A Low Voltage Cathode Ray Oscillograph [1]

By J. B. JOHNSON

SYNOPSIS: A sensitive cathode ray oscillograph is described which operates at the low potential of from 300 to 400 volts. The electron stream comes from a thermionic cathode and is focused by the action of ionized gas in the tube. This gas, at a prèssure of a few thousandths of a millimeter, serves to reduce to 1mm. diameter a spot which would be 1 cm. across in a high vacuum tube. The sensitivity of the tube is such that the deflection of the spot is about 1 mm. per volt applied between deflector plates. When using magnetic deflection, a pair of coils 4 cm. in diameter, placed on the sides of the tube produces a deflection of approximately 1 mm. per ampere-turn of the coils.—*Editor.*

A CATHODE ray oscillograph tube operating at a comparatively low voltage was described by the writer some time ago before the American Physical Society.[2] Since then, the tube has been further improved and its operation studied so that now both the structure of the tube and the principles which have made the construction possible can be described in greater detail.

In the older types of Braun tubes the electron stream is produced by a high voltage discharge through the residual gas in the tube. This requires a source of steady potential of from 10,000 to 50,000 volts, an installation which is expensive, non-portable, and dangerous. In the new type of tube the low voltage operation has been obtained by the use of a Wehnelt cathode as the source of electrons, so that the lower limit of voltage is set by the effect of the electrons on the fluorescent screen and not by the voltage needed to obtain the electrons. At 300 volts the electrons produce quite bright fluorescence on the screen and the tubes are therefore designed to operate at 300 to 400 volts.

The external appearance of the tube is shown in Fig. 1. The electrodes are located at one end of the pear-shaped bulb, and the fluorescent material is deposited on the inside of the larger, flattened end. The tube is provided with a base which fits into a bayonet socket such as is used for vacuum tubes, and all the connections are made through the base. There are two orthogonal pairs of deflector plates inside the tube for electrostatic deflection, while magnetic deflection is produced by applying a field from the outside.

The internal structure differs considerably from that of previous forms of Braun tube and it will therefore be described somewhat fully.

[1] Also published in the *Journal of the Optical Society of America and Review of Scientific Instruments*, September, 1922.

[2] *Phys. Rev.* (2), Vol. 17, p. 420, 1921.

THE FOCUSING

In some forms of Braun tube a sharp spot has been secured by using a very high voltage, and therefore high electron velocity, so that after the electrons have passed through one or two fine apertures to make the beam parallel there is not time enough for the mutual repulsion to spread the beam again appreciably before the electrons strike the screen. With other tubes an external "striction" coil has been used which maintains a strong longitudinal magnetic field in the region between the anode and the cathode and which brings the electrons to a focus on the screen. In the low voltage tube the spreading of the electron stream is greater than in high voltage tubes because of the greater time during which the mutual repulsion of the electrons

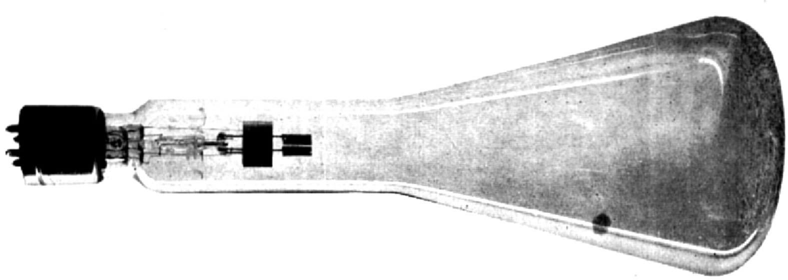

Fig. 1

acts, so that some means of focusing must be used. The electrons can be brought to a focus by a longitudinal magnetic field so adjusted that each divergent electron makes very nearly one complete turn of a spiral and in travelling the length of the tube returns to the axis at the screen. In this way a very sharp spot can be produced, but the sensitivity of the beam to deflection is reduced very much by the directing magnetic field.

The method of focusing that is used in the present tubes grew out of the suggestion by Dr. H. J. van der Bijl, that a small amount of gas be introduced into the tube. This gas, at a pressure of a few thousandths of a millimeter of mercury, serves to reduce to 1 mm. diameter a spot which would be 1 cm. across in a high vacuum tube. The sharpness of the spot depends also upon the current in the electron stream so that the focus may be controlled by the cathode temperature. The mechanism of this focusing action will be explained later.

The presence of this slightly ionized gas also serves the purpose of preventing the accumulation of charges on the glass, and it provides for the discharging of the fluorescent screen so that the electrons can drift back to the metallic circuit.

