The Cathode Ray Tube and Its Applications*

Methods of Construction, and Use as an Oscillograph and as a Wattmeter

By M. E. Tressler, Research Laboratory, Pittsfield Works, General Electric Company

THE cathode ray tube in its simplest form is a glass tube from which the air is exhausted to a vacuum of four to eight microns, *i.e.*, to an air pressure of 0.004 to 0.008 millimeters of mercury.

In one end of the glass tube is a small, flat metal disk which is connected through the glass to a terminal on the outside. This is the cathode. At one side, or in the tube about 15 to 20 cm. away from the cathode, is another metal electrode which is connected through the glass to a terminal on the outside. This is the anode. This is all that is actually required to produce the cathode rays, but in order to make use of them, the rest of the tube must be formed to a particular shape and several parts added.

The diaphragm is usually a glass or metal disk just below the anode which closes the tube with the exception of a small hole in the center of this disk about 0.4 to 0.8 millimeters in diameter. About 35 cm. below the diaphragm is fastened the screen on which the cathode particles strike. This screen is a metal, mica or glass disk coated with some salt which fluoresces when acted upon by the cathode rays. This fluorescence may then be observed visually or it may be photographed.

A sketch of the tube is given in Fig. 1. *C* is the cathode, *A* anode, *D* diaphragm, *S* screen, *R* palladium tube regulator, *F* focusing coil, *Q* quandrants.

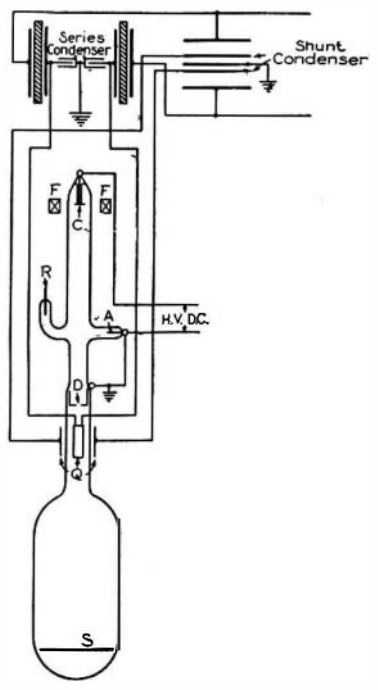


Fig. 1

The tube is operated as follows: The negative terminal of a high voltage (12,000 to 30,000 volts) direct current generator is connected to the cathode and the positive terminal to the anode, the anode being grounded. The voltage to apply depends upon the vacuum maintained in the tube, the steadiness of operation desired, the position, shape and connection of the focusing coil, the intensity of the magnetic field of the focusing coil and other minor influences. With this voltage applied there is a stream of electrons or negatively charged particles shot from the cathode normal to its surface with a velocity of 5,000 to 60,000 miles (8 to 96×10^8 cm.) per second, depending upon the vacuum in the tube and the voltage applied. This discharge of electrons is produced by the electric field between the cathode and anode.

The attenuated gas in the tube is generally understood to consist of a mixture of neutral gas molecules, *i.e.*, molecules where the positive and negative charges are exactly balanced; of gas molecules positively charged because they have lost one or more electrons or negative charges; and of free electrons which have been separated from the gas molecules, these being, of course, negatively charged.

As soon as the electric field is set up the positively charged molecules are attracted toward the cathode and the electrons are repelled. By the time the positively charged molecules have gotten to the cathode, they have attained sufficient velocity so that the force of the collision bumps off one or more electrons. The positively charged molecules in going to the cathode surface also run against neutral molecules and electrons with sufficient force to separate electrons from the neutral molecules and even to lose electrons themselves. The electrons, being negatively charged and of very much smaller size and mass than the molecules, are repelled with much higher velocity from the cathode than the molecules are attracted. These negative particles from the cathode pass down the tube to the diaphragm

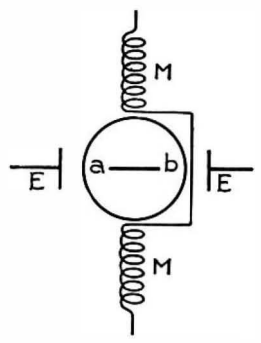


Fig. 2

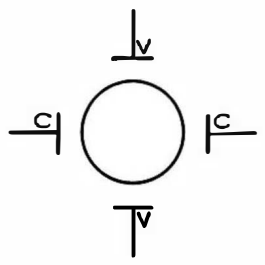


Fig. 2a

where most of them are stopped, except a small beam which passes through the central opening and strikes the fluorescent screen. The diaphragm is grounded so that the charge that would tend to collect on it from the cathode particles is neutralized.

