Thermionics

Thermionics → is the name which has been given to that branch of Physics which deals with the liberation of electrons from metals and other substances. The emission of electrons from the metal heated metals is known as Thermionic and liberate electrons are called Thermions. Moreover the phenomenon of the thermionics is the base of the whole science of electronics.

The first theoretical interpretation of Thermionic emission was given by Richardson on the basis of Classical electron theory of metals.

Richardson → Concluded that the emitted electrons were normally present in a metal and were responsible for the electrical conductivity and again the electrons in the metal behave like molecules in a perfect gas. and, therefore, have a velocity distribution according to Maxwell's Law for a monoatomic gas. The electron can escape from the metal if the K.E due to its velocity normal to the surface is equal to eV.

where, e = electronic charge
V = Pot. difference between the normal surface and the surrounding vacuum

Calculation → $K.E = \frac{1}{2}mu_0^2 = eV$

or, $\frac{1}{2}mu_0^2 = \phi$ $[\because \phi = eV]$ & u_0 = normal component of the velocity

or, $u_0^2 = 2\phi/m$

$\therefore u_0 = \sqrt{2\phi/m}$ ← (1)

ϕ is called the work function which is the work done in removing an electron from the surface.

applying the principles of kinetic theory a relation between the thermionic **Thermionic Current** ← current and the temp of the emitter was obtd as follows:—

Let n = no. of free electrons/c.c in the interior of the metal at T^0K

dn = no. of electrons/c.c having velocity component normal to the surface between u and $u+du$.

According to Maxwell's law

$$dn = n\sqrt{\frac{m}{2\pi kT}}\ \epsilon^{-\frac{mu^2}{2kT}}\ du \quad \text{—— (2)}$$

where T = Absolute temperature
k = Boltzman's Constant
m = mass of electron

∴ The no. of electrons going out per square cm of the surface, the surface being perpendicular to the direction $= \int_{u_0}^{\infty} u\,dn$.

∴ Intensity of the electronic current emitted per square cm of the surface of the metal

$$I = e\int_{u_0}^{\infty} u\,dn$$

or, $$I = ne\sqrt{\frac{m}{2\pi kT}}\int_{u_0}^{\infty} \epsilon^{-\frac{mu^2}{2kT}}\, u\,du$$

or, $$I = \frac{ne}{2}\sqrt{\frac{m}{2\pi kT}}\int_{u_0}^{\infty} \epsilon^{-\frac{mu^2}{2kT}}\, 2u\,du \quad \text{—— (3)}$$

Let $x = u^2$ and $\frac{m}{2kT} = \alpha$

∴ $dx = 2u\,du$

Substituting the value of u^2 in (3) we get

$$I = \frac{ne}{2}\sqrt{\frac{m}{2\pi kT}}\int_{u_0^2}^{\infty} \epsilon^{-\alpha x}\, dx$$

$$= \frac{ne}{2}\sqrt{\frac{m}{2\pi kT}}\left[-\frac{\epsilon^{-\alpha x}}{\alpha}\right]_{u_0^2}^{\infty}$$

or, $$I = \frac{ne}{2}\sqrt{\frac{m}{2\pi kT}}\left[-\frac{\epsilon^{-\alpha u_0^2}}{\alpha}\right]$$

$$= \frac{ne}{2}\sqrt{\frac{m}{2\pi kT}}\left[\epsilon^{-\frac{m u_0^2}{2kT}} \times \frac{2kT}{m}\right]$$

$$I = ne\sqrt{\frac{kT}{2\pi m}}\ \epsilon^{-\frac{mu_0^2}{2kT}}$$

$\frac{1}{2}mu_0^2 = \phi$

$mu_0^2 = 2\phi$

$$\cancel{= ne\sqrt{\frac{k\phi}{2\pi m}}\ [illegible]\ T^{1/2}\ \epsilon^{-b/T}}$$

$$= ne\sqrt{\frac{k}{2\pi m}}\ \epsilon^{-\frac{2\phi}{2kT}}\cdot T^{1/2}$$

$$= ne\sqrt{\frac{k}{2\pi m}}\ \epsilon^{-b/T}\cdot T^{1/2} \quad \left[\because b = \phi/k\right]$$

$$\boxed{I = AT^{1/2}\,\epsilon^{-b/T}}$$

$$\boxed{I = A T^{1/2} e^{-b/T}}$$ where $A = ne\sqrt{\dfrac{k}{2\pi m}}$

T = absolute temp. of the emitter
(It is assumed that n does not vary with temp)

This equation is called Richardson's Equation. It plays a fundamental part in the study of electronics.

