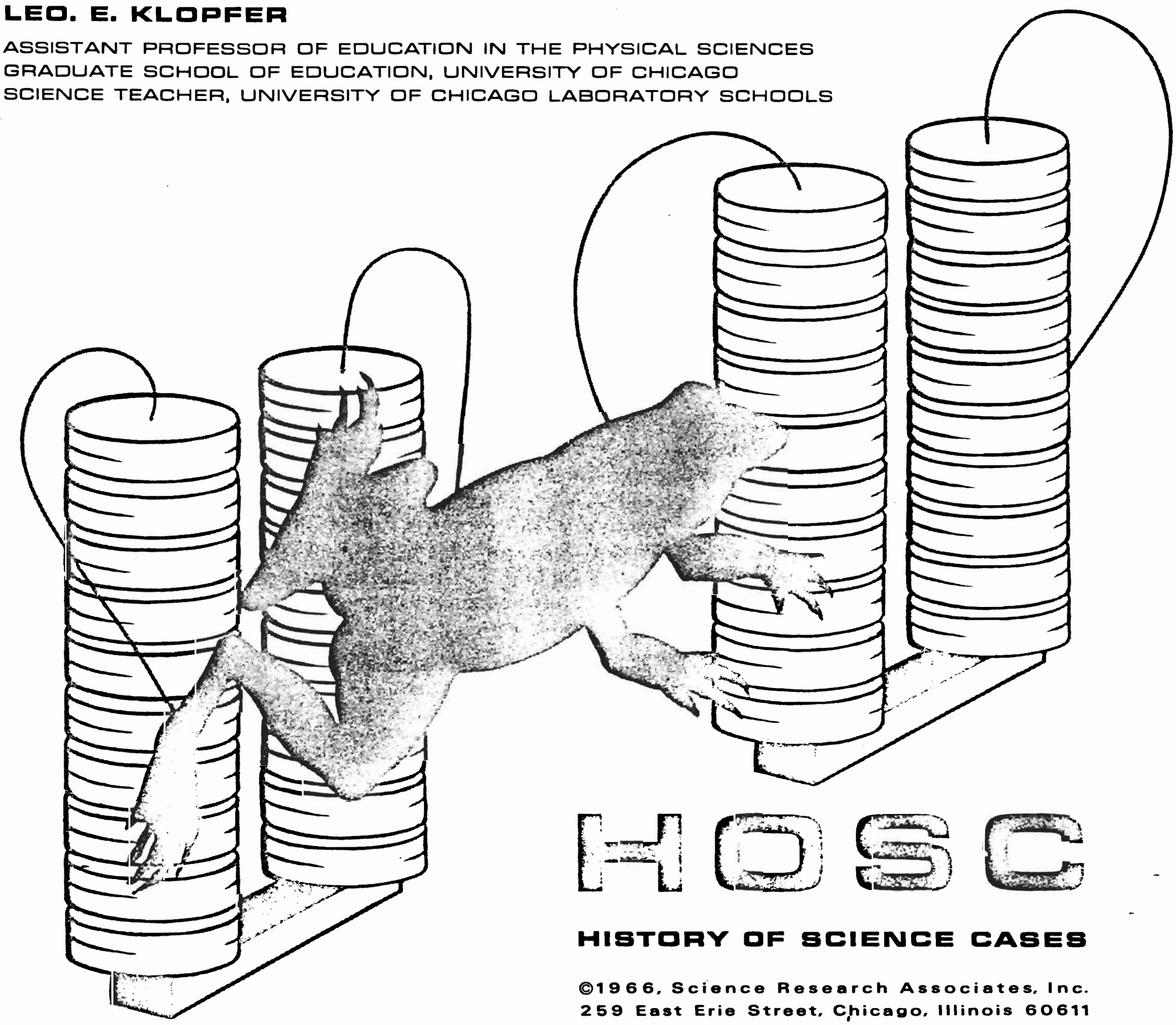
SRA

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

259 East Erie Street, Chicago, Illinois 60611
Printed in U.S.A.

Picture reproduced by courtesy of Historical Pictures Service, Chicago

Count Alessandro Giuseppe Antonio Anastasio Volta, an Italian physicist, is one of the major figures in this story. Volta was born in Como on 18 February 1745. He did not learn to talk until he was four, and his parents thought he was retarded. By the age of seven, however, he had caught up with his agemates and begun to move ahead. He became teacher of physics at the high school in Como in 1774, and the next year invented the electrophorus, a device for building up and storing an electrical charge. He described the device in a letter to Joseph Priestley, the British chemist, and his fame spread. In 1777 he traveled about Europe and met many famous scientists. In 1779 he became professor of physics at the University of Pavia, where he continued his electrical experiments. The success of his electrical theories brought him many honors. Volta was awarded the Copley medal of the Royal Society and called to Paris to give a demonstration for Napoleon. He was made a senator of Lombardy, and in his old age became director of the philosophical faculty at the University of Padua. In 1819 he retired and returned to Como, where he died on 5 March 1827.

The other principal scientists you will meet in this case are:

Pieter van Musschenbroek – Dutch physicist.
Born 14 March 1692 at Leyden. Died 19 September 1761 at Leyden.

Robert Whytt – Scottish neurologist.
Born 1714. Died 1766.

Luigi Galvani – Italian anatomist.
Born 9 September 1737 at Bologna. Died 4 December 1798 at Bologna.

Giovanni Aldini – Italian physicist and physiologist.
Born 10 April 1762 at Bologna. Died 17 January 1834 at Milan.

INTRODUCTION

In this HISTORY OF SCIENCE CASE we will study the development of an important scientific idea. Although we will learn something about the scientific idea itself, our chief interest will be to find out as much as possible about

- how scientists work
- how science advances and the conditions under which it flourishes
- what scientists are like as people
- how the progress of science is affected by social, economic, technological, and psychological factors
- how science is affected by the availability of instruments, free communication, and accurate records

It isn't enough merely to read the story on the left-hand pages of this booklet. The comments and questions in the left margin raise ideas that you should think and talk about. On the right-hand pages the questions are repeated in expanded form, and space has been left for your answers. These questions are not like those found in many textbooks. Usually you will not find simple answers in the story itself. You will have to think for yourself, find ideas and information in other books, and express your own opinions and defend them.

On some of the right-hand pages you will find experiments. Experimental work is a very important part of your study in this case. Do as many of the experiments as you can. They will help you appreciate the situations faced by the scientists in the story as they developed their ideas. Additional activities are found at the end of the booklet, and your teacher may suggest others. On the last page of this booklet is a list of books and articles relating to this particular case.

Some students may feel that this story is out of date because it happened so long ago. Nothing could be further from the truth. The theories of science have changed a great deal, and so have the instruments with which scientists work. But the methods of scientific investigation are much the same today as they were at the time of this story; science is still affected by the rest of society; the personalities of scientists still affect their scientific work; and the progress of science still depends on adequate records, free communication, and improved instruments. These aspects of science were the same yesterday as they are today, and they will remain the same tomorrow.

L.E.K.

FROGS AND BATTERIES

Let's begin with an experiment. Put a metal teaspoon under your tongue. (Use a silver teaspoon if possible.) On the top of your tongue, put a long strip of aluminum foil, and touch the foil to the spoon. Do you feel anything? Is there an acid taste on your tongue? (You're quite normal if there is.) The sensation on your tongue is very much like a mild electric shock. Your tongue has detected electricity. But what is the source of the electricity?

Is this right? (1)

If we think about this little experiment a moment, we can guess that the electricity comes from one of two sources. First, it might come from somewhere in your body. Since metals are good conductors of electricity, we can imagine that the spoon and the foil make a convenient path for the electricity to travel from the bottom of your tongue to the top of your tongue. If the electricity comes from your body, we are dealing here with a kind of "animal electricity." A second possible source of the electricity is the contact between the spoon and the foil. The spoon and the foil are made of different metals and the contact between the two might produce electricity that travels to your tongue. Which view is correct? A good case can be made for either view.

Notice that the observations from our experiment do not provide enough information for us to decide between the two views. We shall need more data and more ideas before we can come to a decision. This situation happens frequently in science. This case is concerned with the very same problem that we have just been trying to figure out. Toward the end of the eighteenth century Luigi Galvani carried out a series of experiments in which he believed he had discovered animal electricity in frogs. Starting from Galvani's experiments, Alessandro Volta later devised the first electric battery. Volta's battery, in turn, found wide use in scientific experiments. In this case we shall follow these exciting events concerning *Frogs and Batteries.*

Why do scientists write letters to one another? (2)

In January 1746 Pieter van Musschenbroek, professor of physics at the University of Leyden, in Holland, wrote a letter to René de Réaumur, a distinguished physicist and biologist, in Paris:

Special equipment is needed in scientific work.

