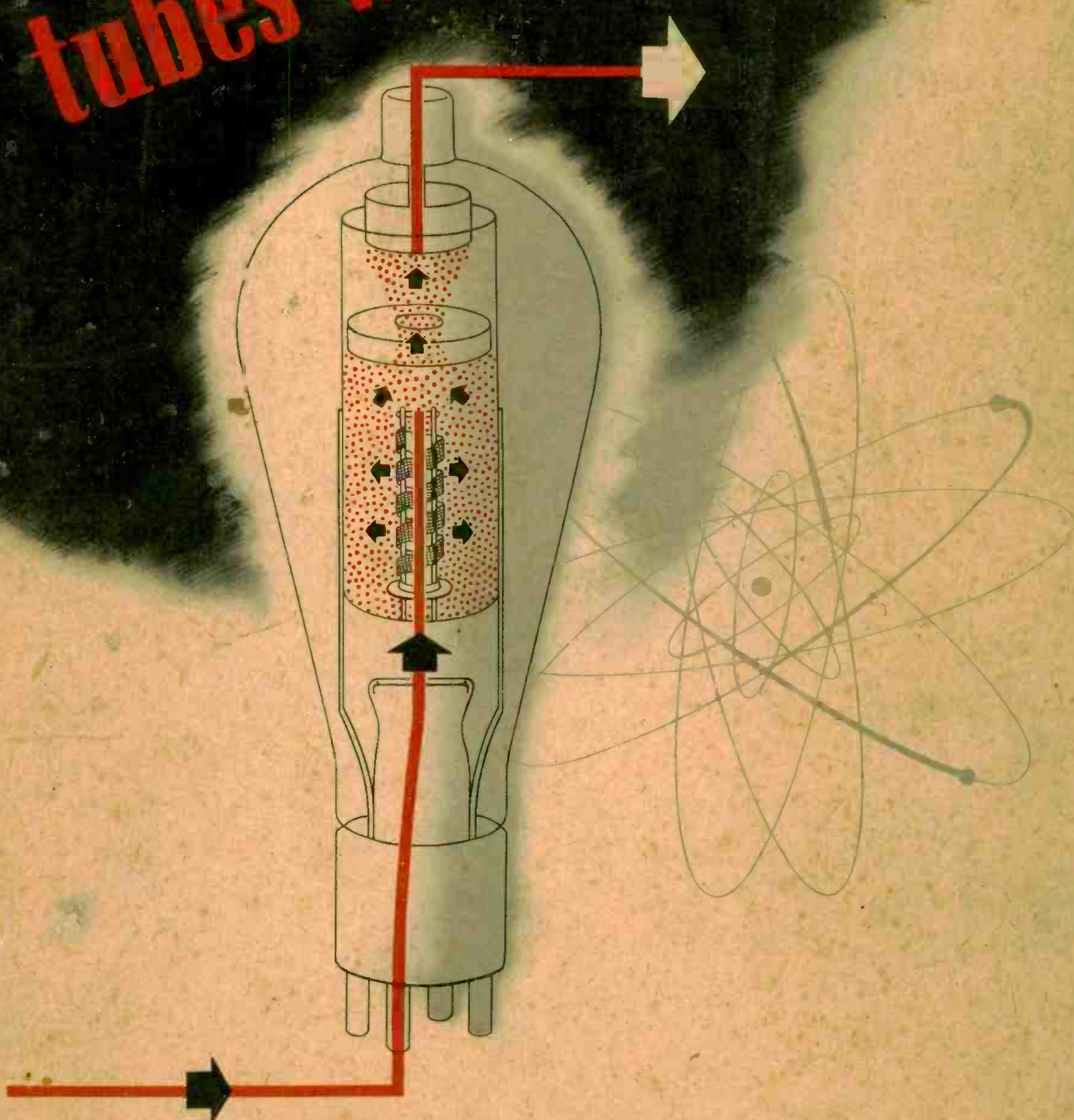
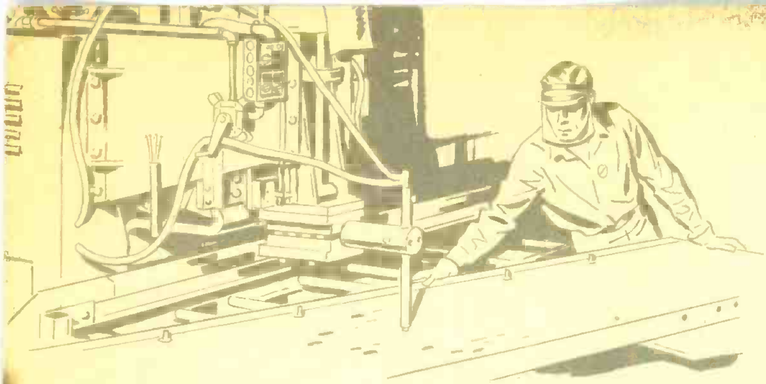
How electronic tubes work



Leader in Radio, Television, and Industrial Electronics

GENERAL ELECTRIC



Electronic Welding

Nearly everyone has at one time or another seen and used electronic tubes.

The tubes in home radio sets are electronic, as are those in transmitters at broadcasting stations.

Even the fluorescent lights in factories, stores, and homes are a form of electronic tube.

X-ray tubes used by doctors and dentists are electronic. So are the picture tubes in television receivers. Electronic tubes operate automatic door-openers, burglar alarms, and a host of other devices.

These are only a few of the uses to which electronic tubes have been put. In recent years—especially during the war—electronic tubes have won a place in industry where they are now performing countless tasks more efficiently and accurately than they have ever been done before.

For example, the high-frequency radio waves used to heat-treat steel for gears and tools are produced by electronic tubes; similar methods are used for bonding layers of plywood in the manufacture of plywood airplane propellers. Electronic heating can do these jobs in a fraction of the time formerly required.

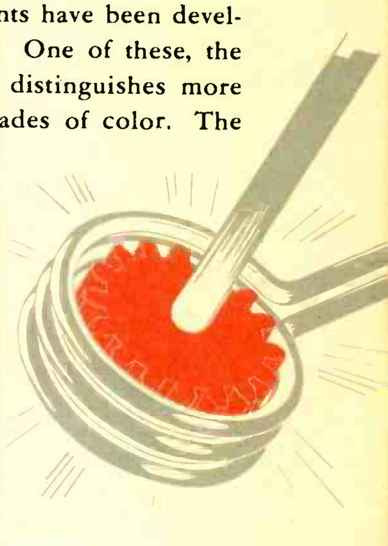
Electronic tubes accurately control the speed of electric motors under varying load conditions. They provide stepless control of lighting circuits—such as the colored lights used for stage effects. They operate d-c motors from a-c lines, and they convert alternating current into the vast quantities of direct current required by chemical plants, shipyards, steel mills and other industries.

In cement mills, electronic apparatus controls the speed and temperature of kilns. In textile plants, the electronic weft-straightener detects skew in cloth and automatically prevents the weft from getting out of line. In the printing industry, photoelectric register equipment controls the registration of color printing. In the plastics industry, electronic timing devices control a sequence of interrelated operations, from the insertion of the plastic compound to the cooling of the finished product.

There are electronic tubes so sensitive they can measure the minute quantities of electricity in the muscles of the human heart; others are sturdy enough to carry 10,000 amperes for such operations as resistance welding.

Highly specialized instruments have been developed around electronic tubes. One of these, the recording spectrophotometer, distinguishes more than two million different shades of color. The electron microscope has extended man's range of vision far beyond the limits of light microscopy, opening vast new fields of research.

Electronic strain gages are used to measure stresses within a bridge structure, or within the parts of a moving machine, so that corrective bracing can be installed and breakdowns prevented, or so that parts can be redesigned with greater margins of safety.

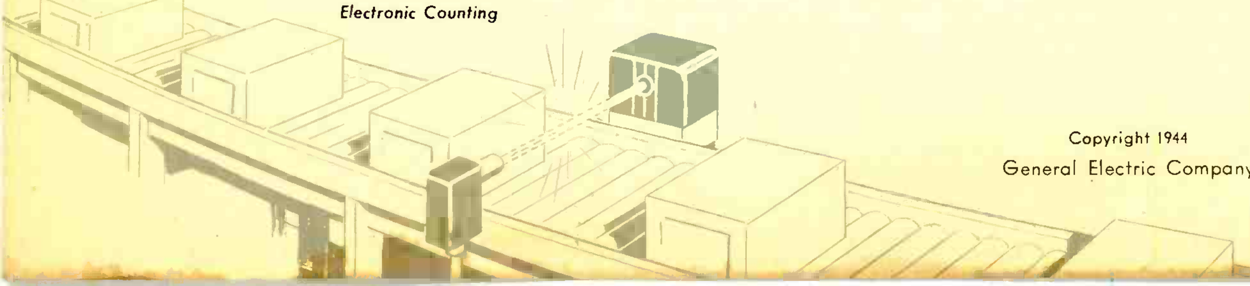


Electronic Heating

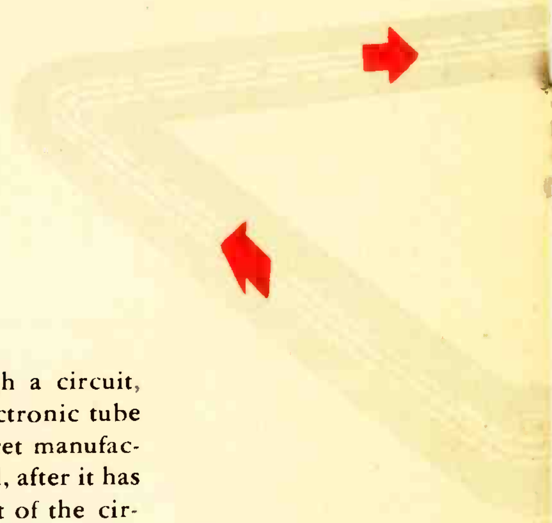
A complete listing of only the industrial uses of electronic tubes would run into hundreds of applications. In almost every type of industry, they have been used to measure and control such chemical and physical quantities as acidity, color, temperature, speed, pressure, and time.

And this is only a beginning. New applications are being found daily by G-E application engineers.

Electronic Counting



An electronic tube is a valve



An electronic tube controls the flow of electric current through a circuit, much as a valve controls the flow of water through a pipe. An electronic tube does not generate an electric current any more than a kitchen faucet manufactures a stream of water. Wires carry electric current to the tube and, after it has passed through the tube, other wires carry it away through the rest of the circuit.

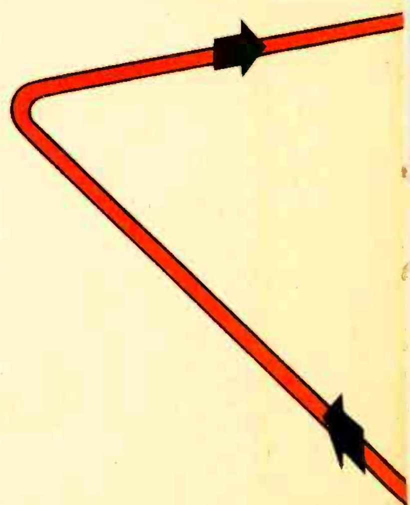
Unlike the valve, the electronic tube has no moving parts and no mechanical inertia to overcome. Its action is completely electrical; therefore, it operates with the speed of light—and that is one of its most valuable features.

Some electronic tubes can smoothly and precisely increase or decrease the amount of current flow. Others can instantaneously stop or start the full flow of current.

Another valuable feature is that only a tiny amount of energy is required to control a large amount of current flowing through the tube.

PRESENTING THE THYRATRON

To clearly illustrate and explain the operation of electronic tubes, this booklet will describe the basic parts, construction, and operation of a specific tube. For this purpose, a *gas-filled* tube, the widely used FG-57 *thyratron*, has been selected.

