Further construction details are given in the reproduction of Volta's paper found on pages 42–43 of Dibner. The shape and size of the disks do not seem to be important to the success of the experiment. We have had very good results with squares of copper and zinc about one inch on a side and 1/32 inch thick.

The questions in this experiment encourage the students to explore some of the variables in the makeup of a voltaic pile and the effects of a change in these variables on the electrical potential of the pile. There is no danger in "playing around" with the pile in this way, as long as the number and size of the disks are kept small. The number of pairs of disks needed to light a flashlight bulb will vary with the constructional details of the pile. We have found that, with one-inch squares of copper and zinc, about 45 pairs of disks generally suffice to light a 1½-volt flashlight bulb.

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36. In this case we have seen a controversy develop from two different explanations for the same phenomenon. Such disagreements happen frequently in science. Although scientists try to follow certain rules in settling such disputes, personal and accidental factors are often important. Go back over the controversy in this case and try to answer these questions:

a) What are the rules for settling controversies in science?

b) How are scientific controversies actually resolved? Are they always resolved?

✔ Much scientific knowledge rests upon the opinions and interpretations of scientists, and it is inevitable that controversies will arise from differences in the opinions of several scientists studying the same phenomenon. Since science is an objective discipline, there must be an objective means for settling such controversies. The means is actually inherent in the structure of science and in the scientific approach.

✔ Every theory must be supported by experimental or observational evidence, and the evidence must be honestly reported. Thus the first step in resolving a controversy is to examine carefully all evidence on both sides. If the experiments and observations are acceptable in the eyes of the scientific community—which acts as judge and jury in such controversies—then the conclusions drawn from this evidence must be examined. If the conclusions on both sides are acceptable to the scientific community, then the controversy must remain unresolved temporarily.

✔ Controversies are resolved through the incorporation of new evidence that supports one view or the other. A decision can then be made on the basis of the new experiments or observations. The viewpoint that most accurately and most consistently describes natural phenomena, as scientists understand them at the time, is generally the one that is accepted.

✔ While controversies are in principle decided in the manner described above, often other factors enter that are not as scientifically objective. The personality differences of two scientists on opposite sides of a question will play some part in the decision, the resolution often being in favor of the man who promotes his ideas more aggressively. The scientist in this position helps to attract followers to his views by a forceful and dramatic presentation of his case. For example, Volta's excellent demonstrations before a group of physicists (who might be expected to favor the idea of physical explanation over the theory of animal electricity) and his judicious neglect of Aldini's experiment helped his case tremendously.

For a discussion of the matter of ignoring certain facts that seem to contradict a theory, see pages 193–195 of Conant. As Conant remarks, "Subsequent events sometimes show this was blind folly, sometimes inspired wisdom."

An interesting controversy exists at the present time among historians and philosophers of science about the means by which scientific controversies are resolved (it will be interesting to see how *that* controversy is resolved). One group holds the traditional view that a new theory is evolved, incorporating all the parts of the old theories that do not disagree with observations. Scientific theories thus evolve gradually, becoming ever more accurate in their explanation of phenomena. This evolutionary view of the history of science is defended on pages 254–296 of Nash.

An opposing group holds that scientific theories do not survive for long, but are overthrown and replaced by new theories that are inherently different. The factors favoring the new theory are chiefly psychological and sociological, and there is no reason to suppose that it is any closer to a "true explanation." This revolutionary view is expounded in a controversial and somewhat difficult book by Thomas S. Kuhn, *The Structure of Scientific Revolutions* (University of Chicago Press, 1962).

NOTES FOR ADDITIONAL ACTIVITIES

ACTIVITY 1
Scientists and Nations

This activity is intended to help illustrate several points. First, it stresses the fact that science is an international activity. Since the phenomena of nature with which science deals are accessible to all, people in every nation can make contributions to science. Here we also emphasize the importance of effective international communication between scientists.

Second, although every nation has the potentiality of making scientific contributions, countries differ in their scientific activity at any given time. (We might take the number of prominent scientists as a rough measure of scientific activity.) Students are asked to consider what social factors operating in a particular country may determine whether the nation is active or relatively inactive in science. Illuminating discussions bearing on this point are found on pages 57–60 of Calder and pages 37–41 and 324–327 of Conant.

