Expt. No. 4. **Fermi energy of a given metal**

Aim:

1) To study the variation of resistance with temp.
2) Use the slope of this linear graph obtained through LSF method to determine electrical conductivity ,relaxation time , mean free path and Fermi energy of a given metal (copper)

Apparatus:

Sample wire (copper) wound on an insulating material, Constant current power supply, digital milliammeter, digital millivoltmeter, heating arrangements, thermometer and cables.

Theory:

´**Fermi level'** is the term used to describe the top of the collection of electronic energy levels at absolute zero temperature. This concept comes from Fermi-Dirac Statistics (Quantum free electron theory). Electrons are fermions & by Pauli's exclusion principle cannot exist in identical energy levels. So at absolute zero they pack into the lowest available energy states and build up a **Fermi Sea** of electronic energy states, The Fermi level is the surface of that sea at absolute zero where no electrons have enough energy to rise above the surface. The concept of Fermi energy is very important for understanding the electrical & thermal properties of solids.

Both the electrical & thermal processes involve energies of a small fraction of electron volts. This implies that the vast majority of electrons cannot receive energy for these processes because there are no available energy states for them to go within a fraction of an electron volt of their present energy. At higher temperatures a certain fraction, characterized by the Fermi function, will exist above the Fermi level. For a metal, the density of conduction electrons can be implied from the Fermi energy. The Fermi energy also plays an important role in understanding the mystery of why electrons do not contribute significantly to the specific heat of solids at ordinary temperatures.

The expression for Fermi velocity is given by

Fermi velocity $V_F = \sqrt{\dfrac{2E_F}{m}}$

Where m = mass of the electron=9.1×10^{-31}Kg

E_F = Fermi energy

V_F = Fermi velocity

The number of free electrons in metal per unit volume is given by n = ρN / M

where N = Avogadro's number =6.023×10^{26} / K mole

ρ = density of the metal

M = mass number of the metal

The electrical conductivity of the metal is given by $\sigma = \dfrac{L}{Ra}$

where L = length of the metal wire

R= resistance at a reference temperature

A= area of cross section of the wire

The relaxation time is given by $\tau = \dfrac{\sigma\, m}{ne^2}$ Where e = electron charge = 1.602×10^{-19}C

If, V_F is Fermi velocity, the mean free path (λ_F) of electrons

$\lambda_F = V_F \,.\, T$

$E_F = V_F^2\ m / 2$

$$E_F = \frac{\lambda_F{}^2}{\tau^2}\frac{m}{2}$$ Substitute for T,

we get $$E_F = \frac{1}{2}\, m\, \lambda_F{}^2 \left(\frac{ne^2}{\sigma m}\right)^2 \qquad \because \tau = \frac{\sigma m}{ne^2}$$

Now substitute for σ, we get $$E_F = \frac{n^2 e^4 \lambda_f^2 R^2 a^2}{2mL^2} \qquad \because \sigma = \frac{L}{Ra}$$

Substitute for $a = \pi r^2$ & multiply and divide by T^2 we get

$$E_F = \frac{n^2 e^4 \lambda_f^2 R^2 \left(\pi r^2\right)}{2mL^2}\frac{T^2}{T^2}$$

or $$E_F = \left(\frac{\mathrm{ne}^2 \lambda_f \mathrm{T}\pi \mathrm{r}^2}{\mathrm{L}\sqrt{2\mathrm{m}}}\right)^2 \left(\frac{\Delta R}{\Delta T}\right)^2$$

$$E_F = \left[\frac{ne^2 \pi r^2 A}{L\sqrt{2m}}\right]^2 x\left(\frac{\Delta R}{\Delta T}\right)^2$$

Where $A = \lambda_F T$ = constant, r is the radius of the wire, L is the length of the wire & (ΔR/ ΔT) is the slope of the st.line of the graph of R Vs T.

