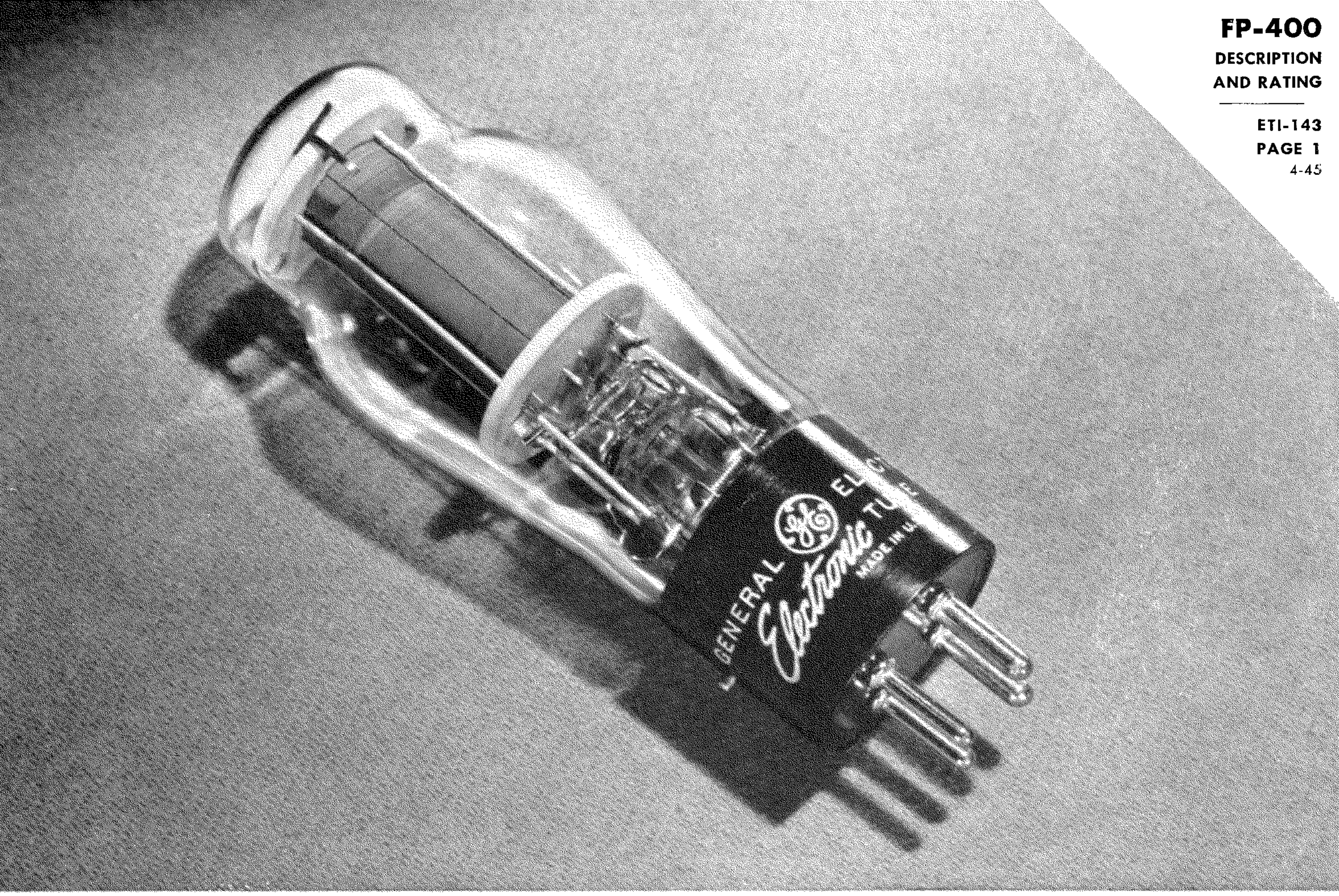

KENOTRON

DESCRIPTION

The FP-400 is a diode designed to be used in the study of electrical discharges in high vacuum. It contains a pure-tungsten filament, located axially in a cylindrical zirconium-coated-nickel anode. It is particularly well adapted to the following studies of fundamental electronic phenomena:

1. The limitation of current by space charge
2. The relation between temperature and electron emission
3. The effect of magnetic fields on electron currents

The pure tungsten filament used renders this tube especially advantageous for emission studies.

