

TRANSISTORIZED!



About the PBS Documentary

The transistor is one of the 20th century's most important inventions. It revolutionized technology and launched the Information Age. Its creation is a dramatic story of top secret research, serendipitous accidents, collaborative genius and clashing egos. *Transistorized!*, the one hour documentary airing on PBS, tells the compelling story of the history of the transistor and the scientists who discovered it. They include William Shockley, who assembled the team at Bell Labs that built the first working transistors, but whose driving ego ultimately ended their collaboration; John Bardeen, a theoretical genius whose profound insights paved the way to the final discovery; and Walter Brattain, whose persistent tinkering led to the breakthrough that resulted in the first transistor.

Host Ira Flatow leads us through a vivid and entertaining tour of the key moments in the history

of the transistor — from the scientific breakthroughs early in the 20th century that set the stage for the invention, through the frustrations and serendipitous accidents that made the first transistor work, to the evolution of the first transistorized products and the birth of Silicon Valley. All inextricably interwoven with the tale of the brilliant collaboration and dramatic demise of the team that made the transistor possible.



Host Ira Flatow takes viewers back in time to recapture the excitement and drama behind the invention that changed the world — the transistor — in the PBS program "*Transistorized!*"

Transistorized!

will be broadcast
nationally on PBS
Monday, November 8,
1999 at 10pm ET.

(Check local listings for the broadcast times in your location.)

To learn more about the transistor visit www.pbs.org/transistor.

To order additional copies of the guide (while supplies last) e-mail transistorized@ktca.org.



Lucent Technologies
Bell Labs Innovations



These educational materials are made possible by a grant from The Lucent Technologies Foundation.



The PBS documentary *Transistorized!* is a co-production of KTCA-TV and ScienCentral, Inc., and is made possible by a grant from the Alfred P. Sloan Foundation.

© 1999, Twin Cities Public Television, Inc. and ScienCentral, Inc. All Rights Reserved



Table of Contents

Lesson 1: The Story of the Transistor 2

Students view the video *Transistorized!* and discuss key factors that led to the invention of the transistor.

Lesson 2: Scientists at Work 4

Students select an electronic invention and research who and what contributed to it.

Lesson 3: Transistors in Your Life 6

Students hunt for transistor-based devices and explain how the transistor affects their lives.

Lesson 4: Using Transistors 8

Students build circuits to see how transistors function as switches or amplifiers.

Profiles of Scientists 11

Ira Flatow with a replica of the first transistor.



Transistorized! Video Index

TIMER/COUNTER

Act I 01:00–18:00 (18 min)

Hell's Bell's Laboratory

The birth of Bell Labs and early advances in electronics.

Act II 18:00–30:00 (12 min)

Miracle Month

Intense research at Bell Labs leads to the first working transistor.

Act III 30:00–48:00 (18 min)

Glory & Intrigue

Advances produce the first transistor radios, but the team of inventors breaks apart.

Act IV 48:00–55:00 (7 min)

Smaller, Cheaper, Faster

The integrated circuit and the Information Age.

Correlations of *Transistorized!* Lessons to National Science Education Standards

Science Content Standards Grades 9–12	Lessons			
	1	2	3	4
Unifying Concepts and Processes				
Systems, order, and organization	•	•	•	•
Evidence, models, and explanation	•	•	•	•
Change, constancy, and measurement	•	•	•	•
Form and function	•	•	•	•
Science as Inquiry				
Abilities necessary to do scientific inquiry		•		•
Understandings about scientific inquiry	•	•	•	•
Physical Science				
Structure and properties of matter	•			•
Motions and forces	•		•	•
Conservation of energy and increase in disorder	•			
Interactions of energy and matter	•			•
Science and Technology				
Abilities of technological design		•	•	•
Understandings about science and technology	•	•	•	•
Science in Personal and Social Perspectives				
Science and technology in local, national, and global challenges	•	•	•	•
History and Nature of Science				
Science as a human endeavor	•	•	•	•
Nature of scientific knowledge	•	•		
Historical perspectives	•	•		•



We encourage duplication for educational non-commercial use.

Transistorized! is a co-production of KTCA-TV and ScienCentral, Inc. To order the video call PBS Learning Media at 1-800-344-3337

These educational materials are made possible by a grant from The Lucent Technologies Foundation.

Lucent Technologies
Bell Labs Innovations



The Story of the Transistor

Background

Bell Laboratories, one of the world's largest industrial laboratories and now part of Lucent Technologies, was originally the research and development arm of the giant telephone company American Telephone and Telegraph (AT&T). One of the first pioneering advances of Bell Labs in the early 1900s was a practical version of the vacuum tube. This device amplified faint telephone signals and was the key to America's coast-to-coast telephone system.



"The transistor was probably the most important invention of the 20th century, and the story behind the invention is one of dashing egos and top secret research. . . ."

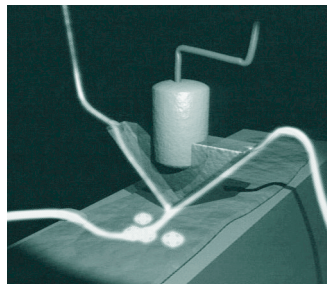
—Ira Flatow,
Transistorized!

It also worked as a high speed on-off switch. Over the next three decades, vacuum tubes were pressed into service for everything from home radios to military radar. Even the first electronic computer relied on vacuum tubes—about 18,000 of them!

But as the uses for vacuum tubes increased, so did the frustration at their limitations. Vacuum tubes were big and clumsy. They used a lot of power, they generated large amounts of heat, and they were fragile. Clearly, a better device was needed. New advances in theoretical physics and quantum mechanics suggested that a class

of materials called semiconductors—materials like silicon or germanium that normally are very poor conductors of electricity—might, under the right conditions, be able to replace the vacuum tube.

