Experiment: 4

DETERMINATION OF FERMI ENERGY

AIM: To determine the Fermi energy and Fermi temperature of the given metal wire.

APPARATUS: Heating arrangement, copper wire, thermometer and multimeter.

INTRODUCTION:

"Fermi level" is the highest energy level occupied by the valence electrons (free electrons in metals) at absolute zero temperature. This concept comes from Fermi – Dirac statistics. Electrons are fermions and by the Pauli's Exclusion Principle cannot exist in identical energy states. So at absolute zero they pack into the lowest available energy states and build up a "Fermi sea" of electron energy states. At absolute zero no electrons have enough energy to occupy any energy levels above the Fermi level. In semiconductors the Fermi level sits between the valence band and the conduction band. The size of the so called band gap between Fermi level and the conduction band determines if the metal is a conductor, insulator and semiconductor.

The concept of the Fermi energy is important for the study of metals, insulators, semiconductors and in understanding other material properties such as electrical and thermal conductivity. Knowledge of the Fermi energy of a material allowed deeper study in many areas of science, such as the thermal and electrical properties of non-conductive materials, like diamonds, electron tunneling and the kinetics of free electrons. The concept of Fermi energy allowed us to understand more about the interactions of electrons and the correlation between energy states and physical properties. Both ordinary electrical and thermal processes involve energies of a small fraction of an electron volt. But the Fermi energies of metals are of the order of few electron volts. This implies that the vast majority of the electrons cannot receive energy for these processes because there are no available energy states for them to go to 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.

Further, in metals, Fermi energy gives us information about the velocities of the electrons which participate in ordinary electrical conduction. The Fermi velocity V_F of these conduction electrons can be calculated from the Fermi energy E_F using ($E_F = ½ mV_F^{\,2}$) the relation,

$$V_F = \sqrt{\frac{2E_F}{m}} \qquad (1)$$

Where m = 9.1×10^{-31} kg is the mass of electron.

E_F is Fermi Energy

V_F is Fermi Velocity

This speed is a part of the microscopic Ohm's Law for electrical conduction. A Fermi gas is a collection of non-interacting fermions. It is quantum mechanical version of ideal gas. Electrons in metals and semiconductors can be approximately considered as Fermi gases. The energy distribution of the fermions in a Fermi gas in thermal equilibrium is determined by their density, the temperature and the set of available energy states using Fermi-Dirac statistics. It is possible to define a Fermi temperature below which the gas can be considered degenerate. This temperature depends on the mass of the fermions and the energy. For metals, the electron gas's Fermi temperature is generally many thousands of Kelvin, so they can be considered degenerate. Since energy possessed by the free electrons at thermal equilibrium is directly depends on **T** (E = kT), Fermi temperature T_F can be obtained by the relation

$$E_F = kT_F \qquad (2)$$

Where k = 1.38 x 10^{-23} J K^{-1} is Boltzmann constant.

FORMULAE:

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

Where E_F is the Fermi energy of the material of the given coil in J
n is the number density of electrons in m^{-3}
m is the mass of electron in kg

e is the charge of the electron in C

A is λ_F X T

λ_F is the mean free path of electrons in m

T is the reference temperature of the wire in K

r is the radius of the copper wire in m

L is the length of the copper wire in m

$\frac{\Delta R}{\Delta T}$ is the slope of the straight line obtained by plotting resistance of the metal against absolute temperature of the metal in ΩK^{-1}

Also, Fermi Energy can be written as, $E_F = C\left(\frac{T}{R}\right)^2\left(\frac{\Delta R}{\Delta T}\right)^2$

