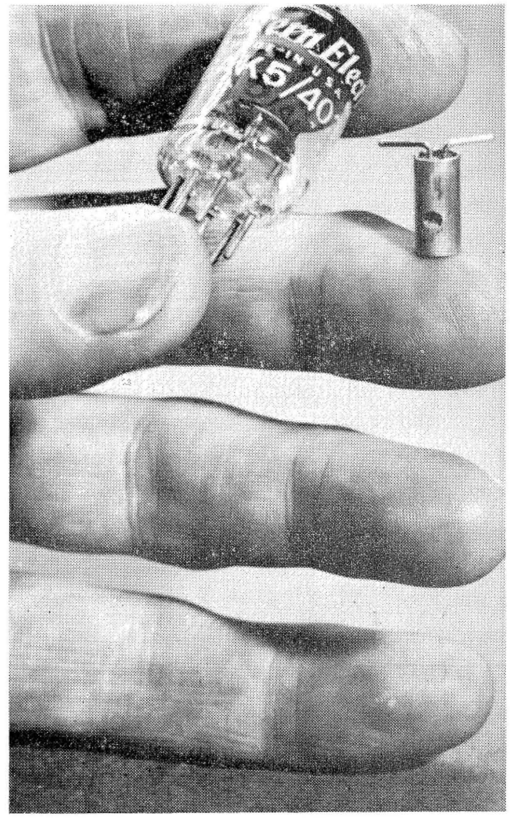
The Transistor

Minute device 3/16 in. in diameter and ½ in. long, capable of performing many functions of vacuum tubes, and experiments with which have resulted in input-output power gain of 100 times, shows great promise in communication and electronic fields



Type-A transistor, compared in size with a 6AK5 vacuum tube

THE transistor—Bell Telephone Laboratories' revolutionary device for performing many of the functions of vacuum tubes—is a tiny giant of efficiency and a new tool with considerable promise in the field of electronics and electrical communication. Experimental models are so small that more than a hundred may easily be held in the palm of the hand. The unit consists of a metal cylinder 3/16 in. in diameter and ½ in. long. Inside is a block of germanium soldered to a metal disc, to which it makes low-resistance contact, and which grounds it to the cylinder. Two 2-mil. phosphor-bronze wires make contact to the upper surface of the germanium, at points about 0.002 in. apart.

An input signal, in series with a small positive bias voltage, is applied between the grounded face and the input cat's whisker. A larger negative bias voltage is applied between the ground and the output point contact. The output signal appears across a load resistor in series with the negative bias. Experiments have resulted in a power gain of 100 times (20 decibels) between the input and output. Transistors are made up only of cold, solid substances, and require no heater or filament power. They draw only 0.1 watt from the bias sources, which is about a tenth the power consumed by an ordinary flashlight bulb. They can deliver 25 milliwatts of useful output, making their overall efficiency 25 per cent.