At Bell Labs, a young, brilliant theoretician, Bill Shockley, was selected to lead a team researching the potential of semiconductor materials. Shockley drafted Walter Brattain, an experimental physicist who could build or fix just about anything, and hired theoretical physicist, John Bardeen. Shockley filled out his team with an eclectic mix of physicists, chemists, and engineers, and they set to work to create a semiconductor amplifier.



In 1945 Shockley proposed an amplifier design in which an electric field would enhance the flow of electrons near the surface of a layer of silicon. His colleagues tried several versions of this "field effect" amplifier but without success. He assigned Bardeen and Brattain to find out why the idea didn't work. It was a productive partnership—Bardeen, the theoretician, suggested experiments and interpreted the results, while Brattain built and ran the experiments. For two years, they did countless tests

Engage

Invite students to think of examples of devices that have become smaller and more compact over the years.

(almost any portable electronic device such as radios, tape players, CD players, computers, and medical devices such as pacemakers and hearing aids)

Ask students to speculate about what kinds of breakthroughs made the smaller devices possible.

Explore

Play the video *Transistorized!*. As students watch, tell them to make a list of key factors that helped the Bell Labs scientists invent the transistor. If time does not permit playing the entire program, play "Act II Miracle Month," which chronicles the invention itself in 1947–48.

Evaluate

Discuss the key factors that students listed during the video. Do those items refer to scientific discoveries only? How important were the personal characteristics of the scientists in the invention of the transistor? Ask students to describe at least two instances from the video in which the work of one researcher depended upon the work of another. What is serendipity and how did it play a role in the process of inventing the transistor? What scientific concepts played an important part in the design of the transistor?



We encourage duplication for educational non-commercial use.

Transistorized! is a co-production of KTCA-TV and ScienCentral, Inc.
To order the video call PBS Learning Media at 1-800-344-3337

These educational materials are made possible by
a grant from The Lucent Technologies Foundation.

Lucent Technologies
Bell Labs Innovations



Resources

Books

Riordan, Michael and Lillian Hoddeson. *Crystal Fire: The Invention of the Transistor and the Birth of the Information Age*. New York: W. W. Norton and Company, 1997.

Articles

Brattain, Walter H. "Genesis of the Transistor." *The Physics Teacher*. (March, 1968) pp. 109-114.

Hoddeson, Lillian. "The Roots of Solid State Research at Bell Labs." *Physics Today*. (March, 1997).

Holonyak, Jr., Nick. "John Bardeen and the Point-Contact Transistor." *Physics Today*. (April, 1992).

Shockley, William. "How We Invented the Transistor." *New Scientist* 21. (December, 1972) pp. 689-91.

Web sites

<http://www.pbs.org/transistor>
Explores the history and technology of the transistor and the people involved in its invention. Also includes information about the making of the *Transistorized!* documentary.

<http://www.lucent.com/ideas/heritage/transistor/>
Includes an historical overview of the transistor, how it works, and its current uses.

<http://www.aip.org/history>
Explores the history of physics and includes links to other fields of science.

on different samples of silicon and germanium. Then in December, 1947, in a combination of brilliant theoretical insight and serendipitous accidents, Bardeen and Brattain produced the world's first semiconductor amplifier—the point-contact transistor was born.

Spurred on by this first discovery, Shockley developed an improved transistor design—the “junction” transistor. It was used throughout the 1950s and 1960's in a variety of electronic circuits, most notably for the first transistor radios. Further refinements led to the modern “field effect” transistor, which has literally become the nerve cell of the information age. Ironically, the modern transistor operates much as Shockley proposed in 1945.

Even though Shockley, Bardeen, and Brattain shared the 1956 Nobel Prize in Physics, jealousies over proper credit for the discovery and its application tore the successful team apart. John Bardeen left Bell Labs for the University of Illinois, and later won a second Nobel Prize—the only scientist ever to win two prizes in physics—for his work in superconductivity. Brattain stayed on at Bell Labs until his retirement in the early 1960s, after which he taught physics at Whitman College in Washington.

Shockley left Bell Labs to start his own semiconductor company in California. Although he was unsuccessful as a businessman, his company sowed the seeds for what became Silicon Valley. Engineers and physicists whom he brought to California went on to invent the integrated circuit, embedding transistors and other electronic parts on one tiny piece of semiconductor. These ultimately became the microchips of today, some holding millions of transistors!

When the transistor was first unveiled to the public, in the spring of 1948, it got little attention, neither in the popular press nor in the scientific community. But in the 1950s it was quickly adopted for industrial and military applications, and, of course, the transistor radio. The transistor was the key to advances in technology. The transistor allowed information to be easily processed and scattered to the ends of the Earth; the miniaturization of electronics made possible human exploration of space; and the advent of the microchip ushered in the age of the PC and the internet. The three inventors could hardly have known the outcome when they made their discovery in 1947—that they were going to change the world.



John Bardeen, William Shockley, and Walter Brattain



We encourage duplication for educational non-commercial use.

Transistorized! is a co-production of KTCA-TV and ScienCentral, Inc. To order the video call PBS Learning Media at 1-800-344-3337

These educational materials are made possible by a grant from The Lucent Technologies Foundation.

Lucent Technologies
Bell Labs Innovations



LESSON 2

Scientists at Work: What'll they think of next?

OVERVIEW

Students work in groups to select an electronic invention and research who and what was involved in its development. Then they create a display that summarizes the main events surrounding the invention's development.

OBJECTIVES

- To understand the value of teamwork in solving problems
- To identify the function of previous research, serendipity, and diverse personalities in the process of invention

Background

The 1956 Nobel Prize in Physics went to William Shockley, Walter Brattain, and John Bardeen for the invention of the transistor. But these talented scientists did not act alone. Their success depended on a rush of profound advances in physics in the first decades of the 20th century as well as the work of their own colleagues.