> "I wish to inform you of a new but terrible experiment, which I advise you on no account personally to attempt. I am engaged in a research to determine the strength of electricity. With this object, I had suspended by two blue silk threads, a gun barrel, which received electricity [from an electrostatic machine]. From the opposite end of the gun barrel hung a brass wire, the end of which entered a glass jar, which was partly full of water. This jar I held in my right hand, while with my left I attempted to draw sparks from the gun barrel. Suddenly I received in my right hand a shock of such violence that my whole body was shaken as by a lightning stroke. The vessel, although of glass, was not broken . . . but the arm and body were affected in a manner more terrible than I can express. In a word, I believed that I was done for."

Can you guess why this name was chosen? (3)

What is the value of new apparatus in science? (4)

Fortunately, Musschenbroek was not done in by this experiment. He was able to continue his research on the device for storing electric charge that he had discovered. Other workers made improvements on this "Leyden jar," and a new tool became available for scientific research. (To learn how the Leyden jar works, see Experiment 1, page 7.) One area of investigation in which the Leyden jar turned out to be particularly important was the study of the muscular contractions of animals.

(Use these right-hand pages to take notes on the experiments and to write out your answers to the questions suggested by the story of the case.)

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?

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

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

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

Pieter van Musschenbroek was born on 14 March 1692 in Leyden. His father was a maker of physical apparatus and Pieter apparently acquired much of his technical inventiveness. Pieter studied medicine, mathematics, and physics at the University of Leyden and received his doctorate in 1715, writing a remarkable thesis on animal physiology. However, his first love was physics, and while visiting London he met Sir Isaac Newton, who encouraged him in that pursuit. He served as professor of physics at the universities of Utrecht and Leyden, and was a member of the Royal Society of London. His many publications included works on magnetic attraction, the refraction of light, and capillary action in the body. He was instrumental in the introduction of Newtonian physics to Holland. With his pupil Cuneua he accidentally—and almost fatally—invented the Leyden jar, a device later developed and perfected by others. He was the author of one of the first texts in elementary physics intended for beginning science students. He died in Leyden on 19 September 1761. *Picture reproduced by courtesy of Burndy Library*

Some problems of science have a long history.

Contractions in the muscles of animals had fascinated scientists and physicians since ancient times. For example, Aristotle, who lived in the fourth century B.C. and is frequently called "the father of biology," prepared an analysis of how the muscles of the limbs must alternately contract and straighten to make it possible for an animal to move. In the second century A.D., Claudius Galen, the most distinguished and influential physician of his time, made many experiments and observations on the contraction and behavior of the different types of muscle tissue. In some of his experiments Galen cut whole muscles out of the bodies of freshly killed animals and pressed them with his fingers or a probe. Galen discovered that when a muscle is stimulated in this way, it contracts. This discovery that muscles, even when removed from an animal's body, react to certain stimuli provided a valuable technique for the study of muscular contraction. We shall see this technique being used constantly by the scientists in this case, and you will use it yourself in your experiments.

What are three types of muscle tissue found in the bodies of animals? (5)

Science is an international activity.

After a lapse of many centuries, during which little work was done beyond the experiments that Galen had made, several investigators in different countries turned their attention to muscular contraction. From many experiments carried out after about the middle of the seventeenth century, a great deal was learned about how different muscles react and function. One of the important contributors to this new knowledge was Robert Whytt (pronounced *white*), professor of medicine at the University of Edinburgh, in Scotland. Whytt was particularly interested in the problem of involuntary muscular motions—motions not consciously controlled by the brain, such as those of muscles that contract the chambers of the heart, are responsible for an animal's breathing, and open and close the pupil of the eye depending on the intensity of the light striking the retina. In *An Essay on the Vital and Other Involuntary Motions of Animals*, published in 1751, Whytt reported his experiments and ideas on these actions of muscles. In Section XIV of that book, he supported his ideas with a description "Of the motions observed in the muscles of animals after death, or their separation from the body." Whytt tells us:

Whytt was a university professor. Is it usual today for scientists to work for universities? (6)

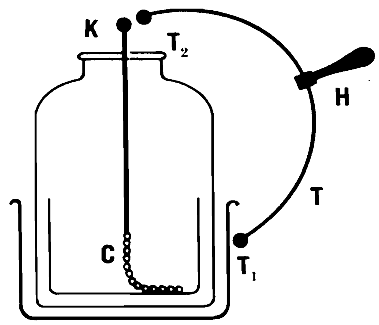
Whytt makes use of Galen's discovery.

> "I have often observed a frog turning from its back to its belly, and leaping about for an hour after the heart and other viscera were cut out; and when its muscles were at rest, they have been brought into convulsive contractions, by pricking them with a pin or a penknife: nay, a frog's limbs seldom fail to move for some time after they are separated from its body. [To see this for yourself, try Experiment 2, page 9.]

EXPERIMENT 1. LEYDEN JAR

To understand how a Leyden jar works, you should first be familiar with the basic facts of static electricity. If you haven't done experiments with static electricity before, you will have fun doing the series suggested in C. J. Lynde's *Science Experiences with Ten-Cent Store Equipment* (New York: Van Nostrand, 1950), pp. 153–70.

A drawing of the Leyden jar that was later used by Galvani is shown in Fig. 5 on page 16. A cross-section drawing of a present-day Leyden jar is given here. It consists of a thin-walled glass bottle coated about halfway up on the inside and outside with metal foil. A metal chain, *C*, connects the inner foil to a metal rod pushed through a rubber stopper. At the end of the metal rod is a metal knob, *K*, which is the contact point for the inner foil. *T* is called the discharging tong. It has an insulated handle, *H*, and a curved metal bar with metal knobs at each end. The Leyden jar is discharged by touching one of the knobs, T_1, to the outside metal foil and bringing T_2 near knob *K*.



Charge a Leyden jar by means of an electrostatic machine or by repeated sparks from an electrophorus (see Lynde, page 165). (WARNING: DANGEROUS! You will get a severe shock if you touch one of the metal parts of the jar while you are grounded, or if you allow your body to complete the circuit of the tong and foil.) Bring a charged electroscope near the outside foil of the Leyden jar and then near knob *K*. Is the charge on the outside of the Leyden jar the same as the charge on the inside?

Now discharge the Leyden jar with the discharging tong. What happens? (The discharge of the Leyden jar so impressed Galvani that he used it as an *analogy* to explain muscular contraction.)

---

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?

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

"A tremulous motion has been observed in the muscles upon the sternum [of a frog] for a quarter of an hour after it was cut out of the body; and, when it had ceased, it was renewed by pricking the fibres of these muscles with the point of a knife. The like tremulous motions have continued for an hour in the muscle of an ox separated from its body immediately after it had been killed, and, upon their ceasing, have been recalled, by pricking its fibers with a sharp instrument. . . .

"A frog lives, and moves its members [when properly stimulated], for half an hour after its head is cut off; nay, when the body of a frog is divided in two, both the anterior and posterior extremities preserve life and a power of motion for a considerable time."

What are some of the possible explanations of muscular contraction? (7)

Regarding the question of the exact nature of the stimulus that causes muscles to contract, Whytt refused to commit himself. Perhaps he felt that scientists did not then understand muscular contraction well enough to answer the question. Though he knew that muscular contractions could be stimulated by electricity, Whytt remarked:

"And as of late years there has appeared a fondness in some, to explain almost every hidden operation in nature by electricity, I thought it might not be improper to show, that the electrical aura . . . will not enable us to account for the motions of muscles, whose fibres or membranes are pricked, torn or otherwise stimulated."

Is Whytt being too cautious here? Why doesn't he suggest a hypothesis? (8)

Instead of trying to explain the nature of the stimulus that causes muscular contractions, Whytt simply called it the "power or influence of the nerves" and left this as an open question for later investigators:

"The immediate cause of muscular contraction, which, from what has been said, appears evidently to be lodged in the brain and nerves, I chuse to distinguish by the terms of the *power* or *influence of the nerves;* and if . . . I shall at any time give it the name of *animal* or *vital spirits,* I desire it may be understood to be without any view of ascertaining its particular nature or manner of acting; it being sufficient for my purpose, that the existence of such a power is granted in general, though its peculiar nature and properties be unknown."

Luigi Galvani was born in Bologna on 9 September 1737. His family was influential in Bologna, and after Galvani completed his doctoral thesis at the age of twenty-five he was immediately appointed lecturer in anatomy at the University of Bologna. His thesis was on the human skeleton and the formation and development of bone, and he continued to practice as a surgeon and obstetrician while lecturing at the university. He was not an impressive speaker, but was a keen experimenter and popular demonstrator. He was a modest and reserved man, reluctant to publish, though he made many important anatomical discoveries. His specialty was the comparison of human and bird skeletons, and he made major contributions to our knowledge of the kidney and ear of birds. Galvani did not participate in the controversy that arose over his theories of animal electricity. Saddened by the death of his wife in 1790 and deprived of his university post because of his refusal to take an oath of loyalty to the Cisalpine Republic established by Napoleon, he died in retirement on 4 December 1798. *Picture reproduced by courtesy of Historical Pictures Service, Chicago*

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?