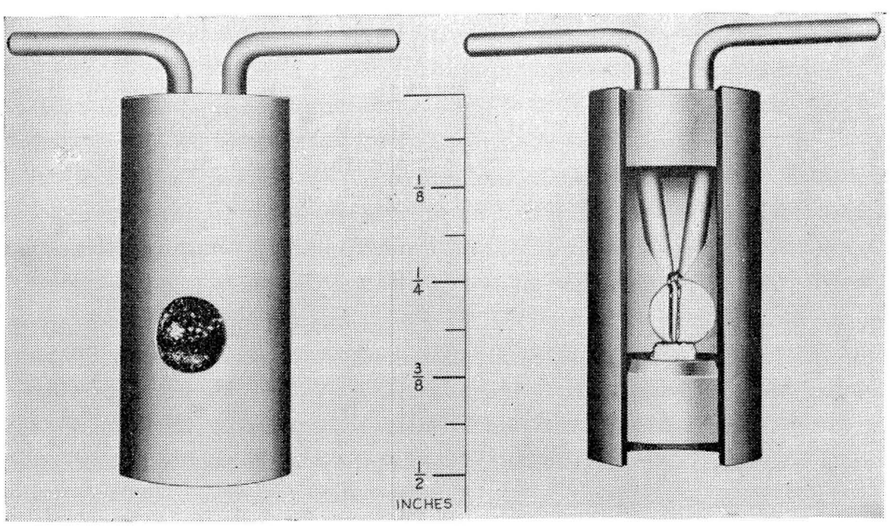
Big Possibilities

Since the device is still in the experimental stage, no data on cost are available. Its essential simplicity, however, indicates the possibility of widespread use, with resultant mass-production economies. When fully developed, the transistor is expected to find new applications in electronics where vacuum tubes have not proved suitable. When first demonstrated by the Bell scientists in July of last year, it was used to amplify the electrical speech waves traveling between two telephones, a function now performed by vacuum tubes. Another demonstration presented a radio receiver containing no tubes. Instead, it contained 11 transistors in the amplifier stages, with two germanium diodes for the mixer and detector stages, and two selenium rectifiers for the power supply. The receiver brought in local stations clearly and with fidelity, delivering 25 mw. of audio power to its loudspeaker. It was also shown in use as an oscillator, generating a standard frequency tone, and as a video amplifier. Because there is no heated cathode, there was no warm-up delay with the transistor radio and video demonstrations. Reception was obtained instantly when the switch was turned on.

Bringing the device to reality involved the work of many scientists and engineers at Bell Laboratories. The key investigations were carried out by Dr. John Bardeen and Dr. Walter H. Brattain, the general research program having been initiated and directed by Dr. William Shockley, one of the country's leading solid-state physicists. The transistor has been termed an excellent example of the fruits of pure, theoretical research; it existed for many months only on paper.

The amplification process can be understood in terms of the discovery made by Dr. Bardeen and Dr. Brattain that the input is surrounded by an "area of interaction." Within this area the electronic structure of the semi-conductor is modified by the input current. With the output point placed in this area, the output current can be controlled by the input current. This control of output current by input current is the basic mechanism of amplification.

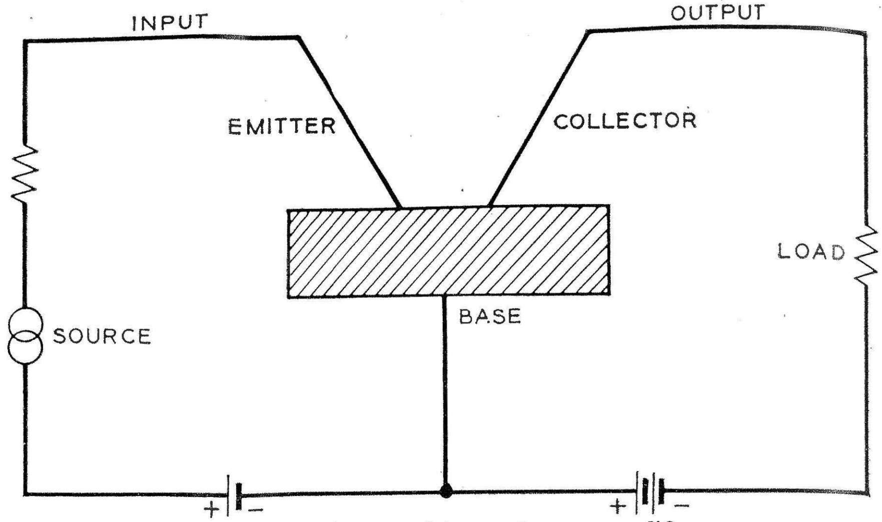
Semi-conductors have for many years been regarded as an ideal field for research at Bell Laboratories be-



Left—Side view of Type-A transistor. Right—Cutaway view of Type-A transistor cause of their practical possibilities and rich scientific interest. These materials, whose electrical properties are intermediate between those of metals and insulators, offered particular promise of useful electrical applications, since their ability to carry electrical current can be changed over wide ranges in various ways. They rely for conductivity on the presence of current-carrying electrons. In metals, which are good conductors, there is a ratio of approximately one current-carrying electron to every atom. In insulators, there are practically no such electrons, and, therefore, little conductivity. In semi-conductors, such as silicon and germanium, some metallic oxides and other compounds, there may be as few as one current-carrying electron for every million atoms. But—and this is the significant feature—this number of carriers may be varied 1,000-fold or more by changing the electronic structure of the materials. Hence the current flowing through the semi-conductor can be controlled.