Third, we wish to combat the notion that advances in science result solely from the efforts of a few great men. For every scientist whose name finds its way into elementary textbooks, there are hundreds of equally hardworking, dedicated men (and women) who have made contributions. Consider the countless experiments and observations, the multitude of papers and reports, the many proposals and counterproposals that are invested in the development of any major scientific idea.

Finally, a number of interesting contrasts can be found in the lives and activities of various scientists. Some are gregarious and some are shy; some have many interests outside science, others appear to be concerned with nothing else; some attain considerable fame in their own time, while some are unrecognized until long after their death; some are very generous and others downright stingy; some are mild and even-tempered, others are fiery and uncompromising; most marry and raise families, but some remain bachelors. As your students report on the lives of the men they have studied, these contrasts can be brought out.

The best sources of information are biographies and biographical dictionaries. A handy classroom source is Isaac Asimov's *Biographical Encyclopedia of Science and Technology* (Doubleday, 1964). In many schools an encyclopedia may be the only source available. The 1960 edition of the *Encyclopaedia Britannica* contains articles on the following scientists mentioned in the activity:

Denmark—Nicolaus Steno

England—Thomas Willis, John Mayow, John Hunter, Augustus Volney Waller, Augustus Désiré Waller

France—Antoine Louis, François Magendie, Charles Richet, Claude Bernard

Germany—Emil du Bois-Reymond, Hermann van Helmholtz

Holland—Jan Swammerdam, Pieter van Musschenbroek, Hermann Boerhaave

Italy—Giovanni Borelli, Giovanni Beccaria, Luigi Galvani, Alessandro Volta, Camillo Golgi

Scotland—Charles Bell, Robert Whytt

Switzerland—Albrecht von Haller

If the encyclopedia is the only source available, you may wish to emphasize the point mentioned above—that many important contributions are made by men who do not achieve great fame.

The number of scientists a given country will produce at a given time and the problems these scientists study are largely a reflection of the country's educational system, the national attitude toward science, and the culture's technological needs for research in a given area.

The important role played by the educational system of a country in producing scientists is quite clear. If a country is to produce many scientists, it must provide an up-to-date, progressive educational system in which to train and prepare 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. Public opinion may either stimulate or retard the training of scientists and the progress of science. A 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 obtain funds for research—will produce many scientists. A country where the public is unwilling to provide an adequate educational system, where scientists are regarded 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 affect 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 funds available for the training of scientists and the support of scientific research.

ACTIVITY 2
An Eleven-Cent Battery

The eleven-cent battery will produce a current as long as the filter paper remains moist. The current diminishes as the paper dries. The filter paper must be between the coins for the battery to work, since the salt solution in the fibers of the paper is the electrolyte of the cell. An electrolytic cell usually consists of two metallic electrodes separated by an aqueous solution of ionic salts. The electrodes must be connected to each other by a conductor external to the electrolytic solution. An electric current is generated through this external conductor as a result of (1) chemical reactions at the surface of each electrode and (2) the migration of ions to the oppositely charged electrodes through the electrolyte. (Note the difference between this modern explanation and Volta's ideas about the production of an electric current in his cell.)

ACTIVITY 3
Volta's Experiments on Sensation

There is no danger of severe shock from the voltaic pile or of damage to the nerves unless a pile with a very large number of plates is used and contact is maintained for a long period. The description in the case should provide its own precautions. A few more details of the experiments can be found on pages 46–48 of Dibner.

QUESTIONS FOR REVIEW

The following questions 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 the objectives for the unit (pages 9–10 of this guide) and pertinent sections of the commentary would be appropriate.

1. What are the three kinds of muscle tissue? How do muscles function?

2. What are the principal parts of a nerve? What is the function of each part?

3. Discuss Galvani's reasoning in the last two paragraphs of the quotation on page 14 of the case.

4. How did the reports of Franklin's kite experiment affect the work of Galvani?

5. How did Galvani explain muscular contraction? How did Volta explain muscular contraction? Who was right?

6. "Chance favors the prepared mind." Explain and discuss this quotation.