8. Whytt seems anxious here not 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?

EXPERIMENT 2. OBSERVATIONS ON MUSCULAR CONTRACTION

Obtain a freshly killed frog and prepare it by removing the lower part of the spinal column and leaving the legs attached to it. See Fig. 2 in the drawing on page 16. Be sure to keep your preparation moist with saline solution while doing this experiment. On your dissected frog's legs preparation, identify the spinal cord and the sciatic nerves.

Place the preparation on a glass plate, and press the spinal cord with a probe. What happens? Now, using your probe, press the sciatic nerve first on one leg, then on the other. Repeat each operation several times. Do you obtain movement of the frog's legs every time? What differences, if any, do you notice in the several trials?

For this part of the experiment you can use the preparation from the first part, or you can dissect out the calf muscle (gastrocnemius) of one leg, leaving the sciatic nerve attached. Place the dissected legs or the muscle on a glass plate. Connect two thin copper wires to the two terminals of a 1.5-volt battery. First touch one of the wires to the sciatic nerve, then the other wire. Does the leg or muscle contract? If so, does it remain contracted? Remove one of the wires from the nerve and then make contact again. What happens? In what other ways could you obtain muscular contractions? Try them.

Is it usual for an instrument from physics to be used in biology? (9)

By the middle of the eighteenth century, scientists had developed improved electrostatic machines for producing electric charge and the Leyden jar for storing this charge. A number of investigators soon found that the muscles of animals could be made to contract when they were connected by a wire with a source of electricity. (See the last part of Experiment 2, page 9.) One of the investigators of this effect was Luigi Galvani, professor of anatomy at the University of Bologna, in Italy. Galvani well knew that when the muscles of an animal—freshly dissected frog legs, for example—were connected with an electrostatic machine, the muscles would contract whenever the machine produced a spark of electricity. How great was his surprise, however, when in the summer of 1786 he observed that prepared frog legs which were *not* connected with the electrostatic machine contracted every time the machine produced a spark! Here is Galvani's account of his experiment:

This experiment is often called an accidental discovery. Was it? (10)

> "I dissected a frog and prepared it [as in Fig. Ω, page 16]. Having in mind other things, I placed the frog on the same table as an electrical machine [Fig. 1], so that the animal was completely separated from and removed a considerable distance from the machine's conductor [of electric charge]. When one of my assistants by chance lightly applied the point of a scalpel to the inner crural nerves of the frog, suddenly all the muscles of the limbs were seen to contract. . . . Another assistant thought he observed that this phenomenon occurred when the spark was discharged from the conductor of the electrical machine [Fig. 1B]. Marvelling at this, he immediately brought the unusual phenomenon to my attention. . . . Hereupon I became extremely enthusiastic and eager to repeat the experiment, so as to clarify the obscure phenomenon and make it known.

Where are the crural nerves located? Is there another name for them? (11)

What attitudes is Galvani demonstrating here? (12)

> "I myself, therefore, applied the point of the scalpel first to one then to the other crural nerve, while at the same time some one of the assistants produced a spark; the phenomenon repeated itself in precisely the same manner as before. Violent contractions [occurred] in the individual muscles of the limbs . . . at the very moment when the sparks were discharged."

What is meant by "changing the variables"? What variables does Galvani change? (13)

Galvani immediately took steps to understand this "obscure phenomenon" by changing the variables of the experiment.

> "I was fearful, however, that these movements arose from the contact of the point, which might act as a stimulus, rather than from the spark. Consequently, I touched the same nerves again in other frogs with the point in a similar manner, and exerted even greater pressure, but absolutely no movements were seen unless someone produced a spark at the same time. Thus I formed the idea that perhaps in order to produce this phenomenon there were required the simultaneous contact of some body and the emission of a spark. I therefore again applied the edge of the scalpel to the nerves and held it motionless. I did this at one time when sparks were discharged and at another when the electrical machine was completely quiet. The phenomenon occurred, however, only as often as a spark was produced."

Observations and ideas continually interact.

Galvani tries to isolate the essential conditions.

Thus Galvani found that an electric spark was necessary to obtain contractions in the muscles of the frog legs. But what else was necessary to get the effect, and what was not needed? By diligently changing the variables in a long series of experiments, Galvani found that a scalpel touching the crural nerves of the frog was not essential. Nor was the man holding the scalpel really

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

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?

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

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?

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

Proper techniques are important.

needed. Even the electrostatic machine was not essential, for the frog legs would also contract when a spark was produced from a Leyden jar (Fig. 5). Only two conditions seemed to be required to obtain the contractions every time there was a spark: (1) some metal object must touch the crural nerves of the prepared frog, and (2) the muscle of the frog's leg must be connected with the ground by some conducting material. Galvani conveniently satisfied the first condition by passing a wire through the end of the frog's spinal cord (Figs. Ω, 2, and 4). The second condition could be met by means of a long iron wire (Fig. Ω), some lead shot (Fig. 6), or the body of the experimenter. (You can repeat Galvani's experiments yourself; see Experiment 3, page 13.)

Who was this American scientist? (14)

How could Galvani have known about the work of this scientist? (15)

Up to this point Galvani had experimented only with electricity produced artificially by an electrostatic machine. Of course, he was familiar with the experiments of an American scientist who had demonstrated that lightning and static electricity are identical. This suggested Galvani's next experiment:

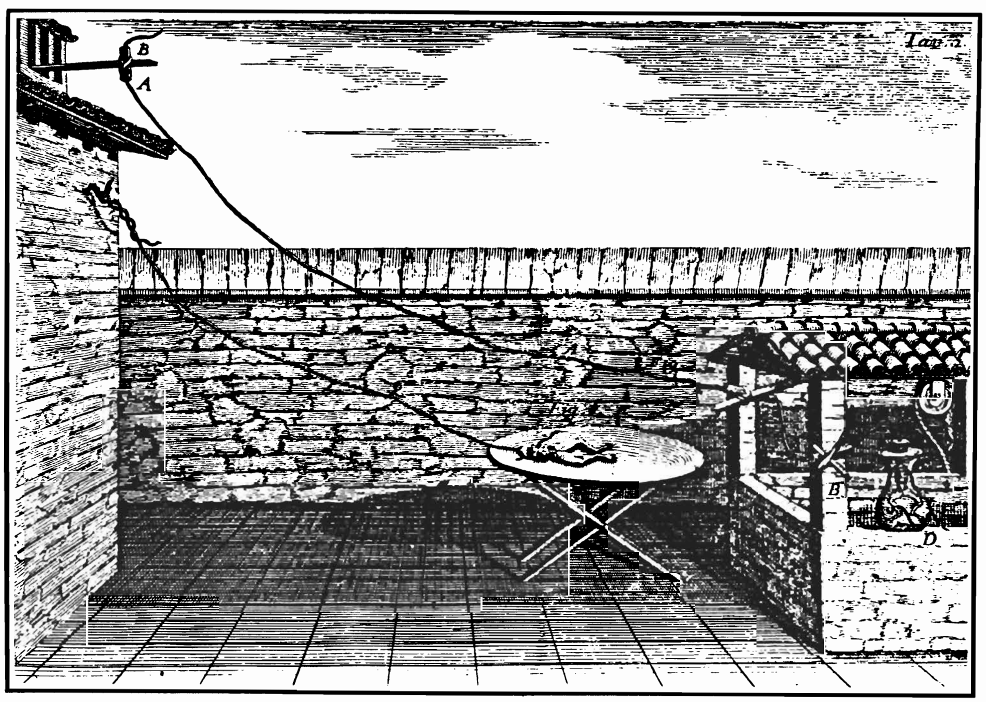
Condition 1

Condition 2

> "In the open air, we set up . . . a long conductor, appropriately made of iron, and fastened one end of it to a high part of the house. When a thunderstorm arose, we fastened the nerves of prepared frogs . . . to the other end. Then we attached to their feet another similar conductor of the greatest possible length so that it might reach down to the water of the well.

Are scientists unemotional in their work? (16)

> "As we hoped, the result completely paralleled that in the experiment with artificial electricity. Whenever lightning flashed, all the muscles simultaneously fell into numerous violent contractions. The contraction preceded and as it were gave warning of the thunder to follow, just as the flash and illumination of lightning is wont to do."



This engraving from Galvani's book, originally published in 1791, shows his experiments outdoors to determine the effects of atmospheric electricity on frogs' legs. The iron wire *AA*, insulated by glass tubing *B*, leads from the roof to the nerve of the frog in the bottle *C*. Another wire *D* leads down the well into the water, serving as a ground. The other frog's legs, lying on the table, are connected to an uninsulated wire. Galvani found that the frogs' legs sometimes contracted even though the air was still. This led him to move his experiments indoors, away from the effects of atmospheric electricity. *Picture reproduced by courtesy of Burndy Library*

EXPERIMENT 3. GALVANI'S FIRST SERIES OF EXPERIMENTS

For these experiments you will need a device that can produce about a quarter-inch (or longer) electric spark in air. Any electrostatic machine (Töpler-Holtz or Wimshurst design), a small Van de Graaff generator, an induction coil, or an automobile spark generator will serve the purpose. You could also use a well-charged Leyden jar. (As in Experiment 1, BE CAREFUL when working with these devices.)

