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A Hollow Cathode Source for the Zeeman Effect

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A modification of the Schüler type of hollow cathode discharge tube adapts it for use in magnetic fields. Details of the design and operating characteristics of the tube are discussed.

EXPERIMENTS to determine under what conditions a hollow cathode discharge could be maintained in a magnetic field were made in this laboratory two years ago by J. R. Platt and one of us[1] (R. A. F.). As a result of these experiments and other tests more recently performed a design has been worked out for a hollow cathode discharge tube which operates satisfactorily in the highest fields attainable with our present apparatus (nearly 17,000 gauss). Because the sharpness of emitted spectral lines characteristic of the Schüler type[2] of discharge tube is largely retained in this source it is well adapted for observation of the Zeeman effect in hyperfine structure.[3] It is also applicable to observation of ordinary Zeeman effects in weaker fields since the sharpness of the lines makes wide separation of the patterns unnecessary.

The glow in an ordinary hollow cathode is much weakened by a magnetic field of a few hundred gauss applied perpendicular to the axis of the discharge and soon entirely extinguished. If the pressure of the gas in the tube is reduced slightly below that for normal operation the appearance of the discharge in a weak magnetic field is somewhat improved. If an abnormally small cathode cavity is introduced the maximum field in which a discharge can be maintained is found to be increased. These two observations may be understood as a consequence of the influence of the field in reducing the *effective* mean free path of electrons in the discharge by causing them to traverse curved paths. Günther-Schulze[4] has shown that a necessary condition for the maintenance of a glow in a cathode cavity is that the electron mean free path approximate the width of the cavity. An indicated modification in adapting the Schüler tube to operation in higher magnetic fields is thus a reduction in the dimension of the hollow cathode.

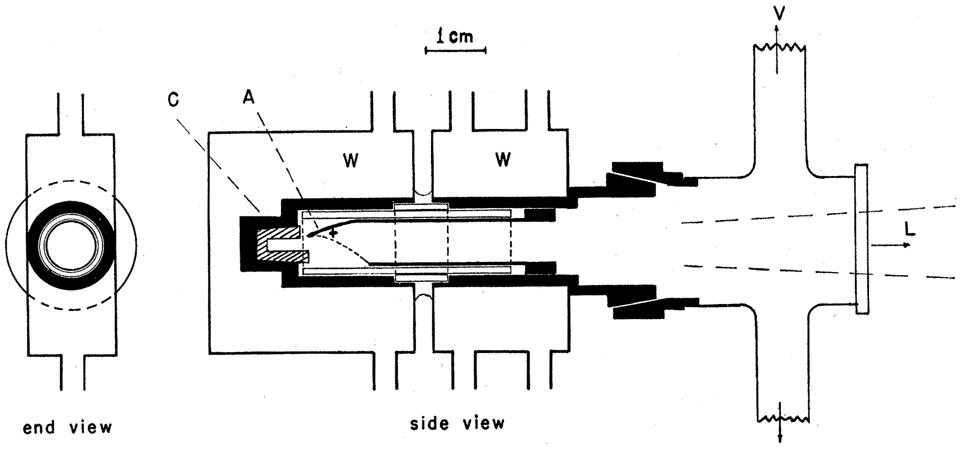

FIG. 1. Detail drawing of hollow cathode discharge tube.

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[1] See J. R. Platt, Master's thesis, Northwestern University, 1937. Also R. A. Fisher, A. S. Fry and J. R. Platt, Phys. Rev. **53**, 934(A) (1938).

[2] H. Schüler, Zeits. f. Physik **35**, 323 (1926); **59**, 149 (1930).

[3] See observations on the Zeeman effect in the hyperfine structure of iodine reported by us in the preceding paper.

[4] A. Günther-Schulze, Zeits. f. Physik **19**, 313 (1923). See also R. A. Sawyer, Phys. Rev. **36**, 44 (1930).

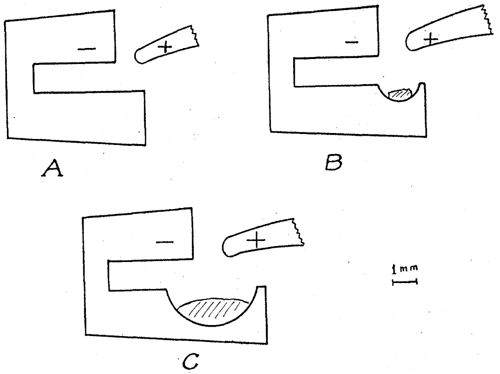


FIG. 2. Relation of anode to cathode in different forms of cathode.

A second effect of the field is a deviation and redistribution of the current in the discharge column extending from the cathode cavity. This effect is so great at higher fields that the anode and cathode must be placed in extreme proximity in order for a discharge to be maintained. The unsymmetrical character of the discharge may be compensated by an unsymmetrical arrangement of the anode relative to the cathode.

General Design of the Tube

After extensive tests involving cathode cavities of various shapes and sizes and various geometrical arrangements of anode relative to cathode a discharge tube was constructed as drawn to scale in Fig. 1. This tube is mounted with its axis horizontal and perpendicular to the magnetic field. It thus permits only observation of the transverse Zeeman effect through the window L at the right. The discharge is carried, as usual, by a properly purified inert gas. The dimensions are such that the tube may be placed between pole pieces 16 mm apart.