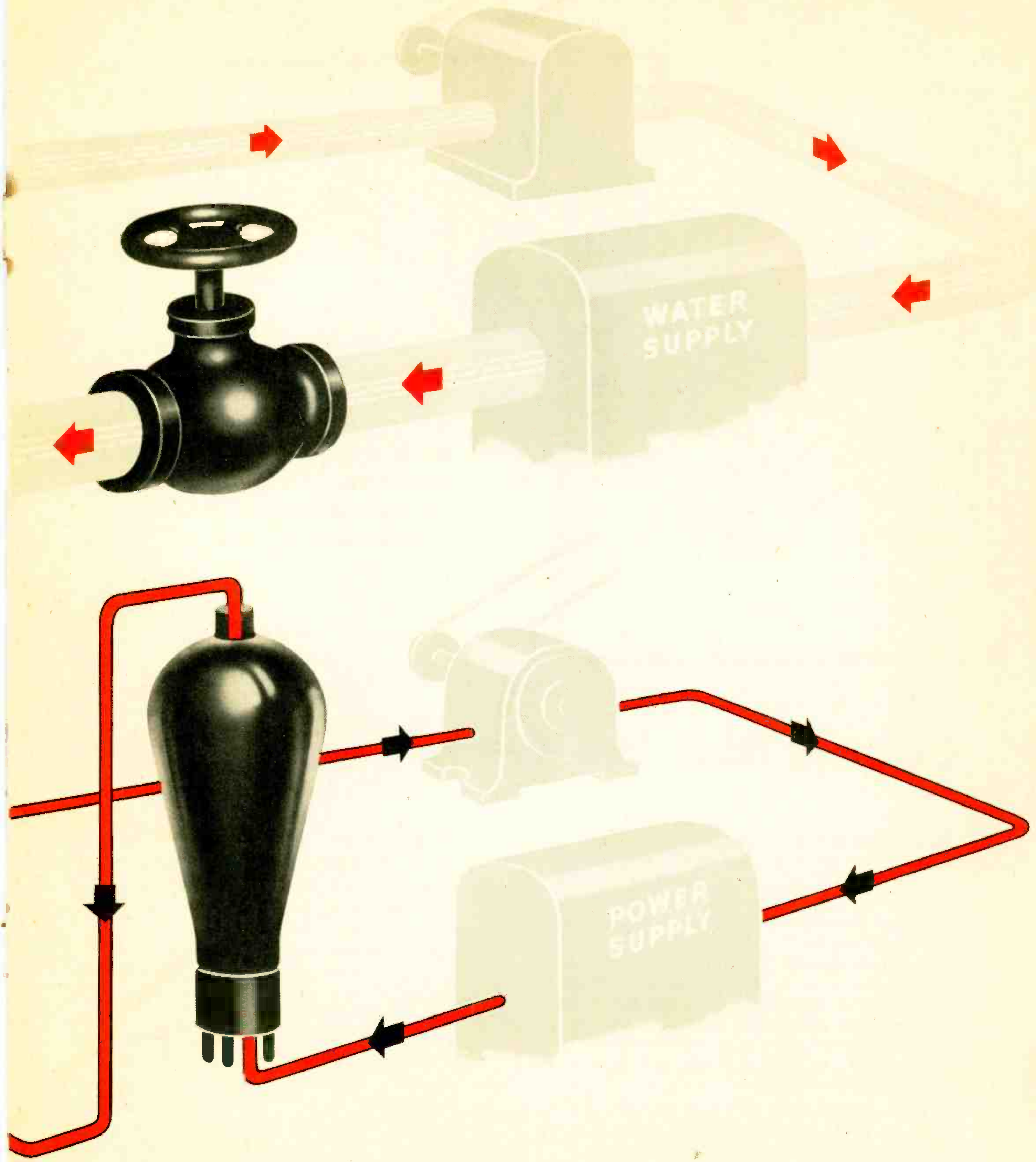


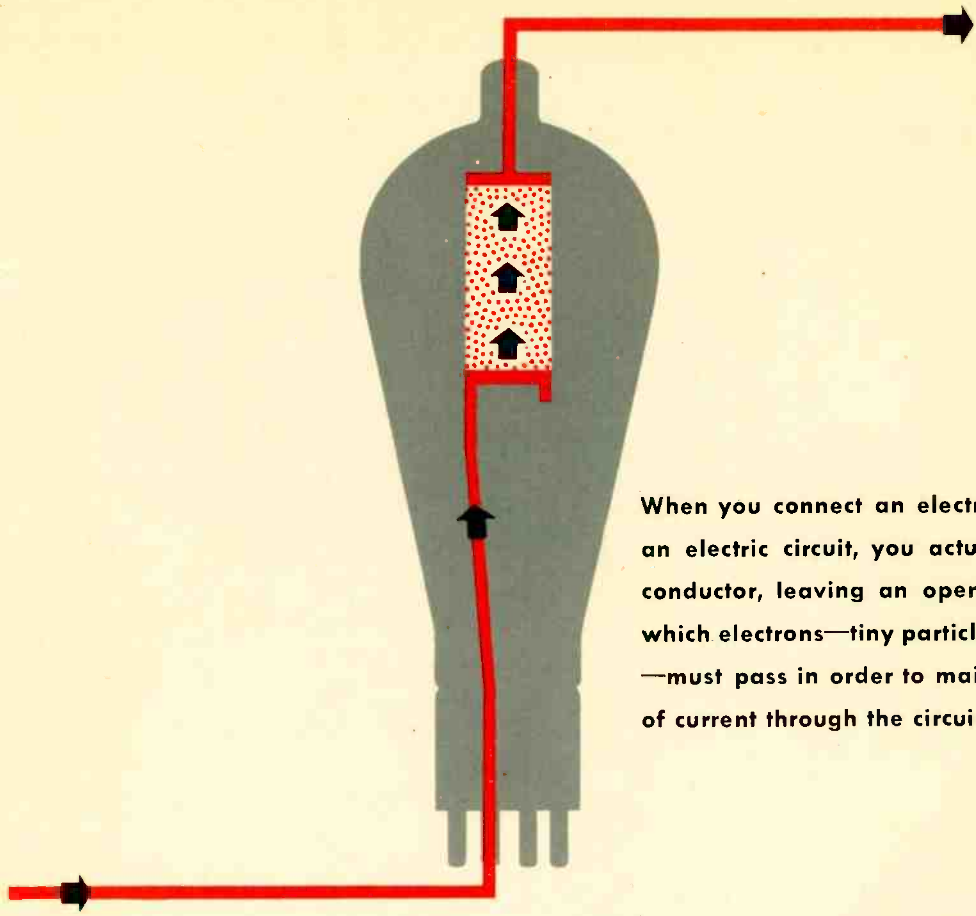
Inasmuch as there are two main classes of tubes, the *high-vacuum* and the *gas-filled*, an explanation of the basic differences between them is given on pages 14 through 17.

Since there are many types of gas-filled and high-vacuum tubes, it is impossible to describe them all in a booklet of this size. However, the basic principles of all tubes are essentially the same, and a thorough understanding of *one* tube will make it easy to understand the operation of *all* electronic tubes.

THE FLOW OF CURRENT

The accepted theory of current is that it flows from positive to negative. Now we know that electrons are always attracted to, and flow toward, the *most positively charged potential*. This is opposite to the direction of current flow. All the circuit diagrams in this book show the direction in which the electrons flow.


WATER SUPPLY
POWER SUPPLY



When you connect an electronic tube into an electric circuit, you actually break the conductor, leaving an open space across which electrons—tiny particles of electricity —must pass in order to maintain the flow of current through the circuit.

Electronic tubes free electricity from the wire

Just as the flow of water in a pipe is the combined movement of a great many drops of water, the flow of electricity in a conductor, such as a copper wire, is the combined movement of a stream of electrons. Each electron carries a tiny quantity of electricity.

As long as electrons remain imprisoned in wire, control over them is limited. But if they can be liberated from the wire under controllable conditions—such as exist within a sealed glass or metal bulb—their usefulness can be greatly increased.

And that is where the electronic tube fits into the picture.

When you connect an electronic tube into an electric circuit, you actually break the conductor, leaving a gap within a sealed enclosure.

Electricity must flow across this gap in order to close the circuit and permit current to flow again.

An invisible stream of electrons—each electron carrying a tiny quantity of electricity—carries the current through the space in the tube.

During the split second when the electric current is a flow of "free" electrons in the tube, it is subject to a method of control which is not possible while electrons are imprisoned in the wire.

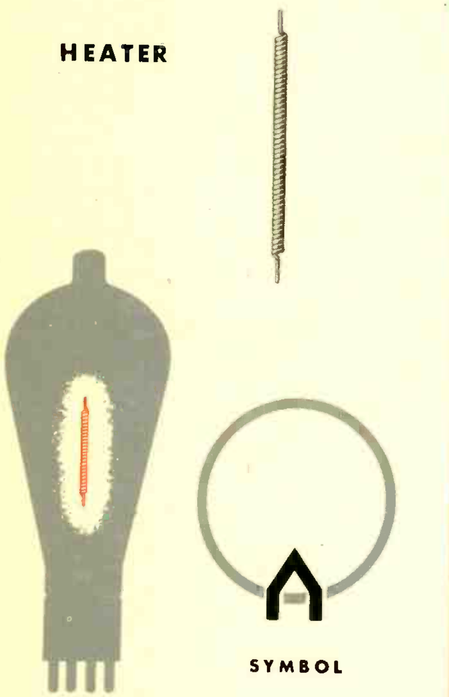
The current can be stopped, started again, increased or decreased—instantaneously, smoothly, accurately, and without mechanical movement, noise, or vibration.

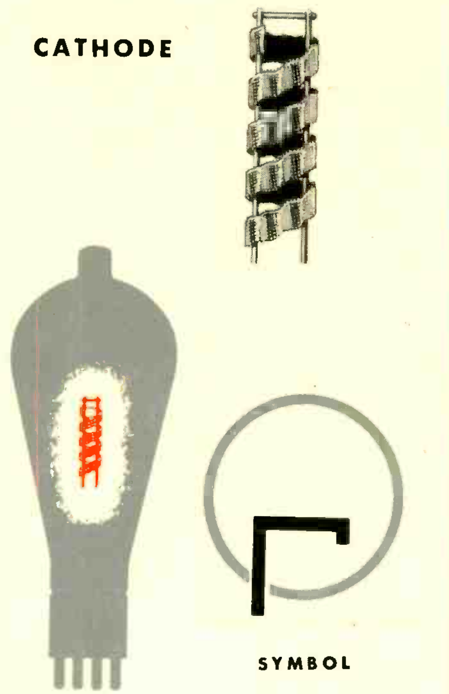
A high-speed mechanical relay or switch is slow by comparison.

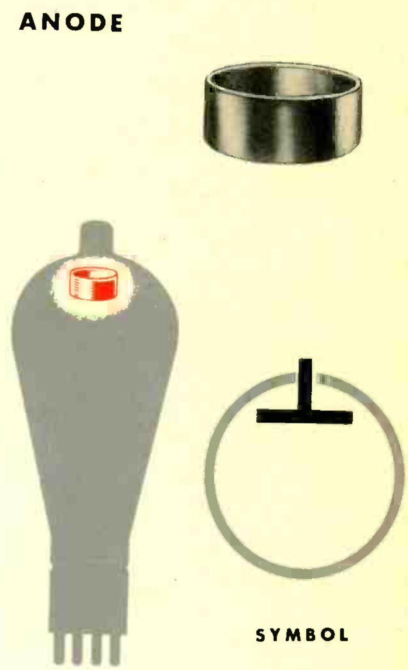
Any electronic tube has four basic parts

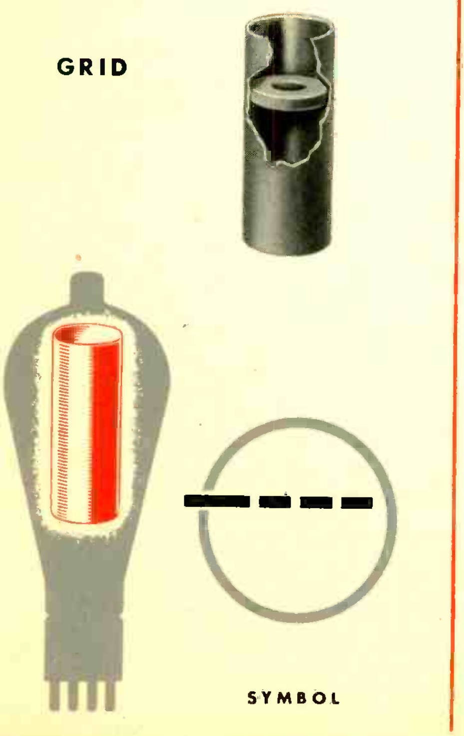
1. A surface which gives off electrons (the cathode)
2. A surface which receives electrons (the anode)
3. A glass or metal envelope (the outside of the tube)
4. Terminals for connecting tube into circuit

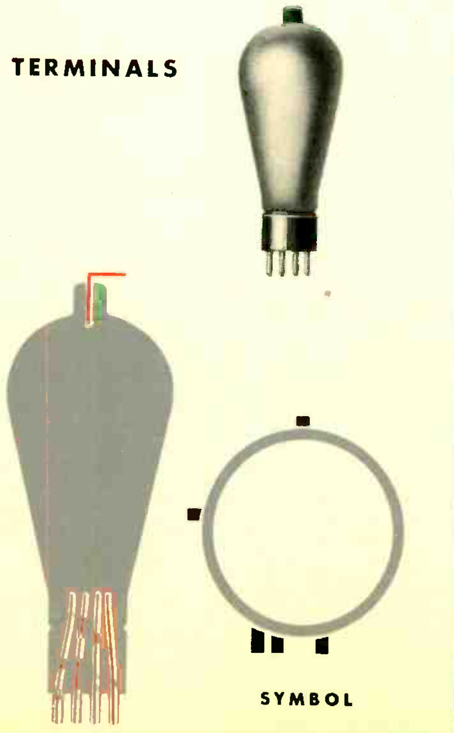
- Some tubes have a fifth part, the grid, which controls the current passing through the tube.
- Some tubes have a separate heating coil to bring the cathode to the temperature required to make it give off electrons.
- The FG-57 thyratron, shown here, has these six parts.

