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A New Design for a High-Voltage Discharge Tube

L. C. VAN ATTA AND R. J. VAN DE GRAAFF, *Massachusetts Institute of Technology*
and
H. A. BARTON, *American Institute of Physics*
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A description is given of tests with a high-voltage tube of simple and rugged design. The tube consists essentially of a fiber cylinder extending between the electrodes and evacuated to a pressure of 4×10^{-6} mm Hg during operation. A potential of 300,000 volts could be maintained on a section of tube 53 cm long. In spite of the fact that the voltage was limited by discharge there was no case of puncture. A simple clear-cut mechanism for the initiation of discharge in vacuum (independent of field currents) is given together with confirming experimental evidence. On this basis there is proposed a method of screening the electrodes to prevent breakdown and permit the application of extremely high voltages to the tube.

CERTAIN high-voltage generators of recent design[1, 2] have made desirable a new type of vacuum tube to be used in conjunction with them. To meet the electrical and mechanical requirements we have developed a vacuum tube consisting essentially of an insulating fiber cylinder, with a helical high-resistance leak, mounted between the high-voltage electrodes. Electrically it thus provides a uniform potential gradient in a cylindrical vacuum space between flat terminal electrodes. Great mechanical strength is obtained by the use of a cylinder of laminated paper impregnated with shellac and securely fastened to metal terminal sections. Such construction permits of extending the size to large dimensions. The experimental development of this type of tube has encountered no serious difficulties and has yielded interesting information.

The voltage source for this preliminary experimental work was a belt electrostatic generator having 24-inch terminal spheres.[3] A fiber cylinder (Textolite, shellac composition No. 974, manufactured by the General Electric Company) 7 inches in diameter and with a $\frac{1}{4}$-inch wall was mounted between the spheres. A leakage resistance of about 3×10^{11} ohms along the surface was provided by a helical india ink line drawn with 3 turns to the centimeter while the cylinder was rotated in a lathe. A thin coating of ceresine protected the tube and ink line against moisture. The ends of the tube were capped with metal disks. Vapor pressure was effectively reduced by a large liquid air trap placed directly in the tube but outside the path of the discharge. In the presence of a discharge the pressure built up to 4×10^{-6} mm as measured on an ionization gauge. After some preliminary trials a potential difference of 300,000 volts was maintained on a 53 cm length of tube.

There was no instance of electrical puncture in the tube in spite of prolonged operation with the voltage limited by discharge. Even efforts to cause puncture by sliding a sharp grounded electrode along the tube produced no disruptive effect. There were several factors tending to eliminate puncture:

(1) The stored energy of the generator was small since its electrostatic capacity was only that of its spherical electrodes.

(2) The voltage source was limited in current to 40 microamperes, and could be reduced by controlling the rate of spraying on the belt.

(3) The helical ink line imposed on the tube and the flat electrode surfaces a uniform gradient of 6000 volts per cm, thus substantially eliminating field currents. In this connection it is interesting to note that the uniformity of the field makes possible accurate control and focussing of the ion beams.

[1] Van de Graaff, Compton and Van Atta, Phys. Rev. **43**, 149 (1933).
[2] Barton, Mueller and Van Atta, Phys. Rev. **42**, 901A (1932).
[3] Van de Graaff, Phys. Rev. **38**, 1919A (1931).

(4) The conductivity of Textolite, being much greater than that of glass, prevented the building up of a disruptive potential difference across the wall of the tube due to the drift of ions.

Since the voltage across the tube was current-limited, a number of tests were made to determine the nature and source of the current:

(1) An attracted-disk voltmeter placed near one of the high-potential spheres showed a steady voltage indicating that the current was at least moderately steady.

(2) With atmospheric pressure in the tube the potential was limited to 500,000 volts by brush discharge in the air outside the tube. This indicates that the former limitation to 300,000 volts was not due to current down the wall of the tube.

(3) Increasing the pressure from 4×10^{-6} mm to 4×10^{-4} mm by the admission of hydrogen did not reduce the voltage below that attainable at the lower pressure. This shows that the discharge is not maintained by the free gas in the volume of the tube.

(4) A solder electrode in place of nickel resulted in a much lower equilibrium voltage as well as a somewhat higher gas pressure. Evidently the voltage is dependent on the nature of the electrode surface.

(5) During outgassing of the electrodes by the discharge the voltage across the tube gradually increased. This indicates that the gas content of the electrode is a factor, as might be anticipated from the fact that solder with its high gas content reduced the voltage.

The experimental evidence given above indicates that the discharge within the tube is due to ionization at the electrode surfaces because of impacts of ions, electrons, and photons. To illustrate this mechanism of breakdown, let us suppose that, on the average, an electron impinging on the anode liberates there A positive ions and B photons which reach the cathode, and furthermore that a positive ion impinging on the cathode liberates there C electrons which pass to the anode, while a photon impinging on the cathode liberates D electrons which pass to the anode. Then evidently the condition for a discharge is that $AC+BD>1$. It seems that this mechanism would explain the initiation of discharge not only in the present experiment but also in certain experiments of others in the past. In many such cases it has been difficult to account for the onset of discharge.

A breakdown by this mechanism can be eliminated by screening the electrodes with grids at such potentials as to trap secondaries produced on these electrodes. The secondaries ejected from the grid will be smaller in number not only by the ratio of projected grid area to plate area, but also because of the fact that the grid may be constructed of such a material as tungsten and may be thoroughly outgassed. The condition for the initiation of discharge then becomes $S_g/S_p \cdot(ac+bd)>1$ where a, c, b, d are the coefficients for the outgassed grids, and S_g and S_p are the areas of grid and plate respectively.

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