If the cathode surface was a perfect plane, all of the cathode particles would start normal to this plane, but as compared with the size of the cathode particles the unevenness of this surface is very large, hence some of the particles start off at an angle other than 90 deg. to the plane of the cathode surface. This tends to make the cathode discharge a diverging one, but even if this were not the case there would be a spreading out of the discharge, due to the repellant force between negatively electrified particles. This spreading out of the discharge is partially overcome by the focusing coil which gives a longitudinal magnetic field in the direction of the stream of cathode rays and which tends to concentrate the rays and hence increase the intensity of the beam passing through the opening in the diaphragm.

The palladium tube regulator which is connected opposite the anode is used for regulating the vacuum when there is an increase of vacuum due to a long continued use of the tube at high voltage. The palladium tube is sealed in the glass and closed at its outer end. When heated to a red heat it allows a small amount of gas to pass through, and hence raises the gas pressure inside the tube.

The diaphragm must be made of a sufficiently dense, thick material so that the cathode rays will not pass through it. A platinum diaphragm 0.005 in. (0.127 mm.) thick will allow the cathode particles to pass through it. A brass cup with walls 0.030 in. thick is commonly used and found satisfactory.

The screen in order to be fluorescent is coated with

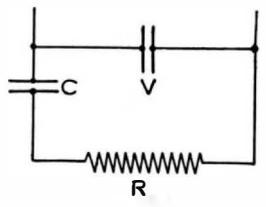


Fig. 3

willemite, zinc sulphide or calcium tungstate. The willemite gives a yellowish-green, fluorescent light when excited by the cathode rays, which is very bright to the eye but is not very active actinically, *i.e.*, when photographed it does not act rapidly on the photographic plate. The zinc sulphide is said to be very actinic, and is used by a great many experimenters with the cathode ray tube. Calcium tungstate has been found to be the most actinic and best suited for our work thus far. It gives a bluish-white fluorescence which is quite brilliant, both visually and actinically.

OTHER METHODS OF PRODUCING CATHODE RAYS

There are several other forms of cathode ray tubes where the electron or cathode discharge is produced in a different manner. Wehnelt's method of obtaining an electron discharge is to coat a platinum strip with a thin film of lime and then to heat the lime to incandescence by causing an electric current to flow through the platinum strip. He has shown that the incandescent lime emits copious steams of electrons in comparatively weak electric fields. This discharge is also largely due to the bombardment of the hot lime by the positive ions or gas molecules, but it is also due to the high temperature zone into which these positive ions flow, the electrons being much more readily separated from them. Of course the velocity of the electrons emitted from the hot lime is very much lower than those which are repelled under a very strong electric field.

The latest and probably the best method of obtaining an electron discharge in a cathode ray tube is by means of the hot tungsten cathode in a very highly exhausted glass tube where the glass and all of the metal parts have been kept in this high vacuum at a high temperature for a sufficient time to get all of the gases out of them.

When the cathode (which in this case is a tungsten wire filament heated to high temperature by an electric current flowing through it) is connected to a high voltage, there is a pure electron discharge from the cathode with no accompanying positive ion bombardment; the tube having been exhausted to such a high vacuum that there is an inappreciable number of positively charged molecules or ions present. In this case the electrons must

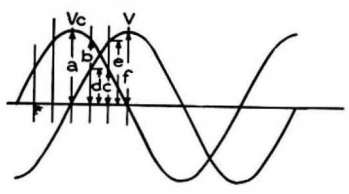


Fig. 4

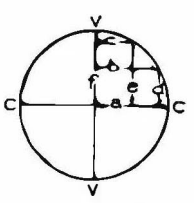


Fig. 5

come from the metal filament itself; the number of electrons, or, in other words, the current flowing depending upon the temperature of the cathode and the voltage applied, and the velocity of the electrons depending upon the voltage only.

USES

The cathode ray tube in practice has been used as an oscillograph and as a wattmeter for measuring very small amounts of power at low power-factors and high voltages. In order to use it as either one of these instruments it requires some method of deflecting the beam of cathode rays after it has passed through the opening in the diaphragm and before it has reached the screen. This is accomplished by means of a transverse electric or magnetic field applied a short distance below the diaphragm opening.

