UNIVERSITY OF WATERLOO

Physics 360/460 – Experiment 4

THERMONIC EMISSION OF ELECTRONS

Purpose: To verify the form of the Richardson-Dushman equation of thermionic emission using a GRD7 tube and obtain a value for the thermionic work function for the tungsten filament.

References:

The following references (electronic copies provided on LEARN) detail the background theory for thermionic emission.

1. T. B. Brown, *Electronics*, New York: Wiley 1954, pg.216-222.
2. J. Millman, *Vacuum tube and Semi-conductor electronics*, New York: McGraw-Hill 1958 pg. 60-79.
3. R. L. Sproull, Modern Physics, 2nd ed., New York: Wiley 1956, pg. 434-443.

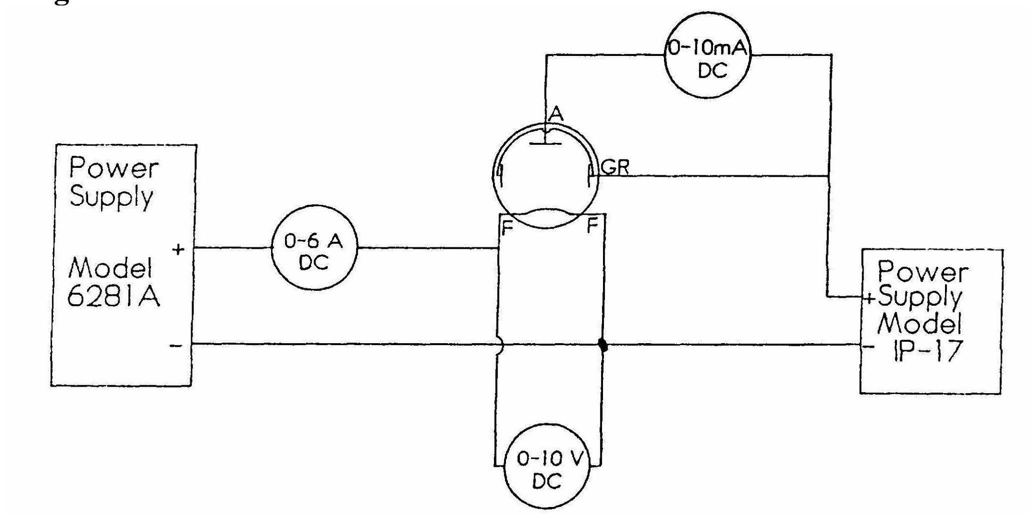
Procedure:

1. With anode voltage, V_a = 300 V, set the filament current, I_f, to give an anode current, $I_a(V_a = 300\text{ V}) = 8.00$ mA. Leave the filament current I_f constant and record the magnitude of the filament voltage, V_f.
2. Measure I_a vs. V_a for V_a = 300 V, 250 V, 200 V, 150 V and 100 V.
3. Repeat steps 1 and 2 for $I_a(V_a = 300\text{ V})$ = 4.00, 2.00, 0.8 and 0.4 mA

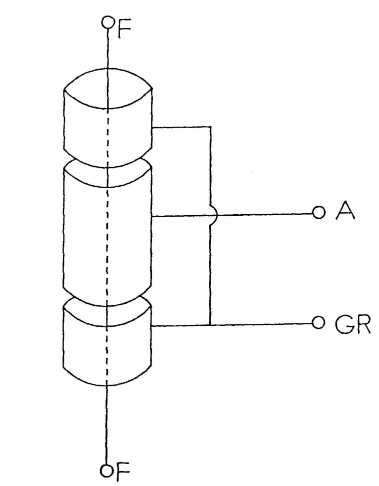
Note: The effective anode voltage is that between the anode and the midpoint of the filament. Thus it is necessary to subtract half of V_f (see circuit) to correct each value of V_a. Note the V_f will be different for each initial setting for I_a.

Apparatus:

Circuit Diagram



Electrode Structure:



Suggested Instrumentation:

Ferranti GRD7 Guard Ring Diode
Healthkit Power Supply Model lP-17 (Plate voltage)
Taylor Multimeter (Plate current)
Simpson 260 meter (Filament voltage)
HP 3468A Multimeter (Filament current)
Harrison Power Supply Model 6281A (Filament current)

Note: Maximum Filament voltage: 6.5 volts
Filament Dimensions: Effective length 14.5 mm x 0.130 mm diameter

Analysis: Plot the I_a vs. V_a to find the values of I_o for different filament currents I_f. From the values of I_o and T, make a plot of I_o/T^2 versus $1/T$ on a semi-log scale. Using this plot, determine the work function of the filament, w_o, in eV. Compare the your value of w_o to literature.

The following empirical equation can be used to relate the filament current to the temperature of the filament in degrees Kelvin

$$T = 60.2\sqrt{B\left(1+83*10^{-6}B\right)}\ \text{K} \quad \text{where} \quad B = \frac{I_f}{d^{\frac{3}{2}}} \quad \frac{\text{A}}{\text{cm}^{\frac{3}{2}}}$$

Additional background information:

Thermionic Emission: Determination of the Work function

Richardson - Dushman Equation:

$$J_o = AT^2 e^{-w_o/KT} \qquad (1)$$

J_o – current density
T – temperature of filament
w_o – is the work function at zero E - field
K – Boltzman constant
A – a constant

The Schottky effect accounts for the fact that an electric field acting on the surface of the metal will reduce the work function. The new work function is now:

$$w = w_o - \sqrt{e^3 E / 4\pi\varepsilon_o} \qquad (2)$$

w – work function at some value of the Electric field
E – Applied Electric field
e – electronic charge

Now the R-D equation, (1), becomes:

$$J = AT^2 e^{-w/KT}, \qquad (3)$$

which can be alternately written as,

$$J = AT^2 e^{-w_o/KT} e^{\frac{\sqrt{e^3 E/4\pi\varepsilon_o}}{KT}}, \quad (4)$$

or

$$J = J_o e^{\frac{\sqrt{e^3 E / 4\pi\varepsilon_o}}{KT}} \qquad (5).$$

Replacing the current density, *J,* with the current, *I*, and taking the natural log of both sides of (5) gives,

$$\ell n(I) = \ell n(I_0) + \frac{\sqrt{e^3 / 4\pi\varepsilon_0}}{KT}\sqrt{E}\,, \qquad (6)$$

which in terms of the anode voltage, *V*, is,

$$\ell n(I) = \ell n(I_0) + C\sqrt{V}\,, \qquad (7)$$

From, (7) it is apparent that a plot of ln(*I*) vs. sqrt(*V*) will allow a determination I_0.

Finally, eqn. (1) (with J_0 replaced by I_0) can be used to determine the work function from a plot of semi-log plot of (I_0/T^2) vs. *1/T.*