ELEMENTS OF MODERN PHYSICS LABORATORY

Course Code- PHY259
Practical-3

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List of Practicals

- To study The Photo Electric Effect using Planck's Constant Set.
- Determine the Planck's constant using LEDs of at least 4 different colors.
- Determine work function of material of filament of directly heated vacuum diode.
- Determine the wavelength of H-alpha emission line of Hydrogen atom.
- Determine the charge of an electron with the help of Millikan oil drop Set.
- Show the tunneling effect in tunnel diode using I-V characteristics.
- Determine the wavelength of laser source using diffraction of single slit.
- Determine the wavelength of laser source using diffraction of double slits.
- Determine wavelength and angular spread of He-Ne laser using plane diffraction grating.
- Determine the absorption lines in the rotational spectrum of Iodine vapor

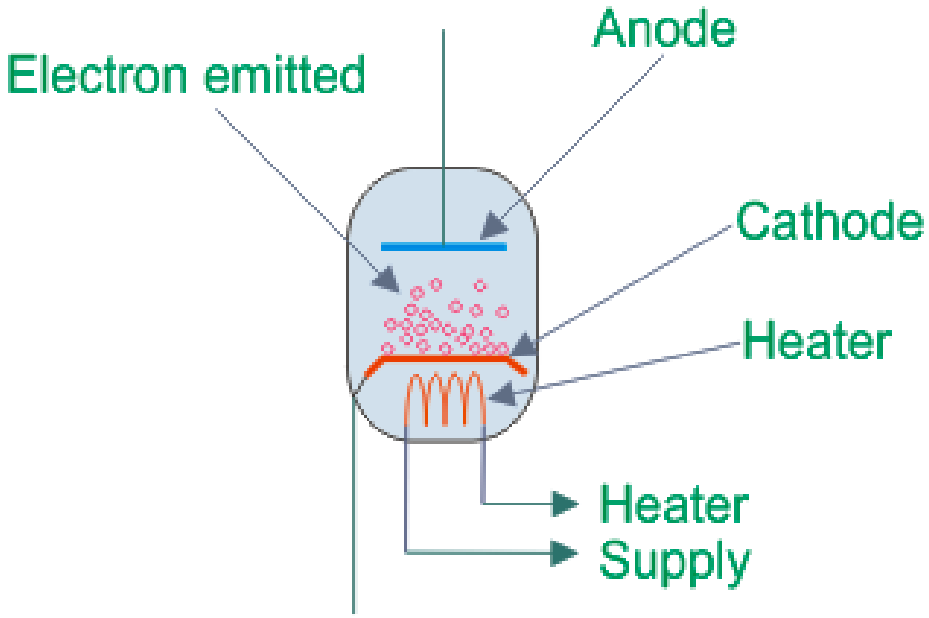
Objective: Determine work function of material of filament of directly heated vacuum diode.

Learning Objectives

1. To understand working of a heated vacuum diode.
2. Work function is a property of the surface of the sample and has very little to do with the bulk of the sample.
3. Will know what a thermoionic emission process.
4. To determine work function of given material.

