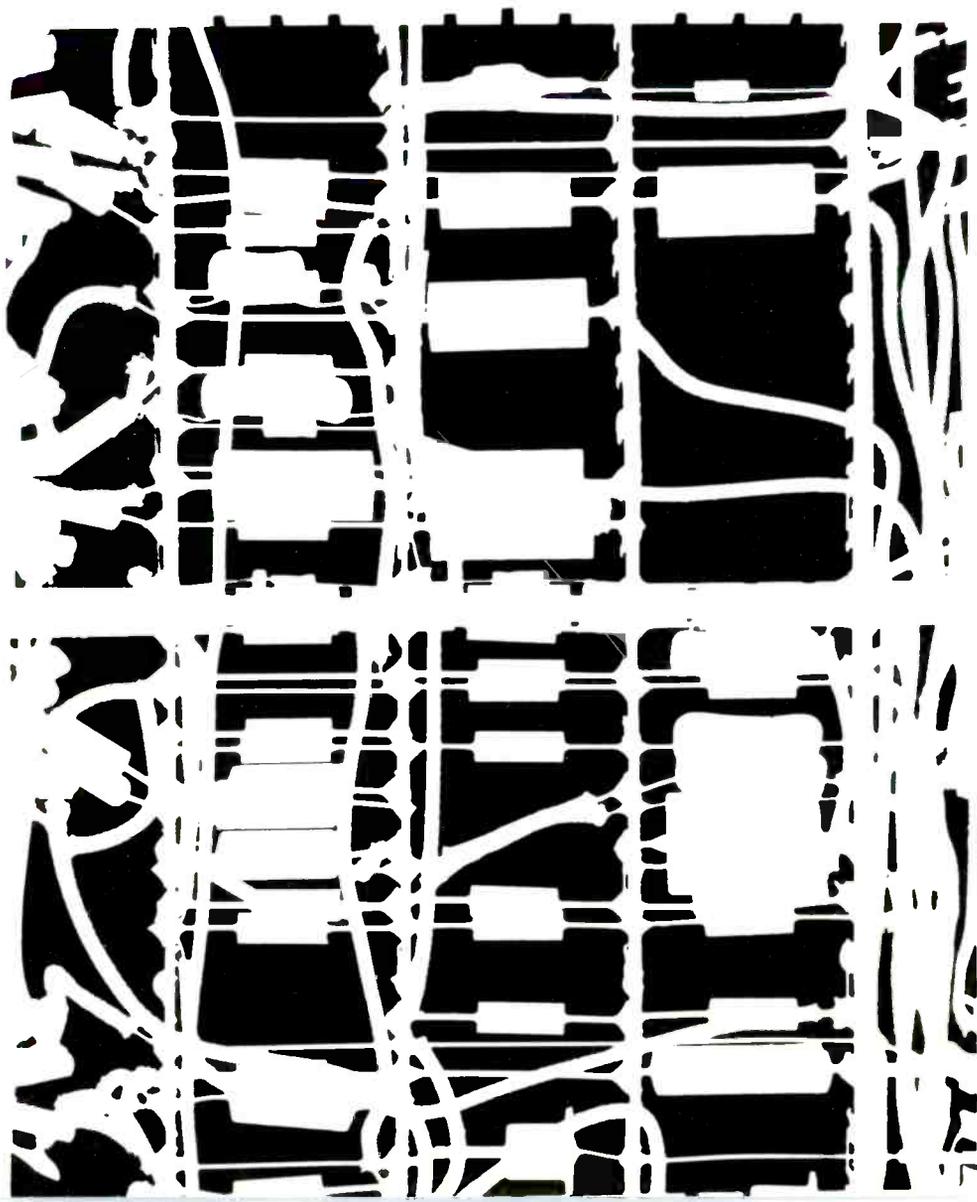


The Boys' Fourth Book of Radio and Electronics

Alfred Morgan



The Boys' Fourth Book of Radio and Electronics

by Alfred Morgan

With illustrations by the author

In this fourth volume of his popular series, Alfred Morgan introduces radio and electronics enthusiasts to the technological miracles of solid state physics, semiconductors, and transistors. In addition to explaining the background and practical applications of these relatively new discoveries, Mr. Morgan presents detailed instructions for constructing solar-powered radio receivers, a galvanometer, a solar powerhouse, a transistor motor, a photoelectric burglar alarm, an automatic light switch, an electronic slavey, a rectifier for recharging storage batteries, and code-practice oscillators. All of these can be built at home and suppliers of the necessary materials are cited.

(CONTINUED ON BACK FLAP)



This book meets textbook specifications. It is Smyth sewn with concealed muslin reinforcement. The sturdy pyroxylin-impregnated cloth over hard-rolled binders board is washable, damp proof, and soil resistant.



(CONTINUED FROM FRONT FLAP)

Also included are a glossary of technical terms and descriptions of the more common semiconductor components used in electronics. There is a special chapter for those interested in becoming amateur radio operators.

Drawing on a lifetime of research and writing, Alfred Morgan has produced another useful and informative book for those interested in radio and electronics.

About the Author

A pioneer in the development of radio telegraphy, Alfred Morgan studied at the Massachusetts Institute of Technology. He collaborated on the development and production of the first shortwave regenerative receivers and was for many years a radio manufacturer.

Mr. Morgan has a rare ability to present scientific material in an interesting and easily understandable way for young readers. His first books were published while his own sons were growing up and his home was practically a workshop, and a proving ground for his ideas—with his sons taking an enthusiastic part in it all.

JACKET DESIGN BY DONALD CREWS

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A more advanced book designed to bridge the gap between elementary radio books and radio magazines.

The Boys' Fourth Book of Radio and Electronics

The Boys' Fourth Book of Radio and Electronics

AN INTRODUCTION TO SOLID STATE PHYSICS,
SEMICONDUCTORS, AND TRANSISTORS

by ALFRED MORGAN

With illustrations by the author

Charles Scribner's Sons New York

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ALTON, ILLINOIS

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The Boys' Fourth Book of Radio and Electronics

CHAPTER 1

INTRODUCTION TO SOLID STATE PHYSICS, TRANSISTORS, AND THE SUBSTANCES CALLED SEMICONDUCTORS • *The Cardiac Implantable Pacemaker. Electronic Computers.*

Here are plans and instructions for building several interesting electronic devices. They are not only useful, entertaining, and instructive but are also excellent science fair projects in the field known as SOLID STATE PHYSICS. Physics is the science that deals with mechanics, electricity, heat, light, and sound, and the branches of science devoted to radiation, cosmic rays, x-rays, gamma rays, and atomic structures. Solid state physics is the branch of physics that deals with SEMICONDUCTORS.

The term SOLID STATE indicates that the essential matter used in the construction of these devices is a solid as opposed to liquid or gaseous matter or to the near-perfect vacuum found in some thermionic tubes. All the apparatus and demonstrations described in this book use one or more of the solid state materials called semiconductors. The term semiconductor is a relatively new word in electronics. It is used frequently in this book and it is well to understand its meaning right at the start.

An Explanation of Semiconductor

An explanation of SEMICONDUCTOR requires the use of other technical terms: electricity, electron, proton, electric current, conductor, electrolyte, insulator, and resistance.

All electronic equipment utilizes ELECTRICITY in some

manner. The exact nature of electricity is not known, but present-day scientific belief is that electricity consists of tiny, invisible, elementary particles called **ELECTRONS** and **PROTONS**. Electrons and protons are constituents of all atoms. Protons exhibit a positive charge of electricity and electrons bear a negative charge. A **MOVING ELECTRON** is an **ELECTRIC CURRENT** and is one of several forms of energy. Billions of moving electrons are required to produce an electric current that has sufficient energy to do useful work.

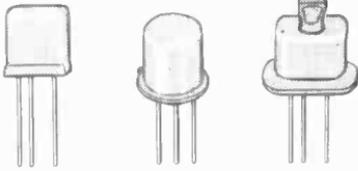
For electrons to move and thus become an electric current, they must have a suitable pathway. Electric currents cannot flow through all substances, but they pass easily through some called **CONDUCTORS**. The metals and certain liquids called **ELECTROLYTES** are **CONDUCTORS**. Electrons do not pass through materials called **INSULATORS** and **NONCONDUCTORS**. Among these are glass, porcelain, mica, and polystyrene. Between the insulators and the conductors are materials that offer great resistance and therefore conduct an electric current poorly. They are called **PARTIAL CONDUCTORS**.

Among the partial conductors, several of special interest to physicists and engineers are those that, when properly prepared in an impure form, are termed **SEMICONDUCTORS**. There are many semiconductors, but germanium, silicon, boron, gallium, indium, selenium, and cadmium sulfide are the most useful. None are quite so useful as germanium and silicon. They are the basic materials of the important semiconductor devices called **TRANSISTORS** and of the semiconductor type of **DIODE**. A diode is a two-electrode device.

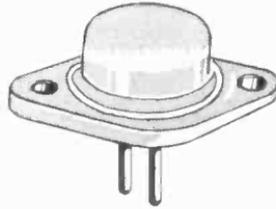
A transistor is a three-electrode semiconductor device. Extensive research in the field of solid state physics by scientists of the Bell Telephone Laboratories produced one of the great achievements of 20th century electronics—the **TRANSISTOR**. It can perform all the functions of a three-electrode vacuum tube for some purposes and has several advantages over the tube. It is much smaller in size, weighs less, has

greater durability, and requires less current to operate.

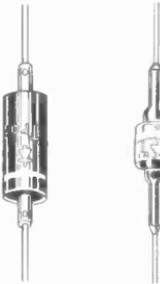
A transistor (the name was coined from TRANSFER and RESISTOR) is a current controller. It can be a rectifier that changes alternating current into direct current. (As a recti-



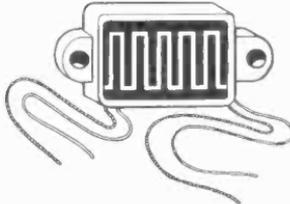
SMALL TRANSISTORS



POWER TRANSISTOR



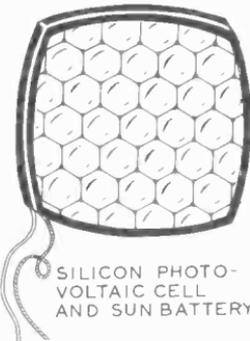
DIODES



CADMIUM-SULFIDE
PHOTOCELL



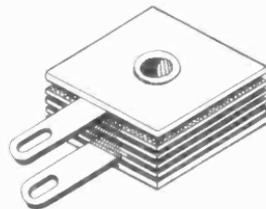
SELENIUM PHOTO-
VOLTAIC CELL



SILICON PHOTO-
VOLTAIC CELL
AND SUN BATTERY



STUD-MOUNT
SILICON
RECTIFIER



SMALL SELENIUM
RECTIFIER

SOME WIDELY USED ELECTRONIC DEVICES THAT UTILIZE SEMICONDUCTOR MATERIALS IN THEIR CONSTRUCTION
(Consult the glossary and index for descriptions and explanations of these components of electronic circuits.)

fier it can act as a detector of radio signals.) It can also be an amplifier, a switch, and an oscillator that can generate either audio- or high-frequency alternating currents. Transistors will give more than 100,000 hours of service under proper conditions and are capable of withstanding physical shocks hundreds of times greater than the force of gravity.

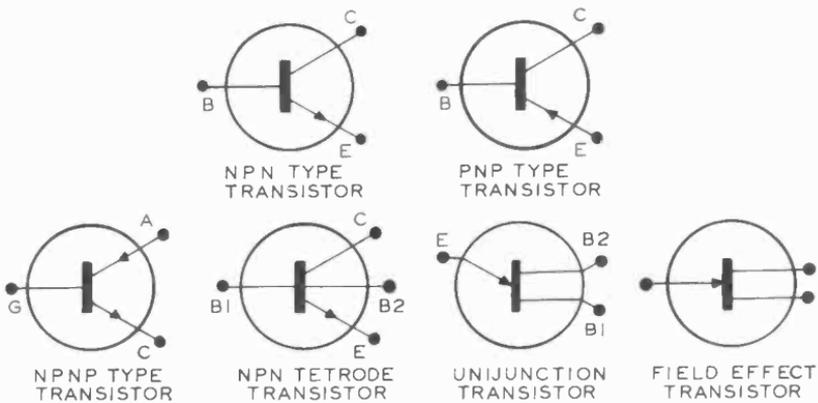
Since its invention in 1948, the transistor has become increasingly important in many industries, and in the personal lives of many people as well. Automatic telephone exchanges, digital computers, satellites, and industrial and military control systems use transistors by the thousands in each installation. A modern satellite may contain as many as 3,500 diodes and 2,500 transistors as part of its complex control and communication systems.

An example of the possible personal value of the transistor to some individuals is the small two-transistor pulser known as a **PACEMAKER**. When connected to ailing hearts, pacemakers have kept thousands of cardiac patients alive and helped them to live nearly normal lives. This wonderful instrument will be discussed in more detail later in this chapter.

The compactness and ruggedness of transistorized equipment opened an entirely new field in the design and construction of portable electronic equipment. Portable apparatus for commercial, military, and private use, such as meteorological instruments, Walkie-Talkies, tape recorders, testing instruments, radio and television transmitters and receivers, automobile radio receivers, radio telephones, and ship-to-shore radios, now often use transistors to replace much bulkier and comparatively inefficient radio vacuum tubes. It should not be assumed, however, that transistors will entirely replace radio vacuum tubes. Transistors have some inherent disadvantages. Among these are unreliability over a wide temperature range and sensitivity to nuclear radiation.

The knowledge and skills of physicists, metallurgists,

chemists, mechanical engineers, electronic engineers, and statisticians are required to build transistors. Since 1948 several varieties of transistor have been developed. The names and symbols for some of these are shown. Numerous types are commercially available, but only two are of interest and use to the young experimenter who may build the apparatus described in this book. They are the NPN and PNP junction types. The meaning of the initials NPN and PNP and of the term "junction type" will be explained later.



Diagrams, called symbols, that represent six of the several varieties of transistor.

The technology of a transistor is based upon the use of a material whose resistance to the flow of an electric current is somewhere between that of a good conductor and that of an insulator, or in other words, a SEMICONDUCTOR. The two semiconductors most used for the manufacture of transistors are the elements germanium and silicon that have first been highly purified and then had a small, carefully measured amount of another element, called an "impurity," or "dope," added. Most transistors are made of refined germanium that has been purified to the extent that only one part in one

billion is an impurity of any sort. A desired impurity is then added to the germanium in the range of 0.5 to 8.0 parts per 100 million parts of germanium. Silicon is used in the manufacture of some transistors, but it is more often used in the construction of diodes and rectifiers.

If a crystal of pure germanium is part of an electric circuit, some current will flow through it, but the volume of current will be extremely small in comparison with the amount of current that would flow (under the same circumstances) through any material classed as a conductor.

The carefully controlled amount of impurity or dope added to germanium prepared for use in the manufacture of transistors increases the conductivity of the germanium, allowing MORE current to flow through it. The impurity used for this purpose is always one of the following elements: indium, arsenic, aluminum, gallium, boron, or phosphorus. The impurities must be added in carefully controlled amounts, otherwise the germanium crystal structure will be so modified that the desired transistor action will not be obtained.

When arsenic or antimony is added to pure germanium, a diamond-shaped crystal structure containing FREE electrons is formed. Electrons are very small, invisible particles that are a part of all matter. They are associated with the elementary charge of NEGATIVE electricity. Free electrons can be moved easily. Germanium crystals containing free electrons are an N-type semiconductor for making transistors, the N signifying NEGATIVE. An electric current can flow through N-type germanium.

When a small amount of indium, aluminum, or gallium is added to pure germanium, a diamond-shaped crystal structure with a DEFICIENCY of electrons is formed. The deficient spot, where an electron is lacking, is called a HOLE. Each hole has a POSITIVE electrical charge and tends to move about in the crystal structure seeking to gain an electron. In its effect, a hole can be considered a free, POSITIVELY charged particle

moving about in the same manner as an electron does in N-type germanium. Germanium crystals containing holes are a P-type semiconductor for making transistors. The P means POSITIVE. An electric current can flow through P-type germanium.

Junction-type Transistors

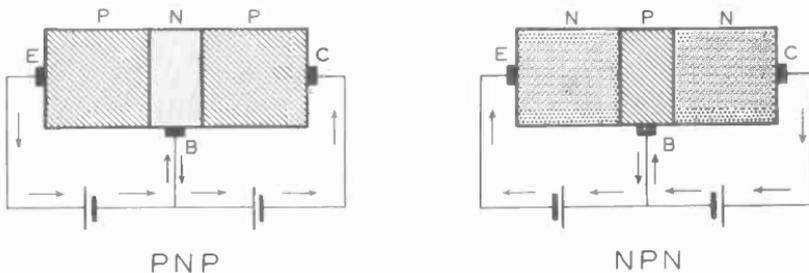
The transistors specified for the projects in this book are the variety called JUNCTION transistors. A junction-type transistor is built like a sandwich. An inner layer of semiconductor material, corresponding to the meat, is enclosed between two outer layers of a different semiconductor material, like the bread in a sandwich. Only tiny pellets or thin wafers of doped germanium are used. Terminal wires are welded to the two outer layers and to the inner layer. The terminals are identified as the EMITTER, BASE, and COLLECTOR.

The Meaning of PNP and NPN

There are two kinds of junction transistors. The PNP type consists of a thin wafer of N (negative)-type germanium between two layers of P (positive)-type germanium.

The NPN junction transistor is a thin wafer of P-type germanium between two layers of N-type germanium.

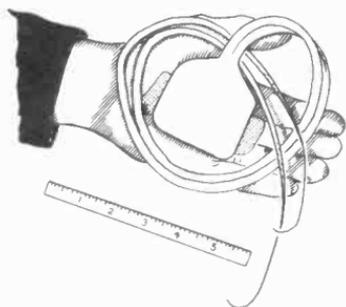
A diagram of each type is shown.



The arrangement of the semiconductor materials in the PNP and NPN junction transistors.

*The Cardiac Implantable Pacemaker:
A Transistor Circuit that Saves Lives*

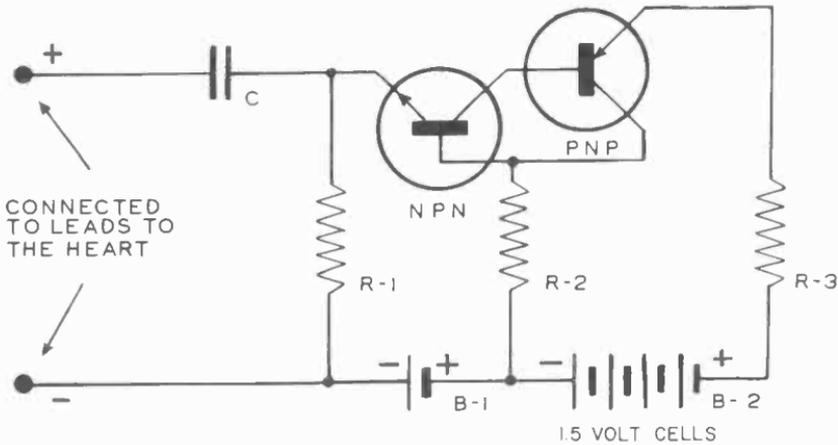
It is reliably estimated that approximately 10,000 men and women in the United States afflicted with a serious heart ailment known as heart block have had their heartbeats restored to normal by a tiny, two-transistor electric pulse generator called a cardiac pacemaker. This development is an interesting and valuable application of the type of circuit known as a transistor pulse circuit. The medical and technical facts presented here are from reprints of articles published in medical journals and furnished through the courtesy of the General Electric Company, Milwaukee, Wis., and the Electrodyne Company, Norwood, Mass. Both firms manufacture cardiac pacemakers and have done much research and development in that field.



A CARDIAC IMPLANTABLE PACEMAKER
The drawing shows the size of the pacemaker in relation to an average hand.

The beating of the normal human heart is produced by an electrical stimulus. This originates in a bundle of tissue at the top of the heart and is sent down a conductive muscular tissue called the bundle of His (pronounced hiss) to the lower tip of the heart. The electrical nerve impulses occur normally at the rate of 72 per minute. They cause the heart muscles to contract at the same rate and to pump blood out of the two chambers of the heart called the ventricles and deliver it to the arteries. Loss of ability to conduct electrical

impulses by the bundle of His is the lesion called heart block. A person suffering from heart block has a very slow heartbeat, and sometimes there is complete cessation of the contractions. If utilized in time, a cardiac pacemaker can often prevent this. A cardiac implantable pacemaker consists of two transistors, three resistors, a small capacitor, and five tiny mercury batteries enclosed in a plastic case that can be implanted under the skin of the chest or abdomen. The pacemaker provides a pulse of electric current seventy times a minute. Two short wires carry the electrical impulses to the heart muscle. Thus the pacemaker replaces the natural electrical nerve impulses that have failed.



The circuit of the cardiac pacemaker, showing conventional schematic symbols that represent two transistors, three resistors, a capacitor, and five small mercury batteries.

The latest design of pacemaker stimulates the heart to beat only when the pace of the natural impulses fails. If the natural pace is too slow, the cardiac pacemaker turns itself on automatically and increases the pulse rate. If the pace

becomes too rapid, the pacemaker turns itself off until it is needed again.

Electronic Computers

A great many problems in engineering, science, business, industry and in military and government operations are completely beyond the powers of human beings to solve without the aid of machines known as electronic computers.

The first computing machine was a device used in ancient Greece and Rome known as an *ABACUS*. It was operated by sliding movable beads or counters along parallel rods. It is still widely used today in Japan, China, and other Asian countries. Numbers are represented by the position of the beads on the rods. Problems in arithmetic are solved by changing the position of the beads.

Modern computers are electronic. The fastest modern computer can do more computing work in three minutes than a man could do in a lifetime. There is no theoretical limit to the application of electronic computers in solving problems. Large numbers of electronic components, such as transistors, amplifiers, diodes, and pulse shapers, are needed in the construction of an electronic computer. The demand for reliable electronic components for computers is an important part of the electronics industry.

CHAPTER 2

SELENIUM, THE FIRST SEMICONDUCTOR •

Alexander Graham Bell's Photophone. Description of a Selenium Cell. Electrical Characteristics of Photovoltaic Selenium Cells. How to Demonstrate the Electrical Energy Produced by a Photovoltaic Cell. Galvanoscopes. Oersted's Discovery. How to Make and Use a Galvanometer.

Many of the most useful facts about electronics have been acquired by long, patient, and costly investigation. On the other hand, some have been discovered accidentally. The fact that the element SELENIUM is a conductor of electric current when exposed to light, and is almost an insulator when in darkness, was an accidental discovery made many years ago at an ocean cable station on a Pacific island. A resistor is a device designed to reduce the flow of current in a circuit. Small rods of selenium were used as resistors in the telegraph apparatus at the station. It was necessary to adjust the resistors from time to time in order to keep the current in the cable at proper strength. Finally, one of the telegraph operators noticed that adjustment was always necessary as the sun rose in the morning and again at night when darkness fell. Careful investigation revealed that the adjustments were necessary because the selenium rods CHANGED THEIR RESISTANCE TO THE FLOW OF ELECTRIC CURRENT WHEN THE LIGHT VARIED.

Selenium Is a Chemical Paradox

The name selenium comes from the Greek word for moon.

It belongs to the same family of elements as sulfur and tellurium. Selenium was discovered in 1817 by Jöns Jakob Berzelius, a Swedish scientist who contributed an abundance of chemical knowledge from which the world has gathered great benefit. Berzelius discovered selenium while studying flue dust from the chimneys of the lead chambers of the sulfuric acid works at Gripsholm, Sweden.

The ordinary stable form of selenium is a crystalline, grayish solid with a semimetallic luster. It might be described as a paradoxical substance because it will behave both as a metal and a nonmetal, as a conductor and as an insulator. Besides being crystalline, selenium can be a shapeless, amorphous mass; or it can be a red powder. When combined with some substances, selenium adds color. In some combinations it removes color. It is also highly poisonous.

About 25 minerals contain a small amount of selenium, but none of them is considered an important commercial source of the element. The principal commercial source of selenium at present is the slime or mud that forms in the tanks used in the electrolytic refining of copper. It is one of the few strategic materials that remain in short supply.

A few years ago the principal commercial uses for selenium were to color glass red for automobile taillights and traffic lights, to act as a catalyst in the production of gasoline, to increase the wearing properties of rubber, to decolorize glass, and to manufacture insecticides for combating red spiders in vineyards and citrus fruit orchards. In other words, its principal uses were in chemical processes. Today, most of the commercial selenium available is used in the electrical and electronics industries. Three properties of selenium make it of great importance in these fields.

1. A thin layer of crystallized selenium will conduct an electric current better in one direction than in the other. This fact has been known since 1884, but it was not extensively utilized until about 1930 when German and American

investigators designed improved, dry-plate, selenium RECTIFIERS.

Rectifiers. (Silicon is also used in the construction of these devices.) Rectifiers change alternating current to direct current. They are extensively used in electroplating and welding; in producing battery chargers, magnet coils, arc lamps; in the operation of direct-current motors; and in radio, television, and other electronic circuits.

2. Another unusual property of selenium has already been mentioned. This is the fact that selenium possesses moderate resistance to an electric current that decreases markedly when the selenium is exposed to light. The change in resistance is proportional to the intensity of illumination. When the light is withdrawn, the resistance of the selenium increases to its original value. The resistance of selenium in darkness may be anywhere from 5 to 200 times its resistance when exposed to light. The cause of this phenomenon is unknown, but it is utilized to make selenium PHOTOCELLS. The uses for photocells steadily increase.

3. The third important electrical property of selenium is its ability to act as a TRANSDUCER and convert light energy directly into an electric current. The word transducer means CONVERTER OF ENERGY. Familiar transducers are the telephone transmitter and receiver, the loudspeaker, and the modern phonograph pickup.

The First Selenium Cell

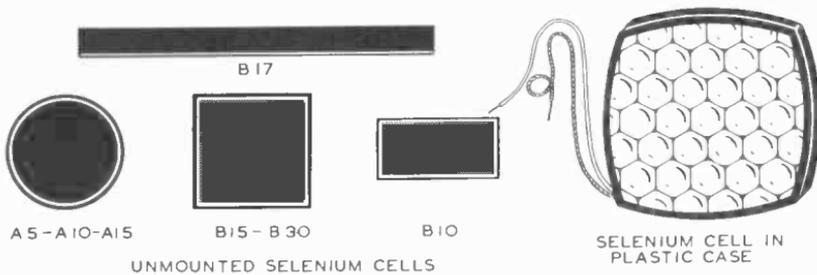
Alexander Graham Bell, the ingenious inventor of the telephone, was the first to utilize selenium's ability to act as a transducer and to make the tiny device called a selenium cell. (It was actually the first useful photoelectric cell, or as it is popularly known, ELECTRIC EYE.) In 1878 Bell and an assistant named Sumner Tainter constructed a PHOTO-

PHONE using a selenium cell. With the photophone they transmitted speech over a beam of light. In the first experiments the sun was the source of light. Later the light from an arc-lamp was used. In 1880 the transmitter was placed on the tower of Franklin College in Washington, D. C., about 700 feet from the receiver in Bell's laboratory window at 1325 L Street and clear speech was transmitted by a light beam over this distance. The light was reflected from a small mirror attached to a diaphragm on the small end of a megaphone. Words spoken into the megaphone caused the mirror to vibrate and produce variations in the light beam reflected from the mirror. One of Bell's selenium cells was connected to a battery and a telephone receiver and placed where it would intercept the light beam. The variations in light produced fluctuations in the current flowing through the selenium cell and telephone receiver. The fluctuating currents in the telephone receiver produced sound waves that repeated the words spoken into the megaphone at the transmitter.

The distance over which Bell's photophone could transmit and receive messages by a light beam was limited to several hundred feet and the instrument had scarcely any practical use. But today, nearly one hundred years later, scientists in the Bell Laboratories are hoping eventually to use light waves like radio waves, as a communications medium. With the device called a MASER, an abbreviated way of saying Microwave Amplification by Stimulated Emission of Radiation, the possibilities are tremendous. A single beam of light produced by an optical maser (or laser) has enough capacity to carry all the telephone conversations, TV pictures, and other types of communication now being sent over the Bell System's nationwide communications network. But extensive communication using light waves will require many years of research to accomplish and perfect.

Description of a Selenium Cell

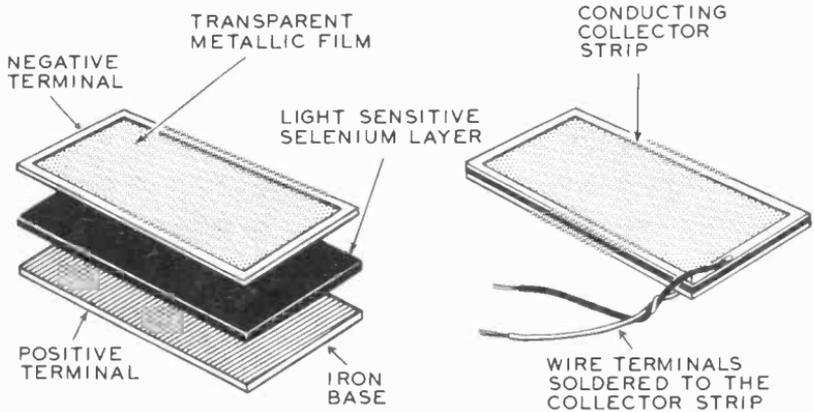
A selenium cell is usually a flat wafer that is square, round, or rectangular. A metal baseplate serves as the positive terminal and may be steel, iron, aluminum, or brass. A thin layer of specially purified selenium is deposited on one side of the base plate. The plate and its selenium coating are then gently heated at 200°C and allowed to cool, thus converting the semi-amorphous selenium into its crystalline allotrope. (Amorphous is a chemist's term which means uncrystallized. An allotrope is one of the forms of an element that can exist in two or more forms. For example, carbon occurs in four allotropic forms: charcoal, lampblack, graphite, and diamond.)



These are the types of cells listed in mail order catalogs. They are readily available to amateur experimenters because of their small cost.

The cooling process is followed by the application of a thin layer of cadmium or cadmium oxide to the surface of the selenium. Next, an ultra-thin layer of gold, so thin that it is transparent, is deposited to increase the conductivity of the sensitive surface. The sensitive surface is blue-brown or brown and has a narrow, silvery collector strip of cadmium alloy applied by a spray process. Flexible lead wires may be soldered to the collector strip, which serves as the negative terminal. The back of the cell is usually coated with

the same silvery cadmium alloy that forms the collector strip. The final step in the manufacture of the cell is the application of a thin coat of a transparent resin to provide a hard protective coating.

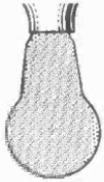


SELENIUM PHOTOVOLTAIC CELL CONSTRUCTION

The selenium photovoltaic cell was the first device to utilize a semiconductor material in its construction. The usual selenium photovoltaic cell consists of a metal plate, one side of which has been coated with a thin layer of selenium. The plate is heated until the selenium crystallizes. A thin film of gold is then sprayed over the surface of the selenium. The gold film is so extremely thin that it is transparent. A narrow silver-colored collector strip of a cadmium alloy is applied to the gold film along the edge. The back of the metal plate bearing the selenium is the positive terminal of the cell. The cadmium collector strip is the negative terminal. The illustration shows an unmounted rectangular selenium cell.

A selenium cell is usually used to convert the light energy falling on its sensitive surface to useful electrical energy. For that reason, it is classified as a PHOTOVOLTAIC cell to distinguish it from a PHOTOCONDUCTIVE cell, which merely changes its resistance under the influence of light.

A selenium cell responds to the same light spectrum as a human eye.



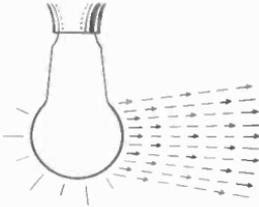
UNLIGHTED LAMP



CELL IN THE DARK HAS VERY GREAT RESISTANCE TO AN ELECTRIC CURRENT



METER INDICATES NO FLOW OF CURRENT



LIGHT FROM INCANDESCENT LAMP LOWERS RESISTANCE OF PHOTOCONDUCTIVE CELL

LIGHT STRIKES CADMIUM SULFIDE PHOTOCONDUCTIVE CELL



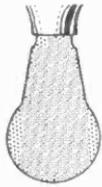
SOURCE OF ELECTRIC CURRENT

METER INDICATES A FLOW OF CURRENT

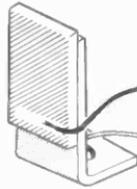
A PHOTOCONDUCTIVE CELL IS NOT A TRANSDUCER

It does not convert light into an electric current. Light causes it to vary its ability to CONDUCT an electric current. A photoconductive cell in the dark has very great resistance to the flow of electric current. Exposure to light lowers this resistance.

The output of a selenium cell can best be demonstrated by connecting the cell to a sensitive meter that measures microvolts or microamperes. (Microvolts are millionths of a volt; microamperes are millionths of an ampere.) The testing and measuring instrument called a volt-ohm milliammeter can measure as little as one milliampere (one-thousandth of an ampere) and has an 0-3-volt scale. It can also be used to measure the voltage output of a selenium cell.



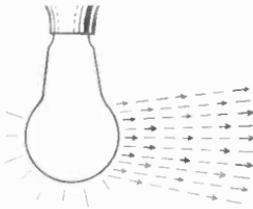
UNLIGHTED
LAMP



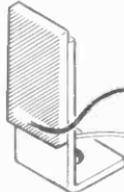
CELL GENERATES NO
CURRENT WHEN IN
THE DARK



METER INDICATES
NO CURRENT

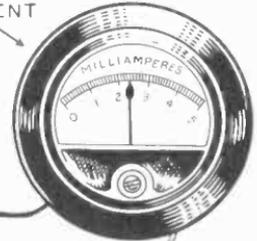


LIGHTED INCAND-
ESCENT LAMP IS
SOURCE OF LIGHT
AND RADIANT
ENERGY



PHOTOVOLTAIC
CELL CONVERTS LIGHT
AND RADIANT ENERGY
INTO ELECTRICAL ENERGY

SENSITIVE METER
MEASURES THE
ELECTRIC CURRENT



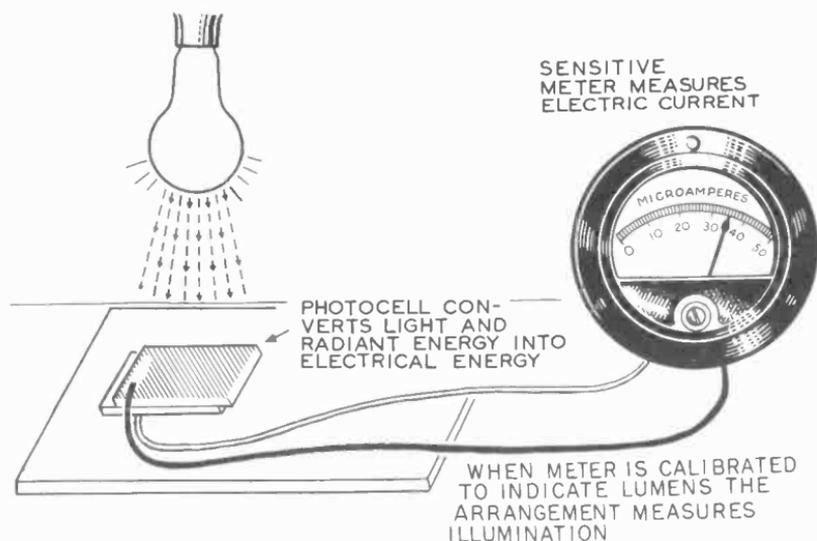
A PHOTOVOLTAIC CELL IS A TRANSDUCER
It converts light energy directly into electric current.

Few young experimenters are fortunate enough to possess sensitive electrical meters, but this handicap can be overcome. Other means can be employed to show that a photovoltaic cell converts light energy into electrical energy.

How to Demonstrate the Electrical Energy Produced by a Photovoltaic Cell

Demonstration with a Telephone Receiver. A telephone receiver is one of the most sensitive electrical instruments. A very small amount of electric current will cause it to pro-

duce sounds audible to human ears. The common type of telephone receiver consists of three essential parts: a pair of small electromagnets, a permanent magnet, and a thin sheet-iron diaphragm. The electromagnets are mounted on the poles of the permanent magnet and are close to the iron diaphragm but do not touch it. The permanent magnet exerts a steady pull on the diaphragm, but the pull of the electromagnets varies with the strength of the current that flows through the human eye. One of the first practical uses for selenium cells was in light meters, which measure illumination and indicate the correct exposure settings for cameras. When light strikes the photovoltaic cell in the meter,



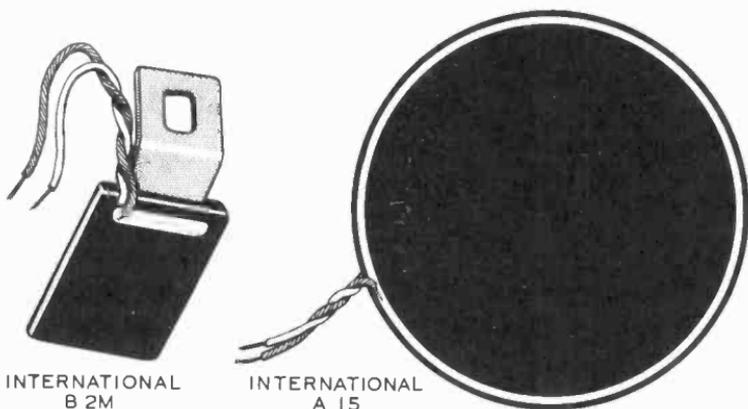
THE PRINCIPLE OF THE LIGHT METER AND EXPOSURE METERS USED TO MEASURE ILLUMINATION

The first extensive use for selenium photovoltaic cells was in meters for measuring illumination. This useful device (the photographer's exposure meter is one form) consists of a selenium photovoltaic cell connected to a microammeter (measures millionths of an ampere). The scale on a light meter is calibrated to read in lumens. (A lumen is a unit of light.)

the electric current that is generated flows through a sensitive microammeter (a meter that measures millionths of an ampere). The current causes a pointer to move and indicate the degree of illumination, or the correct settings for a camera's lens and shutter, depending upon the calibration of the meter.

Some of the Electrical Characteristics of Photovoltaic Selenium Cells

The selenium photovoltaic cells readily available to the amateur experimenter are the smaller sizes of flat cells. They may be square, rectangular, or round. The International Rectifier Corporation's B2M photovoltaic cells and Sun Battery is highly popular for experimental use. It will generate a current of 2 milliamperes ($2/1,000$ of an ampere) in bright sunlight when connected to a load resistance of 10 ohms.



TWO OF THE SELENIUM CELLS USED TO BUILD APPARATUS
DESCRIBED IN THIS BOOK

The light-sensitive area of the circular A15 selenium photoelectric cell is ten times as large as that of the B2M Sun Battery. The cells produce the same voltage in the same light, but the A15 generates ten times as much current as the B2M.

LOAD RESISTANCE is the resistance of the circuit that uses the electrical energy generated by the cell. An **OHM** is the unit of resistance measurement. Average sunlight has an intensity of 10,000 foot-candles. (A **FOOT-CANDLE** is the direct illumination on a surface one foot from the flame of a standard international candle.) (See a dictionary or encyclopedia for definition of an international candle and also of a lumen.)

The over-all dimensions of the light-sensitive surface of the B2M Sun Battery are 0.72 x 0.44 inches, and the effective photosensitive area is 0.26 square inches. The open circuit (no-load) voltage is 0.5 volt. In full sunlight and connected directly to a conventional voltmeter, a Sun Battery will register 0.33 to 0.4 volt. The voltage output of a selenium photovoltaic cell is independent of the area of the cell's sensitive surface. A selenium photovoltaic cell with a sensitive area larger than that of a B2M Sun Battery will not produce any more voltage than a B2M under the same conditions, but it can produce more amperage, or current volume.

The **CURRENT** output of a photovoltaic cell depends upon the intensity of the light striking the sensitive surface, the size of the sensitive area, and the resistance of the load connected to the cell. A large cell will deliver the **SAME VOLTAGE** but **MORE CURRENT** than a smaller cell.

The voltage and current output of a photovoltaic cell are small when compared with the voltage and current of a voltaic cell. A new voltaic cell of the dry-cell type used in flashlights will usually generate a no-load or open circuit voltage of 1.5 volts and produce several amperes. It will deliver sufficient energy to ring an electric doorbell or make the filament of a small flashlight lamp glow. Consequently, when you make an experimental voltaic cell, it is easy to demonstrate that it generates electrical energy. The current and voltage output of a single selenium cell are so small that it will not ring a bell or light a lamp. Evidence that a

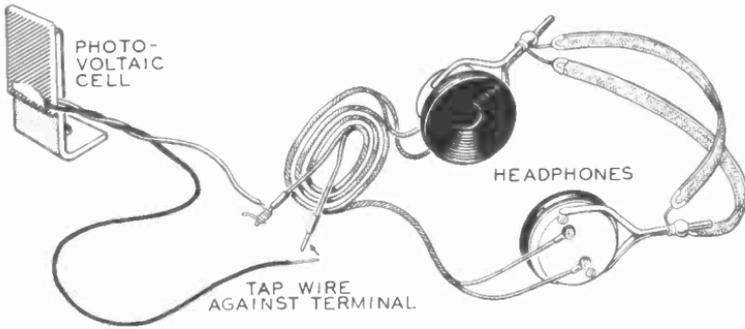
selenium cell converts light energy into electrical energy must be obtained by using a device that will operate its coils. Any change in the magnetic pull on the diaphragm causes it to move. If it moves rapidly enough, it produces sound. The diaphragm may be likened to the tight head of a drum. It requires only a very small disturbance to make it produce sound. When current flows through the coils, the magnetic pull on the diaphragm becomes stronger or weaker, depending on whether the magnetism generated by the electromagnets increases or decreases the pull of the permanent magnet.

Telephone receivers for radio use are wound with wire of smaller diameter than that used in standard receivers for telephone work. Consequently, the electromagnets of the former variety contain a larger number of turns of wire and are more sensitive to weak currents.

Connect a telephone receiver, preferably a radio headset, to a B2M or other selenium photovoltaic cell. Hold the cell so that sunlight strikes its sensitive surface. Hold the telephone receiver to your ear and listen. When current from the cell is flowing steadily through the receiver, no sound will be produced. But if the circuit is closed and opened, so as to turn the current on and off, a clicking sound will be produced by the phones. A click will be produced each time the circuit is opened or closed.

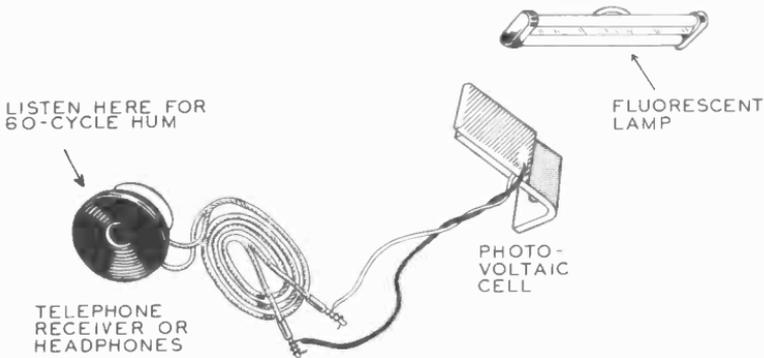
If a selenium cell is connected to a telephone receiver or a headset and the cell's light-sensitive surface is held close to a "common"* fluorescent lamp operated on 60-cycle alternating current—so that light from the lamp falls on the light-sensitive surface of the cell—a 60-cycle hum can be heard in the telephone receiver. The light from a fluorescent lamp operated on 60-cycle current fluctuates in intensity 120 times

* A "common" fluorescent lamp is specified because the circuit of some other types are corrected to reduce or eliminate the light fluctuations.



AN EXPERIMENT

A telephone receiver or a pair of radio headphones connected to a selenium photoelectric cell will reveal that the cell is a transducer. Hold the cell so that sunlight or a strong artificial light strikes its sensitive surface. If the circuit is opened and closed so that the current is turned on and off, clicking sounds will be produced by the phones.



A SELENIUM CELL WILL REVEAL THE FLUCTUATING NATURE OF THE LIGHT PRODUCED BY A FLUORESCENT LAMP OPERATED ON ALTERNATING CURRENT

If the selenium cell is held close to a lighted fluorescent lamp, a humming noise will be heard in the phone or headset. The light from the "common" fluorescent lamp operated on 60-cycle alternating current fluctuates in intensity 120 times a second. The fluctuations, invisible to the eyes, generate a fluctuating current in the selenium cell and the phone or headset and produce a hum.

per second. The fluctuations are too rapid to be seen by human eyes, but a photovoltaic cell responds to them and produces an electric current that fluctuates in strength 120 times per second.

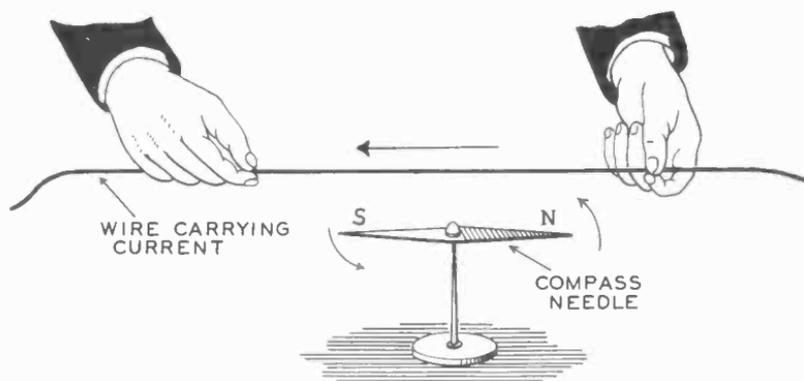
A fluorescent lamp operated on direct current and an incandescent tungsten lamp operated on alternating current will not produce the hum in a telephone receiver. The light from a fluorescent lamp does not fluctuate on direct current; nor does the light from the incandescent lamp fluctuate sufficiently on 60-cycle alternating current for a photovoltaic cell to produce an audible hum in the receiver.

Another device that can be used in experiments with a photovoltaic cell is the GALVANOSCOPE.

How to Demonstrate the Electrical Energy Output of a Photovoltaic Cell

Galvanoscopes. In 1819, Hans Christian Oersted of the University of Copenhagen discovered one of the most useful properties of an electric current. He brought a wire carrying current from a voltaic battery close to a compass needle. The needle moved as it would have if a strong permanent magnet had been brought near. The needle set itself at right angles to the wire while current was flowing. It pointed in one direction when below the wire and the opposite way when above it.

A magnetic field is a region or space traversed by magnetic force. Oersted's experiment revealed for the first time that there is a magnetic field in the space around a wire carrying an electric current. In other words, AN ELECTRIC CURRENT GENERATES MAGNETISM. Lines of magnetic force, in the form of concentric circles, exist around a wire that is carrying a current. The magnetism exists only when current is flowing through the wire. A strong current produces a strong magnetic field; a weak current makes a weak field.



AN EXPERIMENT FOR YOU TO DO THAT DEMONSTRATES
OERSTED'S IMPORTANT DISCOVERY

In 1819 Christian Oersted discovered electromagnetism during the course of a lecture before his students at the University of Copenhagen. This discovery was made by bringing a wire carrying an electric current near a compass needle. The compass needle tried to set itself at right angles to the wire while the current was flowing. This was the first time it was known that an electric current flowing through a wire produces magnetism. Use a dry cell, a piece of insulated wire, and a magnetic compass to make the demonstration.

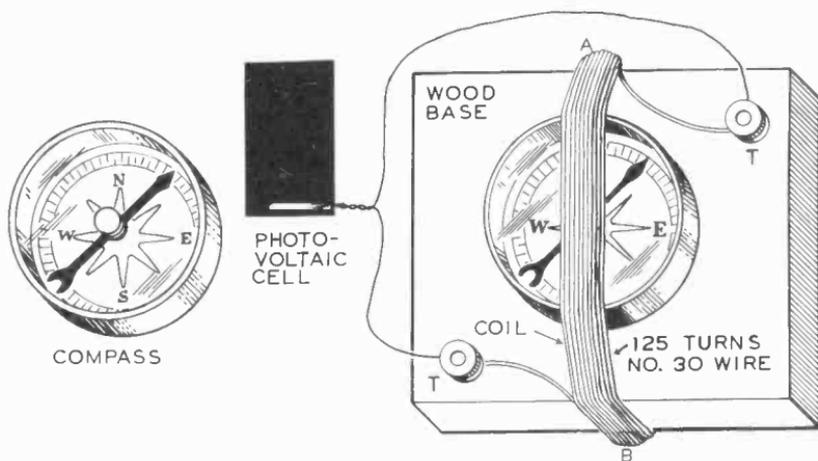
A steady current produces a steady field; a fluctuating current makes a fluctuating field. The magnetism created by an electric current is exactly like the magnetism of a lodestone or a steel magnet, but it is called **ELECTROMAGNETISM**.

It is because an electric current produces magnetism that electricity has the "muscle" to do work for us. For example, whenever electric power is used to lift or to move something or to turn a heavy piece of machinery, electricity produces electromagnetism to carry out the task.

Oersted's discovery can be employed to detect the electric current produced by a photovoltaic cell. The electromagnetism created by a coil of wire surrounding a compass needle will cause the needle to move if a current of electricity flows through the coil. Such an arrangement is called

a GALVANOSCOPE and can be used for detecting small electric currents. If the galvanoscope is provided with a scale, so that the movement or deflection of the needle can be measured, it is called a GALVANOMETER.

A galvanoscope can be made by winding 125 turns of No. 30 B&S enamel-insulated magnet wire around a pocket compass. Wind the wire so that the turns are as close together as possible. This is easier to do if the compass is set on a small block of wood and the wire is wound around both the compass and the wood block (see illustration). Provide two binding posts or Fahnestock clips so that connections can be conveniently made to the terminals of the coil.



HOMEMADE GALVANOSCOPE

A simple scientific instrument to show that a selenium photoelectric cell changes some of the sun's radiant energy to an electric current.

Using the Galvanoscope. The action of a photovoltaic cell and a galvanoscope made with a pocket compass may be demonstrated either indoors or outdoors in sunlight. Set the galvanoscope on a table or on a box where it will be in a level position, away from any magnets or iron or steel objects.

Turn it so that when the compass needle is pointing north and south it is directly under the coil and pointing toward the **A** and **B** shown in the illustration. Connect a photovoltaic cell to the terminals of the galvanoscope without changing its position.

When sufficient light falls upon the cell, it will produce an electric current, and the electromagnetism of the coil will cause the compass needle to move toward an east-west position. The needle will return to a north-south position when the photoelectric cell is in darkness or is disconnected from the galvanoscope.