William Roentgen discovered X-rays at the end of the 19th century. In the same period, J. J. Thomson discovered the electron. At the beginning of the 20th century, Max Planck revealed the quantum nature of energy on the atomic scale. Albert Einstein applied the quantum concept to the relationship between photons of light and electrons. And Niels Bohr, Werner Heisenberg, and Wolfgang Pauli developed the basic ideas of quantum mechanics, which gave scientists the tools to investigate matter at the atomic level.

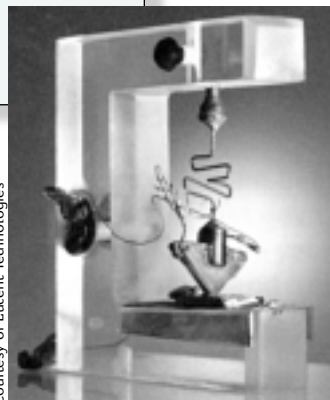
These are the giants of 20th century physics. But teams of Bell Labs scientists who remain largely unknown also made the transistor possible. Russell Ohl, for example, discovered how to add the impurities to silicon that produced its unique electrical properties. Chemists Morgan Sparks and Gordon Teal made the early breakthroughs in growing the crystalline

semiconductors that the first transistors were made of. And Mervin Kelly, a scientist-turned-administrator, provided the vision that drove the Bell Labs research program. As Isaac Newton stated centuries before about his own discoveries, "If I have seen farther than others, it is because I have stood on the shoulders of giants."

Engage

Point out that much of scientific discovery requires teamwork. Write the preceding quote from Isaac Newton on the board. Ask: What do you think Newton meant? What examples can you give where others "stood on the shoulders of giants?" Discuss how the quote applies to scientific research.

Show Act I of the video *Transistorized!*. As students watch, have them list examples where scientists built upon the work of others to develop their own ideas. Have students discuss each example and offer ideas about how the scientists' work might have been affected without the knowledge gained from earlier work.



Courtesy of Lucent Technologies

First transistor (actual size)

Explore

Prepare students for the project by asking: What electronic inventions interest you? List students' answers on the board. You might want to list some examples such as microwave ovens, fax machines, lasers, copiers, computers, and video games. Encourage thought and brief discussion about the inventions with these questions: What do you know about their invention? Who was involved in their development?

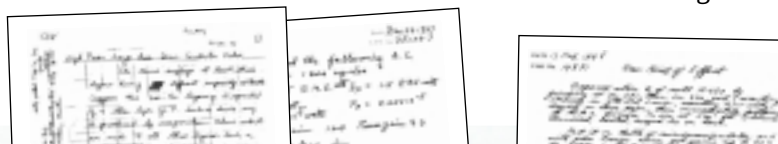
Who received credit for the inventions? What were these people like? What did they need to know? What skills did they need to have? Did each member of the team have the same skills?

Explain that teams of students will answer these and other questions in this project as they probe the process of invention.

Evaluate

After teams have presented their findings, hold a class discussion about the process of invention. At a minimum, students should be able to:

- list instances in which teamwork played a significant role during the development of an invention.
- identify earlier inventions and discoveries that laid the groundwork for later inventions.
- describe the role of any accidental results—serendipity—in the development of an invention.
- recognize that assigning credit for an invention may be a complex issue.



We encourage duplication for educational non-commercial use.

Transistorized! is a co-production of KTCA-TV and ScienCentral, Inc. To order the video call PBS Learning Media at 1-800-344-3337

These educational materials are made possible by a grant from The Lucent Technologies Foundation.

Lucent Technologies
Bell Labs Innovations





Scientists at Work: What'll they think of next?

What You're Going To Do

You're going to work in a team to select an electronic invention and research who and what was involved in its development. Your team will then create a display that summarizes the main events of that invention.

What You'll Need

- large sheet of poster board
- markers and other art supplies
- variety of reference materials about electronic inventions, including books, magazines, software, and web sites

How To Do It

1. Search through reference materials and use your own knowledge to make a list of electronic inventions. Identify the invention your team would like to learn more about. Each team member should investigate one or more of the questions below. You might want to visit the *Transistorized!* web site at www.pbs.org/transistor to see how these questions would be answered for the invention of the transistor.
 - Why was the invention developed? What problem did the invention solve or need did it satisfy? For whom was the invention developed?
 - How was the invention developed? What role, if any, did accident—serendipity—play in its development?
 - Who was directly involved in developing the invention? What was the role of each person?
 - What knowledge did each researcher need? What skills did each research team need?
 - What earlier inventions, theories, or knowledge did the researchers use in their work?
 - Who received the credit for the invention? Why? Were any of the contributors overlooked?
 - What personality traits did each researcher have? How did these traits influence the researcher's role in the invention?
 - What other inventions were developed as a result of your chosen invention?
2. Organize the information. On a large sheet of poster board, create a "family tree" of labeled pictures (or diagrams) showing the inventions, discoveries, scientists, and other researchers that produced your invention.

3. Present your invention's family tree to the class. Describe how the invention was developed. Explain the role and personality of each primary researcher who worked on the invention. If possible, provide an example of the invention for the class to observe. Answer any questions your classmates may have about the invention.
4. After all team presentations are made, discuss any similarities you notice in the development of different inventions.

What Did You Find Out?

1. What are some common traits of the researchers who contributed to the inventions studied by the class? How did the traits contribute to the researchers' success or failure?
2. In general, how did the inventors use teamwork to solve a problem or complete an invention?
3. Did researchers always get the experimental results they anticipated? Were any unexpected results useful in developing their invention?
4. What criteria seemed to be used to assign credit for inventions?

Try This!