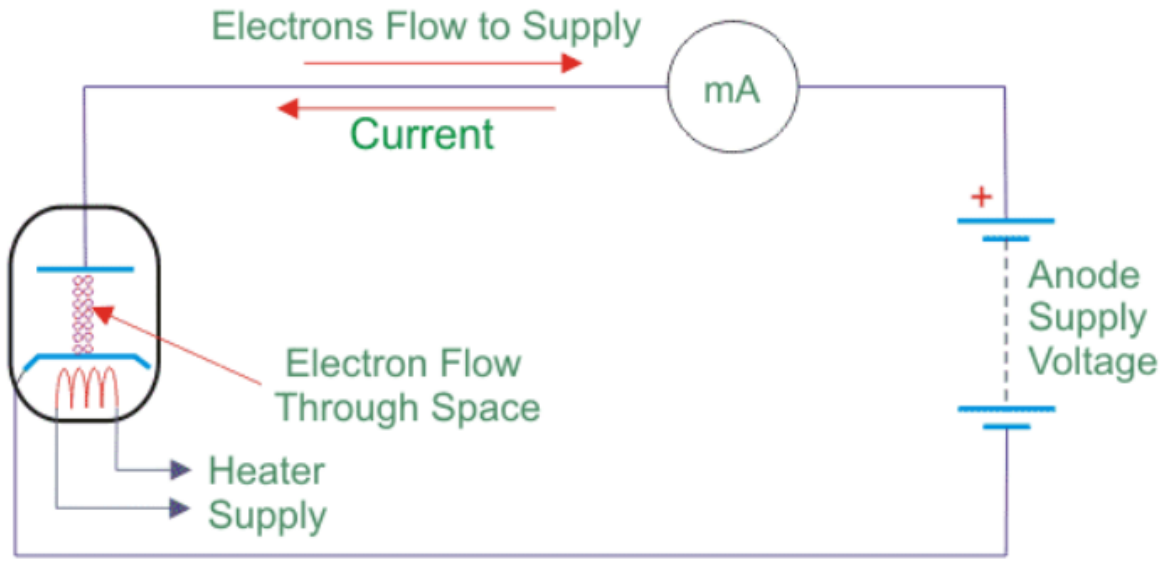
Basic Understandings

Vacuum Diode

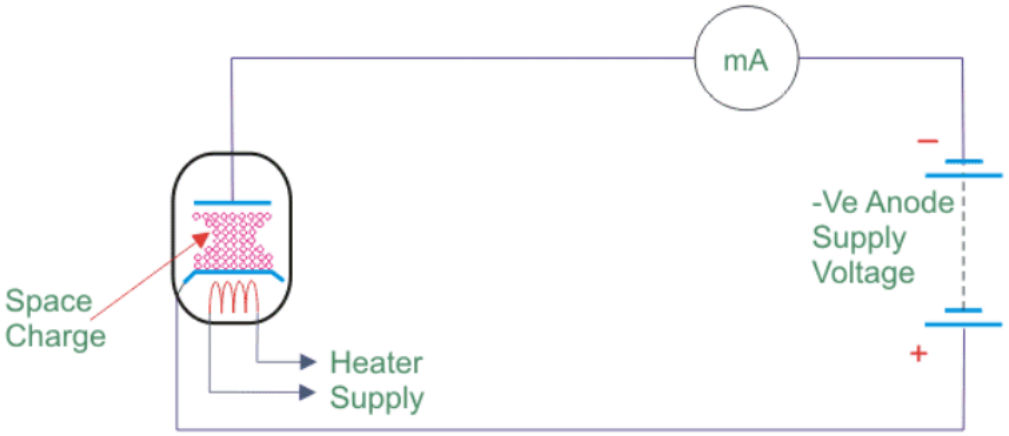


- In November 16, 1904 first **vacuum diode** was invented by Sir John Ambrose Fleming and it is also called the Fleming valve, the first thermionic valve.
- In those days there was no existence of p-n junction in electronics field. A conceptual figure of vacuum diode is shown below.
- Here the **vacuum diode** works mostly like a modern diode. But its size is larger. It consists of a vacuum container with cathode and anode inside.
- This cathode and anode are connected across a voltage source.

- The anode is applied with positive voltage with respect to cathode. It works on the principle of thermionic emission. A filament heats this cathode. Hence electrons get emitted from the cathode and attracted towards the anode.
- If the positive voltage applied at the anode, is not sufficient enough, the anode cannot attract the electrons emitted from the cathode due to hot filament.
- As a result, one cloud of electrons gets accumulated in the space between cathode and anode. This is called space charge.
- Due to this space charge, the further emitted electrons get repealed and come back to the cathode. Hence virtually electron emission stops. No current flows through the circuit.