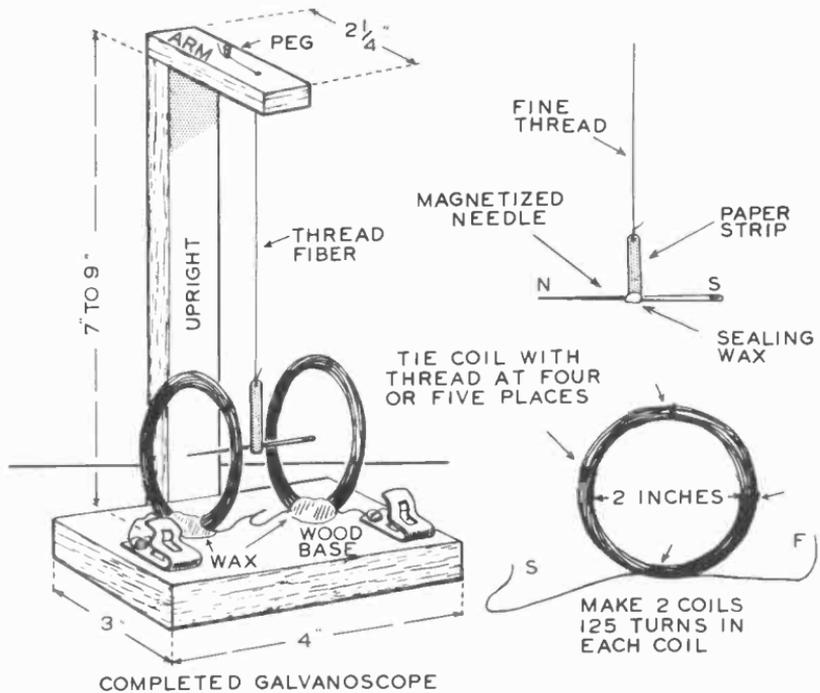
You can provide "artificial sunshine" by arranging a 150-watt reflector-type floodlamp directly above the photovoltaic cell and one foot away from it. Do not place the lamp any closer to the cell or the heat from the lamp may destroy it.

A small photovoltaic cell such as the B2M may cause the needle to move only slightly. An international A15 (a round cell, 2 inches in diameter) has ten times as much sensitive area as a B2M and produces ten times as much current. It will usually cause the needle to move to an east-west position in artificial light. Regardless of the size of the cell, sunlight will generate more current than artificial light and cause the compass needle to move to a greater degree.

When a pocket compass is not readily available for use in a galvanoscope, a sensitive form of this instrument can be made by arranging a magnetized sewing needle so that it can be influenced by the electromagnetism produced by two coils of wire. Use a needle about 1-3/4 inches long. Magnetize it by rubbing one of the poles of a strong permanent magnet from the center of the needle to the eye several times. Test the magnetism in the needle with some iron filings. The filings should cling to the needle in a tuft at each end. Wipe off the filings and cement one end of a paper strip (1/8 inch wide and 1 inch long) to the needle near its center. The paper strip should be slightly closer to the eye than

to the point so that the needle balances and is horizontal when hung by a filament from a thread fastened to the free end of the paper strip. When the magnetized needle is suspended by a thread filament and is free to turn, it is a sensitive compass and points north and south unless disturbed.

Nylon and silk sewing threads are made of a number of fine filaments twisted together. Ordinary thread is too stiff to permit a needle to swing freely, so one filament is used instead of the whole thread. A filament about 7 inches long is required. Cut a piece of thread to that length and untwist



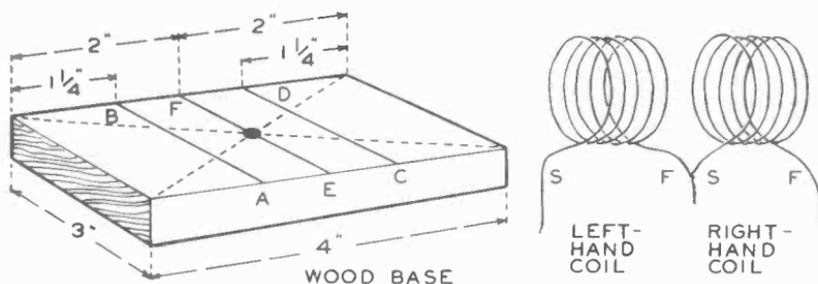
A MORE SENSITIVE GALVANOSCOPE

This instrument will respond to weaker currents than the galvanoscope shown in the preceding illustration. It is the forerunner of the modern voltmeters and ammeters used to measure electric currents. Directions for making and using it are given in the text.

it. Attach one end of one of the thread fibers to the paper strip fastened to the needle.

Make two coils, each 2 inches in diameter, and each consisting of 125 turns of No. 30 B&S or No. 32 B&S insulated magnet wire. Wind the coils on a cylindrical form, such as a small glass tumbler or a round glass bottle 2 inches in diameter. Wind the turns as close together as possible. When 125 turns have been wound on, slip the coil off the form and tie it with thread at four or five places so that it will retain its shape. Leave 5 or 6 inches of wire free at the start and finish of each coil. Attach a small piece of adhesive tape or masking tape to each of the free ends and mark them S or F to indicate whether they are the starting or finishing ends.

Fasten the coils with hot sealing wax to a 3 inch x 4 inch wood base. Before putting them on the base, mark it as shown in the illustration. Draw two parallel black pencil lines, AB and CD, from the front to rear edges and 1-1/4 inches from each side. Draw a third line, EF, from the front to rear edges in the center of the base. Mark the center of this line with a small black circle. The lines AB and CD are guide lines for mounting the coils. Fasten the coils to the base with hot sealing wax. The coils should be parallel and 1-1/2 inches apart. After the coils have been fastened in



THE WOOD BASE FOR THE GALVANOSCOPE

The text explains how to locate the guide lines and coils.

place they should be connected in series by connecting the starting, or **S**, terminal of the right-hand coil to the finishing, or **F**, terminal of the left-hand coil. Current will then pass through both the windings in the same direction. The two remaining terminal leads are then connected to two binding posts or Fahnestock clips at the front corners of the base. If the coils are improperly connected, the galvanoscope will not operate.

Fasten an upright wood strip, 7 to 9 inches long, $\frac{3}{4}$ inch wide, and $\frac{1}{4}$ inch deep, to the rear edge of the base at the center. This is marked **UPRIGHT** in the illustration. Fasten a short wood strip (marked **ARM** in the illustration), $\frac{3}{4}$ inch x $\frac{1}{4}$ inch x $2\frac{1}{4}$ inches, to the top of the upright. Drill two small holes in the arm. The thread filament with the magnetized needle is passed through one of the holes from the underside. This hole is so located that the center of the needle will be in the center of the space between the coils and directly over the circle in line **EF**. The filament is then fastened by passing it through the second hole and wedging it there with a small wood peg.

To use the galvanoscope, place it on a level table and position it so that the direction of the pencil line, **EF**, on the base points north and south. If properly magnetized and suspended, the needle will align itself with the pencil line **EF**. When the terminals of the galvanoscope are connected to a source of current, the magnetism produced in the coils will cause the needle to swing around at an angle to the north-south line.

As previously mentioned in connection with the galvanoscope made with a pocket compass, the needle may not swing far when the galvanoscope is connected to a photovoltaic cell exposed to artificial light. In sunlight, the cell will produce enough energy to swing the needle to a very noticeable degree.

Photoelectric Effects

Some of the electrons in the outer orbit of atoms in crystals of certain elements and compounds are freed from their orbits when exposed to light. Although these electrons are identical to all other electrons, they have a special name. They are called PHOTOELECTRONS, to describe the way they are freed. They produce PHOTOELECTRIC effects that have many practical uses. Among the useful photoelectric effects are:

1. The PHOTOCONDUCTIVE effect. It occurs when light causes the resistance of an element to the passage of an electric current to decrease.
2. The PHOTOEMISSIVE effect. It takes place when light causes photoelectrons to leave an element and surround it like a cloud.
3. The PHOTOVOLTAIC effect. It occurs when light falling on a photovoltaic cell generates a voltage.

SOLAR-POWERED RADIO RECEIVERS THAT YOU CAN BUILD • A Radio Receiver with a Transistor Detector Powered by a Sun Battery. A Pocket-Size Version of the Solar-Powered Radio Receiver. A Radio Receiver with a Transistor Amplifier Powered by a Sun Battery. How to Operate the Receivers on Battery Power.

A radio receiver powered by energy from the sun or from the light of an incandescent lamp should be included in a science fair exhibit devoted to solar cells or semiconductor devices. Such a receiver is an interesting demonstration of the conversion of energy by a photovoltaic cell and of the detection of radio signals by a transistor.*

A complete understanding of semiconductor physics and the theory of transistor operation is not necessary for the construction of any semiconductor device described in this book. The theories of transistor operation cannot be explained simply. It is necessary to have certain fundamental scientific knowledge of physics and chemistry to understand basic explanations of semiconductor action in transistors. There are many books on the subject, and those who have the scientific education to understand them should consult them.

Some of the history surrounding the invention of the transistor should be of interest in a Science Fair Exhibit.

* There is a chapter in *The Boys' Third Book of Radio and Electronics* that the hobbyist may find informative. It is Chapter Five, "The Transistor—What It is—What It Does—How It Works."

The Invention of the Transistor

New inventions are made so rapidly that several patent applications are filed daily at the Patent Office in Washington, D. C. Most of these have little over-all effect on science and industry. But occasionally revolutionary inventions are made. One such was patented in 1948. Drs. William Shockley, John Bardeen, and Walter H. Brattain, at Bell Telephone Laboratories, were engaged in pure research to classify the electrical characteristics of various crystalline metals when they discovered that a not-quite pure crystal of the metal germanium could be made to function like a three-element vacuum tube. It would detect radio signals, rectify, oscillate, and amplify. The resultant device was named the TRANSISTOR because it TRANSFERRED voltage across a RESISTOR.

Like the first vacuum tubes, the first transistors showed great promise but had severe limitations. They were noisy and could handle only limited power.

Soon the best brains and resources of several great research laboratories were devoted to minimizing the transistor's shortcomings and increasing its virtues. The transistor has been improved in many ways since its invention. The cost has greatly decreased and the efficiency has been steadily increased. The next few years promise an equally spectacular growth. The frequency range of transistors will be extended into the ultra-high-frequencies. New designs will extend the power range to make possible control circuits capable of operating at over 50 amperes and 400 volts, in other words, 20 kilowatts. The first transistors could handle only a fraction of one watt.

Radio signals can be received without battery power at the receiver by using a crystal diode detector. When a TRANSISTOR is used either as a detector or an amplifier, a local source of electromotive force is necessary. Energy from the transmitter is then only a sort of trigger that con-

trols the flow of energy supplied by the local source of electromotive force. The force required to operate the conventional transistor radio receiver is usually supplied by one to four small dry cells. ELECTROMOTIVE FORCE supplies energy that moves electrons in the invisible procession called an ELECTRIC CURRENT. The source of electromotive force in a sun-powered radio receiver can be an International-type B2M Sun Battery or an equivalent selenium photovoltaic cell. A silicon photovoltaic cell can also be used.

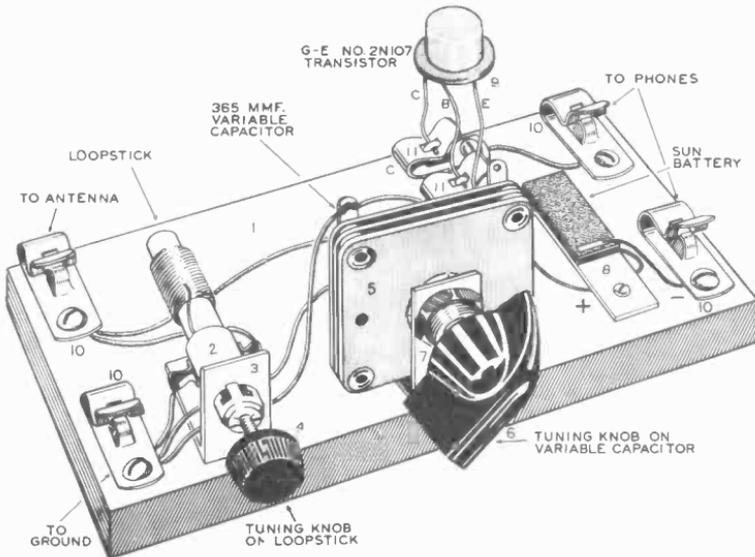
*How to Make a Radio Receiver with a Transistor Detector
Powered by a Sun Battery*

This is a simple, light-powered radio receiver for receiving broadcast programs. It can be tuned to any frequency from 530 to 1600 kilocycles. It consists of an antenna loopstick, a variable capacitor, a transistor, a B2M Sun Battery, and a 2,000-ohm telephone headset. The receiver is tuned by turning the knobs on the loopstick and variable capacitor. It can be adjusted to respond to any frequency in the radio broadcast band by turning the knobs on these tuning devices. When the loopstick and capacitor are carefully adjusted, the desired signal appears with maximum intensity at the transistor—where it is DEMODULATED. Demodulated means “changed from inaudible radio-frequency signals into audible audio-frequency signals.” The transistor functions only when supplied with an electromotive force from the photovoltaic cell, and the photovoltaic cell generates an electromotive force only when light shines upon it. Sufficient energy to produce audible signals will be generated when the illumination falling on the photovoltaic cell is as little as 10 foot-candles.

As explained in the previous chapter, a foot-candle is a unit used to measure illumination. It is the illumination produced on a flat surface by the flame of a standard candle

at a distance of one foot. A standard candle is a 7/8-inch sperm candle burning wax at the rate of 120 grams per hour. (A sperm candle is made of wax obtained from the oil of the sperm whale.) Illumination equal to 10 foot-candles would be that produced on a photoelectric cell located one foot away from 10 standard candles.

The simplest way to make a light-powered receiver is to assemble ready-made components on a wood base. In other words, use "breadboard" type construction. This method also makes it easy to dismantle the receiver and use the components in other projects when desirable. Another feature of this method of construction is that the parts mounted on the base are in the same relative positions as in the schematic circuit diagram. All the parts except the base (1) and the tuning capacitor bracket (7) can be purchased from a dealer in radio supplies.



RADIO RECEIVER WITH TRANSISTOR DETECTOR POWERED BY SOLAR CELL

The following parts and materials are required:

- 1 6-1/4 in. x 4 in. x 3/8-in. shellacked or varnished wood base
homemade (1)
- 1 Antenna loopstick, may be any of the following: Lafayette
MS-11, 240-275Q antenna loopstick; Allied Radio No. 7C034
vari-loopstick; Thordarson-Meissner No. 14-700 micro loop;
Superex vari-loopstick; Philmore No. 1-R841 standard loop
antenna coil (2)
- 1 Mounting bracket for loopstick (3)
- 1 Knob for tuning loopstick (4)
- 1 Argonne No. MS-445 365-mmF single-gang miniature variable
tuning capacitor, or one MS-946 Poly-Varicon miniature single-
gang, 365 mmF variable tuning capacitor (5)
- 1 Knob and dial for capacitor (6)
- 1 Bracket for mounting tuning capacitor, homemade (7)
- 1 B2M Sun Battery or equivalent selenium photovoltaic cell (8)
- 1 General Electric PNP No. 2N107 transistor (9)
- 4 Fahnestock clips, 1-1/16 in. x 3/8 in. (10)
- 3 Fahnestock clips 3/4 in. x 5/16 in. (11)
- 4 3/8-in. No. 6 round-head brass wood screws
- 7 3/8-in. No. 4 round-head brass wood screws
- 1 2,000-ohm telephone headset
- Rosin-core wire solder, hookup wire

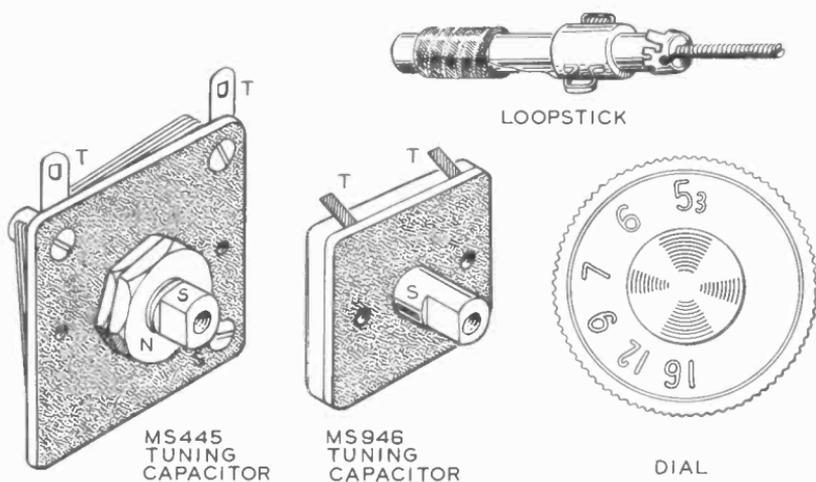
The Loopstick. Several different antenna coils, popularly called loopsticks, are listed in the mail order catalogs of radio dealers. It is necessary to purchase the correct type to use in assembling this receiver. For that reason the catalog list numbers of several loopsticks are given. The basic construction and electrical characteristics of all these are similar. Each consists of a small coil of insulated wire wound on one end of a paper tube about 2 inches long and 9/32 inch in outside diameter. The ends of the winding are connected to two metal terminals near the end of the tube. Loopsticks with three terminals are also manufactured. Do not buy the three-terminal type for this project.

There may also be a coil of 12 to 14 turns of wire wound loosely around the tube, with one end connected to one of the metal terminals. This piece of wire should be removed.

A small rod, made by compressing the powdered iron compound called FERRITE, forms a movable core inside the tube. A knob is placed on the exposed end of the threaded brass rod attached to the ferrite core, so that the core can be rotated and its position in the coil changed. Moving the core slightly in and out of the coil tunes the loopstick.

Assembling the Receiver. The plan shows how to arrange the components on the wood base.

A metal bracket is supplied with each loopstick. The bracket is a flat metal strip about 2 inches long. Bend this 1 inch from one end to form a right angle. Fasten it to the wood base with two 3/8-inch No. 4 round-head brass wood screws. The loopstick is provided with a snap-in device at one end. Push this end into the large hole in the bracket



FOUR OF THE COMPONENTS USED IN ASSEMBLING THE RECEIVER
The letter T indicates a terminal. S is the shaft attached to the movable plates or rotor. N is the nut used to fasten the capacitor to its bracket.

after the bracket has been fastened to the base. Push the loopstick in until it locks into place in the bracket.

Two types of variable tuning capacitors are listed in the catalogs of component parts and materials. Either type may be used. Both are miniature capacitors manufactured in Japan for use in miniature transistor radio receivers. They consist of several small, movable, semi-circular sheet-aluminum plates that can be rotated between another group of rigid, or fixed, plates so as to interleave. The fixed plates are called the *STATOR* and the movable plates are referred to as the *ROTOR*. The movable plates do not touch or make electrical contact with the fixed plates. When interleaved, the two sets of plates are separated by thin sheets of plastic insulation. The plastic insulating material is called the *DIELECTRIC*.

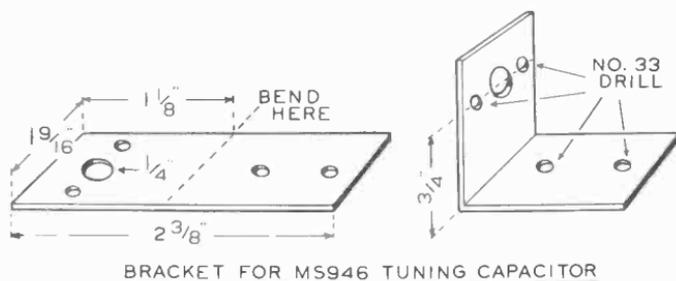
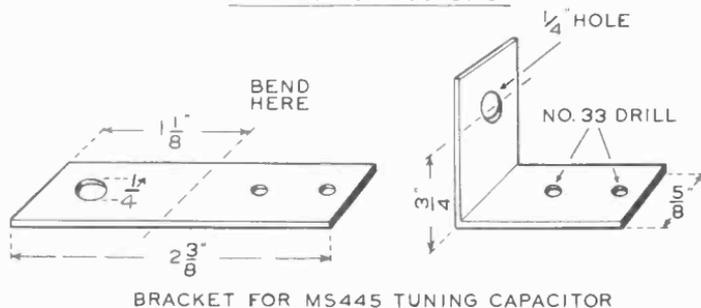
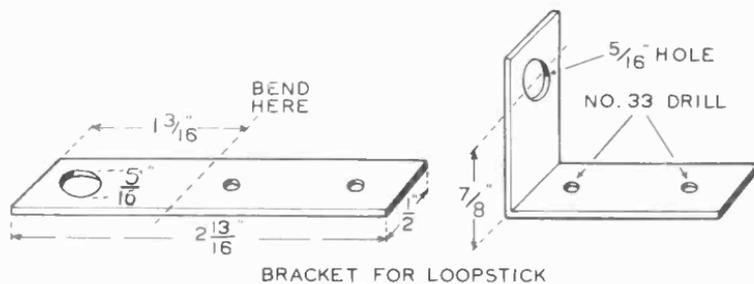
Both capacitors require a homemade mounting bracket. Cut the bracket out of sheet metal with a pair of tinner's snips. Drill and bend it as shown in the illustration. Notice that the bracket to fit one type of capacitor differs slightly from the other.

Fasten the bracket for the loopstick and the bracket for the capacitor to the base before putting either the loopstick or capacitor in place.

If a type MS-445 capacitor is used, push the threaded bushing on the front of the capacitor through the large hole in the bracket, and fasten it in place with the hex nut supplied with the capacitor. Before tightening the nut, turn the capacitor so that the solder lug terminals are at the top.

If a type MS-946 capacitor is used, slip the shaft through the 1/4-inch hole, and fasten the capacitor to the bracket with the two small round-head machine screws supplied with the capacitor.

Hooking Up. A hookup in radio conversation means a circuit,



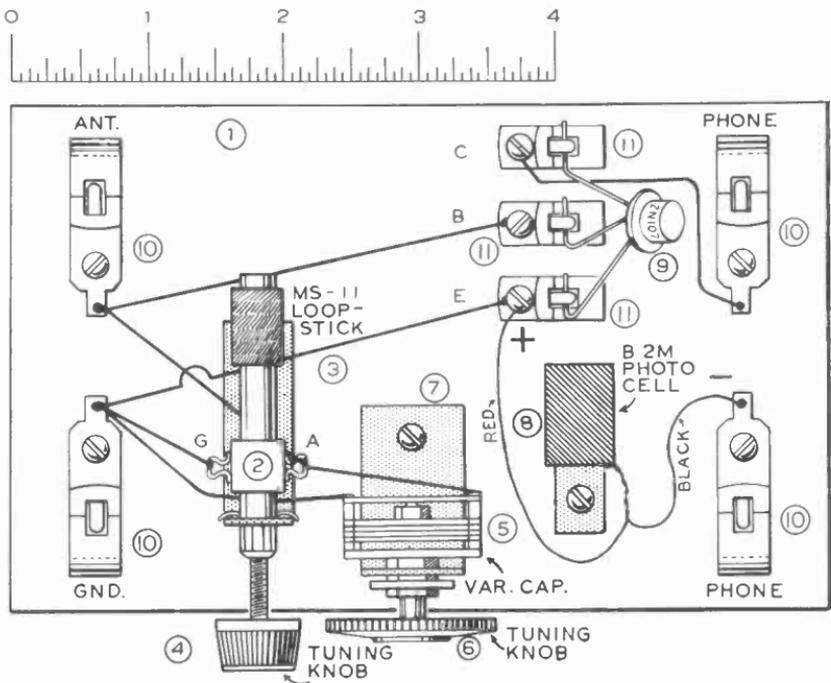
BRACKETS FOR MOUNTING THE LOOPSTICK AND TUNING CAPACITOR
When these parts are not furnished with the components, they can be made out of sheet metal.

and hooking up is doing the wiring or making the connections.

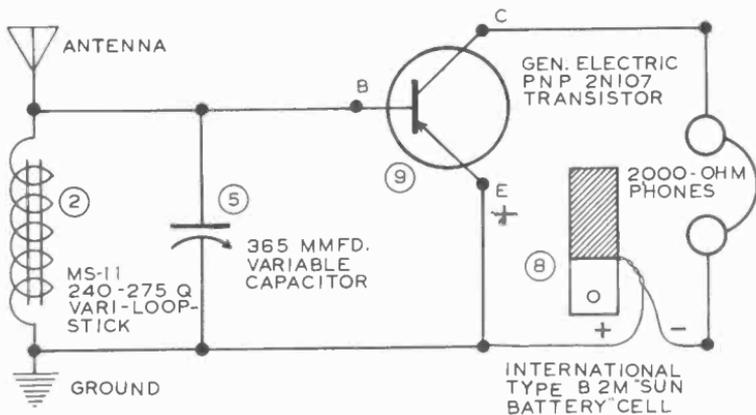
Follow the schematic circuit diagram when making the connections. The plan shows the arrangement of the wiring. Make all wires as short as possible.

Connections can be made to the Fahnestock clips by placing the bared end of a wire under the clip and around the screw which fastens the clip to the wood base. The operation of the receiver will be more dependable if all connections are soldered. The best method is to place a small solder lug under the head of each of the screws used to mount the clips and also under the head of one of the screws used to fasten each bracket. Slip the bared ends of the hook wires into the small holes in the solder lugs and solder them in place.

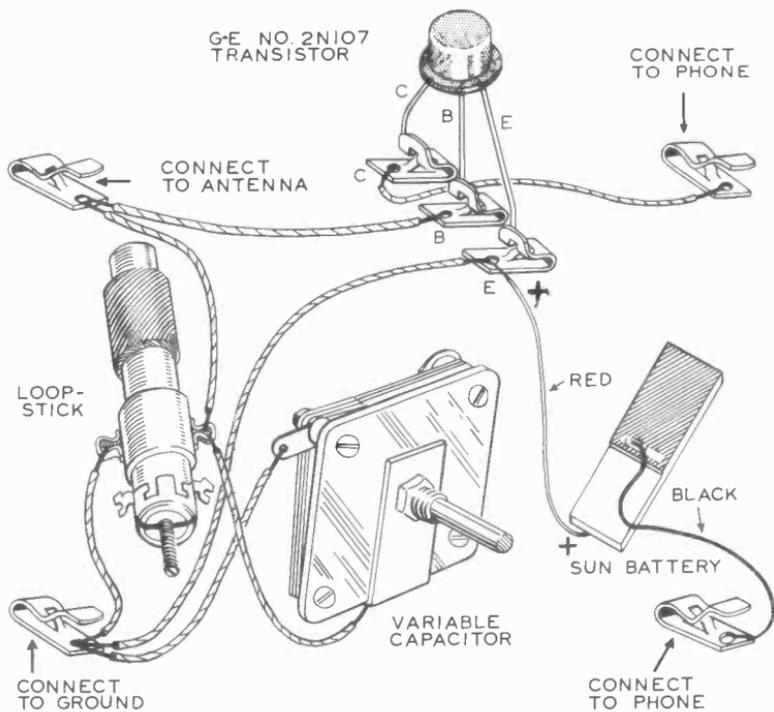
It has already been mentioned that there may be a short length of wire wrapped loosely around the loopstick and connected at one end to one of its terminals (marked A on the plan of the loopstick). Turn the loopstick so that this ter-



PLAN OF THE SUN-POWERED RECEIVER



SCHEMATIC CIRCUIT DIAGRAM



PICTORIAL CIRCUIT DIAGRAM

minal (A) is on the right hand side. Unwind the wire, detach it from the terminal, and discard it. Connect two pieces of hookup wire to terminal A. Connect the other end of one of these hookup wires to the Fahnestock clip marked ANT on the plan. Connect the other wire to the tuning capacitor bracket. The other terminal of the loopstick (marked G on the plan) should be connected to the Fahnestock clip marked GND on the plan.

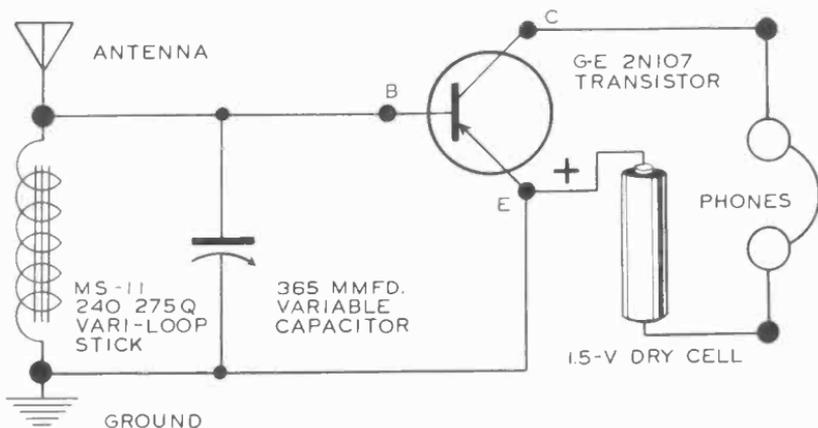
Small Fahnestock clips are used to make connection to the transistor, in place of a transistor socket. The terminal wires on the transistor should not be shortened. The letters E, B, and C, alongside the small clips on the plan, indicate EMITTER, BASE, and COLLECTOR respectively. The illustration identifies the three terminal wires on the transistor. The EMITTER should be connected to clip E, the BASE to clip B, and the COLLECTOR to clip C.

The end of the rotor shaft on both types of capacitor is flat on one side. The dials for the capacitors have a depression in the rear surface that fits over the end of the shaft. A dial is attached to the shaft by a screw with a large concave head. This screw has no slot, but can be tightened or loosened by pressing the ball of the thumb against it and turning it in the desired direction.

How to Demonstrate the Receiver. Connect a 2,000-ohm telephone headset to the two clips marked PHONE on the plan. An antenna 35 to 50 feet long should be connected to the ANT clip. An earth or ground connection is also required; and a wire should be connected from the GND clip to a water pipe, radiator, or other nearby grounded object.

The receiver should be located where the sun will shine directly on the photovoltaic cell, or underneath a lighted 150-watt incandescent lamp. The lamp should be about 2 feet above the photovoltaic cell. Adjusting the knobs on the loopstick and the tuning capacitor should bring in the

signals of any broadcast station located within 25 to 50 miles. When signals are heard, cover the photovoltaic cell with a small piece of paper so that it is in darkness. The signals will immediately cease to be heard. The receiver will operate only when light of sufficient strength falls on the photovoltaic cell. Covering the cell to shield it from the light and then removing the shield will demonstrate this.



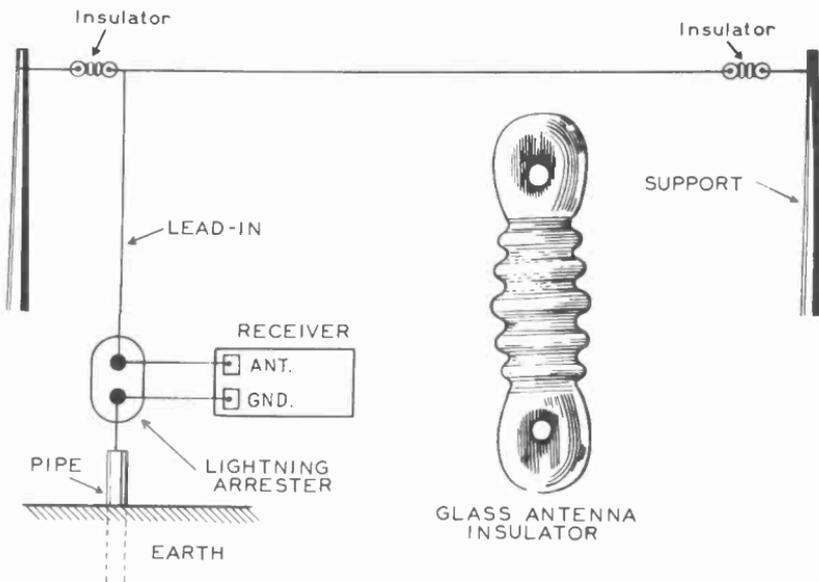
SCHEMATIC CIRCUIT DIAGRAM

This diagram shows how to connect a 1.5-volt dry cell in the circuit to substitute for the sun battery.

The Antenna. The loopstick serves as an antenna and will pick up signals from broadcasting stations only a few miles away. A loopstick has a "directional effect." This means that signals may vary in strength according to the direction in which the loopstick points. Therefore, turning the receiver may sometimes increase or decrease the volume of sound produced in the phones. A suitable antenna is necessary to obtain the best signals from the receiver. The antenna need not be high or long to pick up signals from stations only a few miles away. Nearby stations can usually be received with an indoor antenna consisting of an insulated wire 30

to 35 feet long. To receive the signals of distant stations, an outdoor antenna 75 to 80 feet long may be necessary.

One of the illustrations shows the best way to install an outdoor antenna. It is advisable to use an outdoor lightning arrester with an outdoor antenna. Connect the lead-in wire to one terminal of the lightning arrester and to the ANT terminal on the receiver. Connect the other terminal of the lightning arrester and the GND terminal on the receiver to a piece of 3/4-inch galvanized iron pipe driven 3 or 4 feet into the ground.



AN OUTDOOR ANTENNA SHOULD BE PROVIDED WITH A LIGHTNING ARRESTER

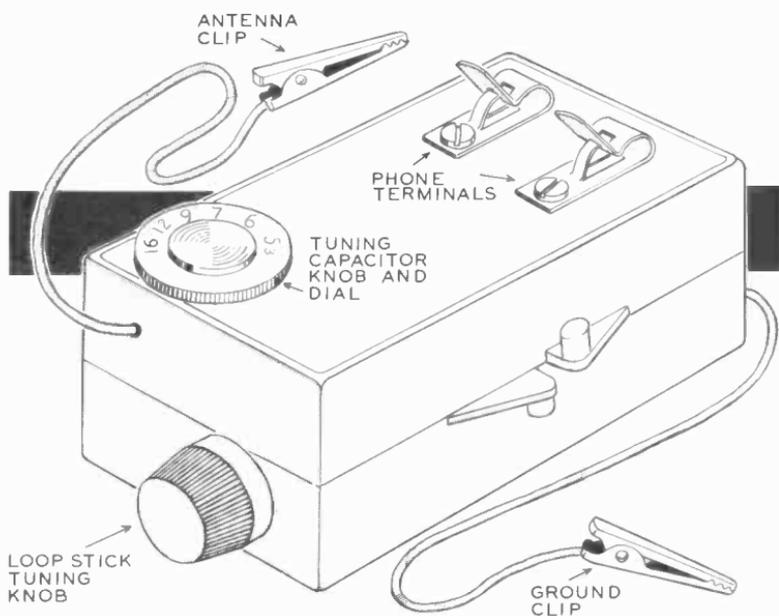
A Pocket-size Version of the Solar-powered Radio Receiver

The experimenter who is reasonably well-skilled in model building can make a small, portable, solar-powered radio receiver that will slip into a coat pocket. The same compo-

nents used in building the receiver just described can be used, with the exception of the B2M Sun Battery, wood base, brackets, Fahnestock clips, and wood screws.

The following additional materials are required:

- 1 3-in. x 2-1/8-in. x 1-1/8-in. plastic box
- 2 1-in. x 5/16-in. Fahnestock clips
- 1 Piece of unclad perforated Bakelite board, 2-13/16 in. x 1-5/16 in. x 1/16 in.
- 3 Flea clips
- 2 24-in. lengths of stranded hookup wire
- 2 Small alligator clips
- 2 3/16-in. 4-36 round-head machine screws with hex nuts to fit
- 2 3/16-in. 6-32 round-head machine screws with hex nuts to fit



A POCKET-SIZE VERSION OF THE SOLAR-POWERED RADIO RECEIVER

The metal bracket that is part of a B2M Sun Battery is an inconvenience if used in this pocket version of the receiver. It should be cut off, or another type of photocell should be substituted. Small, unmounted selenium cells ranging in size from $3/4$ inch x $5/8$ inch to $7/8$ inch x $7/8$ inch are available at low cost. One of these can be used in place of the B2M Sun Battery. There is space to mount two $3/4$ -inch x $5/8$ -inch photocells. If two of these are connected in series, the receiver will produce louder signals than can be produced with one photocell.

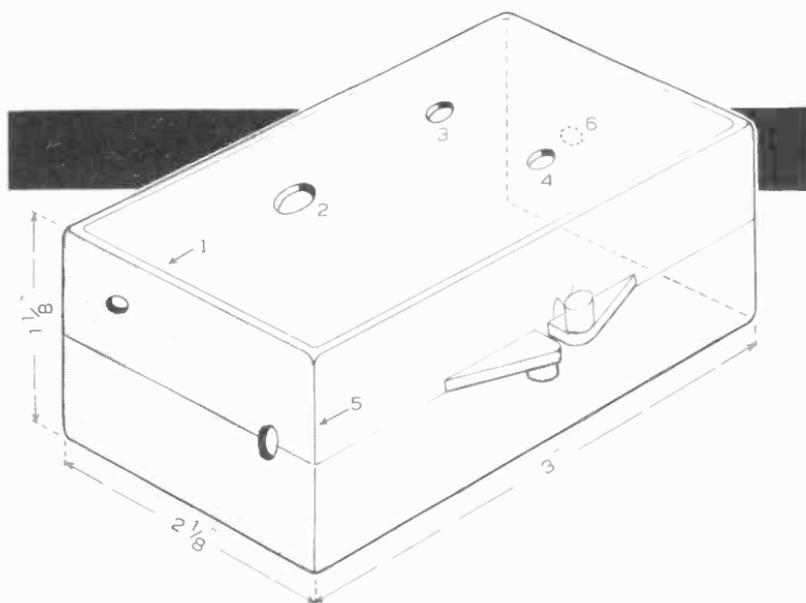
The components are assembled on the perforated board as illustrated. Unclad perforated board is $1/16$ -inch-thick sheet Bakelite (often called phenolic) perforated with $1/16$ -inch-diameter holes $3/16$ inch apart between centers. The name "unclad" distinguishes this material from "copper-clad" board. One side of copper-clad board is covered with a thin layer of copper. Such board is used for making electronic apparatus with printed circuits.

The smallest piece of unclad perforated board listed in catalogs of electronic materials is usually $3-3/8$ inches x $2-7/16$ inches x $1/16$ inch. It is easily cut with a fine-tooth hacksaw blade and should be reduced in size to $2-13/16$ inches x $1-5/16$ inches x $1/16$ inch so as to fit in the plastic case used to enclose the receiver. It serves as the chassis upon which to mount the components. The chassis of a radio is the frame on which are mounted the parts of a receiving set or a transmitter. It is also the name for the assemblage of parts thus mounted.

A transparent, polystyrene plastic case (3 inches x $2-1/8$ inches x $1-1/8$ inch outside and $2-7/8$ inches x 2 inches x 1 inch inside) with a ball-type hinged cover is available from dealers in plastic materials and from some mail order firms that sell electronic gear. The cost is ten cents. It is advisable to buy two of the cases because they break easily while being drilled.

Six holes must be drilled in the case. The illustration shows their location. The holes should be made with sharp twist drills running at medium speed. Use light pressure to feed the drills and hold a wood block firmly against the opposite surface of the plastic where the drill will emerge. All holes except No. 2 should be made with a No. 26 twist drill. Use a 1/4-inch diameter drill to make hole No. 2. The purpose of each hole will be explained later. Experimenters who have the necessary woodworking skill may take pride in building a case from cigar-box wood. The thin cedar or mahogany takes a good finish.

The sketch of the piece of perforated board used as the



A PLASTIC BOX SUITABLE FOR USE AS THE CABINET

It is necessary to drill several holes in the plastic box used to enclose the receiver. Hole 1 is for the antenna wire. 2 is for the capacitor shaft. 3 and 4 are for screws that hold phone clips. 5 is for shaft of loopstick. 6 is for ground wire.

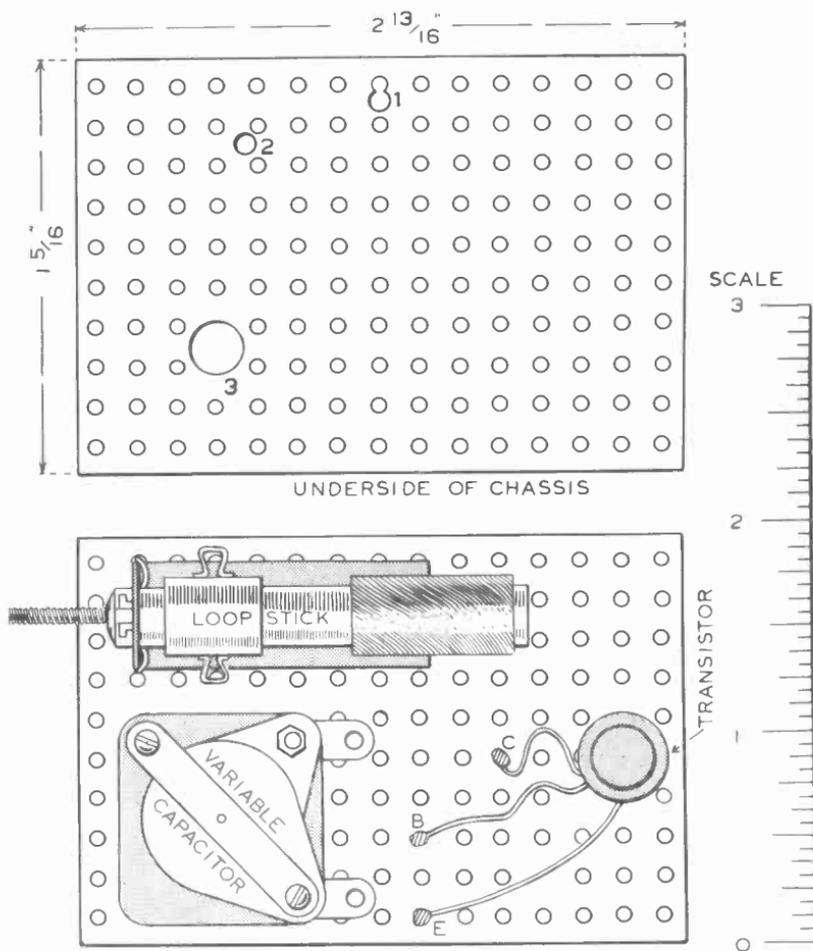
chassis for the receiver components shows three holes marked 1, 2, and 3. These are drilled in the board after it has been cut to size. Holes 1 and 2 should be drilled with a No. 26 twist drill. Hole 3 should be 5/16 inch in diameter. The location of the holes can be determined by using the scale in the illustrations to measure the distance of the holes from the edge of the chassis.

Flea clips are specially designed as anchorage points for miniature electronic apparatus. They are made of silver-plated beryllium copper. They fit snugly in the 1/16-inch holes in perforated copper-clad and unclad boards. To use a clip, simply push it into a chassis perforation and insert the wires that are to be soldered at that point. Three flea clips are required. They are pushed into the perforations marked E, B, and C. When the G-E 2N107 transistor is installed, the wire terminals of the EMITTER, BASE, and COLLECTOR are soldered respectively to E, B, and C.

Assembling. Mount the transistor on the underside of the chassis. Solder a piece of hookup wire to the upper end of each flea clip and push the wires through adjacent perforations. From there, the wires are led and connected to the variable capacitor, photoelectric cell, and PHONE terminal, as shown in the schematic wiring diagram.

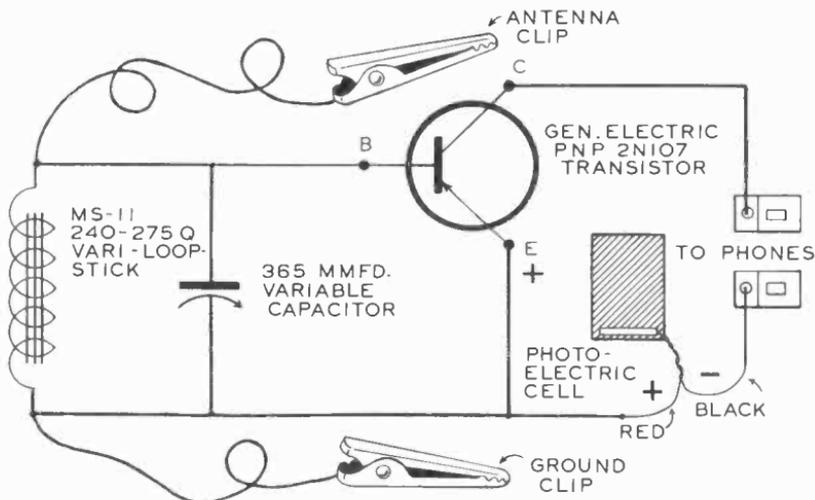
The bracket for the loopstick is fastened to the underside of the chassis, using the two 3/16-inch 4-36 round-head machine screws in holes 1 and 2. The loopstick can then be pushed into position in the bracket. The threaded rod attached to the ferrite core should project through the notch (No. 5 in the case) filed in the upper and lower parts of the plastic case.

The MS-445 tuning capacitor is attached to the underside of the chassis by removing one of the hex nuts and pushing the end of the shaft through hole 3 in the chassis. Place the hex nut on the threaded portion of the bushing

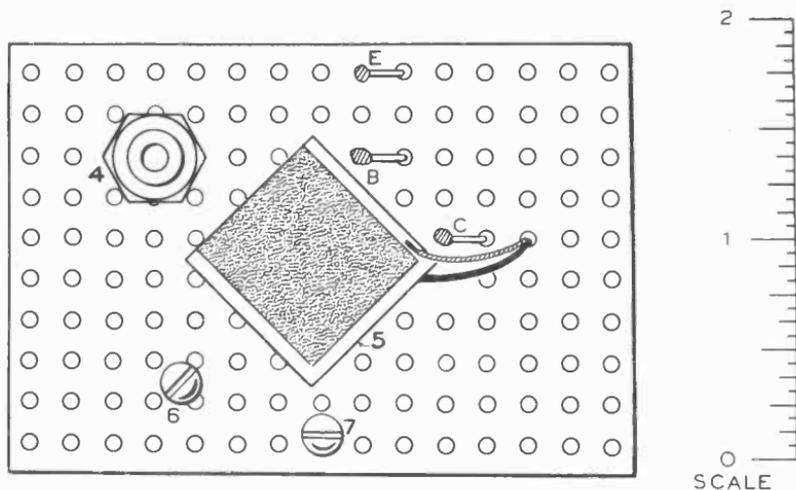


UNDERSIDE OF THE CHASSIS

The components are mounted on a piece of unclad, perforated board. The sketches show the underside of the board both before and after the components have been mounted. The holes marked 1 and 2 are for the screws that fasten the loopstick to the chassis. Hole 3 is for the threaded bushing on the tuning capacitor. The lower sketch shows the loopstick, capacitor, and transistor in place. E, B, and C are flea clips connected to the EMITTER, BASE, and COLLECTOR terminals of the transistor.



SCHEMATIC CIRCUIT DIAGRAM OF THE POCKET RADIO



TOPSIDE OF THE CHASSIS

Screws 6 and 7 fasten the loopstick to the underside of the chassis. 4 indicates the bushing on the capacitor. 5 is the selenium photovoltaic cell. E, B, and C are the EMITTER, BASE, and COLLECTOR terminals.

that projects and tighten it. Use holes 3 and 4 in the plastic case and the two 3/16-inch 6-32 round-head machine screws to fasten the two Fahnestock clips to the top surface of the cover. Place the bared end of a 5-inch length of hookup wire under each hex nut holding the Fahnestock clips. Push the free end of each wire through a perforation in the chassis under the clip. The surplus length is cut off when the hookup is completed. Connect one of the wires to the flea clip marked **C** in the illustrations (connected to the transistor COLLECTOR). The other wire should be connected to the black terminal wire of the photovoltaic cells.

The positive and negative terminals of a selenium photoelectric cell are usually indicated by a red and by a black wire. The black wire is intended to be the negative terminal; the red wire is positive. The black wire is usually soldered to a small, silver-colored conductive strip on the upper (brown), light-sensitive surface. The red wire is soldered to the silver- or gold-colored underside.

Sometimes a mistake is made at the factory and the wires are reversed. The polarity of the terminal wires on a photoelectric cell can be checked by connecting them to a sensitive, low-reading voltmeter or to a milliammeter or microammeter. If the polarity of the meter is not marked, use a strip of copper and a piece of zinc connected to a voltmeter having a 0-2 volts scale to ascertain the polarity of the meter terminals. This simple voltaic cell will give a reading of approximately 0.8 volt when the zinc and copper are immersed in an 8-ounce glass tumbler half-filled with water in which a teaspoonful of salt has been dissolved. The copper is positive. Observe to which terminal of the meter the copper must be connected to obtain a reading. The terminal of the photoelectric cell that moves the needle in the same direction is also POSITIVE. The sensitive surface of the photoelectric cell must be exposed to a strong light during this test.

This radio receiver will not operate when a 2N107 tran-

sistor is used unless the positive terminal of the photoelectric cell is connected to **E** (the **EMITTER**).

Solder a small alligator clip to each of the two 24-inch lengths of stranded hookup wire. Push the free end of one wire from outside the case to the inside through hole **6**. Connect this end to one terminal of the loopstick, to one terminal of the tuning capacitor, and to the flea clip marked **E** that is connected to the transistor emitter. Push the free end of the other wire from outside the case to the inside through hole **5**. Connect the end of this wire to the other terminal of the tuning capacitor and to flea clip **B** connected to the **BASE** terminal of the transistor.

The photoelectric cell, or cells if two are used, should be cemented to the top surface of the chassis at a spot where they will not be in shadows cast by the Fahnestock clips or the dial. The undersurface of a photovoltaic cell should be completely covered with masking tape or Scotch tape before mounting. The cell can then be attached to the chassis with cement or sealing wax.

The alligator clip connected to the wire that comes out of the hole in the front of the case should be connected to an antenna. (The front of the case is the end with the loopstick tuning knob.) The antenna can be an indoor wire 35 to 50 feet long. The alligator clip connected to the wire that comes out of the hole in the back of the case should be connected to the ground (water pipe, radiator, or some other grounded object).

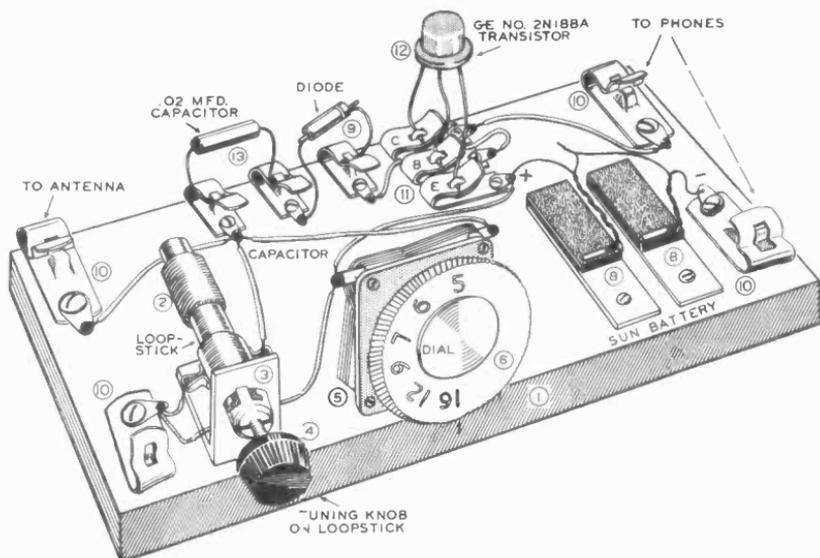
When the sun is not shining, the receiver will operate if the sensitive surface of the photoelectric cell is held within two or three feet of a lighted 100-watt incandescent lamp. Connect a 2,000-ohm headset to the Fahnestock clips on the top of the case. Adjusting the tuning knobs on the loopstick and the capacitor should bring in signals. When the chassis is in its proper position inside the case, the end of the

capacitor shaft will project through hole 2 far enough to permit the capacitor dial to be attached.