Prepare a frog as Galvani did (Fig. 2, page 16) and lay it on a glass plate. With the point of a scalpel, carefully press the sciatic nerve without damaging it. Is there any muscular contraction from stimulation alone? Now touch the sciatic nerve gently with your scalpel, and touch the frog's leg with your other hand while someone else produces an electric spark. (This is Galvani's original experiment.) What do you observe? Does moistening your fingers make any difference? Does the part of the leg that you touch with your hand make any difference?

Change the conditions further by substituting a dry glass rod for the scalpel. Are there any contractions when a spark is produced? Substitute a metal rod for the glass rod. Try a dry plastic rod. Try touching the nerve with one hand while you touch the leg with the other. In each case, what happens when a spark is produced? Can you make any generalizations? (NOTE: Be sure to keep the frog moist with saline solution during your experiments.)

Now pass an iron or copper wire through the end of the frog's spinal column. Suspend the frog by this wire from a clamp on a ring stand. Pierce the leg with another wire which is long enough to touch the ground. Produce an electric spark. Are there contractions with this arrangement? Why, or why not? Continue changing the variables until you can isolate the conditions necessary to obtain contractions. What conditions are essential for obtaining contractions every time there is a spark?

---

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

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

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?

Would you call this a hypothesis? (17)

Galvani was still not satisfied that he had explored fully the problem of muscular contraction. He also wanted to know whether the same effect occurs in calm weather when there is no lightning. He imagined that the daily changes in the electricity of the atmosphere could also produce the muscular contractions. To check on this, Galvani hung some prepared frogs on an iron railing outside his house. The frogs were hung on brass hooks which passed through their spinal cords.

Is patience a desirable characteristic of scientists? (18)

> "At different hours and for a span of many days, I observed the animals . . ., but scarcely any motion was evident in their muscles."

Then, on 20 September 1786, Galvani came upon what he believed to be his most important discovery:

Is impatience a desirable characteristic of scientists? (19)

> "I finally became tired of waiting in vain and began to press and squeeze the brass hooks, which penetrated the spinal cord, against the iron railing. I hoped to see whether muscular contractions were excited by this technique and whether they revealed any change or alteration related to the electrical state of the atmosphere. As a matter of fact, I did observe frequent contractions, but they had no relation to the electrical state of the atmosphere.

What effect does this observation have on Galvani's idea? (20)

> "Now since I had observed these contractions only in the open air and had not yet carried out the experiment elsewhere, I was on the point of [deciding that they] result from atmospheric electricity. . . . For in experimenting, it is easy to be deceived and to think we have seen and detected things which we wish to see and detect.

How true!

> "But when I brought the animal into a closed room, placed it on an iron plate, and began to press the [brass] hook which was fastened in the spinal cord against the plate, behold! the same contractions and movements occurred as before.

What variables is Galvani testing? (21)

> "I immediately repeated the experiment in different places, with different metals, and at different hours of the day. The results were the same, except that the contractions . . . were more violent with some [metals] and weaker with others. Then it occurred to me to experiment with other substances that were either non-conductors or very poor conductors of electricity, like glass, gum, resin, stones, and dry wood. Nothing of the kind happened and no muscular contractions or movements were evident.

From observations and reflection, Galvani slowly gains a new insight.

> "These results surprised us greatly and led us to suspect that the electricity was inherent in the animal itself. An observation that a kind of circuit of a delicate nerve fluid is made from the nerves to the muscles when the phenomenon of contractions is produced, similar to the electric circuit which is completed in a Leyden jar, strengthened this suspicion."

Galvani believed that he had discovered animal electricity. In all the previous experiments, muscular contractions had occurred whenever there was an electric discharge outside the prepared animal, but now the same effect was seen when there was no electric discharge of any kind. What else could cause the contractions except electricity from the animal itself? Galvani thought that this was indeed the cause. By further experiments, he established to his satisfaction that contractions took place whenever the source of electricity within the animal was connected with the muscle of the frog's leg through a conducting arc, or electric circuit. *(Text continues on page 18.)*

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

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

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?

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"?