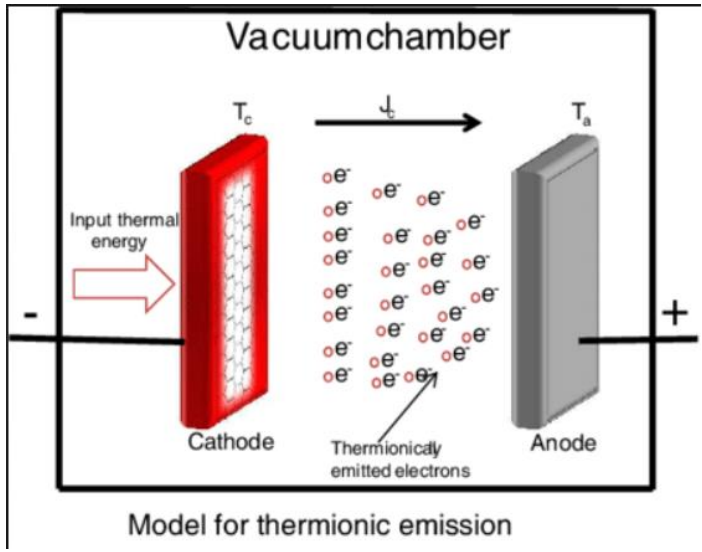
- If the applied voltage between anode and cathode is increased gradually then more and more space charge electrons come to the anode and create vacant space for further emitted electrons.
- So with the increase of voltage across anode and cathode, we can increase the emission rate of electrons.
- At the same time, the space charge gradually vanishes that means it gets neutralised on the anode. Once for certain applied voltage between anode and cathode, the entire space charge vanishes.
- There is no more obstruction for emission of electrons from the cathode. Then a beam of electrons starts flowing freely from cathode to anode through space. As a result, current flows from the anode to cathode.



- On the other hand if anode is made negative with respect to cathode there is no electron emission from it as it is cold not hot. Now the emitted electrons from heated cathode do not come to the anode. Due to repulsion of negative anode strong space charge will be accumulated between anode and cathode.
- Again due to repulsion of this space charge all further emitted electrons come back to the cathode hence no virtual emission takes place hence no current flows in the circuit. So, **vacuum diode** allows current to flow in one direction only.
- Under reverse bias this vacuum diode does not work. This vacuum tube was the basic component of electronics throughout the first half of the twentieth century. It was available and common in the circuit of radio, television, radar, sound reinforcement, sound recording system, telephone, analog and digital computers, and industrial process control.

Thermoionic Emission

- If a tungsten filament is heated to about 2000 ° C, some of the electrons have sufficient kinetic energy to escape from the surface of the wire.
- This effect is called **thermionic emission**.
- It is quite easy to imagine this if we think about a metal wire as a lattice of ions in a sea of free electrons. In effect we are boiling the electrons off.



Model for thermionic emission

Work Function

- The energy required to remove an electron from the Fermi-level of a metal and free it from the influence of that metal is a property of the metal itself. This property is known as the metal's work function (ϕ).
- For this experiment, a filament is heated to the extent that electrons are emitted from the surface of the sample. These electrons must have energy greater than the work function (f) of the emitting surface.
- If the emitted electrons are not removed from the region around the emitting surface, a cloud of negatively charged electrons develops. This is referred to as a space charge (Reich, 1939).

Fortunately, it is possible to reduce and perhaps eliminate the effect of space charges. A positively biased plate near the emitting surface should pull the electrons away from the surface reduce the number of electrons available to cause a space charge. This creates an emission current flow between the emitting surface and the biased plate. The emission current density was first described by Richardson and was modified by Dushman. This paper will refer to the relationship as the Richardson-Dushman equation (equation 1) (Eastman, 1941).