- ◆ Prepare a multimedia presentation of your team's work. You might use HyperStudio or PowerPoint for your presentation.
- ◆ Shockley, Bardeen, and Brattain were physicists. Find out what role chemists played in the development of the transistor. What were the key discoveries in chemistry and who made them? Report your findings.
- ◆ Conduct a survey of several companies who have Research and Development facilities, such as General Electric, IBM, Intel, Lucent Technologies, Motorola, and 3M. Find out each company's policy regarding inventions designed and built by company employees. Are the employees' names included on the patent application? Do employees receive any monetary benefits? Report the results of your survey.



We encourage duplication for educational non-commercial use.

Transistorized! is a co-production of KTCA-TV and ScienCentral, Inc. To order the video call PBS Learning Media at 1-800-344-3337

These educational materials are made possible by a grant from The Lucent Technologies Foundation.

Lucent Technologies
Bell Labs Innovations



LESSON 3

Transistors in Your Life:

A Transistor Hunt

OVERVIEW

In this lesson, students search for transistor-based devices at school. They use the results of their search to explain the significance of the transistor in their lives.

OBJECTIVES

- To find examples of transistors in school
- To realize the number and significance of transistors in everyday life

Background

A transistor is a tiny device that either switches electric current on and off or amplifies an electric current. The original transistors were small cylinders, a bit larger than a pencil eraser. Over the years, scientists and engineers have been able to make transistors tinier and tinier. With the invention of the integrated circuit, or microchip, in which thousands or millions of transistors are deposited on a piece of silicon, transistors have become microscopic.

Transistors are the main component of the microchips used in computers. Computers operate on a binary system, which uses only two digits: 0 and 1. In a computer microchip, transistors act as switches, letting current through to represent the binary digit 1, or cutting it off to represent 0. Every kind of information (words, numbers, pictures, etc.) are converted into strings of 1s and 0s.

Today many household appliances including televisions, VCRs, stereos, telephones, refrigerators, washers and dryers, microwave ovens, alarm systems, and fax machines have chips built into them. The chips allow the devices to process great volumes of information and provide the user with exactly the information desired, from identifying the name and phone number of a caller to playing and replaying the chorus of the latest hip-hop release.

Transistors are also found in pacemakers, hearing aids, cameras, calculators, and watches. Most of these devices draw their power from tiny batteries. Most spacecraft also rely on microchips, and thus transistors. The transistor is truly the “nerve cell” of the information age.

Engage

To introduce the importance of the invention of the transistor, help students visualize its impact on the design of computers. If possible, show students a vacuum tube. If a vacuum tube is not available, you might use a 25-watt light bulb as a model for the vacuum tube. Indicate that ENIAC (Electronic Numerical Integrator and Computer), built in 1946 and considered the first of the modern generation of electronic computers, used about 18,000 vacuum tubes. The machine needed a lot of power to run and produced a tremendous amount of heat. (The air conditioning equipment needed to cool ENIAC was enough to cool the Empire State Building.) What's more, ENIAC occupied a great deal of space—occupying over 150 square meters of floor space and standing 2.5 meters tall. Let students measure and calculate how many classrooms would be needed to fill the space taken up by ENIAC.

If students have not yet viewed the video *Transistorized!*, show the first ten minutes including Ira Flatow describing the vacuum tube

and its drawbacks and discussing Mervin Kelly's vision for a solid state amplifier.

Explore

Prepare students for the project by asking: Where can you find transistors? Where are they most common? What's the big deal about transistors anyway? Explain that they will be able to answer these and other questions in this project as they search for transistors all around them.



Evaluate

After teams have discussed and presented their findings, hold a class discussion about the prevalence of transistors in our lives. At a minimum, students should be able to

- list everyday activities that are monitored or controlled by transistors.
- identify appliances and devices that rely on transistors and which greatly affect our quality of life.
- provide evidence to support or refute the claim that the transistor is the most significant invention of the 20th century.



We encourage duplication for educational non-commercial use.

Transistorized! is a co-production of KTCA-TV and ScienCentral, Inc.
To order the video call PBS Learning Media at 1-800-344-3337

These educational materials are made possible by
a grant from The Lucent Technologies Foundation.

Lucent Technologies
Bell Labs Innovations





Transistors in Your Life: A Transistor Hunt

What You're Going To Do

You're going to work in teams to hunt for transistor-based devices at your school. Then you'll use the results of your search to explain why the transistor is so significant.

What You'll Need

- reference materials about transistors and transistor devices including information from the *Transistorized!* web site: www.pbs.org/transistor

How To Do It

- In your team, use reference materials to become familiar with the wide range of devices that use transistors. You might want to make a list of these devices to refer to on your hunt.
- Search the school for electronic devices that use transistors. List the devices. If you find a particular device in more than one place, note each location on your list. If you are not sure if the device relies on transistors, use your reference materials to check. Make a note of any electrical devices you find that do NOT rely on transistors.
- Discuss your list with your team. Make a three-column chart like the one below. In the first column, identify the five devices your team thinks affect you the most. In the second column, tell why each device is important to your life. In the third column, describe how your life would change without each device.
- Compare and contrast your team's chart with the charts of other teams. What devices did they identify that you did not? Which did they find most important that you did not? If necessary, revise your list to show devices you missed or to eliminate devices that do not contain transistors.

What Did You Find Out?

- How did your top-five devices compare to those of your classmates? Which devices were most often identified by the class?
- Explain why the transistor is considered the most significant invention of the 20th century.

5 devices that affect me most	Why it is important in my life	How my life would change without it

Try This!

- Write an essay on the electronic device that most changed your life.
- Research the size of a modern, individual transistor. Find out how such a small object is manufactured and manipulated.
- Hold a "Day Without Transistors." Give up as many electronic devices as possible for one day. Then discuss how your life was different during that 24-hour period.
- How small can a transistor become? Is there a limit? Explore the ongoing research into these questions and report your findings.
- Work in groups to design an electronic device that solves an everyday problem.