The cathode particles carry a certain charge or quantity of negative electricity and hence when an electric field is applied at right angles to the direction of travel of the particles they are deflected parallel to the direction of the field and if a magnetic field is applied they are deflected at right angles to the direction of the field. This is shown in Fig. 2 where the circle is a section of the tube just below the diaphragm and *M* is a set of magnetic quadrants and at *E* a set of electric quadrants. The deflection due to either field is in the line *a*-*b*.

As accurately as can be measured from photographs, it is found that the deflection of the fluorescent spot on the screen due to the field is directly proportional to the strength of the field; that is, to the voltage applied or to the current through the coil. This is so because the angle through which the beam is deflected is quite small, and therefore the arc of the circle, whose radius is the distance from the quadrants to the screen, through which the spot would travel, is not appreciably different from the distance on the surface of the screen, which is the tangent of the angle. If an alternating voltage is applied, the fluorescent spot vibrates back and forth once per cycle, which makes it appear as a line across the screen.

In order to use it as an oscillograph, it is necessary to have a photographic plate move at right angles to the

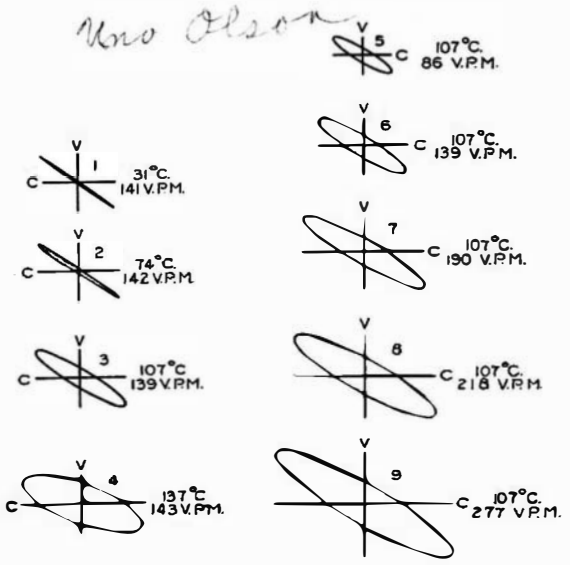
*From the *General Electrical Review*.

direction of vibration of the spot which thereby will show the wave shape.

When it is required to use the tube as a wattmeter, two pairs of quadrants at right angles to each other are required; on one pair a voltage proportional to the current flowing in the circuit is impressed and on the other pair a voltage proportional to the total voltage drop across the apparatus under test is applied.

It is be noticed here that we have assumed that an electric field is used for each pair of quadrants, this being more convenient where losses at high voltages and very small currents are being measured.

The voltage for the current quadrants may be obtained from the potential drop over a capacity or resistance in series with the apparatus or material under test. If a capacity is used the area of the figure traced on the screen will be a maximum when the power-factor is 100 per cent, whereas, when a series resistance is used the



Constant Voltage, Variable Temperature **Fig. 6** Constant Temperature, Variable Voltage

area will be a maximum when the power-factor s 0i per cent. The voltage for the voltage quadrants may be obtained through a potential transformer or from a capacity shunted across the line using two plates of this condenser to step down the voltage. The operation as a wattmeter is shown in Figs. 3, 4 and 5.

Assume that it is desired to determine the loss in a high resistance when subjected to high voltage. The voltage drop over a condenser in series with the resistance is used to produce the current deflection when connected to the current quadrants and the voltage drop over a part of a condenser shunted across the resistance and series condenser is used to produce the voltage deflection when connected to the voltage quadrants, as shown in the circuit of Fig. 1. Taking the simple circuit in Fig. 3, the current in C is in phase with the current in R, but as C is a pure capacity the voltage must be lagging 90 deg. behind the current. This wave is plotted as V_c in Fig. 4.

