AML 883 Selection and Properties of Engineering Materials

LECTURE 21: Origins of electrical properties and magnetic properties

M P Gururajan
Email: guru.courses@gmail.com
Office: MS 207/A-3
Phone Number: 1340

Resistivity

- Why does the electron not accelerate for ever?

Resistivity

- Why does the electron not accelerate for ever?
- Remember why heat took definite time to diffuse though the phonons themselves were travelling with the velocity of sound in the medium?

Resistivity

- Why does the electron not accelerate for ever?
- Remember why heat took definite time to diffuse though the phonons themselves were travelling with the velocity of sound in the medium?
- Mean free path and scattering centres
- Drift velocity – over and above the thermal motion, a net transfer of charge resulting in current

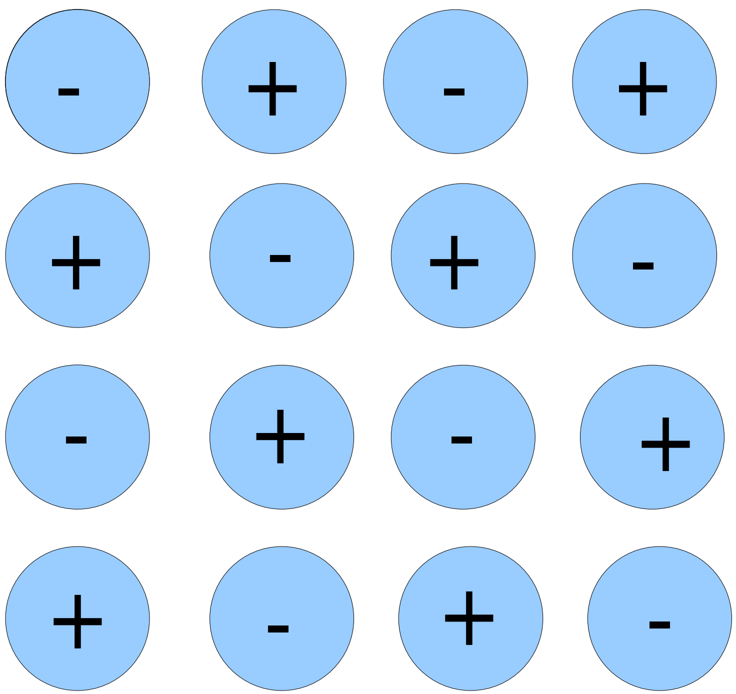
Resistivity

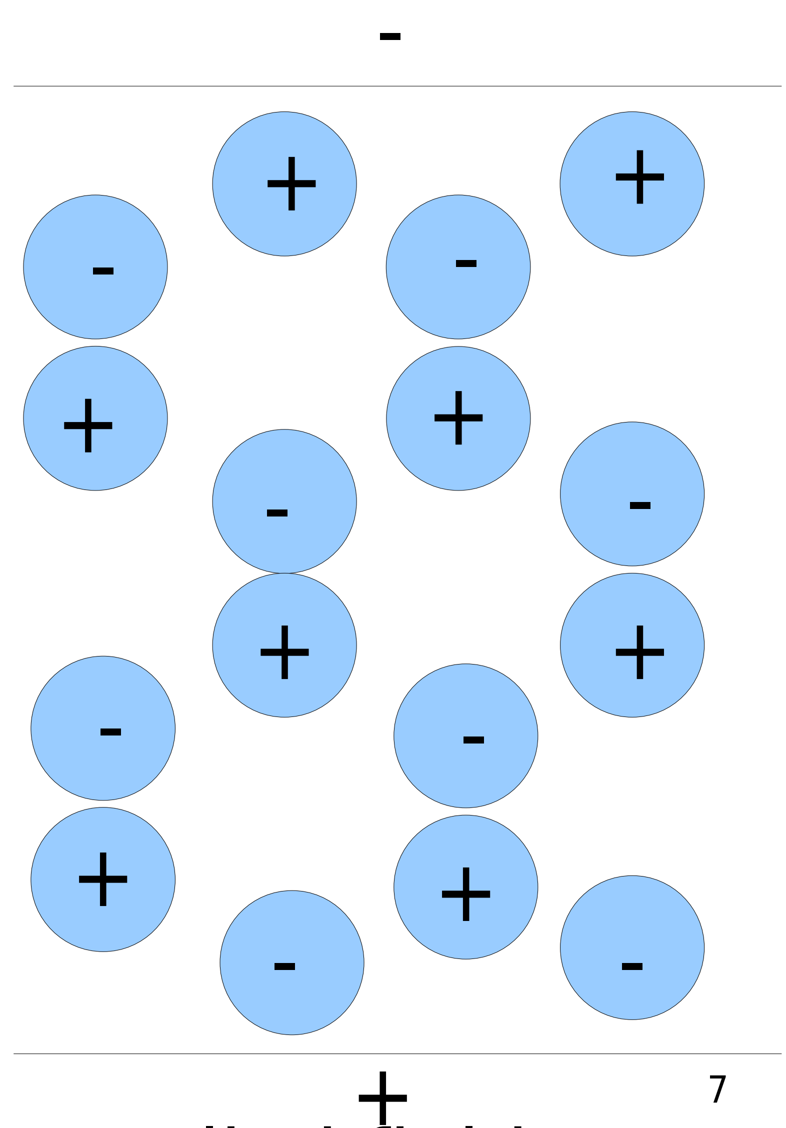
- Drift velocity is small compared to thermal velocities
- However, net current due to the thermal motion is zero
- Conductivity: $n_v e \mu_e$
- Resistivity: inverse of conductivity