The walls of the tube are formed by a brass cylinder 55 mm long having an outer diameter of 15 mm and an inner diameter of 12 mm. This cylinder is divided into two parts which are separated and insulated from one another by a short glass ring having the same inner diameter as the brass. The two parts of the tube and the glass ring are joined by Picein wax. Inside the brass wall is a glass sleeve extending nearly the length of the tube and fitting loosely enough to be withdrawn. At one end of the cylinder is located the hollow cathode (C in the figure). It is a removable plug of some nonferromagnetic metal fitting snugly into a tapered hole at the closed end of the brass cylinder. Extending through the tube inside the glass sleeve is the anode cylinder which is also removable and held in place by friction. At one end of this anode cylinder is a brass ring which fits against the outer wall of the tube. The other end is a tapered prong (A in the figure) resembling somewhat the point of a pen, but with a rounded tip, which extends to a position just above the cathode cavity.

The water-cooling jackets, W, of the two halves of the tube are flat, as shown in the end view, to avoid unnecessary separation of the pole pieces. The metal at the end of the tube surrounding the cathode is machined away to provide more effective cooling. The tube as a whole is connected to the vacuum system through the ground joint shown, which permits convenient access to the removable anode and cathode.

The Cathode and Anode

The cathode cavity is in a removable plug because action of the discharge in the magnetic field causes a groove to be cut rather rapidly into the metal directly below the cavity. Thus after a few hours of operation the cavity is so deformed that the cathode must be removed and machined or replaced by a new one. Aluminum as cathode material is more resistant to this erosion than other metals which we have used. However, if aluminum is attacked chemically by the substance present in the discharge, as it is by iodine, some other metal must be substituted. Tungsten is satisfactory although it is more difficult to machine and more rapidly eroded.

A cylindrical cavity between 1 and $1\frac{1}{2}$ mm in diameter seems to be most satisfactory for

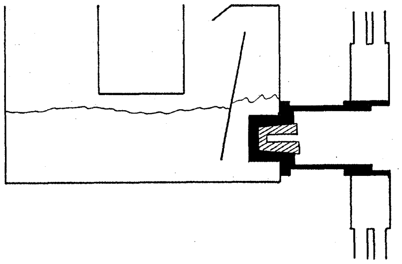


FIG. 3. Detail of liquid-air-cooled cathode.

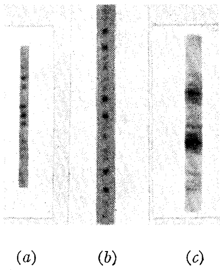

(a) (b) (c)

FIG. 4. Zeeman patterns resolved by Fabry-Perot interferometer. *a*, λ4810 of zinc at 9900 gauss, π components only, 5.2-mm interferometer spacer; *b*, λ5719 of bismuth at 9500 gauss, 2.4-mm spacer; *c*, λ5350 of thallium at fields of 8000, 9000 and 10,000 gauss, 5.2-mm spacer.

operation in fields greater than 10,000 gauss. At lower fields the diameter may be greater. The depth of the cavity is immaterial so long as it is more than twice the diameter. A small shelf extending out from the cathode on the side of the cavity opposite the anode, as shown in Fig. 2, *A*, seems to prolong the life of the cathode.

Substances which are readily vaporized may be introduced into the discharge by being placed inside the anode cylinder. Others, such as the common metals, having low vapor pressures, must be introduced more directly into the cavity. Fig. 2, *B*, illustrates a cathode suitable for exciting such substances. A piece of the substance is placed in a depression in the shelf before the cavity where it receives vigorous bombardment by the discharge. If the substance is melted by the bombardment it may be placed in a larger well as shown in Fig. 2, *C*.

Aluminum is the most satisfactory material for the anode, although molybdenum or tungsten will serve. The tip of the anode should be about 1 mm in front of the cathode face and 1 mm above the opening as shown in Fig. 2. The direction of the magnetic field must be such as to deviate the discharge column issuing from the cavity *downward* and *away* from the anode. If the field is reversed an arc is apt to result.

Chemical attack upon the brass wall of the tube near the cathode may be eliminated by shrinking the end of the glass sleeve until it fits closely around the cathode plug.

A modification of the cathode portion of the tube permitting cooling of the cathode by liquid air has been constructed as shown in Fig. 3. The attached liquid-air chamber is of brass and is covered with thin sheets of cork. The baffles shown prevent the liquid air from being thrown out by the boiling at the cathode.

OPERATING CHARACTERISTICS

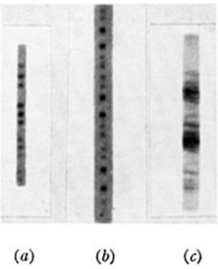
The pressure of the rare gas in the tube for optimum operation depends rather critically upon the field strength and the discharge current and must be readily adjustable. When argon is used the pressure ranges between 5 mm at high fields and 12 mm at low fields. With helium it is somewhat higher.

The potential difference between anode and cathode increases with increasing field, varying from 400 to 800 volts at a current of 100 milliamperes.

The discharge current for stable operation may have any value between 15 and 100 milliamperes. If the higher value is exceeded there is a tendency toward arcing.

When the pressure is properly adjusted relative to the field strength the source operates with perfect stability for hours without attention. The highest field attained by our magnet evidently does not represent a limit in operation of the tube since the discharge seems only to become more intense as the field increases. The hollow cathode glow resembles that in the ordinary Schüler tube except that it is considerably more brilliant. The tube operates satisfactorily in zero field but at an elevated gas pressure.

The sharpness of emitted lines is comparable, although perhaps not quite equal to that attained with the water-cooled Schüler tube. We have resolved Zeeman components whose separation is as little as 0.040 cm^{-1} in the indium spectrum using the water-cooled source. Fig. 4 gives examples of Zeeman patterns observed with this source by means of a Fabry-Perot interferometer. Tests with the liquid-air-cooled cathode have not been extensive enough to determine whether there is a significant gain in line sharpness compared with the water-cooled tube. It may only be said that the liquid-air cooling does not impair the discharge. It is, however, necessary to place the material directly in the cathode in order to obtain any excitation at the low temperature.



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