The voltage across the condenser V is in phase with that across the resistance R and capacity C in series; the wave is plotted as V in Fig. 4, 90 deg. out of phase with the voltage across the series condenser. This is not exactly correct as the voltage across condenser V is at a slight angle to the voltage across the resistance R, depending upon the voltage drop over the condenser C. However, this is not large, as the voltage over the con-

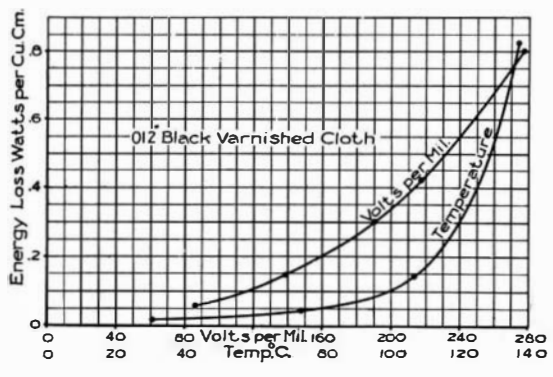


Fig. 7

denser is never greater than 15 per cent of the total voltage across the condenser and loss together.

This slight phase angle is corrected for in determining the true power-factor, by calculating the angular difference due to this series condenser and subtracting it from the measured θ', where $\cos\theta'$ is the measured power-factor, leaving the angle θ whose cosine would be the true power-factor of the material under test.

Now, if we take the line in which the fluorescent spot vibrates, due to the voltage across the series condenser as the axis of abscissa, and the line due to the voltage across the shunt condenser as the axis of ordinates, and plot instantaneous values of the two waves in this coordinate system, it will be seen that the fluorescent spot traces out a closed figure, Fig. 5, on the screen which will be a circle, ellipse or straight line, depending upon, the relative amplitudes of the two voltages and the power-factor of the loss being measured.

In order to know what this loss is in watts, the voltage drop across the series condenser is measured with an electrostatic voltmeter and from the known capacity of this condenser and the frequency and wave shape of the voltage the current flowing in the circuit can be calculated. The current and voltage are now known and it becomes necessary to obtain the power-factor, when the watts can be calculated.

The power-factor is found to be the ratio of the area of the figure as measured, to that of the maximum area which could be obtained with the separate measured deflections. This is determined briefly as follows: The area of the maximum ellipse is $\pi\ ab$, where a is the semi-major deflection and b is the semi-minor deflection. The area of the ellipse, which measures a loss whose power-factor is $cos\ \theta'$, would be $\pi\ ab\ cos\ \theta'$.

Hence $\frac{\pi\ ab\ cos\ \theta'}{\pi\ ab} = cos\ \theta'$, or power-factor, which is the measured area divided by the maximum area calculated from the separate deflections.

With a sine wave in both coördinates, the maximum area would be $\pi/4$ times the product of the length of the two coördinates VV and CC. Then the measured area of the figure divided by the maximum area gives the power-factor. Hence we have measured the voltage, current and power-factor and then can readily calculate the loss.

In Fig. 6 is shown two series of losses; one is the dielectric loss *vs.* temperature on black varnished cloth at a given constant voltage, and the other is dielectric loss *vs.* voltage at a given temperature.

The law of variation of dielectric loss in insulations with variation of temperature and voltage has not yet been determined. If the loss were similar to a resistance loss, we would expect that it would vary as the square of the voltage if the temperature could be kept constant. However, there are several factors which enter into the problem, such as the thickness, area, thermal conductivity, specific heat of and the amount of moisture in, the material under test, the size and material of the electrodes, length of time the voltage is applied, etc., that make the calculation quite difficult and unsolved as yet.

The Fermentation of Indigo

At the suggestion of the Indigo Chemist an enquiry was undertaken into the bacteriological aspects of the fermentation taking place in the indigo steeping vat. As might have been expected, many important facts in connection with the great variations in yield which are known to occur for no obvious reason were brought to light by this enquiry, which, however, has not yet proceeded far enough to afford any complete explanation of the results obtained. It is clear, however, that the success of manufacture as at present carried out depends primarily upon the presence and action of specific bacteria in the steeping vat, and further that in some cases an adverse result is due to the activity and deleterious influence of others. It is a well-known fact that during the earlier days of manufacture the yield of indigo is low but becomes rather suddenly higher, remaining so as long as continued use of the vats persists. Any vats not utilized at first but brought into operation later, exhibit the same phenomenon, clearly showing that the latter is not due to changes in the plant, the water, or methods of manufacture. Well attested cases have been observed of differences in yield of as much as one hundred per cent or more between head factories and their outworks manufacturing plant grown under similar conditions of soil and climate, and it was possible in one instance to arrange to exchange indigo plant from one such factory to another thus eliminating any possible influence of this factor, but without altering the previously observed differences in the respective yields. The most obvious conclusion seems to be that such differences are due to the presence or absence of specific bacteria which multiply in and infect the steeping vats, increasing in number and consequently in their influence upon the character of the fermentation up to the limits of the permanent substratum (in this case the walls and floor of the vat) upon which they remain from one operation until the next; this supposition is supported by observation of the easily verified fact that fermentation commences in the immediate neighborhood of the walls of the vat and gradually spreads therefrom towards the center. Here we have an analogy which such functions as that of the "starter" in dairy work and the bacterial slime of the sewage filter bed, and very probably under natural conditions with the micro-organisms responsible for the retting of jute and flax. Many industries depend upon the intervention of micro-organisms, but whereas in some of them the presence of desirable species and the absence of deleterious ones is ensured by artificial measures as in the case of brewing and distilling, in others it is assumed that the proper organisms will be naturally present in sufficient predominance to ensure satisfactory results. This is the case with such native Indian industries as the fermentation of "Toddy" and "mahua" the retting of jute and the steeping of indigo, but it is becoming daily more clear that the distribution of the necessary and proper micro-organisms is by no means so universal or so fortunate as to carry these and similar operations outside the range of practical artificial regulation.