Resistivity

- Any impediment decreases mean free path (resulting in a decrease of mobility)
- Explains why strengthening also leads to an increase of resistivity
- With increasing temperatures, resistivity increases (for metals) -- why?
- What happens in semi-conductors? Why?

Dielectrics





An ionic crystal with and without applied fields

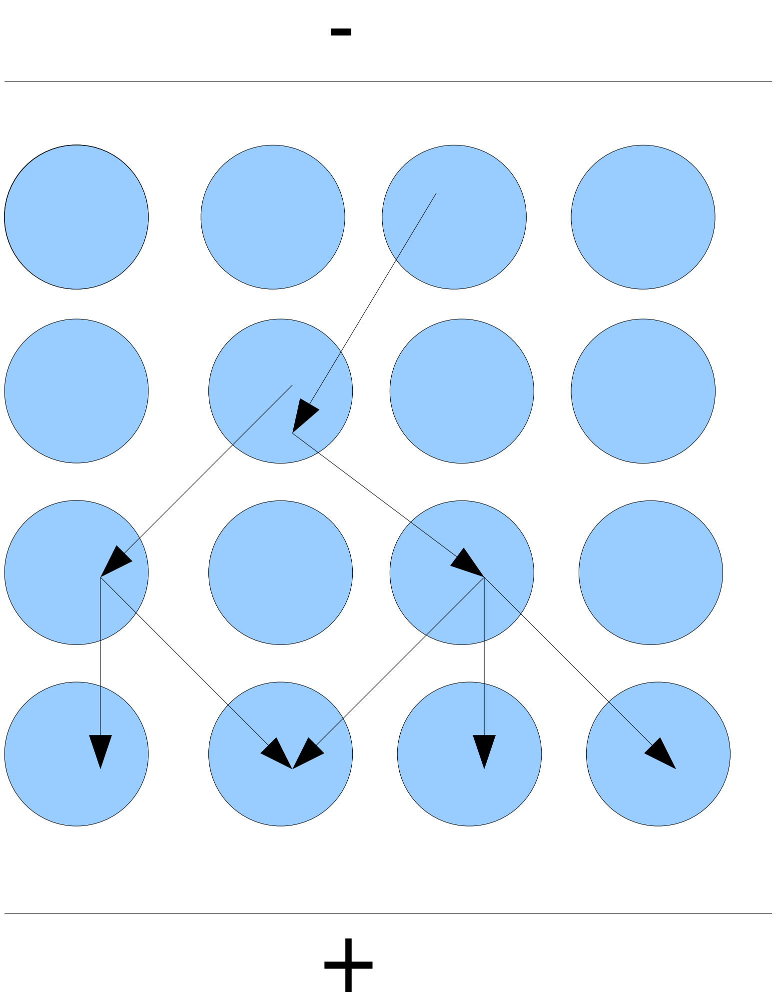
Dielectrics

- Dipole moment of charges -q and +q separated by distance x is qx
- Polarization: dipole moments per unit volume
- Materials that are not ionic (like silicon) also develop dipole moment
- Number of charges per unit volume and amount of displacement – determine the dielectric constant