7. Why do you think a man becomes a scientist?

8. What do you think goes on at a scientific meeting? How is a convention of scientists like a convention of plumbers? How is it different?

9. What effect do you think the invention of the printing press had on the progress of science? Explain.

10. In what ways would a computer be unable to replace a scientist?

11. What is meant by a "testable hypothesis"? How are hypotheses developed?

12. 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."

13. Why is specialized equipment, such as the microscope or the voltaic cell, important to science?

14. What might have been the outcome of the controversy between Galvani and Volta if the personalities of the two scientists had been reversed?

NOTES FOR UNIT TEST

Permission to reproduce the test printed on pages 32–37 can be obtained by writing to:

Permissions Department
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 information below about the different parts of this test and the ways in which these parts are related to the objectives of the unit, which appear on pages 9–10 of this guide.

PART I

This part consists mostly 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 (the "A" objectives listed on page 9).

PART II

This is an attempt to test for some of the "A" and "B" objectives. Principles and concepts presented in the case appear in a new 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, and must also have had extensive practice in scientific reasoning. Class discussions of this case should have contributed some of this practice.

PART III

This part tests for understanding of ideas concerning scientists and scientific work (the "C" objectives). Some of the true-or-false items of Section A involve simple recall of statements of ideas discussed in connection with the case: others call for making rather careful discriminations. It is important that students rewrite false statements, because incorrect ideas should not be permitted to stand.

Section B attempts to measure the student's success in achieving one of the long-range aims of studying the HOSC units: a sensitivity to the nature of the scientific enterprise as evidenced by his ability to recognize fundamental ideas about science when reading unfamiliar materials (see page 10 of this guide). This kind of recognition is exemplified by the marginal comments and questions throughout the case. Nevertheless, the task of inducing general ideas from particular facts is not likely to be easy for many students. The general statements under A of this part of the test can be of great help in accomplishing the task successfully. 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, Section 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 sensitivity to the nature of the scientific enterprise than is Part III, Section B; however, the dual task of recognizing an example and formulating a statement of the general idea is more difficult. The grading of the performance is also more difficult, because it involves numerous separate judgments.

In Section B the student has an opportunity to demonstrate how well he comprehends the principle of the voltaic pile. Some recall is involved, since the question deals with the type of pile that was discussed in the case. (Use of an unfamiliar example would make this an extremely difficult question.) Grading may be difficult here, as it always is whenever an essay answer is required.

POINTS SUMMARY:

PART I	–	12
PART II	–	16
PART III	–	24
		52
PART IV	–	variable (likely maximum – 16)

UNIT TEST

PART I

A. The principal scientists involved in this case study were Giovanni Aldini, Luigi Galvani, Pieter van Müsschenbroek, Alessandro Volta, and Robert Whytt. In front of each of the accomplishments listed below write the *last* name of the man who was responsible for it. For any item that was common knowledge to the men involved, print the letters CK.

____________________ **1.** Discovered that animal muscles contract when removed from the body.

____________________ **2.** Observed convulsive muscular contractions when muscles were pricked or probed long after removal from the animal's body.

____________________ **3.** Proposed that a fluid is passed from the nerves to the muscles when a contraction occurs.

____________________ **4.** Invented an electric battery that produces continuous electric current.

____________________ **5** Discovered that animal muscles contract when stimulated electrically.

____________________ **6.** Designed a piece of equipment that receives and stores electricity.

____________________ **7.** Found that a nerve formed in an arc and dropped on a muscle, without the aid of a conducting material, causes the muscle to contract.

____________________ **8.** Showed that when two different metals and a moist cloth are in contact, electricity is produced.

B. Match each of the definitions given in Questions 9 to 12 below with a word from the list at the right. Write the letter of the word in front of the definition.

__________ **9.** Any substance capable of transmitting electricity.

__________ **10.** A statement of a scientist's ideas about a particular phenomenon.

__________ **11.** An action or agent to which an organism responds.

__________ **12.** A condition that is changed in an experiment.

a. stimulus
b. response
c. contraction
d. variable
e. technique
f. conductor
g. hypothesis
h. phenomenon
i. ground wire

PART II

Each question in this part is followed by four answers. Select the *best answer* on the basis of the information given and your knowledge of biology and scientific reasoning.