The receiver can be demonstrated to your friends at school on the playground or elsewhere outdoors by stretching a 30- to 40-foot insulated wire between two trees and using a fire hydrant or a metal lamppost as a ground connection.

A Radio Receiver with a Transistor Amplifier Powered by a Sun Battery

This receiver is similar in several details to the other receivers described in this chapter. The tuning circuits are identical. The main difference is in the means used to detect or demodulate the received signals. A semiconductor diode



RADIO RECEIVER WITH TRANSISTOR AMPLIFIER POWERED BY SOLAR CELLS

is used in place of a transistor detector. The transistor in the circuit performs as an audio amplifier that increases the strength of the signals after they have been detected by the diode. The source of power required for the transistor consists of two International B2M Sun Batteries connected in series. Any equivalent selenium photovoltaic cells, or two silicon photovoltaic cells in series, can be used in place of the B2M cells.

The following parts and materials are required to build the receiver:

- 1 5-5/8-in. x 3-3/4-in. x 3/8-in. shellacked or varnished wood base (1)
- 1 Antenna loopstick of any of the following varieties: Lafayette MS-11 240-275Q antenna loopstick, Allied Radio No. 1C034 vari-loopstick, Thordarson-Meissner No. 14-700 micro loop, Superex vari-loopstick, or Philmore No. 1-R841 standard loop antenna coil (2)
- 1 Mounting bracket for loopstick (3)
- 1 Knob for tuning loopstick (4)
- 1 Lafayette Argonne No. MS-445, 365-mmf variable tuning capacitor or Allied Radio No. 17L091, 365-mmf variable tuning capacitor (5)
- 1 Knob and dial for tuning capacitor (6)
- 1 Bracket for mounting tuning capacitor (7)
- 2 B2M Sun Batteries or equivalent photovoltaic cells (8)
- 1 General Electric 1N64 Diode or Sylvania 1N64 Diode (9)
- 4 Fahnestock clips, 1-1/16 in. x 3/8 in. (10)
- 6 Fahnestock clips, 3/4 in. x 5/16 in. (11)
- 1 General Electric PNP 2N188A transistor (12)
- 1 .02-mfd Argonne oil-filled fixed capacitor (13)
- 4 3/8-in. No. 6 round-head brass wood screws
- 12 3/8-in. No. 4 round-head brass wood screws

Assembly. The components are arranged on a wood base as shown in the plan. Notice that the base is slightly smaller

than the base for the receiver with the transistor detector. A larger base can be used, but the smaller one is suggested in order to provide practice in connecting components that are close together.

A bracket in the form of a metal strip is usually supplied with each loopstick. This should be bent into an L shape, as shown in the illustrations. It will be necessary to make a bracket for the tuning capacitor. Cut a strip 2-3/8 inches x 5/8 inch out of sheet metal with a pair of tinner's snips. Drill and bend the strip as illustrated.

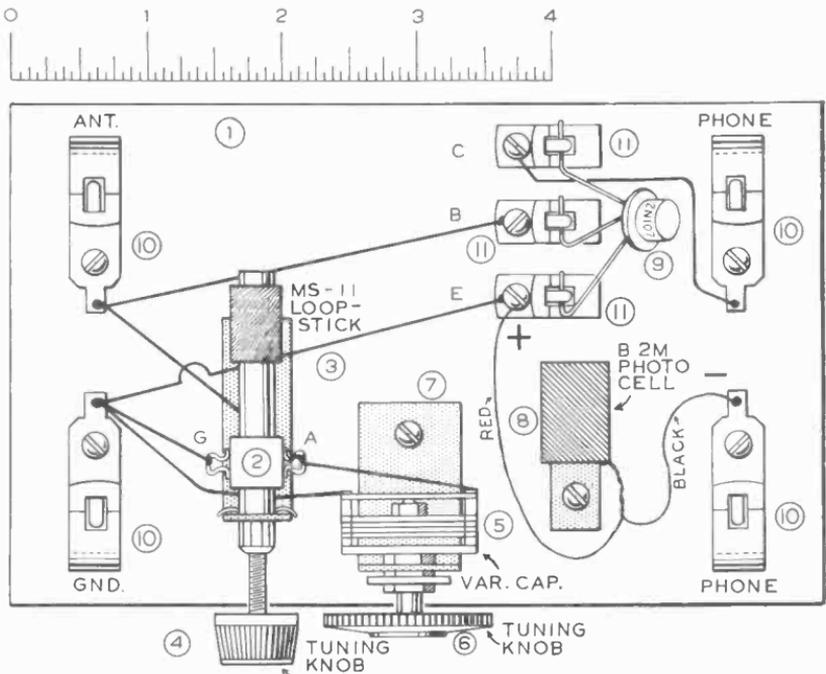
Fasten both brackets to the wood base before attaching either the loopstick or capacitor. Otherwise it will be impossible to put in the screws that hold the brackets to the base. To mount the loopstick on its bracket, push the end from which the threaded shaft projects into the large hole until it locks in place. If an MS-445 tuning capacitor is used, push the threaded bushing on the front of the capacitor through the large hole in the bracket and fasten it with a hex nut. Before tightening the nut, turn the capacitor so that the solder lug terminals are at the top. Both solder lugs are connected to the same terminal of the capacitor. The other terminal of the capacitor is the bracket. When an MS-946 capacitor is used, fasten it to its bracket with the two small machine screws packed with the capacitor.

Hooking up. The components can be connected without soldering. It is recommended, however, that the ends of all wires be soldered except the terminal wires of the transistor, diode, and .02-mfd fixed capacitor. The terminals of these three components should be clamped in the small Fahnestock clips. Use only rosin-core solder in making the soldered connections.

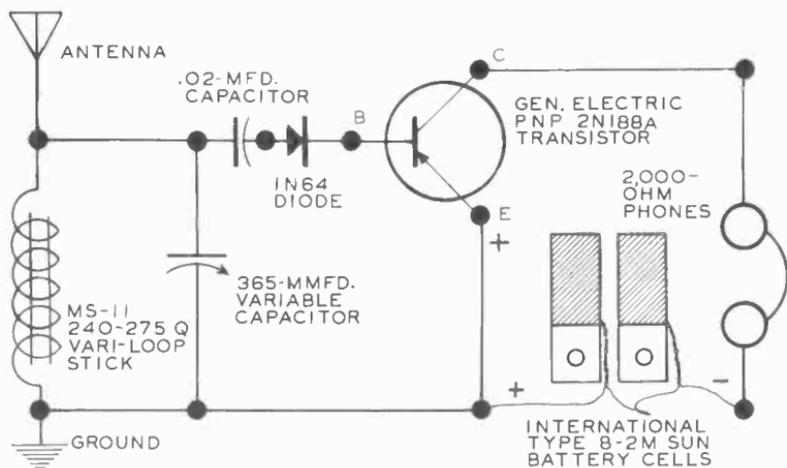
The directions for building the receiver with a transistor detector explained that there is an 18-inch length of wire wrapped loosely around the loopstick. One end of this

wire is attached to one of the loopstick terminals. Turn the loopstick so that the loopstick terminal to which the wire is connected is on the right hand side. Unwind the wire and detach it from the terminal. Solder two pieces of hookup wire to terminal A. Connect one of these wires to the tuning capacitor bracket and the other to the Fahnestock clips marked H and ANT. The other terminal of the loopstick (marked G) should be connected to Fahnestock clip GND.

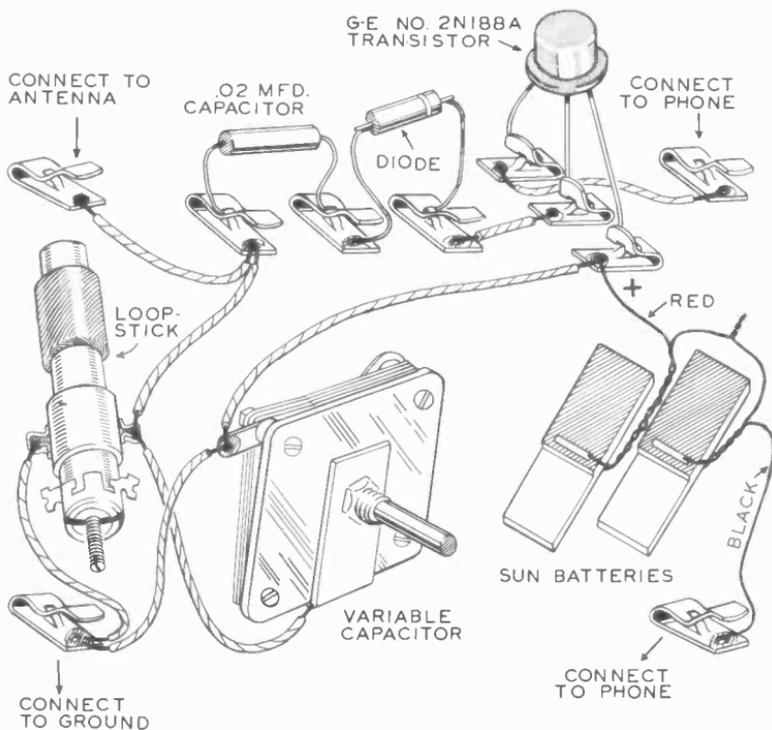
One of the illustrations identifies the terminal wires on the PNP 2N188A transistor (12). The letters E, B, and C alongside the small clips in the plan indicate EMITTER, BASE and COLLECTOR, respectively. The ends of the terminal wires on the transistor should be bent at right angles and the EMITTER connected to clip E, the BASE to clip B, and the COLLECTOR to clip C.



PLAN OF RADIO RECEIVER WITH DIODE DETECTOR AND TRANSISTOR AMPLIFIER



SCHMATIC OF THE CIRCUIT DIAGRAM



PICTORIAL CIRCUIT OF DIAGRAM OF RECEIVER

Two photovoltaic cells are required to operate the G-E PNP 2188A transistor satisfactorily in its role of amplifier. When performing as an amplifier, the transistor increases the strength of the signals produced in the phones. The cells are mounted on the base alongside each other and to the right of the tuning capacitor. The red wire on each cell is the **POSITIVE** terminal, and the black wire is the **NEGATIVE** terminal. The cells must be connected in series so that the battery thus formed will deliver twice the voltage of a single cell. The **POSITIVE** terminal must be connected to clip **E** and the **NEGATIVE** terminal to the clip marked **PHONE** at the front right-hand corner of the base.

Operation. An antenna 35 to 50 feet long should be connected to the **ANT** clip. An indoor antenna can be used in localities where there are broadcasting stations within a few miles. An earth or ground connection is also required. The wire should be connected from the **GND** clip to a water pipe, steam radiator, or other nearby grounded object.

Connect a 2,000-ohm telephone headset to the two clips marked **PHONE**. Place the radio receiver where bright sunshine will fall upon the photovoltaic cells. Adjusting the knobs on the loopstick and tuning capacitor should bring in the signals of any broadcast station within 50 miles. The first time a station announces its call letters and identifies itself, determine its frequency in kilocycles by referring to a radio program. Then adjust the tuning dial so that the numerals indicating the same frequency embossed on the dial coincide with a black mark made on the base immediately under the dial. The dial provided with the capacitor is molded plastic and is calibrated with six numbers indicating a frequency range of 530 to 1,600 kilocycles. These frequencies constitute the U. S. Broadcast band.

When sunshine is not available, the receiver can be operated by artificial light. The light from a 150-watt incan-

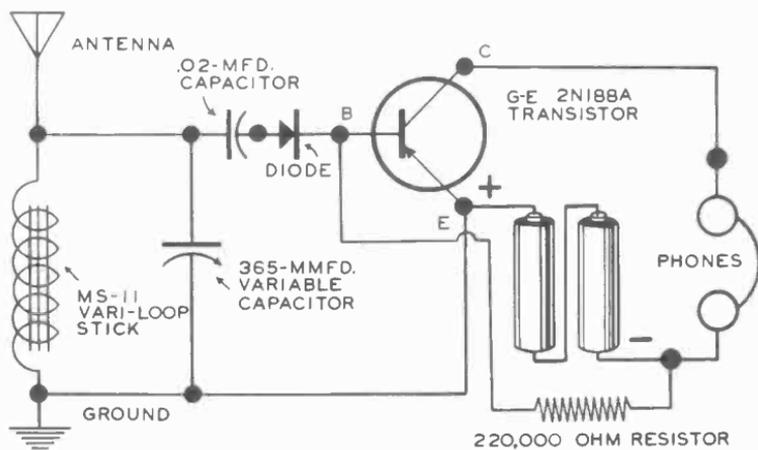
descent lamp, two to three feet from the receiver, will produce good signals.

How to Operate the Receiver on Dry Battery Power

The receiver can easily be changed to operate on power from a dry battery when sunshine or artificial light is not available to energize the photovoltaic cells.

Disconnect the terminals of the two photovoltaic cells from the Fahnestock clip marked **PHONE** and from the Fahnestock clip **E** connected to the **EMITTER**. Solder two terminal wires about 10 inches long to a battery holder for two size-AA penlite cells. Solder a short piece of wire to the contacts on the battery holder so that the two cells will thus be in series when placed in the holder.

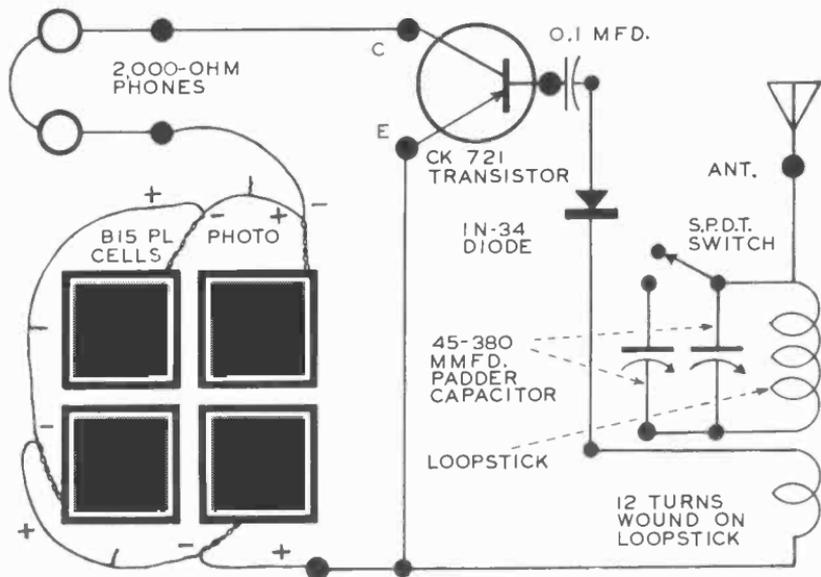
Connect the positive terminal of this 3-volt battery to the small Fahnestock clip to which the transistor's **EMITTER** is connected. This is marked **E** in the plan and circuit diagrams. Connect the negative terminal of the battery to the



SCHEMATIC CIRCUIT DIAGRAM SHOWING HOW TO SUBSTITUTE TWO DRY CELLS FOR THE SUN BATTERY

Fahnestock clip marked **PHONE** at the lower right-hand corner of the base. The receiver is then ready to operate. To conserve the dry cells when the receiver is not in use, remove them from their holder.

One of the illustrations is a schematic circuit diagram in which two dry cells have replaced the photovoltaic cells. The diagram shows a 1/2-watt, 220,000-ohm resistor con-



AN OPPORTUNITY TO BE YOUR OWN TECHNICIAN AND ELECTRONICS ENGINEER

This is a schematic circuit diagram for a simple radio receiver with a transistor amplifier operated by four photocells. Constructional details are not supplied. Study the circuit carefully and make a list of the components required and the specifications of each. When the components have been purchased, make a full-size drawing of a suitable wood base with the parts arranged on it. The amplifier is a CK 721 high-gain transistor. The detector is a 1N34 germanium diode. Four photoelectric cells connected in series are required to supply sufficient voltage to the amplifier. Notice that the loopstick is one of the type with three terminals.

nected from the small Fahnestock clip to which the transistor **BASE** is connected (marked **B** in the diagram) to the negative terminal of the battery. It is not necessary to use this resistor, but it will probably improve the signals if added to the circuit.

*SILICON CELLS—THEY CONVERT THE SUN'S
RADIANT ENERGY DIRECTLY INTO USEFUL
ELECTRICAL ENERGY • Uses for Silicon Cells.
Sunshine Will Operate an Electric Motor.
Experimental Solar Powerhouses.*

Our sun, that brilliant celestial body round which the Earth and other planets revolve, sends out a vast amount of energy. Only a small portion of the total energy radiated by the sun reaches the Earth; this small portion which does is still a fantastic amount of energy. It is more than that produced by all the motors, engines, generators, and power dams in the world.

Anything that can be converted into work and that can arise from work is ENERGY. Energy can also be the capacity for doing work. It is reliably estimated that our planet receives more than 1,000,000,000,000,000 kilowatt hours of electrical power energy from the sun each day. You can better understand what a tremendous amount of energy this is when you consider that a 100-watt bulb lighted for ten hours consumes one kilowatt hour of electrical energy. (Kilo means 1,000. A kilowatt is a 1,000 watts.)

Energy has different forms. Those forms of greatest interest and use in electronics are radiant, electromechanical, and chemical energy; and heat, light, and electricity.

Scientists have long been aware of the tremendous energy reaching us from the sun, 93,000,000 miles distant, and have dreamed of converting it into useful power. Working models of many devices for that purpose have been made from time

to time. Most of these plans for utilizing solar power have been arrangements for focusing sunlight with mirrors or lenses so as to concentrate its heat energy on a hot air engine or the boiler of a steam engine in order to utilize the heat energy to power the engine. Until 1954 it was not possible to convert more than a small fraction of the energy in sunlight into a useful form of power. But basic research on the properties and characteristics of semiconductor materials used in the manufacture of transistors revealed new possibilities for harnessing sunlight.

In April, 1954, Bell Telephone Laboratories announced the invention of the Bell Solar Battery, an event of great scientific importance. At long last, a significant percentage of the sun's radiation reaching the Earth could be converted DIRECTLY into useful amounts of electric current. No elaborate apparatus, no machines, no moving parts were necessary.

In the early days of its development, the Bell Solar Battery converted 6 per cent of the light energy that shone upon its surface into electric current. Silicon solar cells are now manufactured that convert 12 per cent of the energy they receive from sunshine into electrical power. This makes the efficiency of silicon solar cells favorably comparable to that of the best gasoline and steam engines.

Description of a Silicon Solar Cell. A scientific team consisting of G. L. Pearson, D. M. Chapin, and C. S. Fuller of Bell Telephone Laboratories invented the Bell Solar Cell while doing basic research on the properties and characteristics of the element SILICON, a semiconductor material. As explained previously, silicon is one of the earth's most abundant materials. Oxygen is the most abundant element, silicon is second.

The process of manufacturing silicon solar cells is very complex and requires some forty different processes. It

begins with the chemical refining and purification of silicon to the point where it contains only one part of impurity in one billion parts of silicon.

The present standard commercial silicon cell without its terminals and mount appears to be a rectangular wafer of brown or dark blue-gray silicon. Actually, it consists of two layers of silicon, each of which contains a different, carefully controlled, chemical impurity. One layer is made of ultrapure silicon to which has been added a tiny amount of the element arsenic at a ratio of about one part arsenic to one million parts of silicon. This arsenic-doped silicon is called negative, or N-type, silicon and is rich in electrons. (The letter N is an abbreviation for negative. Electrons are negative particles of electricity.) The second layer is made of ultrapure silicon to which has been added a very small amount of the element boron. The boron-doped layer is positive, or P-type, silicon. It is deficient in electrons but rich in positive charges called HOLES. (The letter P is an abbreviation for positive.)

The Effect of Light on a Silicon Solar Cell. P-type silicon and N-type silicon have different electrical conductivity. When a wafer of P-type silicon is placed in intimate contact with a wafer of N-type silicon, there is a boundary area, or junction, between them called the P-N junction. It is located about 1/10,000 of an inch beneath their contacting surfaces. In this thin barrier between an electron-rich region and a hole-rich region, there exists a strong electric field. An electric field exerts a force on both electrons and holes and causes them to move when they are free to do so. It moves holes in one direction and electrons in the opposite direction.

When light penetrates doped silicon crystals, it liberates electrons and holes so that they are free to move. The electric field formed by moving electrons then forces free elec-

trons to one side of the barrier, making it negatively charged. The free holes are forced to the other side, making that area positively charged. This displacement and forcing of the newly freed positive holes and negative electrons into two groups produces a voltage between the two layers in the cell. This voltage is the source of the electrical energy produced by a silicon solar cell.

Connecting the cell terminals to an external circuit permits a current to flow. Thus the direct conversion of light energy into electrical energy is accomplished without elaborate apparatus or moving parts.

Uses for Silicon Solar Cells

Silicon solar cells are now manufactured under the Bell patents by Hoffman Electronics Corporation and International Rectifier Corporation. The cells are listed in the catalogs of several electronics distributors and are available to the amateur experimenter. Cells may be connected in groups to form SOLAR BATTERIES. Solar batteries have begun to find use in many industrial and military areas. With further development they are likely to bring amazing and beneficial changes in our everyday life.

By far the most glamorous use for silicon solar batteries up to the present has been in satellites and space vehicles. The U. S. weather-eye satellite Tiros is equipped with 9,260 silicon solar cells that keep its nickel-cadmium storage batteries charged.

The U. S. Coast Guard is using silicon solar batteries to recharge the storage batteries that operate coastal navigation lights and warning beacons. Extremely small silicon cells with an active area of approximately .01 square inch are used extensively in electronic computer operations to read film and punched tape and cards.

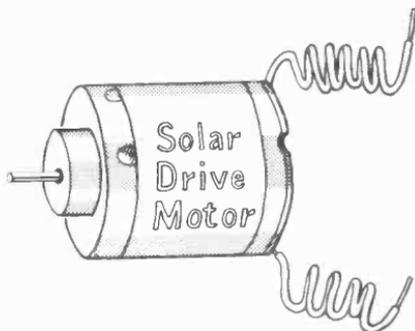
Sunshine Will Run an Electric Motor

One of the most impressive demonstrations of the conversion of the radiant energy of sunshine into electrical power occurs when photovoltaic cells are used to drive an electric motor. This is an excellent science fair project. The process occurs in three stages. First, the radiant energy of sunlight is converted into electrical energy. This electrical energy is then converted into electromagnetism. The electromagnetism then produces mechanical energy that turns the motor.

Special motors are required for this demonstration. Suitable for the purpose are the International Rectifier Solar Drive Motor and the Distler, or Aristorev, D. C. Ball-Bearing Motor. Both of these are available at many hobby shops. The International motor is manufactured in Japan and distributed in this country by International Rectifier Corporation, 1521 East Grand Ave., El Segundo, Calif. 90245. The Distler, or Aristorev, motor is manufactured in Belgium. It is distributed in the U. S. by the Aristo-Craft Company, 184 Pennsylvania Ave., Newark, N. J. 07114. Both motors have anti-friction bearings and operate on direct current only. The



WOOD PULLEY



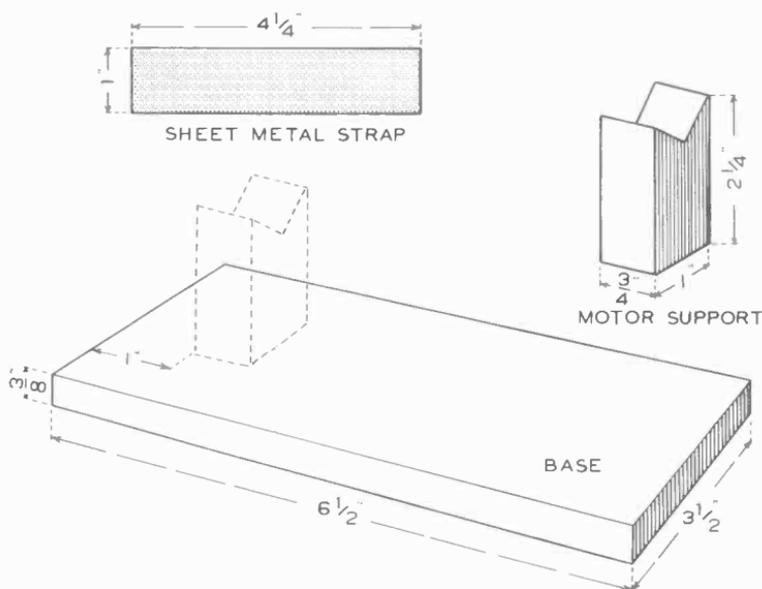
A SMALL, EFFICIENT, BALL-BEARING MOTOR

The commutator and brushes are small in order to reduce friction. The motor will revolve at good speed on the current generated by two to four silicon solar cells exposed to bright sunlight.

Distler motor is listed in the catalog of Lafayette Radio Electronics Corporation at \$2.69.

Either motor will run nicely on the current generated in bright sunlight by two S5M selenium cells or four S1M silicon cells. They are the most efficient small motors on the market at present. It is necessary to use a motor of the Distler or Solar Drive type because of the extremely low voltage and low current produced by solar cells. Many small motors, particularly those that retail for less than \$2.00, require more power than is produced by two or three small solar cells. When acquiring a motor to demonstrate the motive power in sunshine, make certain that it is one of the special motors named above or a similar type.

Motor Mounting. For the best demonstration, mount the

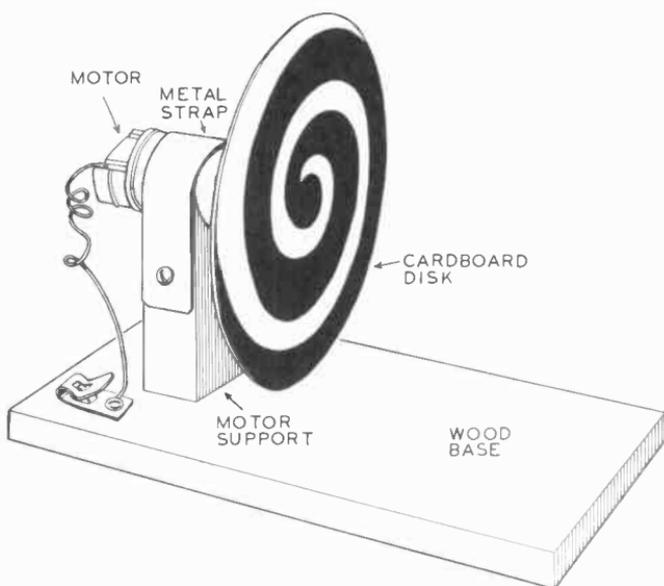


HOW TO MOUNT THE MOTOR ON THE BASE

The parts used to mount the motor on a wood base are easily made in the school or home workshop.

motor in a V-shaped groove cut in a wood block fastened to a 6-1/2-inch x 3-1/2-inch wood base. The motor is secured to the block by a strap of sheet metal. The terminals of the motors designed to be operated by solar cells are two flexible wire leads. These wires sometimes break when handled too much. They should be connected to two binding posts or Fahnestock clips on the wood base so that it will not be necessary to disturb the wires when connecting or disconnecting the motor. If a small switch is included in one of the wires between the motor and the solar cells, the motor can be stopped and started at will when the cells are in bright sunshine.

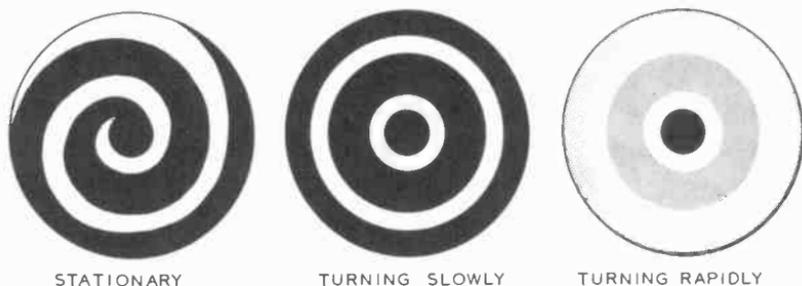
A cardboard disk about 3-1/2 inches in diameter, mounted



SCIENCE FAIR DEMONSTRATION

The revolution of the motor shaft is more readily seen by an audience when the motor shaft is equipped with a cardboard disk bearing a spiral pattern.

on the shaft, will make the motor's motion more visible. If the disk bears a design, such as a spiral, it makes a more attractive demonstration of the conversion of energy. The disk must be accurately centered and should not wobble.



THE CARDBOARD DISK SHOULD BE ABOUT $3\frac{1}{2}$ INCHES IN DIAMETER

Four S1M silicon cells connected in series-parallel have an output of 0.6 to 0.90 volt and 20 to 32 milliamperes when in full sunlight. They will run either the Solar Drive or Distler motor. The S3M and S5M cells contain two selenium elements connected in series in each cell, thereby doubling the output voltage. The S3M has an output of 0.6 to 0.85 volt and 10 to 16 milliamperes. The S5M cell is an extra-high efficiency selenium type with an output of 0.6 to 0.85 volt and 18 to 25 milliamperes. These output figures were obtained in full sunlight, using conventional volt and milliamperage meters.

Two S3M cells or two 85M cells connected in parallel will run either motor at moderate speed in full sunshine. When sunshine is not available, the light from a 150-watt, reflector-type, incandescent lamp can be substituted.

The motor can be tested by connecting the terminal wires to a 1.5-volt flashlight cell. This should drive the motor at high speed. It is advisable not to connect the motor to more than one flashlight cell. If a motor fails to run after con-

siderable use, the failure is often due to dirt on the commutator and brushes. These can be cleaned with a swab made by wrapping a small tuft of cotton around the end of a toothpick. The cleaning is a delicate procedure and practically a job for a watchmaker.

Experimental Solar Powerhouses

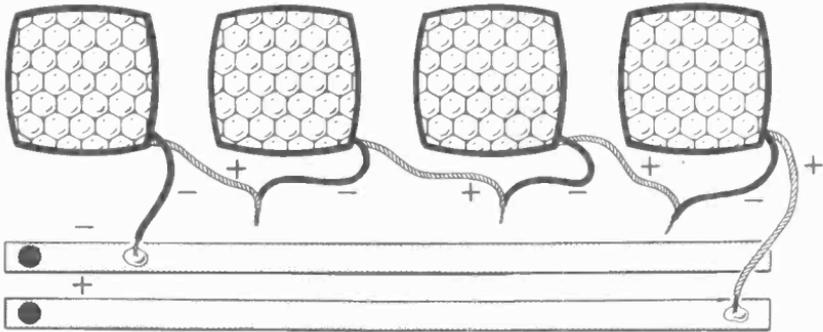
There is no limit (except the expense) to the amount of electrical power that can be produced from sunlight by photovoltaic cells. More power is obtained by using more cells. Both selenium and silicon photovoltaic cells can be used, but it is advisable not to use both varieties in the same circuit.

Four S1M (silicon), four S3M (selenium), or four S5M (selenium) photovoltaic cells mounted on a wood base make a practical experimental solar powerhouse. They can drive a small motor or otherwise demonstrate the production of electric current from sunshine.

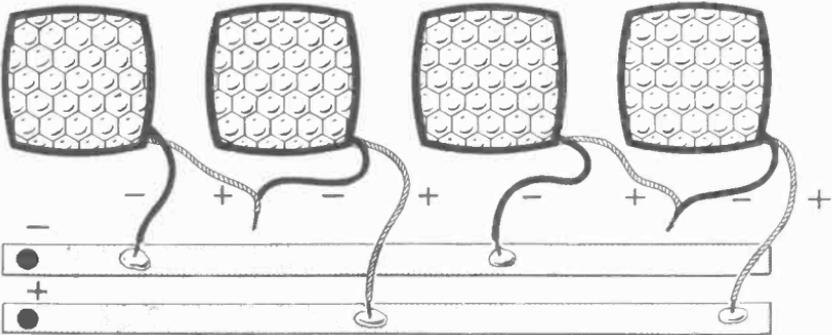
A silicon photovoltaic cell will deliver more power than a selenium photovoltaic cell of equal size when exposed to the same light. Selenium photovoltaic cells are lower priced. Unmounted selenium photovoltaic cells of the flat type (not in a molded plastic case) are often available at bargain prices. If the flat type of selenium photovoltaic cell is used to build a solar powerhouse, each cell should have a sensitive surface area of at least two squares inches if the powerhouse is to be used for driving a motor.

Small photovoltaic cells can be attached to a wood base, in fact to almost any surface, with Duco cement or with double-faced, pressure-sensitive adhesive tape. Peel the backing from one side of the tape and press the tape against the back of the cell. Then remove the backing from the other side of the tape and press the cell against the spot where it is to be mounted. The terminal leads of the photovoltaic

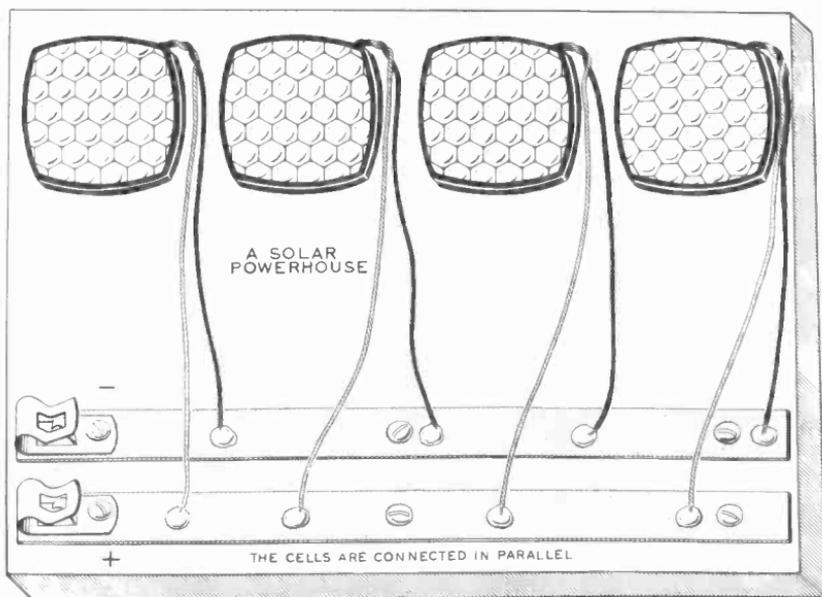
cells are soldered to two BUS BARS. In an electrical device, a bus bar is one of the main bars or conductors carrying an electric current. In this instance these are strips of thin sheet copper, 1/2 inch wide and about 1/4 inch shorter than the wood base. A Fahnestock clip is mounted at one end of each strip. Each strip is fastened to the base with three small round-head brass screws.



A SOLAR POWERHOUSE CONSISTING OF FOUR S1M SILICON CELLS CONNECTED IN SERIES



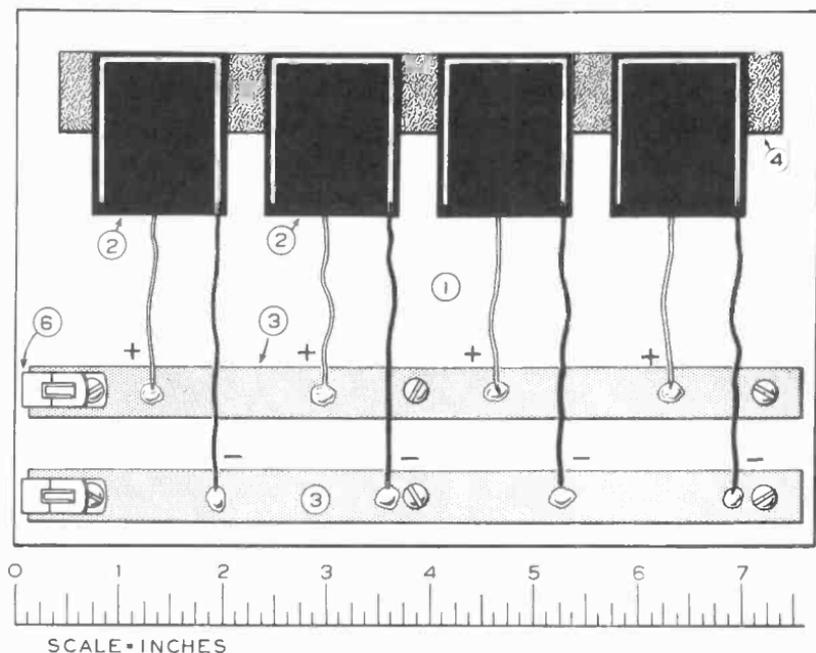
A SOLAR POWERHOUSE CONSISTING OF FOUR S1M SILICON CELLS CONNECTED IN SERIES-PARALLEL



FOUR SIM SILICON CELLS CONNECTED IN PARALLEL

How to Connect the Cells to Obtain Maximum Power. Four photovoltaic cells can be connected in three ways: **SERIES**, **PARALLEL**, and **SERIES-PARALLEL**. All three methods are illustrated. (The term **MULTIPLE** is often used in books on electronics as a substitute for the word **PARALLEL**. They mean the same thing. The **CURRENT** is increased by connecting cells in **PARALLEL**. The **SERIES-PARALLEL** connection doubles both current and voltage. The following table shows the comparative outputs of the three methods of connecting four SIM silicon cells.

	SERIES	PARALLEL	SERIES-PARALLEL
Volts	1.2 to 1.80	0.3 to 0.45	0.6 to 0.90
Milliamperes	10 to 16	40 to 64	20 to 32

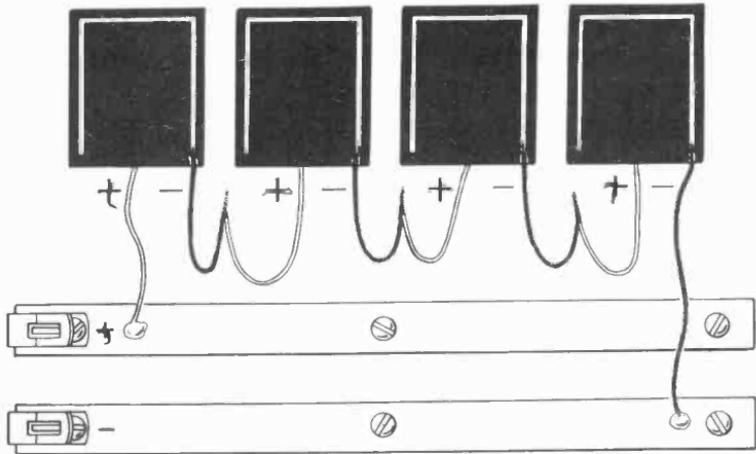


A SOLAR POWERHOUSE COMPOSED OF FOUR SMALL SELENIUM CELLS WITHOUT PLASTIC CASES

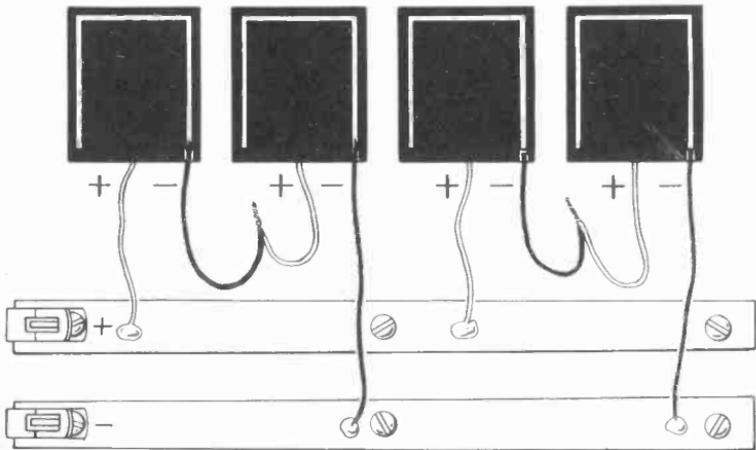
The cells are shown connected in multiple (same as parallel). They may be connected in series or in series-multiple (series-parallel), depending upon the voltage and current output that will be most suited to the load. (See the next illustration.)

The greatest efficiency is obtained from photovoltaic cells when the load is "matched to the cells." The load resistance of the motor, relay, etc., for a silicon cell operated in sunlight should be in the 15- to 20-ohm range. The load for selenium cells should be from 75 to 125 ohms to obtain the most efficiency. The Distler and Solar Drive motors have a load resistance of about 4 ohms when stationary. When turning at moderate speed, their effective load resistance is approximately equivalent to 35 ohms. Therefore, it is more efficient

SERIES



SERIES-MULTIPLE

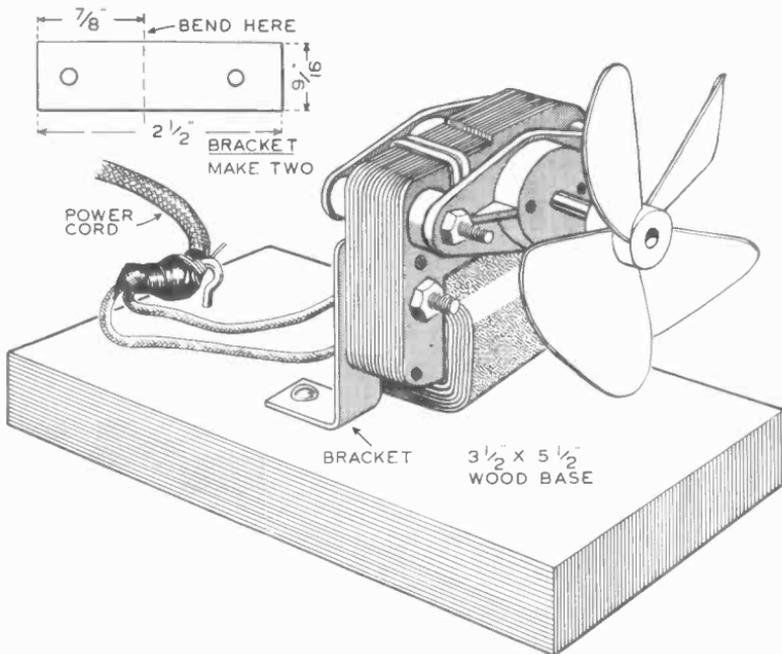


SERIES AND SERIES-MULTIPLE CONNECTIONS FOR FOUR CELLS

to drive these motors with silicon cells than with selenium cells. The most effective way to connect several cells to

match the load is often best determined by experimenting.

The terminals of small selenium and silicon photovoltaic cells are usually two small flexible wires. One wire is red and the other is black. The red wire is the positive terminal; the black wire is the negative terminal. If a number of similar cells are to be connected in series, the red wire (positive terminal) of each cell is connected to the black wire



AIR CONDITIONING FOR SOLAR CELLS

When artificial light (from an incandescent lamp) is used to demonstrate a solar powerhouse, the lamp must be close to the cells. The heat generated by the lamp will damage the cells unless they are cooled. This can be accomplished by one of the small, low-cost, motor-driven fans of the type used to cool radio tubes. The illustration shows a suitable small motor and fan mounted on a wood base. The motor is fastened to the base by means of two L-shape metal brackets.

(negative terminal) of the next cell. The voltage between the free ends of the group will be increased in direct proportion to the number of cells in series. The series arrangement, however, will not deliver any more current, or quantity of electricity, than a single cell. The parallel method of connection is to connect all the positive terminals together and all the negative terminals together. When the cells are joined in this way, the voltage is the same as that of one cell, but the current is greater. When both greater voltage and current than one cell can deliver are desired, the cells should be connected in series-parallel.

*THE STOCKMAN MOTOR • A Transistor Motor
that Will Run on Solar Power.*

This fascinating new variety of electric motor is a direct-current machine. It was developed by Dr. Harry E. Stockman, professor of electrical engineering at Lowell Technological Institute, Lowell, Mass. It is unique in principle and design when compared to an ordinary direct-current motor. The latter type usually has a commutator and two brushes that conduct current to a revolving armature, as in the Distler and Aristorev motors described in the last chapter. These parts are subject to wear due to friction and require proper maintenance in an industrial motor. The Stockman motor has neither commutator nor brushes; there is no electrical connection with the rotating part (the armature). A transistor makes this design possible.

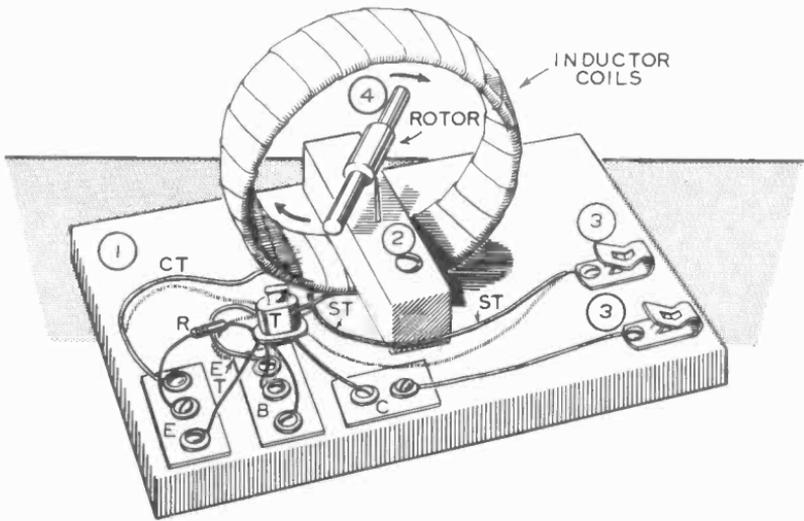
Modern direct-current motors have characteristics that make them more desirable than alternating-current motors for some purposes. For example, the turning power, or TORQUE, of a direct-current motor, when starting and at low speed, is much greater than that of an alternating-current motor of equal size at the same speed. In addition, the speed of a direct-current motor can be more easily and widely varied by control devices.

The Stockman motor is not yet ready for commercial use. The principle of the motor is apparently capable of much further development. But it is reasonable to predict that industrial direct-current motors without commutators, brushes, or moving contacts will be manufactured some day.

You will have to make your own parts for this model of a Stockman motor. The model described in the following pages will run at high speed when connected to four SIM silicon cells connected in series-parallel. The solar cells must be in bright sunlight. In the absence of sunlight, artificial light may be used. When desirable, two penlight batteries connected in series may be substituted for the solar battery.

The armature of the motor is a small permanent magnet in the form of a round bar. It is pivoted at its center on a needle point so that it can spin with a minimum of friction in the magnetic field of two coils of wire called INDUCTOR coils. These coils, together with a transistor, a resistor, and the motor terminals, are mounted on a wood base.

Probably a greater degree of mechanical skill and care



A HOMEMADE SUN-POWER TRANSISTOR MOTOR

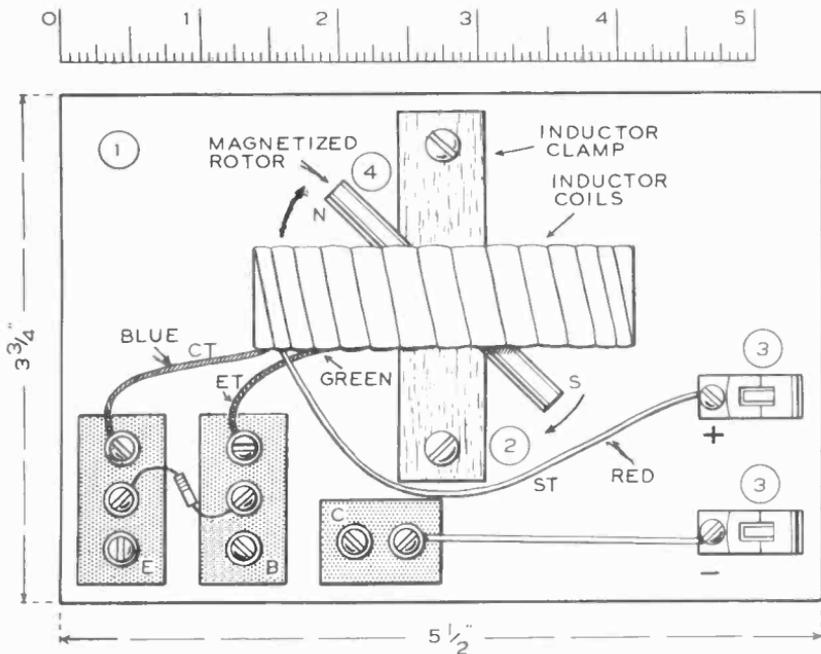
A model of a unique type of motor developed by Dr. Harry E. Stockman, professor of electrical engineering at Lowell Technological Institute. 1, Base. 2, Inductor clamp. 3, Motor terminals. 4, Rotor. T, Transistor. R, Resistor. E, B, C, Terminal plates connected respectively to the EMITTER, BASE, and COLLECTOR.

is necessary to wind the coils and make the rotor for the motor than is required for the construction of any other project in this book. High school students who can use the facilities of the school shop will find access to a lathe, drill press, and grinder of great help.

The following parts and materials are required to make the transistor motor:

- 1 Wood base, 5-1/2 in. x 3-3/4 in. x 1/2 in. (1)
- 1/4 lb. No. 34 B&S enamel magnet wire
- 1 GE 2N107 PNP transistor (T)
- 1 1/2-watt, 1,500-ohm resistor with gold band (R)
- 1 Wood strip (inductor clamp) 2-3/4 in. x 5/8 in. x 5/8 in. (2)
- 1 Round wood core 2-7/16 in. in diameter x 3/4 in. thick
- 2 Stiff cardboard disks, 3-3/4 in. in diameter x 1/16 in. thick
- 2 Pieces brass or copper sheet 1-1/4 in. x 9/16 in.
- 1 Piece brass or copper sheet 7/8 in. x 9/16 in.
- 2 Binding posts or Fahnestock clips (3)
- 2 Round Alnico No. 5 permanent bar magnets, 1 in. long x 3/16 in. in diameter (4)
- 1 Small darning needle
- 1 Piece copper, brass, or steel tubing, 5/8 in. long with inside diameter of 3/16 in.
- 1 Piece steel drill rod 3/16 in. in diameter and 1/4 in. long
- 8 Small brass washers which will slip over No. 4 brass screws
- 1 8-penny finishing nail
- 2 No. 7 round-head brass wood screws, 1 in. long
- 1 1/4-in. x 2-in. round-head stove bolt and washer
- 1 Sheet No. 00 sandpaper
- 1 2-in. x 1/4-in. round-head stove bolt
- Roll of 3/4-in. masking tape, hookup wire, white shellac, Krylon crystal-clear lacquer in spray can, 3/4-in. wide paper strips

Start to build the motor by making a wood base 5-1/2 inches long, 3-3/4 inches wide, and 1/2 to 3/4 inch thick



PLAN OF THE SUN-POWER TRANSISTOR MOTOR

The transistor is not shown in this illustration. The emitter, base, and collector terminals of the transistor should be connected respectively to terminal plates E, B, and C. ST indicates the starting turn of the inside coils; CT, the center tap between the two coils; ET, the end turn of the outside coil.

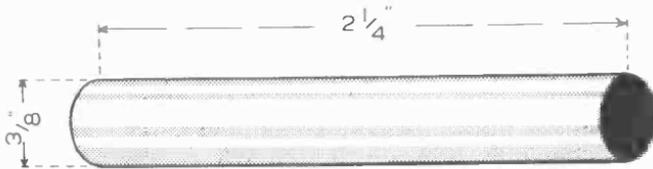
from seasoned lumber. Smooth all surfaces with fine sandpaper and apply a coat of white shellac or varnish. Apply a second coat when the first is dry.