Dielectric loss

- Polarization in an alternating field
- Ions oscillate – more often than not, out of phase
- A molecule like water with its own dipole moment rotates
- In the process of rotations, the molecules interfere with each other, dissipating energy as heat

Dielectric breakdown



At first, electron gets ripped from a weak spot – defect with high concentration
Leads to accelerating electron
Leads to an avalanche
Exactly like lightning

s

Piezo-electric materials

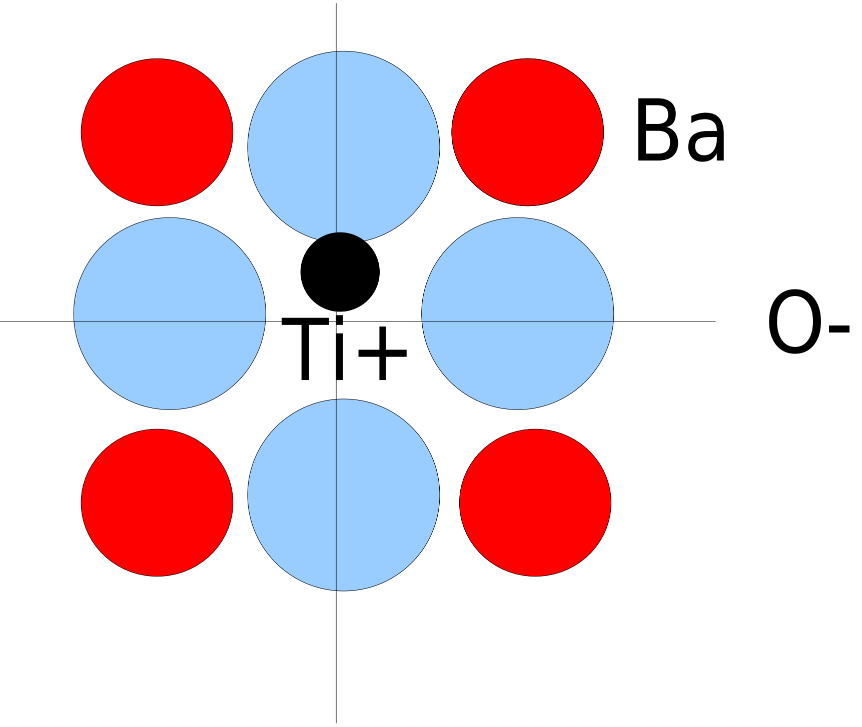
- Non-centrosymmetric crystals
- Each molecule carries a permanent dipole moment
- Surfaces are charged – collect ions and get neutralised
- Squeeze the crystal – dipole moment changes – surface charge changes – leads to a potential
- Potential can be big enough to lead to sparking – gas lighter
- Inverse is also true

Pyro-electric materials

- Materials with permanent dipole moment
- Temperature changes the structure such that the collected charges on surface flow since the net dipole moment has changed

Ferro-electric materials

- Special type of piezo-electric materials
- Unsymmetric structure but also the ability to switch asymmetry



Ferroelectric materials

- Above Curie temperature, asymmetry disappears
- Absence of external field, domain structure
- Applied field – polarization
- Poling
- Hysteresis curve – saturation polarization, remanent polarization, coercive field,

Magnetic Materials

Properties

Ampere's law

Current i through a coil of n turns and length L generates a magnetic field of magnitude H = ni/L (Amps/Metre)

Magnetic field is a vector field

Force on a wire

A current i flowing in a single loop of area S generates a dipole moment of magnitude m = iS (A. metre squared)

Magnetic moment is a vector with its direction given by the normal to the area

Permeability of vacuum

Loop of area S carrying current i placed in a field H at right angles to the field, experiences a torque $T = \mu_0 m H$

(Units N m)

$$\mu_0 = 4\pi \, x \, 10^{-7} \, henry/metre$$

Permeability of vacuum

Magnetic induction or flux density

$$B = \mu_0 H \, Tesla$$

A magnetic induction of 1 Tesla exerts a torque of 1 Nm on a unit dipole at right angles to the field H

Magnetization

$$B = \mu_0 (H + M) = \mu_R \mu_0 H$$

$$M = (\mu_R - 1) H = \chi H$$

Suppose a material fills the coil: magnetization M (A/m)