1. Tanya was carefully dissecting a white rat in her biology laboratory. She had carefully removed the skin from the rat's left rear leg in order to examine the muscle structure, and was about to remove one of the large leg muscles. As her scalpel touched the muscle, the leg suddenly moved. Tanya jumped and nearly screamed. "Mr. Teclaw," she called, "my rat is still alive!" While Mr. Teclaw was walking from his desk, Eric came to look over Tanya's shoulder. "Just because his leg twitched doesn't mean your rat is alive," Eric said scornfully.

However, Eric pointed out quite correctly that the bending of the leg was definitely

a) caused by two dissimilar metals in contact.
b) like the discharge of a Leyden jar.
c) an example of muscular contraction.
d) evidence that there was atmospheric electricity in the room.

2. Mr. Teclaw listened to the argument for a moment. "Can you give me four reasons why the leg movement doesn't prove that the rat is alive, Eric?" Of the four reasons Eric gave, which one is NOT correct?

a) Muscular contractions can occur in dead animals.
b) Tanya might have caused the contraction by pressing on a nerve and thus stimulating it.
c) The nerves of a dead animal can still conduct impulses to the muscles.
d) Touching a nerve with a metal object will produce an electric current, which will stimulate the nerve.

3. Mr. Teclaw turned to Tanya. "How about you? Can you give me four reasons why you think the rat could not be dead?" Of Tanya's four reasons, which one is NOT correct?

a) There is no visible source of electricity here that could have caused the bending of the rat's leg.
b) Dead animals can't move.
c) Response to a stimulus is one of the defining characteristics of living things.
d) If the rat were thoroughly dead—cold and stiff—it wouldn't react this way.

4. "Well," said Mr. Teclaw. "In a way you're both right. In one sense the nerves and muscles of the rat are still alive, because they still respond to a stimulus. But the rat is dead, because its brain and heart and lungs have stopped operating. In a few hours even the nerves and muscles will be dead. But why don't you see if you can find out why the leg reacted?" Eric suggested that they dissect the leg carefully, separating the sciatic nerve from the muscle itself. Then he poked the muscle with the tip of the scalpel. When he did so,

a) an electric spark was produced and the leg muscle contracted.
b) no electric spark was produced and the leg muscle contracted.
c) an electric spark was produced and the leg muscle did not contract.
d) no electric spark was produced and the leg muscle did not contract.

5. Tanya explained quite correctly that with this arrangement the leg muscle

a) contracted because an electric current was produced by the contact of the metal scalpel with the muscle.
b) did not contract because there was no source of electricity.
c) contracted because the muscle was directly stimulated by the pressure of the scalpel.
d) did not contract because electric current could not flow through the dissected nerve of the rat.

6. Then Tanya tried an experiment. The rat was lying in a copper pan, and there was a pool of saline solution in the botton of the pan. She carefully placed one end of the scalpel on the exposed muscle and laid the other end of the scalpel in the pool of solution in the bottom of the pan. This time,

a) an electric spark was produced and the leg muscle contracted.
b) no electric spark was produced and the leg muscle contracted.
c) an electric spark was produced and the leg muscle did not contract.
d) no electric spark was produced and the leg muscle did not contract.

7. "How can you explain that?" challenged Tanya. Which of the following would be the best explanation that Eric could give?

- **a)** Animal electricity produced in the muscle caused a spark to jump from the steel scalpel to the copper pan.
- **b)** Electricity from the atmosphere traveled through the completed circuit and caused the muscle to contract.
- **c)** Electricity was produced by the contact of copper and steel, flowed through the circuit, and stimulated the muscle.
- **d)** Nothing happened, because there was no Leyden jar or electrostatic machine nearby to produce an electric spark that could stimulate the muscle.

8. "You haven't really proved very much yet," said Mr. Teclaw. "There is one more experiment you could perform that would very strongly support your explanation." Which of the following experiments would provide evidence to support your answer to the previous question?

