THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

FOR THE PROMOTION OF THE MECHANIC ARTS

Hall of the Institute,

Philadelphia, June 2, 1926.

Report No. 2853.

Investigating The Coolidge Tube

invented by

Doctor William D. Coolidge, of Schenectady, New York.

Application dated

THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

For the Promotion of the Mechanic Arts

Committee on Science and
the Arts Case No. 2853.

Hall of the Committee,
Philadelphia, June 2, 1926.

The Franklin Institute of the State of Pennsylvania, acting through its Committee on Science and the Arts, investigating the Coolidge Tube, invented by Doctor William D. Coolidge, of Schenectady, New York, reports as follows:

The X-Ray Tube which is the subject of this report was devised by Doctor W. D. Coolidge of the Research Laboratory, of the General Electric Company, at Schenectady, New York.

In an article on "A Powerful Rontgen Ray Tube" published in the "Physical Review" for December, 1913, Doctor Coolidge describes this tube as follows:

"The structural features of the new tube which differ from those of the ordinary type are the following:

"The pressure, instead of being, as in the ordinary tube, a few microns, is as low as it has been possible to make it, that is, not more than a few hundredths of a micron.

"The cathode consists of a body which can be electrically heated

(such as a tungsten or tantalum filament) and, suitably located with reference to this portion, an electrically conducting ring or cylinder, consisting preferably of molybdenum or tungsten or other refractory metal. The ring or cylinder is connected either to the heated portion of the cathode or to an external source of current by means of which its potential may be brought to any desired value with respect to the heated portion. The heated portion of the cathode serves as the source of electrons, while the ring or cylinder assists in so shaping the electrical field in the neighborhood of the cathode that the desired degree of focussing of the cathode-ray stream upon the target shall result.

"The anticathode, or target, functions at the same time as anode.

"The operation is satisfactory only when the vacuum is exceedingly high, so high that the ordinary tube would carry no current even on 100,000 volts.

"As will be seen from the characteristics of the tube, it gives, in operation, no evidence of positive ions. This makes the theory of its operation exceedingly simple.

"The discharge appears to be purely thermionic in character.

"The rate of emission of electrons from the filament appears to be in accord with Richardson's Law, which says that the maximum thermionic current, which can be drawn from a hot filament is

$$i = a \sqrt{T} e^{\frac{b}{T}}$$

where T is the absolute temperature, e is the base of the natural system of logarithms, and a and b are constants.

"In the particular tube described in detail in this paper, this

simple law accounts perfectly for the conductivity of the tube. With still higher temperatures, however, the discharge currents would be found to increase at a much slower rate than that required by the above law. .....

"This description relates to tube No. 147 which was used in getting the data for the following tables. Plate I shows a complete assembly of the tube.

"In the diagram, 25 is a tungsten filament in the shape of a flat, closely wound spiral. It consists of a wire 0.216 mm. in diameter and 33.4 mm. long with 5 1/2 convolutions, the outermost of which has a diameter of 3.5 mm. It is electrically welded to the ends of two heavy molybdenum wires 14 and 15, to the other extremities of which are welded the two copper wires 16 and 17. These in turn are welded to the platinum wires 18 and 19. The molybdenum wires are sealed directly into a piece of special glass, 12, which has essentially the same temperature coefficient of expansion as molybdenum. This first seal is simply to insure a rigid support for the hot filament, the outer seal being the one relied upon for vacuum tightness. The outer end, 13, of the support tube is of German glass like the bulb itself, and it is therefore necessary to interpose at S a series of intermediate glasses to take care of the difference in expansion coefficients between 12 and 13. The small glass tube 20 prevents short-circuiting of the copper wires, 16 and 17.

"The filament is heated by current from a small storage battery which is, electricelly, well insulated from the ground.

"In the circuit are placed an ammeter and an adjustable rheostat and, by means of the latter, the filament current can be regulated, by very fine steps, from 3 to 5 amperes. Over this current range, the potential drop through

the filament varies from 1.8 to 4.6 volts and the filament temperature from 1690 to 2540 degrees absolute.

"The focusing device consists of a cylindrical tube of molybdenum 21. It is 6.8 mm. inside diameter and is mounted so as to be concentric with the tungsten filament, and so that its inner end projects 1.0 mm. beyond the plane of the latter. It is supported by the two stout molybdenum wires 22 and 23, which are sealed into the end of the glass tube, 12. It is metallically connected to one of the filament leads, at 24.

"Besides acting as a focusing device, it also prevents any discharge from the back of the heated portion of the cathode.