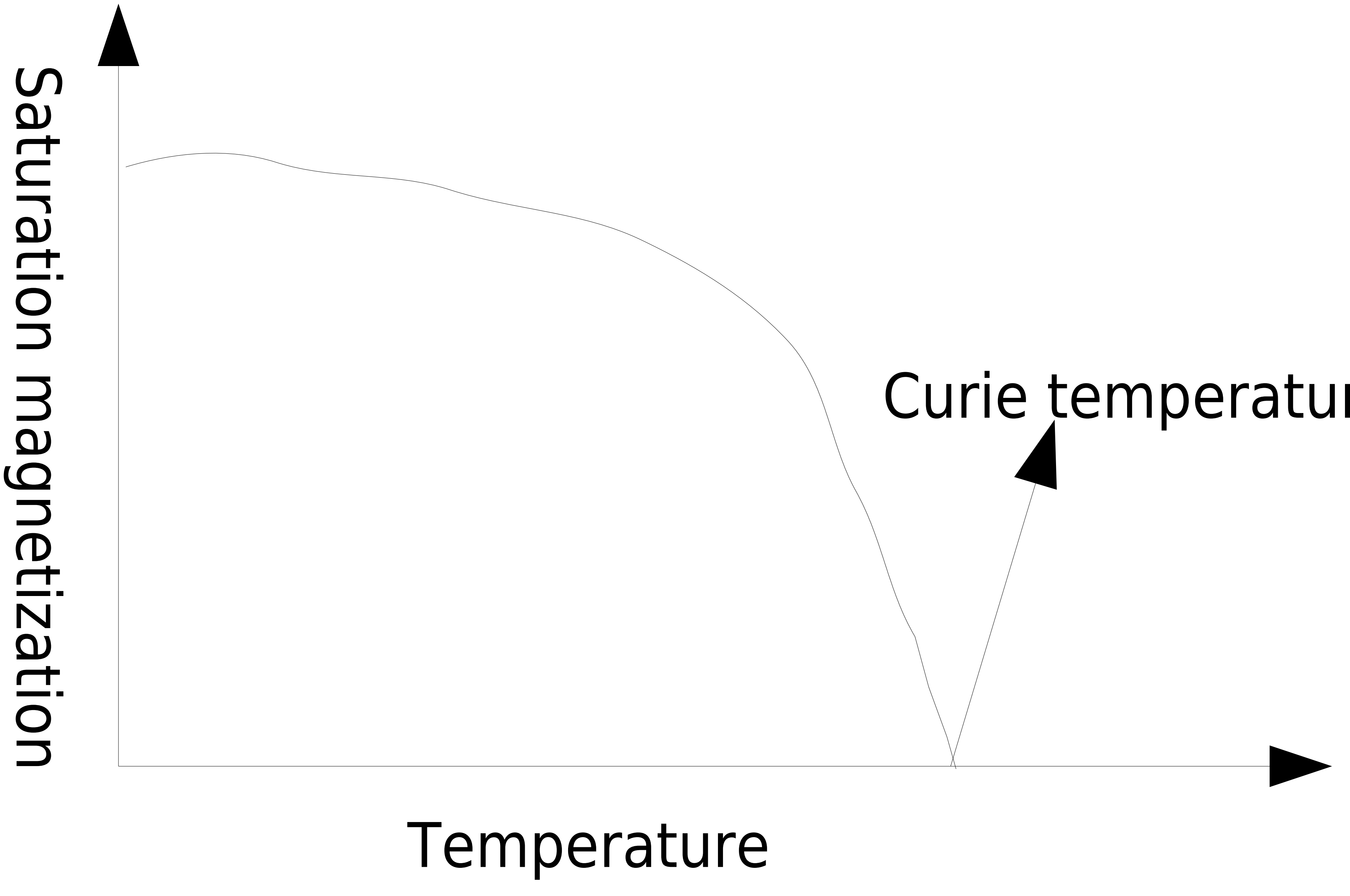
Relative permeability

Magnetic susceptibility

Permeability and susceptibility

- M is a response of the material to H
- M and H are coupled
- Relative permeability and magnetic susceptibility are not only material dependent but also dependent on H, applied field
- Paramagnetic – magnetization in the magnetic field is negligible
- Ferro- and ferri-magnetic – strong magnetization

Saturation magnetization



Magnetic properties measurement

- Field versus magnetization
- Hysteresis loop
- Coercive field, saturation magnetization, remanent magnetization
- Fat and thin loops – hard and soft magnets
- Charts – remanence and coercive field, saturation magnetization and susceptibility