AML 883 Selection and Properties of Engineering Materials

LECTURE 22: Magnetic properties

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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

$$T = \mu_o m H$$

(Units N m)

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

Permeability of vacuum

Magnetic induction or flux density

$$B = \mu_o H \, Tesla$$

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

Magnetization

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

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

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

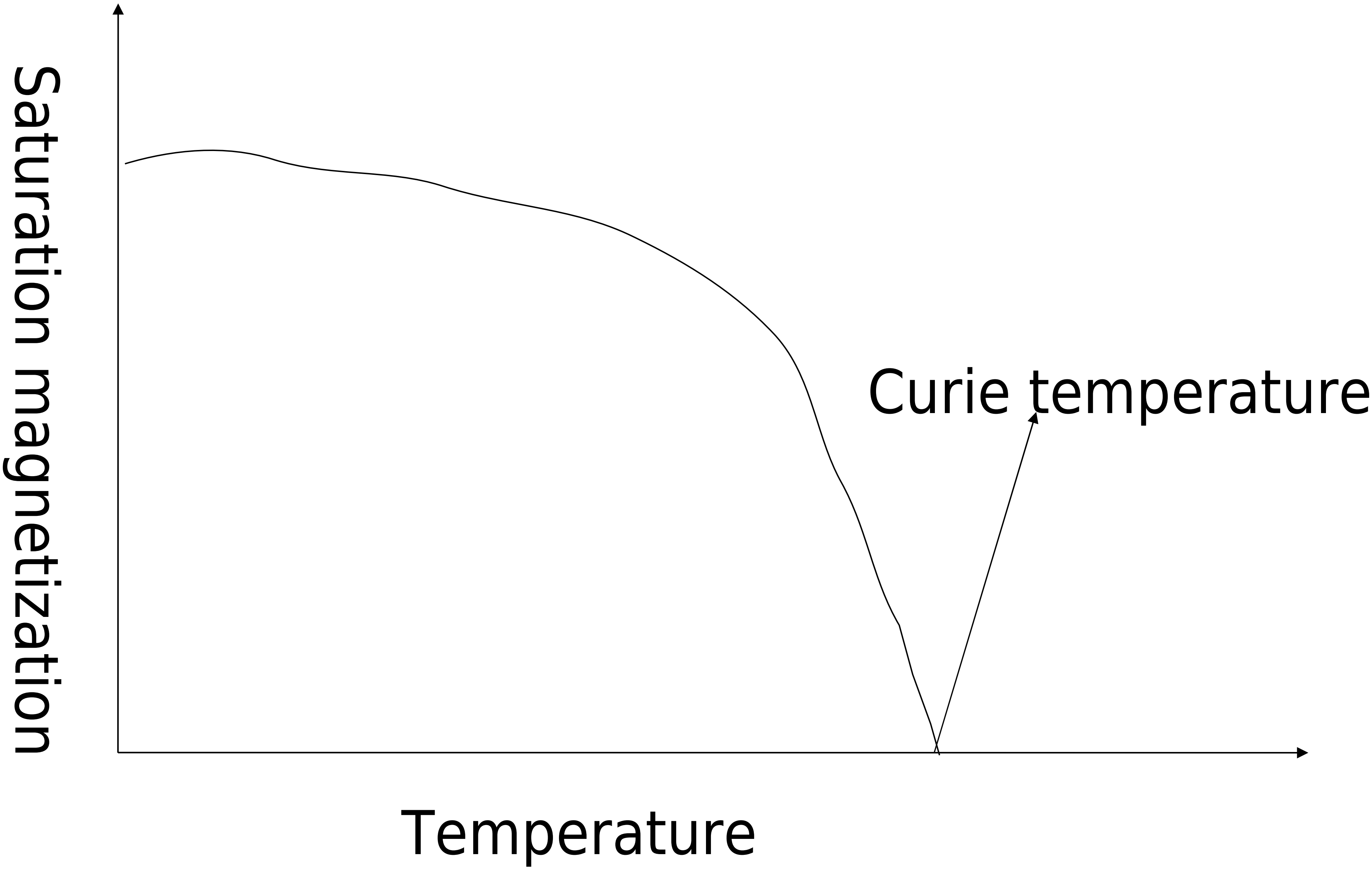
Relative permeability

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

Applications

- Soft – easy to magnetize, high flux densities and easy to demagnetize
- Thin hysteresis loop with steep magnetization curve in the beginning
- Permendur (Fe-Co-V) alloys, Metglass, Silicon (1-4%)-Fe alloys, Ni-Fe, cubic ferrites
- Hysteresis and eddy current losses (and their dependence on frequency)

Applications

- hard – high remanence and high coercive field (hard to demagnetize)
- Fat hysteresis loop
- Alnico, hexagonal ferrites, samarium cobalt, neodymium-iron-boron

Applications

- Storage -- hard magnets with a squarish hysteresis loop
- Magnetic read/write – soft core in head and small stable domains embedded in a background with opposite direction of magnetization
- Rewritable – Fe_2O_3, CrO_2 – 0.1 micron long with aspect ratio of 20:2
- Hexagonal ferrites – read only

Origins of magnetism

- Orbital movement of electrons
- Spin
- Unpaired electrons – each give one Bohr magneton moment
- Paramagnetic
- Exchange energy
- Ferro, anti-ferro and ferri-magnetism
- Curie temperature
- Domains – why? Minimization of external field

Origins of magnetism

- Lorentz force
- Saturation magnetization
- Iron
- Why make alloys if iron is the best? Coercive field – pin the domain walls
- Magnetically hard is mechanically hard too – why?
- Magnetic anisotropy
- Energy product – roughly area of the magnetization loop