"The anticathode or target 2, which also serves as anode, consists of a single piece of wrought tungsten, having at the end facing the cathode a diameter of 1.9 cm. By means of a molybdenum wire 5, it is firmly bound to the molybdenum support 6. This support is made up of a rectangular strip and, riveted to this, three split rings 11, 11, 11, all of molybdenum. The split rings fit snugly in the glass anode arm 7. They serve the double purpose of properly supporting the anode and of conducting heat away from the rectangular strip and so preventing too much heat flow to the seal of the lead-in-wire 9.

"The bulb is of German glass and about 18 cm. in diameter.

"The exhaust is as thorough as possible.

"For the earlier tubes, mercury pumps were used, with a liquid-air trap between tube and pump to eliminate mercury vapor. The whole tube, while connected to the pump, was in an oven and was heated at intervals to 470° C. Between heating operations the tube was operated with as heavy discharge currents as the conditions of its vacuum would permit. For hours the tube

would show the characteristics of an ordinary Rontgen tube, and in many cases a several days' application of the above treatment was required to entirely eliminate these characteristics and to realize an essentially pure electron discharge.

"The exhaust time has been greatly reduced in two ways. The massive tungsten anode is given a preliminary firing to a very high temperature in a tungsten-tube vacuum furnace. The molybdenum support is also fired, to a somewhat lower temperature, in the same manner. In the second place, a Goede molecular pump has been substituted for the mercury pumps and, at the same time, a very large and short connection has been adopted between tube and pump.

"In the later stages of the exhaust a very heavy discharge current is maintained continuously on the tube for perhaps an hour, the temperature of the bulb being kept from rising too high by the use of a fan.

"The pressure in the finished tube is very low, certainly not more than a few hundredths of a micron and probably much less than that.

"The tube was connected as shown in the diagram of Plate II in which, T is the tube; B is a small storage battery; A is an ammeter; R is an adjustable rheostat which can be controlled from behind the lead screen which shields the operator from the Röntgen rays; S is an adjustable spark gap with pointed electrodes, which can also be operated from behind the lead screen; and M is a milliampere-meter which can be read from behind the screen.

"As the high potential is connected to the battery circuit it is necessary that the latter shall be thoroughly insulated from the ground.

"As a high potential source, a 10 K.W. Snook machine ..... was used. This consists of a rotary converter driven from the direct current end and delivering alternating current at 150 volts and 60 cycles per second to

a closed magnetic circuit step-up transformer with oil insulation. From the secondary of this transformer the high voltage current is passed through a mechanical rectifying switch (which is direct-connected to the shaft of the rotary) and the milliampere-meter M, to the tube. The output of the transformer is controlled by a variable resistance in the primary.

"Throughout these experiments a fan was kept blowing on the tube. Without this fan, the gas pressures in the tube would be slightly higher, and the discharge currents would be in consequence slightly lower."

The fundamental United States Patent on the Coolidge Tube, No. 1,203,495, was issued to Doctor Coolidge on October 31, 1916. In connection with the specifications, mention is made of some of the disadvantages attending the use of the gas tubes of the prior art. Among these may be mentioned the following: The pressure of the gas in the tube is variable and any change in gas pressure changes the resistance and the penetrating power of the rays; the changes in gas pressure increase with use and finally render the tube useless; many of the positive ions strike the tube wall instead of the cathode causing disintegration and cracking of the tube; many tubes of the prior art show a variable location of the focal spot and hence do not give a clearly defined picture on the screen; the speed of some of the electrons coming from the cathode to the target is reduced by impact with gas molecules and this causes a lack of uniformity in the penetrating power of the x-rays; secondary cathode rays from the anticathode, bombard the anterior hemisphere of the tube and produce secondary x-rays from the glass, blurring the picture on the screen, and care must be taken that there is no reversal in the applied electromotive force such as to make the target function as cathode since this leads to changes in gas

pressure.

Thirty-three claims are allowed in this patent, the third reading:

> "An electrical vacuum discharge tube, comprising an envelop, cooperating electrodes, at least part of one of which is adapted to be maintained at incandescence, the vacuum within said envelop being so high that evidences of positive ionization are substantially absent during operation and means for focusing the discharge."

A modification of the original Coolidge Tube is shown in Plate III in which the upper figure is that of the entire tube and in the lower figure the details of the cathode are shown. This is known as the Radiator tube, so named from the cooper radiator, shown at the right of the upper figure. The purpose of this radiator is so to reduce the temperature of the target by conduction through the cooper rod supporting it, that its temperature will be always lower than that of the cathode. By this means the current is always in one direction and the tube can be used across the terminals of a high tension transformer without the use of a rectifying device. The rapid withdrawal of heat from the target prevents the heating of the glass bulb of the tube and hence the bulb of this tube is much smaller than in one without the radiator.