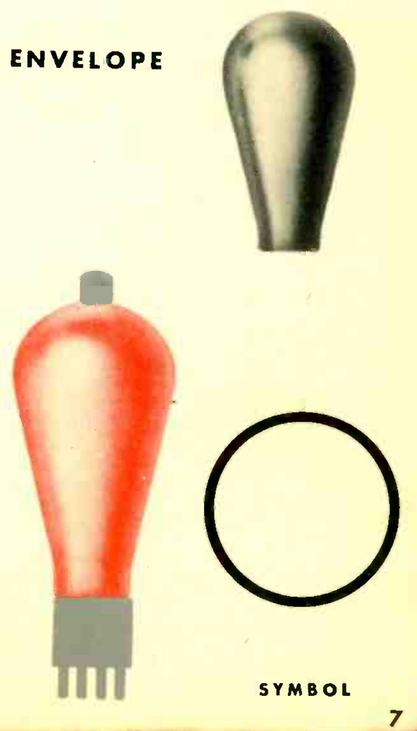


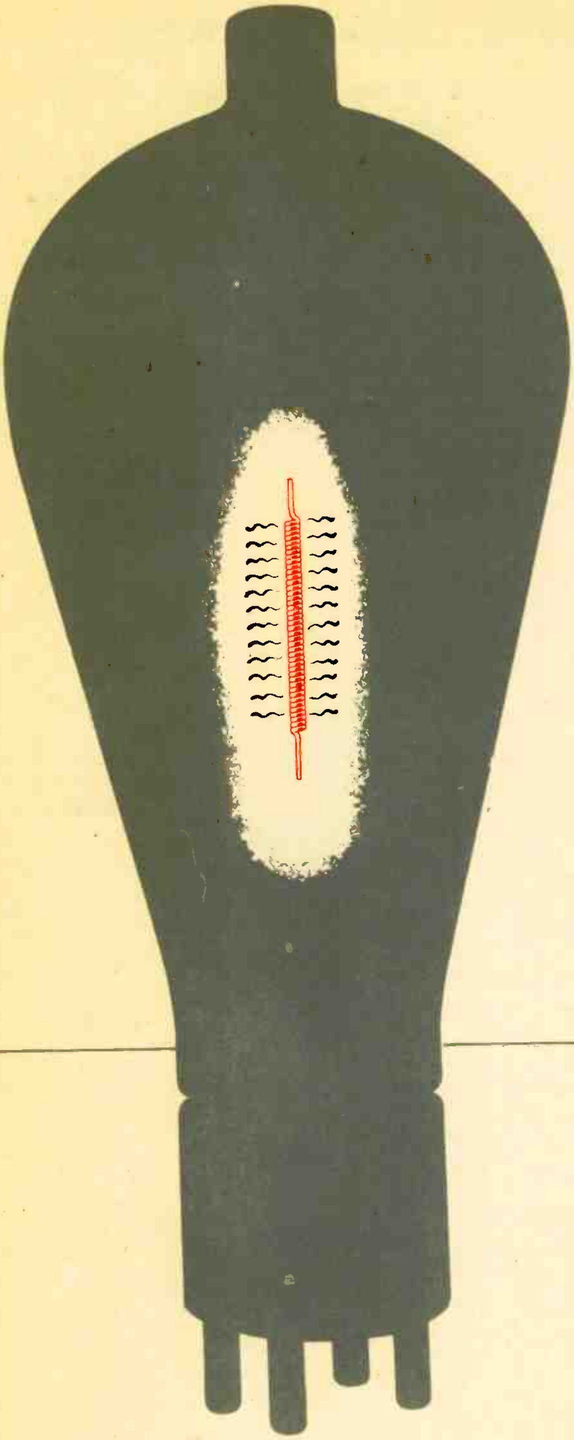












What the **HEATER** does

The heater heats the cathode

In most tubes the cathode is heated to make it give off electrons. There are two methods of heating the cathode, each of which has special advantages for certain applications.

One method is to build the cathode in the form of a filament which is heated by its own resistance when a current is passed through it. These self-heated filament cathodes look much like the filament of an incandescent lamp.

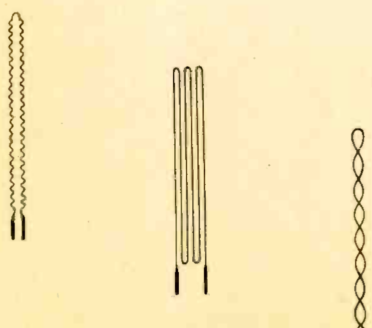
The other method is to use a separate heating coil inside the cathode. This heating coil is called the heater.

The heater is made of a metal with a high melting point, such as tungsten. Operating temperatures vary; in the thyratron tube shown here, the heater operates at a temperature of about 1800° Fahrenheit and heats the cathode to about 1600° Fahrenheit.

The cathode is *not* heated to its operating temperature by the main current flowing through the tube.

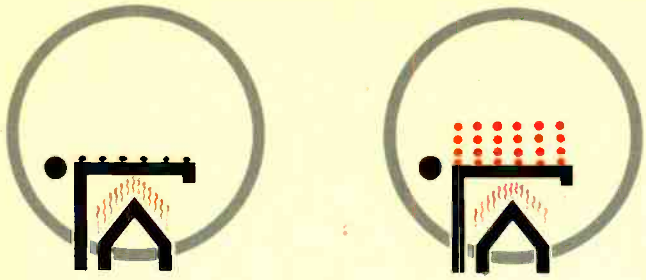
A separate circuit, fed by a low-voltage transformer or battery, supplies the current for heating either the filament-type cathode or the heater.

The thyratron tube shown here requires 4.5 amperes at 5 volts in the heater circuit.

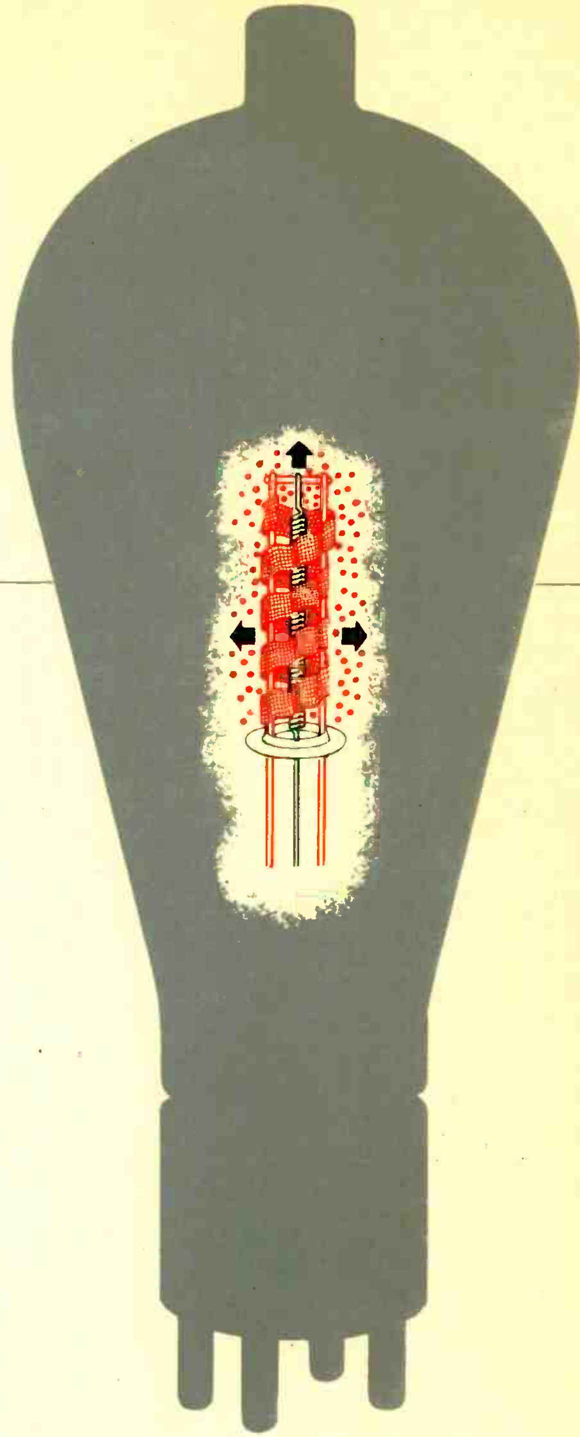


TYPICAL HEATERS

What the **CATHODE** does



When heated the cathode gives off electrons



When an electronic tube is connected into a circuit, the conductor is actually broken. The cathode inside the tube is one end of the broken conductor and the anode is the other. To re-establish a flow of current through the circuit, electrons must flow across the gap between the cathode and the anode.

Electrons cannot get across this gap without assistance. They must first be released from the cathode so the anode can "pull" them across the gap. Heating the cathode is one way to liberate electrons, and it is the method used in most tubes.

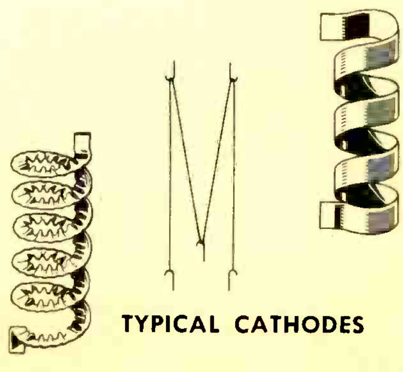
When the cathode is heated electrons boil off its surface—much as steam is boiled off the surface of water.

Heated cathodes—whether of the directly or indirectly heated type—are made of a metal having a high melting point, such as nickel alloy, coated with certain chemical compounds to increase their ability to give off electrons.

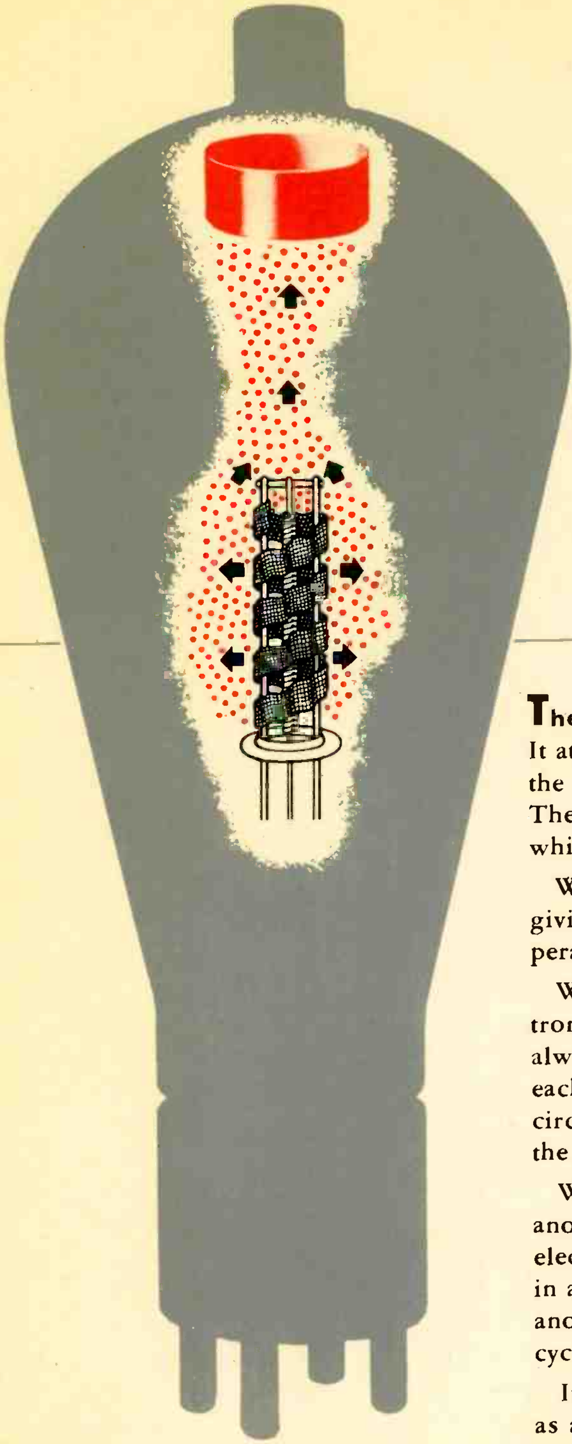
Whether a cathode should be directly or indirectly heated depends on the electrical characteristics desired for the tube and the materials used.