Now taking log of both the sides we get

$$\log I = \log A + \frac{1}{2}\log T - b/T$$

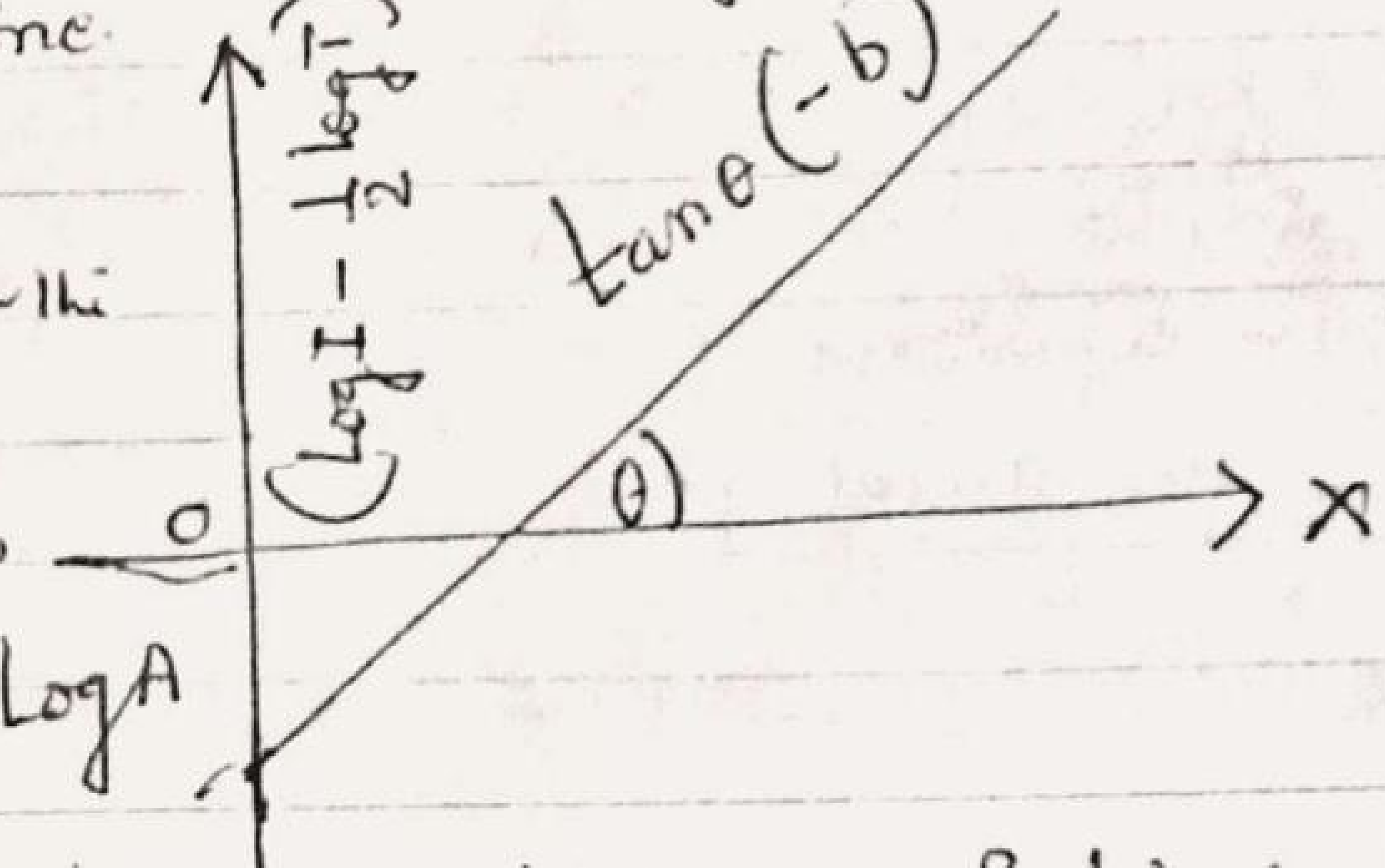
$$\text{or, } \left(\log I - \frac{1}{2}\log T\right) = \log A - b/T$$

Now plotting a graph taking $1/T$ along x-axis and $\left(\log I - \frac{1}{2}\log T\right)$ along the y-axis we get the nature of the graph a st. line

whose slope $\tan\theta = -b$.

and whose intercept on the y-axis equal to $\log A$.

The values of A and b thus obtained do not at all agree with those expected by theory.



~~But~~ So Richardson's equation was subject to objection ~~Criticism~~

The electrons inside the metal don't obey Maxwell's Law of velocity distribution on which the calculation was based.

Reasons → (1.) If the electrons follow the Maxwell's each electron would possess an average $K.E = \frac{3}{2}KT$.

But this contradicts by expt on sp. ht of the metals.

(2) In photo electric phenomenon the maximum K.E of the electrons which escape by Einstein's relation

$$\frac{1}{2}mV_{max}^2 = h\nu - \omega.$$

ν = frequency of the light
h = Planck's Constant
ω = Constant, depending on the nature of the metal.

Later on in 1921 S. Dushman modified this equation to the form

$$\left[I = AT^2 e^{-b/T} \right]$$

This equation is known as the Richardson-Dushman equation for temp limited current. This is probably more correct than the $T^{1/2}$-formula since it does not assume that n and ϕ are independent of T. Hence T^2-formula represents experimental facts better than the $T^{1/2}$-formula.