Where, C = constant = 11.22 x 10^{-19} J and

R is resistance at reference temperature T

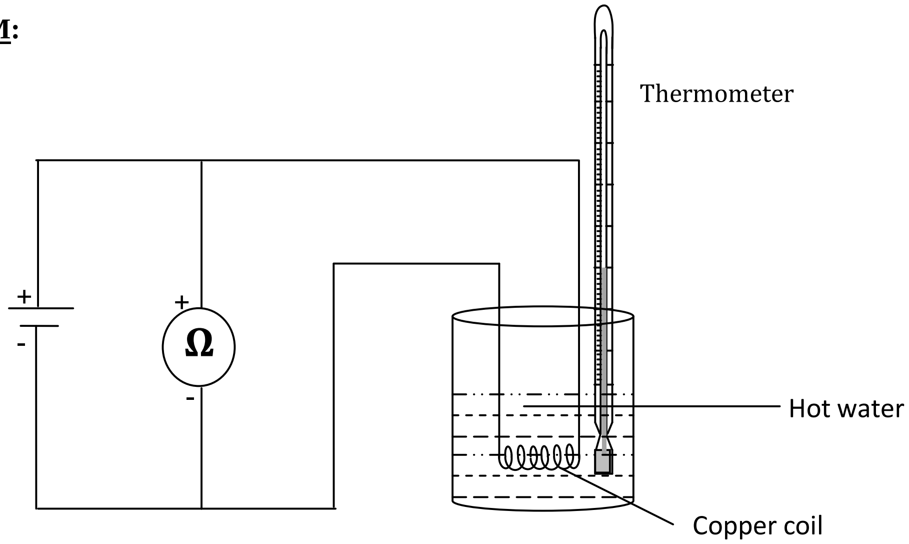
(b) $T_F = E_F / k$

Where, T_F is the Fermi temperature in K

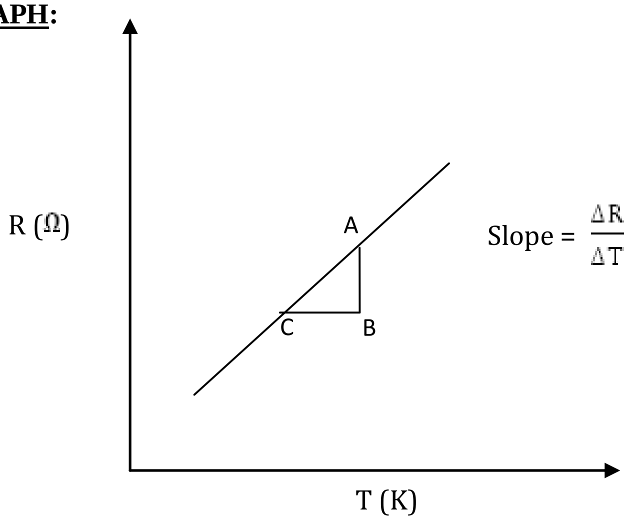
K = Boltzmann constant = 1.38×10^{-23} J/K,

E_F is Fermi energy in J

CIRCUIT DIAGRAM:



NATURE OF GRAPH:



TABULAR COLUMN:

Temperature		Resistance (Ω)
T (ºC)	T (K)	
85		
80		
75		
70		
65		
60		

PROCEDURE:

1. The connections are to be made as shown in the circuit diagram

2. Thermometer is immersed in the glass test tube containing copper coil.

3. The water is heated to a temperature around 85 ºC.

4. The value of resistance to be noted from the multimeter at every interval of 5 ºC as the temperature gradually decreases up to 60 ºC.

5. A graph is drawn taking temperature in kelvin along X-axis & the resistance on Y-axis .The slope (ΔR/ΔT) of the straight line is calculated.

6. Fermi energy and Fermi temperature are to be calculated using the given formulae.

RESULT:

1. The Fermi energy of the given metal is found to be $\mathbf{E_F}$ = ………………… J
   ………………. eV

2. The Fermi temperature of the given metal is $\mathbf{T_F}$ = ………………………… K

PROPORTIONAL ERROR CALCULATION:

$$E_F = C\left(\frac{T}{R}\right)^2\left(\frac{\Delta \mathrm{R}}{\Delta \mathrm{T}}\right)^2$$

$$\frac{\delta E_F}{E_F} = 2\left(\frac{\delta T}{T} + \frac{\delta R}{R}\right)$$

where, δT and δR are the least counts of the thermometer and ohmmeter respectively.

Result: The Fermi energy of the given material = $E_F \pm \delta E_F$
= ………………

References:

1. Solid State Physics, S O Pillai, New Age International publn, 6th Edn, (page 230-249).
2.University Physics, Hugh D Young, Pearson Education, Eleventh Edition, 1999, (Page 1627-1629,1708-1719).