We encourage duplication for educational non-commercial use.

Transistorized! is a co-production of KTCA-TV and ScienCentral, Inc. To order the video call PBS Learning Media at 1-800-344-3337

These educational materials are made possible by a grant from The Lucent Technologies Foundation.

Lucent Technologies
Bell Labs Innovations



LESSON 4

Using Transistors:

Let's Get Transistorized!

OVERVIEW

In this lesson, students build two circuits and explore how transistors function.

OBJECTIVES

- To observe how a transistor functions in a simple circuit
- To understand amplification—that a small current at the input of a transistor controls a larger current at its output

Background

When Bell Labs introduced the transistor in June of 1948, a spokesman proudly announced “This cylindrical object . . . can amplify electrical signals. . . . It is composed entirely of cold, solid substances.”

The cold, solid substance that makes the transistor possible is the *semiconductor*, a class of material that includes silicon and germanium. Semiconductors are normally very poor conductors of electricity. But with the addition of tiny amounts of other elements, which provide carriers for electric current, they can become good conductors.

The first transistor, invented in 1947, was the point-contact transistor. William Shockley improved on this design with his junction transistor, a three-layer sandwich of different types of semiconductor.

The diagram illustrates the basic design of an NPN

junction transistor.

Two slices of N-type semiconductor, the *emitter* and the *collector*, form a sandwich with a layer of P-type semiconductor, called the *base*. P- and N-type semiconductors are made with different impurities, and the name indicates the dominant type of charge carrier.

The interface between the layers, called the P-N junction, allows the

transistor to function as either an insulator or a conductor. If the collector and emitter are connected to a battery, the electrical charges at the P-N junctions form an electrical barrier and no current flows between the emitter and the collector. The transistor acts like an insulator or a switch that is turned off.

When a positive voltage is applied to the base, electrons are pulled out of the junctions and they no longer act as barriers. Now electrons can flow from the emitter through the base to the collector. The transistor acts as a conductor, or a switch that's turned on. (If the voltage applied to the base is negative, the transistor turns off again.)

Transistors do not create electric current, they only control electric current supplied to them. The *input* current at the base controls the *output* current flowing between the emitter and the collector. The

transistor can turn on or off if the base current turns on or off. If the base current

varies, so does the output current, which is how a transistor functions as an amplifier. It's similar to the way you control the flow of water with a faucet. With a small hand movement, you can turn the water on or off, or adjust the flow between a trickle and a rushing stream.

Most early commercial transistors were junction transistors and are the type used in the activity on the next

two pages. However, the most common modern transistor, the one that is found by the millions in computer chips, is the metal oxide semiconductor (MOS) field effect transistor. The transistor has evolved since its invention, but the principle of a small current controlling a larger one is the same effect that Bardeen, Brattain, and Shockley first revealed in 1947.

Engage

As explained in *Transistorized!*, the invention of both the transistor and the vacuum tube grew out of the need to amplify weak electric current. Begin by demonstrating a weak current that students can recognize and experience. Connect a circuit using wire, a 9-V battery, an LED, a resistor, and a microammeter to measure current. Have students note what happens when they complete the circuit first by connecting the leads together (relatively large current and the LED lights), and then by holding the leads in their hands (very small current and the LED does not light). **Safety:** The current in this circuit is small enough to perform this activity safely, but caution students not to try this activity with other wires or power sources.

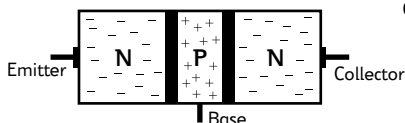
Have students offer their ideas on what an amplifier is and how to amplify a current. Point out that most electronic devices run on a small current that is amplified.

Explore

Have students perform the activity to see how transistors amplify current.

Evaluate

After the activity, discuss students' results and the activity questions.



We encourage duplication for educational non-commercial use.

Transistorized! is a co-production of KTCV-TV and ScienCentral, Inc. To order the video call PBS Learning Media at 1-800-344-3337

These educational materials are made possible by a grant from The Lucent Technologies Foundation.

Lucent Technologies
Bell Labs Innovations





Using Transistors: Let's Get *Transistorized*!

What You're Going To Do

You're going to build two simple transistor circuits, each using a single transistor. These circuits will allow you to observe the operation of a transistor as an amplifier, just as Walter Brattain did at Bell Labs in the winter of 1947. In the first circuit, you'll use the transistor to control the brightness of a light; in the second, the transistor will turn the current flowing through your body into sound!

Part 1: Light Touch

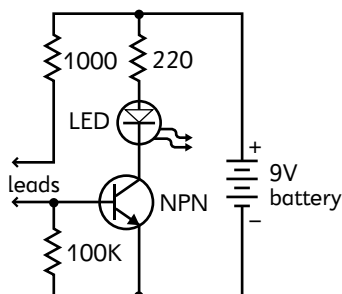
Construct the first circuit using a single transistor, an LED, a power source, and a resistance. The brightness of the LED will indicate the relationship between the current going to the base of the transistor—its input—and the current flowing from the transistor's collector to the emitter—its output.

What You'll Need

- 9-V battery and clip with leads
- breadboard
- hook-up wire
- LED
- 220-ohm resistor
- 100K-ohm resistor
- transistor, 2N2222A (Si type, NPN, Radio Shack part number 276-2009)
- microammeter (0–50 000 μA range)

How To Do It

1. Work in groups of three or four. Assemble the circuit shown in the diagram. Match the leads on the transistor to the diagram, and identify the base, emitter, and collector. Check with your teacher if you are unsure of the connections.
2. Complete the input circuit with the two leads, using each method listed below.
 - gently squeezing the leads
 - tightly squeezing the leads
 - dipping the leads in water
 - increasing the distance between the leads in water



- making a dark line with pencil and touching the leads to it.
- increasing the distance between the leads on the pencil streak

In your lab book, make a table similar to the one shown in which to record the intensity of the light for each method. You might use terms such as *dim*, *average*, and *bright*, or develop a number scale with 1 = very dim and 5 = very bright. (In your table, include a column for sound intensity for Part 2.)