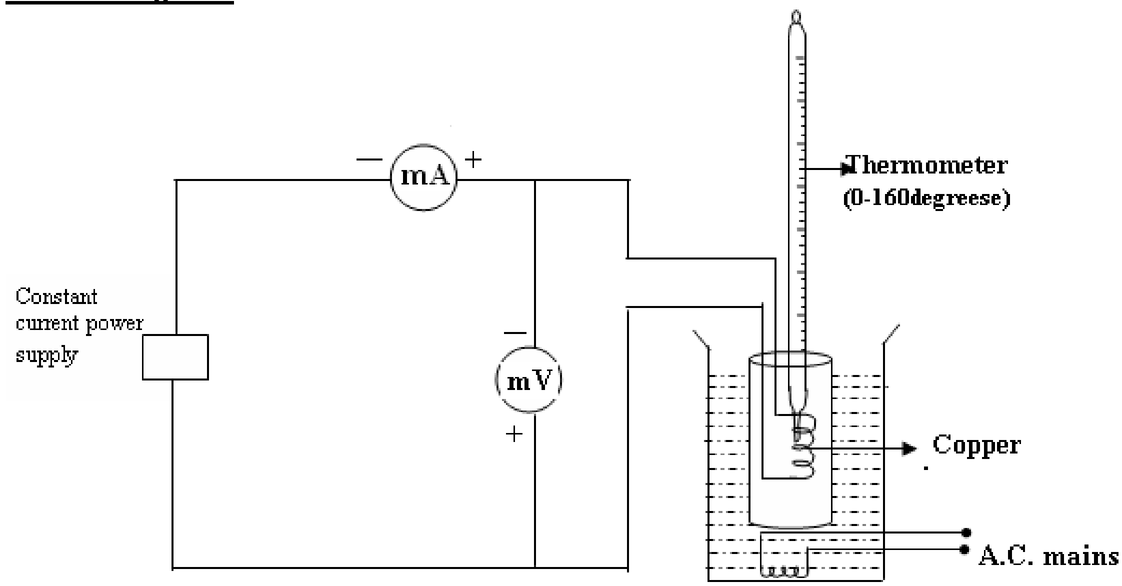
Procedure:

- The connections are to be made as shown in the circuit diagram
- A thermometer is immersed in the beaker containing copper coil.
- When the thermometer attains high steady temperatures, the temperature and corresponding voltage & current are noted down.
- The trial is repeated taking voltage & current readings for the interval of 5^0C until the temperature reaches 45^0C.
- A graph is drawn taking temp in degree Kelvin along X-axis & the resistance on Y-axis .The slope (ΔR/ΔT) of the straight line is calculated.
- Hence the Fermi energy is calculated using the formula

$$E_f = .\left[\frac{ne^2 \pi r^2 A}{L\sqrt{2m}}\right]^2 x\left(\frac{\Delta R}{\Delta T}\right)^2 = \ldots\ldots\ldots\ldots \text{eV.}$$

where $A = \lambda_F T$ = constant = for the temperature 318K, L is the length & r is the radius.

Circuit Diagram:



RECORD OF OBSERVATIONS:

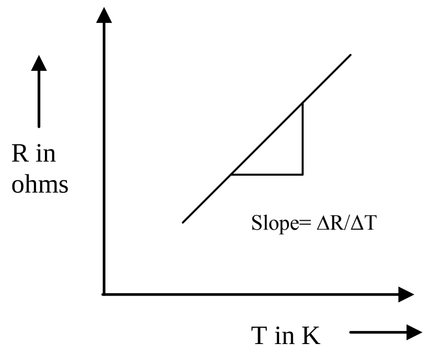
1. Length of the copper coil L =3.6 ± m
2. Radius of the copper wire r= 0.26± mm
3. Area of cross-sectional area = a = πr^2 = ……….± m^2

Given: Electron density n = 8.464×10^{28} Kg/mol.
Fermi velocity of the copper V_f = 1.57 ×10^6 m/s
Charge of the electron e= 1.6x10^{-19} Joules
Mass of electron m=9.1x10x^{-31} Kg

Tabulations:

	TEMPERATURE		VOLTAGE (MV) V	CURRENT (MA) I	RESISTANCE (Ω) R= V/I
	^{0}C	K			
Error	±	±	±	±	
	80				
	75				
	70				
	65				
	60				
	55				
	50				
	45				

Nature of graph:



Calculations:

At 318 degree K,

1. Electrical conductivity $\sigma = L / Ra =$ ………/ Ώm

2. Relaxation time $\tau = \frac{\sigma\, m}{ne^2}$ = ……………sec

3. Mean free path $\lambda_F = V_F\ \tau =$ ……………..m

3. Constant $A = \lambda_F\ T =$ ………………..

5. Fermi energy $E_f = \left[\frac{ne^2 \pi r^2 A}{L\sqrt{2m}}\right]^2 x \left(\frac{\Delta R}{\Delta T}\right)^2$ = …………Joules

where ($\Delta R / \Delta T$) is the slope of the graph.

/ 1.6×10^{-19}= eV

Results:

Fermi energy = E_F = ----------------eV

Estimation of percentage error:

Obtained value of E_F =………..eV

Standard value of **(E_F) = 7.28 eV** (for copper) **(Literature value)**

% of error = (Standard value-obtained / Standard value) x 100 =....
Allowed % of error = ±20%

Viva Questions:

1) What is Fermi energy?
2) Define the relaxation time and Fermi velocity?
3) Define Fermi-Dirac distribution
4) Define Pauli's Principle
5) Is Fermi energy depends on temperature?

Moore's law, an observation made by Intel co-founder Gordon Moore in 1965, notes that the transistor density on integrated circuits doubles every year or so.