$$J = AT^2 \epsilon^{-\frac{\phi/k}{T}} \qquad (1)$$

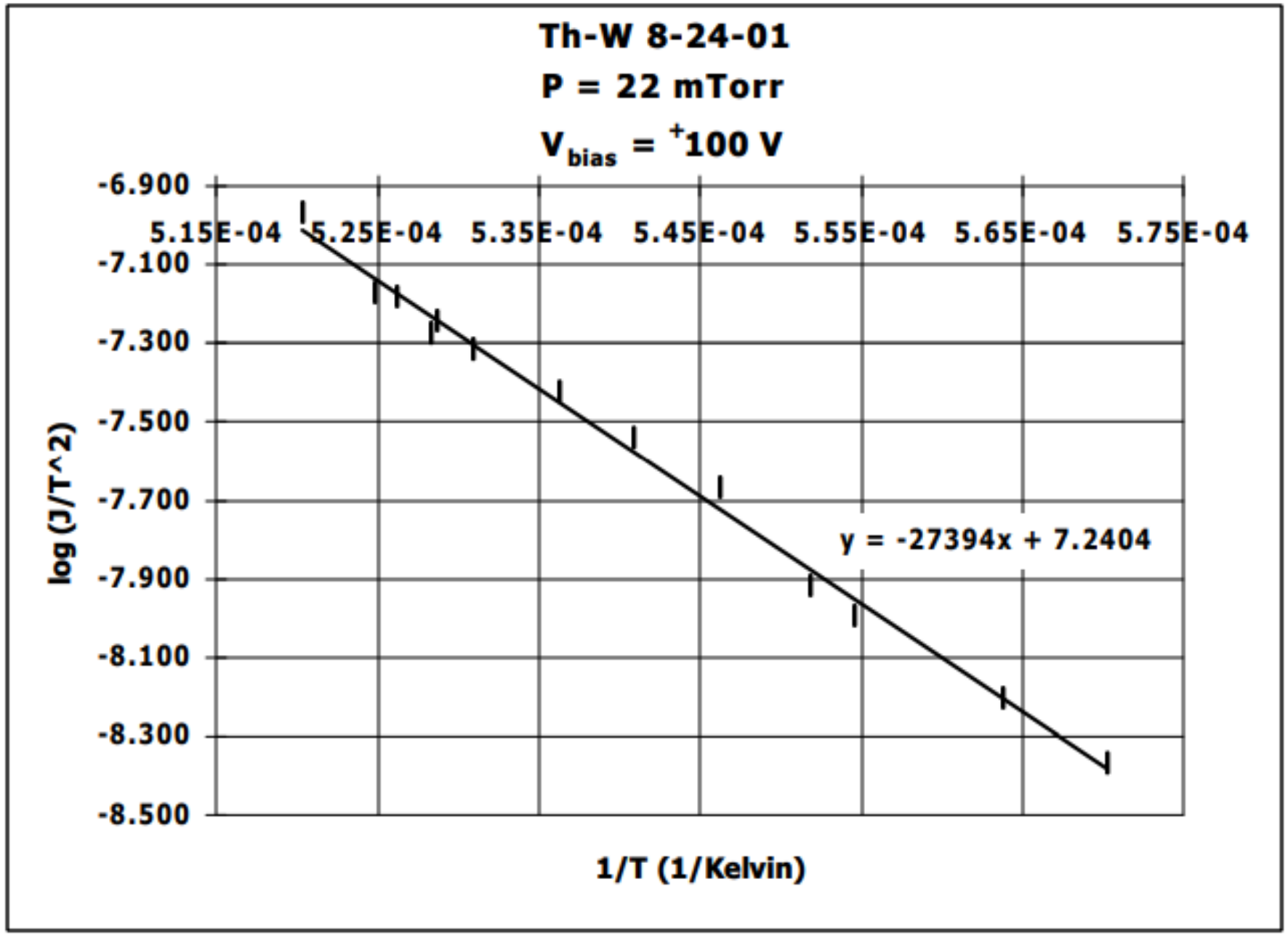
Where:

J = emission, amps/cm^2 of hot emitting surface.
A = a constant for metals.
T = temperature of hot surface, in Kelvin.
ϕ = work function, measured in electron volts or eV.
k = Bolztmann's constant (1.371×10^{-23} $^{Joule}/_{Kelvin}$).

Current density can be determined by using a digital multimeter to record current traveling from a filament of known surface area to the bias plate. The relationship between the resistance and the temperature of tungsten can be used to determine the temperature of a tungsten filament. Rearranging the Richardson-Dushman equation for thermionic emission yields the following:

$$\log (J/T^2) = \log(A) - \frac{\phi/k}{T} \qquad (2)$$

The line produced by plotting *log(J/T^2) vs 1/T* will have a slope of ϕ/k. This allows us to determine the work function of the filament.


Th-W 8-24-01
P = 22 mTorr
V bias = +100 V
-6.900
-7.100
-7.300
-7.500
-7.700
-7.900
-8.100
-8.300
-8.500
5.15E-04
5.25E-04
5.35E-04
5.45E-04
5.55E-04
5.65E-04
5.75E-04
log (J/T^2)
y = -27394x + 7.2404
1/T (1/Kelvin)

The slope of the trendline is $-\phi/k$. This allows us to determine the work function. Equations 7 through 13 below show a sample of determining the work function from the slope of the above trendline.