Circuit completed by	Light intensity	Sound intensity
gently squeezing the leads		
tightly squeezing the leads		

3. Draw a copy of the circuit diagram in your lab book. Use arrows to show the direction in which the current flows through the circuit. Remember that current flow is from positive to negative. Label the input circuit and the output circuit of the transistor.
4. Repeat one of the methods that gives a reasonably bright light. Place the microammeter in series with the input leads and record the reading. Then move the microammeter so that it is in series with the LED and record that reading.

FYI

The P and N in transistor nomenclature indicate the type of charge carriers that exist in the materials that form the transistor. In an N-type material, the carriers are negatively charged electrons, and in P-type material the carriers are positively charged. These are places where electrons could exist and are called *holes*.

What Did You Find Out?

1. Which methods allowed the light to glow the brightest? the dimmest?
2. Which methods allowed the most current to pass through them? the least? How do you know?
3. How good an amplifier was your circuit? How much larger was the output current than the input current? Where did the “additional” current come from?



We encourage duplication for educational non-commercial use.

Transistorized! is a co-production of KTCA-TV and ScienCentral, Inc. To order the video call PBS Learning Media at 1-800-344-3337

These educational materials are made possible by a grant from The Lucent Technologies Foundation.

Lucent Technologies
Bell Labs Innovations



Using Transistors: Let's Get *Transistorized!*, continued

Part 2: The Human Sound Machine

Now, you'll modify your circuit by adding new parts. The transistor is very responsive to changes in its input. The input current can fluctuate thousands—even millions—of times per second, and the output current will respond accordingly. The additions to the circuit will produce an oscillating current, varying several thousand times per second, at the transistor's input. You'll hear the resulting output through the speaker.

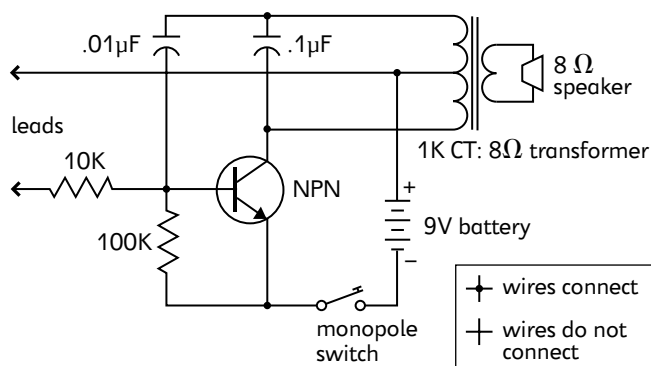
What You'll Need

(in addition to Part 1 materials)

- wire
- 10K-ohm resistor
- 100K-ohm resistor
- switch
- capacitors (0.1 microfarad and 0.01 microfarad)
- 1K CT: 8-ohm transformer
- 8 ohm speaker

How To Do It

1. Assemble the circuit shown in the diagram. You may choose to solder or use common IC Experimenter boards.



2. Complete the circuit with the leads using each method listed in Part 1. Record the intensity of the sound for each method. You might use terms such as *hum*, *squawk*, and *squeal*, or develop a number scale with 1 = very low and 5 = very loud.
3. Draw a copy of the circuit diagram in your lab book. Use arrows to show the direction in which

the current flows through the circuit. Label the input circuit and the output circuit of the transistor.

FYI

The MOS transistor—the modern transistor used in computer chips—is similar in operation to the one that Shockley first proposed. It consists of a semiconductor through which current can flow, and an electrode that is insulated from this semiconductor. The voltage applied between the insulated electrode and the semiconductor controls the current through the semiconductor. The principle is similar to water flowing through a piece of flexible tubing. When the tubing is squeezed, the flow of water is decreased. Squeeze hard enough, and the flow stops. In the MOS transistor, the voltage applied to the control electrode is what does the squeezing.

What Did You Find Out?

1. Which methods produced the loudest sounds? the softest?
2. Which methods allowed the most current to pass through them? the least? How do you know?
3. Discuss with your group the advantages you think transistor switches might have over mechanical switches. What quality of transistors—high reliability, small current amplification, or instant response—do you feel is the most important for transistors used in computers? in medical equipment such as pacemakers? in guided missiles?

Try This!

- ▶ Use your circuit to test how well other methods and materials conduct electricity.
- ▶ If possible, attach an oscilloscope to your circuit and analyze the waves you are hearing.
- ▶ Using Ohm's Law, $I = V/R$, calculate the currents in the first circuit.
- ▶ Reverse the polarity of the battery and repeat each activity. What happens?



We encourage duplication for educational non-commercial use.

Transistorized! is a co-production of KTCA-TV and ScienCentral, Inc. To order the video call PBS Learning Media at 1-800-344-3337

These educational materials are made possible by a grant from The Lucent Technologies Foundation.

Lucent Technologies
Bell Labs Innovations



PROFILES OF SCIENTISTS

Every day at Lucent Technologies, scientists are researching, inventing, and developing innovative technologies that are changing our world. Through their passion, excitement, curiosity and persistence, they pave the way for a future generation of scientists.



PHILIP J. MUÑIZ

Bell Labs

Engineering Research Center

Philip Muñiz works in the RF (radio frequency) / High Speed Design and Manufacturing group helping to design technologies that will improve communications access around the world.

I wake up excited to go to work every day—I love my job and I love interacting and working with other people.