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

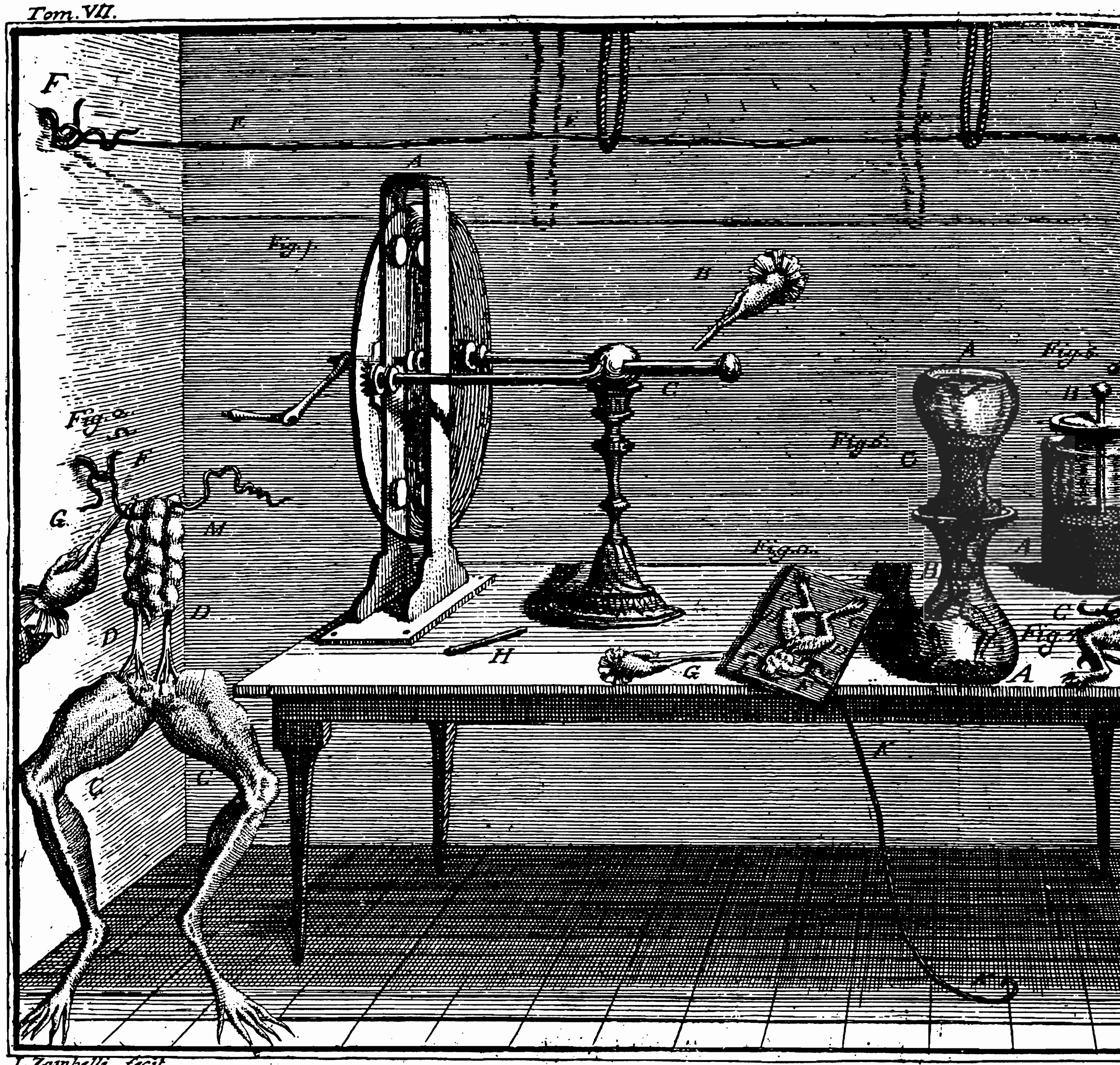


Fig. 2 Fig. 1 Fig. Ω Fig. 6 Fig. 5 / Fig

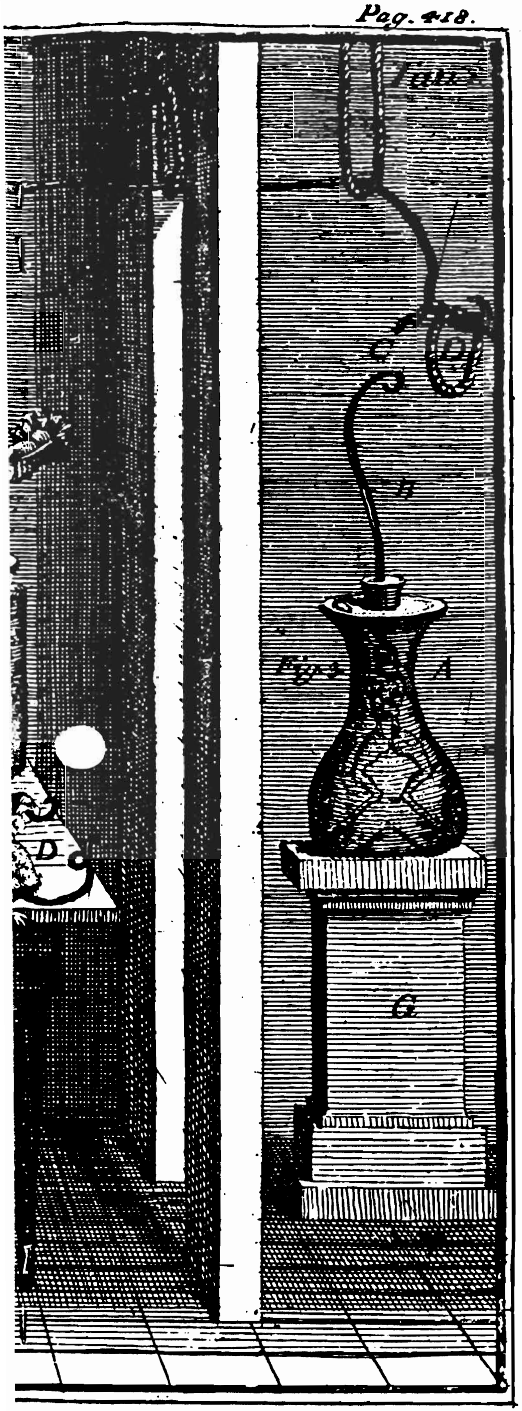


Fig. 3

This engraving was taken from Galvani's book *De viribus electricitatis in motu musculari commentarius*, published in Bologna in 1791. A key to the figure is given below. *Plate reproduced by courtesy of Burndy Library*

Fig. Ω. Illustrating the experiments to determine the essential conditions for obtaining muscular contractions.
- *CC* Limbs
- *DD* Inner crural nerves
- *E* Iron wire penetrating the spinal cord
- *F* Spinal cord
- *G* Iron rod which touches the iron wire *E* when a spark is discharged from the electrical machine
- *H* Glass rod which touches the iron wire *E* when a spark is discharged
- *KK* Iron wire connected to the nerves

Fig. 1. Electrical machine.
- *A* Disk
- *B* Iron rod, by means of which a spark is discharged
- *C* Conductor

Fig. 2. Frog prepared for experiment.
- *CC* Limbs
- *DD* Inner crural nerves
- *F* Metal wire which penetrates the spinal cord through the vertebral openings
- *G* Iron rod
- *M* End of spinal column

Fig. 3. Illustrating an experiment on the effect of distance from the electrical machine on obtaining contractions.
- *A* Glass jar in which the prepared frog is enclosed
- *B* Iron wire attached to the hook of the frog
- *C* End of the suspended iron wire, to which iron wire *B* is joined
- *D* Silk loop
- *EEE* Iron wire which is joined to iron wire *B* and serves as a very long conductor to the nerves
- *F* Iron hook to which the iron wire *E* is connected

Fig. 4. Essential conditions for obtaining muscular contractions.
- *C* Metal conductor to the nerves
- *D* Metal conductor to the muscles

Fig. 5. Leyden jar.
- *A* Jar with small lead shot used by hunters
- *B* Conductor to the inside of the jar
- *C* Hand of the man who discharges a spark from the conductor *B*

Fig. 6. Apparatus designed by Galvani to demonstrate contractions conveniently.
- *A* Inverted jar with small lead shot *C* which connects by an iron wire to the hook in the nerves of the frog
- *B* Similar jar enclosing the animal and more of the small lead shot *A* which connects with the muscle

This painting, which hangs in the University of Bologna, shows Galvani demonstrating the contraction of frogs' legs to members of his household, including his wife Lucia. Lucia Galvani was the daughter of Professor Domenico Galeazzi, who had been one of Galvani's teachers of anatomy. Lucia was a learned and charming woman, and she and Galvani were active members of a group of young scientists who met regularly at Professor Galeazzi's home for discussion and experimentation. It was at these meetings that Galvani learned of the invention of the Leyden jar. Looking over Galvani's shoulder is his physicist nephew, Giovanni Aldini, another active member of this group who became the chief defender of Galvani's theories of animal electricity. *Picture reproduced by courtesy of Burndy Library*

"Now, to throw further light on the problem, I had the greatest success in placing a frog on a non-conducting surface, like glass or resin, and then applying to it first a conducting arc and next one [that was] non-conducting. One end of the arc I attached to the hook fastened in the spine; the other to the muscles of the limbs or feet . . . Contractions are produced by the conducting arc, but they are absent with a . . . non-conducting arc. In this experiment, the conducting arc consisted of iron wire and the hook was of brass."

Is Galvani's report of this experiment complete? See Experiment 4, page 19.

Thus Galvani was convinced that animal electricity was responsible for the muscular contractions. He continued experimenting in an effort to develop a complete theoretical explanation of the effect, which he likened to the process that takes place when a Leyden jar is discharged. In presenting his theory, Galvani gave an explanation of the cause of muscular contraction, the problem which Whytt had left unresolved some three decades earlier. (See page 8 above.) A summary of Galvani's theoretical explanation is given in the box below.

What is a theory in science? How is it different from a hypothesis? (22)

Galvani's Explanation of Muscular Contraction

1. Animals have an electricity that is peculiar to themselves, which is called Animal Electricity.

2. The nerves have the greatest attraction for this animal electricity, and they distribute it.

3. The inner substance of the nerve is specialized for conducting electricity, while the outer, oily layer prevents its dispersal [like insulation around a wire].

4. The receivers of animal electricity are the muscles, and they are like a Leyden jar. [A Leyden jar can be given a negative charge on the outside and a positive charge on the inside.]

5. Muscular contraction occurs when the electricity inside the muscle is discharged via the nerve to the outside. This discharge of the muscular Leyden jar furnishes an electrical stimulus to the irritable muscle fibers, which therefore contract.

Note the postulates, or assumptions, that Galvani makes (Statements 1 through 4) to support his explanation of muscular contraction (Statement 5).

EXPERIMENT 4. GALVANI'S SECOND SERIES OF EXPERIMENTS

This is the series of key experiments in which Galvani believed he had discovered animal electricity. You can do them easily yourself without any special apparatus.

Prepare a frog as Galvani did (Fig. 2, page 16), and lay it on an iron plate (a sheet cut from an ordinary "tin" can will serve nicely). Touch one end of a short copper wire to the sciatic nerve of the frog and touch the other end of the wire to the iron plate. What do you observe? Substitute other metals for the copper wire. Substitute a glass rod, a strip of paper, a piece of wet string, your hand, and so on. What happens each time?

Now place the frog on a glass plate and try arcs consisting of pairs of two different materials, both metals and nonmetals. What materials must be in the arc for you to obtain contractions? Where does the electricity that is causing the muscular contractions come from?

Form an arc of two dissimilar metals, say copper wire and iron wire or copper wire and a zinc strip. With the prepared frog on a glass plate, apply both ends of the arc to the sciatic nerve. Is there a contraction of the muscles? Similarly, apply both ends of an arc consisting of two dissimilar metals directly to the muscle. Does the muscle contract? What do these last two experiments show? If Galvani did experiments similar to these, did he take them into account in his theory of muscular contraction?

---

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

What kind of publication was this? What functions do such publications serve? (23)

Why "revolutionary" age? (24)

1792 was a tough year for European frogs.

In 1791 Galvani published a full account of his experiments and his theoretical explanation in Volume 7 of the *Proceedings* of the Bologna Academy of Science and Arts. His paper was reprinted separately in 1791 and in 1792 with the title *De viribus electricitatis in motu musculari commentarius* (Commentary on the Effects of Electricity on Muscular Motion). Galvani's work aroused great interest among scientists and laymen all over Europe. Everywhere his experiments were repeated. In that revolutionary age, people were excited by the possibilities of the release of this new "vital force," animal electricity. They captured and dissected great numbers of frogs to see the phenomenon of animal electricity for themselves and to ponder its significance.

Among those who became interested in this strange phenomenon was Galvani's countryman, Alessandro Volta, professor of physics at the University of Pavia. In 1793 he reported:

Why do scientists repeat experiments? (25)

Do all scientists have "so profound an intelligence"? (26)

> "Having, in the first instance, repeated the different experiments of Galvani, I afterwards examined the results; and was thus enabled to make several discoveries which had escaped Galvani and the other naturalists who had followed him in the [direction] he had, with so profound an intelligence, pointed out.

Volta's attitude here is critical and skeptical.

