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The S-Tube Rectifier

A Paper Presented by *Howard J. Tyzzer** at meeting of Radio Club of America, Columbia University, March 31, 1922

THE various tubes about to be described make use of gaseous conduction. Due perhaps to the somewhat limited knowledge concerning this type of conduction, gaseous tubes have often been considered unreliable and inconsistent. However, our knowledge of the electron theory in its present state of completeness enables us to predict and account for many of the phenomena which have proved baffling heretofore.

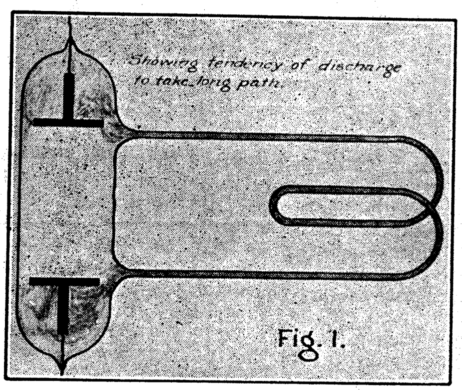

Fig. 1.

One of these phenomena, or perhaps it might better be called a principle of gaseous conduction, is responsible for a new group of useful devices. Mr. C. G. Smith, who has investigated this principle and invented the devices resulting from it, has termed it the "Short Path Principle".

If two electrodes are placed in a tube of gas at fairly low pressure and connected to a source of moderately high voltage, there will be a current discharge between them. Seemingly strange to relate, the bulk of the discharge tends to follow a long path as from the sides and backs of the electrodes rather than the shorter path lying directly between them. (Fig. 1). An analysis of this conduction, based on the electron theory, offers an explanation for this.

Pure gaseous conduction is a result of bombardment of the gas atoms by the free electrons in the gas. In other words in any gas there are a few free electrons which are not associated with any particular atom. When an electric field is applied to the gas, these free electrons are attracted by the positive electrode; and if their path is uninterruped, they travel toward it with rapidly increasing velocity. Generally the path of the electron is more or less obstructed, depending upon the gas pressure, as an electron cannot travel any great distance without colliding with an atom. If the electron has attained sufficient velocity, it will disrupt the atom by dislodging from it another electron, thus leaving a positive ion. To have sufficient velocity to ionize, the electron must travel through a certain potential drop or voltage difference. This is known as the "ionizing potential", and is a value which varies with different gases. At atmospheric pressure the atoms in a gas are fairly close together, and an electron cannot travel any great distance without colliding with one of them. Hence for ionization at atmospheric pressure, the potential gradient must be steep or the voltage between electrodes must be high to impart, in the short path between atoms, sufficient velocity to the electron to ionize. As the pressure is reduced, the mean free path between atoms is increased, and inasmuch as the free electron can travel through a greater distance without danger of collision, the voltage between electrodes may be correspondingly less for ionization.

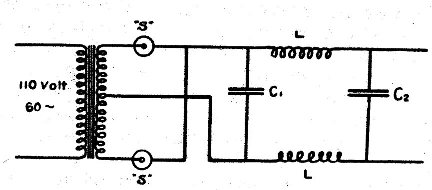

Fig. 2

If the electrodes in a gas at low pressure are placed close together, so that the distance between them is small as compared with the mean free path, it is conceivable that an electron would probably pass through the entire distance between electrodes without encountering an atom. If this is true, there will be no ionization and hence no conduction, providing *all* the paths are kept short.

A tube was constructed in accordance with this theory, and this was found to be true.

By applying a radial magnetic field, it was found possible to force the electrons to take a longer curved path, collide with

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atoms, ionize them and so cause conduction. The point at which conduction began was quite pronounced; hence the device made a capital relay.

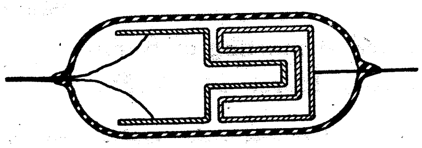

Fig. 3.

By shaping the electrodes as shown in Fig. 3, the magnetic field necessary for conduction when the inside electrode is positive, or the anode, is less than when the outside is made positive. Fig. 4 shows the reason for this; the magnetic field necessary to cause an electron to entirely miss the positive electrode is much less in "A" than in "B". Hence the device rectifies by the application of a permanent magnetic field of proper strength. Fig. 6 shows the tube with the permanent magnet in place. Two collars made of soft iron are used in conjunction with the magnet to obtain even distribution of magnetic flux throughout the active portion of the tube.

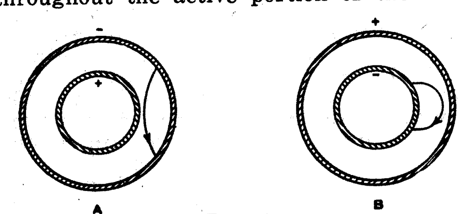

Fig. 4.