Filamentary (directly heated) cathodes heat more quickly than indirectly heated cathodes and are used where quick heating is desired. A much larger emitting surface can be heated efficiently with the indirect method. Therefore, indirectly heated cathodes are generally used in tubes which are expected to carry large currents.

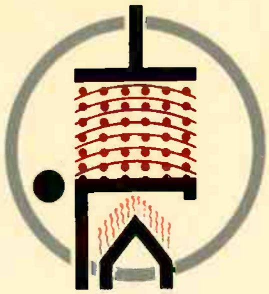
Other methods of liberating electrons are used in certain types of tubes. Phototubes utilize light beams to liberate electrons from the cathode; glow tubes are actuated by the potential gradient (difference in voltage) between the cathode and the anode; mercury-pool tubes release electrons by means of an arc drawn between the surface of the mercury and the anode, which is started by a special electrode called the ignitor.



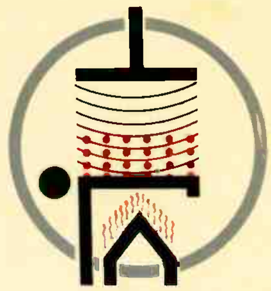
TYPICAL CATHODES



What the **ANODE** does



1. When it is positively charged, the anode attracts electrons.



2. When it is negatively charged, the anode cannot attract electrons.

The anode is the other end of the broken conductor in the tube. It attracts the billions of electrons that are "boiled" off the surface of the cathode, thus establishing a flow of current through the tube. The anode is frequently referred to as the *plate,* and the current which flows through the tube is called the *plate current.*

While the anode (or plate) can attract electrons, it is incapable of giving off electrons as long as the tube is operating at the proper temperature.

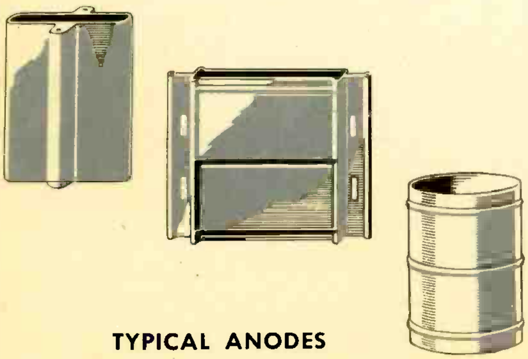
When a positive voltage is applied to the anode, it attracts the electrons given off by the cathode. The reason for this is that electrons are always negatively charged, and opposite electrical charges attract each other. Therefore, if the tube is being used in a direct-current circuit, the anode must always be connected to the positive side of the circuit.

When a tube is connected into an alternating-current circuit, the anode is positive during half of each cycle. During this half cycle electrons leave the cathode and are attracted by the anode, resulting in a flow of current through the tube. During the half cycle when the anode is negative, electrons cannot reach the anode. During this half cycle, current cannot flow through the tube.

It is this characteristic of an electronic tube which enables it to act as a rectifier, changing alternating current into direct current.

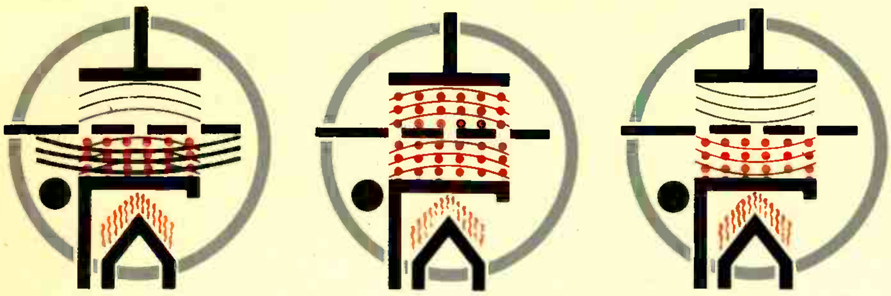
The higher the positive voltage applied to the anode, the greater its ability to attract electrons, and the greater the rush of electrons to it—up to the limit of the ability of the cathode to give off electrons.

Different materials are used in fabricating anodes. They include tungsten, molybdenum, nichrome, graphite, nickel, and tantalum. Different shapes, also, are used. Material used and shape selected depend on the desired electrical characteristics and the amount of cooling necessary. (The anode must not be permitted to overheat.) The FG-57 thyratron tube shown here has a carbonized-nickel anode.

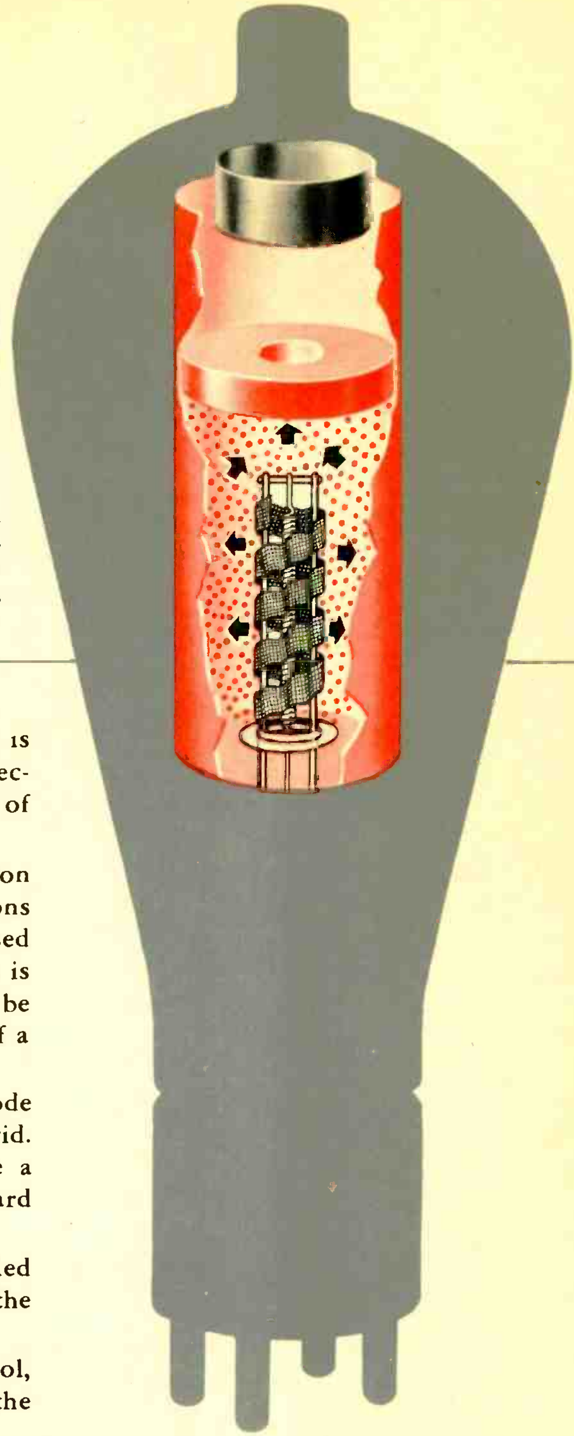


TYPICAL ANODES

What the GRID does



1. When more than a certain critical value of negative voltage is applied to the grid, electrons cannot reach the anode. 2. When the negative voltage on the grid is reduced below the critical value, the grid suddenly permits the full flow of electrons from the cathode to the anode. 3. Flow of electrons stops when the anode voltage becomes negative. Cycle then repeats.



The grid is the controlling or "valve" electrode of the tube. It is located between the cathode and the anode in the path of the electrons. Some tubes have several grids to permit greater range of control over the plate or anode current.

The grid in any gas-filled tube, including the FG-57 thyratron shown here, controls only the point in the cycle at which electrons will start to flow to the anode. For example, if the tube is being used to control a resistance-welding circuit in which the welding time is required to last only five one-thousandths of a second, the grid can be made to hold the current off until the last five one-thousandths of a second of the positive side of the cycle. (See Figure 4, page 17.)

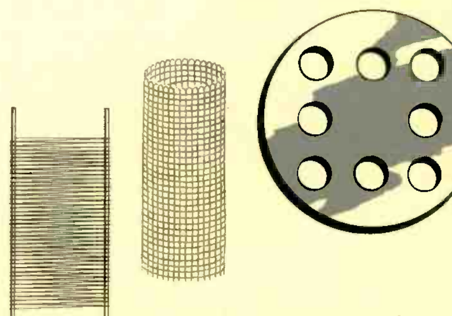
The grid in the FG-57 will not permit electrons to reach the anode as long as a certain negative voltage value is maintained on the grid. When this voltage becomes less negative, the grid works like a trigger, suddenly permitting the full flow of electrons to start toward the anode.

Once the flow of electrons has started, the grid in any gas-filled tube loses control over the flow until the next cycle; that is, until the anode has become negative and stopped the flow of electrons.

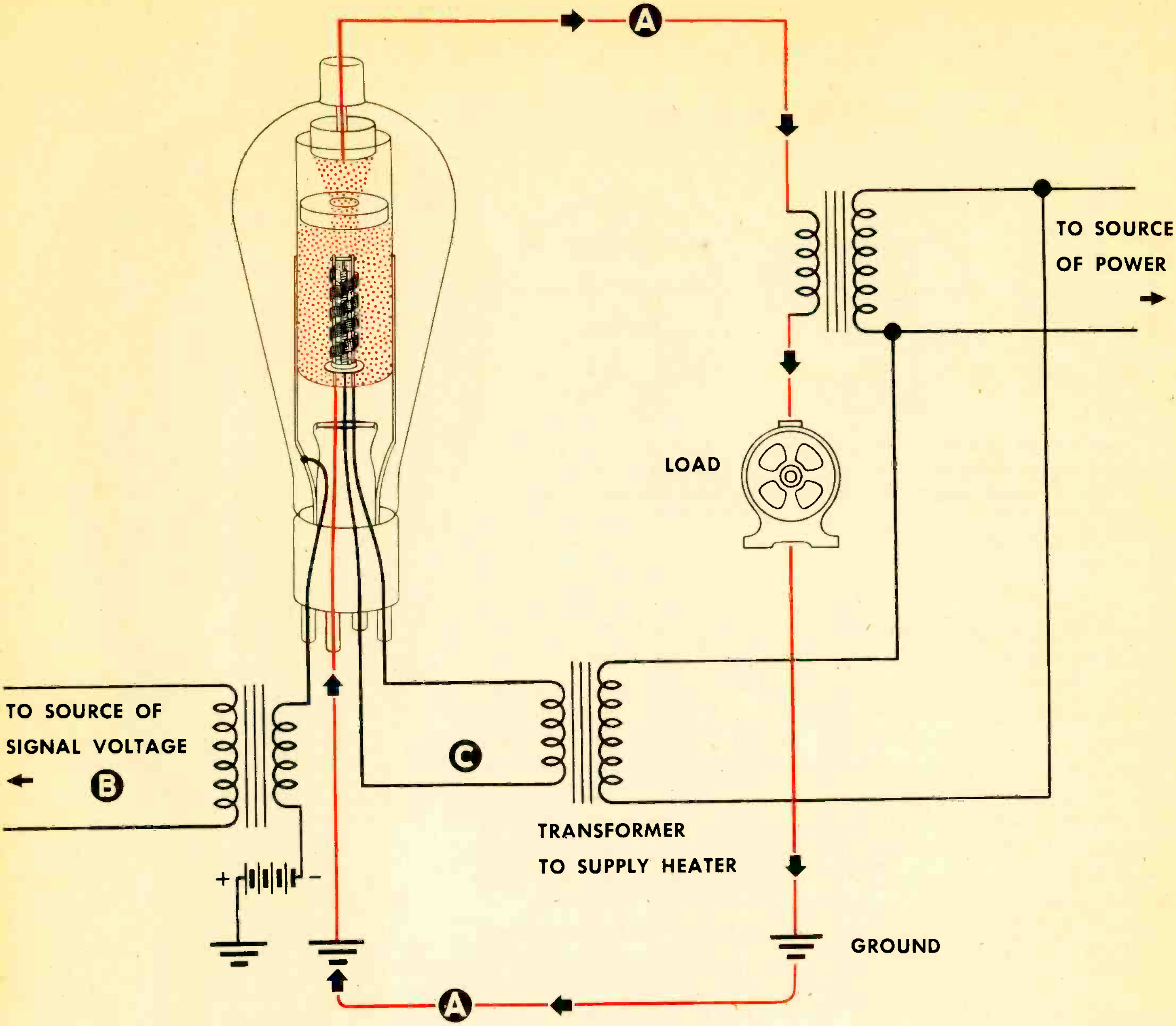
After the flow of electrons has stopped, the grid regains control, and once more will prevent the start of the flow until voltage on the grid again becomes less negative.