To me, good scientists or engineers are people who have a deep curiosity about the world around them, and an interest in improving the world and how we interact with that world. I believe wireless communication can provide such benefits as a quicker response worldwide to tragedies like earthquakes.

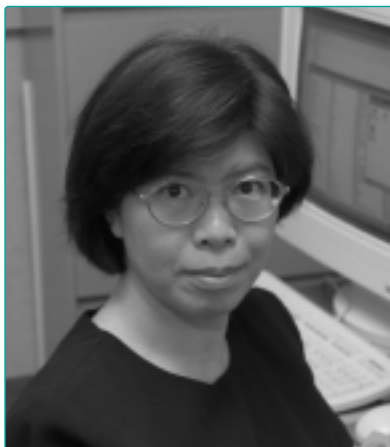
While I've always been curious about how things work, I didn't always know what I wanted to do. Life is a series of figuring out what you don't like to do.

Right out of high school, I spent four years in the army, worked as a carpenter's apprentice, and worked in an office delivering mail and running errands. When the company I was working with at the time offered me training in computers, I took it. That's where I learned I had an interest in computers.

Ten years out of high school, I decided to go back to school full-time to earn a degree in computer science with an electrical engineering minor, and later I earned my graduate degree in Engineering Science while working full-time. That wasn't easy, but I did it!

You should remember that the door doesn't always open all the way. You need to be flexible and willing to look at opportunities in lots of different ways. My opportunity to work as a permanent employee at Lucent didn't come for 3 years. I proved myself as a contractor and subsequently, they hired me.

I've worked at Bell Labs for 12 years now, and I get paid to play!



CHILIN SHIH

Bell Labs

Language Modeling Research Department

Chilin Shih works on the multilingual text-to-speech systems. These systems translate the complexities of written language into speech. Some of the languages Shih has worked on include Mandarin, Spanish, Italian, Japanese, Romanian, Russian, Navajo, Greek, and Hindi. Check out the Bell Labs website for all the languages currently available, and to experience for yourself how it works: <http://www.bell-labs.com/project/tts/>

I really like that I'm working on something that is not abstract, that actually talks and that people are using and enjoying. The text-to-speech systems can help teach languages, read to the blind, be the voice for those who have lost theirs, and operate as a messaging system. It has a direct link to this society and gives back to it.

In order to make text-to-speech actually recreate speech, you must understand the properties of speech from every perspective: physics, psychology, linguistics, math and statistics, engineering, computer science, and algorithms.

You collaborate with experts in all different fields, and, over the years, you become a semi-expert in everything. I am constantly learning.

It is important that you have a broad-based training because you never know what you are going to do in your life. I wanted to write novels, majored in literature in college, and got a graduate degree in linguistics. There is no education that is useless. Every background I have gives me a unique perspective in looking at the problem I am trying to solve.

Never let what you don't have put you down. You can always look at things positively and negatively. Think of what you have and build on it. What you don't have doesn't matter because you can still learn it now. Every day is a learning opportunity.



We encourage duplication for educational non-commercial use.

Transistorized! is a co-production of KTCA-TV and ScienCentral, Inc.
To order the video call PBS Learning Media at 1-800-344-3337

These educational materials are made possible by
a grant from The Lucent Technologies Foundation.

Lucent Technologies
Bell Labs Innovations





JOHN ROGERS

Bell Labs

Condensed Matter Physics Research

John Rogers researches and develops new microfabrication and patterning techniques. The rubber stamp he's helped develop can imprint features on a variety of surfaces and materials that cannot be processed with conventional methods. This breakthrough innovation may lead to novel applications in the communications realm and plastic transistors with features as small as those in their silicon counterparts.

I love discovering how something works, how to make it work better, and how to make things that are new and people haven't thought of before. I work with a variety of materials, many of them so small that you can't see them through even the most powerful optical microscopes. The systems, objects, and apparatus that I work with in the lab are all interesting at a very basic level, and they can grab the attention even of non-scientists — high power, multi-colored pulsed lasers, fine strands of glass wrapped tightly with microscopic silver and gold microcoils, rubber diffraction gratings, and glowing polymer films.

I am also fortunate to work with people who are experts in just about any field of science or technology you could imagine. Science is incremental and collaborative—everybody's work relies on others' past work. Bell Labs provides a great environment for collaboration and flexibility. There are a million things to do here.

I feel like I always knew that I wanted to be a scientist. My dad has a Ph.D. in physics and my mom is a poet who writes about nature and science, so I was exposed early on to thinking about the aesthetic side of science as well as to a more rigorous approach to what happens around us. In my work, I'm surrounded by visually stunning and beautiful objects, while learning to understand them, how to make them, and how to manipulate them. It's the beauty of science that draws you in and the depth of understanding that keeps you there.



YVES DARYL JEAN, GOPAL PINGALI, AGATA OPALACH

Bell Labs

Visual Communications Research Dept.

Yves Daryl Jean: Specializes in 3D computer graphics rendering and visualization.

Gopal Pingali: Specializes in image and video analysis, integrated audio-visual processing and multimedia computing.

Agata Opalach: Specializes in the extraction, visualization, and quantitative analysis of three-dimensional data.

This team of scientists created LucentVision™, the first real-time visual information system for sports broadcast. The system uses computer vision techniques to track the position, direction, and speed of movement of players and the ball. Multiple cameras attached to a computer are used to determine player and ball motion. The information stored by the computer is analyzed and presented to viewers as virtual reality replays and color-coded charts using 3D computer graphics and animation techniques. You can see how they chart the tennis game at www.atptour.com.

One of the most exciting things about this project is being able to apply our research to a live event in the real world and then broadcast that back for an audience to understand aspects of the game in an easier, quicker, and more compact way. People, from coaches to broadcasters, are using this technology to help analyze players' game strategies.