Prior to the invention of the transistor, varying conductivity in semi-conductors was employed in rectifiers, such as copper-oxide and selenium rectifiers, and silicon detectors. Bell scientists have long been active in the development of semi-conductor rectifiers. Before the war they had developed silicon detectors for microwave radio, and these were supplied for use in wartime radars. Largely as a result of radar interest, research and development on semi-conductor point-contact rectifiers and the phenomena involved in their operation have been stimulated at other industrial and several university laboratories.

In critically examining the implications of the prevailing theory of electrical conduction in semi-conductors, Dr. Shockley was able to predict that it should be possible to control the meager supply of electrons inside a semi-conductor, by influencing them with an electric field imposed from the outside, without actually contacting the material. In early experiments, however, the electrons seemed to get trapped in the surface of the material, and did not behave just as anticipated. This part of the problem was tackled on a theoretical basis by Dr. Bardeen. He developed a theory of what happened at the surface, which was able to explain satisfactorily many of the observed facts and which led to further experiments in collaboration with Dr. Brattain. In the course of these experiments they invented the transistor.



Circuit showing transistor used as an amplifier

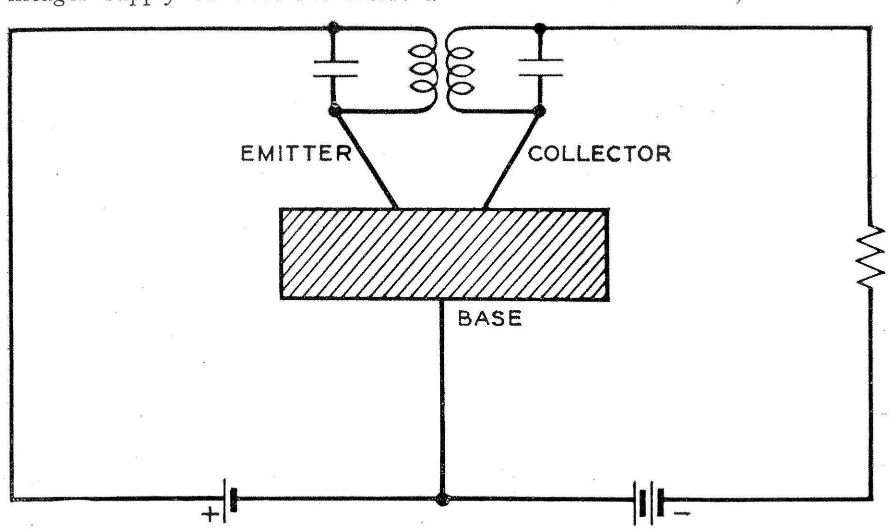
Transistor action depends upon the fact that electrons in a semi-conductor can carry current in two distinctly different ways. This is because most of the electrons in a semi-conductor do not contribute to carrying the current at all. Instead they are held in fixed positions and act as a rigid cement to bind together the atoms in a solid. Only if one of these electrons gets out of place, or if another electron is introduced in one of a number of ways, can current be carried. If, on the other hand, one of the electrons normally present in the cement is removed, then the "hole" left behind it can move like a bubble in a liquid and thus carry current.

In a transistor made of semi-conductor which normally conducts only by the extra electron process, current flows easily into the input, which is at a low positive voltage, and out of the output point, which is at a higher negative voltage. The area of interaction is produced by "holes" introduced by the input current and collected by the output point.

Second Type Transistor

A short while ago, Bell Laboratories announced a second type of transistor, which may have some advantages over the first model. This unit, called a "coaxial," uses a disc of germanium, similar to the original transistor, but its point contacts are placed differently. The disc, which has depressions ground into each side of its center section, is fitted into the center of the cylinder. At the point where it is ground down, the disc is only a few thousandths of an inch thick. The cat's whiskers are placed against the disc on opposite sides. The new unit provides a desirable "shielding" which isolates the input and output circuits. While this is not essential now, it may be advantageous at a time in the future.

The "coaxial" transistor was developed by Dr. Winston E. Kock and R. L. Wallace, Jr., who based their design on an earlier discovery by Dr. J. N. Shive. All are members of the Laboratories technical staff. The name "transistor" was evolved from the prefix "trans," which designates the translational property of the device, and the root "istor," which classifies it as a solid-state circuit element in the same general family with resistor, varistor and thermistor.



Circuit showing transistor used as an oscillator