The effect of the grid in high-vacuum tubes is quite different, for it never loses control over the flow of electrons. Instead, the flow is at all times proportional to the voltage applied to the grid, and any change in grid voltage causes a proportional change in the amount of current flowing through the tube. (See Figure 2, page 16.)

In both the gas-filled and high-vacuum tubes, the power required in the grid is very small. Therefore, a relatively small amount of power in the grid of an electronic tube can precisely control a much larger amount of power in the plate circuit.



TYPICAL GRIDS



The TERMINAL connections

The terminals are the electrical leads on the tube which provide for connection of the cathode and anode into the main circuit, and connection of the heater and grid to their respective supply circuits.

There are three separate circuits in an electronic tube having a grid, and for each additional grid there is one additional circuit. Tubes having no grid have only the heater and cathode-to-anode circuits; or, in the case of tubes having an unheated cathode (such as phototubes and glow tubes) only the cathode-to-anode circuit.

On the diagram, the circuit labeled (A) is the cathode-to-anode circuit. The load is a motor.

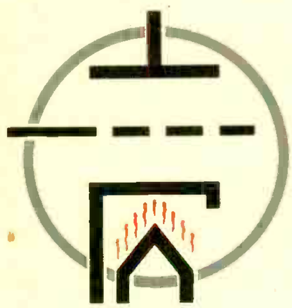
The grid-control circuit (B) is made up of two parts, a source of d-c (in this case a battery) and a source of a-c.

The d-c, called the *grid bias,* is a current through the grid that creates a negative field strong enough to prevent any electron flow to the anode. Thus, no current can flow through the main circuit (A).

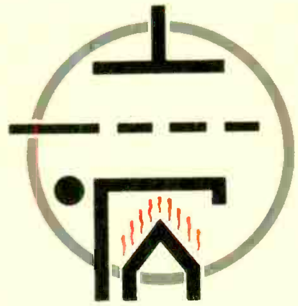
At the instant current-flow through circuit A is desired, the *grid bias* is neutralized by the *signal voltage.* Neutralizing the *grid bias* permits electrons to reach the anode. Thus, the *signal voltage* is a "trigger" that releases the full flow of current through the tube.

Circuit (C) is the heater circuit and supplies the current for heating the cathode to the temperature at which it gives off electrons. A transformer generally supplies this circuit.

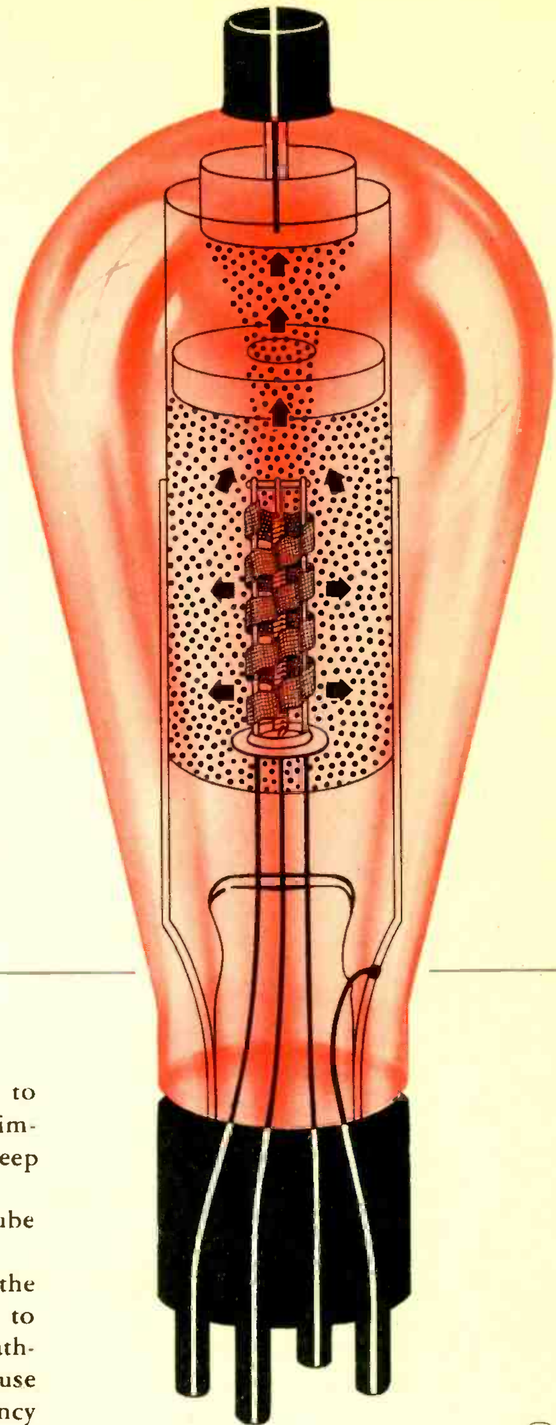
What the ENVELOPE does



Symbol for high-vacuum tube



Symbol for gas-filled tube



The chief function of the envelope, or outside of the tube, is to maintain the vacuum in the tube. In some tubes it also has an important function in dissipating the heat created in the tube so as to keep it at a proper working temperature.

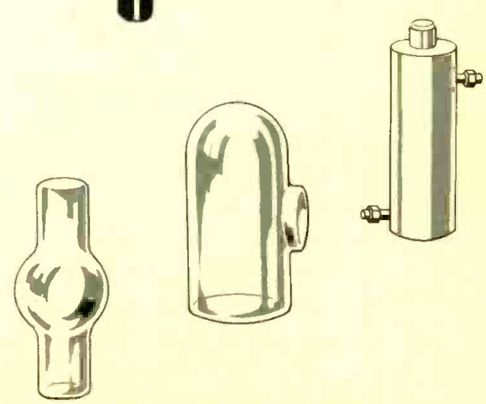
It is necessary to enclose the metal parts (electrodes) of the tube in a vacuum.

If the cathode were to be heated to its operating temperature in the presence of air, the oxygen in the air would cause the cathode to burn up. Even if air would not result in the destruction of the cathode, it would cause corrosion of the metal parts, or would cause the formation of a coating of oxides, thus reducing the efficiency of these parts.

The envelope maintains controlled gas-pressure conditions, ranging from a very high degree of vacuum to the low pressure of gas used in the thyratron, Type FG-57.

There are two basic types of electronic tubes—high-vacuum and gas-filled.

In making a gas-filled tube, the air is first pumped out until a high vacuum is created. Then, before the tube is sealed, a tiny quantity of argon, neon, mercury vapor, or some similar substance is inserted. (However, the pressure is still well below that on the outside of the tube.) This gas or vapor is chemically inert, which means that it will not combine with any of the metals used in the tube.

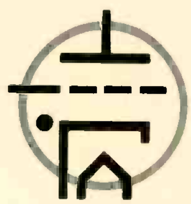


TYPICAL ENVELOPES

Gas-filled and high-vacuum tubes and how they differ

There are two basic types of electronic tubes. Both types are necessary, since each possesses characteristics either lacked by the other or superior to those of the other. Generally speaking, gas-filled tubes are necessary where large amounts of current must be controlled, as in resistance welding. High-vacuum tubes are necessary in jobs calling for continuous control of relatively small currents.

High-vacuum tube



Gas-filled tube

The major distinctions between gas-filled and high-vacuum tubes are these:

1. High-vacuum tubes work like a throttle in that they provide continuous and uniform control of the amount of current flowing through the tube.

2. Gas-filled tubes work like a switch. They are capable of accurately and instantaneously closing a heavy-current circuit.

3. Gas-filled tubes will carry heavy current much more efficiently than high-vacuum tubes of the same size. This heavy current is conducted with a low and relatively constant voltage drop.

4. High-vacuum tubes can be used as distortionless amplifiers, gas-filled tubes cannot.

It has already been explained that a gas-filled tube also is a relatively high-vacuum tube, for the gas it contains is at an extremely low pressure—far below atmospheric pressure. The presence of this small amount of gas, however, is the key to the difference in operation of the gas-filled and high-vacuum tubes.

Space Charge and Ionization

In both the gas-filled and high-vacuum tubes, electrons are given off by the cathode. These electrons are drawn to the anode by the attractive force of its positive charge (remember that opposite electrical charges attract each other).

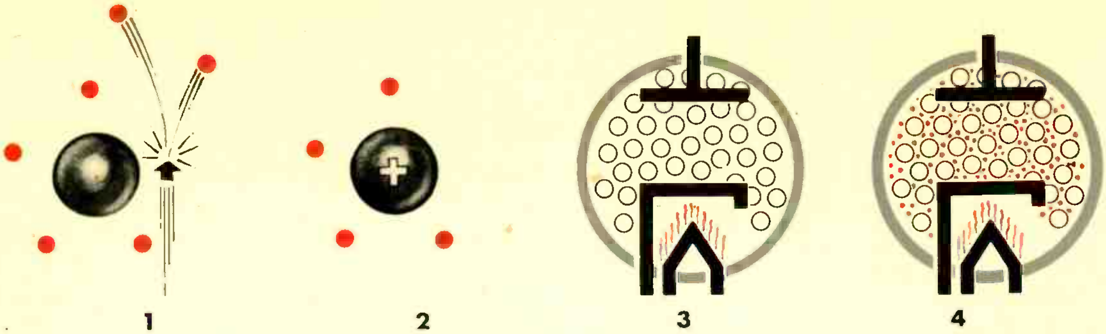
The effect of the billions of electrons passing between the cathode and anode is to create a strongly negative electric field (remember that electrons are always negative). This field is known as *space charge.*

This negative field, due to the space charge, cancels part of the positive field created by the anode, thus reducing the ability of the anode to attract electrons. This is known as *space-charge effect* and is the basic reason for the inability of high-vacuum tubes to carry as large a current for their size as gas-filled tubes.

When a small amount of gas is placed in the tube it fills the space in the tube with gas molecules which, by comparison to the tiny electron, are very large. A gas molecule consists of a nucleus, which is positively charged, and a number of electrons which revolve about it much like the planets of a miniature solar system. There are just enough electrons to balance the positive charge on the nucleus and make the molecule electrically neutral.

Electrons emitted by the cathode travel with tremendous velocity and when one of them collides with a gas molecule the impact knocks one or more electrons out of the molecule. These molecules, which have lost some of their electrons and are now positive, are called ions. The process is called ionization.

The electrons knocked out of the molecules join with the stream of electrons moving toward the anode. The ions remain in the tube for a relatively long time and neutralize most of the effect of the space charge. The effect of ionization is to permit more electrons to reach the anode. Thus, ionization is responsible for the greater current-carrying capacity of gas-filled tubes.



IONIZATION **1.** An electron is knocked out of a neutral gas molecule. **2.** A molecule which has lost an electron is no longer neutral, but is positive. **3.** These positive molecules are called ions. **4.** When enough ions form, they neutralize most of the space charge, permitting more electrons to reach the anode.

The distinctions between gas-filled and high-vacuum tubes can best be understood when presented in the output diagrams for each tube.

Assume that a typical current—the 60-cycle, 110-volt alternating current—is being used in the tube's cathode-to-anode circuit.

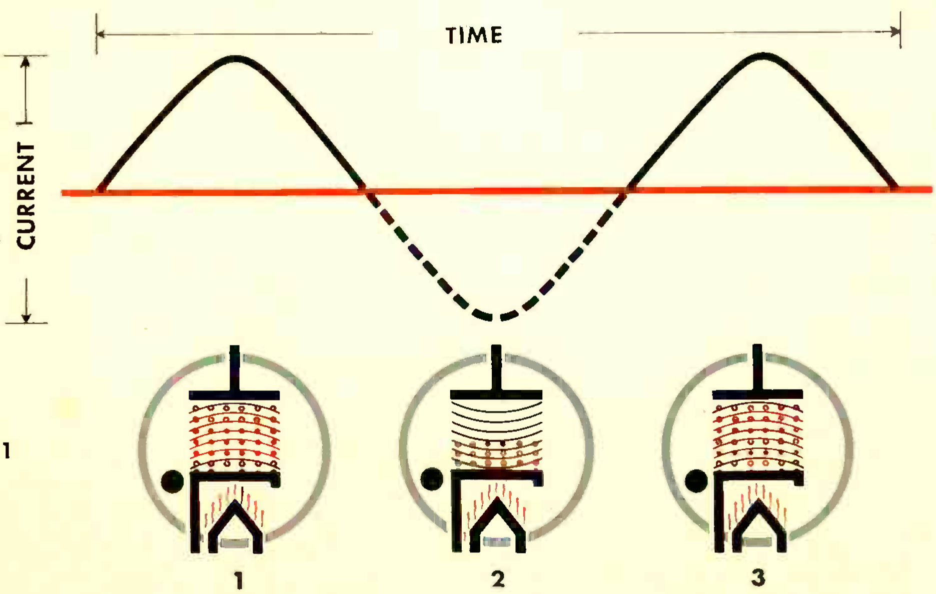
Such a current changes direction 120 times a second—twice each cycle. The usual diagram for this current is shown below. What is shown here takes place in 3/120 of a second.