> "In examining the principal questions, it has not hitherto been established whether, in the Galvanic experiments, the very powerful contractions excited in the muscles, and the movements of the limbs, on account of the double contact [between the muscle and] the nerve of the animal, well prepared and carefully dissected;—it has not, I say, been ascertained whether these movements and contractions . . . take place because of electricity produced by the metals in the conducting arc, or, on the other hand, by the simple force of animal electricity, as is asserted by Galvani."

Clearly, Volta was not convinced that Galvani's experiments had demonstrated animal electricity, and he was dubious about Galvani's theoretical explanation of the muscular contractions. Being dissatisfied, Volta sought another explanation. He recalled one of his earlier experiments:

> "Some time ago I had occasion to demonstrate, by indubitable experiments, that metallic substances . . . are not only the most perfect conductors of electricity, but even become exciters [or sources of electricity] by the means of simple contact. It was already known, that metals . . . possess the power of transmitting electricity very readily, . . . but I was enabled to make the discovery [that electricity was created when two dissimilar metals were in contact]."

What variables did Volta change? (27)

Here was a valuable clue, for there had been two dissimilar metals in contact in all of Galvani's most significant experiments (pages 14 and 18 above). Volta repeated many of Galvani's experiments and added others of his own. He found, for example, that he could obtain muscular contraction in frog legs when he touched only the muscle in two places with a conducting arc. He also obtained contractions when he touched only the nerves with two dissimilar metals in contact. Finally, Volta gave his own theoretical explanation of muscular contraction, which is summarized at the top of page 22.

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

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?

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?

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

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?

Note the assumptions that Volta makes to obtain his explanation.

> Volta's Explanation of Muscular Contraction.
>
> 1. Electricity is produced when two dissimilar metals are in contact.
>
> 2. For the electricity produced by two dissimilar metals to flow, there must be a third component in the circuit. This third component must be a poorer conductor of electricity than the metals.
>
> 3. Liquids and moist materials, such as fresh animal tissues, are conductors of electricity, but poorer conductors than metals.
>
> 4. Motion of muscles occurs when the fresh muscle tissue is in a circuit with two dissimilar metals in contact. Electricity then flows through the muscle tissue, which is stimulated to react in its characteristic way and contracts.
>
> 5. Nerves are also excellent conductors. If a nerve is in contact with an electric circuit, it is stimulated. The nerve rapidly conducts the electricity to the part with which it is connected (the receptor). If the receptor is a muscle, the muscle is stimulated and contracts. This is an alternative way to produce muscular contraction.

That old school spirit!

Why would this be an important experiment? (28)

Now there were two possible explanations for the same phenomenon. Some scientists supported Galvani's explanation of animal electricity, while others favored Volta's idea of two dissimilar metals in contact. The fascination of the subject, as well as the traditional rivalry between the nearby universities of Bologna and Pavia, helped to bring about an exciting controversy. Galvani himself, being of a retiring nature, took no active part in the controversy, but he devised new experiments to support his position. Accordingly, in 1794, he instructed his nephew, Giovanni Aldini, who had assisted him before, to attempt to obtain muscular contractions in frog legs *without* using any metallic connections. Aldini did so:

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

"I made Signor Galvani's usual preparations, but I did not peel the skin from the lower members as I had done previously. . . . I left the skin open by a small incision, enough to permit the underlying muscles to receive their corresponding crural nerves upon them. Thereafter, I let the crural nerves fall in the shape of an arc on the underlying lateral crural muscles so that they would come into contact with one another in the incision of the skin . . . It appeared to me quite often that the muscular contractions were stronger than usual. Having observed this, I also tried a similar experiment with the external crural nerve by similarly applying it in the shape of an arc, not in the muscles of the thigh, but of the leg . . . exactly where the muscle remained uncovered by the incision in the skin.

"The result of the experiment was the same; the contractions appeared very strong and lasting, and very often equally strong not only when the muscle was struck or was dropped, but also when it was just touched very lightly." [What techniques did Aldini use in this experiment? See Experiment 5, page 25.]

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

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

Giovanni Aldini (1762–1834) was the nephew of Luigi Galvani, and an active supporter of Galvani's theory of animal electricity. When Volta published his theory of the cause of muscular contraction in 1792, it was Aldini who wrote an answer in defense of Galvani's theory. He became so active in the controversy that most of Volta's later statements were directed to Aldini rather than to Galvani. Aldini had no medical training and showed none of Galvani's restraint in publishing his ideas. He advocated the use of Galvanism for the cure of blindness resulting from smallpox and for the treatment of insanity. He was appointed professor of physics at Bologna in the year his uncle died, and organized a scientific society there to support the study of Galvanism. He traveled to Paris and London to give demonstrations, and performed a series of experiments on the beheaded corpse of a murderer executed at Newgate Prison. The results led him to believe that electric shock might revive persons overcome by drowning or suffocation. He was so active and dramatic in his presentations that the quiet and sensitive Galvani was almost forgotten. *Picture reproduced by courtesy of Burndy Library*

Efficient communication of information and ideas is vital to science.

Aldini's success in obtaining contractions without metals certainly provided evidence for Galvani's belief in animal electricity. Unfortunately, the report was published in an anonymous book which attracted little attention. Volta, on the other hand, pursued his interpretation with great vigor. He carried out many careful experiments and wrote many vigorous letters explaining his ideas to scientists in Italy, Germany, France, and England. For example, in a letter Volta wrote to Tiberius Cavallo in England, he was not at all restrained:

> "The name of animal electricity is by no means proper, in the sense intended by Galvani, and by others; namely, that the electrical fluid becomes unbalanced in the animal organs, and by their own proper force, by some particular action of the vital powers. [See points 2 and 3 in Galvani's theoretical explanation, page 18.]
>
> "No, this is a mere artificial electricity, induced by an external cause, that is, [this artificial electricity is] excited originally in a manner hitherto unknown, by the connexion of metals with any kind of wet substance. And the animal organs, the nerves and the muscles, are merely passive, though [the nerves and the muscles are] easily thrown into action whenever, by being in the circuit of the electric current, produced in the manner already mentioned, they are attacked and stimulated by it, particularly the nerves."

Do you detect any differences in the personalities of Galvani and Volta from their styles of writing? (30)

Once again, in this letter, Volta mentions an electricity "excited originally in a manner hitherto unknown," and this is a reference to his idea of a three-element circuit as a source of electricity [see point 2 in Volta's theoretical explanation, page 22]. Volta used this idea in designing the first electric battery. He described this new instrument in a paper, "On the Electricity excited by the mere Contact of conducting Substances of different kinds," which was published in the *Philosophical Transactions* of the Royal Society of London in 1800.

Are ideas or instruments more important in science? (31)

The Philosophical Transactions is a scientific journal, but what is the Royal Society? (32)

EXPERIMENT 5. ALDINI'S EXPERIMENT

To guard himself against the criticism that electricity was produced by the contact of two materials with different conducting properties, such as the skin and tissues of the frog (Volta would be quick to point this out), Aldini had to work very carefully. He described his techniques as follows:

> "I insulated the nerve located in the hind portion of the thigh from any other adjoining part up to the back of the knee [popliteus]. I then pulled it out from the thigh and I put a small and very thin glass plate near the popliteal muscle, so that it would not come into contact with the muscle in the adjoining parts when I would bend it, since otherwise it would disturb the promptness and precision of the experiment. Having done this, I took the nerve by means of a very small and very thin glass or rosin cylinder, and I folded it on this cylinder, and then I brought it in the direction of the exposed muscle. At this point, I suddenly pulled the cylinder away, letting the nerve fall on the muscle."

In doing this experiment, you may insulate the nerve and the muscle with a double layer of adhesive tape instead of a "very thin glass plate." For the "very thin glass or rosin cylinder," use a solid glass rod. Do you obtain contraction when the nerve is allowed to fall on the muscle? If so, is this evidence of animal electricity? Why, or why not? What is the importance of using the proper techniques in scientific work?

---

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

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

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.

Here is Volta's description of the construction and operation of his new instrument in its original form:

> "Thirty, forty, sixty, or more pieces of copper, or [better] silver, [are] applied each to a piece of tin, or zinc, which is much better, and as many strata of water, or . . . [better] salt water, lye &c. or pieces of pasteboard, skin &c. well soaked in these liquids. Such strata [are] interposed between every pair . . . of two different metals in an alternate series, and always in the same order of these three kinds of conductors, [and that is] all that is necessary for constituting my new instrument, which . . . imitates the effects of the Leyden flask . . . However, it far surpasses the virtue and power of these [Leyden flasks], as it has no need, like these, of being previously charged by means of foreign electricity, and as it is capable of giving a shock every time it is properly touched, however often it may be." [See Experiment 6, page 27, and Activity 2, page 30.]