The bar magnet that forms the rotor may be a piece of hardened, magnetized carbon-steel drill rod or it may consist of two round Alnico bar magnets joined together by a short piece of tubing. Both types are illustrated. Some skill in metal-working is required to make either type of rotor.

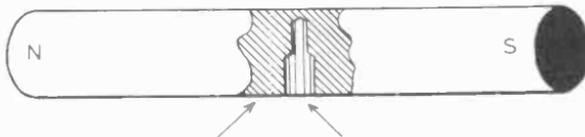
The rotor made of drill rod is easier to make but will not be as strong a magnet and will not perform as well as the rotor made of Alnico magnets.

Carbon-steel drill rod is used in machine shops for making small tools and steel parts. It is sold in 3-foot lengths by dealers in mill and machinist's supplies. Your shop teacher may be able to provide a piece $3/8$ -inch in diameter or tell you where to purchase it.

Cut off a piece exactly $2-1/4$ inches long. The rod can be cut slightly oversize with a fine-tooth hacksaw and finished to exact size by filing. The best way to cut the rod accurately is to chuck it in the headstock of a metal turning lathe and use a machinist's cutting-off tool.



CARBON STEEL DRILL ROD



CROSS-SECTION SHOWS BEARING FORMED BY DRILLING DRILL $3/16$ " DEEP WITH NO. 27 DRILL $5/16$ " DEEP WITH NO. 52

DETAILS OF MAGNETIZED ROTOR MADE OF DRILL ROD

Rotor Bearings. Use a center punch to make an indentation exactly in the center of the rod $1-1/8$ inches from each end. Clamp the drill rod in a vise, and center the point of a No. 52 twist drill in the punch mark. Drill a hole in the rod

5/16-inch deep. Drill slowly and carefully so as not to break or overheat the small drill. Apply a drop or two of thin oil to the drill. When the hole is 5/16-inch deep, withdraw the drill and counterbore the hole to a depth of 1/8 inch with a No. 27 twist drill. The cavity thus formed by drilling is the rotor bearing. When the motor is completed, the bearing rests on the point of a needle. The completed rotor **MUST BALANCE**. Test it on a needle point. If one end drops below the level of the other, file or grind enough metal off the lower or heavier end to make the rotor rest in a horizontal position.

When a piece of **SOFT** steel is magnetized it does not retain much magnetism after the magnetizing force is removed. In order to retain sufficient magnetism (residual magnetism) to be a useful permanent magnet, steel must be hardened before it is magnetized.

The rotor is hardened by heating it in a gas flame or a charcoal fire until it is bright red. While still red hot, it is plunged into a bucket of cold water. Cut a piece of stiff iron wire about 15 inches long from a wire coat hanger and twist one end around the center of the rotor. The wire will serve as a handle for placing the rotor in the fire and water. Allow the rotor to remain in the water until cold. When cold, it will be "glass hard" and is then ready to be magnetized.

Wrap about 125 turns of No. 14 or 16 B&S insulated magnet wire around the rotor. Connect one end of this wire to the positive terminal of a fully charged, 6-volt, automobile storage battery. Do not allow the current to flow through the wire for more than a second or two, or the wire will become very hot. "Make and break" the circuit twenty to twenty-five times in this manner. Then remove the wire from the rotor. The rotor will now be a fairly strong bar magnet.

This rotor made of 3/8-inch magnetized carbon steel drill rod will not have as much residual magnetism as a rotor made of two Alnico round bar magnets 3/16-inch in diam-

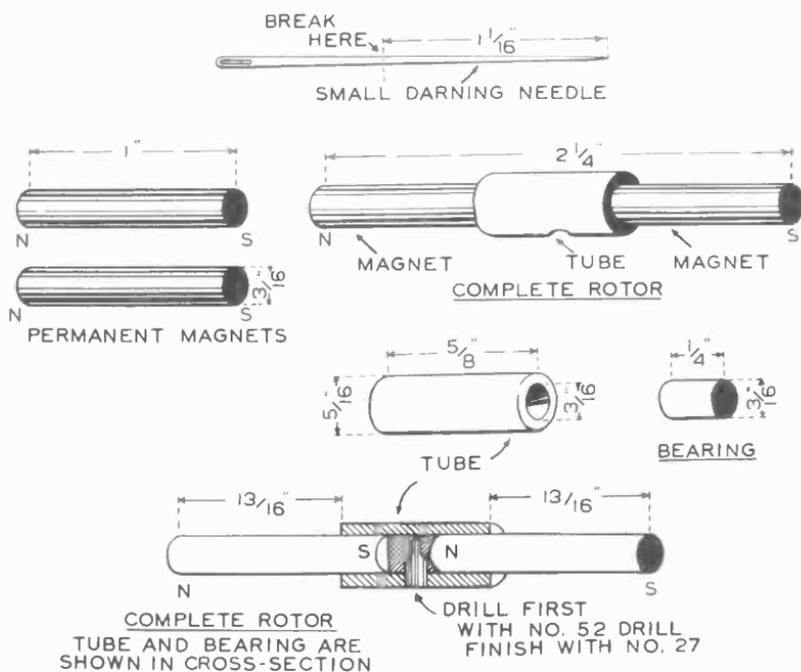
eter and 1 inch long. Both types of rotor will perform satisfactorily when the motor is connected to two 1.5-volt flashlight cells in series, but the motor with the Alnico magnets will run faster. And a motor with an Alnico rotor will require less sunlight on its solar cell.

Round Alnico bar magnets, 1 inch long and 3/16 inch in diameter, for making a rotor may be purchased by mail from either of these firms:

Miami Magnet Company, 3240 N. W. 27th Ave., Aviation Bldg. No. 43, Miami, Fla. 33133.

Terry Sales Corporation, 1041 Silver Beach Road, Riviera Beach, Fla. 33404.

The minimum order accepted is \$1.00. Send a check or



DETAILS OF ROTOR MADE OF TWO ALNICO MAGNETS

money order for that amount and you will receive five or six of the magnets postpaid.

Alnico Magnet Rotor. The magnets should be joined by forcing one end of each into a metal tube $\frac{5}{8}$ inch long and having an internal diameter of $\frac{3}{16}$ inch. The ends of the magnets in the tube are separated by a piece of iron or steel rod $\frac{3}{16}$ inch in diameter and $\frac{1}{4}$ inch long (marked BEARING in the illustration showing the details of the magnetized rotor.) A piece of copper tubing having an outside diameter of $\frac{1}{4}$ inch can be purchased from an automobile service station. The inside diameter of the tubing will probably be slightly under $\frac{3}{16}$ inch. It can be brought to size by reaming with a $\frac{3}{16}$ -inch twist drill. A piece of tubing $\frac{5}{8}$ inch long is required. The $\frac{1}{4}$ inch x $\frac{3}{16}$ inch piece of round iron or steel rod will be the rotor bearing. It must be pushed into the tube until it is in the center, equidistant from each end. The north (N) pole of one magnet is pushed into the tube until it touches the bearing. The south (S) pole of the second magnet is pushed into the opposite end of the tube until it also touches the bearing. The bearing and the magnets can be permanently fastened in place with a small amount of an epoxy cement such as "Plastic Steel."

It has already been explained that the CENTER of the rotor is drilled to a depth of $\frac{3}{16}$ inch with a No. 52 twist drill and counterbored to a depth of $\frac{1}{8}$ inch with a No. 27 twist drill. When the rotor is set on a needle point, it must rest in a horizontal position. If one end rests down at an angle, showing that it is heavier than the opposite end, grind off some of the metal from the heavy end. Continue this adjustment until the rotor balances horizontally.

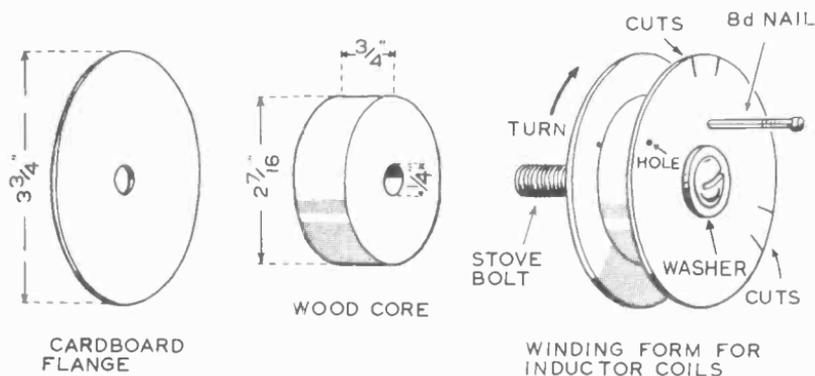
How to Make the Winding Form and Wind the Coils

The sketch of the complete motor does not reveal that

there are two coils concealed under the tape covering. But when the circuit diagram is examined, it will be seen that there are. They are concentric coils; that is, they have a common center. They are close together; one coil is wound over the other. When an electric current flows through either coil, a magnetic field is created within and around it. The field exists as long as the current flows and for a fraction of a second after the current ceases.

Each coil consists of 900 turns of No. 34 B&S gauge, enamel-insulated magnet wire wound on a homemade winding form. Slightly less than 1/4 pound of the wire is required. This is enough for both coils. (One quarter of a pound of magnet wire is usually the smallest amount sold. It is supplied on a metal or wood spool.)

The winding form is spool-shaped. It has a wood core 2-7/16 inches in diameter and 3/4 inch wide. The core is turned on a lathe. The two flanges are disks 3-3/4 inches in diameter and are made of stiff cardboard 1/16 inch thick. They are cemented to the sides of the core. If necessary, the flanges can be stiffened by applying two coats of shellac. A 1/4-inch hole is drilled through the center of both flanges and the core. A 1/4-inch round-head stove bolt, 2 inches



THE FORM FOR WINDING THE COILS

long, is slipped through the hole. When the end of the bolt is clamped in a bench vise, it serves as a shaft around which the winding form rotates. An 8-penny finishing nail is driven into one side of the form, $7/8$ inch from the center, and used as a crank to turn the form. A washer next to the head of the bolt and another washer on the bolt between the vise and the adjacent flange will reduce friction.

Cut several strips of paper $3/4$ inch wide and 2 feet long. Smear both sides of the strips with Vaseline. Wind them snugly around the wood core until the latter is built up to a diameter of $2-1/2$ inches. Make a small hole with a large pin through the flange on the nail side of the winding form. The hole should be even with the surface of the paper wound around the core. Make four small cuts in the edge of the same flange (see illustration). Smear the inner side of both flanges with Vaseline. The purpose of the Vaseline is to prevent the wire from sticking to any part of the core and flanges. It will permit easy removal of the coil when winding has been completed.

No. 34 B&S gauge enamel insulated magnet wire is small; its diameter is only 0.0055 inch. Consequently, it is easily broken. It must be handled with care. Mount the spool of wire so that it can turn freely without any strain on the wire as it is drawn off the spool.

To wind the first coil, push about 10 inches of the wire through the small hole in the flange, from the inside to the outside. Secure the free end of this wire to the flange by weaving it in the cuts made in the edge of the flange.

Whether the form is turned with the right hand and the wire guided with the left, or vice versa, is a matter of individual choice. The form should be turned so that the top moves away from the operator in a clockwise direction, as indicated by the curved arrow in the illustration. Guide the wire so that the turns are side by side as much as possible and are not badly crisscrossed. Count each turn of the

winding form and write down every 50 or 100 turns so that you will not forget the count.

Every time approximately 125 to 150 turns have been added to the coil, spray it with crystal-clear Krylon spray lacquer from a pressure can. Wind a total of 900 turns on the form. Spray the winding 6 to 10 times during the process so that the turns are thoroughly impregnated with the spray. (Krylon clear spray coating can be purchased at hardware stores.) This lacquer will dry overnight and bind the turns of wire into a solid coil that can be removed easily from the winding form.

When 900 turns have been wound on the form, spray the winding and cover it with two layers of 3/4-inch masking tape. Make a loop 10 or 12 inches long and twist it so that the wires become twisted. Push the twisted portion through a pinhole in the cardboard flange on the nail side of the winding form. This second pinhole should be even with the surface of the masking tape. Push the twisted wires through the hole from the inside out. Secure the free end of the twisted portion by weaving it back and forth in the cuts in the edge of the flange.

The second, or outer, coil should be wound over the first, or inner, coil in the same manner and in the SAME DIRECTION. Turn the winding form in the same direction and add an additional 900 turns of wire. Spray this second winding each time 125 to 150 turns have been added. When the second coil is complete, wind on a layer of 3/4-inch masking tape. Cut the wire between the winding form and the spool. Leave a free end 10 or 12 inches long. Tie two or three knots in this wire so that it can be identified easily as the outside terminal of the outside coil.

Put the form with its two coils where it will not be disturbed for twenty-four hours. During this time the spray coating will harden and bind the turns of wire together. At the end of this period, detach the terminal wires from the

flange and remove both cardboard flanges from the wood core. Use care not to disturb any of the turns of wire in the coils. If the turns are loose in any visible areas, spray them with Krylon and allow to dry again for twenty-four hours. When the spray has dried, it should be possible to pull out the strips of Vaseline-covered paper from around the wooden core and remove the core from the coils. The two windings should not be separated from each other. In effect, the completed inductor is a single coil of 1,800 turns with a wire tap in the center at the 900th turn.

The terminal wires of both coils should be carefully connected to pieces of stranded hookup wire about 6 inches long. If wires of different colors are available, use red, blue, and green.

Connect RED to the FIRST, or starting, turn (ST) of the INSIDE coil.

Connect BLUE to the CENTER, or twisted, wire (CT) that is the last turn of the inner coil and the FIRST turn of the outer coil.

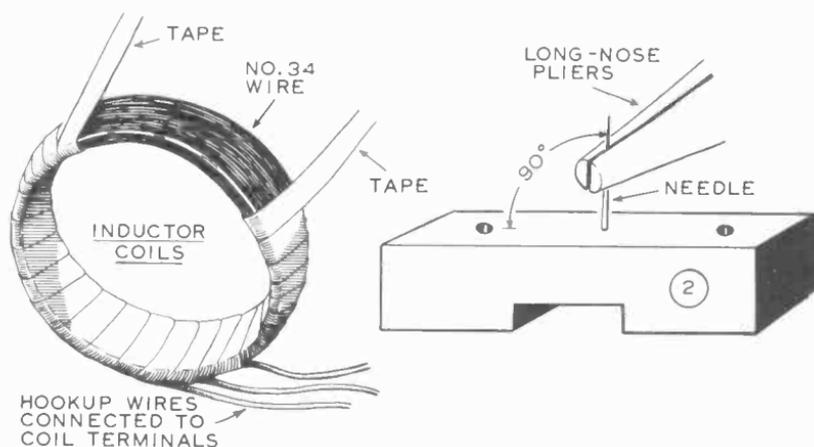
Connect GREEN to the LAST, or end, turn (ET) of the OUTSIDE coil.

Scrape the insulation off the enamel wire for a distance of 3 to 4 inches. Use a dull knife or very fine abrasive paper. Great care should be exercised not to cut or break the No. 34 wires. Remove the insulation from one end of each piece of hookup wire for a distance of 1/2 inch. Wind the bared portion of one of the No. 34 wires tightly around the bared portion of the hookup wire of the color indicated above. (Consult the wiring diagrams.) Cover the bared portion of the wire with a small piece of masking tape. Connect the two other No. 34 terminals to pieces of hookup wire in the same way. If the splices are properly made, soldering is not required, but soldered connections are preferred and should be made when possible.

If the No. 34 wire is broken in the winding process, clean

off the enamel insulation from the two ends with No. 00 sandpaper and twist the ends tightly together for a distance of $3/4$ inch. Cover the joint with thin paper. Here also, soldering is not necessary but is desirable when possible.

The splices between the coil ends and the hookup wires should be firmly anchored to the inductor by binding them with masking tape. If $3/4$ -inch-wide tape is cut lengthwise so as to form strips $3/8$ -inch wide, it will conform better to the curve of the inductor. When the splices have been anchored, wind the whole inductor with $3/8$ -inch-wide masking tape.

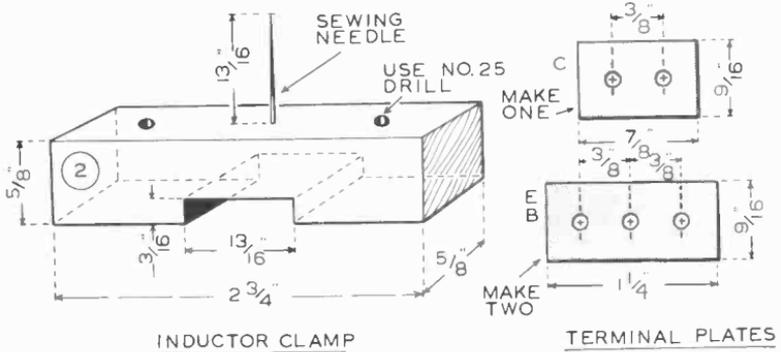


THE COIL TERMINALS ARE CONNECTED TO THREE FLEXIBLE WIRES

How to Assemble the Motor. Make three terminal plates, E, B, and C, out of thin-sheet brass or copper. Make one plate $7/8$ inch x $9/16$ inch and two plates $1-1/4$ inches x $9/16$ inch. Drill as shown in the illustration. Fasten them to the wood base with No. 4 round-head brass screws and washers. The location of the plates and the two binding posts, or Fahnestock clips, can be determined by scaling the plan.

The inductor coils are fastened to the motor base by a

wood clamp. The bottom of the clamp has a recess approximately $13/16$ inch x $3/16$ inch so that it will fit over the coil. The clamp is secured to the motor base by two 1-inch No. 7 round-head brass wood screws. These slip into two holes made in the clamp with a No. 25 twist drill. Do not use steel screws as a substitute for brass screws to fasten the clamp. The exact position of the clamp and inductor can be ascertained from the plan.

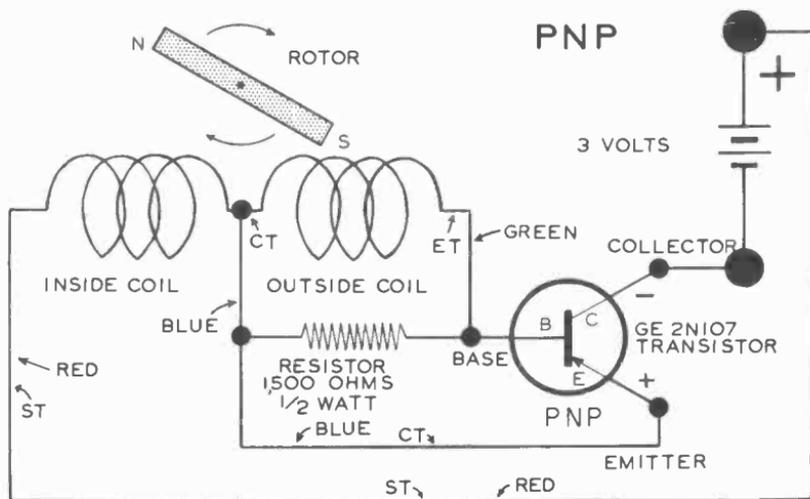


DETAILS OF INDUCTOR COIL CLAMP, ROTOR PIVOT, AND
TERMINAL PLATES

The pivot upon which the rotor turns is the pointed end of a small darning needle set in the inductor clamp. Hold the needle securely in a pair of pliers so that about $1-1/16$ inches of the pointed end projects from the jaw of the pliers. Break the needle so that the piece with the point is $1-1/16$ inches long. The blunt end of this piece is pushed into a small hole made in the exact center of the upper surface of the clamp. The small hole is made by driving the pointed end of a needle into the wood for approximately $1/4$ inch. When this is pulled out, the blunt end of the piece of needle that is to serve as the pivot is pushed into the hole with a pair of long-nosed pliers. The needle must be perpendicular

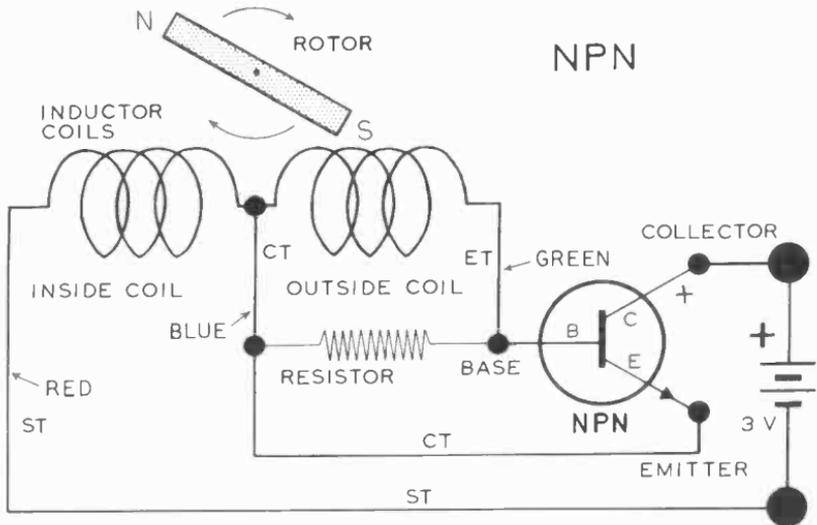
to the surface of the clamp, and the point must be so located that the rotor will be in the center of the inductor.

The Motor Circuit. One of the illustrations is a schematic diagram of the motor circuit. The components must be connected exactly as shown in this diagram or the motor will not operate. The wiring shown in the first two illustrations in this chapter will help to clarify the schematic diagram. (On the next page is a schematic diagram of the circuit when an NPN transistor is used.)



THE SCHEMATIC CIRCUIT OF THE TRANSISTOR MOTOR WHEN A PNP TRANSISTOR IS USED

ST indicates the starting turn of the inside coil. CT is the center tap between the two coils. ET is the end turn of the outside coil.



SCHEMATIC CIRCUIT WHEN AN NPN TRANSISTOR IS USED

Notice that the polarity of the battery is reversed so that the collector (C) is positive. One terminal (ST) of the inside coil is connected to the negative terminal of the battery. The other terminal (CT) of the inside coil is connected to the emitter.

PHOTOCONDUCTIVE CELLS—CADMIUM SULFIDE
PHOTOCELLS • *How to Build an Automatic
Light Switch.*

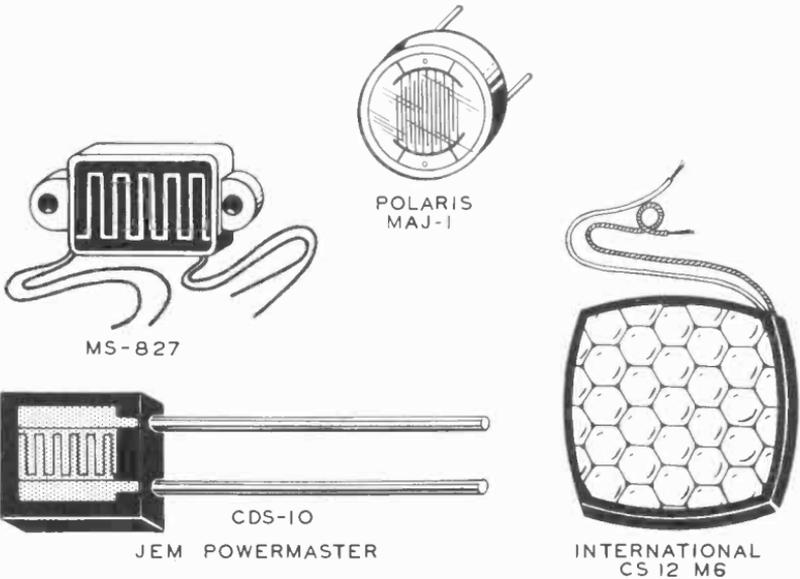
The element CADMIUM is a soft, silver-white metal with a slight tinge of blue. It is a member of the chemical group that includes zinc and mercury. Cadmium is obtained from certain zinc ores, usually as a by-product in the smelting and refining of zinc. Many iron and steel articles, such as wire, screws, nuts, bolts, tools, and automobile parts, are electroplated with cadmium to protect them against rust. Most chromium-plated parts of automobiles are first plated with cadmium.

The most important compound of cadmium is cadmium sulfide (chemical symbol CdS), an expensive yellow pigment known as "cadmium yellow." Once used only as a paint color, it now has an important place in electronics. It has the useful characteristic of undergoing a great change in its resistance to an electric current when moved from light into darkness or from darkness into light. Consequently, it is used in the manufacture of photoconductive cells. For example, the small photoconductive cell known as the Maj-1 photocell is a cadmium sulfide photocell. Its resistance varies from approximately 10 million ohms in total darkness to approximately 200 ohms when illuminated by a strong light.

Unlike selenium and silicon, cadmium sulfide has no photovoltaic property. It does not generate an electric current when exposed to light. Light only lowers its resistance to an electric current. A cadmium photocell can be operated

on 120-volt alternating current and does not require a highly sensitive relay. These characteristics make it well adapted to use as the "eye" for burglar alarms, automatic door openers, light switches, etc.

The door that opens automatically when you approach it and many other modern devices operated by an electric "eye" are usually applications of the cadmium sulfide cell.



FOUR KINDS OF CADMIUM SULFIDE PHOTOCELLS

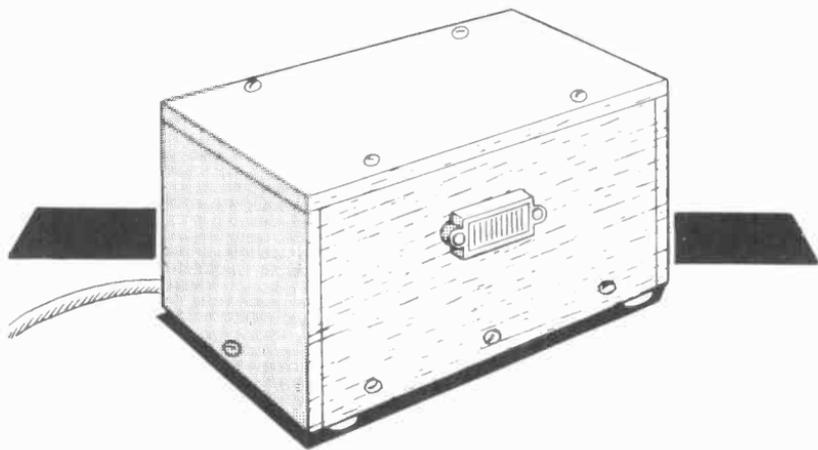
These are photoconductive types of photocell. They do not generate electric current. They change their resistance to electric current under the influence of light. They have high resistance when in darkness but comparatively low resistance when exposed to light.

Cadmium sulfide cells may vary in appearance but they all embody the same principle. Each consists of two separate metal grids. The space between the grids is filled with cadmium sulfide. When the cadmium sulfide is in darkness, its resistance is so great that the grids are practically insulated from each other. When light strikes the cadmium sulfide, it loses most of its resistance and current can flow from one grid to the other.

How to Make an Automatic Light Switch

One need never come home to a wholly darkened house or apartment. It is not necessary to let a lamp burn all day in order to accomplish this. A light-sensitive switch controlled by a cadmium sulfide photocell will automatically turn lamps off at dawn and on at dusk. The switch is a dependable device that can automatically turn on a porch light, doctor's sign, show window display, table lamp, or night light.

The construction of a homemade automatic light switch only involves fastening a few components in a 6-3/4-inches x 3-1/2-inches x 3-3/8-inches wooden box and connecting them according to the wiring diagram shown in the illustration. The light-sensitive cadmium cell is fastened on the outside of the box where it will be exposed to daylight when placed in operation.



A HOMEMADE AUTOMATIC LIGHT SWITCH WITH A CADMIUM
SULFIDE PHOTOCELL

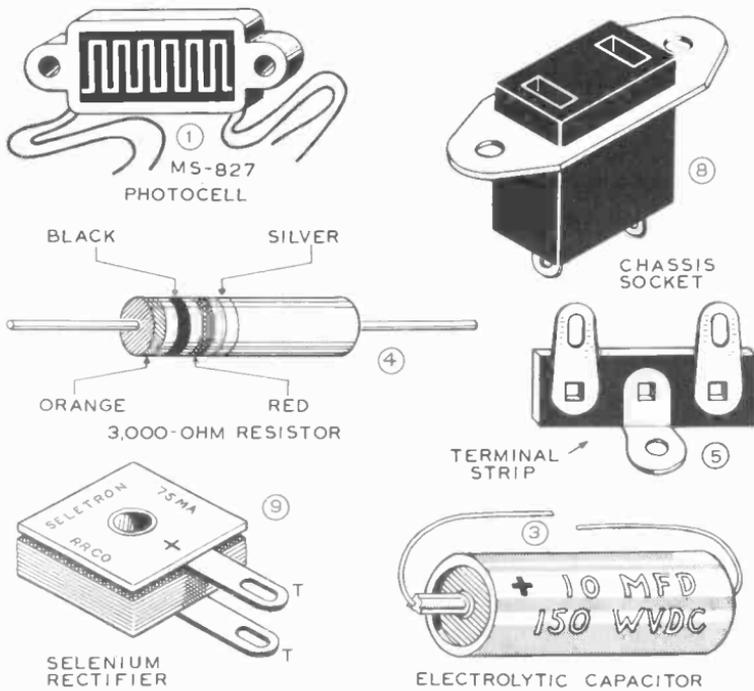
The components and materials required to assemble the automatic light switch are:

- 1 Polaris Maj-1 cadmium sulfide photocell (1)
- 1 Potter and Brumfield type RS5D, 5,000-ohm sensitive relay (2)
- 1 10-mfd, 150 WVDC miniature electrolytic capacitor (3)
- 1 1/2-watt, 3,000-ohm resistor (4)
- 1 International Rectifier Corp., type T065/075, 130-volt, 75-mil-liampere selenium rectifier (9)
- 1 Chassis AC socket (8)
- 5 2-lug terminal strips (5)
- 1 Attachment plug for 120-volt AC outlet (6)
- 1 6-ft. length double-conductor cord (7)
- 1 Piece of sheet metal 1-1/4 in. x 1-1/2 in. (10)
- 7 3/8-in. No. 4 round-head wood screws
- 1 3/4-in. No. 4 round-head wood screw
- 4 Rubber-head tacks
- 2 1/8-in. 4-40 round-head machine screws

The Enclosure. The enclosure for the switch can be made of plywood. It should be partly fastened with screws to permit easy opening if necessary. The size and shape of the six pieces of wood for the enclosure are shown in the illustration. The rectangular hole in the front panel is for the chassis AC socket. The double conductor cord that connects the switch to the 120-volt power supply passes through the 1/4-inch diameter round hole below and to the left of the rectangular hole.

The materials required to make the enclosure are:

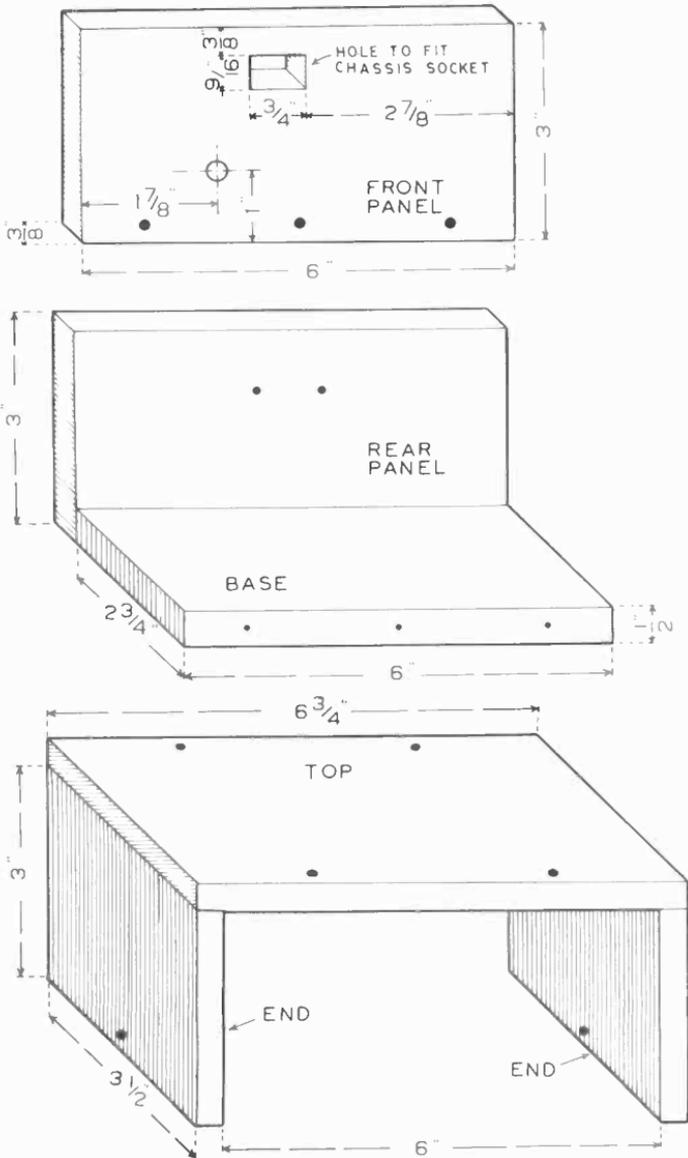
- 1 Wood base: 6 in. x 2-3/4 in. x 1/2 in.
- 1 Front panel: 6 in. x 3 in. x 3/8 in.
- 1 Rear panel: 6 in. x 3 in. x 3/8 in.
- 1 Top: 6-3/4 in. x 3-1/2 in. x 3/8
- 2 Ends: 3-1/2 in. x 3 in. x 3/8 in.
- 8 5/8-in. No. 4 round-head wood screws
- Wire brads



THE PRINCIPAL COMPONENTS USED IN BUILDING THE LIGHT SWITCH
 The terminals of the rectifier are marked T in the illustration. The positive terminal is identified by a plus sign.

The ends are fastened to the top with small wire nails and glue. The other parts of the box are held together by 5/8-inch No. 4 round-head screws. Drill clearance and pilot holes for the screws to avoid splitting the plywood.

The switch should rest on a window sill when in operation. The appearance of the enclosure will be improved if it is stained or painted to match or harmonize with the color of the window frame. If the enclosure is to be painted, first apply a coat of shellac. This will prevent the paint from sinking in and will probably make it unnecessary to put on two



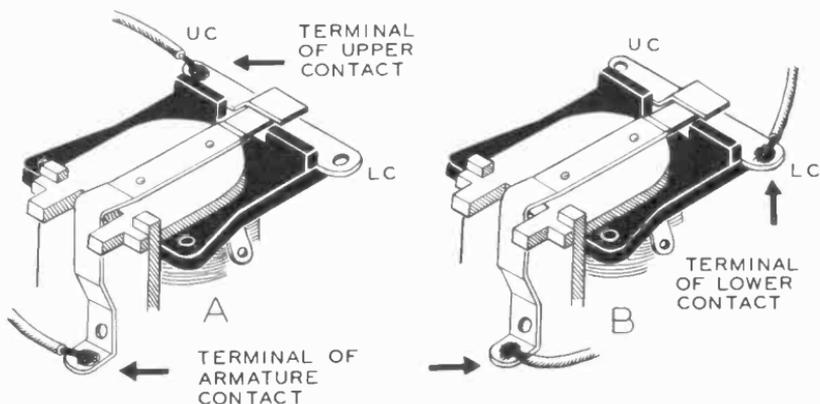
THE WOOD PIECES FOR THE ENCLOSURE

coats of paint. Drive a rubber-head tack into the underside of the base near each corner.

Cadmium Sulfide Photocells. There are several small, slightly different cadmium sulfide photocells available. Some are cylindrical in shape, others are rectangular. Four types are shown in the illustration. All are constructed on the same basic principle and all can be used to build an automatic light switch. Each cell consists of two metal grids enclosed in transparent plastic. The space between the grids is filled with cadmium sulfide. When the cell is in complete darkness, the resistance of the cadmium sulfide is so great that the grids are practically insulated from each other. For example, the Lafayette MS-827 cadmium sulfide photocell (made in Japan and measuring only 1-1/4 inches x 9/16 inch x 1/8 inch overall) has a resistance of approximately 1,000,000 ohms or more in the dark. The current through the cell in the dark at 120 volts is then only 0.00012 amperes or less. This is insufficient to operate a relay. When the cell is exposed to strong sunlight, the resistance drops to a few hundred ohms. Enough current can then pass to operate a sensitive relay. A current of 60 milliamperes (0.060 amperes) can pass through an MS-827 cell without causing damaging heat. Small cadmium sulfide cells can handle 1/2 watt continuously and operate a relay in 1/10 second. The terminals connected to the grids of small cadmium sulfide photocells are usually two pins or two flexible wires located at opposite ends of the cell.

The Relay. An electric relay makes it possible to employ a small amount of electrical energy to switch on or off a much greater amount of current. The current of 60 milliamperes in the control circuit is too small to light a lamp directly or to operate any of the devices it might be desirable to control

with a cadmium sulfide photocell. It is necessary therefore to use a sensitive relay in the circuit.



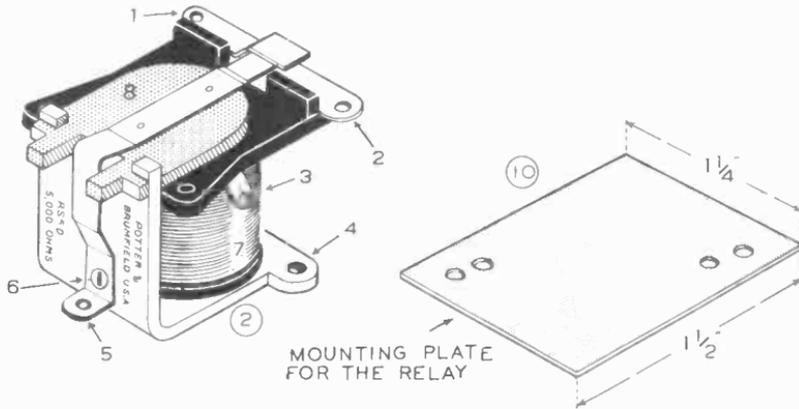
THE UPPER PORTION OF THE RELAY

The letters **UC** and **LC** are abbreviations for "upper contact" and "lower contact."

The Potter and Brumfield RS5D, 5,000-ohm Sensitive Relay. This is a small, lightweight, single-pole, double throw relay that can be operated by a very small amount of power, namely 0.060 watt. The contacts are small bars of palladium able to carry 2 amperes on 120 volts AC. (Palladium is a rare metal of the platinum group.) This relay should not be used to turn on and off more than two 120-volt, 100-watt lamps. If it is desirable to operate more lamps, the RS5D relay should be connected to a power relay having contacts large enough to carry 5 amperes or more.

The base of the RS5D relay has two mounting holes threaded for size 4-40 screws. Fasten the relay to a 1-1/2-inch x 1-1/4-inch rectangle of sheet metal with two round-head 4-40 machine screws 1/8 inch long. The sheet-metal mounting plate can be a piece of galvanized iron sheet or a piece of metal cut from the side of a tin can with a pair of

tinner's snips. Drill four holes in the mounting plate with a No. 30 twist drill. Two of the holes should be aligned with the threaded holes in the base of the relay.



THE RS5D POTTER & BRUMFIELD RELAY AND THE SUB-BASE FOR THE RELAY

1, upper contact. 2, lower contact. 3, coil terminal. 4, base. 5, terminal of armature contact. 6, screw to adjust armature spring. 7, coil. 8, armature.

The 10 Mfd., 150 WVDC Electrolytic Capacitor. The purpose of this capacitor is to smooth the direct current produced by the rectifier. The specification "150 WVDC" is an abbreviation for "150 working volts of direct current" and means the capacitor can be used in a 150-volt direct-current circuit without breaking down. The capacitor is marked with a plus, or positive, symbol near one end that indicates the positive terminal. Care should be exercised to connect it as shown in the schematic circuit diagram.

Low-voltage, 20 MA Selenium Rectifier. The rectifier is included in the circuit to change the 120-volt AC to DC.

Together with the electrolytic capacitor, it provides a fairly smooth direct current without 60-cycle fluctuations or ripples that, if present, would cause the armature of the relay to vibrate or "chatter" instead of closing firmly.

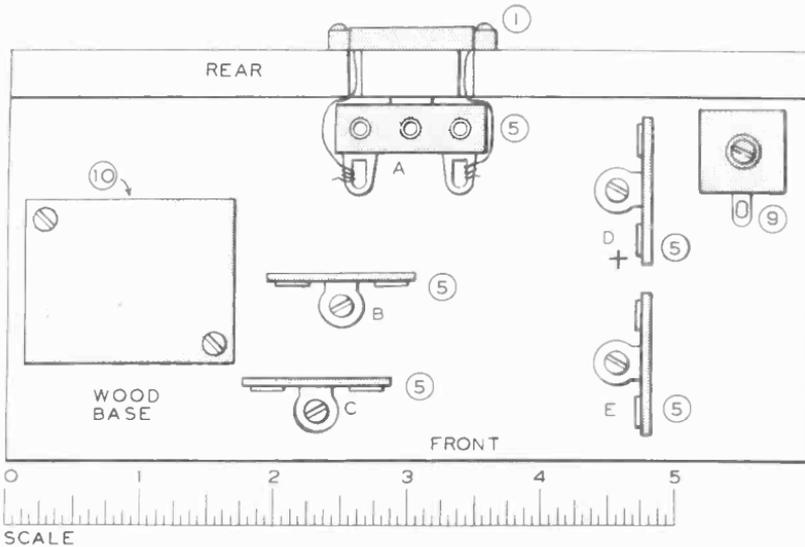
Terminal Strips. The most convenient way to mount and connect the components of the light switch is to use 2-lug terminal strips or tiepoints. Use 3/8-inch No. 4 round-head wood screws to fasten four 2-lug terminal strips on the base and one on the inside of the panel as shown in the plan and other illustrations. The terminals of each component are connected to a terminal strip. The components are then connected in circuit by the wires soldered to the lugs on the terminal strips. All connections should be carefully soldered. Use only rosin-core solder.

Assembling. Fasten the back panel to the rear edge of the base with three 5/8-inch No. 4 round-head wood screws. Drill two holes in the back panel one inch apart, 3/4 inch from the upper edge, and at equal distances from the ends. Make the holes with a No. 30 twist drill. Slip the terminal wires of the photocell through the holes from the outside. Fasten the photocell over the holes on the outside of the panel. Use two small tacks or two small round-head screws to secure the photocell in position. Two mounting holes in the plastic case are provided. Fasten one 2-lug terminal strip on the inside of the rear panel near the photocell terminal wires.

Fasten the four remaining terminal strips to the base with 3/8-inch No. 4 round-head wood screws as shown in the plan. Use the scale to determine the exact position of the screws fastening the terminal strips.

Place the relay on the upper surface of the sheet-metal mounting plate and fasten it with two 4-40 round-head machine screws threaded in the two tapped holes in the bot-

tom of the relay. When the plate has been attached to the relay, secure it to the wood base with 3/8-inch No. 4 round-head wood screws in each of the holes in the corners of the mounting plate. The relay will sit level on the base if a shallow hole is drilled in the base under the heads of the 4-40 screws.



PLAN OF LIGHT SWITCH

The position of the relay mounting plate (10), rectifier (9), photocell (1), and terminal strips (5) can be determined by measuring with the scale at the bottom of the illustration.

Wiring. Shorten the terminal wires on the electrolytic capacitor and the 3,000-ohm resistor to 7/8 inch.

Fasten the terminal wires of the capacitor to the lugs on the terminal strip marked **B** on the plan.

Fasten the terminal wires on the resistor (4) to the lugs on terminal strip **E**.

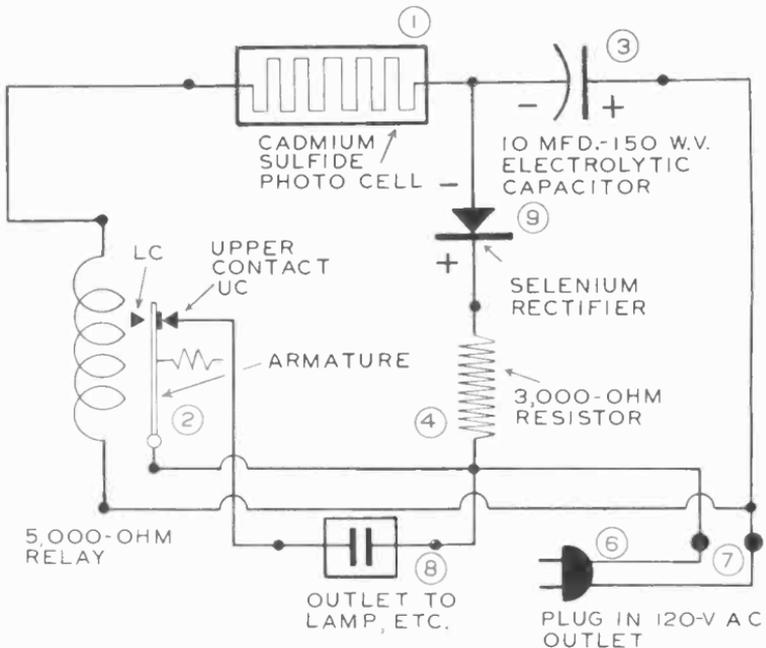
Connect the terminal wires on the photocell (1) to the lugs on terminal strip **A**.

Slip the end of the double-conductor cord through the 1/4-inch round hole in the front panel, and connect the bared ends to the lugs on terminal strip **C**.

Use stranded hookup wire to connect the components shown in the schematic circuit diagram. Solder all connections with rosin-core solder. Connect the terminals of the rectifier to the lugs on terminal strip **D**.

One terminal of the selenium rectifier is marked with a positive sign. This terminal should be connected as shown in the circuit diagram. Otherwise the switch will fail to operate.

The terminal of the contact on the relay armature is the end of the spring that projects slightly below the head of the small screw on the back of the relay. (See illustration of



SCHEMATIC CIRCUIT DIAGRAM OF THE AUTOMATIC LIGHT SWITCH
The positive and negative terminals of the electrolytic capacitor and the rectifier must be identified and connected as shown.

relay.) The terminals of the coil winding on the relay project from opposite sides near the top of the coil.

How to Test the Switch. Make the test at night or when darkness is available. Push the attachment plug (6) into a 120-volt AC outlet. Push the plug connected to a table lamp into the chassis AC socket (8) on the front panel of the switch. If the room is dark, the table lamp should light. Now shine the beam of a bright flashlight at the photocell from a distance of 5 or 6 feet. If all is in good order, the table lamp should go out.

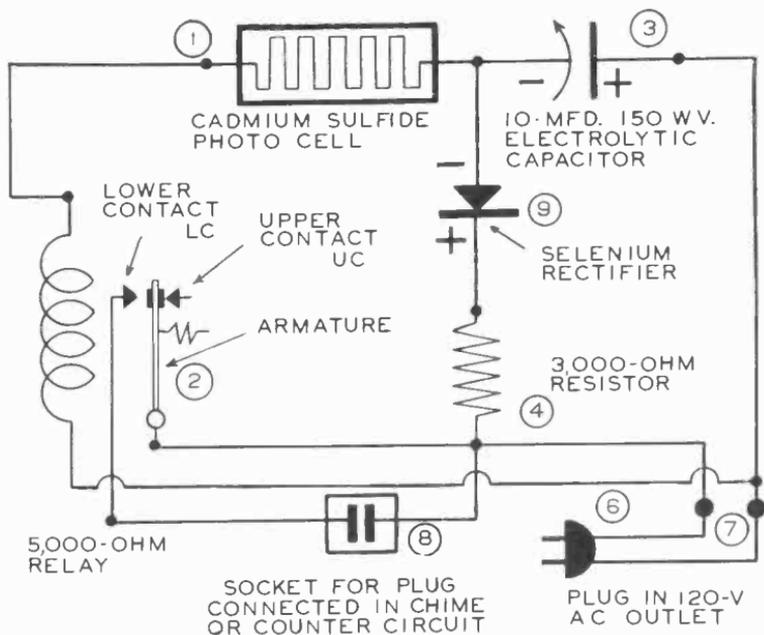
Trouble Shooting. Defective components, lack of power, or a mistake in wiring are the only causes for failure of the switch to operate.

A test should show 120-volt AC across the terminals of the chassis AC socket when the armature is up. There should not be any voltage shown at this point when the armature is down. Electrolytic capacitors are sometimes defective. Check the armature and the moving contact on the relay. Is the small screw that holds the spring attached to the armature firmly in place? Is the armature free to move up and down? Is the upper contact on the relay bent downward so that the armature cannot move? If so, bend it slightly upward.

When all efforts to find the cause of non-operation have failed, the circuits and components must be checked with an electronic volt-ohmmeter. It may be necessary to have a radio service man do this.

Operation. When tests prove the switch ready to use, place it on a window sill with the rear panel facing outdoors so that the photocell can receive full daylight. Push the attachment plug connected to the switch into a convenient 120-volt AC outlet. It may be necessary to use an extension cord.

Push a plug connected to the lamps to be turned on and off into the chassis AC socket. During daylight, the relay armature will be drawn down, the relay contacts will not touch, and the lamps will remain unlighted until dusk. When darkness comes, the armature will move upward, bringing the contacts together and causing the lamps to light.

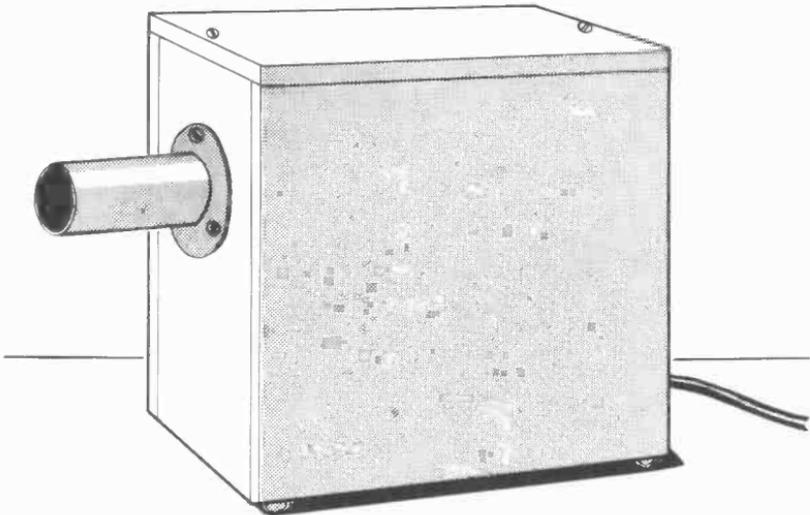


**SCHEMATIC CIRCUIT DIAGRAM OF THE AUTOMATIC LIGHT SWITCH
ARRANGED TO LIGHT A LAMP, RING A CHIME, OR OPERATE A
COUNTING DEVICE**

FAST-ACTING PHOTOELECTRIC BURGLAR ALARM

The apparatus described in this chapter is a light-controlled switching device, or relay. It utilizes a beam of light and a cadmium sulfide photocell to ring a bell or light a signal lamp when an intruder interrupts the beam of light. The apparatus is divided into two units. The unit containing the photocell is called the relay, or control; the unit that furnishes the light beam is the light source. Suitable light sources will be described in the next chapter.