The Electrode Unit

With gas present in the tube, steps have to be taken to guard against arcing and the injurious effects of positive ion bombardment on the cathode. This is done by making the volume of gas surrounding the electrodes very small. For this purpose the cathode and anode, themselves small, are sealed into a short and narrow glass tube so that the volume exposed to both electrodes in common is less than 1 cu. cm. All paths between the electrodes are then so short that at this low pressure there is not sufficient ionization to build up an arc.

The structure of this unit, or "electron gun" is shown in Fig. 2. The cathode, *f*, is an oxide coated platinum ribbon of the same kind

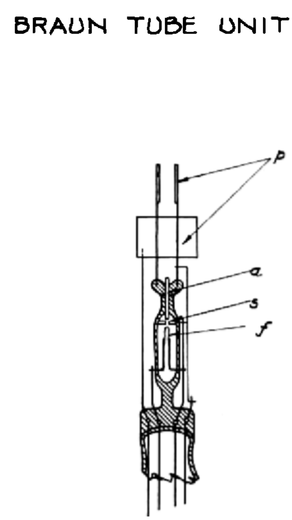

Fig. 2

as the filament in our audion tubes. The anode, *a*, is a thin platinum tube 1 cm. long and 1 mm. in diameter, one end of which is about 1 mm. from the top of the filament loop, the other end opening into the main tube towards the fluorescent screen. Between the cathode and the anode and connected to the cathode is a metal shield, *s*, with a small aperture through which the electrons must pass in going to the anode. Nearly all of the electrons must then go to the inside of the tubular anode, and a small fraction of them pass through the whole length of the anode and form the beam in the main part of the tube.

The deflector plates, *p*, are also mounted rigidly on this unit. In order to avoid large differences of potential in the tube, one plate from each pair is permanently connected to the anode, the variable potentials being applied to the other plates. The complete unit is mounted at the small end of the tube with the anode and deflector plates toward the fluorescent screen.

The Filament

In some early forms the filament was bent into a simple hair pin loop which was placed close to the aperture in the shield. It was then found that the positive ions striking the filament from the direction of the anode soon destroyed the oxide coating and left the filament inactive. This trouble was largely overcome by placing the filament out of the direct path of the positive ions. The flat filament is now shaped into a ring as shown in Fig. 3, slightly larger in diameter than

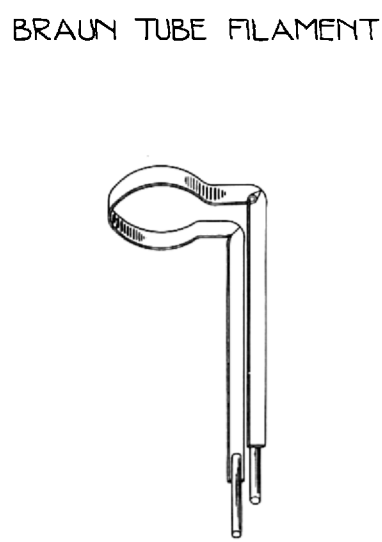

Fig. 3

the aperture in the shield and is placed coaxial with the anode. The momentum of the positive ions then carries them past the active part of the filament and they strike where little damage can be done. The length of service of the tube is still limited by the filament life, but this has been increased by the above artifice so that the tube now gives around 200 hours of actual operation.

The Deflector Elements

The deflector plates are made of German silver, which is non-magnetic and which has a high specific resistance that diminishes the effect of eddy currents when magnetic deflection is used. The plates are 13.7 mm. long in the direction of the tube axis and the separation between them is 4.7 mm.

The sensitivity of the tube is such that the deflection of the spot is about one mm. per volt applied between the deflector plates. When