The following are some characteristics of the tube. Unless the filament is heated there is no conductivity in either direction and no current will pass, even on the application of very high voltage. It is a unidirectional tube, no current passing except when the hot filament is the cathode. The amount of current passing through the filament, hence its temperature, determines the amount of the current discharge. The penetrating power of the rays is determined by the voltage across the tube terminals; the focal spot is fixed in position and continuous operation is possible without a change of characteristics.

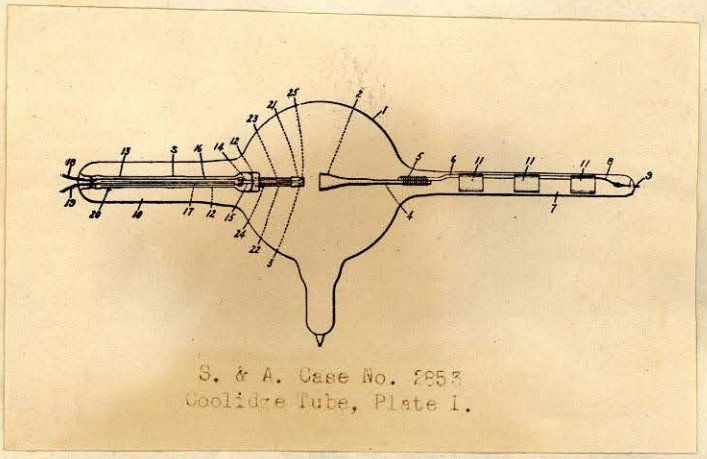
The Institute's Committee has been in correspondence with users of this tube and has received very commendatory comments on its use.

In consideration of the originality and ingenuity shown in the development of a vacuum tube that has simplified and revolutionized the production of x-rays, THE FRANKLIN INSTITUTE awards its HOWARD N. POTTS MEDAL to Doctor William D. Coolidge, of Schenectady, New York.

Wm B Wilson
President

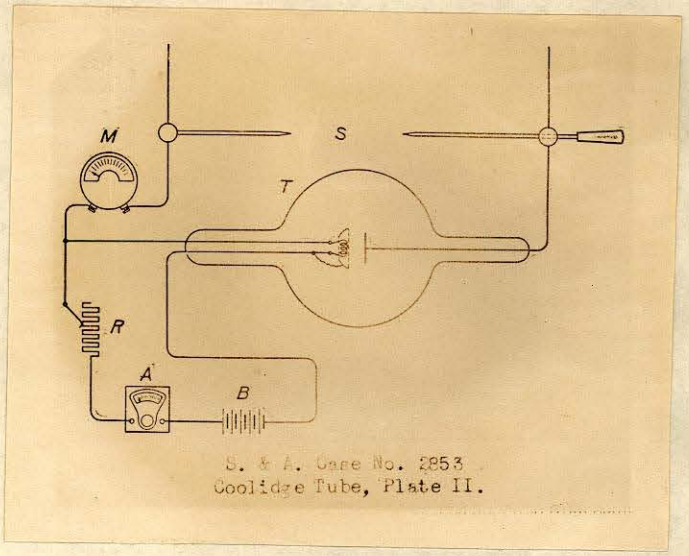
Howard McClenahan
Secretary

Clarence A Hall
Chairman of Committee on Science and the Arts.



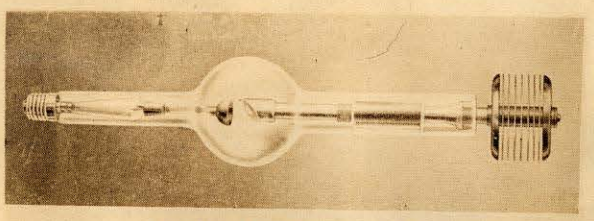
S. & A. Case No. 2853
Coolidge Tube, Plate I.

PLATE I.

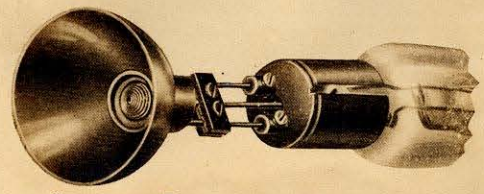


S. & A. Case No. 2853
Coolidge Tube, Plate II.

PLATE II.



RADIATOR TYPE COOLIDGE X-RAY TUBE



CATHODE OF RADIATOR TYPE COOLIDGE X-RAY TUBE

S. & A. Case No. 2853
Coolidge Tube, Plate III.

PLATE III.