$$J = AT^2 \epsilon^{-\frac{\phi/k}{T}} \tag{7}$$

$$\log (J/T^2) = \log(A) - \frac{\phi/k}{T} \tag{8}$$

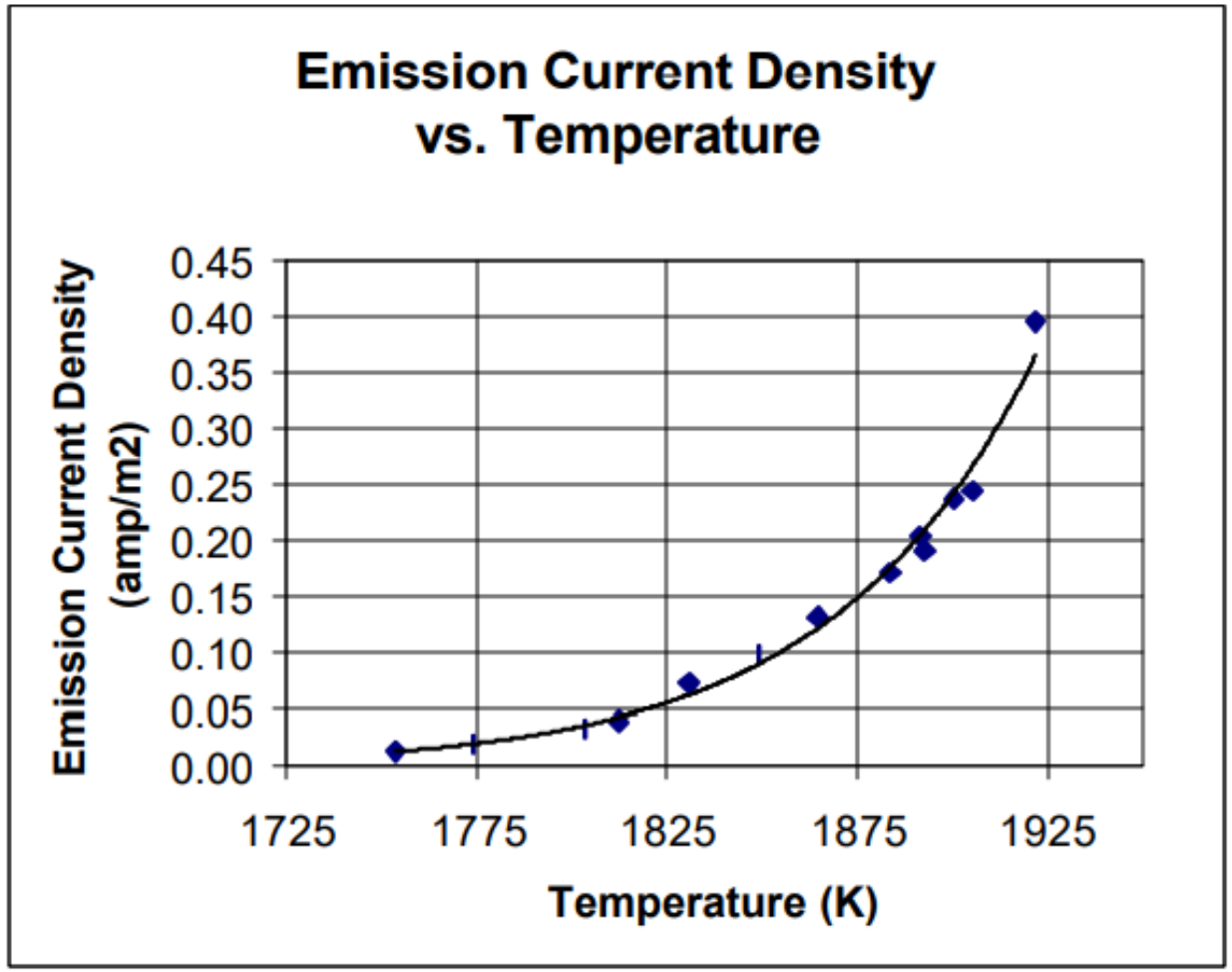
$$m_{slope} = -\phi/k \tag{9}$$

$$\phi = -m_{slope} \bullet k \tag{10}$$

$$\phi = \text{-}(\text{-}27394 \text{ Kelvin}) \bullet (1.371 \times 10^{-23 \text{ Joule}/\text{Kelvin}}) \tag{11}$$

$$\phi = \frac{3.756 \times 10^{-19} \text{Joules}}{1.602 \times 10^{-19 \text{ Joules}/\text{eV}}} \tag{12}$$

$$\phi_{experimental} = 2.34 \text{ eV} \tag{13}$$


Emission Current Density
vs. Temperature
Emission Current Density
(amp/m2)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1725
1775
1825
1875
1925
Temperature (K)