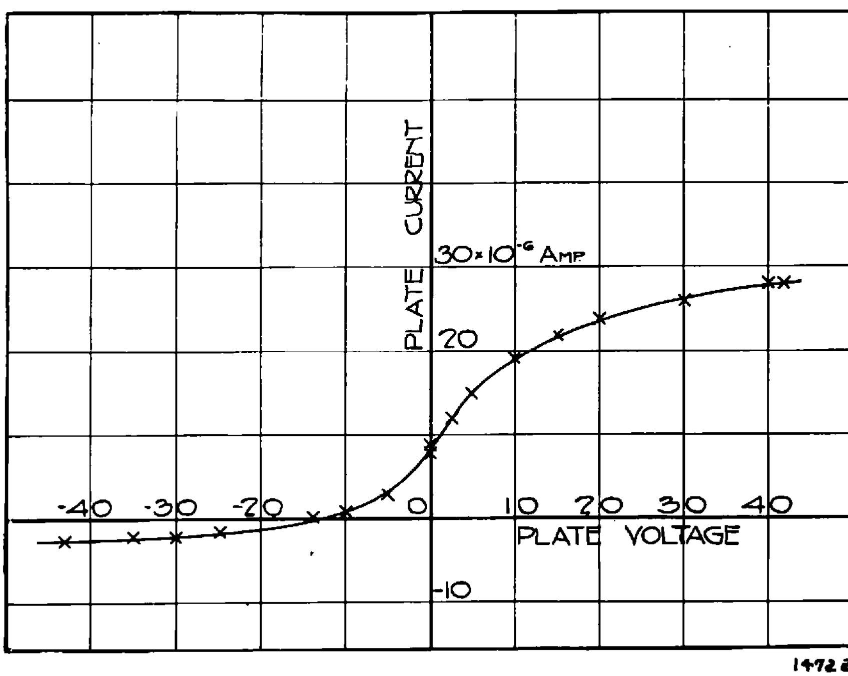

Fig. 4

using magnetic deflection, a pair of coils 4 cm. in diameter placed on the sides of the tube at the level of the deflector plates produces a deflection of approximately 1 mm. per ampere-turn flowing in the coils.

The electrons striking the screen drift back to the anode structure, and most of them are collected by the deflector plates. There is also a small ionization current flowing to the plates. The tube is therefore not strictly an electrostatic device, and this must be kept in mind when using it. Fig. 4 shows the current flowing to the two free plates at various voltages with respect to the anode. With the large positive values of plate voltage the current to the plates is practically equal to the current in the electron stream and consists largely of the returning electrons. The small current in the other direction when the plate voltage is negative is a measure of the ionization in the tube.

The Fluorescent Screen

The screen is spread on the inner surface of the large end of the tube, using pure water glass for binder. The active material consists of equal parts of calcium tungstate and zinc silicate, both specially prepared for fluorescence. This mixture produces a generally more useful screen than either constituent alone. The pure tungstate gives a deep blue light which is about 30 times as active on the photographic plate as the yellow-green light of the silicate, while the silicate gives a light which is many times brighter visually than that from the tungstate. By mixing the two materials in equal parts a screen is produced which is more than half as bright visually as pure zinc silicate and more than half as active photographically as pure calcium tungstate.

For mechanical strength the end of the bulb which carries the screen is rounded outwards so that the screen is not a plane surface. This introduces a distortion of the fluorescent pattern which in most instances is negligible. If the pattern is recorded by a camera whose lens is D cm. from the end of the tube, then the apparent reduction of the deflection produced by the curvature of the bulb is given in terms of the deflection y approximately by

$$\Delta y = \frac{20 + D}{400\,D}\,y^3\ cm.$$

The Function of the Gas

The part which the gas plays in focusing the beam of electrons is an interesting phenomenon which depends upon the difference in the mobilities of electrons and positive ions. The electrons of the beam are pulled toward the common axis by a radial electric field produced by an excess of positive electricity in the electron stream and an excess of negative electricity in the space outside the beam. This distribution is produced as follows: Some of the electrons of the stream, in passing through the gas, collide with gas molecules and ionize them. Both the colliding electrons and the secondary electrons leave the beam but the heavy positive ions receive very little velocity from the impact and drift out of the beam with only their comparatively low thermal velocity. Positive ions, therefore, accumulate down the length of the stream and may exceed in number the negative charges passing along. At the same time, electrons are moving at random outside the stream, producing negative electrification. There is then a field surrounding the stream which tends to pull the electrons inward. If there were only the mutual repulsion between the electrons to compensate for, this would be done when the number of positive ions in the beam equals the number of electrons. There is in addition an original divergence of the beam which must be overcome. If this divergence is assumed to be one degree from the axis and the electron current 2×10^{-5} amp., then a simple calculation shows that the radial field required to pull the beam to a focus at the usual distance is about one volt per cm. This field strength is produced, with beams of the ordinary intensity, if there are four positive ions for each electron in the stream, a condition which seems not unreasonable.

The number of ions per electron in the stream is probably constant as the current in the stream is varied, since the conditions of collision and recombination are not altered. When the current is increased, therefore, the total positive ionization of the beam increases, the field around the beam becomes stronger, and the electrons are brought to a focus in a shorter distance.

These deductions have been confirmed experimentally. That the focusing of the stream depends upon the current flowing was one of the earliest observations made in developing the tube and this method has been used ever since to obtain a sharp spot. The point of convergence can be seen moving in the manner expected when the current is changed, and the effect has been further verified by using a tube with a movable fluorescent screen so that the length of the electron beam could be varied. The presence of the electric field around the beam was shown by the effect of two beams on each other, in a tube in which there were two electron streams crossing each other at right angles at their mid-points, each falling on a fluorescent screen. When one beam was moved away from the other by a field between the deflector plates, the second beam moved as if attracted by the first. The directed electrons in each beam were attracted toward the positive ionization in the other, and for one particular adjustment of the tube the displacement was such as would have been caused by a field of about 3 volts per cm., a result not far different from that previously calculated.