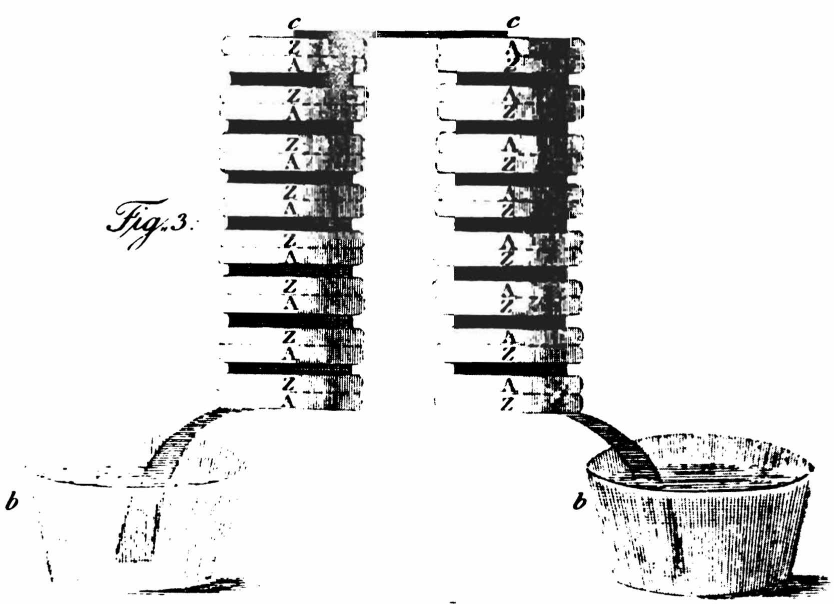
Can you suggest any other arrangements? (33)

Volta called his new apparatus an "artificial electric organ," but this form of electric battery was soon given the name "voltaic pile." Using the same principle, he devised several other ingenious arrangements of the three elements to make various types of electric batteries. Unlike electrostatic machines and the Leyden jars, which give only a short burst of electricity, Volta's electric batteries provided man, for the first time in history, with a source of continuous electric current.

How is applied science different from science? (34)

We are all familiar with the many practical applications that were found for Volta's battery and its improved forms. Much more dramatic was the effect that the voltaic pile had on scientific experimentation at the beginning of the nineteenth century. Not only biologists, but physicists and chemists as well, enthusiastically adopted this new source of a steady electric current to open up vast new fields of investigation. Volta himself used his battery to explore how the human senses are stimulated. He demonstrated that a stimulated nerve will react only with its characteristic response. For example, an optic nerve always gives a visual sensation, even when stimulated by pressure or electricity. (See Activity 3, page 31.) Volta thus opened the way to an understanding of nerve physiology.

What were some of the scientific uses of the voltaic pile? (35)



This engraving was in the published edition of Volta's letter to the Royal Society of London, describing his invention of the electric pile. The pile consists of pairs of disks of zinc *(Z)* and silver *(A)* separated by paper or cloth soaked in brine. With thirty such pairs connected in a pile, a person placing a finger in each of the cups *(b)* received a small but continuous shock. Volta pointed out that his device did not merely produce a brief spark as did the Leyden jar, but that it seemed to contain "an inexhaustible charge, a perpetual action or impulsion on the elastic fluid." *Picture reproduced by courtesy of Burndy Library*

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

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

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

EXPERIMENT 6. THE VOLTAIC PILE

Cut twenty or more thin disks of each of two dissimilar metals. Copper and zinc make a good combination. (Silver and zinc are best.) Cut pieces of filter paper to fit in between each pair of metals in contact. As Volta did, make a pile of your metal disks and moistened paper, keeping them always in the same order (for example: copper, zinc, paper, copper, zinc, paper, and so on). Connect copper wires to the bottom and top disks of your voltaic pile. Touch the free ends of the wires with your fingers. Do you get a mild shock?

Can you increase the effect by moistening your fingers? Can you increase the effect by attaching metal strips or plates to the bottom and top disks of the pile? In what other ways can you increase the effect?

How many disks do you need in your pile to light a flashlight bulb?

How are controversies in science resolved? (36)

With the excitement over the success of his battery, Volta's theoretical explanation of muscular contraction triumphed. Volta was applauded and honored by scientists and princes alike. Among scientific men Galvani's ideas about animal electricity were all but forgotten, and Volta's theory carried the day.

Now, more than a century and a half after this famous controversy, we can better evaluate the position of each side.

Let us first look at Volta's views. The last two points of Volta's explanation of muscular contraction (page 22 above) were essentially correct. However, physicists and chemists who further studied the voltaic pile soon found that Volta's idea that the contact of two dissimilar metals produces electricity (point 1) was incorrect. Although his idea of the three-element circuit was most useful in leading Volta to devise the first electric battery, this idea has been replaced by an explanation in terms of chemical reactions between the adjacent materials. You can find the details of the present-day explanations in almost any chemistry textbook.

Volta was also wrong in denying that there could be an electricity in animals which, as Galvani put it, "is peculiar to themselves." On the other hand, Galvani was wrong in believing that animal electricity was the cause of the muscular contractions in his experiments with conducting metal arcs. However, Aldini's experiments (pages 22 and 25 above) demonstrated that such an animal electricity does exist. This form of animal electricity was identified as the "injury current" by later investigators. Thus the first two points in Galvani's theoretical explanation (page 18 above) are correct.

Animal electricity does indeed exist. In fact, even some plants produce electricity. Scientists have developed delicate instruments to measure the electricity generated by a cell in its life processes.

Bioelectricity has become an important and exciting area of scientific research. The sharp controversy about animal electricity between Galvani and Volta at the close of the eighteenth century caused other scientists to study more carefully the connections between electricity and life. Many of the properties of animal electricity were investigated by the electrophysiologists of the nineteenth century (see Activity 1, page 30). Animal electricity, as well as plant electricity, is being actively studied today. Frogs and batteries are still being used in this work.

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 two questions:

a. What are the rules for settling controversies in science?
b. How are such controversies actually resolved? Are they always resolved?

ADDITIONAL ACTIVITIES

ACTIVITY 1
Scientists and Nations

Here, listed by the countries in which they lived, are the names of scientists who contributed to our knowledge of muscular contraction and nerve physiology during the seventeenth, eighteenth, and nineteenth centuries. (Electrophysiologists of the nineteenth century are identified by the letter *e*.)

Denmark—Nicolaus Steno

England—William Croone, Thomas Willis, John Mayow, Francis Glisson, James Keill, Benjamin Wilson, James Douglas, James Parsons, John Hunter, Alexander Stuart, Edward Whittaker Gray, Augustus Volney Waller, Augustus Désiré Waller (e)

France—Jean Antoine Nollet, Antoince Louis, François Magendie, Charles Richet, Claude Bernard

Germany—Herman von Helmholtz (e), Emil Du Bois-Reymond (e), Ludimar Hermann (e)

Holland—Jan Swammerdam, Pieter van Musschenbroek, Hermann Boerhaave

Italy—Giovanni Alfonso Borelli, Giovanni Battista Beccaria, Felice Fontana, Luigi Galvani, Alessandro Volta, Giovanni Aldini, Leopoldo Nobili (e), Camillo Golgi, Carlo Matteucci (e).

Scotland—Robert Whytt, Charles Bell

Switzerland—Albrecht von Haller, Luis Jallabert, J. G. Sulzer

Members of the class may wish to use this list as a starting point for special reports. In your library research and your report about one of these men, you will want to find out and discuss the answers to the following questions: Who was the man? What did he learn about muscular contraction or nerve physiology? What other contributions did he make to science and to society outside science?

From the list of countries above you can see that science is an international activity. This fact suggests other subjects from which you might choose a topic for a written report. How did these men, some living great distances from one another and speaking different languages, learn of each other's work? How do American scientists today learn of the work of foreign scientists? Are there barriers other than language to efficient international communication between scientists? Write an essay discussing these problems.

Finally, isn't there something peculiar about the above list? Although there are representatives of eight nations on the list, there were certainly many more countries in the world. Why aren't scientists listed from these other countries? (The list is a fairly complete one for the period, so incompleteness isn't the answer.) With the help of the library card file and your school librarian, you may be able to locate books discussing the social, cultural, and intellectual histories of such countries as England, France, and Italy during the periods when these scientists were alive. See whether you can discover from these books what factors operating in a particular country at a particular time are likely to produce a large number of scientists and scientific discoveries. Write an essay discussing your own generalizations on the subject and any evidence you have to back up these generalizations. Why is it important for us today to know what factors help a nation produce many scientists and scientific ideas?

ACTIVITY 2
An Eleven-Cent Battery

You can easily make a simple battery for eleven cents from two dissimilar metals, a penny (95 percent copper) and a dime (90 percent silver). Simply cut a piece of filter paper, dip it in a salt solution, and place it between the penny and the dime. With two lengths of copper wire, connect the penny and the dime with the terminals of a galvanometer (an instrument for detecting an electric current) Do you get a current from your eleven-cent battery? Will your battery produce a current with the penny and the dime in contact and the moistened filter paper on one side? Explain this effect.

Now try a twenty-two-cent battery, a thirty-three-cent battery, a forty-four-cent battery, and so on. Do you get a linear increase in the current produced? Why, or why not?