TECHNICAL INFORMATION

These data are for reference only. For design information refer to specifications.

GENERAL CHARACTERISTICS

Number of electrodes 2

Electrical

Filament—Pure tungsten
- Voltage . . . . 4.0 volts
- Current . . . . 2.25 amperes
- Average filament lead resistance, excluding filament . . . . 0.08 ohm

Mechanical

Maximum over-all dimensions
- Length (free length of filament) . . . . 1.25 inches
- Diameter . . . . 0.005 inch

Anode, zirconium-coated-nickel, inside diameter . . . . 0.620 inch
Base . . . . Medium 4-prong bayonet
Mounting position . . . . Vertical or horizontal

Electronic TUBE

TECHNICAL INFORMATION (CONT'D)

MAXIMUM RATINGS

	Typical Operation	Maximum Ratings	
Filament voltage	4.0	4.75	volts
Filament current	2.25	—	amperes
Anode voltage	100	125	volts
Anode current	0.025	—	amperes
Anode dissipation	—	15	watts
Magnetron characteristics			
Magnetic field for anode voltage = 80 volts			
At normal anode current	Below 80 gauss		
At minimum anode current	Above 130 gauss		

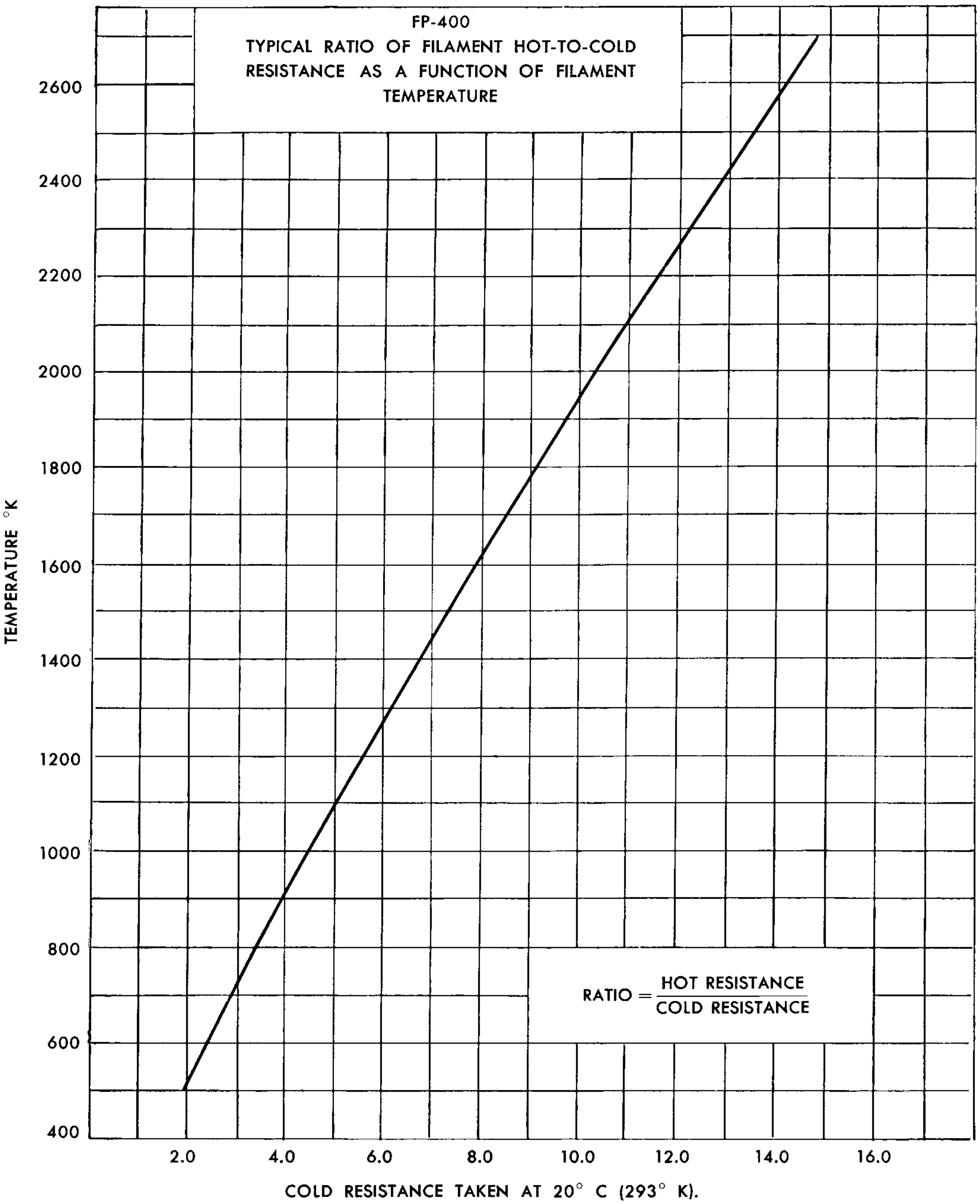

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FIG. 1

FP-400 ANODE CURRENT CHARACTERISTICS

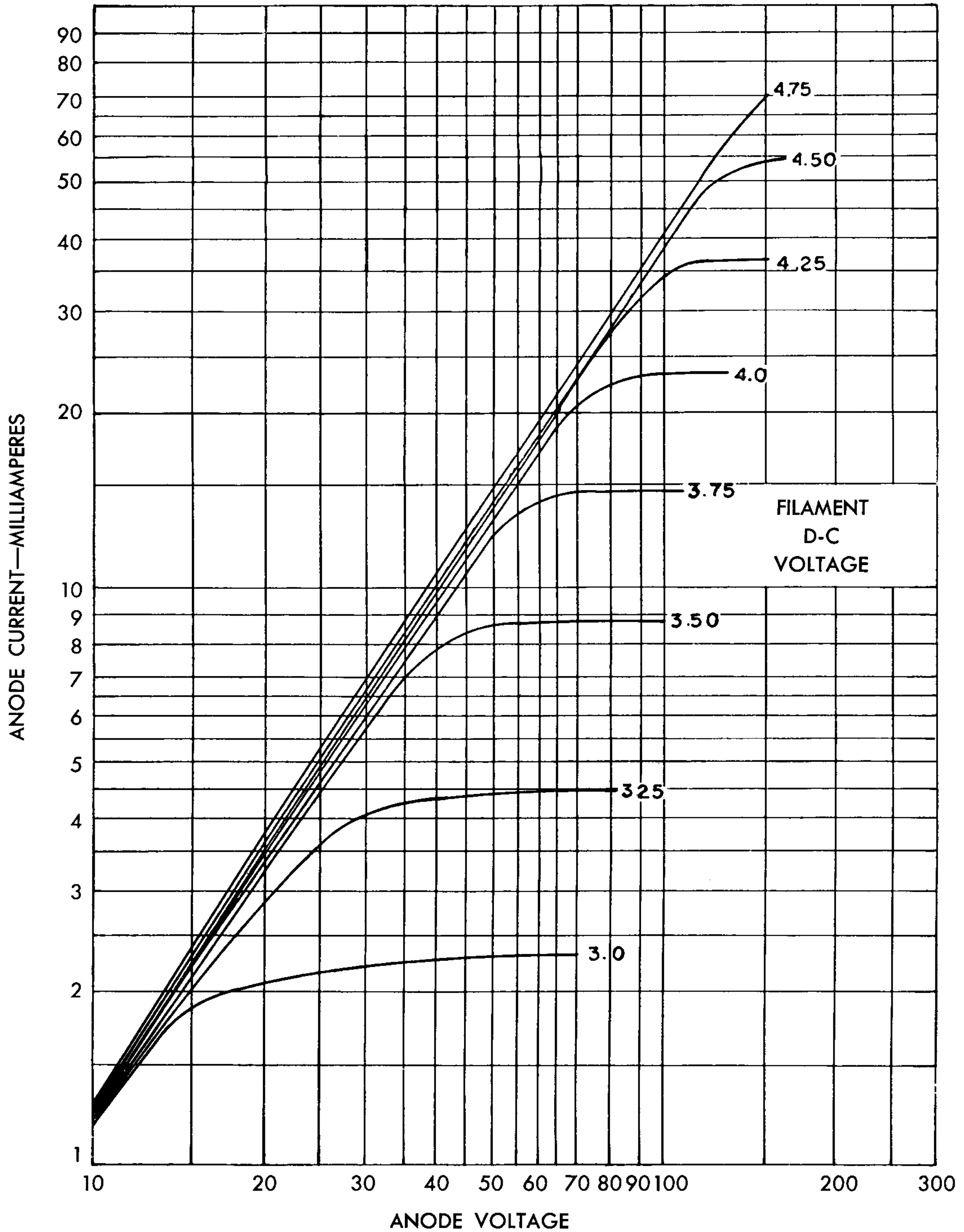

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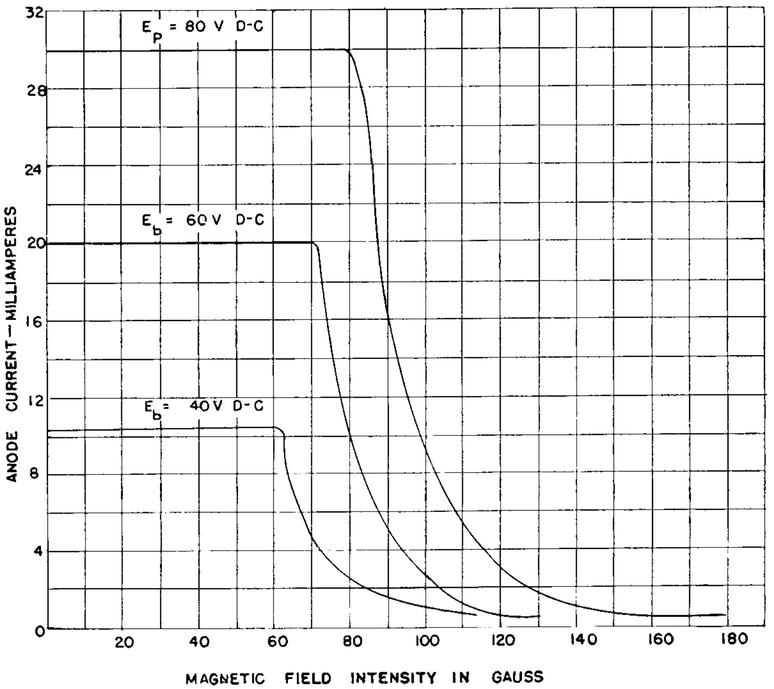
FIG. 2

FP-400

TYPICAL MAGNETIC CONTROL CHARACTERISTICS



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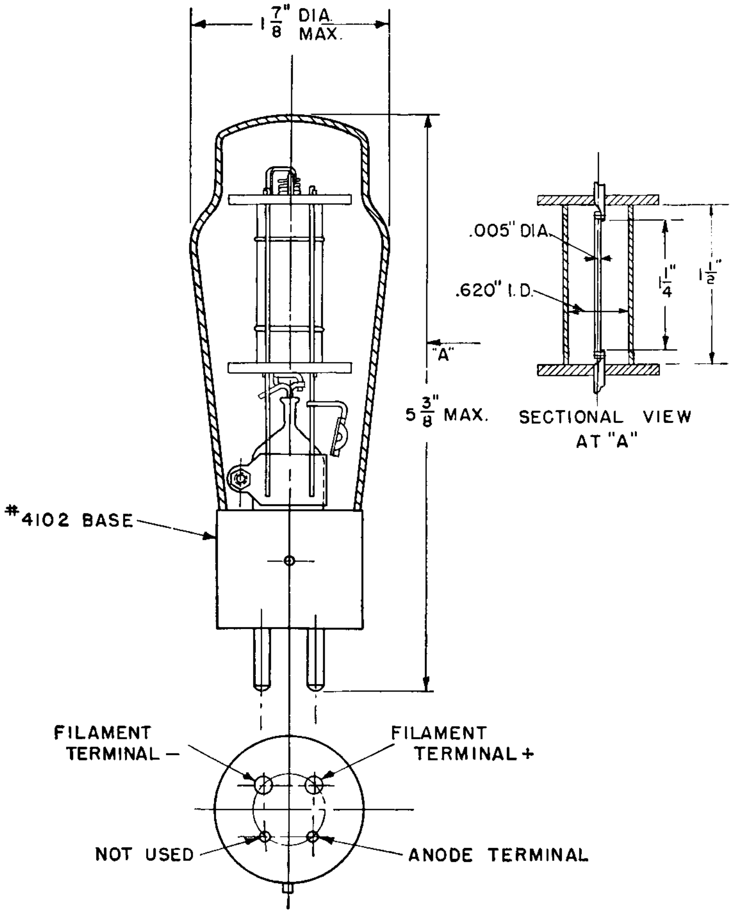