Since the beam must produce its own positive ionization some time must elapse before it can produce by collisions the required number of positive ions. Calculation shows this time to be of the order of

10^{-6} second. When the beam moves it has to build up the ionization as it goes along, and we should expect that when deflected very rapidly it might no longer be focused, due to lack of positive ions in its path. A test was made of this by applying a high frequency potential on the deflector plates so that the spot described an elliptic pattern. At a frequency of 10^5 cycles per second the line was still sharp, but at 10^6 cycles there was a noticeable widening of the line which is probably to be ascribed to imperfect focusing at this high speed.

In these experiments the evidence all points to the view that the focusing of the electrons is caused by an excess of positive charge in the beam itself, produced by ionizing collisions of the electrons with the gas molecules. Further confirmation is found in the fact that a focus is much more readily obtained in the heavier gases having slow molecules, such as nitrogen, argon or mercury vapor, than in hydrogen and helium where the mean velocity of the molecules is greater. The tubes are therefore filled with argon, the heaviest available permanent gas which does not attack the electrodes. The best pressure for the length of tube adopted and for the current which can be obtained in the beam is 5 to 10 microns, and this leaves considerable latitude for the adjustment of the electron current to get a sharp focus.

Examples of the Use of the Tube

Because of the small amount of auxiliary apparatus required with this form of Braun tube it has proved to be a very convenient laboratory instrument. It has found application in studying the behavior of vacuum tubes and amplifier and oscillator circuits, of gas discharge tubes, of relays, and of numerous other kinds of apparatus, both at low and at high frequencies. Some reproductions of photographs of various types of curves are given below to illustrate the kind of results which are possible with this oscillograph.

Fig. 5 shows the hysteresis curve of a sample of iron wire. The wire was placed in a small solenoid with one end toward the side of the tube. The magnetizing current passed through a resistance, the voltage drop of which was applied to one pair of deflector plates so as to give a deflection proportional to the magnetizing field. The stray magnetic field from the iron itself produced the deflection proportional to the induction. Alternating current was used, and the exposure was 20 seconds with lens opening *f* 6.3 and speed roll film.

In Figs. 6a and 6b are shown the current-voltage relations of an oscillating vacuum tube. The axes were obtained by grounding one or the other deflector element.

The measurement of modulation in a radio transmitting set has

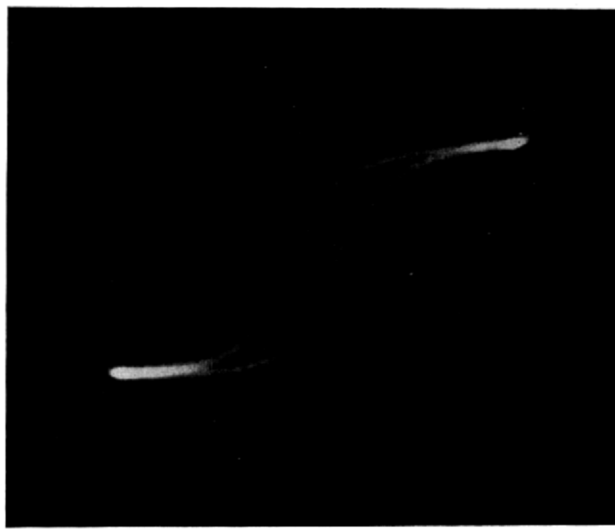

Fig. 5

been reduced to a fairly simple process by means of the cathode ray tube. The low frequency modulating voltage, controlled by the

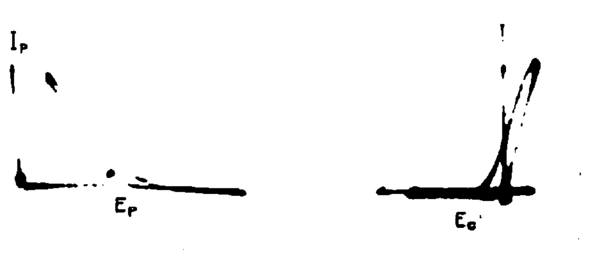

Fig. 6

voice, is applied to one pair of deflector plates, while the radio frequency output, with amplitude varying according to the low frequency voltage, is applied to the other pair of deflector plates. The resulting pattern on the screen is a quadrilateral of solid fluorescence, since the

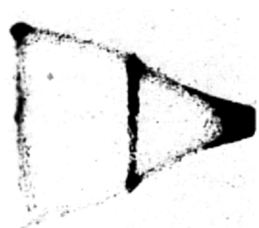

Fig. 7

two frequencies are not commensurate. The two vertical sides indicate the greatest and the least amplitude of the high frequency, while the other two sides show the current-voltage characteristic of the transmitter. Fig. 7 shows such a pattern (retouched), the edges being much brighter than the centre. The exposure was two minutes using a Seed 23 plate and *f* 6.8 lens opening.