Because electrons can leave the cathode but cannot leave the anode, electronic tubes permit current to flow in only one direction and only during the positive portion of each cycle. The negative portion of each cycle (represented by the dotted lines) is eliminated by the tube.

In other words, the current is being continuously turned on and off. It is on for 1/120 second and off for 1/120 second—see Figure 1. The output of the tube is, therefore, a pulsating direct current. The pulsations can be removed by filters.

Figure 1 illustrates the output of a tube having no control grid. Since it is utilizing only half of the current wave (one side of the cycle only), it is known as a half-wave rectifier. If two tubes are connected so that the cathode of one is connected to the anode of the other, thus conducting both halves of the cycle, the output will be an alternating current which can be controlled cycle by cycle. This type of circuit is used for resistance welding.

Fig. 1



HOW A SIMPLE RECTIFIER WORKS **1.** Anode is positive and attracts electrons. **2.** Anode is negative and does not attract electrons. **3.** Cycle repeats—each step lasting 1/120 second.

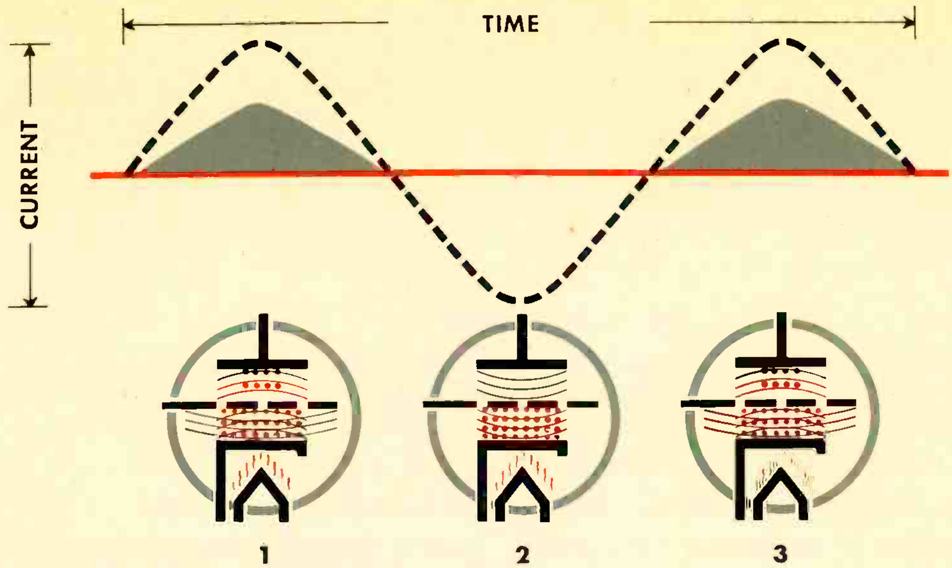


Fig. 2

THE GRID ACTION OF A HIGH-VACUUM TUBE **1.** Grid is cancelling part of effect of anode; only part of electrons are reaching anode. **2.** Anode is negative and does not attract electrons. **3.** Cycle repeats.

Assume now that we replace this rectifier tube with a high-vacuum tube containing a grid. Assume also that the grid is set to reduce the flow of current through the tube by one half. The diagram for the output wave of this tube is shown in Figure 2 (dotted line represents the maximum output of the tube; solid area is the output permitted by the grid).

The diagram shows that the controlled-output wave has the same shape as the full-output wave. This means that the tube has exerted a continuous and uniform control of the current during the entire period of flow.

This continuous and exact control is the reason for using high-vacuum tubes for amplification. For example, if we had a very faint current—too weak to be used directly—it would be used as the *signal-voltage* on the grid of the tube. Every variation in the shape of its wave, no matter how small or complex, would be faithfully reproduced in the

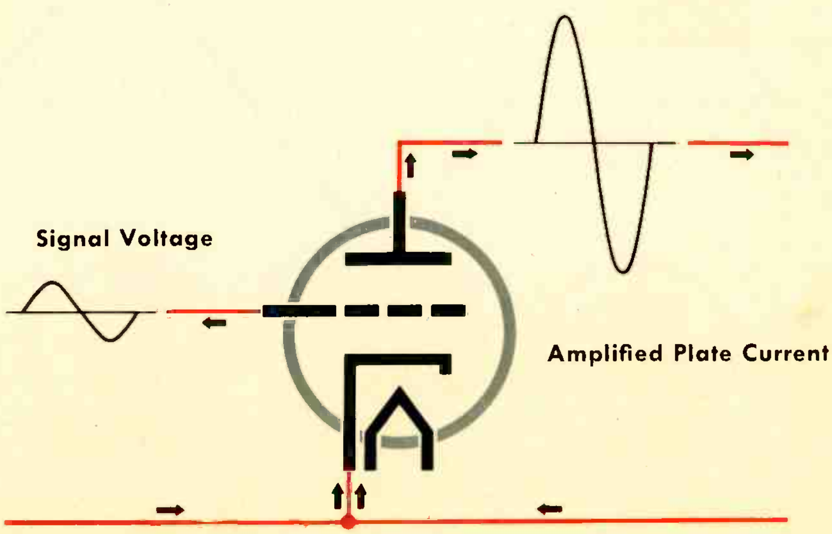


Fig. 3

HOW AN AMPLIFIER WORKS—The plate-current wave takes exactly the same shape at the signal voltage. Since the plate current is many times larger than the grid current, this results in amplification.

output wave of the tube. This output wave would be an amplified (enlarged) "image" of the grid wave. Figure 3 on page 16 illustrates this.

Now, suppose that the high-vacuum tube is replaced by a gas-filled tube in which the grid is set to reduce the flow of current through the tube by one half. The output diagram for this is shown in Figure 4.

In this case, the output diagram does not have the same shape as the uncontrolled output wave. Instead, it shows that the current did not flow at all during the first quarter of a cycle. At this point, the full flow of current suddenly came on and remained on for a quarter of a cycle. During the negative half-cycle (the period when the anode is negative and prevents electrons from flowing) the current remained off, as it did in the vacuum tube.

Since the controlled wave does not have the same shape as the uncontrolled wave, the gas-filled tube cannot be used as an amplifier without distortion. Because the current is being switched on and off, part of the signal voltage would be lost during each cycle.

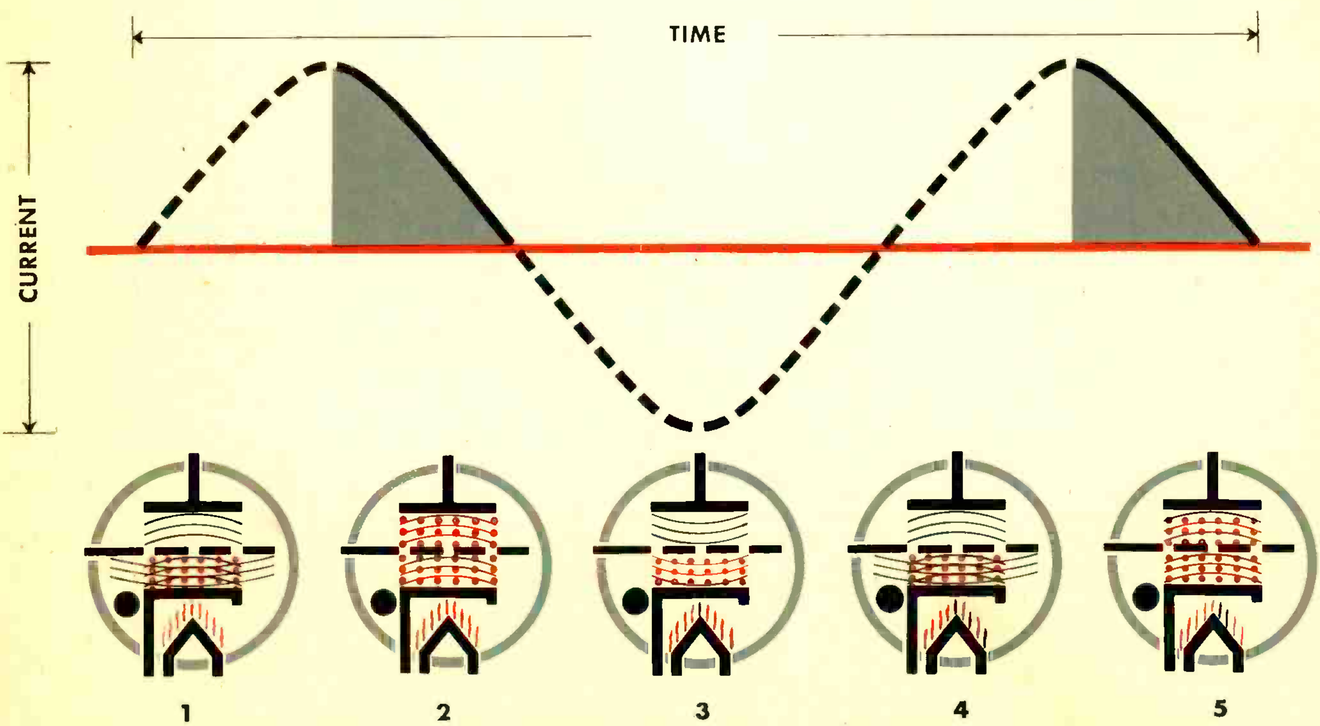
The diagrams illustrate the basic differences between high-vacuum and gas-filled tubes. The high-vacuum tube works like a rheostat, the gas-filled tube works like a switch.

Although the same average amount of current was permitted to flow through both tubes, the method of control was different.

In the gas-filled tube, the current was completely off for a quarter of a cycle and completely on for a quarter of a cycle—in short, the average flow was reduced by turning it off for part of the time.

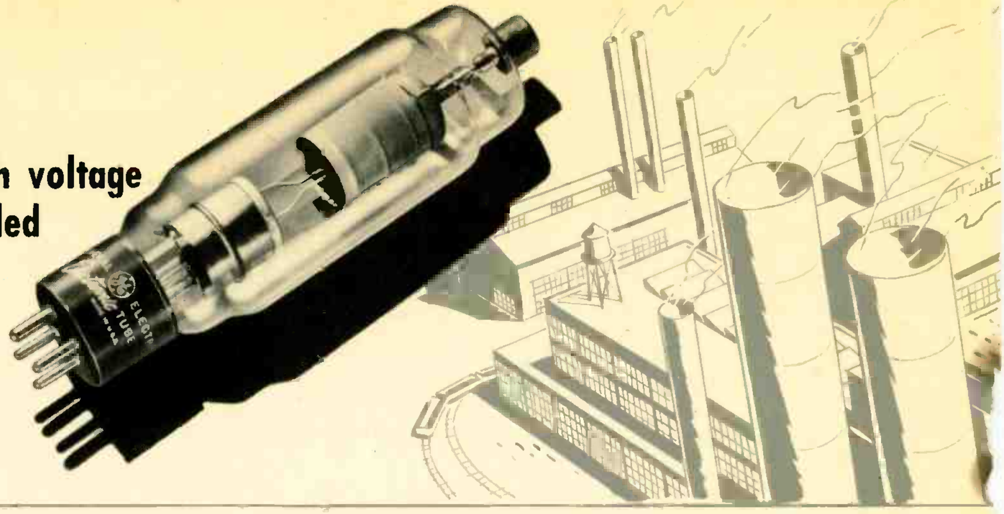
The high-vacuum tube reduced the average flow of current by throttling down the flow—just as the flow of water from a faucet is reduced by turning the handle.