- **a)** Repeat the same experiment, but use a copper rod instead of the steel scalpel.
- **b)** Repeat the experiment, but set off a spark from an electrostatic machine nearby.
- **c)** Repeat the experiment, but be sure that the pan was clean and dry.
- **d)** Connect the two ends of the leg muscle by an arc of crural nerve.

PART III

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

	Column A	Column B
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.		par. 1
1. Because scientists are dealing with objective facts, their personalities and temperaments have little effect on their work.	________	________
2. Often the work done in science doesn't provide final answers, but instead opens new fields of study.	________	________
3. When the results of his research are published, a scientist can be sure that others in his field will be informed of his work.	________	________
4. The workers in the various fields of science generally contribute little to each other's knowledge and progress.	________	________

5. Continued studies and experiments are required even though a theory has been reasonably tested and verified. ________ ________

6. Postulates or assumptions which support a good explanation or theory are necessarily correct. ________ ________

7. Science is an international activity. ________ ________

8. Scientists occasionally ignore facts that do not agree with their theories. ________ ________

B. The selection below contains illustrations of numerous ideas about scientists and scientific work like those discussed in *Frogs and Batteries*. 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 in Section A above—both the true statements that were given and the true statements that you wrote.

Read the selection carefully. When you find an illustration for one of the ideas in Section A, underline it and 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 "par. 1" has been written in Column B.

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

ELECTRICAL FISHES

1 Studies of seven families of fish, commonly called electrical fish, have helped answer some of the major questions that biologists have asked about the importance of electricity in living animals.

2 Studies of these fish are by no means a recent development. The ancient Romans and Egyptians knew of them and were awed by the powerful shocks that they produced. Until 1750, however, no one was able to offer a convincing explanation of these shocks. One intriguing attempt at an explanation was made by Giovanni Borelli, an Italian scientist, in 1685. Borelli suggested that the fish could rapidly contract their muscles to deliver sharp blows.

3 After the invention of the Leyden jar, many scientists began to study electrical phenomena. Laurens Storm van's Gravesende, of the Dutch West Indies, and the French naturalist Michel Adanson suggested that an electrical fish stored electrical charges in much the same way as a Leyden jar. In 1772 John Walsh of England was able to show that the shock from one of these fish could be used to charge a Leyden jar, which would then produce a spark. Other scientists in different parts of the world—Henry Cavendish in

England, Hugh Williamson in the United States, and Lazzaro Spallanzani in Italy—verified by other experiments that these fish do indeed produce an electric charge. The published reports of all these scientists added to the knowledge available to experimenters all around the world.

4 In 1775 Henry Cavendish built and demonstrated a wood and leather model of an electrical fish that could be charged with a Leyden jar and would then give a powerful shock to anyone placing his hand in the salt water around the artificial fish. Galvani knew of these experiments, and must have considered them as strong evidence for his theory that animal muscles could produce electricity. Both Galvani and Volta experimented with these electrical fish as they tried to understand the method by which electricity is produced and causes muscles to move in living beings. With the invention of the voltaic pile, however, scientists began to turn their attention to studies of more controlled electrical sources, and interest in the electrical fish waned.

5 Interest was revived in 1842 when Carlo Metteucci and Emil du Bois-Reymond demonstrated that animal muscles are indeed able to produce a weak electrical current. Because Volta's explanation of the origin of electrical impulses in the early frog experiments had been accepted and Galvani's theory of animal electricity had been rejected, scientists had ignored the electrical fish. Now that fresh evidence was available to show that animal tissues could produce electricity, scientists again became interested in the study of the powerful electrical shocks produced by these fish. Studies by embryologists and comparative anatomists soon showed that the electrical organs of these fish had evolved from what were originally muscles. They showed that these muscles had evolved into thin membranes that did not contract, but stored electrical charge. By the late nineteenth century, electrophysiologists were able to explain the workings of these "electroplaques," and showed that they operated much like a voltaic pile.

6 At the same time other scientists were attempting to understand the action of electricity in the tissues of other vertebrates, including man. In the 1860s Wilhelm Krause and Wilhelm Kühne suggested that electrical currents are produced in the nerves, and that these currents stimulate the muscles and cause them to contract. Shortly thereafter du Bois-Reymond theorized that the nerves secrete a chemical that passes into the muscle and stimulates it. Experimental evidence was available to support both of these theories.

