MATERIAL SCIENCE (FORMULA NOTES)

Introduction

CONDUCTORS

Constants

Planck’s constant h = 6.626 × 10-34 J s

Rest mass of electron m = 9.109 × 10-31 kg

Charge of electron e = 1.602 × 10-19- C

Units

Quantity	SI units		Other units
	Unit	Symbol	
Resistivity ρ	Ohm metre	Ohm in	Micro ohm-inch, ohm-cm
Temperature coefficient of resistance α	Per Kelvin	K^{-1}	Per °F
Conductivity σ	Per ohm per metre	$ohm^{-1}\ m^{-1}$	Mho/cm
De Broglie wavelength λ	metre	m	Å
Wave number k	Per metre	m^{-1}	–
Kinetic energy E Fermi energy E_F	Joule	J	erg, eV
Drift velocity $\bar{v}$	metre per second	$m\ s^{-1}$	–
Field gradient ε	Volt per metre	$V\ m^{-1}$	Volts/mil
Current density Je	Ampere per m^2	$A\ m^{-2}$	Amp/cm2

THE FREE ELECTRON THEORY

The de Broglie wavelength of an electron λ is related to its momentum mv as

$$\lambda = \frac{h}{mv}$$

Where h is Plank's constant, m is the mass of the free electron and v is its velocity. The wavelength is inversely related to the magnitude of the wave number vector k:

$$K = \frac{2\pi}{\lambda}$$

As the velocity of the free electrons is much smaller than that of light, we can ignore relativistic effects and use the classical relation for kinetic energy E.

$$E = \frac{1}{2}mv^2$$

Substitute the above values from equations, we obtain

$$E = \frac{h^2k^2}{8\pi^2m}$$

CONDUCTION BY FREE ELECTRONS

The force experienced by an electron of charge e in an applied field of gradient 'ε' can be equated to the force as defined in the classical law:

$\varepsilon e = ma$

when m is the mass of the electron and a is the acceleration due to the applied field.

If the average collision time is τ and v_d is the drift velocity acquired by the electrons.

$$m(v_d/\tau) = \varepsilon e \text{ or } v_d = \frac{e\varepsilon\tau}{m}$$

The flux Je due to the flow of electrons is called the current density:

$$Je = nev_d = = \frac{ne^2\varepsilon\tau}{m}$$

where n is the number of free electrons of charge e. This is in the form of Ohm's law. As conductivity σ is by definition the flux per unit potential gradient, we have

$$\sigma = \frac{ne^2\tau}{m}$$

The electrical resistivity ρ is the reciprocal of conductivity.

INSULATING MATERIALS

A good insulating material should possess the following characteristics:

i. Large insulating resistance.

ii. High dialectic strength.

iii. Uniform viscosity—it gives uniform electrical and thermal properties.

iv. Should be uniform throughout—it keeps the electric losses as low as possible and electric stresses uniform under high voltage difference.

v. Least thermal expansion.

vi. When exposed to arcing should be non-ignitable.

vii. Should be resistance to oils or liquids, gas fumes, acids and alkalis.

viii. Should have no deteriorating effect on the material, in contact with it.

ix. Low dissipation factor (loss tangent).

ix. High mechanical strength.

x. High thermal conductivity.

xi. Low permittivity.

xii. High thermal strength.

xiii. Free from gaseous insulation to avoid discharges (for solids and gases).

xiv. Should be homogeneous to avoid local stress concentration.

xv. Should be resistant to thermal and chemical deterioration.

CLASSIFICATION OF INSULATING MATERIALS

The insulating materials can be classified in the following two ways:

A. Classification according to substances and materials.

B. Classification according to temperature.

A. Classification According to Substances and Materials:

i. Solids (Inorganic and Organic):
Mica, wood, slate, glass, porcelain, rubber, cotton, silk, rayon, terylene, paper and cellulose materials etc.

ii. Liquids (Oils and Varnishes): Linseed oil, refined hydrocarbon mineral oils, spirit and synthetic varnishes etc.

iii. Gases: Dry air, carbon dioxide, argon, nitrogen etc.

B. Classification According to Temperature:

Class	Insulating materials Included	Assigned limiting Insulating temperature
Y (Formerly O)	Cotton, silk, paper, cellulose, wood, etc., neither impregnated nor immersed in oil. Materials of Y class are unsuitable for electrical machines and apparatus as they deteriorate rapidly and are extremely hygroscopic.	90°C
A	Materials of class Y impregnated with natural resin, cellulose esters, insulating	105°C

	oils etc. Also included in this list are laminated wool, varnished paper.	
E	Synthetic resin enamels, cotton and paper laminates with formaldehyde bounding etc.	120°C
B	Mica, glass fibres, asbestos with suitable bonding substance, built up mica, glass fibre and asbestos laminates.	130°C
F	Materials of class B with bonding materials of higher thermal stability.	155°C
H	Glass fibre and asbestos materials, and built up mica, with silicon resins.	180°C
C	Mica, ceramics, glass quartz without binders or with silicon resins of higher thermal stability.	above 180°C

MAGNETIC MATERIALS

Magnetic materials are used in electric motors, transformers, loudspeakers, cranes, data processing, and in households. Hard magnets must retain their magnetization even in stray magnetic fields, and soft magnets must change their magnetization with the lowest possible resistance.

Magnetic Descriptions of Atoms & Ions

Diamagnetic - Atoms or ions with a closed shell of electrons, all of the electrons are paired.

Paramagnetic - Atoms or ions with unpaired electrons, where the moment of an atom with unpaired electrons is given by the spin, S, and orbital angular, L and total momentum, J, quantum numbers.

The field of the sample in the applied field is known as its magnetization, M, where H is the applied field.

The magnetic flux density, B, is given by:

$$B = \mu 0(H+M)$$

μ_0 is the permeability of free space, $4\pi \times 10^{-7}$ Hm^{-1}

where H is the symbol for henry

$\mu_0 H$ is the induction generated by the field alone

$\mu_0 M$ is the additional induction contributed by the sample

Typically, the magnetization is discussed in terms of the **magnetic susceptibility,**

$$\chi = \frac{M}{H}$$

Ferromagnetism – Magnetic moments of atoms align to produce a strong magnetic effect. For ferromagnetism, the Curie Law becomes χ = C / (T − Tc) , where T_C is the Curie Temperature.

Antiferromagnetism – magnetic moments of atoms align anti-parallel to produce a strong magnetic effect. For antiferromagnetism, the Curie Law becomes χ = C / (T + T_N), where TN is the Neel temperature.

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