The circuit of the relay is so arranged that the alarm bell will continue to ring and the signal lamp will remain lighted until the relay is reset, even if the intruder steps out of the light beam after it has been interrupted for only a fraction



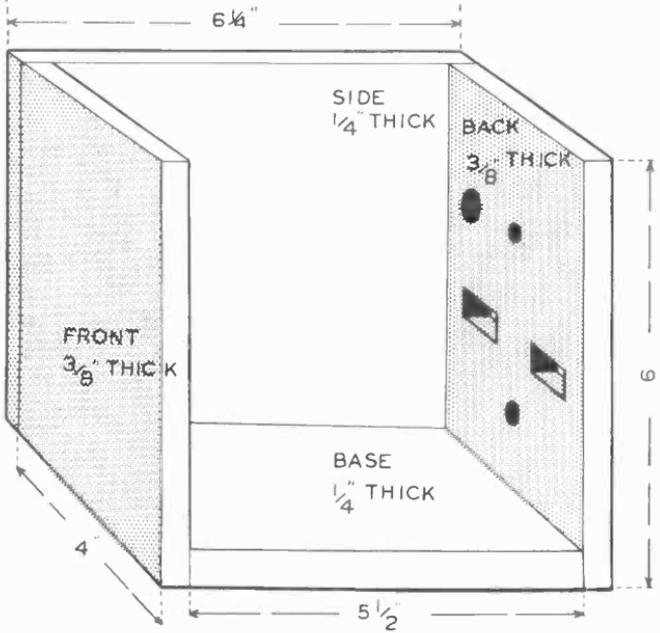
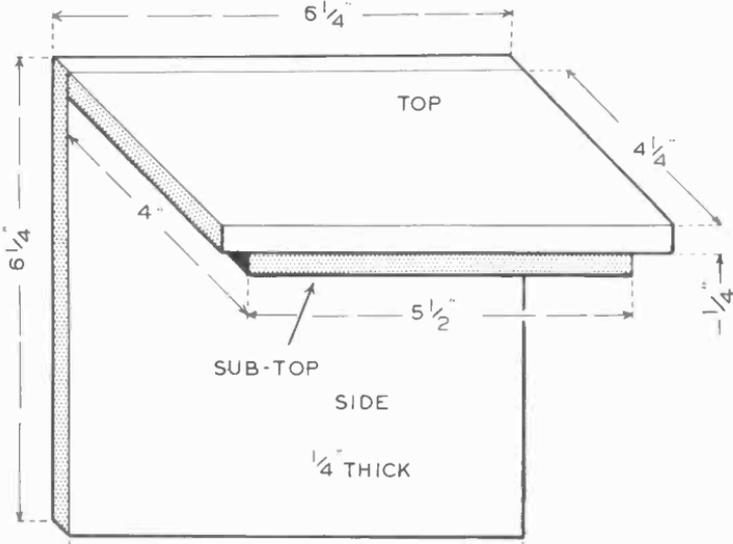
THE CONTROL UNIT, OR RELAY, FOR THE FAST-ACTING
BURGLAR ALARM

of a second. The relay is reset by pressing a push button on the back of the cabinet. A single-pole, single-throw switch may be used in place of the push button, provided it is closed only momentarily. Both units are operated on the 120-volt power and light circuit. The alarm bell and signal lamp may be located at any desirable place.

The components and materials, other than those for the cabinet, required to make the photoelectric alarm are:

- 1 Polaris Maj-1 LDR-C1 light dependent resistor (1)
- 1 Sensitive Sigma No. 11FZ 9,000-ohm AC/SIL Relay (2)
- 1 1-watt, 1,500-ohm silver-band carbon resistor (3)
- 1 5,000-ohm linear or No. 4 control with knob (4)
- 1 Normally open-type push button switch or a single-throw toggle switch (5)
- 2 Chassis AC sockets (6) (marked OUTLETS TO SIGNALING DEVICES in schematic diagram)
- 1 Attachment plug for 120-volt AC outlet (7)
- 1 6-ft. length double conductor cord (8)
- 5 2-lug terminal strips or tiepoints
- 10 3/8-in. No. 4 round-head wood screws
- 4 Rubber-head tacks
- 1 Piece of tin plate 7 in. x 2-1/2 in. for making shield
- Hookup wire, rosin-core solder

The Cabinet. The cabinet for the control is a rectangular, plywood box 6-1/4 inches x 6-1/4 inches x 4-1/2 inches. The top and one side are removable in one piece so that the interior is easily accessible. The details and dimensions are illustrated. The bottom, back, and both ends of the cabinet are permanently fastened together with glue and small wire nails. After smoothing with fine sandpaper (No. 00), apply two coats of white shellac to both the inside and outside of the cabinet. Four holes are cut in the left hand end of the cabinet for the power cord, chassis AC socket, control, and



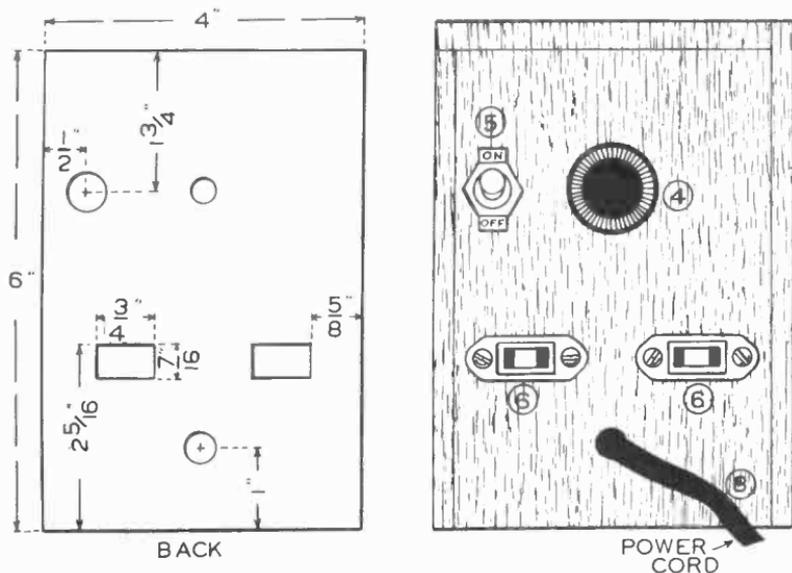
THE CABINET OR ENCLOSURE

push button, or reset switch. These holes should be cut before the cabinet is assembled.

The wood parts required for the enclosure are:

- 2 Pieces of plywood 6 in. x 4 in. x 3/8 in. (Front and Back)
- 1 Piece of plywood 5-1/2 in. x 4 in. x 1/2 in. (Base)
- 1 Piece of plywood 6-1/4 in. x 6 in. x 1/4 in. (Side)
- 1 Piece of plywood 6-1/4 in. x 6-1/4 in. x 1/4 in. (Side)
- 1 Piece of plywood 6-1/4 in. x 4-1/4 in. x 1/4 in. (Top)
- 1 Piece of plywood 5-1/2 in. x 4 in. x 1/4 in. (Sub-top)

Drive a rubber-head tack into the underside of the base near each corner.



DETAILS OF THE BACK OF THE CABINET SHOWING OPENINGS FOR RESET SWITCH, CONTROL, SOCKETS, AND POWER CORD

The right-hand sketch shows 4, the adjustment knob; 5, reset switch; 6, chassis AC sockets; 8, power cord. The left-hand sketch indicates placement of openings for the components.

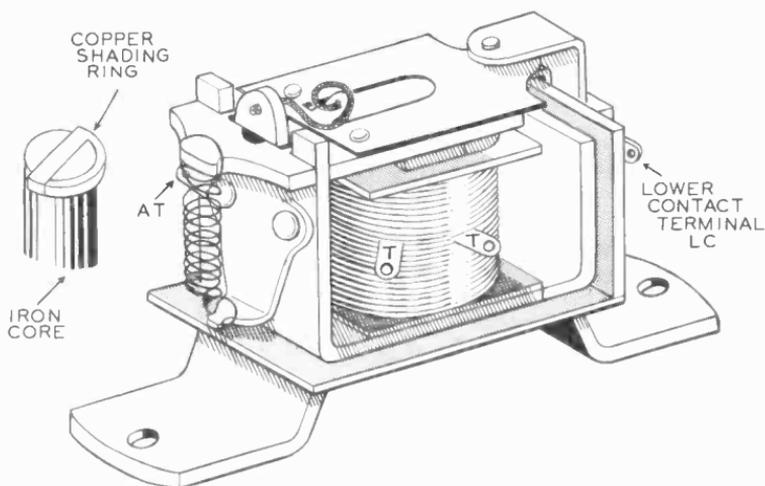
Polaris Maj-1 Photocell. This cadmium sulfide light-dependent resistor is made in Holland and is imported by the Polaris Electronics Corp., 17 E. Pershing Road, Kansas City, Mo. 64108. It is listed in the catalogs of several electronics firms as the Polaris Maj-1 resistor photocell. It is known also as an LDR-C1 light-dependent resistor in the Allied Radio catalog.

The Polaris Maj-1 is approximately 1/2 inch in diameter and 5/16 inch thick. Its terminals are two wires projecting from the back, 3/8 inch apart. The advantage of this photocell is its small size and great sensitivity. Several were tested prior to building the model of this photoelectric relay. They proved to have a resistance of 10,000,000 ohms when in total darkness. This resistance dropped immediately to approximately 20 ohms when the photocells were illuminated by the light beam from a two-cell flashlight.

The maximum permissible voltages which can be applied to the Polaris Maj-1 without damage to the photocell are 20 volts DC and 120 volts AC (peak). When the alarm is connected to a 120-volt outlet, the voltage is kept below the 120-volt limit by the resistance of the 1,500-ohm resistor, 5,000-ohm control, and 9,000-ohm relay. All current that flows through the photocell also passes through these resistances and is thereby limited.

Relay. The 9,000-ohm Sigma No. 11FZ AC/SIL relay is a very sensitive type which has a shaded pole on the electromagnet that makes it suitable for operation on alternating current. The relay is also made without a shaded pole for direct-current use and is listed as 11F-9,000 G/SIL. The direct-current model would not prove satisfactory for this project. No rectifier and capacitor are included in the circuit, as in the light switch described in the preceding chapter; an AC relay must be used.

The bottom of the relay is a sheet-iron plate with two holes for the screws used to fasten it in place.



THE AC RELAY

The two terminals marked T are the terminals of the coil, or electromagnet. The terminal of the upper contact, UC, is behind the relay and therefore cannot be seen in this sketch. AT indicates the armature terminal. The left-hand sketch shows how the shading ring is fitted on the upper end of the magnet core.

The 1,500-ohm Resistor. This should be a carbon resistor of 1-watt capacity. Its resistance need not be exactly 1,500 ohms. The type marked with either a silver or gold band will be satisfactory. The resistance is indicated by the colored bands when the resistor is held so that the bands are at the left-hand end. A brown, a green, and a red band, reading from left to right, indicates 1,500 ohms. A fourth band, either silver (plus or minus 10 per cent) or gold (plus or minus 5 per cent), indicates the accuracy of the resistance marking. The purpose of the resistor is to aid the relay winding and 5,000-ohm control in limiting the amount of current that can flow through the photocell.

5,000-ohm Control. A variable control may have one of three different tapers. The taper indicates the rate at which the resistance varies when the knob is turned. The control used in this project should have a linear, or No. 4, taper. The amount of current flowing through the relay and photocell, and the sensitivity of the alarm, may be adjusted to some extent by turning the knob on the control.

Assembling. Mount the Polaris Maj-1 photocell in the center on the front of the cabinet about two inches from the top. Make two small holes $3/8$ inch apart at the spot where the photocell is to be located. If you do not have a small twist drill (No. 55 to 60) make the holes by driving small wire nails through the wood. Pull the nails out and slip the terminal wires on the back of the photocell through the holes. The photocell should be on the outside of the cabinet, the terminal wires on the inside. Bend down the portion of each wire that projects through the holes.

Fasten a 2-lug terminal strip to the inside of the cabinet just above the photocell terminal wires. Solder a piece of tinned hookup wire to each of the terminal wires. Extend the hookup wires to the lugs on the terminal strip.

Use $3/8$ -inch round-head wood screws to secure the relay and two 2-lug terminal strips to the base inside the cabinet.

Push one end of the flexible power cord through the $3/8$ -inch hole in the back of the cabinet near the base. Tie a knot in the cord inside the cabinet so that it cannot be pulled out. Solder the ends of the wires in the power cord to the lugs on one of the 2-lug terminal strips. Connect an attachment plug to the ends of the wires in the power cord on the outside of the cabinet.

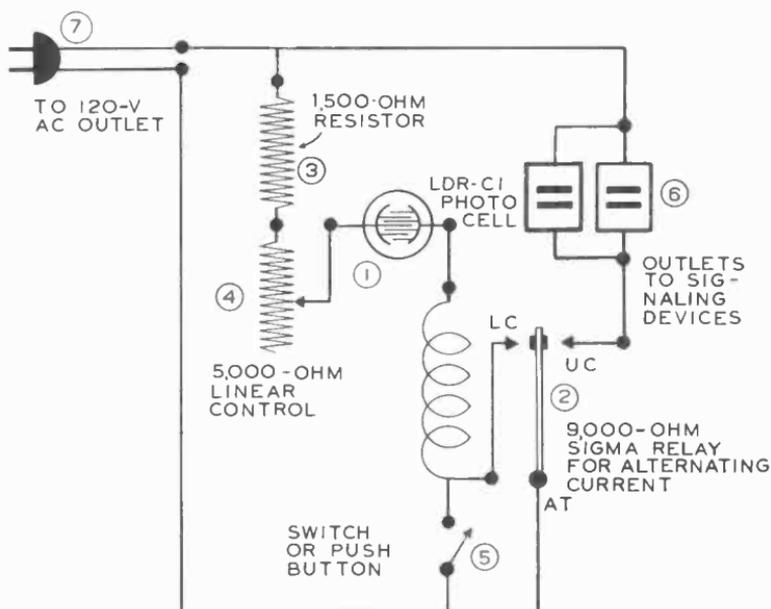
Solder the terminals of the 1,500-ohm resistor to the lugs on the second 2-lug terminal strip.

Mount the push-button switch, or a toggle switch; the 5,000-ohm control; and the chassis AC socket in the holes

prepared for them in the front of the cabinet.

Wiring. Connect the components as shown in the schematic wiring diagram. Solder all connections. Use stranded, tinned hookup wire and rosin-core solder.

There are five terminals on the relay. Two are the terminals of the relay coil winding; a third terminal is attached to the armature (AT). The remaining two (marked UC and LC in the circuit diagram) connect with the upper and lower fixed contacts. The armature terminal connects with the contact that moves up and down between the fixed contacts. A wire soldered to the armature terminal (AT) should be connected to one terminal of the push-button switch and to one of the lugs on the terminal strip to which the power cord is connected. One terminal of the relay coil should be connected to the lower contact (LC) and to the terminal of



THE SCHEMATIC CIRCUIT DIAGRAM OF THE BURGLAR ALARM

the push-button switch not connected to the power cord. When the push-button switch is properly connected, it will, if pressed, make a short circuit between the armature and the lower contact. Solder a wire to the other terminal of the relay coil, and connect it to one of the terminal strip lugs connected to the photocell.

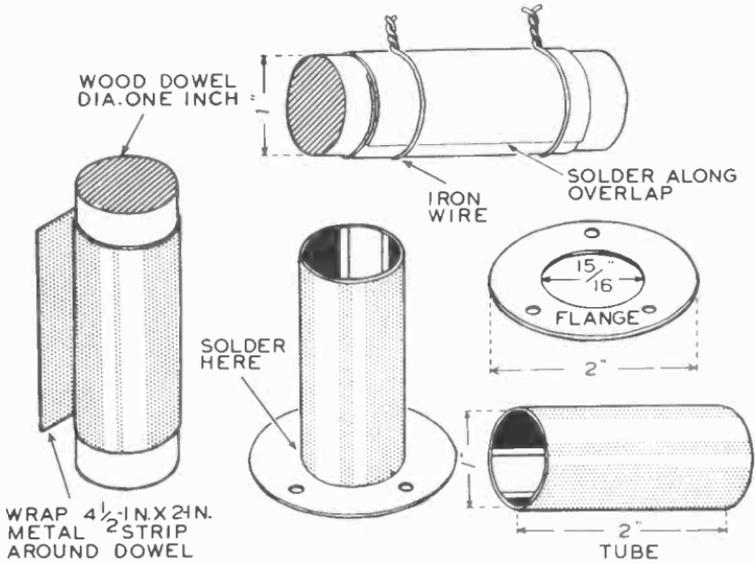
Connect the upper contact terminal (UC) to one of the terminals on each chassis AC outlet. The other terminal of each chassis AC outlet should be connected to one terminal of the 1,500-ohm resistor and to the power cord.

There are three terminals on the 5,000-ohm control. Connect one of the outside terminals on the control to the 1,500-ohm resistor and the center terminal to the terminal of the photocell not connected to the relay.

The Shield. It is necessary for the photocell to be protected from ambient light, in other words, from light coming in from the sides, from general illumination, or from any source other than the control beam. Only light coming directly from the control beam should strike the photocell. This is accomplished by providing a shield in the form of a metal tube 1 inch in diameter and 3 inches long.

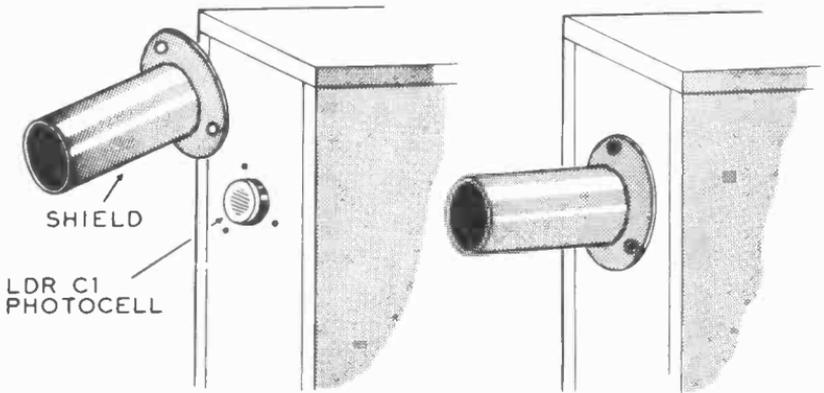
The tube can be made from the sheet metal cut from the side of a one-gallon "tin can." Cut a strip of the metal 2 inches wide and 4-1/2 inches long. Clean both sides of the metal by rubbing it with fine sandpaper. It may be coated with a plastic in place of tin to prevent it from rusting, but this material must be removed before it can be soldered. Wrap the clean metal strip around a piece of wood dowel one inch in diameter. Bend the metal until it fits the dowel snugly. A loop of iron wire around each end, twisted lightly with pliers, will help in forming the tube. Solder along the overlap so that the cylinder retains its size and shape when the wires are removed.

Cut a second piece of sheet metal in the form of a circle



THE SHIELD

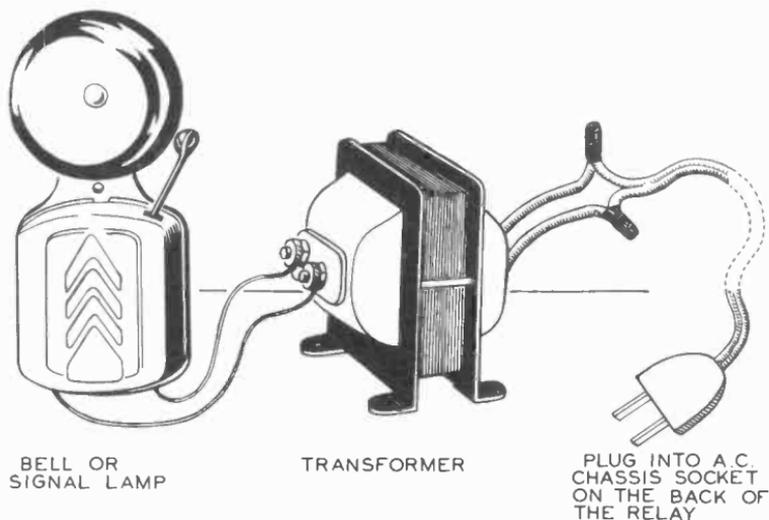
This consists of a tube and flange made of thin sheet metal.



The shield is fastened to the front of the cabinet and protects the cadmium sulfide photocell from all light except that which enters the front end of tube.

two inches in diameter. Make a 3/4-inch hole in the center. Drill three holes in the ring thus formed for No. 4 wood screws. The ring is to be used as a flange for the tube. Solder it to one end of the tube as shown in the illustration. Paint the inside and outside of the completed shield with flat black paint so that no light will be reflected from its surface. Slip the flange over the photocell and fasten it in place on the side of the cabinet with three No. 4 round-head wood screws.

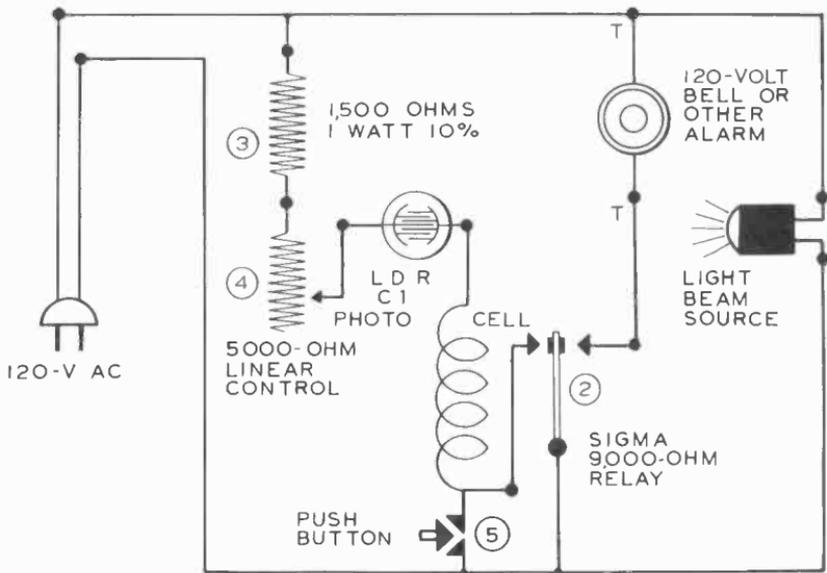
The Signaling Device. This may be a 120-volt bell or 120-volt lamp connected to the chassis AC sockets on the back of the alarm cabinet. Either or both may be used. It is sometimes difficult to purchase a 120-volt bell. In that case, use an ordinary bell and an 8- to 10-volt bell-ringing transformer. Connect the secondary of the transformer to the bell and



An electric bell can be used as the signal device by connecting it to a bell-ringing transformer.

the primary to a plug that can be pushed into one of the chassis AC sockets.

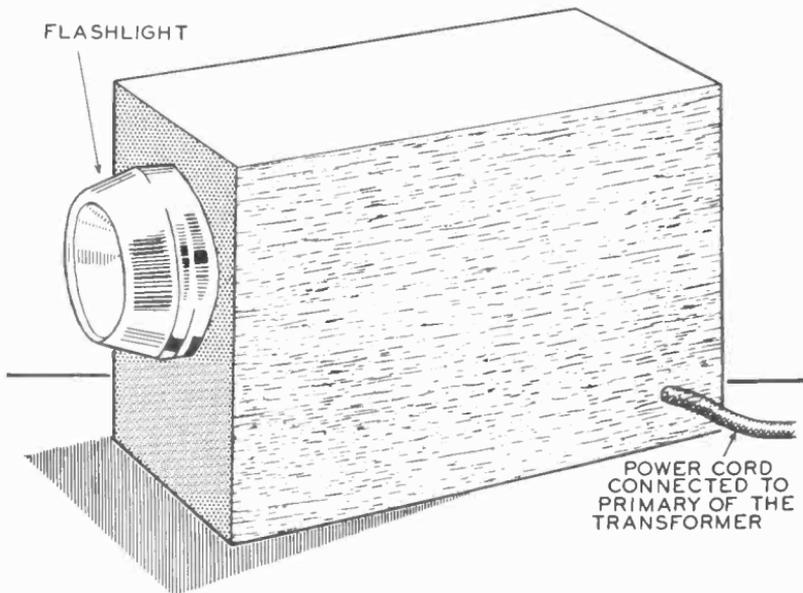
The photocell unit and the light source should be installed a few feet apart near a door, window, or passageway where an intruder might enter.



SCHMATIC CIRCUIT THAT INCLUDES A LIGHT-BEAM SOURCE AND 120-VOLT BELL OR OTHER ALARM SIGNAL

LIGHT SOURCES FOR OPERATING A
PHOTOELECTRIC ALARM

The photoelectric burglar alarm described in the last chapter can be tested and its action demonstrated with the light from a 2- or 3-cell flashlight. The flashlight should be the focus, or spotlight, type that produces a narrow, concentrated beam of light covering a very small area. If the alarm is to be a permanent installation and in operation continuously or for long periods of time, the 120-volt AC should



LIGHT SOURCE CONSISTING OF WOOD CABINET ENCLOSING A
FLASHLIGHT WITH 6.3-VOLT LAMP OPERATED ON A
FILAMENT TRANSFORMER

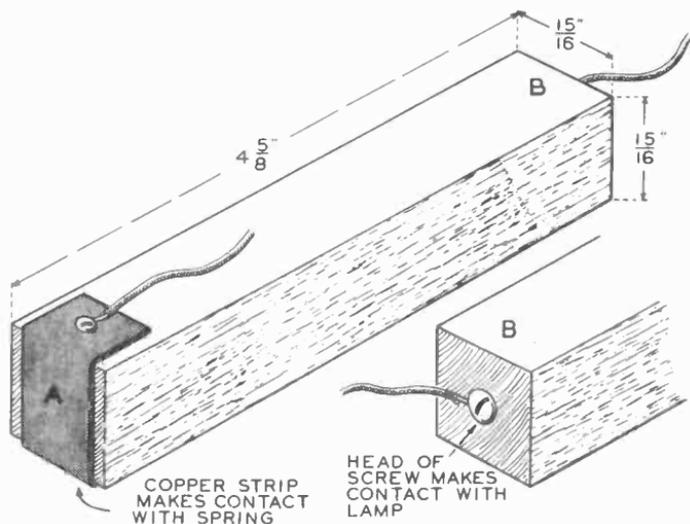
be used to power the light source. The small dry cells used in flashlights do not last long in continuous use and they would be an expensive source of power. If the distance between the photoelectric cell and the light source is limited to a few feet, a flashlight can be used in a permanent installation by altering it so as to operate on current supplied from a 120-volt AC outlet. The dry cells in the flashlight are removed.

The following parts and materials are required:

- 1 2-cell flashlight for size-D cells
- 1 Piece of pine or other softwood 4-5/8 in. x 15/16 in. x 15/16 in. to fit inside the flashlight case
- 1 Small filament transformer with 6.3-volt secondary (Knight No. 62G030 filament transformer or equivalent)
- 1 6.2-volt flashlight lamp with base to fit the socket in flashlight reflector
- 1 Power cord and attachment plug
- 1 Piece of thin sheet brass or copper 2 in. x 3/4 in.
- 2 2-ft lengths of connecting wire
- 1 3/4-in. No. 8 round-head brass wood screw
- 2 3/8-in. No. 4 round-head brass wood screws

A filament transformer is used in many radio receivers and amplifiers to reduce the 120-volt AC to the voltage required to operate the tube heaters. A small 120-volt filament transformer with a secondary that will deliver 6.3 volts and about 1 ampere of current is a standard size. It is carried in stock by dealers in radio and electronic parts.

A No. 8 round-head brass wood screw is inserted in the center of one end of the 4-5/8 inches x 15/16-inch x 15/16-inch piece of wood. The strip of sheet metal is fastened to the opposite end. The arrangement should slip into the case of a standard 2-cell size-D flashlight and fill the space formerly occupied by the two size-D cells. If not, change the



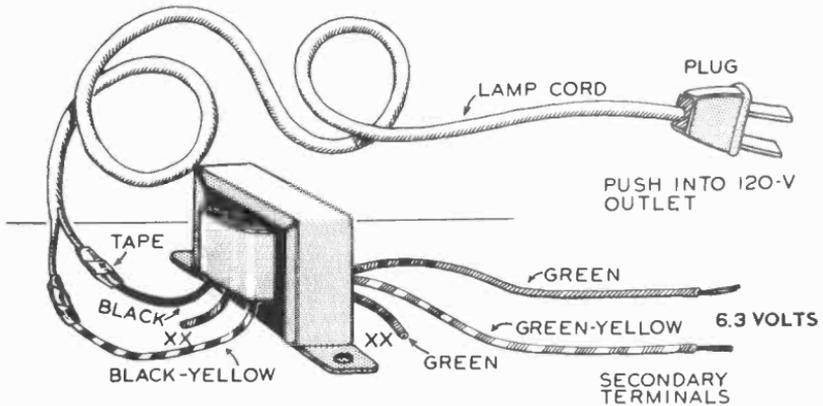
A WOOD ADAPTER IS SUBSTITUTED FOR THE FLASHLIGHT CELLS TO MAKE CONTACT WITH THE LAMP AND CASE

dimensions of the wood block as may be necessary. A flexible wire should be connected to the No. 8 brass screw and another similar wire connected to the brass or copper strip at the opposite end. Both wires are led out through a small hole drilled in the flashlight case and are connected to the green and yellow wire and one of the two green 6.3-volt wires of the filament transformer. Remove the lamp originally supplied with the flashlight and substitute a 6.3-volt lamp with a similar base. The copper strip at the end of the wood piece should make contact with the spiral spring in the end of the flashlight case, and the head of the screw at end **B** should make contact with the base of the flashlight lamp.

When the primary of the transformer is connected to the power cord and the plug is pushed into an outlet connected to the 120-volt AC power supply, the switch on the

flashlight will still function. It can be used to turn the lamp on and off.

If appearance is important, the flashlight and transformer can be enclosed in a small homemade cabinet having an opening in one end for the light beam. If you wish to save time, mount the flashlight and transformer on a wood frame, as shown on page 166 of *The Boys' Second Book of Radio and Electronics*, by this author. It is also published by Charles Scribner's Sons.



A 6.3-VOLT FILAMENT TRANSFORMER SUPPLIES CURRENT TO THE LAMP

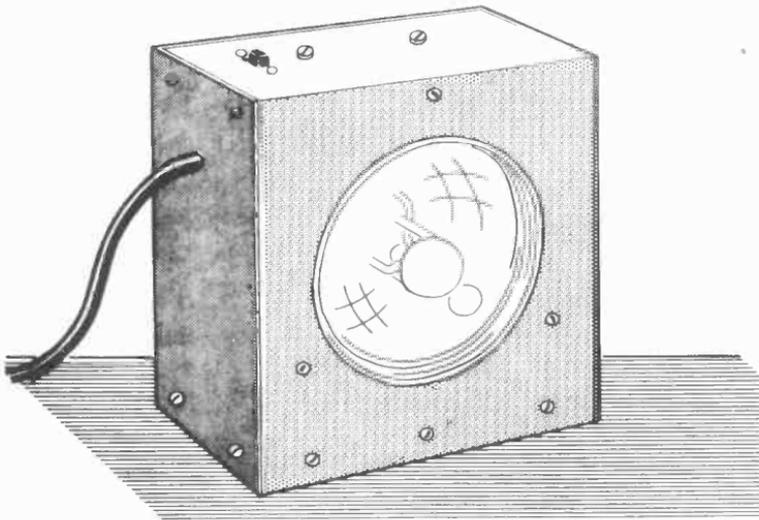
Connect one of the two wires on the adapter to one of the green wires on the transformer and the other to the green and yellow wire. The other green wire should be shielded with insulating tape.

For the alarm to operate, the two units must be located so that the beam from the light source shines directly into the tubular shield around the photocell. The light beam must strike the cadmium sulfide cell. The control unit and the light source may be set several feet apart, depending upon the strength of the beam from the light source. When the installation is to be permanent and not just a demonstration, both the relay and light source should be fastened in

position so that they cannot be moved until it is desirable to remove or relocate them. If either unit is shifted so that the light beam does not shine on the cadmium sulfide cell, it will cause the alarm to sound. It can be stopped by momentarily closing the on-off switch. If either unit is installed outdoors, it must be protected from rain and snow.

A Light Source with a 500-foot Beam

There are several light sources on the market that contain a 6-volt sealed-beam spotlight lamp powered by 120-volt AC through the medium of a small step-down transformer. The beam from these lamps will actuate a cadmium sulfide cell at a distance of 250 to 500 feet. The sealed-beam spotlight lamps are similar in construction to the sealed-beam lamps used as automobile headlights, but they are focused



A LIGHT-BEAM SOURCE CONSISTING OF A METAL CABINET ENCLOSING A SEALED-BEAM SPOTLIGHT LAMP AND A STEP-DOWN TRANSFORMER

so that they throw their light in a narrow beam. When a sealed-beam lamp is lighted, considerable heat is developed. For that reason, the lamp and transformer are enclosed in a metal cabinet. A metal cabinet will radiate and dissipate heat more rapidly than a cabinet made of wood.

The Allied Radio Corporation sells a light-source kit that is easily assembled. It consists of a metal cabinet, a step-down transformer, and a transformer-operated sealed-beam lamp. A removable, deep-red plastic filter that reduces light-beam visibility comes with the kit. The filter produces light near the infrared region that is practically invisible by day and barely seen at night.

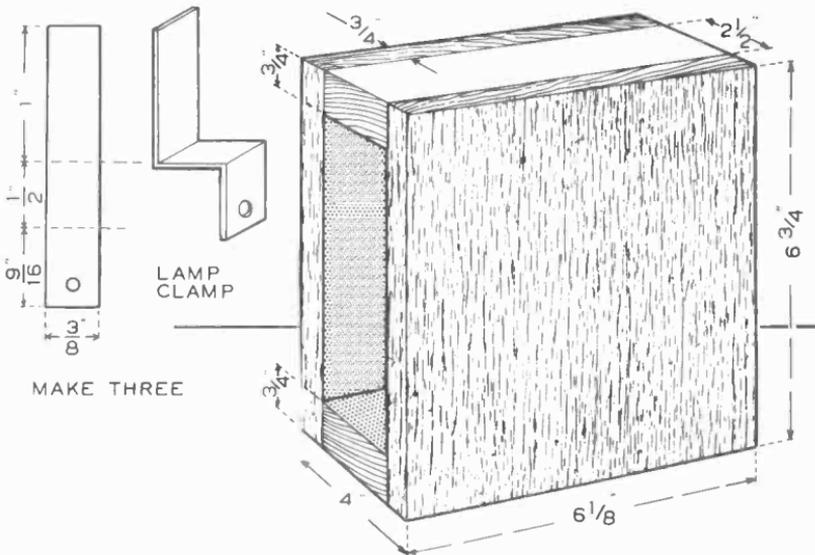
If an Allied kit is purchased, complete printed instructions will be found enclosed with the parts. If you wish to build your own source light of this type "starting from scratch"—

The following materials will be required:

- 1 No. 4515 Tung-Sol 6-volt sealed-beam spotlight lamp
- 1 Allied step-down transformer, 120-volt primary, 5-volt secondary (Allied Radio Corp. part No. 105200)
- 1 Single-pole ON-OFF toggle switch
- 1 Power cord and plug long enough to reach nearest available 120-volt AC outlet.
- 1 Piece of galvanized iron or aluminum sheet (.020 to .024 in. thick) 15 in. x 7 in.
- 1 Piece of galvanized iron or aluminum sheet (.020 to .024 in. thick) 7 in. x 8 in.
- 3 Pieces of sheet metal approximately 2-1/8 in. x 3/8 in. x 1/32 in. for clamps
- 1 Wood base 6-1/8 in. x 3-15/16 in. x 3/4 in.
- 5 1/4-in. 6/32 round-head machine screws with nuts to fit
- 9 3/8-in. No. 4 round-head wood screws
- 6 1/4-in. No. 6 sheet metal screws
- 2 Pieces of pine 6-3/4 in. x 6-1/8 in. x 3/4 in.
- 2 Pieces of pine 6-1/8 in. x 2-1/2 in. x 3/4 in.

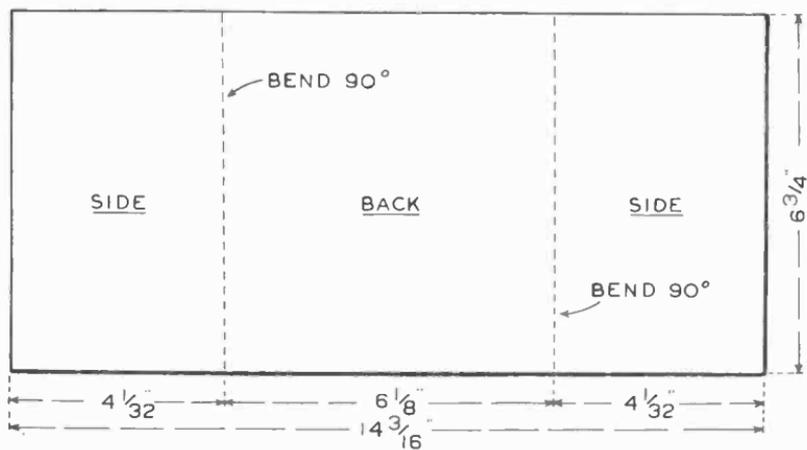
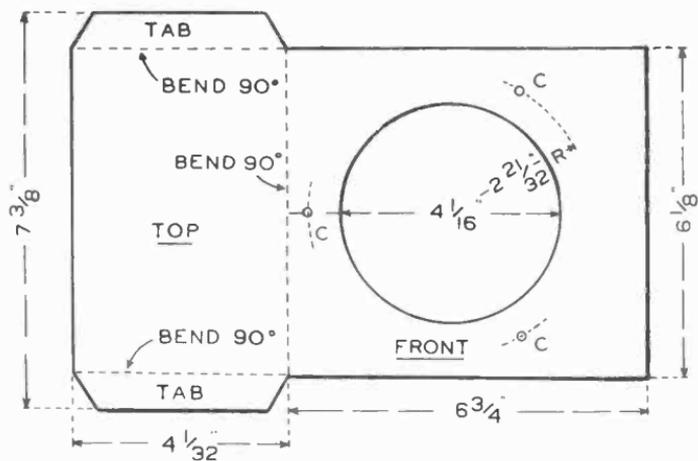
The Form. The four pieces of pine in the above list are used to make a 6-3/4-inch x 6-1/8-inch x 4-inch hollow rectangular form as shown in the illustrations. This is used for bending the two pieces of sheet metal. The metal should be held firmly in position against the wood with two carpenters C clamps. A rubber mallet is useful for bending the metal without producing dents and tool marks.

Assembling. Fasten the front of the cabinet to the front edge of the wood base with three No. 4 round-head wood screws (marked A in the right-hand sketch). Drill six holes (marked A) near the bottom edge of the back and sides, as in left-hand sketch, and fasten this part of the cabinet to the side and back edges of the wood base with No. 4 round-head wood screws. Drill two holes (marked F in the illustra-

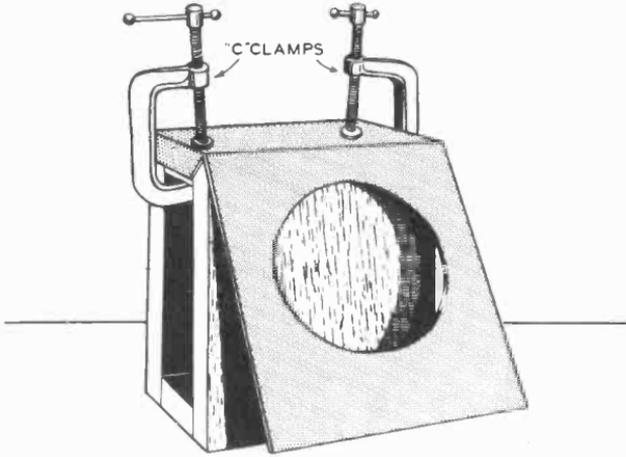


WOOD FORM FOR BENDING THE SHEET METAL PARTS

The clamps are made of sheet metal and are used to fasten the lamp in the front of the metal cabinet.

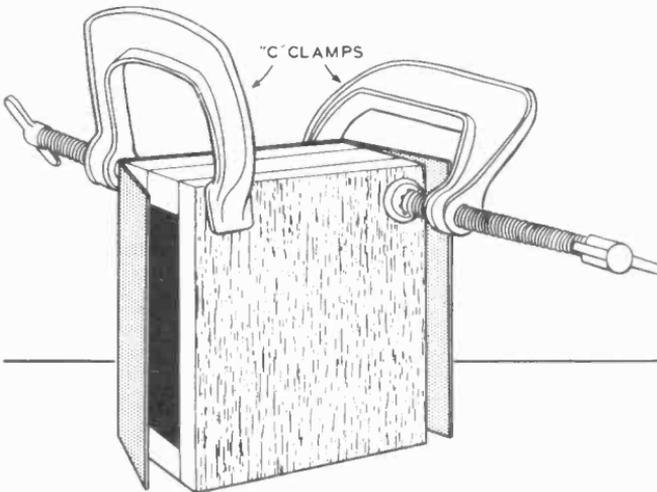


PATTERNS FOR CUTTING THE SHEET METAL PARTS



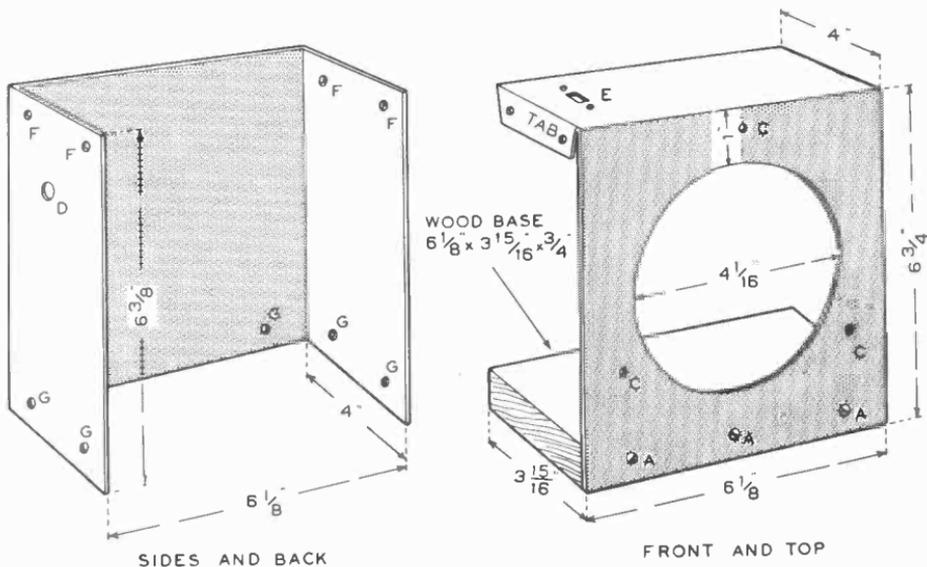
THE TOP AND FRONT OF THE METAL CABINET

The top and front of the form and two "C" clamps are used to bend the metal in this operation.



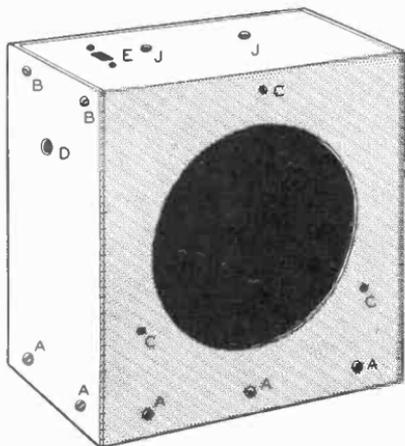
THE BACK AND SIDES OF THE CABINET

The back and sides of the form and two "C" clamps are used as a "jig" for bending the sheet metal cabinet.



THE COMPLETED PARTS FOR THE CABINET

It is necessary to drill and cut a number of holes in the cabinet. These are marked with identifying letters in the above illustration. Their location and purpose are explained in the text.



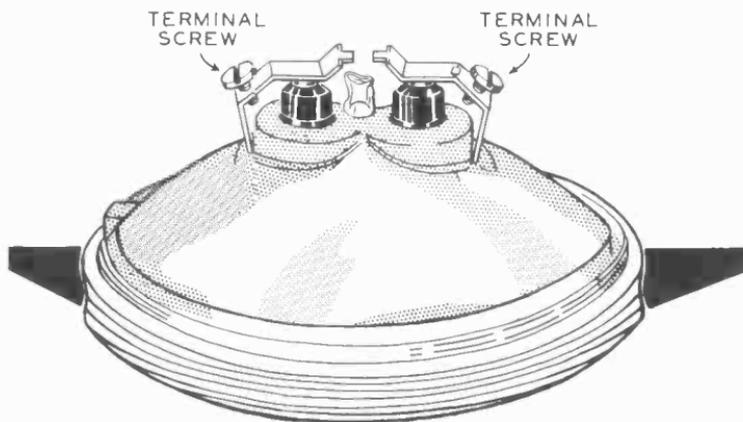
THE CABINET

tion) near the upper edge of each side, and in each tab. Use 1/4-inch No. 6 sheet metal screws (marked **BB** in the illustration of the cabinet) to fasten the sides to the tabs. The "on-off" switch is fastened to the top of the cabinet with sheet metal screws at **E**. The handle of the switch projects through the rectangular hole **E**.

The sealed beam spotlight lamp is fastened inside the cabinet with three homemade lamp clamps held in place by three 6-32 machine screws and nuts. The holes for the screws are marked **C** in the illustration showing the complete cabinet.

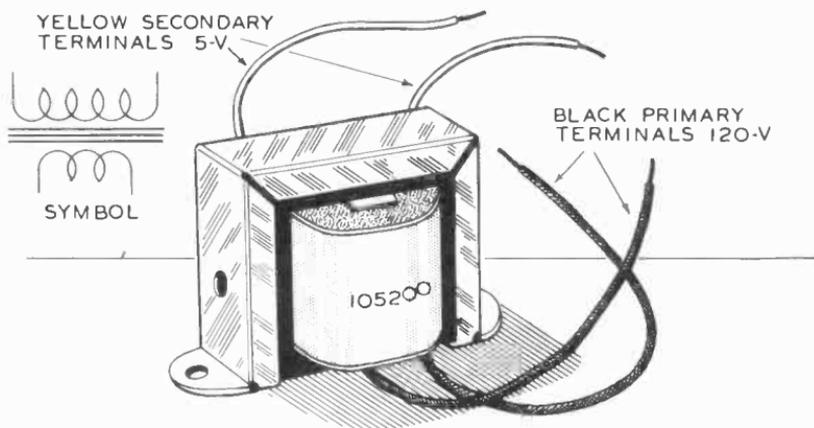
The step-down transformer can be fastened inside the cabinet to the wood base with two round-head wood screws or to the cabinet top on the inside. In the latter case, it will be necessary to drill two holes (marked **J**) in the top of the cabinet. Use two 1/4-inch 6-32 machine screws and nuts for fastening.

Connect the two secondary (yellow) terminal wires of the transformer directly to the terminal screws on the sealed beam spotlight lamp. The two black wires on the transformer are the primary terminals. They should be connected



NO. 4515 TUNG-SOL 6-VOLT SEALED-BEAM SPOTLIGHT LAMP

to the power cord and the switch so that the switch can be used to turn the 120-volt power on and off. The power cord enters the cabinet through the hole (D) in the left side. Tie a knot in the cord inside the cabinet so that any strain caused by pulling the cord will be against the knot and not against the connections. The outer surface of the cabinet should be painted to harmonize with its surroundings.



NO. 105200 STEP-DOWN TRANSFORMER, 120-V PRIMARY,
5-VOLT SECONDARY

A PHOTOGRAPHER'S ELECTRONIC SLAVEY

When a photograph is to be made by using a flashlamp, it will usually be a better photograph if more than one source of light is used. A picture taken with only one flashlamp, attached to or close to the camera, often has the undesirable quality of "flatness." A photograph of the same scene with a molded, or three dimensional, quality can be produced by using two or three properly placed flashlamps.

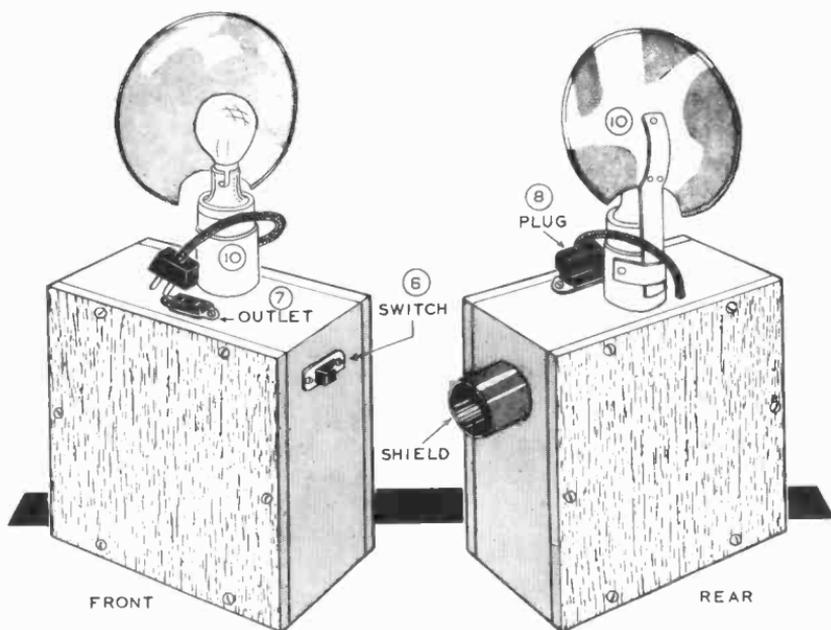
The additional flashlamps can be fired by arranging wiring to connect them to the shutter switch on the camera, but this is not as convenient as using a "slavey."

Slavey is a name given by photographers to a device that is not part of the camera and is not connected to it by wires, but nevertheless will fire a flashlamp when the flash on the camera is fired.

A slavey is an electronic device. It utilizes two semiconductors, one, a photoelectric cell; the other, a transistor. When light from the flash at the camera strikes the selenium cell in the slavey, it causes the flashbulb on the slavey to fire. Many amateur photographers will find one or two slaveys to be valuable additions to their photographic equipment.

How to Build a Slavey

The slavey described in this chapter consists of a wood cabinet housing a selenium cell, transistor, switch, and battery. A lamp socket and reflector, mounted on top of the cabinet, are shown in the illustrations. If desirable, the



TWO VIEWS OF PHOTOGRAPHER'S HOMEMADE ELECTRONIC SLAVEY

slavey can easily be arranged to fire an electronic flash instead of a bulb.