Fig. 4



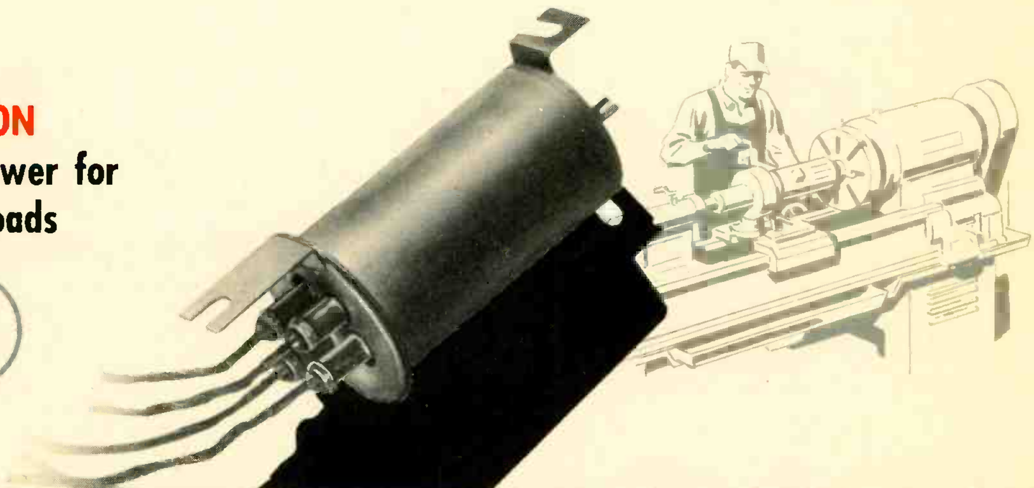
THE GRID ACTION OF A GAS-FILLED TUBE—1. Grid prevents flow of electrons—completely cancels effect of anode. **2.** When less than a minimum voltage is applied to grid, full flow of electrons is suddenly released. **3.** Anode is negative and does not attract electrons. **4-5.** Cycle repeats.

The **KENOTRON**
supplies d-c where high voltage but low current is needed



The **PLIOTRON** is opening the great field of electronic heating

The **PHANOTRON**
supplies d-c power for intermediate loads



The **IGNITRON** is a heavy-duty power supply

A **kenotron** is a high-vacuum, hot-cathode tube without a grid.

The kenotron supplies high-voltage d-c (40,000 to 150,000 volts) for applications where current requirements are low as compared with the heavy currents required for welding.

Kenotrons are used by electrical manufacturers and power companies for testing cable insulation. Weak spots in the insulation can be accurately located even if the cable is installed underground.

Kenotrons supply the high voltages necessary to filter air by electrical precipitation. The air is ionized and the negatively charged dust adheres to plates positively charged by the kenotrons. Even small particles that defy all other air-cleaning devices can be removed.

In the same way, smoke from the chimneys of factories and smelters can be minimized. Valuable material can often be recovered as a by-product of this smoke abatement.

In the manufacture of sandpaper an electrostatic field created by kenotrons causes the abrasive particles to be deposited on the adhesive paper with the sharp ends upward.

A **pliotron** is a hot-cathode, high-vacuum tube with one or more grids for controlling the plate current.

The pliotron was created to produce the high-frequency waves used in radio broadcasting.

A General Electric scientist, Dr. W. R. Whitney, discovered that these high frequencies could be used to produce heat inside the human body—and the pliotron came into widespread use in diathermy.

Today, high-frequency induced heating is one of the fastest growing fields of industrial electronics.

Electronic heating has reduced to seconds, the time required to surface-harden gears, crankshafts, valves, and other machine parts which industry is now producing by tens of millions.

Electronic heating has speeded the production and improved the quality of plywood such as is now produced for the construction of airplane propellers.

A **phanotron** is a hot-cathode, gas-filled tube without a grid and, therefore, with no control over the plate current. It is a general-purpose a-c to d-c rectifier for use where current requirements are about 30 amperes or less.

One large industrial application is as a d-c power supply for magnetic chucks that hold magnetically the work being machined.

It is also used as a d-c supply for automatic battery chargers for the big commercial storage batteries used for standby and similar service.

In certain control applications, phanotrons supply d-c power to other electronic tubes.

Another important use is as a d-c power supply for magnetic separators used in removing iron and steel particles from nonmagnetic material, such as wood scrap, before processing.

The **ignitron** is a gas-filled tube with a mercury-pool cathode. An ignition electrode (ignitor) causes a stream of electrons to leave the cathode from points on the mercury pool called cathode spots. The ignitor, therefore, controls the starting of the plate current—just as the grid does in the thyratron.

The ignitron has two main industrial uses:

It supplies the heavy current used in spot or seam welding of aluminum alloy, stainless steel, and many other types of metal.

It is also being used in place of rotating machinery for changing alternating current into direct current.

In this field ignitrons have important advantages over ordinary mechanical devices:

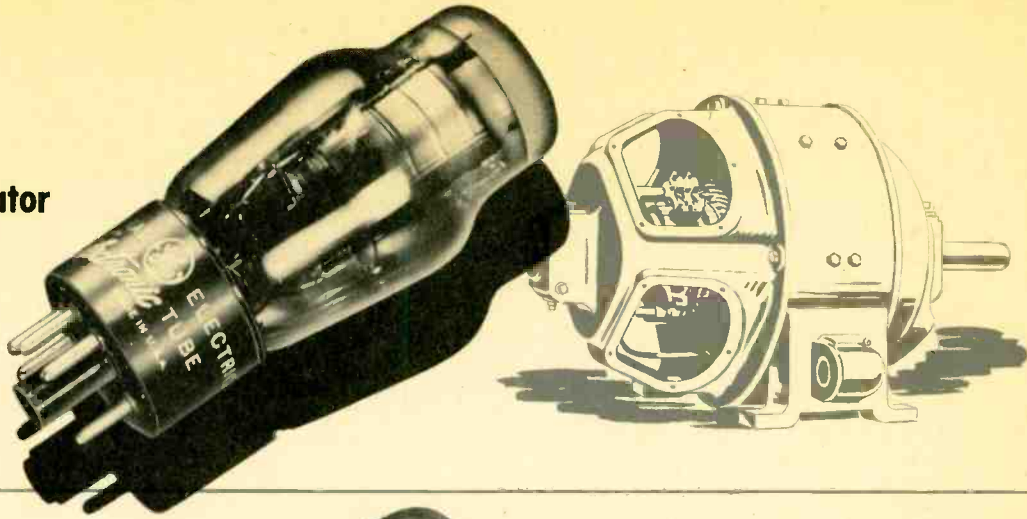
There are no moving parts, one reason for the low maintenance expense of electronic equipment.

No special foundation is required, as is the case with rotating equipment for changing a-c to d-c.

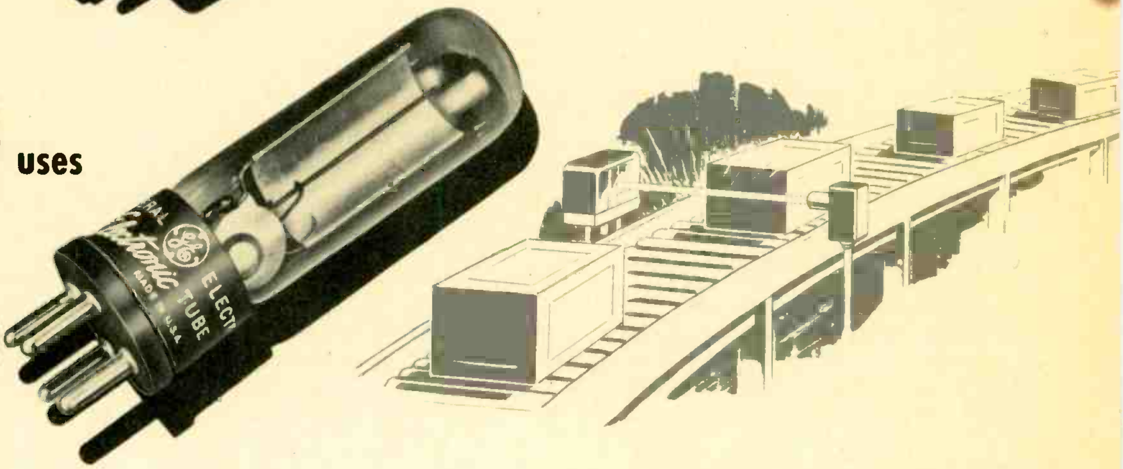
Only a few minutes are required to replace tubes, eliminating long shutdowns. An ignitron tube lasts for several years.

Fire and explosion hazards are reduced by the sealed construction.

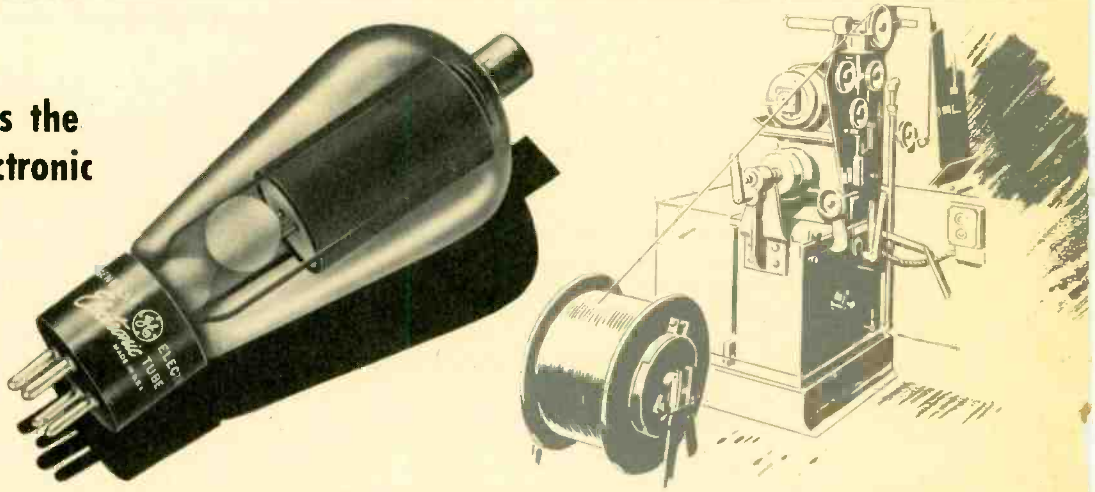
The **GLOW TUBE** is a voltage regulator



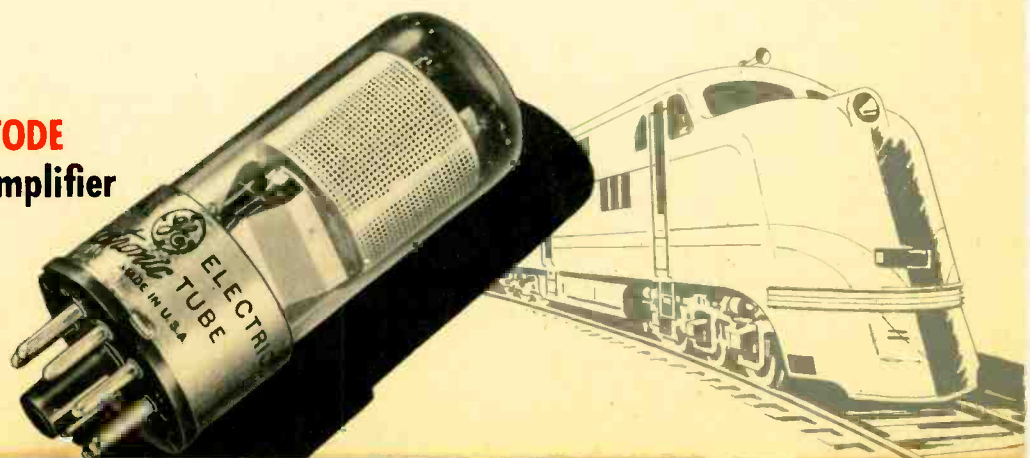
The **PHOTOTUBE** has hundreds of uses in industry



The **THYRATRON** is the most versatile electronic tube in industry



The high-vacuum **PENTODE** is a general-purpose amplifier

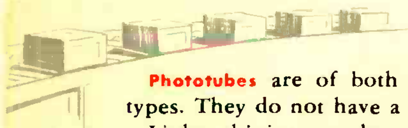


A **glow tube** is a cold-cathode, gas-filled tube without a grid. Electrons are literally pulled out of the cathode by a high potential gradient at the surface of the cathode (difference in voltage between cathode and anode).

The glow tube has a constant voltage characteristic. This means that regardless of changes in the amount of current flowing through it, within its rating the voltage drop across a glow tube always remains practically constant.

Because of this the glow tube can be used as a voltage regulator. In automatic motor-control applications, the glow tube, with the aid of other tubes, automatically regulates the field and armature voltages so that motor-speed remains constant regardless of load or changes in line voltage.

The simplicity of the circuit is a major advantage of this tube over other methods of providing a constant d-c voltage across a load.



Phototubes are of both the gas-filled and high-vacuum types. They do not have a grid.

Light, shining on the cathode of a phototube, causes electrons to be emitted. A potential of from 15 to 25 volts on the anode is sufficient to attract any electrons that are emitted. Small pliotrons are used to amplify this tiny current created in the phototube so it can operate the desired mechanism.