OUTLINE
FP-400 KENOTRON

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INSTALLATION

Mechanical

Mountings should minimize danger from vibration and impact. Special attention should be given the socket to assure firm, low-resistance contact with the filament terminals of the base.

Cooling

All apparatus should be arranged to allow free circulation of air around the bulb which becomes very hot during operation and, therefore, should neither come in contact with any metallic object nor be subjected to drops or spray of liquid.

Electrical

The filament may be operated from either an a-c or a d-c source. For accurate measurements of filament voltage and current, a d-c source is preferable. The voltage rating of the filament makes the use of a six-volt battery convenient.

The anode-circuit return lead should be connected to the negative filament terminal when d-c filament supply is used. The negative filament terminal of the base (see outline) is connected in the tube through the lowest possible lead resistance to the end of the filament.

OPERATION

Maximum ratings and typical operating conditions are given above. It should be recognized that the life of a tungsten filament decreases with increased temperature, and that at temperatures above about 2600 K, the length of life of tungsten filaments under tension is difficult to predict due to the possibility of rupture caused by accelerated crystallization.

The theoretical space-charge equation for concentric cylinders is,

$$I = 14.65 \times 10^{-6} \frac{V^{3/2}}{rB^2} \text{ amperes per centimeter length of filament}$$

Where V = anode voltage and
r = anode radius (centimeters)

B^2 is a function of the ratio of the anode radius to cathode radius. The derivation of this equation, and values of B^2 may be found in the references (1) and (2).

The space-charge equation may be applied without major discrepancies to practical cases, particularly where the variation of current with voltage is desired. Where an actual filament is used as the emitter, and it is desired to obtain the anode current for a given anode voltage, some correction must be made to allow for the fact that the filament is cool at each end. For the FP-400, satisfactory results are obtained by basing the calculations on a filament length of one inch. A more accurate correction for each filament temperature may be obtained by using the theory of end losses (3).

For a study of space-charge, curves similar to those shown may be plotted from data taken in the laboratory. (For use in the study of emission, it is convenient to measure the saturated emission currents at different filament voltage levels while obtaining these data. At each filament voltage level, the filament current should be measured accurately.)

These curves may be checked as to slope (the exponent in the space-charge equation) by plotting slightly to one side a straight line representing the equation, $I = KE^{3/2}$ where K is arbitrarily chosen to make the line fall near the curves.

The several causes for the deviation of the curves from a straight line before saturation occurs form an interesting field for qualitative studies.

The Relation between Temperature and Electron Emission

The data necessary for this study may be obtained while making measurements of the space-charge limited currents, as described above.

Dushman's equation (4) for thermionic emission is,

$$I = AT^2 E^{-\frac{b_o}{T}} \text{ amperes per square centimeter}$$

Where T = absolute temperature of the emitter
A = 60.2
b_o = 52,400 for pure tungsten

Observed values of the properties of tungsten have been recorded by H. A. Jones and I. Langmuir (5).

The saturated emission currents measured may be checked against the corresponding filament temperature, using the Dushman equation or the observed properties of tungsten. Actual filaments, however, always vary in temperature from the center to each end, due to the cooling effect of the leads. A temperature may be found by means of the hot-to-cold resistance ratio.