Electronic components and hardware required to build the slavey:

- 1 RCA No. 2N301 transistor (1)
- 1 MK-15 Motorola power transistor mounting kit or equivalent (2)
- 1 Holder for size AA 1.5-volt flashlight cell (3)
- 1 A15PL International Rectifier Corp. photocell (4)
- 3 2-terminal solder lug strips, or tiepoints (5)
- 1 Single-pole miniature on-off switch (6)
- 1 Chassis AC receptacle (7)
- 1 Plug to fit chassis AC receptacle or outlet (8)
- 5 1/4-in. 6-32 binding-head machine screws
- 5 1/4-in. x 3/32-in. 6-32 hex nuts

- 1 Size AA dry cell
- 6 Size D 1.5V dry cells
- 1 Piece of Bakelite unclad board 5-1/8 in. x 3-7/8 in. x 1/16 in. (9)
- 1 Socket and reflector for flashlamp (10)
- 1 Piece of sheet tin, 12 in. x 3 in.
- 4 1/4-in. No. 4 round-head wood screws
- 6 3/4-in. No. 4 round-head wood screws
- 8 5/8-in. No. 4 round-head wood screws
- 30 3/4-in. wire nails
- 1 Wood cylinder, 3 in. long and 1-11/16 in. in diameter
- Stranded plastic-covered hookup wire, glue, shellac, or varnish

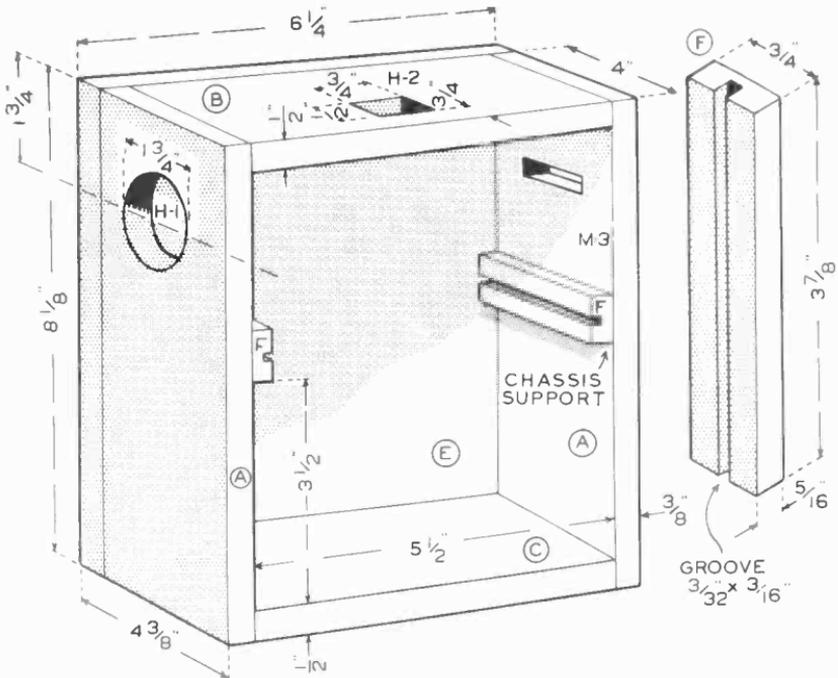
Wood parts required for the cabinet:

- 2 Sides 8-1/8 in. x 4-3/8 in. x 3/8 in. (A)
- 1 Top 5-1/2 in. x 4 in. x 1/2 in. (B)
- 1 Bottom 5-1/2 in. x 4 in. x 1/2 in. (C)
- 1 Front 8-1/8 in. x 6-1/4 in. x 3/8 in. (D)
- 1 Back 8-1/8 in. x 6-1/4 in. x 3/8 in. (E)
- 2 Chassis supports 3-7/8 in. x 3/4 in. x 5/16 in. (F)

Parts required for the 9-volt battery holder:

- 1 Base 5-7/16 in. x 3-7/8 in. x 3/8 in. (B)
- 2 Sides 3-7/8 in. x 2-5/8 in. x 3/4 in. (S)
- 1 Clamp 5-7/16 in. x 3/4 in. x 3/8 in. (C)
- 2 3/4-in. round-head wood screws

The Cabinet. The bottom (C), top (B), sides (A), and back (E) of the cabinet are fastened together with glue and 3/4-inch wire nails. The front of the cabinet is attached with eight 5/8-inch No. 4 round-head wood screws. This is not put in place until the slavey is completed. No glue is used on the front since it must be removable for inspection and battery replacement.



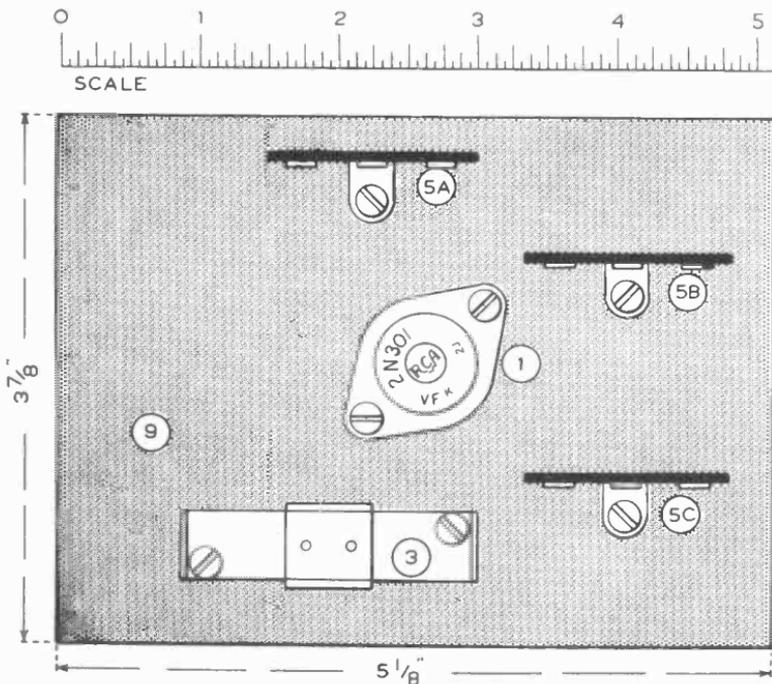
DETAILS OF THE CABINET FOR THE ELECTRONIC SLAVEY

The completed cabinet should be given two coats of shellac or varnish to seal the wood against moisture and consequent warping. The two grooved supports for the chassis are fastened to the sides. The chassis should slide into the grooves in the supports.

The Chassis. The electronic components (except the flash-bulb socket, chassis outlet, and on-off switch) are mounted on a chassis which consists of a piece of unclad Bakelite board $5\text{-}1\frac{1}{8}$ inches x $3\text{-}7\frac{7}{8}$ inches x $1\text{-}16$ inch. The term "unclad" means without a coating of copper. Copper-clad board is for making printed circuits. Dealers in electronic supplies carry perforated board in stock more often than solid board. Perforated board is filled with $1\text{-}16$ -inch holes

on 3/16-inch centers. Perforated board can be used as a chassis for the slavey although the perforations will be useless.

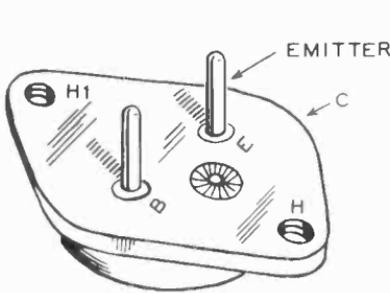
The plan of the chassis shows the location of the transistor (1), the 1.5-volt AA battery holder (3), and the three terminal solder lug strips or tiepoints (5A), (5B), and (5C). The battery holder and three tiepoints are fastened to the base with 1/4-inch 6-32 binding-head screws and nuts. The screws pass through holes in the board made with a No. 27 twist drill. The nuts are placed on the lower ends of the screws on the underside of the board. The exact location of the parts mounted on the chassis can be determined by using the scale at the top of the illustration. Trace the scale on a



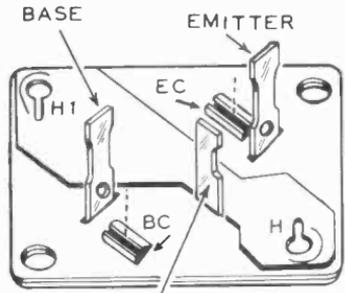
RCA 2N301 power transistor (1). 1.5-volt AA dry cell holder (3). Tiepoints (5A), (5B), and (5C).

piece of tracing paper or cloth and use it as a rule to measure distances.

The Transistor. The RCA 2N301 transistor is fastened to the chassis by the two 3/8-inch sheet metal screws that are furnished in the power transistor mounting kit. The screws pass through two holes in the transistor, then through two



BOTTOM VIEW OF POWER TRANSISTOR

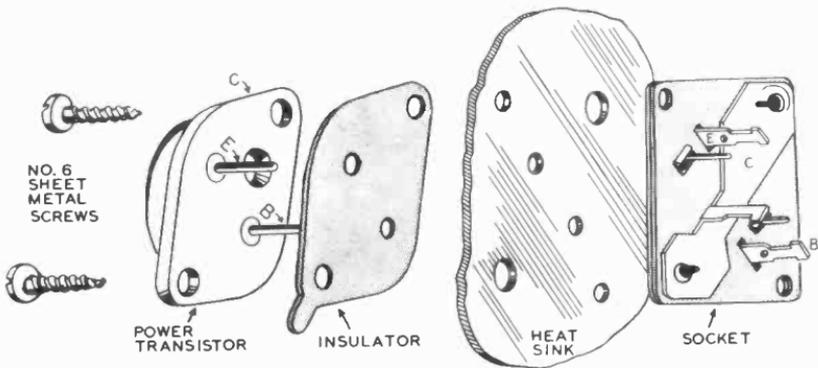


COLLECTOR

BOTTOM OF SOCKET FOR POWER TRANSISTOR

RCA 2N301 POWER TRANSISTOR AND SOCKET

The sheet metal screws to fasten the transistor and socket to the chassis are slipped through the holes in the transistor marked **H** and **H1** and threaded into the holes in the socket marked **H** and **H1**.



MOUNTING KIT FOR A POWER TRANSISTOR

No. 27 twist-drill holes in the chassis directly underneath and thence into the terminal plate. The flat side of the terminal plate is placed against the underside of the chassis. The sketch of the power transistor and socket identifies the BASE, COLLECTOR and EMITTER terminals. Scratch the letters **B**, **C**, and **E** on the terminal plate so that the three solder lugs connecting with the transistor terminals can be readily identified.

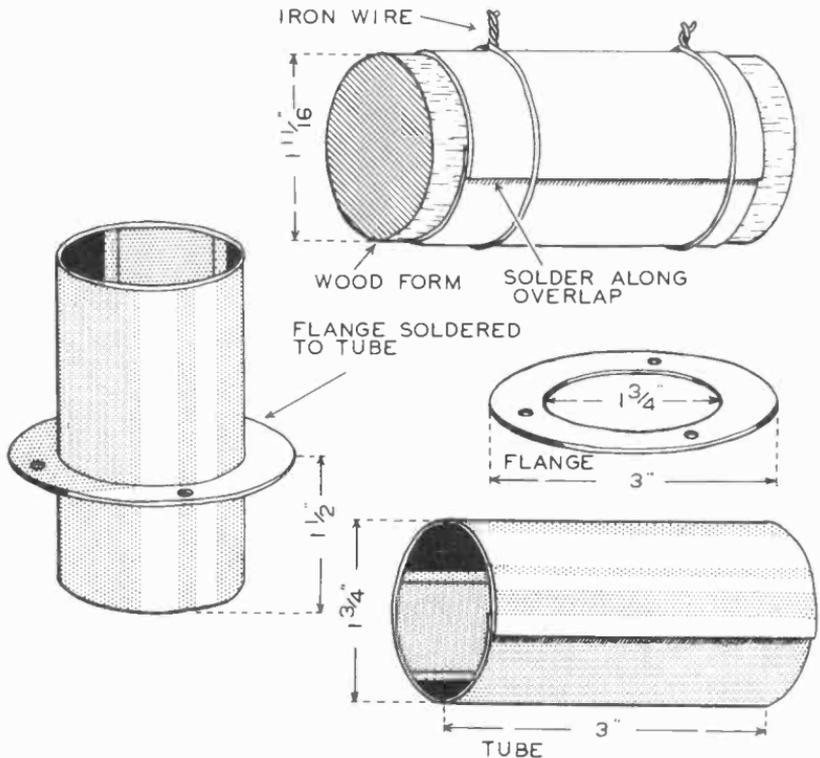
The Photocell. The A15PL International selenium photocell is a disk 2 inches in diameter. It is placed inside the cabinet on the end of a tubular metal shield. The photocell is attached to the inside end of the tube with Scotch tape or masking tape. The sensitive surface of the cell should be placed over the opening in the tube so that it will be exposed to any light that enters the opposite end.

A portion of the tube (the open end) projects through the 1-3/4-inch hole (**F**) in one side of the cabinet. The tube is held in place by a flange that is fastened to the inside surface of the side of the cabinet by three 3/8-inch No. 4 round-head wood screws.

The Shield. It is necessary for the photocell in the slavey to be shielded from ambient light, that is, light coming from the sides, from general illumination or from sources other than the controlling, or master, flash at the camera. The shield is a tube made from sheet metal cut from the side of a 1-gallon can. Cut a strip of the metal 3 inches wide and 5-1/4 inches long. Clean both sides of the metal by rubbing it with fine sandpaper. The metal may be coated with a plastic varnish in place of tin to prevent it from rusting. In that case all of the varnish coating must be removed wherever wires are to be soldered. Wrap the cleaned metal strip around a wood cylinder 1-11/16 inches in diameter, or around any cylindrical object of that dimension. Bend

the metal until it fits the form snugly. A loop of iron wire around each end and the center, twisted tightly with pliers, will help to draw the metal into shape. The edges should overlap slightly. Solder along the overlap so that the cylinder retains its size and shape when the wire loops are removed.

Cut a second piece of sheet metal in the form of a disk 3 inches in diameter. Make a hole 1-3/4 inches in diameter in the center. Drill three holes in the ring thus formed with a No. 35 twist drill. Locate the holes 120 degrees apart. The ring is to be used as a flange for the tube. Slip it over the tube and solder it in place 1-1/2 inches from one end (see illustration). Paint both the inside and outside of the com-

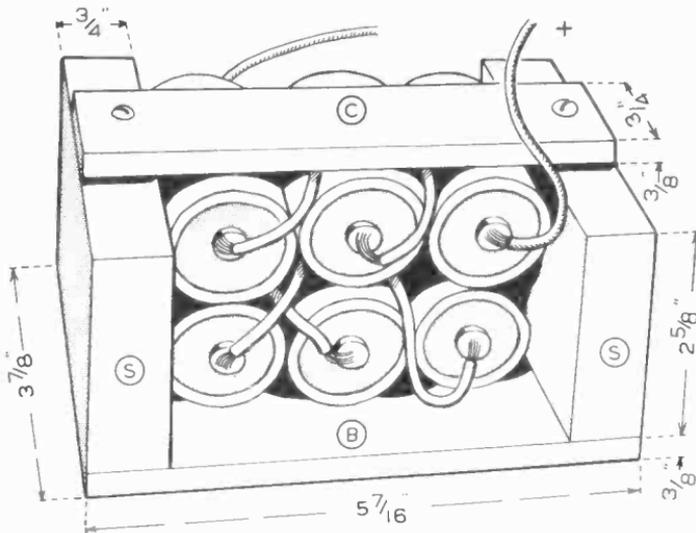


THE TUBULAR SHIELD THAT PROTECTS THE PHOTOCCELL FROM AMBIENT LIGHT

pleted shield with flat black paint so that no light will be reflected from its surfaces.

The Battery. A 9-volt dry cell battery or an 8-volt Mallory mercury battery is used to supply the current that fires the flashlamp on the slavey. The mercury battery is used when it is desirable to keep the size and weight of the slavey as small as possible, but the dry cell battery is preferable for general use.

The 9-volt battery consists of six size D 1.5-volt dry cells clamped together in a homemade battery holder and connected in series by five short lengths of hookup wire soldered to the cell terminals. Solder a 10-inch length of insulated (red) wire to the positive 9-volt terminal and a piece of equal length with blue or green insulation to the negative 9-volt terminal. This use of colored insulation makes it easy to identify the polarity of the wires.



THE 9-VOLT BATTERY AND BATTERY HOLDER

How to connect six flashlight cells in series to form a 9-volt battery.

The sketch of the six dry cells assembled in the battery holder shows them clamped firmly in place by the wood strip marked (C). If the battery holder is made in accordance with the specified dimensions, it will slip into the lower part of the cabinet under the chassis.

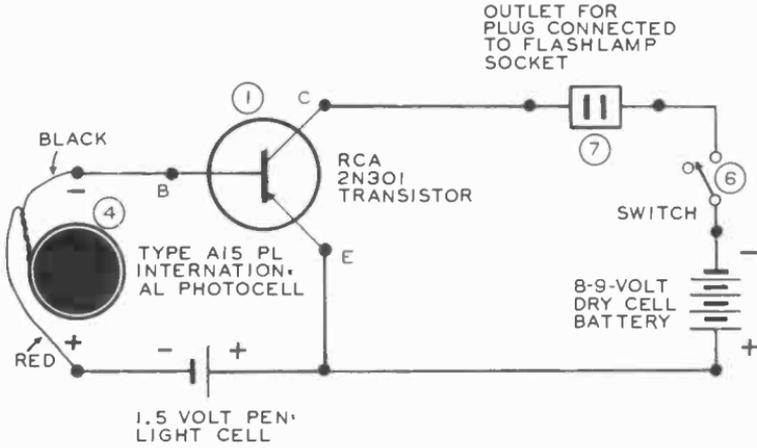
The Socket and Reflector. The socket and reflector for a flashbulb to be mounted on the top of the slavey can be purchased from a dealer in photographic supplies. Reflectors and sockets are manufactured in great variety. It is not necessary for these parts to be exactly the same as the socket and reflector illustrated at the beginning of this chapter.

Mount the socket and reflector on the top of the cabinet with a screw and spring washer that permits them to be turned a full 360 degrees horizontally. Connect the socket to an attachment plug that will fit into the chassis AC receptacle set in the top of the cabinet. Use a short piece of flexible lamp cord to make the connection.

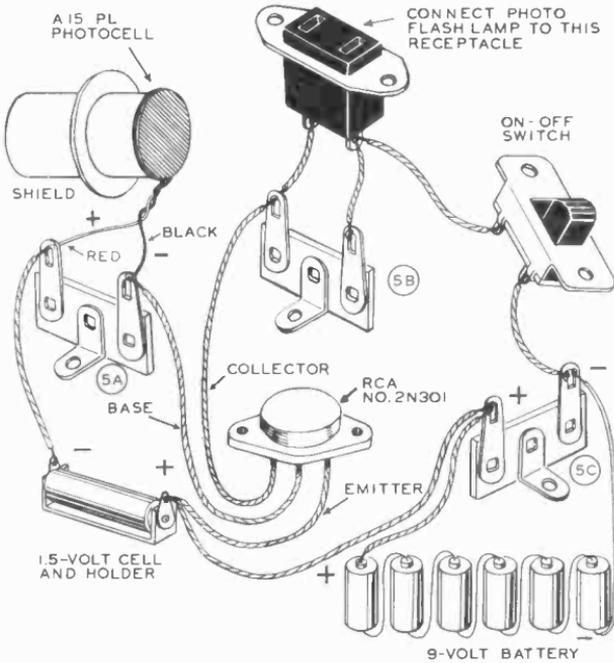
Assembling and Connecting. The chassis is pushed into the grooves in the supporting strips attached to the sides of the cabinet. The transistor, 1.5-volt battery, and tiepoints should be on top. The chassis board should slide all the way into the cabinet. While the slavey is being wired, it is pulled out as far as it will come and still be supported by the slots.

Two wiring diagrams or hookups are shown. One is a pictorial wiring diagram to show the arrangement of the wiring. The other is a schematic diagram to show the circuit. Use stranded hookup wire and solder all connections with rosin-core solder.

The on-off switch is mounted in the rectangular hole provided for it in the side of the cabinet. It is connected in the circuit so that it can be used to open and close the 9-volt battery supply.



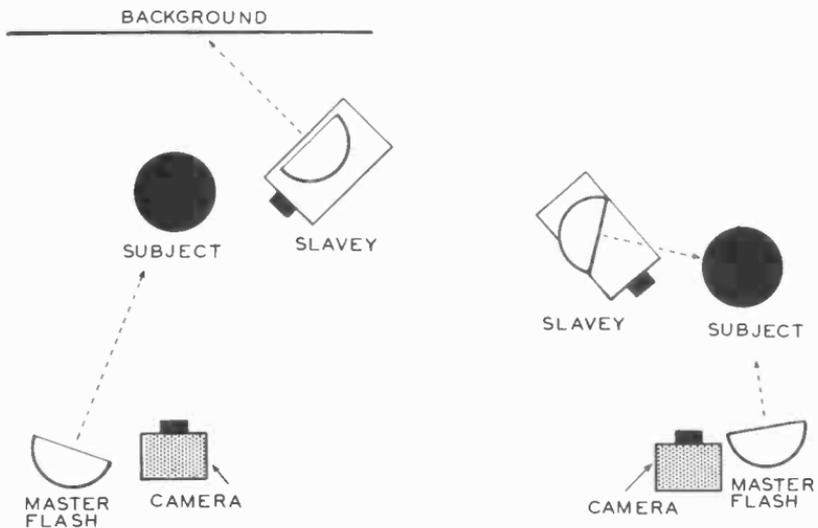
SCHEMATIC CIRCUIT DIAGRAM OF THE SLAVEY



PICTORIAL WIRING DIAGRAM OF THE SLAVEY

It is important to observe all polarities and to make all connections exactly as indicated. If the terminal wires on the A15PL photocell were connected correctly at the factory, the RED wire terminal is POSITIVE and the BLACK wire is NEGATIVE. Note that the positive terminal of the photocell should be connected to the negative terminal of the 1.5-volt pen-light dry cell.

Operating the Slavey. To use the slavey, place it so that the tubular shield projecting from one side points directly at the master flashlamp at the camera. Preferably, the slavey should be on the same level as the master lamp so as to pick up the maximum illumination available from the flash. The reflector on the slavey is turned so that the light from the



DIAGRAMS SHOWING HOW THE SLAVEY IS POSITIONED TO AID IN LIGHTING

Direct light from slavey should not shine into camera.

slavey flashbulb will help to illuminate the photographic subject.

When taking a picture, the switch on the slavey should be set at the ON position. When not in use, set it at the OFF position. Otherwise, a slow leakage of current through the circuit will occur and eventually exhaust the batteries.

When the slavey is set so that sufficient light from the master flash enters the shield and illuminates the selenium cell, the voltage generated by the photocell will increase the current flowing through the slavey flashbulb sufficiently to fire it. The transistor in the circuit may be likened to the trigger of a gun. The voltage generated by the photocell is the pressure on the trigger that will fire the gun. If the pressure (voltage) becomes great enough it pulls the trigger.

An electronic flash or stroboscopic light cannot be used as the master to fire the slavey. The duration of a stroboscopic light is too short to cause sufficient current to flow in the slavey long enough to fire its flashbulb.

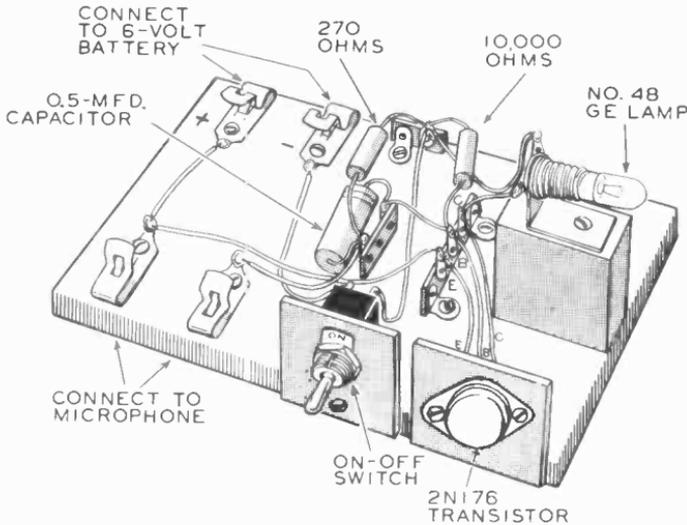
The distance between the master flash and the slavey at which the slavey will operate is limited. The stronger the master flash is, the greater the distance can be. When using the average flashbulb, the distance usually can be great enough for all practical purposes.

AN EXPERIMENTAL PHOTOPHONE • *Music and Speech via a Beam of Light*

It was mentioned briefly in Chapter One that Alexander Graham Bell and an assistant named Sumner Tainter constructed a "photophone" in 1878. This was the first contrivance entitled to be dubbed a "wireless telephone." There were no interconnecting wires between the transmitter and the receiver. The Bell photophone transmitted speech over a beam of light. Bell and Tainter devised nearly fifty different ways to MODULATE, or cause a beam of light to fluctuate in step with the vibrations of sounds—a marvelous accomplishment in that day and age. Today, almost a century later, when all materials required to build a photophone are readily available, it is not difficult to arrange an apparatus to modulate the light of a small flashlight lamp in step with sounds of voice and music and thereby demonstrate the principle of Bell's photophone.

The modern radiophone transmits its signals and messages over electromagnetic waves, popularly called radio waves. Light waves are also electromagnetic waves but are of very much higher frequency than radio waves.

Telephoning over a beam of light is of renewed interest at this time when research has shown that a laser beam can be used to carry communications for long distances. A laser beam is a powerful form of light beam. A laser beam generated on Earth has been flashed on the Moon, 240,000 miles away. It is not unreasonable to expect that some day in the future a large portion of long distance communications may be carried via modulated laser beams.



THE PHOTOPHONE TRANSMITTER

The letters **E**, **B**, and **C** identify the wires connected respectively to the **EMITTER**, **BASE**, and **COLLECTOR** of the transistor.

How to Build a Photophone

The experimental photophone described here will not operate when the transmitter and receiver are separated more than a few inches, but even this short distance is sufficient to demonstrate that a beam of light can become a carrier for sound. It gives an instructive demonstration of the process called modulation. This simple photophone is an excellent science fair project.

The first illustration in this chapter is a perspective sketch of the photophone transmitter without the carbon microphone and battery. When the photophone is in use, the microphone and 6-volt dry cell battery are connected to the Fahnestock clips provided for that purpose.

The transmitter components (except microphone and battery) are mounted on a 6-3/4-in. x 4-1/2-in. x 1/2-in. wood

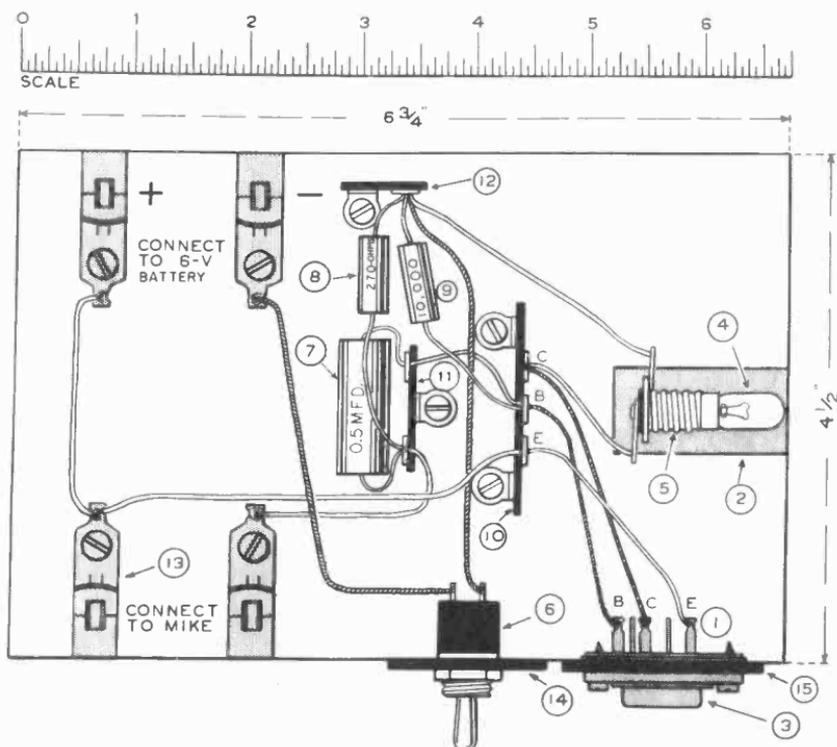
base. The base should be shellacked or varnished on all surfaces to seal it against moisture.

The parts required to build the photophone transmitter:

- 1 Wood base 6-3/4 in. x 4-1/2 in. x 1/2 in. (1)
- 2 Wood supports 2 in. x 1-1/2 in. x 3/4 in. for lamp (2)
- 1 RCA 2N176 transistor (3)
- 1 Power transistor mounting kit
- 1 GE No. 48 2-volt miniature pilot lamp with screw base (4)
- 1 Socket for miniature screw-base pilot lamp (5)
- 1 Battery "on" and "off" switch (6)
- 1 0.5-mfd 200 WVDC tubular capacitor (7)
- 1 1/2-watt, 270-ohm gold-band resistor (8)
- 1 1/2-watt, 10,000-ohm gold-band resistor (9)
- 1 3-lug tiepoint or solder lug terminal strip (10)
- 1 2-lug tiepoint or solder lug terminal strip (11)
- 1 Single-lug tiepoint or solder lug terminal strip (12)
- 4 Fahnestock clips or binding points (13)
- 1 Phenolic-board switch panel 2 in. x 1-1/2 in. x 1/16 in. (14)
- 4 3/8-in. No. 6 round-head brass screws
- 9 3/8-in. No. 4 round-head brass wood screws
- 1 Phenolic-board transistor panel 2 in. x 1-3/4 in. x 1/16 in. (15)
- 1 Carbon microphone (16)
- 1 6-volt dry cell battery
- Solder, hookup wire

The arrangement of the parts on the base is shown in the plan.

The wood base and the wood block that support the lamp socket are homemade. It is also necessary to make two small panels, one for the on-off switch and one for the power transistor socket. Make the panels of Bakelite or phenolic board, 1/16 inch thick, or of sheet Masonite 1/8 inch thick. The dimensions of the panels and the size and location of the holes to be drilled in them are shown in one of the illustrations.

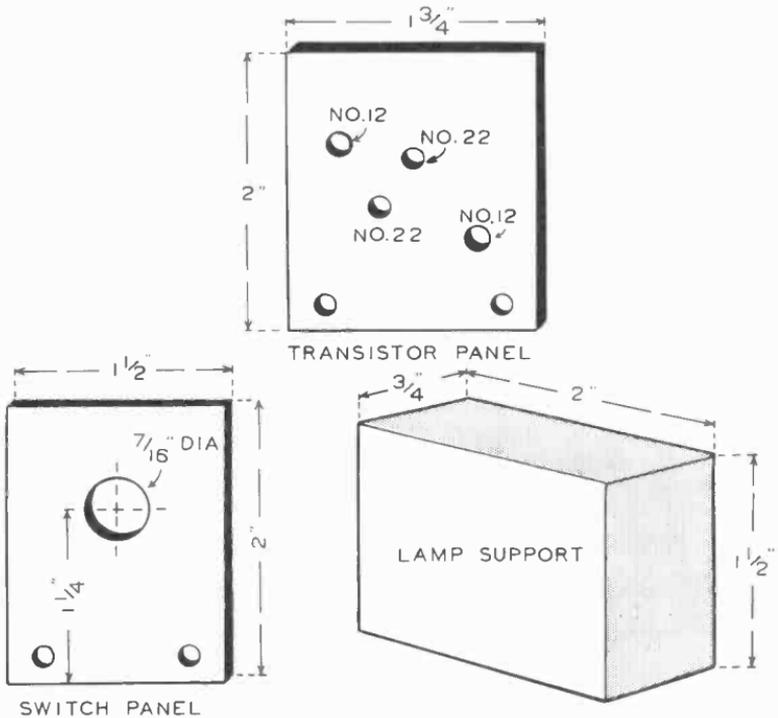


PLAN OF THE PHOTOPHONE TRANSMITTER

The numerals enclosed in small circles correspond to the identifying numerals in the list of parts.

All components, other than the homemade parts, are listed in the large electronic mail-order catalogs.

The miniature lamp must be a General Electric No. 48 pilot lamp with a screw base. The filament wire in some lamps is coiled like a spiral spring. The General Electric No. 48 miniature lamp has an uncoiled 2-volt filament. The light produced by an uncoiled filament fluctuates more rapidly with changes in the filament current than the light from a lamp with a coiled filament. It is necessary to use a No. 48 General Electric lamp. This lamp is listed in both the Lafayette and Allied catalogs.



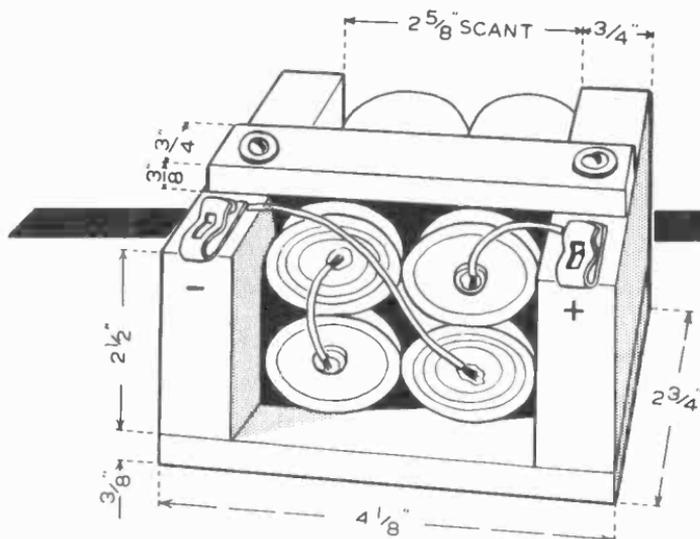
DETAILS OF THE LAMP SUPPORT AND PANELS

The underside of a power transistor is usually marked to indicate the **EMITTER** and **BASE** terminals. These terminals are two slender pins that extend from the underside of the transistor. The **COLLECTOR** terminal is the case of the transistor. An RCA 2N176 power transistor is not marked so that the uninitiated can distinguish the **EMITTER** terminal pin from the **BASE** terminal pin.

The photophone transmitter requires a 6-volt dry cell battery. This can be a Burgess No. F4BP 6-volt weatherproof general purpose battery or its equivalent, or it can consist of four size-D 1.5-volt flashlight cells connected in series and clamped together in a homemade battery holder. Do not use more or less than 6 volts. A higher voltage will burn out

the lamp; a lower voltage will not provide satisfactory operation.

One of the illustrations shows a convenient method of mounting four size-D dry cells in a homemade battery holder.



BATTERY HOLDER FOR FOUR SIZE-D CELLS

Materials required to make a battery holder:

- 1 Piece of plywood 4-1/8 in. x 2-3/4 in. x 3/8 in.
- 2 Pieces of pine 2-3/4 in. x 2-1/2 in. x 3/4 in.
- 1 Piece of plywood 4-1/8 in. x 3/4 in. x 3/8 in.
- 2 Fahnestock connectors
- 2 3/4-in. No. 6 round-head wood screws
- 2 3/8-in. No. 4 round-head wood screws
- Hookup wire and solder

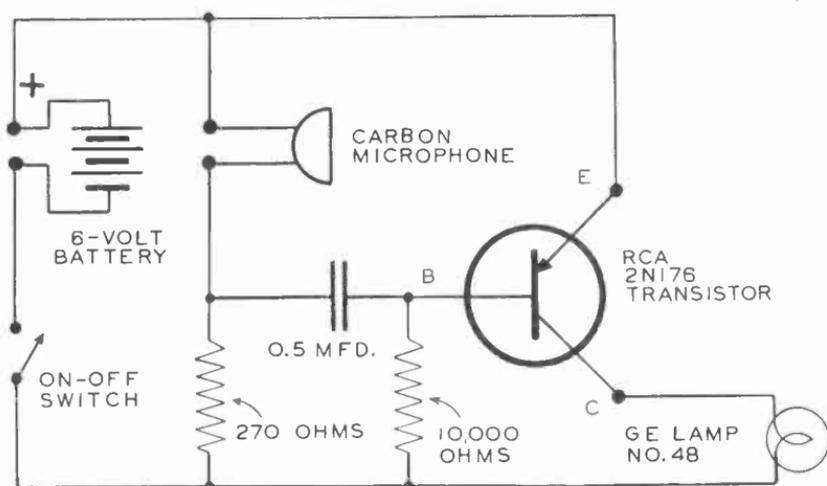
Connect the cells in series with three short lengths of wire soldered to the terminals. Solder a longer piece of wire to each of the 6-volt terminals. Connect each of the long

wires to a Fahnestock connector and mark with a plus or minus sign so they can be readily identified.

The Microphone. The microphone connected to the photophone must be the carbon type. A ceramic or crystal mike can be used in some circuits but not in this one. A second-hand microphone from an old telephone, or a low-priced carbon microphone such as Radio Shack Corporation's Catalog No. 27T1425 carbon microphone, can be used.

The Resistors. The two resistors used in the transmitter circuit should be the gold-banded grade. The resistance of a gold-banded type resistor will not vary more than 5 per cent from the resistance indicated by its color bands, but a silver-banded resistor may vary 10 per cent.

One of the illustrations is a schematic circuit diagram for use in wiring the transmitter. Use stranded hookup wire. It is advisable to solder all connections, using only rosin-core solder.



SCHMATIC CIRCUIT DIAGRAM FOR PHOTOPHONE TRANSMITTER

After a few days or weeks, the wood base may shrink slightly so that the screws holding the Fahnestock clips to the base may be loose. Tighten the screws again if necessary.

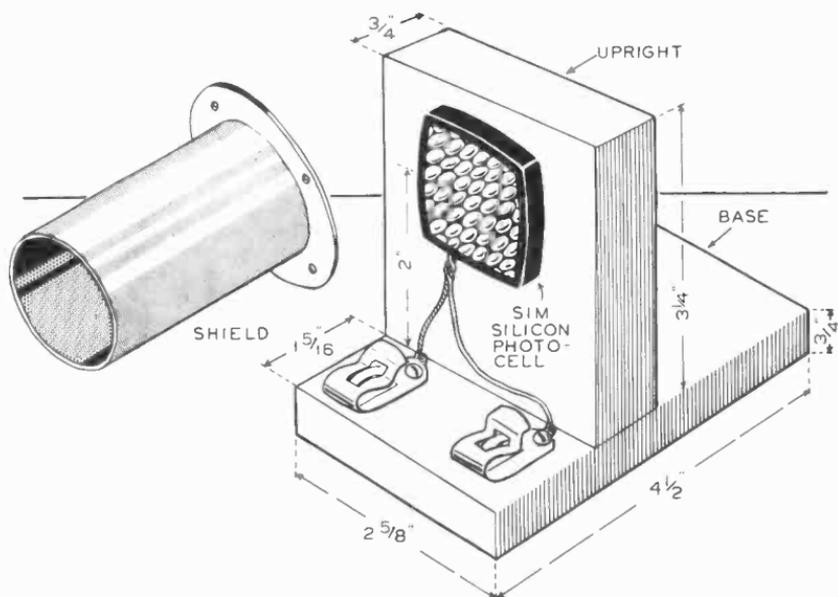
Testing the Transmitter. When the transmitter has been wired, it is ready to test. In the circuit shown in the wiring diagram, the current flowing through the No. 48 lamp is controlled to a great extent by the current passing through the microphone. Words or sounds directed into the microphone cause the current flowing through the microphone, the 270-ohm resistor, and the 6-volt battery to fluctuate in step with the sound vibrations. These fluctuations are amplified by the 2N176 power transistor, and the current flowing through the lamp filament varies accordingly. The variation is sufficient to cause the light to flicker faintly.

The Photophone Receiver

Some of the flickering can be seen by the unaided eye, but most of the modulation can be detected only by a photoelectric cell and an amplifier. The photophone receiver described here consists of an International Rectifier Corporation S1M silicon photocell, an amplifier, a speaker, and a battery. The photoelectric cell can be handled most conveniently if it is mounted on a pedestal as shown in the illustration.

Parts required to build the photophone receiver:

- 1 Wood base 4-1/4 in. x 2-5/8 in. x 3/4 in.
- 1 Wood upright 2-5/8 in. x 3-1/4 in. x 3/4 in.
- 1 International Rectifier Corporation S1M silicon cell
- 2 Fahnestock clips
- 1 Piece of sheet metal 5-5/16 in. x 2-1/2 in.
- 1 Piece of sheet metal 2-5/8 in. x 2-5/8 in.
- 6 3/8-inch No. 4 round-head wood screws



THE PHOTOPHONE RECEIVER

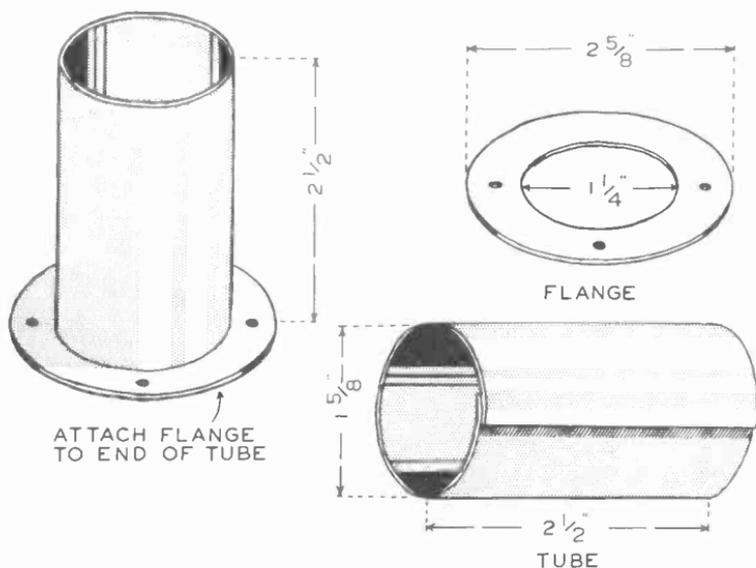
When the wood upright and base are fastened together, as shown in the illustration, they form an upside-down letter T. The silicon photoelectric cell is cemented to one face of the upright. The cell should be located so that its center is 2 inches above the base, in other words, 2-3/4 inches above the table top or any surface upon which the base rests. (The No. 48 lamp which is a part of the transmitter is also 2-3/4 inches above the surface on which the transmitter rests.)

It is not necessary to cement the photoelectric cell so that it is attached permanently to its pedestal. Although a photoelectric cell mounted on a pedestal is useful for many experiments, there may be times when it is desirable to remove the cell and use it in other demonstrations. The terminal wires attached to the cell should be connected to two Fahnestock clips mounted on the base.

When in operation as part of a photophone, the photoelec-

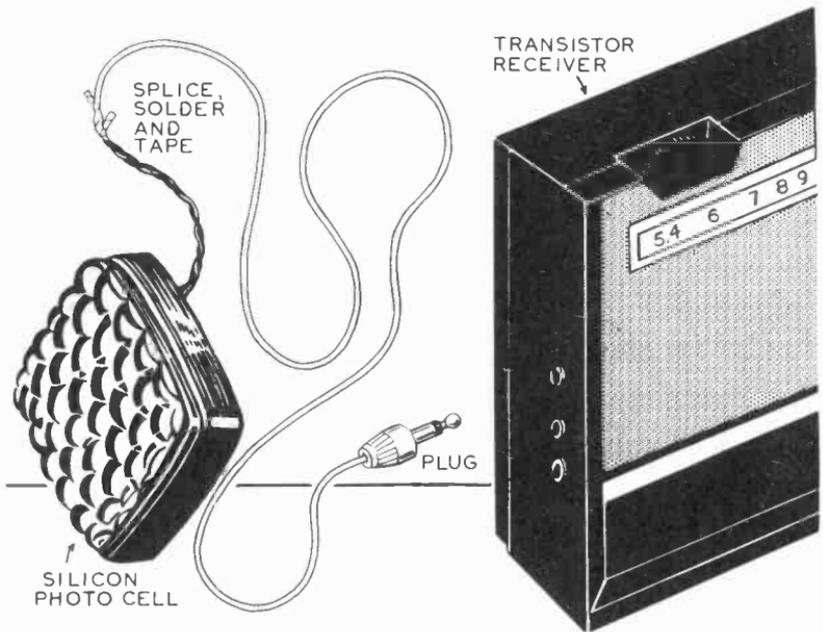
tric cell must be shielded from all light except that coming from the transmitter lamp. The operation of the photophone can be demonstrated to a small group in a dark room, but when it is shown to a large group or at a science fair where darkness is not practical, the cell should be covered with a tubular shield open only at the ends. A suitable shield is illustrated. It is in the form of a tube and can be made of cardboard or the sheet metal cut from a can. In either case, the interior should be given a coat of flat black paint to prevent reflection from its surface.

Some portable transistor receivers are equipped with two or three phone jacks that make the input and output terminals of the amplifier readily accessible. A phone plug connected to an earphone and pushed into one of the jacks makes "private listening" possible. A similar phone plug connected to a photoelectric cell and pushed into the proper jack will connect the cell to the input of the audio amplifier.



DETAILS OF SHIELD FOR PHOTOCCELL AT RECEIVER

When such a receiver is available, it will not be necessary to build an amplifier to demonstrate the performance of a photophone receiver. Connect one end of a short piece of double conductor wire to the Fahnestock clips on the receiver. Connect the other end to the terminals of a sub-miniature phone plug. When the receiver is turned on, current fluctuations generated by the photoelectric cell will be fed into the input of the audio-amplifier in the receiver. If the current variations are of audio-frequency, they will produce sounds via the loudspeaker.



THE AUDIO AMPLIFIER IN A PORTABLE RADIO RECEIVER MAY BE UTILIZED AS PART OF THE PHOTOPHONE BY CONNECTING IT TO A SILICON PHOTOCCELL

(Consult Chapter 12 for additional suggestions.)

How to Demonstrate the Photophone

Connect the terminals of a carbon microphone to a piece of double conductor wire about 20 feet long. Do not use a longer piece. Connect the other end of the conductor to the Fahnestock clips at the front of the base (see illustrations). Connect the 6-volt battery to the Fahnestock clips at the rear edge of the base.

The microphone should be located in a room adjacent to the one in which the photophone transmitter is set up. The door between the rooms should be closed so that sounds and words picked up by the microphone cannot be heard directly via air waves but only when transmitted over the photophone. An assistant to speak or sing into the microphone while tests or demonstrations are being made will be very useful. A portable radio receiver can be used as a substitute for an assistant. Place it in the adjoining room where the microphone is located. Set the microphone close to the radio receiver (6 to 12 inches) so that sounds coming from the speaker will be picked up. Tune the radio receiver to a broadcasting station. Turn the volume up to normal and give your attention to the photophone transmitter.

Turn the switch on the transmitter to the "on" position. The No. 48 lamp should light but not to full brilliance. If the lamp flickers noticeably when the microphone picks up sounds, that is a good sign. It is an indication that the light is being modulated. When the photophone and receiver are set up for their first test, place them so that the distance between the lamp and the photocell is only about one inch. If the apparatus performs satisfactorily the distance may be increased slightly. At best, however, it will operate only when the space between the two is not more than a few inches. The distance can be increased somewhat by using an "optical system" between the lamp and the photocell.

The system consists of a magnifying lens placed in front of the photocell where the light from the lamp will pass through it and be focused on the photocell.

The fact that the light from the little No. 48 lamp is actually modulated so that its beam carries words and music across space is easily demonstrated by holding a piece of opaque cardboard between the lamp and the photocell. As soon as the light beam is interrupted, the transmission ceases.

RECTIFIERS FOR CHANGING ALTERNATING CURRENT TO DIRECT CURRENT • The Difference between Alternating Current and Direct Current. How to Build Rectifiers for Recharging Storage Batteries.

When certain materials are pressed together to form a junction, the junction has low resistance to the flow of electric current in one direction and a very high resistance to current flow in the opposite direction. Such an arrangement is useful as a RECTIFIER for changing alternating current into direct current.

The electric current called DIRECT current flows in one direction. It moves like a stream of water through a hose. ALTERNATING currents do not flow steadily, always moving in one direction like a stream of water. They move first in one direction and then in the opposite one. They swing back and forth like the pendulum on a clock. The alternating current commonly used for house-lighting makes 60 complete swings, or reversals of direction, every second. Each swing is called a CYCLE. The current is therefore referred to as "60-cycle AC." The letters DC and AC are, respectively, abbreviations for DIRECT CURRENT and ALTERNATING CURRENT.

Why Alternating Current Is Sometimes Changed to Direct Current

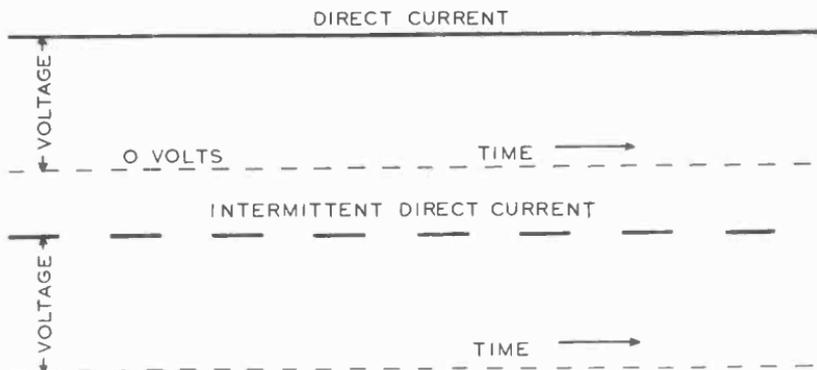
Direct current is necessary for recharging storage batteries, for electro-plating, and for other purposes. Many

modern automobiles are equipped with a generator that produces alternating current; but the current passes through a rectifier and is changed to direct current for charging the car's storage battery. Direct current is required in some of the circuits in radio and television receivers and for driving some types of electric motors and switching gear. There may be a rectifier in your livingroom and you have not been aware of it. It is in the television receiver.

There are several methods for changing alternating current to direct current. None are as convenient and as efficient as rectifiers made of semiconductor materials. These act as electrical "valves" and permit current to flow in one direction only. When an alternating current flows through these rectifier "valves," it flows for only half of each cycle. Consequently the direct current from a single rectifier unit operating on 60-cycle alternating current flows in pulses that occur 60 times per second. The pulses are all in the same direction. The result is an intermittent direct current.

Four rectifier units can be connected in a bridge circuit so that current from both halves of the alternating current cycle are utilized. This arrangement is called a **FULL-WAVE** rectifier. The resulting direct current is in the form of pulses that occur 120 times per second when 60-cycle current is rectified. The pulses can be smoothed out so that the rectified current is much like the direct current from a battery. Smoothing is accomplished by adding capacitors and choke coils to the circuit.