7 Throughout the first half of the twentieth century the controversy continued between those who proposed a chemical explanation of nerve-muscle interactions and those who proposed an electrical explanation. As new instruments and techniques became available, new experimental evidence was produced to support both sides of the controversy.

8 Studies of curare, the South American Indian arrow poison, and other dangerous poisons such as strychnine and cocaine showed that these poisons produced some sort of chemical interference with normal nerve-muscle interactions. On the other hand, increasingly delicate and accurate electronic equipment made possible experiments which showed that small electrical currents were definitely involved in the transmission of nerve impulses.

9 As chemists gained an increasing understanding of the electrical effects of chemical reactions, more and more biologists began to believe that the best explanation of nerve impulses would involve both chemical and electrical effects. Even today, complex biophysical experiments are producing new evidence to help explain these complicated electrochemical reactions within the nerves and muscles.

10 Of the more than five hundred species of electrical fish, only twenty have been carefully studied. There is still much to be learned about the production of electricity in these fish. This knowledge will undoubtedly help provide a more complete explanation of the action of nerves in other forms of life as well.

PART IV (optional)

A. In the selection "Electrical Fishes" there are a number of illustrations of ideas about scientists and scientific work that were not included in the true statements of Part III, Section A. Reread the selection to see whether you can spot them.

Write a concise statement of any new ideas (such as those discussed in *Frogs and Batteries*) for which you find an illustration in the selection. Give the number of the paragraph in which the illustration appears.

B. Suppose you are given the materials listed below, and asked to construct from them a source of electrical current. Circle the items you would use, and draw a diagram of the way in which you would assemble your apparatus. Label the materials in the diagram.

distilled water
copper disks
steel scalpel
saline solution
cloth disks
soap
frog muscle
zinc disks
plastic rod
alcohol solution
copper wire
plastic disks
wood disks
glass rod

KEY FOR UNIT TEST

Part I
(1 point for each correct answer)

1. CK	**5.** CK	**9.** *f*
2. Whytt	**6.** van Musschenbroek	**10.** *g*
3. Galvani	**7.** Aldini	**11.** *a*
4. Volta	**8.** Volta	**12.** *d*

Part II
(2 points for each correct answer)

1. *c*	**5.** *c*
2. *d*	**6.** *b*
3. *b*	**7.** *c*
4. *b*	**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. F	A scientist's attitudes and personality may have a great effect on the way he works and the way he interprets data.	X
2. T		par. 6 (sentence 4) and par. 7 par. 10 (sentences 2 and 3)
3. F	If his results are published in an obscure journal, the scientists's work may not be noticed. In fact, he cannot ever be certain that his work will be noticed.	X
4. F	It is quite common for the facts and methods used in one field of science to be used in another.	par. 3 (sentences 2 and 3) par. 5. (sentences 4 and 6) par. 9 (sentence 1)
5. T		par. 5 (sentences 2 and 3) par. 7 par. 10 (sentence 2)
6. F	Wrong reasoning isn't always apparent at first, even though the theory itself is useful. Later experimenters may find other evidence that the theory is useful, though the original assumptions were wrong.	par. 5 par. 9