The cold resistance is measured at room temperature. If the room temperature is appreciably different from 20 C, a correction on the measured value may be used. This measurement will include the filament resistance, and the resistance of the filament leads. The resistance of the filament alone may be found from the known length and diameter of the filament and the properties of tungsten (5). In this way, the resistance of the leads may be found.

The hot resistance of the filament circuit is found by measurements of voltage and current. The usual precautions regarding voltmeter current should be observed when making such measurements. The hot resistance may then be corrected for the resistance of the leads, and the ratio of hot-to-cold resistance found.

The temperature determined in this way will obviously be an average value, less than the center

See Footnotes 1, 2, 3, 4, 5 and 6 on page 6.

temperature of the filament, and greater than the temperatures.

It will also be subject to major errors because of the errors of measurement in finding the cold resistance. The emission determined by use of this temperature will usually be far below that measured, because of the exponential increase of emission with temperature.

The temperature at the center of the filament may be discovered with a high degree of accuracy by determining the function, A' (amp/(cm)3/2) and arriving at the corresponding temperature (5). Then, the emission to be expected from the entire length of filament running at this maximum temperature may be corrected by means of the factor obtained from the theory of end losses; (3), (5):

$$f = \frac{V + 2\triangle V}{V + 2\triangle V - 2\triangle V_H}$$

Where V is the filament voltage

$\triangle V$ is a function of the maximum temperature and the filament-to-lead-junction temperature

$\triangle V_H$ is a function of the exponent (with respect to temperature) at which the property (emission) increases, and the temperature

The lead-junction temperature of the FP-400 filament may be considered one-quarter the maximum temperature. The leads connected to the filament are molybdenum, 0.030 inch in diameter. Another method of arriving at a temperature, in this case too low, is to measure the input to the filament, in watts, and use the function W' (watts/length $\times$ diameter) to find the temperature (5). On the chart, "Specific Characteristics of Ideal Tungsten Filaments" (5), the function I' (amperes/length $\times$ diameter) may be found directly, if desired.

When the Dushman equation is used to check the variation of emission with temperature against the measured values, it will be found that the value of A given in the emission equation will not apply to the experimnetal results; the discrepancy depends on whether an average temperature or the maximum temperature of the filament has been found. If the maximum temperature has been found, the factor, f (a function of temperature), mentioned above may be used to correct the value of A in the Dushman equation for the effect of end losses (5). If the value of A in the Dushman equation is corrected for one of the points taken, so that the calculated emission agrees with that actually obtained, the other points will agree quite well with the equation.

The Effect of Magnetic Fields on Electron Currents

The FP-400 is designed to demonstrate the influence of a magnetic field on a moving stream of electrons. The theoretical and actual performances of magnetrons are discussed in the references (1), (6).

The tube may be surrounded by an air-cooled field coil which will produce flux parallel with the filament. The flux produced by this coil should be measured. Data may then be taken for curves showing the cut-off characteristics of the tube. The critical value or cut-off value of flux is given by the relation—

$$H = \frac{6.72\sqrt{V}}{r} \text{ gauss}$$

Where V is the anode potential in volts and r is the anode radius in centimeters the effect of a non-parallel field may be observed. Once the FP-400 has been "calibrated," it may be used to explore other unknown magnetic fields.

Footnotes: (1) *Electrical Discharges in Gases—Review of Modern Physics,* pp. 191-257 Vol. 3, No. 2 April, 1931.
(2) *Space-charge Between Coaxial Cylinders—Physical Review*—October, 1923.
(3) *Effects of End Losses on the Characteristics of Filaments of Tungsten and Other Materials—Physical Review*—pp. 478-503, Vol. 35, No. 5, March 1, 1930.
(4) *Thermionic Emission—Review of Modern Physics,* pp. 381-476, Vol. 2, No. 4, October 1930.
(5) *The Characteristics of Tungsten Filaments as Functions of Temperature, General Electric Review*—pp. 310-319, June, 1927; pp. 334-361, July 1927; pp. 408-412, August, 1927.
(6) *The Magnetron-Journal AIEE,* September, 1931.

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