Engineers draw a simple picture of a direct current by representing it as a straight line. An intermittent direct current is illustrated by a broken straight line. Alternating current is pictured by a waving line that crosses and recrosses a straight line. The effect of half-wave rectification is to eliminate every other alternation, as shown by a series of curved lines. A full-wave rectifier provides twice as many



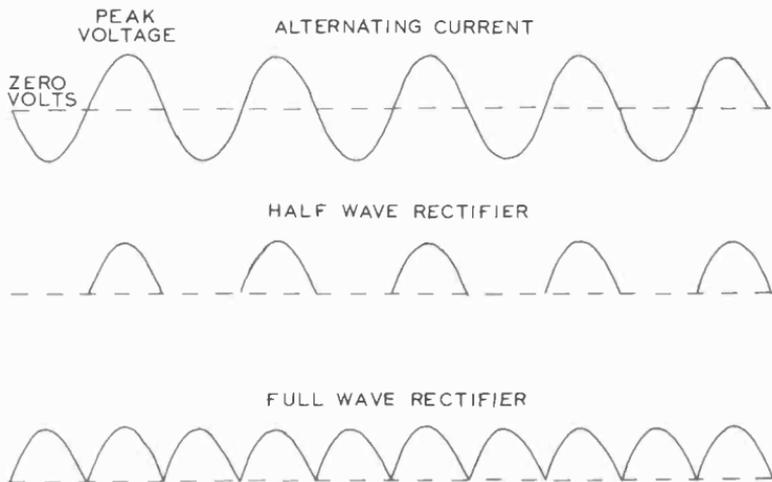
AN ENGINEER'S PICTURE OF DIRECT CURRENT

The unbroken straight line represents a steady direct current. The broken straight line represents an intermittent direct current. The distance between the solid line and the dotted base line indicates voltage or current; the greater the distance, the higher the voltage or current.

voltage and current impulses, or ripples of direct current, as a half-wave rectifier.

Since this book is concerned essentially with semiconductors, only rectifiers that utilize semiconductor materials will be explained. One of the illustrations shows a stud-mount silicon power rectifier and a small, disk-type selenium rectifier. Both make use of semiconductor materials and are excellent "electrical valves."

Disk-type rectifiers are used in television receivers and battery chargers. They are constructed of disks that range in size from less than 1/2 inch square to 6 inches square or more. Selenium disk rectifiers are made of iron or aluminum disks coated on one side with selenium; copper-oxide disk rectifiers are made of copper disks coated on one side with a thin layer of cuprous oxide. Stacking several disks of either the selenium or copper-oxide rectifiers in a series increases their voltage rating. The disks in both selenium and

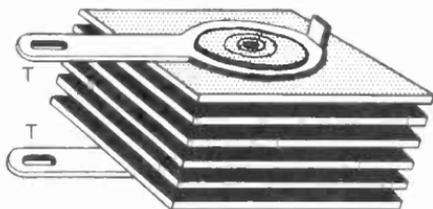


PICTURE OF ALTERNATING CURRENT AND RECTIFIED CURRENT

An engineer's graph of an alternating current represents it as a waving line that crosses and recrosses a straight, broken base line. The broken line represents zero volts or current. The peaks of the curves are the peaks of voltage or current, or both. The portions of the curves above the broken line represent the current or voltage (or both) as rising from zero to a maximum and then falling away to zero. The portions of the curves below the broken line represent the current or voltage (or both) flowing in the **OPPOSITE** direction, increasing to a maximum, dying away to zero, and then flowing in the direction of the original alternation.



STUD-MOUNT SILICON
RECTIFIER



DISK RECTIFIER—SELENIUM
OR COPPER OXIDE

SMALL SEMICONDUCTOR RECTIFIER UNITS

The letter T indicates the rectifier terminals.

copper oxide rectifiers have a dual purpose. Part of each disk is a rectifying surface, and the whole disk is a heat radiator serving to keep the rectifier cool.

How to Make a 2-Ampere Half-wave Rectifier

Recently developed small rectifiers called stud-mount silicon powers rectifiers probably will soon replace copper-oxide and selenium disk rectifiers for storage battery charging and other power purposes. These units are smaller and more efficient than disk-type rectifiers of equal capacity.

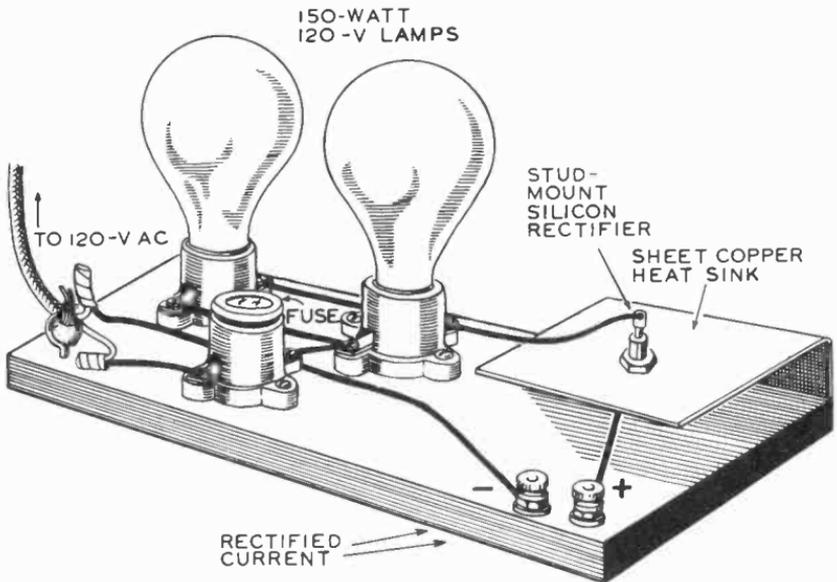
It is not difficult to build a 2-ampere, half-wave rectifier.

The following materials are required:

- 1 Wood base 10 in. x 5 in. x 3/4 in.
- 3 Flat-base porcelain lamp sockets
- 1 10-ampere plug fuse
- 1 6-ft. length double-conductor wire and plug
- 2 Binding posts or terminals
- 1 2-ampere, 400 PIV stud-mount silicon rectifier
- 8 3/4-in. No. 8 round-head wood screws
- 2 10-32 hex brass nuts and washers
- 1 Small screw eye
- 1 Piece of sheet copper 4-3/4 in. x 3 in.

Stud-mount silicon rectifiers are available from any of the mail-order electronic firms in both 2-ampere and 12-ampere size rated at 50, 100, 200, or 400 PIV. The initials PIV are an abbreviation for "peak inverse voltage." It is not necessary to explain this term. When purchasing a unit for this rectifier specify a "2-ampere 400 PIV unit."

A stud-mount silicon power rectifier develops considerable heat when operating. Excess heat will destroy the unit. It must therefore be kept cool by mounting it on a heat sink, or radiating surface, that will dissipate the heat rapidly

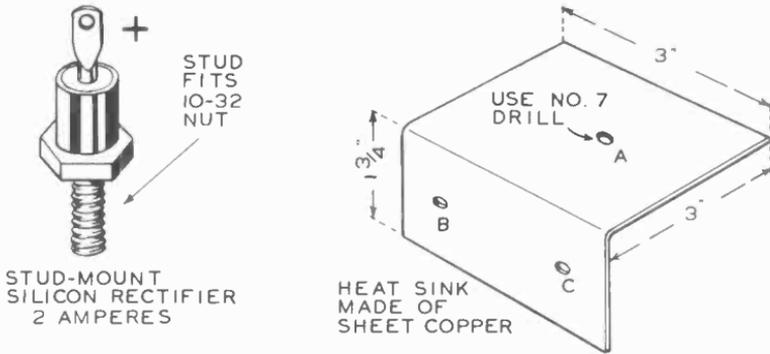


A HOMEMADE, 2-AMPERE HALF-WAVE RECTIFIER

into the atmosphere. Copper is an excellent heat conductor and makes a good heat sink. The rectifier can be prevented from overheating by mounting it in the center of a heat sink consisting of a 4-3/4-inch x 3-inch copper sheet about 1/16 inch thick. The sheet is bent at right angles and fastened to the rear edge of the base with two round-head screws. (See illustration.)

Mount the rectifier in hole A made with a No. 7 drill in the center of the heat sink. Use a piece of fine sandpaper to remove all tarnish and brighten the metal on both sides of the sheet close to the hole. Push the 10-32 threaded stud through the hole and put on one of the hex nuts. Tighten the nut until it is firm, but do not apply too much force or the silicon wafer in the stud may be damaged. The second nut and the washers are used to connect a wire to the stud.

The position of the three flat-base lamp sockets, the screw

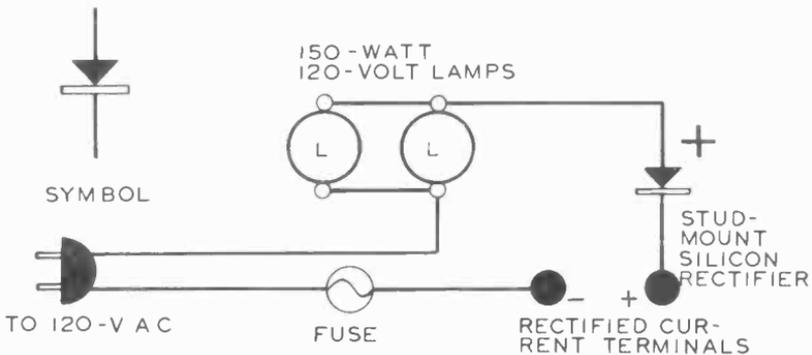


A STUD-MOUNT SILICON RECTIFIER MUST BE KEPT COOL BY A HEAT SINK

A, hole for rectifier stud. B and C, holes for screws that attach heat sink to wood base.

eye, and the terminals can be ascertained from the illustration showing the whole unit. One of the sockets is used as a receptacle for the fuse plug. The two lamp sockets are connected in parallel and in series with the power source and rectifier unit. The screw eye is used as an anchorage for fastening the power cord.

The schematic circuit diagram shows how the components are hooked up. The small eyelet is one terminal of the



SCHEMATIC CIRCUIT DIAGRAM FOR HALF-WAVE RECTIFIER

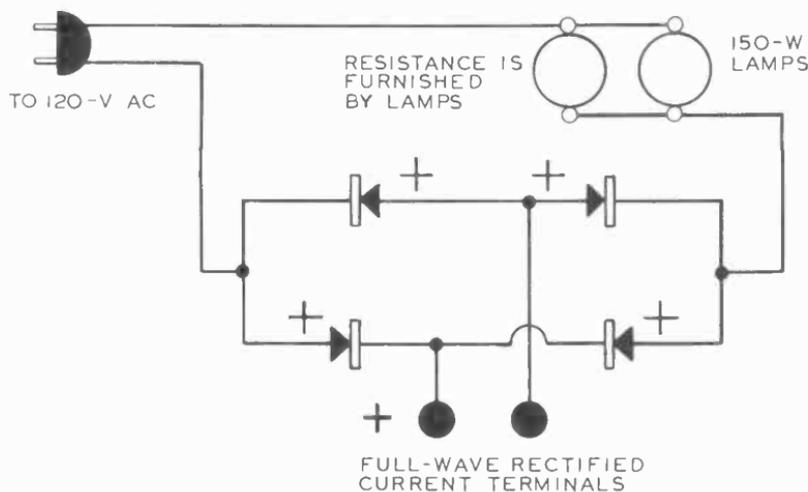
rectifier unit and also the top. The body of the unit and the threaded stud are the second terminal. Current will pass through the rectifier from the eyelet to the threaded stud. A wire from the stud to one of the rectified current terminals should therefore be marked POSITIVE. The heat sink is also positive.

When the rectifier is connected to the 120-volt AC power supply and to a storage battery, it will not operate until a 120-volt, 150-watt lamp is screwed firmly into each of the two lamp sockets. The lamps provide a resistance that will not permit more than approximately 2 amperes of half-wave rectified current to pass. The rectifier may be used to recharge both 6-volt and 12-volt automobile batteries. If lamps that are smaller than 150 watts are used, for example 100-watt or 75-watt lamps, they will provide more resistance and less than 2 amperes will flow.

A 2-ampere Full-wave Rectifier

Both halves of the 120-volt alternating current may be rectified by using four rectifier units connected in a bridge circuit, as shown in one of the illustrations. This full-wave rectifier will not deliver more than the 2-amperes that is the maximum capacity of the rectifier units. But it will deliver twice as much energy for recharging a storage battery and will cut by half the time required for recharging the battery with the half-wave model.

Four 2-ampere 400 PIV rectifier units are required when the full-wave bridge circuit is used. Each of these must be cooled by mounting on a heat sink. Four separate pieces of copper sheet, each 4 inches x 5 inches, or one large piece 8 inches x 10 inches can be used as the heat sink if each rectifier unit is insulated from the copper by a mica washer. It is not advisable to make a rectifier with a one-piece heat sink unless some silicone grease is available. Then the rectifier



SCHEMATIC CIRCUIT DIAGRAM FOR FULL-WAVE RECTIFIER

units should be spaced 4 inches apart and each unit must be carefully insulated from the sheet copper by mica washers. Mica is not a good heat conductor and the washers will interrupt the passage of heat from the rectifier unit into the copper unless the washers are liberally smeared with silicone grease. This type of grease is an excellent heat conductor and will overcome the interference of the mica washers in the heat conduction and cooling process. Silicone grease for sale in small quantities is difficult to purchase, and it may be necessary to use four separate heat sinks. The four pieces of copper should be mounted so that they do not touch each other. They thus are electrically insulated from each other.

Disk Rectifiers

The rectifiers that provide direct current for recharging storage batteries at automobile service stations are usually the copper-oxide or selenium disk type. So are the small

battery chargers for home use. As stated earlier in this chapter, stud-mount silicon rectifiers will eventually replace the copper-oxide and selenium type; but they are still of interest as useful applications of semiconductor materials.

Copper-oxide Rectifiers

A copper-oxide rectifier consists of one or more pairs of copper and lead disks. Each copper disk is coated with a barrier layer by heating the disk to high temperature and quenching it in water. This treatment produces a thin, red film of cuprous oxide* next to the copper. The outer surface of the cuprous-oxide coating will then be covered by a layer of black cupric oxide, the chemist's name for copper oxide. Both layers of oxide are removed from one side of the disk, but only the black cupric oxide should be removed from the other side. One side of the disk is now pure copper but the other is covered with a thin layer of red cuprous oxide. Between the copper and the layer of cuprous oxide there has been formed a very thin barrier layer that permits current to flow in one direction only.

When a lead disk is placed in contact with the cuprous oxide on one side of the disk, and the copper and the lead are connected to a source of alternating current, the current can flow through in one direction but not so readily in the opposite direction. When the lead contact disk is negative and the copper positive, the resistance of the cuprous-oxide film to the flow of current is high. When the copper disk is negative and the lead contact disk is positive, the resistance of the cuprous-oxide film and barrier layer to the flow of current is low.

* There are two atoms of copper and one atom of oxygen in a molecule of cuprous oxide. A molecule of cupric oxide contains one atom of copper for each atom of oxygen.

The Theory of Operation. The theory of operation of a copper-oxide rectifier is interesting because it involves a metal rich in free electrons (copper) and a semiconductor (cuprous oxide) in which free electrons are scarce. Thus the theory has a touch of modern physics. It was the theory about semiconductors and "holes" in semiconductors where there are no electrons that guided scientists in the development of the transistor.

All dry-disk rectifiers consist of two good conductors, a barrier layer, and a semiconductor. In the copper-oxide rectifier, the copper and lead disks are the good conductors; the cuprous oxide is the semiconductor. The rectifying action occurs in the copper disk, the cuprous-oxide layer, and in the barrier layer formed between them. The lead disk serves merely to make contact with the cuprous oxide.

As already explained, copper is rich in free electrons, but free electrons are scarce in cuprous oxide. The behavior of the electrons in a rectifier explains how it changes AC into DC.

It has been explained in Chapter 4 that a voltage, or potential, or electromotive force, or whatever you may wish to call it, is the force that moves electrons. An electromotive force can cause electrons that are standing still to move. It can increase the speed of those that are already moving. When an electromotive force that makes the copper disk negative and the lead disk positive is applied to the disks, free electrons in the copper move toward the lead. They push through the barrier layer and the cuprous oxide and enter the lead, thus establishing a conductive path through the rectifier. When the electromotive force is reversed, so that the copper disk is positive and the lead disk is negative, a few free electrons try to move from the cuprous oxide into the copper. Since cuprous oxide has only a few free electrons, only a few electrons pass through the barrier layer and into the copper disk. Under this condition only a very

small current flows. This current is called the REVERSE CURRENT OR BACK LEAK. In a good rectifier under proper operating conditions, the volume of the forward current may be 800 to 1500 times that of the reverse current.

Selenium Rectifiers

Small selenium disk rectifiers are used in radio and television receivers. They are quite similar to copper-oxide rectifiers in appearance, construction, and operation. The back disk, or plate, in a selenium rectifier is nickel-plated steel or aluminum. A thin layer of selenium is spread on one side of this disk and crystallized by a carefully controlled heat treatment. A very thin layer ($\frac{4}{1,000,000}$ of an inch thick) of an alloy with a low melting point is then sprayed on the surface of the selenium. This thin metallic film forms a barrier layer that permits the passage of electrons in one direction but not in the opposite direction. A metal disk called the front plate is laid against the barrier layer. When the rectifier is connected in a circuit and an electromotive force is applied to the plates, the same sort of action occurs as in a copper-oxide rectifier. Current can flow readily from the front plate through the barrier layer and selenium to the back disk. Since selenium is a substance that has few free electrons, its resistance is great to a reverse current trying to pass from the base plate through the selenium and barrier layer to the front plate.

AMPLIFIERS—MODULES • A Public Address System. A Telephone Amplifier.

The words **AMPLIFY** and **AMPLIFIER** are important in electronics. Amplify, as used in electronics, means to increase current or voltage, or both, through control of a larger amount of power than that originally present. The apparatus for accomplishing this is called an **AMPLIFIER**. Before amplifiers were developed, listeners to a radio broadcast used telephone receivers. Telephone receivers respond to very weak currents and were the only instruments available that could change the feeble currents delivered by a radio receiver into audible sounds. A radio receiver does not produce sufficient current to operate a loudspeaker satisfactorily without the assistance of an amplifier.

A practical amplifier was an unfulfilled dream of scientists and engineers for many years. The dream was not realized until Lee DeForest produced the first three-element radio tube, called at that time the **AUDION** and now known as a **TRIODE**. At first, the audion was thought to be only a new and sensitive detector of wireless telegraph signals. But there were other talents contained in the onion-shaped glass bulb. The first to be revealed was the remarkable ability to amplify, or magnify, feeble currents of electricity.

The first audion amplifiers were cranky and undependable. The vacuum in the glass bulb was not high; some air remained. Audions often exhibited the temperament sometimes ascribed to prima donnas. Then along came H. D. Arnold, an engineer of the American Telephone and Telegraph Company, and Dr. Irving Langmuir, a former college

professor and in later years a recipient of the Nobel prize in chemistry. Langmuir had recently abandoned teaching at Stevens Institute of Technology in Hoboken, N.J., to take up research work in the laboratories of the General Electric Company at Schenectady, N.Y. Each of these men began to experiment in his own way with audions. They were not long in discovering that "hard" tubes—those having a very high vacuum—were dependable and far superior to the "soft" low-vacuum tubes produced by DeForest.

The practical limit of conversation by telephone before 1914 was not much more than 1,000 miles. But when Dr. Arnold and his colleagues of the Bell Laboratories made more efficient amplifiers, telephony across the continent became a comparatively simple matter. Today it is possible to talk to any place where wires can be stretched or radio beams can be directed. Amplifier tubes used in telephony are called REPEATERS and are now a necessary part of the world's communication systems. Powerful amplifiers are an essential part of every radio broadcasting station and television transmitter. There are small amplifiers in your record player and radio and television receivers. Amplifiers have made possible hundreds of useful scientific instruments that did not exist at the beginning of the century.

Modern amplifier tubes consist of three or more metal electrodes enclosed in a glass or metal envelope from which almost all trace of air and gas has been pumped. The electrodes are metal conductors that provide voltage across the vacuum and by which current enters or leaves the vacuum tube. An electric current to heat the negative electrode, called the CATHODE, which serves as a provider of electrons, is required to operate the tube. Operation of a vacuum amplifier tube depends upon the flow of electrons from the cathode to a plate electrode, or ANODE and the control of this flow by intermediate GRID ELECTRODES.

The experimenter who wishes to build a vacuum tube

amplifier is advised to buy one of the many complete kits that are available. Assemble it according to the detailed instructions accompanying the parts. You will not only have a better amplifier, but will save money by buying a complete kit instead of the separate components. Amplifier kits of several sizes and for various purposes are listed in the electronic mail-order catalogs. (See pages 162 to 191 in *The Boys' Third Book of Radio and Electronics* for a description of an audio amplifier that you can build.)

The vacuum tube amplifier now has a rival. The rival is the TRANSISTOR. Transistors may never entirely replace the vacuum tube for some purposes but they have opened an entirely new field in the development of portable equipment. A transistor requires no heating current to serve as the provider of electrons, and its size is about one-thousandth that of a vacuum tube of equivalent capacity. Transistors are now being used in increasing quantities as substitutes for tubes in hearing aids, tape recorders, automobile radios, marine radios, photographic equipment, walkie-talkies, and television receivers.

Two Varieties of Amplification

The number of cycles that an alternating current goes through in one second is called its frequency. Frequencies in radio circuits range from 20 cycles per second to many millions per second. Power-line circuits usually have a frequency of 60 cycles per second.

Alternating currents that change direction of flow at a frequency of less than 20,000 cycles per second in a radio circuit are called AUDIO-FREQUENCY currents. Audio-frequency sounds, with the exception of those at the bottom and top of the range, are audible to the human ear. Frequencies of over 20,000 cycles per second are called RADIO FREQUENCIES. They are inaudible to human ears.

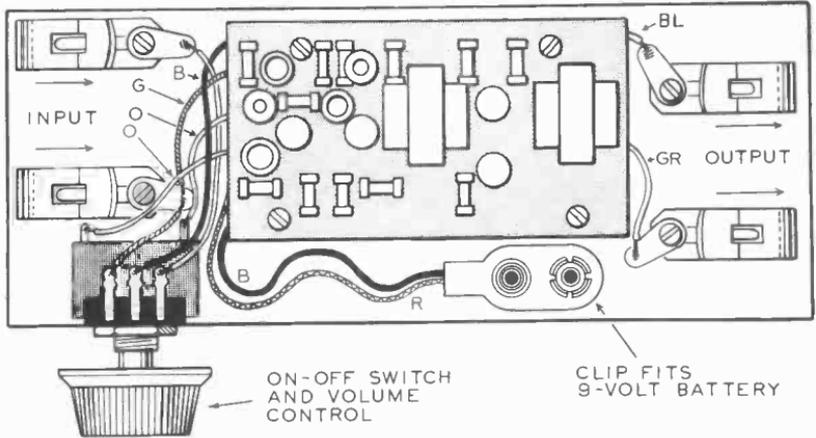
The modern radio receiver employs two varieties of amplification. The radio-frequency amplifier in a radio receiver builds up the weak radio-frequency antenna currents before they are fed into the detector. This increases the sensitivity of the receiver by building up weak signals before they reach the detector. After the signals have been demodulated by passing through the detector, they are fed into an audio-frequency amplifier to increase their power.

When it is desirable to obtain more amplification than one amplifier can provide, two or more may be connected in STAGES, or cascade. Because a certain amount of distortion and noise develops in the amplification process, and each stage multiplies this, it is therefore not usual to build amplifiers of more than three stages for ordinary use. Amplifiers with more than this number of stages are usually restricted to laboratory purposes.

Subminiature Audio Amplifiers

Several types of miniature, factory-built, audio-transistor amplifiers are available from distributors of electronic equipment. These well-designed little instruments range in size from 2-3/4 inches to 5 inches in length. They employ printed-circuit construction and are completely assembled, with the exception of a volume control and on-off switch. The purchaser must buy, in addition to the amplifier, a volume control, on-off switch, and battery. The total cost of an amplifier and control is less in each instance than the over-the-counter cost of the component parts. For example, a complete 3-transistor subminiature audio amplifier and volume control may be purchased for less than \$4.50.

The hobbyist who wishes to experiment with a small amplifier or to incorporate one into other equipment will save time, effort, and money by the purchase of these units.

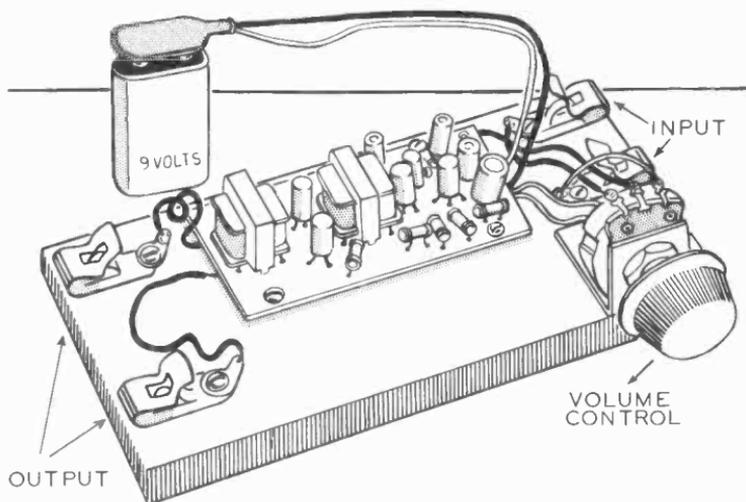


PLAN OF A PK-543, SUBMINIATURE 4-TRANSISTOR AUDIO AMPLIFIER; VOLUME CONTROL; ON-OFF SWITCH; AND INPUT AND OUTPUT TERMINAL CLIPS MOUNTED ON 6-INCH X 3-INCH X 1/2-INCH WOOD BASE

The wire leads are color-coded. They may be identified in the illustration as follows: B and BL, black. G and GR, green. O, orange. R, red.

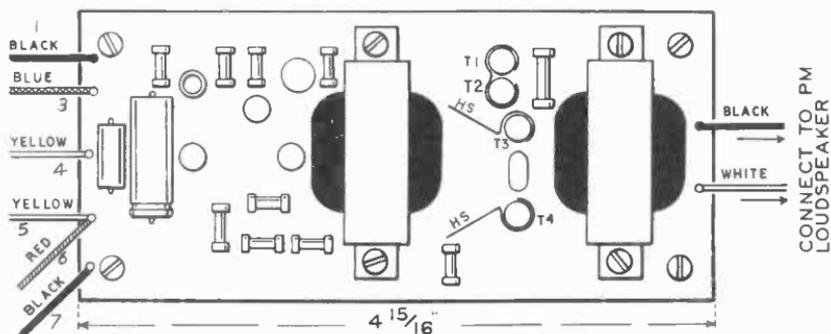
A subminiature amplifier can be incorporated into a radio receiver or other instrument that requires an amplifier by mounting it on the same baseboard or in the same cabinet. Four holes are provided at the corners of the printed-circuit board for the mounting screws. When an amplifier is to be used for miscellaneous experiments, it is advisable to mount the amplifier, volume control, and necessary terminals on a small wood base. Fasten an L-shaped bracket, upon which the volume control and on-off switch can be mounted, near the front left-hand corner of the base. Two pairs of Fahnestock clips or binding posts connected to the input and output terminals of the amplifier are recommended.

More amplifiers are used to strengthen the signals picked up by radio and television receivers than for any other purpose except as part of the telephone service. The signals



SUBMINIATURE 4-TRANSISTOR AMPLIFIER MOUNTED ON WOOD BASE WITH VOLUME CONTROL AND TERMINAL CLIPS

This is the same amplifier shown in the preceding illustrations, but the components have been assembled on the printed circuit board in a reversed position.

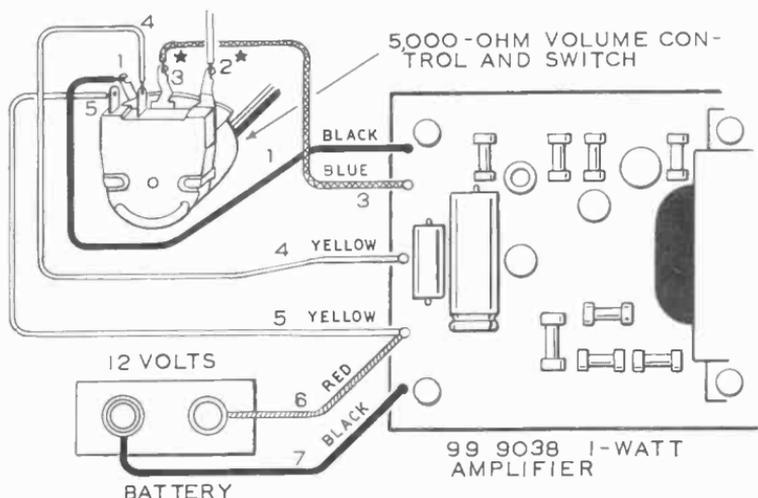


1-WATT, 4-TRANSISTOR, PUSH-PULL AUDIO AMPLIFIER
T1, T2, T3, and T4 are transistors. HS indicates radiating fins to dissipate heat.

picked up by an antenna and demodulated by a receiver are too weak to operate a loudspeaker or a television tube until they have been amplified.

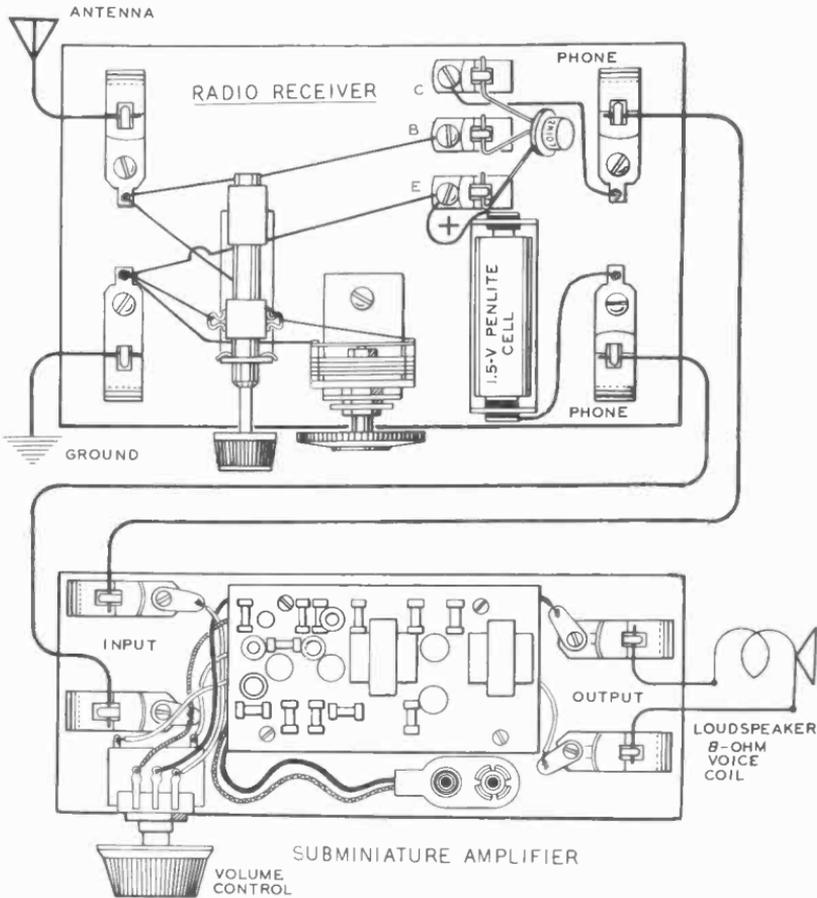
A good demonstration of the effect of an amplifier can be made by connecting a subminiature amplifier to a radio receiver with a diode or transistor detector. The radio receiver with a transistor detector powered by a sun battery described in Chapter Three is a good one for this experiment. Remove the sun battery and replace it with a size AA 1.5-volt flashlight cell. One of the illustrations shows how the receiver should be connected to the amplifier. Notice that a volume control and loudspeaker are included in the circuit. When the receiver is tuned to a radio station and the volume control is properly adjusted, signals should come in with room-volume. Without the amplifier, they will be only loud enough to be heard in a pair of headphones.

The term **IMPEDANCE** is often used in electronics, especially in a discussion of transistor amplifiers. Impedance



CIRCUIT DIAGRAM SHOWING HOW TO CONNECT A BATTERY, VOLUME CONTROL, AND SWITCH TO THE 1-WATT PUSH-PULL AMPLIFIER

is the amount of opposition to current flow in a circuit that is more than the opposition of ohmic resistance alone. It must be given consideration whenever signals are to be fed into or out of a transistor amplifier at greatest efficiency. The greatest transfer of power occurs when there is an "impedance match." For example, the impedance of the output circuit of a radio receiver should match the impedance



SUBMINIATURE AMPLIFIER CONNECTED TO RADIO RECEIVER WITH TRANSISTOR DETECTOR

of the input circuit of the amplifier to which it is coupled. Also, the impedance in the output circuit of an amplifier should match the impedance of the loudspeaker.

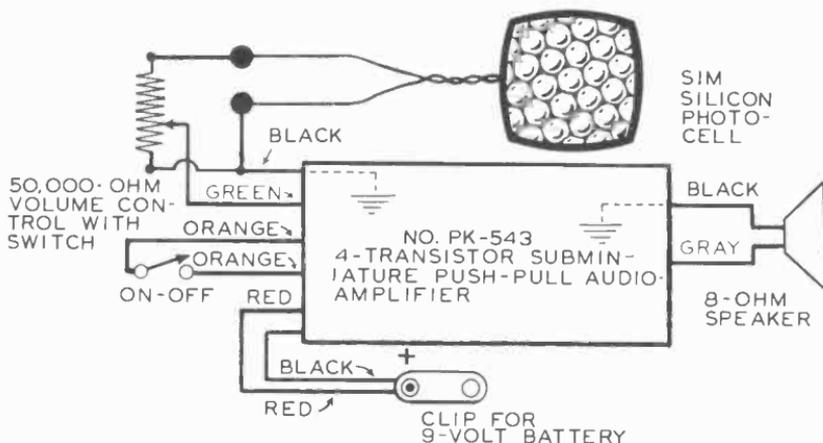
Small low-cost matching transformers for transistor circuits are listed in the mail order catalogs of dealers in electronic supplies. These transformers and a few resistors offer the young experimenter an opportunity to experiment and observe the effects of impedance adjustments.

A radio receiver tuned to the strong signals of a nearby broadcasting station and a silicon photoelectric cell in strong light can overload the first stage of a small transistor amplifier. If the sounds from the loudspeaker are mushy and distorted, try to clear them by adjusting the volume control. If this is ineffective, reduce the strength of the input signals by inserting fixed resistors in series with one of the input wires. It will be necessary to determine the proper amount of resistance experimentally.

A subminiature audio amplifier connected to an S1M silicon photoelectric cell is a compact and efficient photophone receiver. The circuit for a No. PK-543 amplifier and a silicon photoelectric cell is illustrated. The amplifier, volume control, loudspeaker, and photoelectric cell should be mounted on the same base and arranged so that the interconnecting wires are as short as possible.

When using an amplifier with either a radio receiver or a photoelectric cell, the wires connecting the receiver output or the photoelectric cell output to the amplifier input should be twisted together along their length in order to cut down hum pickup. Hum may sometimes be reduced by merely reversing input connections.

A 99-9038 1-watt amplifier can also be used in a photophone receiver and in many instances will produce louder signals than a PK-543. Silicon photocells deliver much more energy to an amplifier than a diode or transistor detector. For that reason it is necessary to use a 50,000-ohm volume



A PHOTOPHONE RECEIVER USING SUBMINIATURE PUSH-PULL AMPLIFIER

control, instead of the 5,000-ohm control usually employed with the PK-543 and 99-9038 amplifiers.

Modules

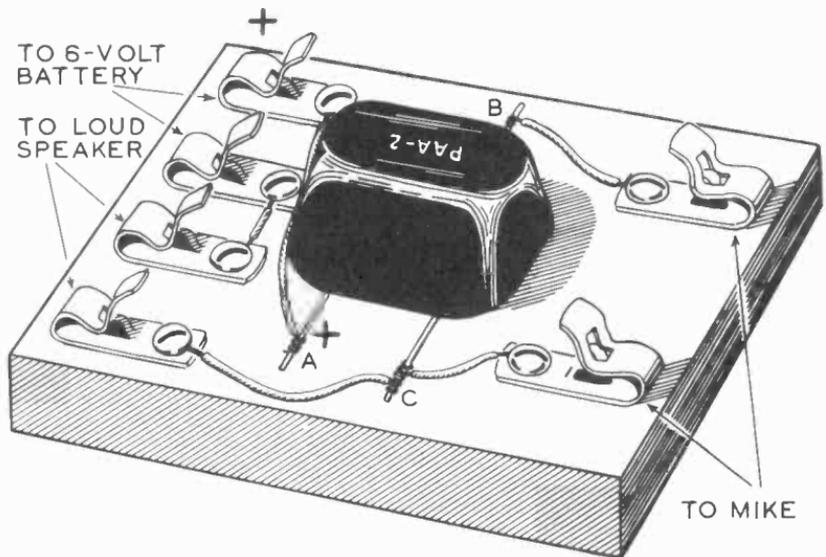
The transistor is one of the first important devices to extend the domain of the human mind. The mechanical and electrical characteristics of the transistor have made it possible to build machines that can perform more mathematical calculations in one second than a man working with pencil and paper could in ten years. The requirements of calculating machines, missiles, and satellites for compact, lightweight, space-saving electronic circuits have resulted in new methods of construction unknown a few years ago. Today, a complete audio amplifier can be built in a smaller space than is occupied by a dime. This subminiature apparatus is not of any practical value to the amateur experimenter or hobbyist, except as a scientific curiosity.

Transistors, small capacitors, and various miniature components of electronic circuits have, however, resulted in

the production of small, self-contained electronic instruments called solid state MODULES. These are complete electronic circuits (except battery) that are encapsulated in small molded plastic cases.

Public Address Amplifier. For example, the PAA-2 public address amplifier module for use with a carbon microphone measures only 1-1/2 inches x 1-1/4 inches x 3/4 inch. When connected to a carbon microphone and a battery, this instrument will operate a loudspeaker of almost any size. The module retails for less than \$2.00 and there are more than a dozen different modules available. They include modules for fire alarms, burglar alarms, guitar amplifiers and telephone amplifiers, all priced at not more than \$3.50.

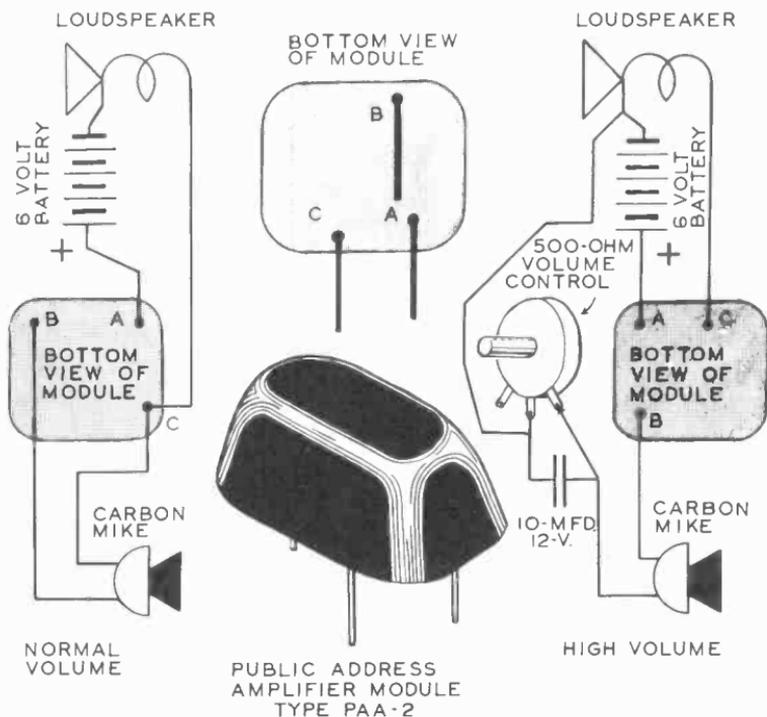
The PAA-2 module makes a practical and useful instrument for addressing small groups and can be the means of much entertainment at clubs and parties. A 6-volt battery and a carbon microphone are required to operate the ampli-



PUBLIC ADDRESS AMPLIFIER MODULE MOUNTED ON WOOD BASE

fier. A crystal or ceramic microphone is not usable in this instance.

It is advisable to cement the flat underside of the module to a small wood base. Three bare-wire leads project from the bottom of the module. Solder a 4-inch length of small flexible wire to the end of each lead. Soldering should be done as quickly as possible. Grasp the lead being soldered with a pair of pliers so that the plier jaws act as a heat sink and prevent excess heat from being conducted along the lead into the interior of the module. Connect the wires



MODULE PAA-2 PUBLIC ADDRESS AMPLIFIER AND CIRCUITS

When the amplifier is used in a room of average size, make the circuit connections as shown in the left-hand diagram. If more volume is required for a large room or small hall, use the hookup shown in the right-hand circuit diagram.

soldered to the leads to six Fahnestock clips or binding posts. These will provide convenient terminals for connecting the battery, speaker, and microphone.

A 6- to 10-inch permanent magnet speaker will provide enough sound volume for a large room. The quality of the sound will depend to some extent on the manner in which the microphone is used and the quality of the loudspeaker. The microphone should be held close to the lips but not so close as to muffle sounds. A good grade of loudspeaker will have better tone than a cheap one.

Telephone Amplifier. There are several telephone pickup coils listed in catalogs of electronic components. When one of these coils is placed under the base of a telephone instrument and connected to the input of a tape recorder, it will make a tape recording of any conversation sent or received over the telephone.

A typical pickup coil consists of a small coil of wire enclosed in a small, flat, rectangular case. One terminal of the coil is connected to an insulated flexible wire lead. The other coil terminal is connected to a woven wire shield surrounding the insulated wire. This construction is used to reduce noise and prevent feedback. The woven shield is covered by a cotton braid. The leads therefore appear at first glance to be a single-conductor flexible wire. Actually the wire is one terminal of the coil and the shield the other.

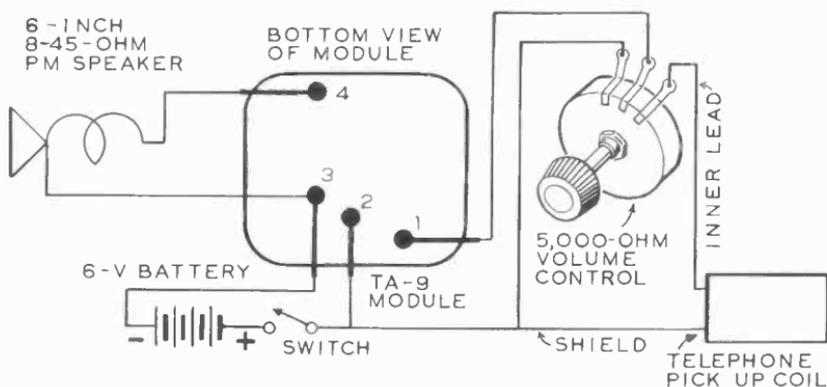
There is a telephone amplifier module called the TA-9 available for use with a pickup coil. The input impedance of the amplifier module matches the impedance of the rectangular pickup coil described in the preceding paragraph.

A TA-9 amplifier module, telephone pickup coil, 5,000-ohm volume control, 6-volt battery, and loudspeaker (the voice coil may vary in resistance from 8 to 45 ohms) will make group listening to a telephone conversation possible

without the expense of extension telephones. No unlawful connection need be made to the telephone.

There are four bare-wire leads protruding from the underside of the TA-9 module. Connect a flexible wire to each of these leads. Use care in the soldering. Cement the module to a small wood base upon which the loudspeaker, volume control, and battery and pickup-coil terminals are located. Use a 6-inch loudspeaker.

Place the flat pickup coil under the base of the telephone instrument. When you make a call or a call comes in, turn the amplifier switch to the ON position and adjust the volume control. A coil in the base of the telephone instrument produces a magnetic field that induces currents in the pickup coil. These feeble currents are magnified by the amplifier. It may be necessary to move the pickup coil to different positions under the base of the telephone instrument until the best location is found.



CIRCUIT FOR CONNECTING TELEPHONE AMPLIFIER MODULE,
LOUDSPEAKER, VOLUME CONTROL, AND TELEPHONE PICKUP
COIL FOR GROUP LISTENING

THINGS YOU SHOULD KNOW ABOUT CIRCUITS, SYMBOLS, RESISTORS, SOLDERING, ETC.

Symbols

The same radio circuit can often be illustrated by two different types of diagram. One is called a PICTORIAL circuit diagram and the other a SCHEMATIC circuit diagram. The pictorial diagram is more easily understood by the novice in electronics. It consists of small sketches or "pictures" of the components in the circuit and shows the interconnecting wires. But a pictorial diagram of an elaborate circuit would be difficult to draw, and some of the connections might be obscure. So a schematic circuit is more often used.

Radio engineers, servicemen, and experienced amateurs prefer schematic diagrams. In these, symbols are used to denote the various coils, capacitors, resistors, and other components that comprise the circuit. There is a pictorial circuit diagram on page 41 and a schematic diagram of the same circuit on the same page.

All of the symbols used in the circuit diagrams in this book are illustrated in this chapter. They are the standard symbols used by engineers and are an "electronic shorthand." As soon as the meaning of these symbols is memorized, schematic circuit diagrams are no longer a mystery. Copy a few of the circuit diagrams shown in previous chapters and, using the chart as an identification guide, write down the names of the different components that appear in the circuits. This will help you to memorize the symbols and give a mental picture of what is being represented by the circuits.



ANTENNA



GROUND



CONNECTED WIRES



CROSSING WIRES NOT CONNECTED



FIXED CAPACITOR



FIXED CAPACITOR



VARIABLE CAPACITOR



ELECTROLYTIC CAPACITOR



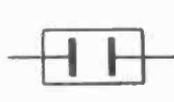
TERMINAL OR BINDING POST



SPST SWITCH



PUSH BUTTON



POWER OUTLET



RESISTANCE



VARIABLE RESISTANCE



INDUCTANCE



POWER PLUG



VARIABLE INDUCTANCE



AIR-CORE TRANSFORMER



IRON-CORE TRANSFORMER



EARPHONE



SINGLE CELL



BATTERY



SPEAKER



TELEPHONE HEADSET



DIODE



PNP TYPE TRANSISTOR



NPN TYPE TRANSISTOR

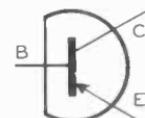
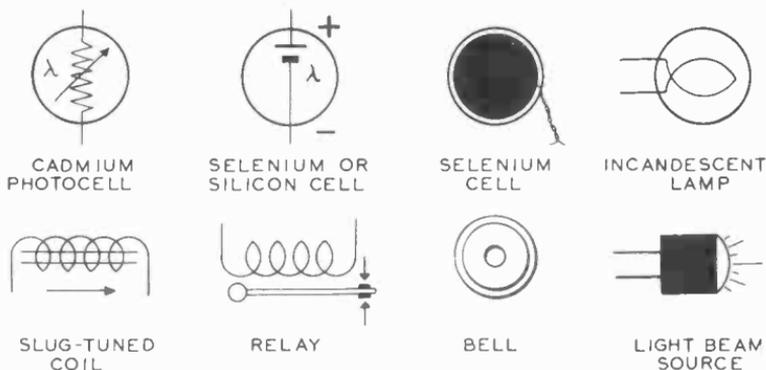


PHOTO-MULTIPLIER TRANSISTOR

SYMBOLS USED IN DIAGRAMS OF SCHEMATIC RADIO CIRCUITS
 Here and in the illustration that follows are the symbols used in the schematic circuit diagrams in this book.



THE SYMBOLS USED IN THE SCHEMATIC CIRCUIT DIAGRAMS,
CONTINUED

Resistors

Resistance to the flow of electric current may be objectionable in some portions of an electrical or electronic circuit. On the other hand, resistance is necessary in some circuits and is purposely placed there. Small units of resistance called **RESISTORS** are usually more numerous than any other kind of component in electronic circuits. There are **FIXED** and **VARIABLE** resistors. The resistance of variable resistors is adjustable. The resistance of fixed resistors is not adjustable.

The fixed resistors used in electronic circuits are small cylindrical units with two terminal wires. The ability of a resistor to oppose the flow of electric current is measured in units of resistance called **OHMS**.

The amount of energy a resistor can carry without becoming overheated indicates its size and is rated in **WATTS**. The physical dimensions vary in accordance with the rating in watts. One-half-, one-, and two-watt resistors are the sizes used most often in the electronic circuits described in this

book. The resistance value in ohms of small fixed resistors is indicated by four colored rings.

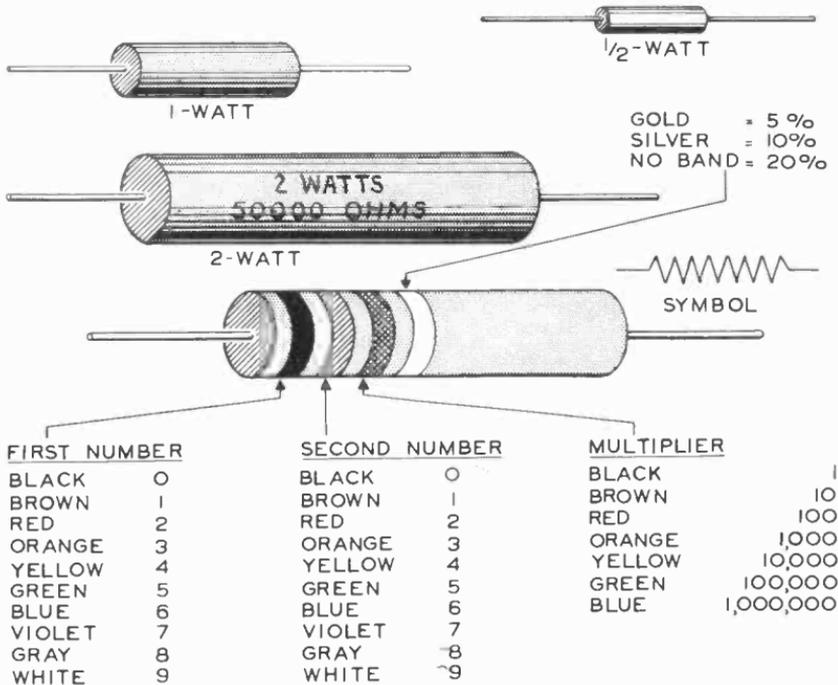
Check Your Resistors before Using

A careful experimenter checks the value of each resistor before using it in order to insure that the resistance is as called for in the circuit diagram. In circuit diagrams the numerals indicating the value of a resistor are sometimes followed by the Greek letter omega (Ω), which is the symbol for ohms. The capital letter *K* is often used to indicate 1,000 where space is restricted. For example, 10K and 10,000 are the same value of resistance. MEG is an abbreviation for one million. A 1-MEG resistor has a resistance of 1,000,000 ohms.

The Radio Manufacturers Association has adopted a standard color code for resistors, so that the resistors of all manufacturers are marked in the same manner. Ten colors are used. Each color represents a figure. The END band represents the first figure of the resistance. The second band indicates the second figure, and the third band shows the number of zeros that follow the second figure.

Resistors often bear a fourth colored band to indicate the tolerance or accuracy of the resistance indicated by the first three color bands. A gold band means that the ohmic resistance may vary five per cent more or less than the value indicated by the first three bands. A silver band means that the resistance may vary ten per cent more or less than the value indicated by the bands. If there is no gold or silver band, the resistance may vary twenty per cent from the value indicated by the color bands.