It was in this tube that a discovery was made which placed gaseous conduction in an entirely different plane. Previous to this time difficulty had been experienced due to gradually diminishing gas pressure, gas being absorbed by the electrodes. This was the only apparent limitation to the life of the tube. Evidently the positive ions approached the negative electrodes with such a high velocity that they embedded themselves below the electrode surface. Here they combined with an electron and became an atom of gas again held in captivity by the cathode. This theory was envolved by Mr. Smith, and in proof of it a tube was constructed in which the cathode, or negative electrode, was molten tin. In this tube the gas pressure remained practically constant over long periods of operation. Provision was made whereby the surface of the molten tin could be observed through a microscope, and tiny bubbles of the collected gas could actually be observed bursting out at the surface of the electrode. Different materials were used in the cathode, and finally it was found that carbon, due presumably to its porosity, allowed the imprisoned gas to escape, thus keeping the pressure constant. Tubes of this type were operated for several thousand hours continuously without any noticeable change. Although a thoroughly practical proposition in this form, the desirability of eliminating the magnet was apparent, and further research work was conducted with this objective in mind.

As a result of this investigation and

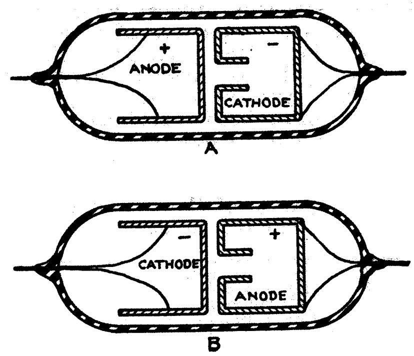

Fig. 5

work, a tube was devised in which the conduction was entirely dependent upon the static field created by the elctrodes. A schematic cross-section view of the electrodes is shown in Fig. 5. The anode is just a plain flat electrode as before, but the cathode is cup-shaped with a small tube-like opening, as illustrated. Free electrons are drawn from all parts of the cup through this opening to the anode. In doing so they traverse a long path, collide with

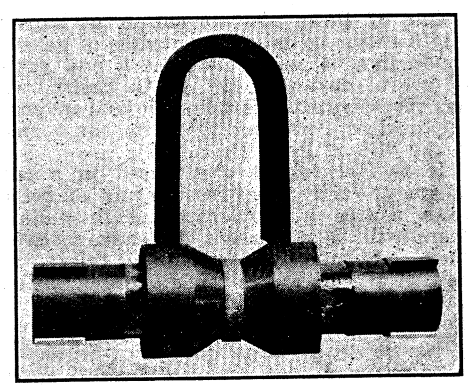

Fig. 6

atoms, and ionize them. The action is cumulative and hence the tube conducts.

When the cup is made positive, the action is quite different. Positive ions in the cup being much larger in bulk are less mobile, and but comparatively few of them wander sluggishly out through the opening to the cathode or negative electrode. In fact the positive ions form a sort of cloud at the end of the tube inside the cup and tend to neutralize the negative static field created by the cathode. The movement of the positive ions is so sluggish and the number which reach the cathode so few that the current conduction is less than one-half of one per cent of the normal current carrying capacity when the polarity is reversed. The device is therefore a perfect rectifier for all practical purposes.

Fig. 8 shows a detailed cross-section of the tube that is being placed on the market. It will be noted that the tube is fitted with a screw base which utilizes the ordinary incandescent lamp socket, thus simplifying installation problems. The cup and active surface of the anode is carbon and the gas used is helium at about 12 mm. pressure. The size of this particular tube is more evident in Fig. 7. It is made for supplying D.C. plate potentials for 5-watt vacuum tubes. They are rated at 20 watts each, normal current being 50 milliamps. The tube has a practically constant drop of 150 volts, and will stand 2000 volts in the reverse direction. Fifty milliamperes is a very conservative rating and is based on continuous duty. Two rectifier tubes, one in each side of the line as in Fig. 2, will supply sufficient current for one 50-watt Radiotron. This, of course, is an overload on the tubes and is not recommended except for intermittent use. It is, however, the sort of test that the tubes are subjected to before leaving the factory. Tubes will operate in series for higher voltage and in parallel for higher currents, if a stabilizing resistance is used with each tube. The life of the tube is practically indefinite and can only be terminated by mechanical breakage or subjecting it to several times normal current, thus overheating it.

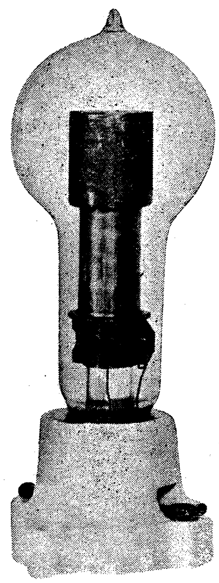

Fig. 7

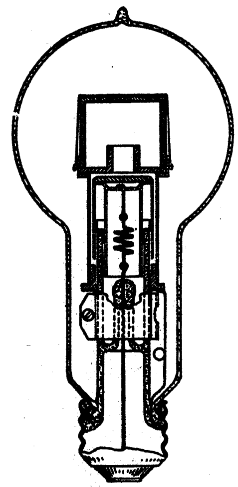

Fig. 8.

It has been shown where, by application of the "Short Path Principle", gaseous conduction has been successfully controlled. Moreover it is to be expected that where the controlling energy is less than the energy controlled there are possibilities of an amplifier and oscillator. This is true with the "S" Tube and already laboratory models of amplifiers, oscillators, and even detectors have been constructed so we can see that the rectifier is but a forerunner of many useful devices.