7. T par. 3 (sentences 2, 3, and 4)

8. T X

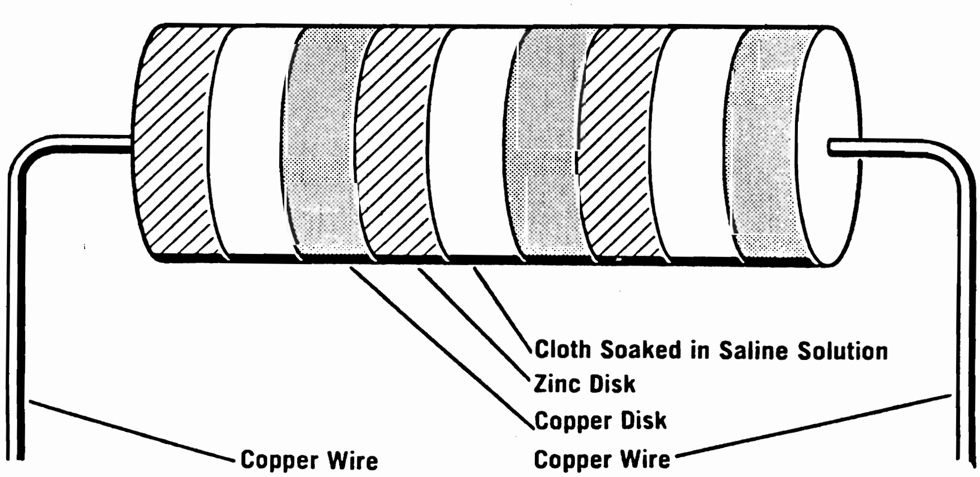
Part IV

A. (2 points for each correct idea ferreted out and referred to an appropriate paragraph)

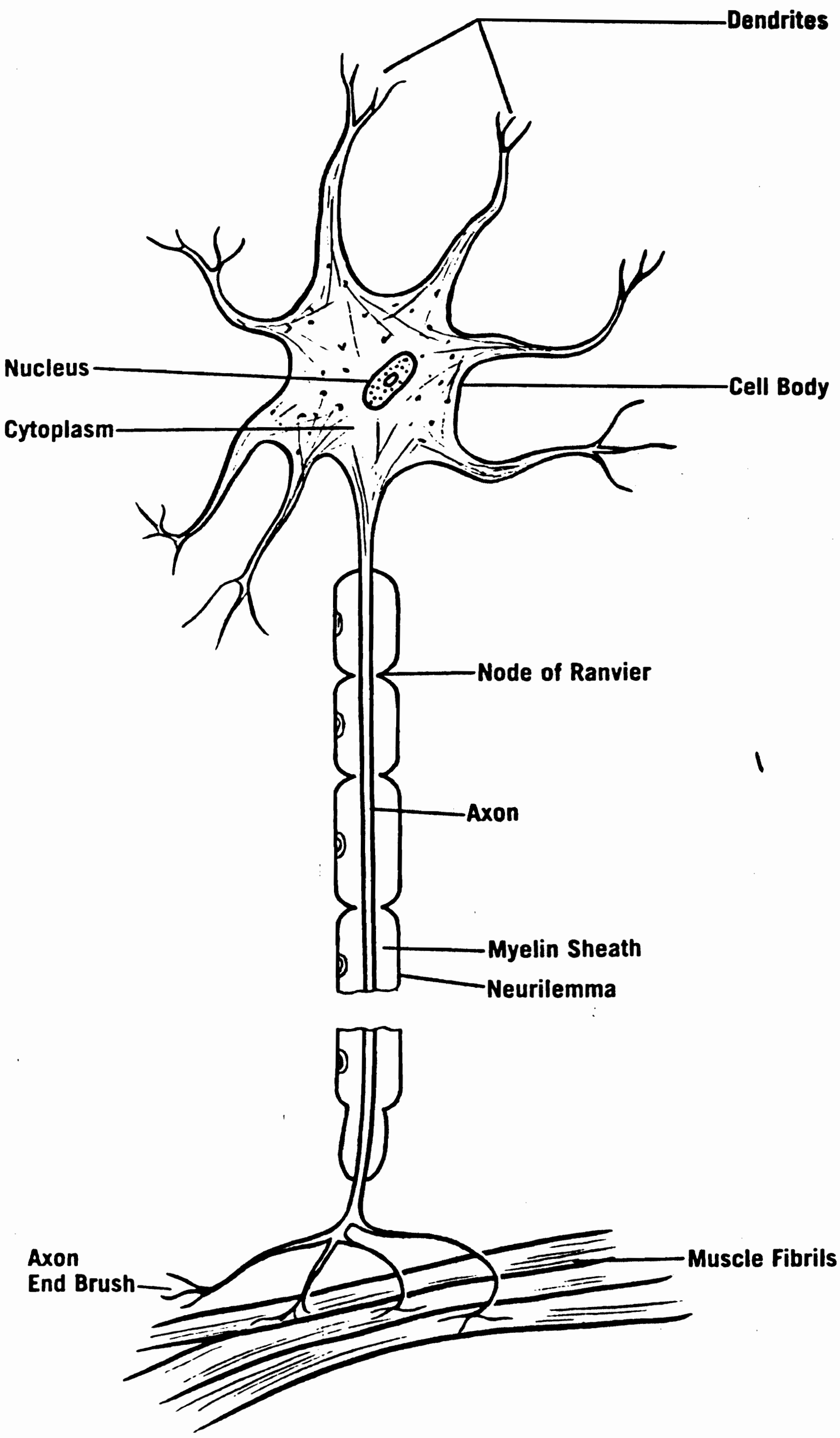
Some of the ideas illustrated in the selection and not cited in Part III, Section A, are listed below. Students may find others, which may be counted as correct if they are referred to an appropriate sentence or phrase in the selection.