The inquiry in connection with indigo is at present in too early a stage to warrant any confident assumption that it will be possible to apply the methods of the distillery or the dairy with economic success to a raw material, such as the indigo plant, but should further work confirm the conclusions set forth above, it would appear that very considerable improvements in the methods of manufacture may be obtained by artificially ensuring the presence of the necessary organisms in the steeping vat.

It has been ascertained that two distinct types of fermentation may be found in the steeping vats. one in which copious evolution of nitrogen takes place the only other gas given off being carbon dioxide, and the other in which hydrogen is liberated in addition to these two. In the former case, during the factory period of fermentation, about twelve hours, nitrogen forms sometimes as much as 98 per cent of the evolved gases the remainder being carbon dioxide; later these proportions are slowly reversed, but this reversal is of no importance as not affecting factory conditions and requiring 48 hours to 60 hours to complete.

In the second case the evolved gases after 12 hours are composed of about equal parts, some 33 per cent each of nitrogen, hydrogen and carbon dioxide. It is remarkable that no trace of methane has been found in any of the numerous fermentations carried out, and it is also of great interest to note that in some instances in contradistinction to the high nitrogen evolution frequently found, very small quantities of this gas were evolved.

It is clear therefore that the character of the fermentation must be governed by that of the bacterial complex fortuitously present, and that this may vary essentially and profoundly even in contiguous localities. This variation will have a special interest and importance in connection with the decomposition of organic matter in soil under varying conditions, and must be taken into careful consideration in advancing any theories based upon observation of chemical changes due to bacterial action in soils under otherwise apparently similar conditions.

Numerous species of bacteria have been isolated in the course of this enquiry and their physiological activities with regard to the processes of fermentation investigated. It has been possible to place some of them definitely, either in the class of beneficial or deleterious organisms, but much further work will have to be done before their true functions in this connections are fully understood. It is of interest to note that one bacterium has been identified with the unfortunate condition which sometimes arises in the "beating" or oxidizing process known as "green vat."—Annual Report of the Board of Scientific Advice for India.

Observations on the Friedel-Crafts Reaction

A reversal of the Friedel-Crafts reaction can in general be brought about with more or less facility by the action of aluminium chloride on the alkyl-benzene in presence of a large excess of benzene. In the case of the xylenes alone, this reaction does not succeed, but when polyethyl-, isopropyl-, butyl-, and amylbenzenes were boiled with aluminium chloride in presence of ten times their weight of benzene, quantities of the monoalkylbenzene, varying in each case were formed according to the scheme:—

$$C_6H_4(C_2H_5)_2 + C_6H_6 = 2C_6H_5(C_2H_5).$$

Of the greatest interest however was the formation in excellent yield of toluene and cumene from cymene, which is available in large quantities as a by-product of the sulfite-cellulose process. Ninety grms. of cymene in 900 grms. of benzene gave, on boiling for 10 hours with 4.5 grms. of aluminium chloride, a yield of 44 grms. of toluene and 68 grms. of cumene, corresponding to 80 per cent of that theoretically possible, leaving a residue of only 3–4 grms. of gummy material. The polyhalogen derivatives of benzene could not be decomposed by the action of aluminium chloride and benzene in this manner.—Note in *Jour. of Soc. of Chem. Ind.*, in a paper by E. Boedtker and O. M. Halse, in *Bull. Soc. Chem.*