Check each resistor before you connect it in a circuit. Compare its wattage and the resistance indicated by its bands with the specifications in the schematic wiring dia-



RESISTOR COLOR CODE

This chart and the explanation in the text will enable you to determine the resistance and the size of any standard, color-coded, fixed radio resistor.

gram that you are using. You can generally ascertain the capacity of a resistor by its size and by comparing it with the full-size resistors in the illustration. You can find out its resistance in ohms by the color bands with which it is marked. Each band is code for a numeral. For example, the first band on a 10,000-ohm resistor is brown (1). The second band is black (0) and the third is orange (000). A fourth band of gold would mean that the actual resistance may vary between 9,500 and 10,500 ohms.

Soldering

Soldering is an important operation in the construction of some electronic circuits. The wires used to connect the components should be soldered to the terminals. Use “push-back” wire for making connections. This is insulated copper wire that is coated with tin so that solder will adhere to it easily. It is not necessary to cut and scrape off the insulation. It may be pushed back out of the way.

Soldering is not difficult, and you should master the art if you wish to build your own electronic apparatus. If you are a beginner at soldering, practice by following the instructions. If your efforts do not result in neat, firm, soldered joints, ask someone who has had experience to help you and show you the “trick.”

To solder. A small electric iron, a flux, and solder are required. These, plus a bit of knowledge, experience, and the ability to take pains, are all that is necessary.

A small, 25-watt electric soldering iron is the correct size to use for most transistor circuits. An iron of larger size is clumsy and generates too much heat for circuits with small components.



SMALL SOLDERING IRON (25-WATT) FOR TRANSISTOR CIRCUITS

The name soldering “iron” is somewhat of a misnomer. The bit, or tip, that actually does the soldering is made of copper or a copper alloy, not of iron.

To put a new electric soldering iron into service, plug

it into an 120-volt outlet. When the copper tip reaches a temperature hot enough to melt a piece of rosin-core solder held against it, rub solder over the entire tip. If the solder does not "flow," that is, spread and form a coating on the copper, file the tip lightly and rapidly. As quickly as possible rub more rosin-core solder over it before the tip has time to lose its bright color. This preliminary to soldering is called "tinning the iron." The iron must be properly tinned before it will solder successfully.

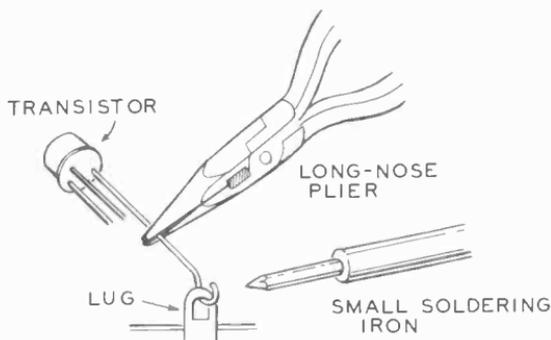
Solder will stick only to bright, clean metal from which all dirt, scale, oxide, and grease have been removed. The terminals of most radio components are tinned (coated with tin), and solder will usually adhere to them readily. But it may be necessary to scrape the surface of the metal until it is bright and clean. Use fine sandpaper or a knife blade to do this.

It is almost impossible to solder without a flux. The purpose of the flux is to remove and prevent the formation of an oxide on the surface of the metal during the soldering process. There are a number of different fluxes, but rosin is the only safe one to use in soldering electronic circuits. For small work, wire solder is most suitable. Wire solder with a rosin core makes additional flux unnecessary.

Apply the hot tip of the iron to the surfaces to be joined and hold it there a moment to heat them. Then apply some rosin-core solder, holding it against the tinned point of the iron and the surfaces to be joined so that it melts and flows into the joint. Remove the iron and when the joint has cooled test it by pulling and wiggling the connection. If the joint is loose or pulls apart, solder it again. The wire must not be moved while the soldered joint is cooling.

A transistor is easily damaged or destroyed by the heat of a soldering iron. When soldering the terminal wires of a transistor you must take every precaution to prevent heat

from traveling along the wire and reaching the transistor. Hold the wire in the jaws of a pair of long-nose pliers so that the pliers act as a heat sink and absorb the heat. Apply heat for the shortest time needed to make a good soldered connection.



TRANSISTORS ARE EASILY DAMAGED BY EXCESS HEAT

If a transistor is to be connected in a circuit by soldering its own wire leads, avoid cutting the leads short. Use a pair of long-nose pliers as a heat sink and shield. Clean and brighten the leads and joint before soldering so that the connection can be made quickly without too much heat. Grasp the transistor lead being soldered, as close to the free end as possible, in the jaws of the pliers. Use a small or miniature soldering iron and first-quality rosin-core wire solder. Recommended irons include American Beauty Nos. 3118 and 3120, G.E. Type 6A (212, 210 or 214), Lenk Nos. 251 and 256, Vasco No. 316, and Ungar No. 776.

HOW TO BECOME AN AMATEUR RADIO OPERATOR • *Learning to Telegraph. How to Secure an Amateur License. Where to Obtain Materials.*

Many men and boys and even some girls, interested in electronics, eventually become amateur or "ham" radio operators and "get on the air" with their own transmitters. There are many reasons for becoming a ham. Amateur radio is one of the best hobbies. It is open to any citizen of the United States, regardless of age or sex, if he or she meets the requirements of the Federal Communications Commission.

All transmitters, except those operating a distance of only a few feet or on the Citizen's Band, require a government-issued STATION LICENSE and a government-issued OPERATOR'S LICENSE.

A PERMIT and identifying CALL LETTERS for a Citizen's Band transmitter can be obtained merely by filing an application. But the practical range of a Citizen's Band station is limited to a few miles.

The range of an amateur station can be almost unlimited at favorable times. The most fun and excitement of amateur radio is in operating on the amateur frequencies that make it possible to communicate with other amateur operators who are hundreds of miles away and at times to "work" hams in foreign lands.

No license or permit of any sort is needed to build, own, or operate a radio RECEIVER in the United States of America. But the TRANSMISSION of radio messages is controlled by

federal laws, and in order to own and operate an amateur transmitting station in the United States it is necessary to have two licenses. Both of these are issued by the Federal Communications Commission in Washington, D. C. Both licenses must be obtained BEFORE an amateur station of any kind is operated. The station license authorizes the use of an amateur station at a specified address. The applicant for an amateur radio operator's license must demonstrate his ability to send and receive the Continental Morse Telegraph Alphabet (usually called "code") at the rate of five words per minute for the Novice and Technician Class licenses or thirteen words per minute for the Conditional and General Class licenses. In addition, the applicant must pass a written examination designed to test his familiarity with the federal radio law and regulations and his knowledge of the elementary radio theory required to operate amateur transmitting equipment intelligently.

Novice Class License

There is no age limit for amateur licenses and no fee for the Novice Class examination or license.

Any U. S. citizen who has never held any amateur license issued by any agency of the government is eligible to take the Novice Class Examination. This examination will include the code test, even if the applicant intends to use phone rather than telegraphy. Everyone has to take the code test.

A Novice Class license is normally valid for a period of one year only and may not be renewed. By the end of a year, the licensee is supposed to qualify for a higher and more privileged class of license.

The holder of a Novice Class license is granted privileges for a period of one year to operate a transmitter on the following frequency bands and types of emission:

1. 3700-3750 kilocycles, C. W. (Continuous Wave) only (radiotelegraph code)
2. 7150-7200 kilocycles, C. W. only (radiotelegraph code)
3. 21,100-21,250 kilocycles, C. W. only (radiotelegraph code)
4. 145-147 megacycles, C. W. or voice (radiotelegraph code or voice)

The direct current input to the plate of the vacuum tube or tubes supplying power to the antenna connected to the transmitter shall not exceed 75 watts and all emissions of the transmitter must be crystal controlled.

The knowledge of elementary radio theory and practice required to pass a Novice Class examination can be acquired by experimenting and reading radio books and magazines.

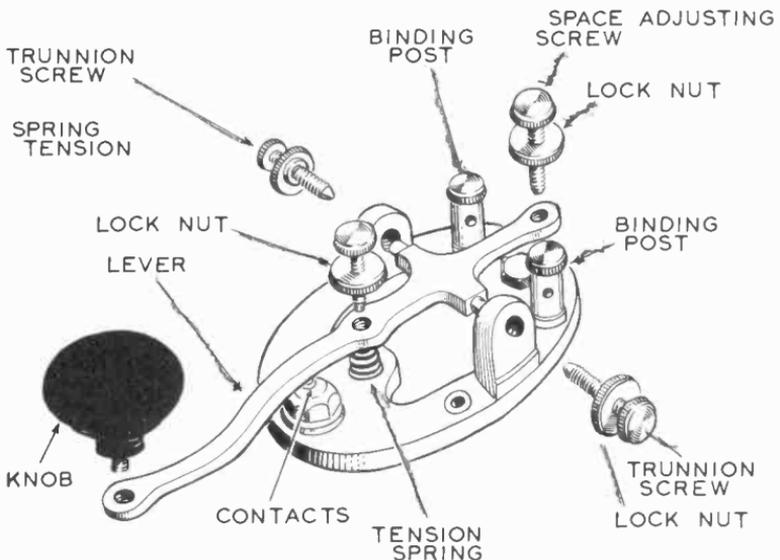
Novice examinations are given by volunteer examiners who are over 21 years of age and who hold a General or higher class amateur license. The examiner may be selected by the applicant and is usually someone in the applicant's own neighborhood. The applicant must secure Form 610 from the district office of the Federal Communications Commission.

The radiotelegraph code test is given first. The sending and receiving tests are both five minutes in length. If sixty-five consecutive letters, numerals, and punctuation marks are read and written correctly during some part of the five-minute period, the applicant may then demonstrate his ability at transmitting. If sixty-five consecutive characters are sent correctly in one minute, sometime during the five-minute transmitting test, a passing mark is awarded. The examiner completes Form 610 and his certification that the applicant has passed the code test and sends them to the Federal Communications Commission, Gettysburg, Pa. 17325, with a request for the written examination.

*Suggestions for Learning to Send and Receive
Radiotelegraph Signals*

The first step in learning to telegraph is to memorize the telegraph alphabet so that the sound of each character can be called to mind instantly. Do not think of the telegraph characters as dots and dashes as they are ordinarily represented on paper, but consider them to be *DI* and *DAH* sounds in which a dot represents the sound *DI* as in *DIT* and a dash represents the sound *DAH*. For example, do not think of the letter *B* in the code as *DASH, DOT, DOT, DOT*. Think of it as the sound *DAH-DI-DI-DIT*. Note that the last *DI* in a code character is often pronounced *DIT*.

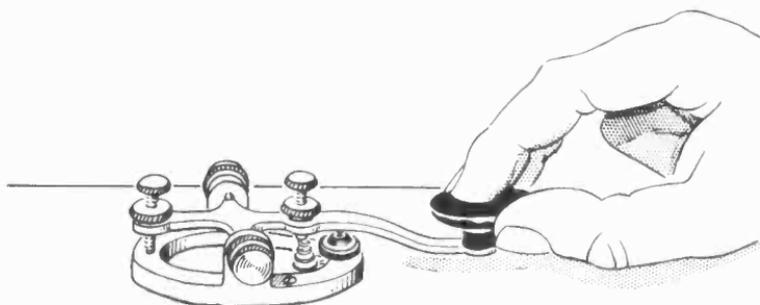
When all the letters, numerals, punctuation marks, and signals have been memorized, practice reading signs, pages from books, and other printed matter in *DI-DAH* language.



A WESTERN UNION TYPE KEY

This is the standard key used by telegraphers and the best type for a beginner to use when learning to telegraph.

It helps, in learning to receive signals, if sending is practiced at the same time. The simplest way to do this is to connect a standard telegraph key to a code-practice oscillator. If the control on the oscillator is properly adjusted, the circuit oscillates at an audio-frequency and produces sounds in the headphones or loudspeaker when the key is pressed. Adjusting the control varies the frequency of the oscillator so that an exact imitation of the sound of radio-telegraph signals can be obtained.



THE CORRECT METHOD OF HOLDING THE KEY WHEN TRANSMITTING

The key should be fastened to a table or desk, far enough back from the front edge to provide room for the forearm to rest on the surface while transmitting. The tips of the thumb and of the second finger grasp the edge of the knob on top and bottom on opposite sides and help the spring to raise the knob and lever. The thumb and both fingers are also used to push the knob down.

How to Build a Code-practice Oscillator

Two schematic circuit diagrams of transistor code-practice oscillators are illustrated. One is designed for use with a 2,000-ohm telephone headset. The other will operate a loudspeaker.

The following components are needed for the transistor code-practice oscillator for use with headphones:

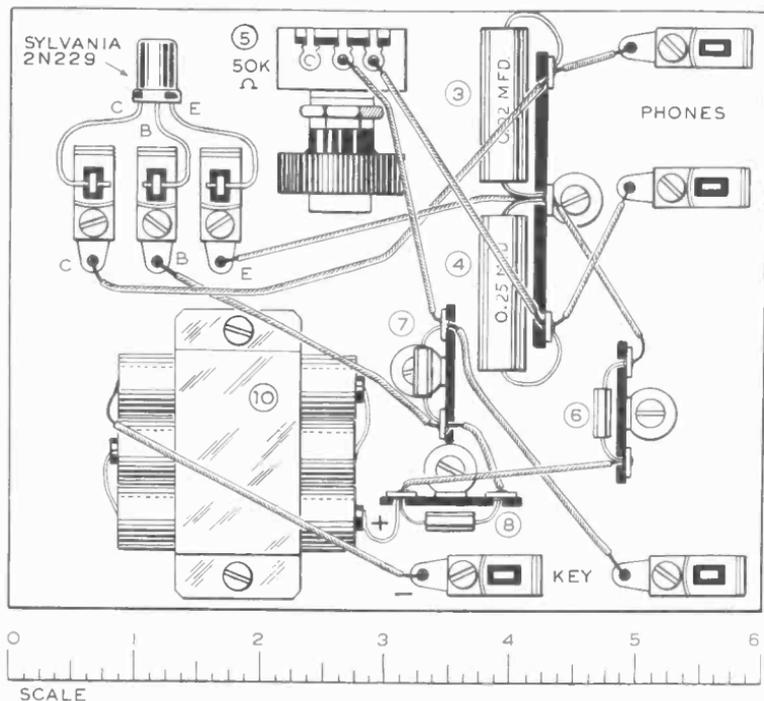
- 1 Wood base 6 in. x 5 in. x 3/4 in.
- 1 No. 2N229 Sylvania transistor (1)
- 1 2,000-ohm magnetic-type headset (2)
- 1 0.02-mfd, 400-volt tubular capacitor (3)
- 1 50K-ohm volume control with mounting bracket and knob (5)
- 1 1-watt, 27K-ohm gold-band resistor (6)
- 1 1-watt, 1,500-ohm gold-band resistor (8)
- 1 Morse telegraph key (9)
- 3 1.5-volt, size AA cell and holder (10)
- 4 1-in. x 3/8-in. Fahnestock spring contact clips
- 3 3/4-in. x 5/16-in. Fahnestock spring contact clips
- 14 No. 4, 3/8-in. round-head wood screws
- 1 3-lug tiepoints
- 3 2-lug tiepoints
- 7 Solder lugs
- 1 Strip of sheet metal 3-3/4 in. x 1 in.
Shellac, rosin-core solder, hookup wire

Shellac the wood base. When it is dry fasten the tiepoints and the Fahnestock contact clips to the wood base in the locations indicated in the plan. Place a solder lug under the head of each screw used to fasten a Fahnestock clip. The lugs will make it easy to connect a wire to the clips by soldering.

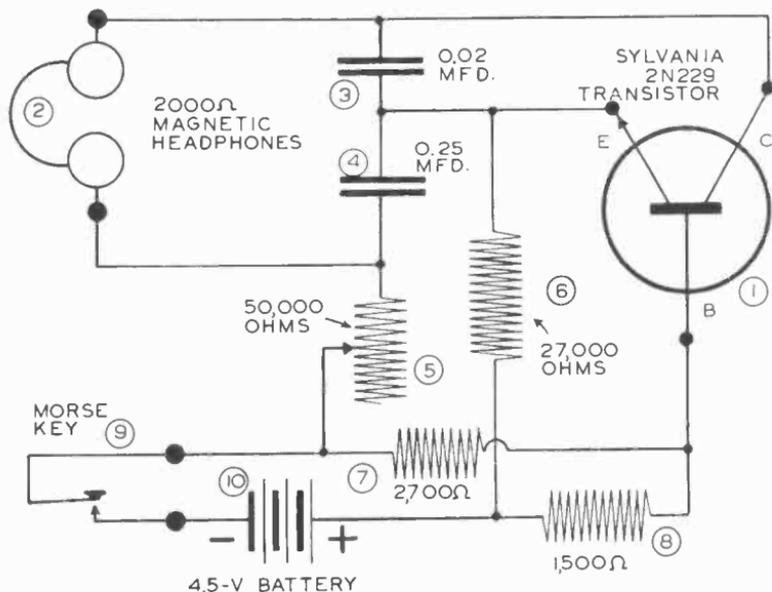
Connect the three dry cells in series so they deliver 4.5 volts and clamp them to the base with a 3-3/4-in x 1-inch metal strip cut from a tin can. Solder all connections with rosin-core solder. Connect the batteries so that the positive and negative terminals are as indicated in the illustration. Failure to do so may damage the transistor. When the wiring has been completed connect the key and phones to their respective terminals. Listen in the headphones and press the key. Adjust the control to obtain the desired pitch of sound. The oscillator is now ready to produce dots and dashes.

Magnetic headphones are specified in the list of required components. Some experimenters may have a headset with crystal receivers. The oscillator will not operate with crystal phones. The impedance of a 2,000-ohm headset with magnetic phones is required in the circuit.

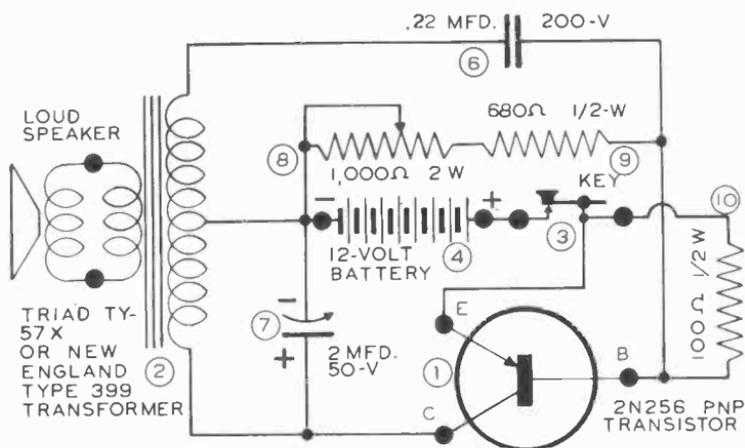
The novice telegrapher will progress more rapidly when the coaching and criticism of an experienced and skilled operator is available. The best substitute for such assistance is for two or more beginners to learn the code together and practice sending to each other with the oscillator. An oscillator with a loudspeaker is the better one to use when two or more beginners are working together.



PLAN OF THE OSCILLATOR



SCHEMATIC CIRCUIT OF TRANSISTOR CODE-PRACTICE OSCILLATOR FOR USE WITH HEADPHONES



SCHEMATIC CIRCUIT FOR A TRANSISTOR CODE-PRACTICE OSCILLATOR FOR USE WITH A LOUDSPEAKER

The following components are required to build a transistor code-practice oscillator equipped with a loudspeaker:

- 1 Wood base 6 in. x 5 in. x 3/4 in.
- 1 2N256 PNP transistor (1)
- 1 Triad TY-57X transformer or New England type 399 transformer (2)
- 1 Morse telegraph key (3)
- 8 1.5-volt Size AA cells and holders (4)
- 1 .22-mfd, 200-volt tubular capacitor (6)
- 1 2-mfd, 50-volt electrolytic capacitor (7)
- 1 2-watt, 1,000-ohm volume control with knob and mounting bracket (8)
- 1 1/2-watt, 680-ohm, gold-band resistor (9)
- 1 1/2-watt, 100-ohm, gold-band resistor (10)
- 6 1-in. x 3/8-in. Fahnestock clips
- 3 3/4-in. x 5/16-in. Fahnestock clips
- 3 2-lug tiepoints
- 1 3-lug tiepoints
- 14 No. 4, 3/8-in. round-head wood screws

The schematic circuit of the oscillator is illustrated. A drawing showing the arrangement of the parts on their wood base has been omitted purposely. Omission of a plan gives the experimenter an opportunity to do some engineering.

The parts should be assembled on a shellacked wood base approximately 6 inches x 5 inches x 3/4 inch. Before fastening them in place, set them on a 6-inch x 5-inch cardboard or paper base. It is for you to decide where to locate each component. Here are a few tips to guide you:

The loudspeaker may be mounted on the same base as the rest of the oscillator, or it may be located in another part of the room. If it is mounted on the base, it should be fastened to the back edge and face forward toward the operator. The volume control and the two Fahnestock clips to which the key will be connected should be near the front edge. The

two Fahnestock clips to which the 12-volt battery will be connected should be located near the rear edge of the base.

The tiepoints to which the resistors and capacitors are to be attached should be located so that the connecting wires are as short as possible.

Connect the 100-ohm resistor (10) to a 2-lug tiepoint.

Connect the 0.22-mfd capacitor (6) to a 2-lug tiepoint.

Connect the terminals of the volume control (8) and the 680-ohm resistor (9) to a 3-lug tiepoint.

Connect the terminal leads of the 2N256 PNP transistor to the three small Fahnestock connectors but do not solder them.

When you have found the best location for each component, mark its position on the cardboard or paper plan. Use this as a guide in fastening the components permanently in place. Solder all connections with rosin-core solder.

The easiest way to connect the 8 cells in the battery is to place them in two 4-cell battery holders. Size AA cells will operate the oscillator for many hours. But if the instrument is to be used for teaching more than one person, it will receive much more use. Then it is advisable to use size C or size D cells.

It requires greater space than is available in this book to give more than brief suggestions for learning to send and receive radiotelegraph signals. It is suggested that the beginner at telegraphy send to The American Radio Relay League, Inc., Newington, Conn. 06111, for the following publications:

How to Become a Radio Amateur

The Radio Amateur's License Manual

Learning the Radio Telegraph Code

Operating an Amateur Radio Station

These four publications will be sent postpaid upon receipt of \$2.00. The American Radio Relay League, Inc., is a non-profit organization of "hams" devoted entirely to the devel-

opment and protection of the art of amateur radio communication.

Where to Obtain Materials

The average radio and television service shop can usually furnish any of the tubes, fixed capacitors, resistors, volume controls, and batteries required to build the apparatus described in this book. Other components such as transistors, variable capacitors, relays, transformers, etc., can be obtained from any of the large mail-order firms listed below. Each of these firms issues a mail-order catalog and will send you a copy if you write and ask for it. Neither the author nor the publisher has any interest in these businesses and does not assume any responsibility in your dealings or transactions with them. Write for catalog to:

Allied Radio Corporation
100 North Western Ave.
Chicago, Ill. 60680

Lafayette Radio Electronics Corporation
Jericho Turnpike, Syosset
Long Island, N. Y. 11791

Burstein-Applebee
1012 McGee St.
Kansas City, Mo. 64106

Radio Shack
730 Commonwealth Ave.
Boston, Mass. 02215

Olson Electronics, Inc.
260 S. Forge St.
Akron, Ohio 44308

Technical Terms

The purpose of this volume is to teach the novice in electronics how to construct several interesting pieces of solid state apparatus and at the same time explain some of the elementary principles of that branch of electronics. Most of the technical terms are explained in the text where they first occur. A few that require a long explanation will be found only in this glossary. Some readers who may wish to consult other books or some of the popular radio magazines will find it useful to refer occasionally to this abbreviated dictionary of electronic and electrical terms.

- A. Abbreviation for ampere, the standard measuring unit of electrical current.
- A. C. Abbreviation for alternating current. The direction of flow of alternating current reverses or alternates at regular intervals. Two succeeding current reversals are termed one cycle. During a cycle, the voltage rises from zero to maximum in one direction, falls back to zero, rises to a maximum in the opposite direction and then returns to zero. One-half of a cycle, or the rise and fall of voltage and current in one direction, is an alternation. The number of complete cycles which occur in one second is the frequency of an alternating current. A. C. with a frequency of 60 cycles is used in most American homes for light and power.
- AERIAL. Also called an antenna. A coil, a conductor or an array of conductors intended to intercept or radiate electromagnetic waves.

- AIR CORE.** Some radio coils (wire coils used in electronics) are wound over a non-metallic hollow form in which air forms the core. The core is then called an air core to distinguish it from a core of magnetic material such as ferrite or iron.
- ALTERNATING CURRENT.** The direction of flow of alternating current reverses or alternates at regular intervals. See explanation under A. C.
- ALTERNATION.** One-half of an alternating current cycle, or the rise and fall of an alternating current in one direction.
- ALTERNATOR.** An electric generator or dynamo for producing an alternating current.
- AMMETER.** An instrument for measuring in terms of amperes the strength of an electric current flowing in a circuit.
- AMP.** Abbreviation for ampere.
- AMPERE.** The standard unit used to describe the amount of electric current passing a certain point in a circuit at a particular time. One ampere is the amount of current flowing in a circuit of one-ohm resistance under a pressure of one volt. One ampere equals the flow of 6.24 billion billion electrons (one coulomb) per second. So named in honor of Andre M. Ampère, the French physicist who discovered many valuable facts about electric currents.
- AMPLIFICATION, AUDIO.** The increase or augmentation of the electrical energy in a circuit having a frequency under 20,000 cycles per second.
- AMPLIFICATION, RADIO-FREQUENCY.** The increase or augmentation of the electrical energy in a circuit having a frequency of 20,000 or more cycles per second.
- AMPLIFICATION, REGENERATIVE.** Amplification that is secured by coupling the plate circuit of a vacuum tube to the grid circuit so as to feed back part of the plate current

to the grid. May also be produced in a transistor circuit by proper coupling.

AMPLIFIER. A device used to increase or augment the electrical energy in a circuit.

AMPLIFIER TRANSFORMER. A primary and a secondary winding, either with or without an iron core, used to couple an amplifier tube or transistor amplifier to a circuit.

AMPLIFY. To increase or make stronger.

AMPLITUDE. The peak value of a radio wave measured from its zero line to its crest.

AMPLITUDE MODULATION. The change of a radio-frequency carrier wave to make it carry a message by varying the amplitude of the wave.

ANODE. A positively charged electrode which attracts electrons.

ANTENNA. Also called an aerial. A coil or conductor or an array of conductors intended to radiate or intercept electromagnetic waves.

APERIODIC CIRCUIT. An untuned circuit.

ATMOSPHERICS. Electrical disturbances in the atmosphere that cause noise in radio receivers. Often called static.

ATOM. The smallest particle of an element.

AUDIBILITY. The ratio between the current producing a signal in a sensitive telephone receiver or loudspeaker and the current producing a signal which is just audible.

AUDIO-FREQUENCY CURRENT. Usually an alternating current whose frequency is capable of producing sounds that can be heard by the human ear. The current of a radio signal has an audio-frequency after it has been demodulated by a detector. An intermittent direct current which is interrupted or varied 20 to 20,000 times per second can also produce audible sounds in a telephone receiver or loudspeaker.

AUDIO TRANSFORMER. A transformer for handling currents at audio frequencies.

- AUTOTRANSFORMER.** A transformer which has a single winding that is tapped to form a primary and secondary.
- BAFFLE.** The partition used in mounting loudspeakers to "baffle" or prevent sound waves produced by the back of the speaker diaphragm from cancelling the sound waves from the front of the diaphragm.
- BAKELITE.** A synthetic resin made from phenol and formaldehyde used in the manufacture of varnishes, panels, molded plastics, cements, and insulating compounds.
- BAND.** A narrow band of radio frequencies or wavelengths containing side waves and frequencies caused by modulation.
- BASE (TRANSISTOR).** The center region of a transistor between the emitter and collector.
- BATTERY.** Two or more voltaic cells or two or more secondary cells (storage cells) connected together.
- BATTERY, PRIMARY and VOLTAIC.** A battery that produces current by chemical action in which the cathode is consumed. Dry cells connected together are a common form of primary battery.
- BATTERY, SECONDARY.** A storage battery. The current it produces is generated by chemical action after the battery has first been charged by passing a current through it.
- BIAS VOLTAGE.** A fixed voltage applied to a component of a circuit. A bias voltage applied to the base of a transistor or to the grid of a vacuum tube determines the normal current that will flow through the device.
- BROADCAST.** The one-way transmission of news, music, entertainment, or other matter addressed to the public and not to individuals. Not point-to-point transmission.
- BROADCAST BAND.** The band of wavelengths used by commercial broadcast stations. The United States amplitude modulated (AM) broadcast band includes frequencies from 540 to 1600 kilocycles.

- BUG.** A fault or malfunction in a component or circuit. Also a high-speed telegraph key which makes dots automatically.
- BUZZER.** An electromagnetic signalling device with a vibrating armature which makes a buzzing sound.
- BY-PASS CAPACITOR.** A fixed capacitor that offers low impedance to radio-frequency currents but high impedance to audio-frequency currents and infinite resistance to direct current.
- CAPACITANCE.** A measure of the amount of direct current charge which a capacitor can store. Capacitance is measured in farads. The ordinary capacitor is measured in microfarads or millionths of a farad.
- CAPACITATIVE REACTANCE.** The opposition offered to an alternating current by a capacitor. Capacitive reactance varies with the frequency of the current.
- CAPACITOR.** Formerly called a condenser. Used to provide capacitance in a circuit. A capacitor can store electrons. Consists of two sets of metal plates separated by air or some insulating material (dielectric). A capacitor partially impedes the flow of alternating current but completely blocks the flow of direct current.
- CARRIER.** A radio-frequency, electromagnetic wave produced by a transmitter that may be modulated to convey information, music, etc.
- CATHODE.** A negatively charged electrode that emits electrons.
- CATHODE RAY.** An electron beam emitted by the cathode in a cathode-ray tube.
- CATHODE-RAY TUBE.** A tube used in television, radar, and oscilloscopes in which a moving electron beam is focussed on a fluorescent screen at one end of the tube.
- CHANNEL.** A narrow band of radio wavelengths.
- CHOKE.** A coil with either an iron or air-core included in a

circuit to supply inductance which will impede or retard certain frequencies. A large amount of inductance that will smooth ripples in direct current. Smaller chokes will pass direct current and low-frequency alternating current but prevent the passage of high frequencies.

COAXIAL CABLE. A cable that contains one wire with a second wire surrounding and shielding it. Desirable and efficient for transmitting high frequencies.

COLLECTOR. The output element in a transistor that collects the current generated at the junction between the base and emitter.

COMPONENT. One of the complete units that performs one or more functions in a circuit. Generally used in combination with other components. The capacitors, resistors, coils, transformers, etc., in a circuit are its components.

CONDENSER. A term formerly used as the name for a capacitor.

CONDUCTOR. A solid, liquid, or gas through which an electric current can flow.

CORE. A soft-iron center on which the coils of electromagnets and transformers are wound. Radio-frequency transformers have air-cores or small cores made of an iron compound.

COULOMB. The electrical unit of charge used in measuring quantity of electricity. An electric current of one coulomb per second equals one ampere. In other words, a coulomb is the quantity of electricity transferred by a current of one ampere in one second.

COUNTER ELECTROMOTIVE FORCE. A voltage that is in the opposite direction and opposes the voltage causing it.

COUNTERPOISE. A system of wires raised a few feet above the earth and insulated from it that is used in place of the usual ground connection.

COUPLING. The relation which permits the transfer of elec-

- trical energy between two circuits or two components of a circuit by means of a magnetic or electrostatic field.
- CURRENT, ELECTRIC.** The flow of electric charge between two points whenever there is a voltage between them and they are electrically connected together. Current is measured in amperes.
- CYCLE.** Two succeeding alternations in which the current changes from zero to maximum in one direction, back to zero and to a maximum in the opposite direction and then back to zero again.
- DAMPED WAVE.** A radio wave of constantly decreasing amplitude.
- DAMPING.** The decrease in the amplitude of radio waves or high-frequency currents.
- DB.** Abbreviation for decibel.
- DEBUG.** To remove a fault or malfunction in a component or circuit.
- DECIBEL.** The unit used to compare ratios of power, voltage or current in wire or radio communication and to measure the relative loudness of sounds.
- DECREMENT.** The rate of damping of a radio wave or high-frequency current.
- DEMODULATION.** The process of sorting out the audio-frequency groups of pulses generated in an antenna by a carrier wave. The same as detection.
- DETECTION.** The same as demodulation. The process of extracting from a radio wave the signals imparted to it at the transmitter.
- DETECTOR.** When presented with antenna currents generated by a modulated carrier wave, a detector will separate the information and convert it into a form of current that will operate a telephone receiver, printing machine, loudspeaker, etc. The modern detector is a vacuum tube, crystal diode, or a transistor.

- DIELECTRIC.** A non-conducting material such as air, mica, paper, plastic, oil, etc., used for storing electrostatic energy. The insulating material between the electrically charged plates of a capacitor is a dielectric. The distinction between an insulator and a dielectric is in application rather than composition.
- DIODE.** A device with two electrodes which permits the flow of current to occur in one direction only. It is used in radio as a detector for AM signals and may be a vacuum tube or in semiconductor form. Acts as a rectifier or valve and changes A. C. to D. C.
- DISTORTION.** An undesirable change in the form of a wave or of a signal.
- EARTH.** A connection to the ground or earth.
- ELECTRODE.** A terminal of a source of electricity. Either conductor by which current enters and leaves an electrolyte or a vacuum.
- ELECTROLYTE.** A chemical solution which will conduct an electric current. More specifically, it is the acid or alkaline solution used in batteries, chemical rectifiers and a specific type of capacitor.
- ELECTROLYTIC CAPACITOR.** A fixed capacitor in which one conducting surface is an electrolyte either in liquid or paste form and the other is aluminum foil. The electrolyte forms a thin film of aluminum oxide on the aluminum foil when the latter is connected to a positive current force. Aluminum oxide is an insulator and serves as the dielectric in the capacitor.
- ELECTROMAGNETIC WAVES.** The waves used in radiotelegraphy, radar, radiotelephony and television.
- ELECTROMAGNETISM.** Magnetism which is created by an electric current flowing through a conductor.
- ELECTROMOTIVE FORCE.** The voltage or electrical pressure that causes an electric current to flow along a conductor.

- ELECTRON.** The smallest known negatively charged stable particle. Electrons are present in all matter.
- EMITTER.** The source of the electric current in a transistor. The volume of current which flows from the emitter to the collector is determined primarily by the voltage or difference of potential between the base and emitter.
- FARAD.** The basic unit of capacitance. The capacitance of capacitors of practical size is expressed in microfarads. A microfarad is one-millionth of a farad (abbreviated MFD).
- FIELD.** Abbreviated term for magnetic or electrostatic field.
- FILAMENT.** In a vacuum tube, an electrically heated wire or chemical coating that furnishes electrons and forms the cathode. In an incandescent lamp, an electrically heated wire that radiates light.
- FIXED CAPACITOR.** A capacitor, the capacitance of which cannot be varied.
- FLUX.** Magnetic lines of force.
- FM.** Frequency modulation.
- FREQUENCY.** The frequency of the alternating current used for light and power refers to the cycles per second. Almost all commercial power plants in the United States and Canada generate current with a frequency of 60 cycles per second.
- Frequency may also refer to the cycles per second of the high-frequency currents used to generate electromagnetic waves. They are measured in kilocycles. A kilocycle is 1,000 cycles.
- FULL-WAVE RECTIFIER.** A rectifier that utilizes both halves of an alternating current cycle and changes the A. C. to D. C.
- FUSE.** A protective device for electrical circuits. It consists of a strip or wire made of an alloy with a lower melting point than that of copper, designed to melt in case ex-

cessive current heats the circuit. A fuse which melts or "blows" protects the wiring by shutting off the current.

GAIN. The increase in signal power produced by an amplifier is termed the gain and is usually indicated in decibels.

GALVANOMETER. A sensitive instrument used to detect or measure weak currents.

GRINDERS. The most common type of noise caused by static or atmospheric in a radio receiver. They are grinding sounds produced in telephone receivers and loudspeakers.

GROUND. A conductor which makes a low resistance contact with the earth. Also the metal frame or supporting chassis of an electrical device.

HALF-WAVE RECTIFIER. A rectifier which utilizes one-half of each alternating current cycle.

HEAT. A form of energy consisting of electromagnetic waves of a frequency between the frequencies of light waves and radio waves.

HEATER. In a vacuum tube an electrically heated wire which heats the cathode.

HENRY. The measuring unit for inductance. A henry is the amount of inductance in a circuit in which the electromotive force induced is 1 volt when the inducing current varies at the rate of one ampere per second. Named in honor of Joseph Henry, an American scientist born in 1797 who made one of the first electromagnets.

IMPEDANCE. The total opposition of a circuit to the passage of an alternating current. Impedance consists of resistance similar to the direct current resistance plus a reactive opposition due to inductance and/or capacitance in the circuit.

INDUCTION. The transfer of energy from one conductor to another by magnetism, electromagnetism or electrostatic stress.

INDUCTIVE COUPLING. The coupling of one circuit to another to bring about a transfer of energy by means of induction.

INPUT CIRCUIT. The primary of a transformer or the grid circuit of an electron tube. The base in a transistor corresponds to the grid in a vacuum tube.

INSULATION. A material that will not conduct a current of electricity. Also a material that has an extremely high resistance to an electric current.

ION. An atom or a group of atoms bearing an electric charge. In a gas, a combination of several molecules with an electron. Ions impart conductivity to a gas or liquid.

JACK. A device fitted with spring contacts into which a plug is inserted to complete the circuit through the apparatus connected to the plug.

JOULE. The unit of electrical work or energy. The energy spent when a current of one ampere flows through a resistance of one ohm for one second.

JUNCTION. A joining, also a seam. The boundary between P-type and N-type semiconductor material in a transistor, diode, or rectifier. The basis for transistor and diode action. Current flows through a junction more easily in one direction than in the other.

KILO. A prefix which means one thousand. A kilowatt, a kilovolt, and a kilocycle are respectively 1,000 watts, 1,000 volts, and 1,000 cycles.

LAMINATIONS. Thin sheets of iron or steel used as the cores

of coils, transformers, motors, and other electrical apparatus.

LASER. An amplifying or generating device for producing coherent light signals. The name is coined from the initial letters of the words which describe the process, namely, Light Amplification by Stimulated Emission of Radiation.

LEAD-IN. The conductor which connects a radio receiver or a radio transmitter to the antenna.

LOUDSPEAKER. A device that changes electrical energy into audible sounds without the use of telephone receivers held to the ears.

MAGNET. A piece of steel or steel-containing compound capable of exerting magnetic force.

MASER. An amplifying or generating device for producing microwave signals. The name MASER is derived from the initial letters of the words which describe the process.

MEG. A prefix meaning one million. A megohm is 1,000,000 ohms, often popularly called a "meg."

MEGACYCLE. One million cycles.

MFD. Abbreviation for microfarad.

MHO. The unit of conductance.

MICRO. A prefix meaning one-millionth.

MICROAMPERE. One-millionth of an ampere.

MICROELECTRONICS. A branch of the electronic art that uses extremely small electronic parts.

MICROFARAD. One-millionth of a farad.

MICROMICROFARAD. One millionth of a microfarad, or picofarad.

MICROMINIATURIZATION. A system of design and construction that results in a reduction in size of the components in a circuit. Employed in computers and space vehicles.

MICROPHONE. A device for changing sound vibrations into corresponding variations of an electric current. There are several types of microphone or "mike" as they are popularly called.

MICROVOLT. One-millionth of a volt.

MIKE. A popular name for a microphone.

MILLI. Prefix meaning one-thousandth.

MILLIAMMETER. An instrument calibrated to measure current by one-thousandth of an ampere.

MILLIVOLTMETER. An instrument calibrated to measure voltage by one-thousandth of a volt.

MMFD. Abbreviation for micromicrofarad, now also called picofarad (pf).

NEGATIVE ELECTRICITY. Electrons.

NON-CONDUCTORS. Substances which do not conduct an electric current.

OHM. The unit used to express resistance. An ohm is the unit of resistance through which one volt will cause a current of one ampere to flow in a direct current circuit.

OHM'S LAW. The relationship between current, electromotive force and resistance which states that the current in amperes in a direct current circuit is equal to the electromotive force expressed in volts divided by the resistance in ohms.

OSCILLATIONS. Alternating currents of high frequency.

OSCILLATOR. An apparatus for generating radio-frequency currents.

OSCILLOSCOPE. An electronic device which utilizes a cathode ray tube and associated circuitry to produce a visual display of an electric waveform or signal on a fluorescent screen.

OUTPUT CIRCUIT. The secondary of a transformer. The plate circuit of an electron tube. The collector in a transistor

is the output element and is analagous to the plate in a vacuum tube.

OXIDE. A coating which forms on metal surfaces and must be removed before a good electrical connection can be made.

PHOTO-TUBE. A vacuum tube type photo-electric cell, sometimes popularly called an "electric eye," in which the electron emission is produced by light falling upon a photo-sensitive element.

PIEZO CRYSTAL. Certain crystals, such as quartz, tourmaline, and Rochelle salts, produce electricity when squeezed or subjected to pressure. They are called piezo crystals. Piezo is a Greek word that means pressure. When an electromotive force is applied to a piezo crystal, the crystal changes its shape. Piezo crystals are used to control the frequency of circuits, in phonograph pickups, crystal microphones and earphones.

POTENTIAL. The name of the condition that causes electrons to move. Its other name, **ELECTROMOTIVE FORCE**, is self-revealing, for "motive" means causing motion. Note that potential is often wrongly defined in terms of pressure. It is rather work done per unit charge, e.g.: $V = J/Q$.

POTENTIOMETER. A variable resistance having three terminals and usually connected across a source of voltage. It utilizes the voltage drop which occurs in resistance. By adjusting the potentiometer the amount of voltage drop can be closely regulated.

PRIMARY. The input winding (the winding to which current is supplied) of a transformer.

PRIMARY CELL. A voltaic cell. Electricity is generated by chemical action in a primary cell and one of the electrodes (the cathode) is consumed in the process.

PUSH-PULL AMPLIFIER. A system of arranging a stage of amplification whereby two electron tubes or two tran-

sisters have the load divided between them by utilizing a center-tapped transformer. The arrangement permits increased capacity without an increase in distortion.

Q. A useful measure of coil efficiency in a tuned circuit is designated by the letter "Q." It is the ratio of the coil's reactance to its effective series resistance.

QUARTZ CRYSTAL. An accurately ground piezo-electric crystal mounted between two metal electrodes and used in radio receivers and transmitters to establish a selective radio-frequency circuit.

RADIO-FREQUENCY. An arbitrary classification of frequency, usually considered to be a frequency of about 20,000 cycles.

RECTIFIER. A device that converts alternating current into a current having a large unidirectional component.

RESISTANCE COUPLING. The coupling established between two circuits when they have a resistance in common. Sometimes employed in an amplifier.

RESISTOR. A unit designed to reduce the flow of current in a circuit.

RESONANCE. A circuit can be brought into resonance at a given frequency by varying either the inductance or capacitance or both. The process of making this adjustment is called tuning the circuit. When a condition of resonance exists the total opposition to the flow of current is then simply the resistance of the circuit and there is neither lag nor lead in the voltage and current impulses.

RHEOSTAT. A variable resistance device that can be adjusted to control the flow of current.

SECONDARY CELL. A storage cell.

SELECTIVITY. The ability of a receiver or circuit to discriminate between signals of different frequencies.

STATIC. Electrical disturbances that cause noises in a telephone receiver, loudspeaker or on a television screen.

STRAYS. Man-made static.

SUPPRESSOR GRID. A third grid used in pentode tubes.

TRIMMER. A small capacitor used to balance a circuit, compensate variations between sections of a gang capacitor, adjust radio-frequency transformers, etc.

TUNED CIRCUIT. A circuit in which the capacity and inductance are adjusted to produce a desired frequency of oscillation.

TUNING. The adjustment of inductance or capacity which brings a circuit into resonance with a desired frequency.

VARIABLE CAPACITOR. A capacitor the capacitance of which can be gradually increased or decreased.

VOICE COIL. A small coil of fine wire attached to the diaphragm of a loudspeaker.

VOLT. The unit of electromotive force. The electromotive force which produces a current of one ampere when applied to a resistance of one ohm.

VOLTAGE DROP. That part of the electromotive force that is expended in overcoming the resistance or impedance of a circuit.

VOLTMETER. A device for measuring the voltage of an electric current.

WATT. The unit of electric power represented by the amperage and voltage in a circuit. One watt is the power represented by one ampere at one volt. Named after James Watt, the inventor of the steam engine.

Common Semiconductor Components Used in Electronics

This list presents the more common semiconductor components used in electronics. It does not offer an exhaustive study of each component but provides a brief and simple description that may lead anyone interested in electronics to investigate the same subjects in a more comprehensive volume dealing with semiconductors.

Each of the first nine components in the list have two terminals or electrodes and are therefore called DIODES. The remainder have three terminals or electrodes and are therefore termed TRIODES.

SOLAR BATTERY (SILICON). A solar battery converts light energy directly into electricity.

A single cell in a silicon solar battery consists of a very thin layer of P-type silicon which has been diffused on a wafer of N-type silicon. This P-type layer forms the positive terminal of the cell. The N-type silicon forms the negative terminal.

An electric field called the barrier forms at the junction between the N-type material and the P-type material during the absence of illumination. The field results from electrons in the N-type material combining with holes from the P-type material.

New electrons and holes are liberated in the silicon and attracted by the electric field at the junction when the junction between the two semiconductor materials is illuminated. Thereby the P-type silicon acquires a positive charge and the N-type becomes negatively charged. If the positive and negative terminals of the cell are connected to an external circuit, current flows through the circuit.

DIAC. This is a two-terminal, three-layer "sandwich" of alternate P-type and N-type semiconductors that has

negative resistance characteristics. It is a bilateral device which will function when either a positive or negative voltage is applied. A diac is useful as a relaxation oscillator and also as a phase control in a triac circuit. A relaxation oscillator is an oscillator whose fundamental frequency is controlled by the time of charging or discharging a capacitor or coil through a resistor, producing wave forms that may be either saw-tooth or rectangular.

DIODE (COPPER OXIDE). A semiconductor device consisting of one or more pairs of copper and lead plates. One side of each copper plate is coated with cuprous oxide. A soft lead plate is used to make contact with the cuprous oxide layer. A rectifying barrier is formed in the junction between the metallic copper and the cuprous oxide. Small copper oxide diodes or rectifiers are used in some instrument circuits. Large copper oxide diodes or rectifiers are used for recharging storage cells but are being replaced by more efficient selenium and silicon rectifiers.

DIODE (JUNCTION). Junction diodes are manufactured from both germanium and silicon semiconductor. The germanium variety is used mainly as signal detectors and the silicon diodes primarily as power rectifiers.

A junction diode consists of a piece of N-type semiconductor joined to a piece of P-type semiconductor. The point where the two semiconductor materials make contact with each other is called the PN junction. All rectifying characteristics occur at the junction.

DIODE (POINT-CONTACT). Point-contact diodes are used primarily as radio-frequency signal detectors. They may be manufactured from either germanium or silicon. Point-contact diodes made from germanium are used for low-frequency signal applications. The silicon variety is used primarily as radio-frequency signal detectors.

A point-contact diode is a wafer of N-type semiconductor material on the surface of which a small P-type semiconductor region is formed. A pointed wire called a "cat whisker" makes contact with the P-type area.

DIODE (SELENIUM). A thin film of selenium deposited on an iron plate forms a PN rectifying junction that has high resistance to current in one direction and low resistance to current in the other direction. A conductive metal coating is deposited on the exposed side of the selenium film. Electrons flow more freely from the metallic coating to the selenium than in the opposite direction. This produces a rectifying action used in battery chargers, power supplies, etc., to change A. C. to D. C.

DIODE (TUNNEL). This heavily-doped, two-element-junction diode can be used either as an amplifier or as an oscillator at ultra-high frequencies and microwave frequencies. The semiconductor material used in its construction is usually gallium arsenide which has been heavily doped with impurities. The name "tunnel" derives from the fact that its charge carriers, namely electrons and holes, under proper conditions suddenly "tunnel" through the electrostatic field barrier at the PN junction. The applications of a tunnel diode include service in power supplies ranging up to 50,000 volts and thousands of amperes.

DIODE (ZENER). A voltage-regulating device that utilizes semiconductor silicon in its construction. Also called an avalanche diode. When a zener diode is placed in circuit as a voltage regulator there is a small amount of reverse current through the diode until the applied voltage reaches a value known as the "avalanche" point. When this happens the zener diode suddenly becomes a good conductor and an "avalanche" of current passes through.

TRANSISTOR (EPITAXIAL). This three-terminal semiconductor device provides better performance than the

common junction transistor. It operates well at high frequencies and handles large power at high voltage.

TRANSISTOR (FIELD EFFECT). A high impedance semiconductor component with characteristics very similar to those of a vacuum tube. Used in circuits with frequency modulation "front ends," high input-impedance voltmeters, frequency converters, oscillators, balanced modulators and audio-amplifier preamplifiers.

TRANSISTOR (JUNCTION). There are two basic junction transistors, PNP and NPN. Both consist of a "sandwich" of alternate slabs of N-type and P-type semiconductor (usually germanium). The two outside slabs (the collector and emitter) of the PNP type are P-type semiconductor. The center slab (base) is N-type semiconductor. The configuration of the NPN junction transistor is two slabs of N-type material on the outside (collector and emitter) and a slab of P-type material (base) between them.

TRANSISTOR (MESA). A mesa transistor provides improved performance over a junction transistor. It has good power-handling ability and good high-frequency current gain. The name mesa was given to the device because of the shape of its semiconductor material.

TRANSISTOR (UNIUNCTION). This semiconductor device displays negative resistance characteristics and performs well in timing circuits, SCR trigger circuits, oscilloscope sweep circuits, and as a relaxation oscillator.

Integrated Circuits

Through the use of the technique of microminiaturization developed by Jack Kilby of Texas Instruments, Inc., transistors, diodes, resistors and capacitors are fabricated into the body of a tiny semiconductor wafer of silicon called a CHIP. The process uses photoengraving and etching and results in miniaturization. Thus all the components of a functional electronic circuit are integrated within the tiny silicon chip. This accounts for the name INTEGRATED CIRCUIT (IC).

The fact that 150 completed chips can be placed on one side of a Lincoln penny without overlapping gives a good idea of the small size of a completed chip. It is by using integrated circuits that we can place complex satellites in orbit around the earth and in space. IC's now make possible desk size computers that would have required several hundred square feet of floor space less than 20 years ago.

IC's are of three types depending on their method of manufacture and of two types depending upon their internal circuit. Actually they can be considered to be of six kinds, namely; hybrid digital, hybrid linear, thin-film digital, thin-film linear, planar digital, and planar linear. Integrated circuits are quite complex and the newcomer to this branch of transistor electronics should become acquainted with the special installation and rating methods IC's require.

There is great scarcity of informative printed matter on the subject of integrated circuits. There are few books on the subject which are useful to hobbyists and experimenters. A recent paperback called *Integrated Circuits, Fundamentals and Projects*, published by Allied Radio Corporation, can be recommended to the newcomer in this field.

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