An interesting aspect of this project has been meeting another world — the sports world. It's exciting that we have to learn about their world—how they work, their lingo, etc.—and they have to learn about ours. A big part of science is explaining what you have so that others can understand its potential value and build upon it. We had to sell this idea to the Lucent corporate people as well as to the ATP tennis group. We probably wouldn't be doing this now if we weren't good at communicating our ideas.

Only a team of people could pull off something as big and complex as what we are doing. Each member has his or her own specialty and his or her own contribution, yet we all learn from one another.

The fact that we have different personalities and different backgrounds makes it a more enjoyable and rich situation. But, what bonds us together is working toward a common goal and producing something that is very interesting. When you work with people who are extremely competent and whom you trust and who share your vision, it seems like you can do almost anything!

For information about career opportunities at Lucent Technologies, visit <http://www.lucent.com>.

For more information about Bell Labs innovations visit <http://www.bell-labs.com>



We encourage duplication for educational non-commercial use.

Transistorized! is a co-production of KTCA-TV and ScienCentral, Inc.
To order the video call PBS Learning Media at 1-800-344-3337

These educational materials are made possible by
a grant from The Lucent Technologies Foundation.

Lucent Technologies
Bell Labs Innovations



CREDITS

Educational Materials Production Team

Richard Hudson – Executive Editor
Cori Paulet – Project Specialist
Norbert Een – Production Manager

Editorial/Production Management

Navta Associates, Inc.
Jeanne Grogan
Bob Mudd
Glen Phelan

Lesson Writers

Ernestine Giesecke
Gary Harris
William J. Weber

Content Consultants

Michael Riordan
Lillian Hoddeson
Dr. James Mallmann, Professor of
Physics, Milwaukee School of
Engineering

Designers

Art Director for Poster – Bart Tourville
Cover and Poster Design – Alec Syme
Guide Design/Production – Carrie
Schuler, Navta Associates, Inc.

Show Credits

Produced by

Gino Del Guercio
Boston Science Communications

Host

Ira Flatow

Directed by

Gary Glassman

Written by

Gino Del Guercio
Ira Flatow

Cast in order of appearance

Reporter	Paul Horn
Bown	Elliot Cohan
Shockley	Gary Henoeh
Brattain	David G. Bouvier
Bardeen	Richard O'Rourke

History and Technology Consultants

Lillian Hoddeson
Michael Riordan

Advisory Board

Julia Phillips
James Trefil
Glenn Zorpette

Production Manager

Norbert Een

Off Line Editor

Tom Lynn

On Line Editor

Steven Flynn

Principal Videographer

Jim Kron

Audio Design

Mitch Griffin

Graphic Design

Denise Fick

Original Music

Michael Bard
Newton Bard Studios

Animation

Sean Maynard

Scheduling Coordinator

Ann Morris-Tucker

Associate Producers

Amy L. Retzinger
Megan Mylan
Melanie Kron
Susan Katz

Production Assistants

Amy Dobson
Isaac Lodico
Hema Shah

Location Set Designer

Catha Sideman

Transistor Replica

Kevin Aylesworth

Adapted from the book *Crystal Fire: The
Invention of the Transistor and Birth of
the Information Age* by Michael Riordan
and Lillian Hoddeson

Project Partners:

Materials Research Society
The David and Lucile Packard
Foundation
The Lucent Foundation
American Institute of Physics

Special Thanks to Individuals:

Gene Anderson
James Anderson
Jim Bardeen
William Bardeen
Bob Brattain
Walter Brown
Pat Colquette
Mike Cross
Peder Estrup
Phil Foy
John Goleney
Michael Geselowitz
Jerry Gordon
Sheldon Hochheiser
Nick Holonyak, Jr.
George Indig
George Kaczowka
Bud Krueger
Chris Langhart
Ian Mackintosh
Milt Margolis
Tom Pickett
Ian Ross
Truman Schwartz
Stephen Segaller

Eliot Sivovitch
Arthur Torsiglieri

Special Thanks to Institutions:

Alfa Aesar, Inc.
AT&T Archives
Alexander Graham Bell Association for
the Deaf
Brown University
Fairchild Semiconductor
Historical Electronics Museum
J. F. Ptak Science Bookstore
Liberty Photo Service
Pavek Museum of Broadcasting
Providence Biltmore Hotel
Stanford University
US Naval Research Laboratory
University of Illinois
Whitman College

Executive Producers:

for ScienCentral
Ira Flatow
Eliene Augenbraun
for KTCA
Richard Hudson

Vice President, National Productions

Gerald Richman

Lucent Technologies
Bell Labs Innovations



These educational materials are made
possible by a grant from The Lucent
Foundation.

Lucent Technologies, headquartered in Murray Hill,
N.J., designs, builds, and delivers a wide range of
public and private networks, communications
systems and software, data networking systems,
business telephone systems, and microelectronics
components. Bell Labs is the research and
development arm for the company. For more
information on Lucent Technologies, visit its web
site at <http://www.lucent.com>.



The PBS documentary *Transistorized!* is a co-production
of KTCA TV and ScienCentral, Inc., and is made possible
by a grant from the Alfred P. Sloan Foundation.

Companion web site, www.pbs.org/transistor,
produced by ScienCentral, Inc. in association with the
American Institute of Physics, www.aip.org, and made
possible by a grant from The David and Lucile Packard
Foundation.

To order a copy of the *Transistorized!*
video, please call PBS Learning Media at
1-800-344-3337



We encourage duplication for educational non-commercial use.

Transistorized! is a co-production of KTCA-TV and ScienCentral, Inc.
To order the video call PBS Learning Media at 1-800-344-3337

These educational materials are made possible by
a grant from The Lucent Technologies Foundation.

Lucent Technologies
Bell Labs Innovations