- New knowledge and equipment are important to scientific advance. (pars. 3, 5, 7, 8, and 9)
- A scientific fact may not be interpreted in the same way by all scientists. (pars. 6 and 7)
- The work of one scientist is often directly related to, or based on, the work of another. (pars. 4, 5, 8, and 9)
- New and seemingly more important discoveries elsewhere may cause scientists to neglect a worthwhile field of investigation. (par. 4)
- Scientists communicate through publications. (par. 3)
- The principles discovered by one scientist may explain discoveries by others and unify knowledge in his entire field. (par. 5)
- A theory is a scientist's view concerning certain observed phenomena in the natural world. (pars. 4, 6, 7, and 9)

B. (6 points)
To assemble the best possible source from these materials, a voltaic pile, the student would need to use the copper disks, zinc disks, and the cloth disks soaked in the saline solution. Each unit of the pile should consist of a copper disk and a zinc disk separated by a saline-solution-soaked cloth disk. As many units as desired can be stacked together. The ends of the pile should be connected by copper wire to complete the circuit and obtain an electrical current. One end of the pile must be a copper disk and the other end a zinc disk.



A Myelinated Motor Neuron of a Vertebrate Peripheral Nerve



SOURCES OF QUOTATIONS

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14, 16	From **The History of Biology: An Introduction,** by F. S. Bodenheimer. Copyright 1958 by Dawsons of Pall Mall, 16, Pall Mall, London S.W. 1. Reprinted by permission; pp. 381–84; translated from the original paper by Matthias Jakob Schleiden, "Beitrag zur Phytogenesis," **Archiv für Anatomie, Physiologie, und wissenschaftliches Medizin,** Part II (1838).
18, 20, 22	From **Classics of Biology,** by August Pi Suner. Copyright (English translation) 1955. Reprinted by permission of Philosophical Library and Sir Isaac Pitman & Sons, Ltd.; pp. 24–26; translated from the original German book by Theodor Schwann, **Mikroskopische Untersuchungen über die Übereinstimmung in der Struktur und dem Wachsthum der Thiere und Pflanzen** (Berlin, 1839).
24 (top)	From "The Cell Theory: A Restatement, History, and Critique," by J. R. Baker, **Quarterly Journal of Microscopical Science,** 1949, Vol. 90, by permission of The Company of Biologists Limited; p. 103.
24 (other)	From **Classics of Biology,** by August Pi Suner. Copyright (English translation) 1955. Reprinted by permission of Philosophical Library and Sir Isaac Pitman & Sons, Ltd.; p. 27; translated from the original German book by Theodor Schwann, **Mikroskopische Untersuchungen über die Übereinstimmung in der Struktur und dem Wachsthum der Thiere und Pflanzen** (Berlin, 1839).
26	Rudolf Virchow, **Cellular Pathology,** translated from the German by Frank Chance (New York, 1858), p. 54.
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29 (right), 30, 31, 32	Mordecai L. Gabriel and Seymour Fogel (eds.), **Great Experiments in Biology** (Englewood Cliffs, N.J.: Prentice-Hall, 1955), pp. 240–45; translated by M. L. Gabriel from the original paper by Walther Flemming, "Beiträge zur Kenntniss der Zelle und ihrer Lebenserscheinungen," **Archiv für mikroskopische Anatomie, 16:** 302–406 (1879).

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