ACTIVITY 3
Volta's Experiments on Sensation

Although Volta was not a physiologist, he employed electrical stimulation of the senses to demonstrate the effects of his new instrument, the voltaic pile. The descriptions of his experiments, taken from Volta's paper of 1800, are clear enough so that you can repeat them with your voltaic pile:

"The effects sensible to our organs produced by an apparatus formed of 40 or 50 pairs of plates . . . are reduced merely to shocks: [yet] the current . . . excites not only contractions and spasms in the muscles, convulsions more or less violent in the limbs through which it passes in its course; but it irritates also the organs of taste, sight, hearing, and feeling . . . and produces in them sensations peculiar to each.

"And first, in regard to the sense of feeling: If, by means of an ample contact of the hand [well moistened] with a plate of metal, . . . I establish on one side a good communication with one of the extremities of my apparatus; . . . and on the other I apply the forehead, eye-lid, tip of the nose, also well moistened, or any other part of the body where the skin is very delicate: if I apply, I say, with a little pressure, any one of these delicate parts, well moistened, to the point of a metallic wire, communicating properly with the other extremity of the said apparatus, I experience, at the moment that the conducting circle is completed, at the place of the skin touched, and a little beyond it, a blow and a prick, which suddenly passes, and is repeated as many times as the circle is interrupted and restored. [But if the contacts are not broken] I feel nothing for some moments; afterwards, however, there begins at the part applied to the end of the wire, another sensation, which is a sharp pain (without shock), limited precisely to the points of contact, a quivering, not only continued, but which always goes on increasing to such a degree, that in a little time it becomes insupportable . . .

"In regard to the sense of taste, I had before discovered . . . that two pieces of these different metals . . . applied in a proper manner, excited at the tip of the tongue very sensible sensations of taste [and] that the taste was decidedly acid . . . But when I have said here, that exactly the same phenomena take place when you try, instead of one pair of these metallic pieces, an assemblage of several of them ranged in the proper manner; and that the said sensations of taste . . . increase but a little with the number of these pairs, I have said the whole. . . .

"In regard to the sense of sight . . . I was surprised to find that, with 10, 20, 30 pairs, and more, the flash produced neither appeared longer and more extended, nor much brighter than with one pair. [With an apparatus of 20 or 30 pairs, etc., a bright flash of light] will be produced by applying the end of a metallic plate or rod, placed in communication with one of the extremities of the apparatus, to [the ball of the eye, or the eyelid well moistened], while with one hand you form a proper communication with the other extremity; by bringing, I say, this [second] plate into contact not only with the eye or any part of the mouth, but even the forehead, the nose, the cheeks, lips, chin, and even the throat, . . . which must [merely] be well moistened before they are applied to the metallic plate. The form as well as the force of this transient light which is perceived varies a little, if the places of the face to which the action of the electric current is applied be varied. . . .

"But the most curious of these experiments is, to hold the metallic plate between the lips, and in contact with the tip of the tongue; since, when you afterwards complete the circle in the proper manner, you excite at once, if the apparatus be sufficiently large and in good working order, . . . a sensation of light in the eyes, a convulsion in the lips, and even in the tongue, and a painful prick at the tip of it, followed by a sensation of taste.

"I have now only to say a few words of hearing. . . . I introduced, a considerable way into both ears, two probes or metallic rods with their ends rounded, and I made them communicate immediately with both extremities of the apparatus. At the moment when the circle was thus completed I received a shock in the head, and some moments after (the communication continuing without any interruption) I began to hear sounds, or rather noise, in the ears, which I cannot well define: it was a kind of crackling with shocks, as if some paste . . . had been boiling. . . . The disagreeable sensation, and which I apprehended might be dangerous, of the shock in the brain, prevented me from repeating this experiment."

READING SUGGESTIONS

• Baker, Jeffrey J. W. "Muscle Contraction," *Science and Math Weekly*, Vol. 4, No. 23 (11 March 1964), pp. 268–269.

• Carrier, Elba O., and Klopfer, Leo. E. "Frogs and Electricity," *Science World, Edition 2*. Vol. 13, No. 5 (3 April 1963), pp. 13, 30–31. [About Galvani and Aldini.]

• ——. "Sixteen Pieces of Silver," *ibid.*, Vol. 13, No. 6 (17 April 1963), pp. 18–19. [About Volta.]

• Conant, James B. *Science and Common Sense*. New Haven: Yale Univ. Press, 1951. Paperbound Y32, 1960. See pp. 108–114.

• Davon, H. *A Textbook of General Physiology*. Boston: Little, Brown, 1959. [Bioelectricity is discussed in Chapters 10–19.]

• Dibner, Bern. *Galvani-Volta: A Controversy That Led to the Discovery of Useful Electricity*. Norwalk, Conn.: Burndy Library, 1952. [Also available in paperbound.]

• ——. *Alessandro Volta and the Electric Battery*. New York: Franklin Watts, 1964. [An excellent short biography and account of Volta's work.]

• Galambos, Robert. *Nerves and Muscles*. (Anchor Science Study Series S 25.) New York: Doubleday, 1962. Paperbound.

• Galvani, Luigi. *Commentary on the Effects of Electricity on Muscular Motion*. Translated by Margaret Glover Foley. Introduction and notes by I. Bernard Cohen. Norwalk, Conn.: Burndy Library, 1953.

• Graubard, Mark. *The Foundations of Life Science*. New York: Van Nostrand, 1958. [Chapter on muscles and muscular contraction, pp. 229–249. Also see chapters on the frog, nerves, nervous system, and sensations, pp. 281–228 and 250–294.]

• Shippen, Katherine B. *The Bright Design*. New York: Viking Press, 1949. [Short and simple chapters on Leyden jars, Galvani, and Volta, pp. 41–44 and 52–61.]

• Stacy, R. W. *Biological and Medical Electronics*. New York: McGraw-Hill, 1960.

• Suckling, E. E. *Bioelectricity*. (BSCS Pamphlet No. 4.) Boston: Heath, 1962.

SOURCES OF QUOTATIONS

PAGES

2 — Isaac Newton, **Philosophical Transactions.** London, 1672. Vol. 1, p. 678.

4 — Isaac Newton, **Optical Lectures.** London, 1728. P. 5.

4, 6 — William Hyde Wollaston, "A Method of Examining Refractive and Dispersive Powers by Prismatic Reflection," **Philosophical Transactions.** London, 1802. Vol. 92, pp. 367–80.

7 — Henry Crew, **The Rise of Modern Physics.** Baltimore: Williams & Wilkins, 1928. P. 156.

8, 11, 12 — Joseph von Fraunhofer, "Determination of the Refractive and Dispersive Power of Different Kinds of Glass, with Reference to the Perfecting of Achromatic Telescopes," in **Prismatic and Diffraction Spectra,** J. S. Ames, ed. London and New York: Harper & Brothers, 1898. Pp. 1–10. This is an abridged translation of the original German paper, "Bestimmung des Brechungs- und Farbenzerstreuungs-Vermögen verschiedener Glassarten in Bezug auf die Vervollkommnung achromatischer Fernröhre," which appeared in **Denkschriften der königlichen Akademie der Wissenschaften zu München,** 1817, Vol. 5, pp. 193–226.

15 — From "The Test-Tube Method for Flame Testing," by Arthur R. Clark, **Journal of Chemical Education.** Easton, Pa., **12,** 242 (1935). Copyright 1935, Division of Chemical Education, American Chemical Society.

16, 20, 22 — Gustav Robert Kirchhoff, "Concerning the Fraunhofer Lines," **Philosophical Magazine,** Series 4, Berlin, 1860. Vol. 19, pp. 193–97. English translation of the original German paper, "Über die Fraunhoferischen Linien," in **Monatsberichte der Akademie der Wissenschaften zu Berlin,** October 1859, pp. 662–64.

18, 20 — From **Researches on the Solar Spectrum and the Spectra of the Chemical Elements,** by G. Kirchhoff, translated by Henry Roscoe, by permission of Macmillan & Co., Ltd. Cambridge and London, 1862. Pp. 14–15.

21 — "Arrangement for Viewing Absorption Spectra," by W. C. Badcock, from **The Science Masters' Book,** Series II, Part I, **Physics,** edited by G. H. J. Adlam, published by John Murray Ltd., by permission of the Association for Science Education and School Science Review. London, 1936. Pp. 162–63.

24 — From "Bunsen Memorial Lecture," by Henry Roscoe, **Journal of the Chemical Society.** London, 1900. Vol. 77, pp. 513–54.

26–28 — Joseph von Fraunhofer, "Short Account of the Results of Recent Experiments on the Laws of Light," in J. S. Ames, ed., **op. cit.,** pp. 39–60. An abridged translation of the original German paper, "Kurzer Bericht von den Resultaten neuerer Versuche über die Gesetze des Lichtes," Gilbert's **Annalen der Physik.** Leipzig, 1825. Vol. 74, pp. 337–78.