The high-vacuum phototube is used in applications requiring great stability and instant response to light changes.

The gas-filled phototube is used in applications requiring extreme sensitivity. However, if light changes are rapid, the gas-filled phototube loses its advantage over the high-vacuum phototube in sensitivity. The gas-filled photo-tube also has a higher output for a given amount of light than does the high-vacuum phototube.

The kinds of jobs done by phototubes are generally familiar . . . opening doors, counting, sorting, grading, maintaining precise register in printing and papermaking, detecting pinholes in sheet metal, actuating safety devices, setting off burglar alarms, and performing many other tasks dependent upon the interruption of a beam of light.

Phototubes can be designed to operate on either visible or invisible light.

The **thyratron** is a hot-cathode, gas-filled tube with one or more grids to control the starting of the plate current.

In resistance welding, the thyratron times the heavy welding currents (supplied by the ignitron) with the split-second precision that has made possible high-production welding of aluminum alloys and stainless steel.

Thyratrons also run d-c motors directly from a-c lines, thus in many cases eliminating the need for d-c distribution lines and rotary converters. With thyratron control, any desired motor speed can be held constant regardless of changes in the load. This is especially valuable in such applications as wire-reeling and in various machine-tools.

It is the thyratron that executes the "orders" of the photo-tube, or electric eye, in sorting, grading, counting, detecting flaws in steel plates, synchronizing conveyors, and operating safety devices.

The thyratron not only has the ability to control the currents supplied by tubes such as the ignitron, but it can also act as a self-controlled power tube for intermediate loads.

The shield-grid thyratron will operate with a much smaller grid current than the regular thyratron.

The **pentode** is a multi-grid, high-vacuum tube that provides extremely high amplification. Therefore, it is valuable as an intermediate stage in circuits involving phototubes and glow tubes. It amplifies the tiny output voltage of a glow tube or phototube until it is capable of actuating the grids of such tubes as thyratrons.

All of the multi-grid high-vacuum tubes, including the pentodes, are actually pliotrons.

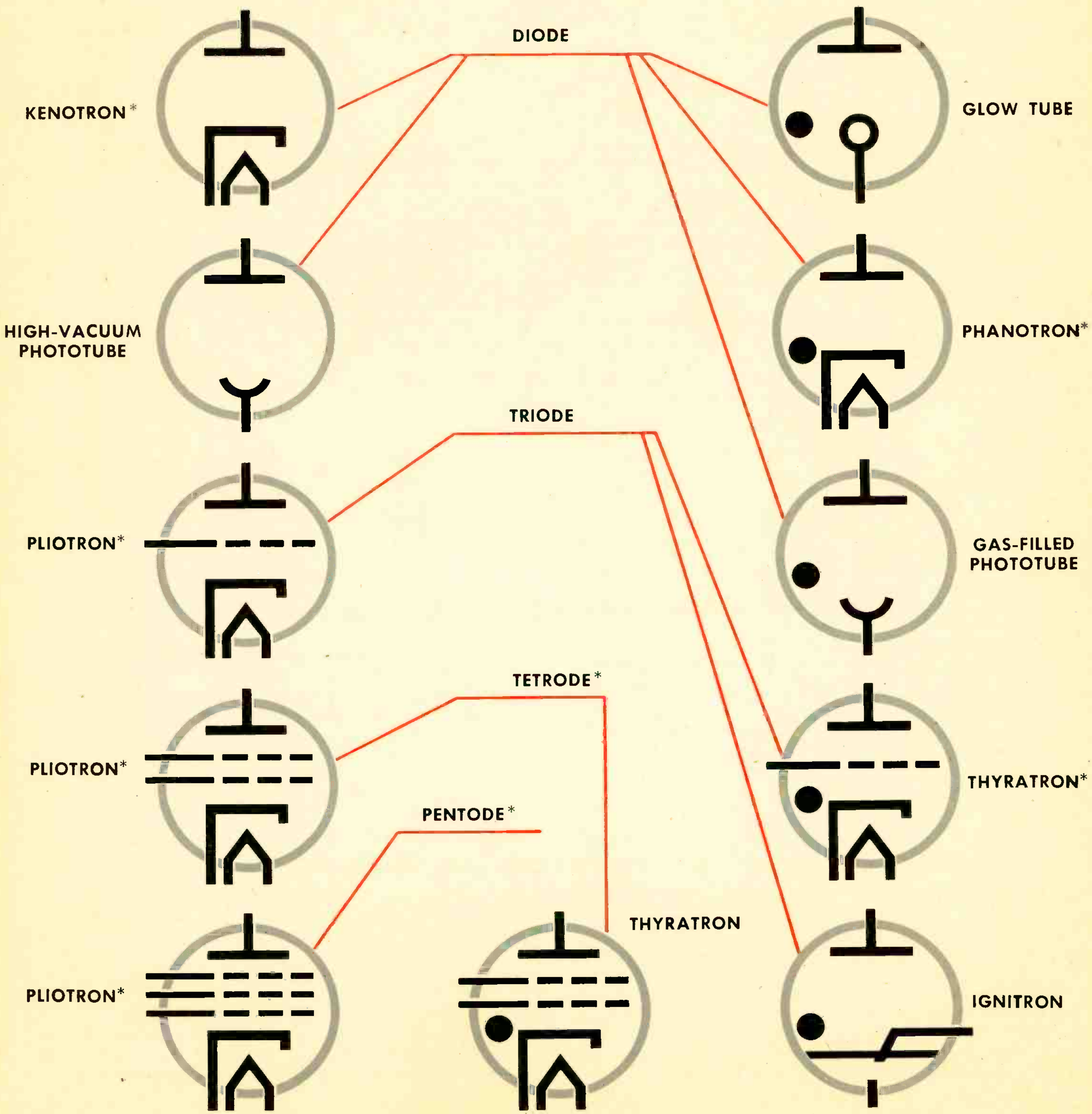
Pliotrons of this type are used in photoelectric relays, automatic train-control and cab-signaling equipment, and in elevator-leveling apparatus.

Pentodes, of course, are widely used in radio circuits.

THE FAMILY TREE OF ELECTRONIC TUBES

Hot Cathode (indirectly heated)
Phototube Cathode
Cold Cathode
Mercury-pool Cathode

Filamentary Hot Cathode; also Heater
Grid
Ignitor (used with mercury-pool cathode)
Anode
Indicates gas-filled tube



* These tubes, although shown here with indirectly heated cathodes, are also made in types having filamentary cathodes (self-heated).

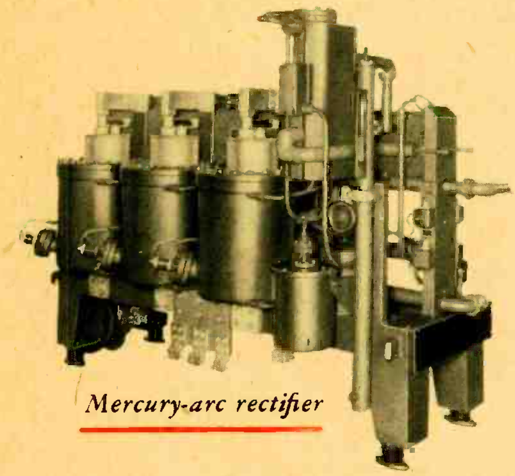
A Few of the Standard G-E Industrial Electronic Devices--Ready for Installation

Photoelectric relay

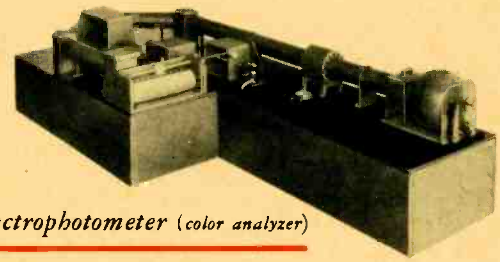
Time-delay relay

Spot-welding control

Induction heater



Mercury-arc rectifier



Spectrophotometer (*color analyzer*)

Vibration-velocity meter

Insulation-resistance meter

Phano-charger (*battery charger*)

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Completely engineered and standardized G-E industrial electronic apparatus is available, ready for installation in your plant. Or, if you need special equipment for your particular application, our engineers will be glad to discuss your requirements and then arrange to design special equipment to meet your needs.

In all cases, our recommendations are based on an intimate knowledge of industry's requirements. Also, since General Electric builds the complete electric equipment into which the electronic circuit blends, you can be assured that electronic apparatus will be used only when such equipment will do the job best.

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It is the purpose of General Electric tube engineers to help you in the application of electronic tubes—whether they are used in your own manufacturing processes or in electronic devices which you build and sell.

Even though war projects now consume most of our engineering time, we shall try to give each problem as much attention as possible.

Put your ideas on paper with the aid of your own engineers—clearly, completely, and with a full statement of the purpose you hope to accomplish. This information will help make our electronic tube engineering service more valuable to you.

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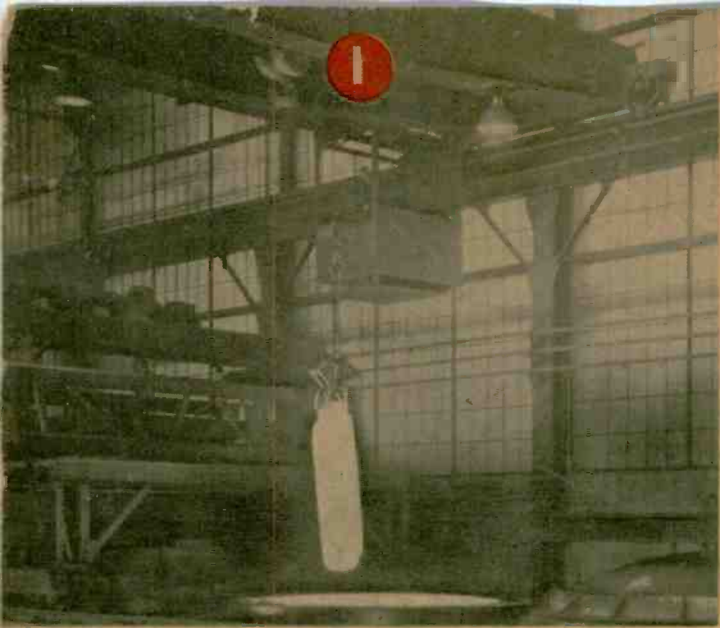
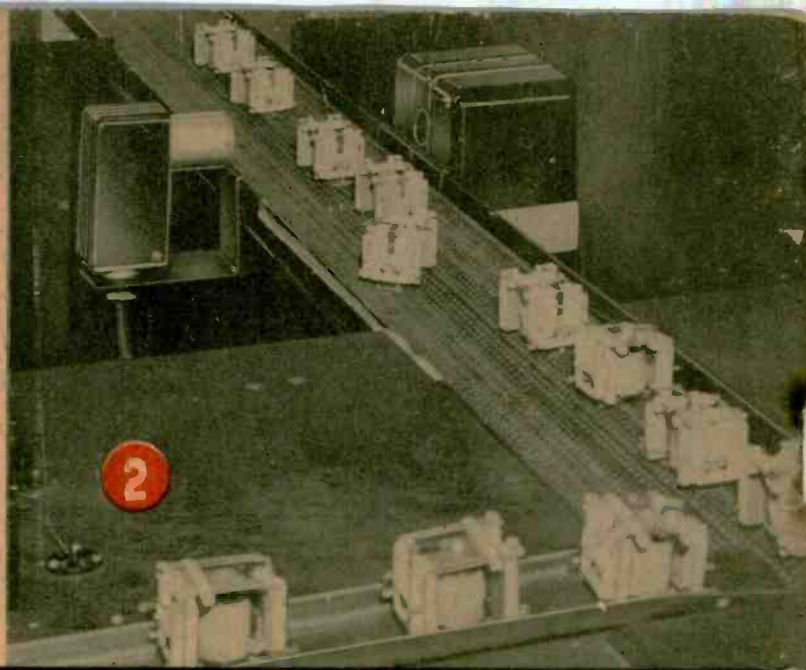
Write to General Electric, Electronics Department, Schenectady, N. Y.





ELECTRONIC TUBES AT WORK FOR INDUSTRY

1. D-c power for this crane is provided by G-E ignitron rectifiers. Installation at plant of Adirondack Steel Foundries.

2. Relays on this production line are counted by a G-E photoelectric relay.

3. Power for this d-c motor is supplied directly from a-c distribution lines by means of G-E electronic tubes.

4. High-production spot-welding of aluminum for airplanes, such as the Boeing Flying Fortress, is made possible by electronic welding control.

5. Constant motor speed, regardless of changes in line voltage and load, is provided by G-E electronic-tube control.

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