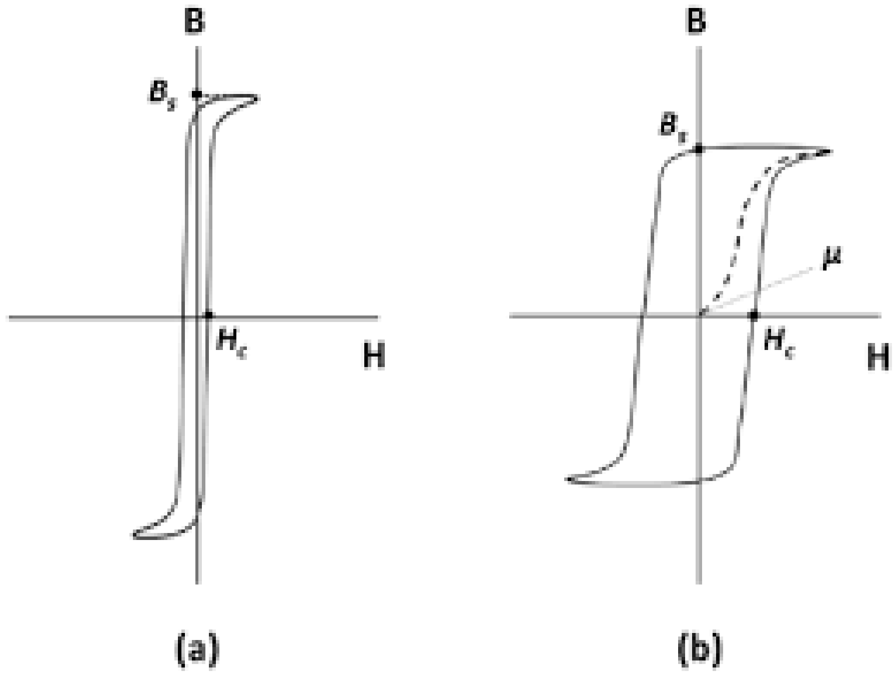
CHAPTER 12

Magnetic Materials

Classification: Mechanic response

Soft	Hard
Easily magnetized	Almost impossible to magnetized
Lose of magnetic behavior	Don’t lose magnetic behavior
Large values of susceptibility and permeability	Small values of permeability and susceptibility
Electromagnets	Permanent magnets
Fe-Si, Fe-Ni, ferrites…	Fe-Ni-Al, Co-Alloys

Magnetic field, permeability and magnetization



- Electric current through a coil with n turns produces a magnetic field.

$$H = n\frac{I}{l}$$

- n: number of turns
- l: length of the coil (m)
- I: is the current (A).
- H: Magnetic field (A/m) or oersted

  4πE-3 oersted = A/m

Example

An iron bar magnet having a coercivity of 4000 A/m is to be demagnetized. If the bar is inserted within a cylindrical wire coil (a solenoid) 25 cm long and having 150 turns, what electric current is required to generate the necessary magnetic field?

Electric current?

$$H = 4000\ A/\text{m}$$
$$n = 150$$
$$l = 25\ cm = 0.25m$$

Magnetic field, permeability and magnetization

- Permeability

$$\mu_r = \frac{\mu}{\mu_0}$$

$\mu > \mu_0$ If the magnetic moments are in the same direction of the applied field.

$\mu < \mu_0$ If the magnetic moments oppose the field.

μ_0: 4πE-7 H/m

- Magnetization

$$B = \mu_0 H$$

$$B = \mu H;\ B = \mu H + \mu M$$

$$M = \frac{\#\frac{at}{uc}\left(\#\frac{Magneton}{at}\right)\mu_B}{a_0^3}$$

$$X_m = \frac{M}{H} = \mu_r - 1$$

X_m: Magnetic susceptibility

M: Magnetization (A/m)

B: inductance (H or Teslas)

Moment of electrons: Bohr magneton (9.27×10^{-24} A·m²)

Example

Estimate the magnetization that might be produced in a bar made of Nickel.

- $a_0(Ni) = 3.52 \times 10^{-10}\ \mathrm{m}$

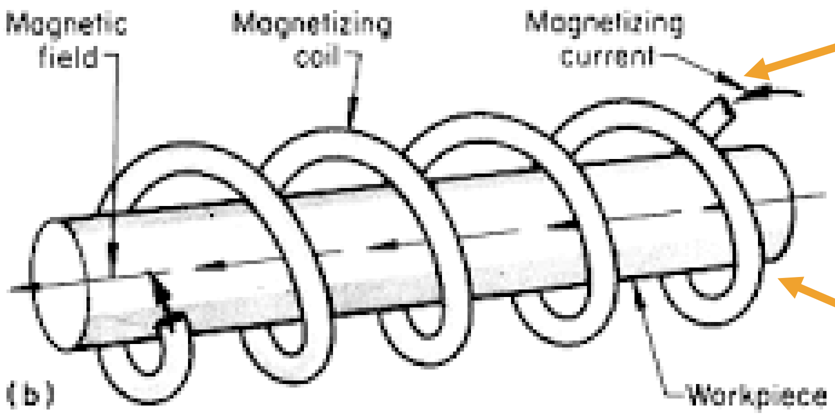
Magnetization?

$$a_0(Ni) = 3.52 \times 10^{-10}\ \mathrm{m}$$

$$Oxidation\ number = 2$$

$$FCC \rightarrow 4\frac{at}{uc}$$

Recap



M1= Material of the coil that will produce the magnetic field

$$H = n\frac{I}{l}$$

M2= Material that will be magnetized

$$B = \mu_0 H$$

$$B = \mu H + \mu M$$

$$M = \frac{\#\frac{at}{uc}\left(\#\frac{Magneton}{at}\right)\mu_B}{a_0^3}$$

Example

0.0015 at% of Ni is inserted in copper, this material maximum permeability of 4.5×10^{-3} H/m when an inductance of 3.5 $(A{\cdot}H)/m$^2 is obtained. The alloy is placed in a 20-turn coil that is 20 cm in length. What current must flow through the conductor coil to obtain this field?

$$a_0(Ni) = 3.52 \times 10^{-10}\ \mathrm{m}$$
$$a_0(Cu) = 3.61 \times 10^{-10}\ \mathrm{m}$$

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$$a_0(Cu) = 3.61 \times 10^{-10}\ \text{m}$$
$$Oxidation\ number\ of\ Ni = 2$$
$$FCC \rightarrow 4\,\frac{at}{uc}$$

$$\mu_{alloy} = 4.5 \times 10^{-3}\ H/\mathrm{m}$$

$$B = 3.5\frac{A \cdot H}{m^2}$$

$$n = 20$$

$$l = 20\ cm$$

Recap: units

$$H = n\frac{I}{l}$$

$$H = \frac{A}{m}$$

$$B = \mu_0 H$$
$$B = \mu H + \mu M$$

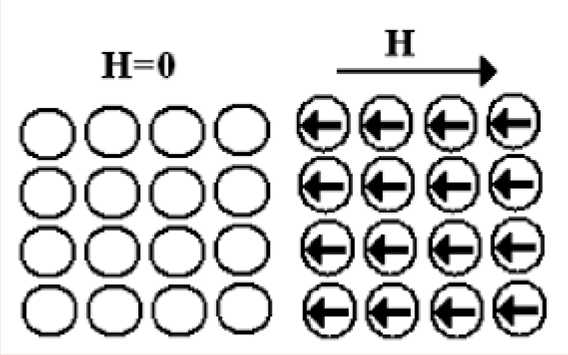
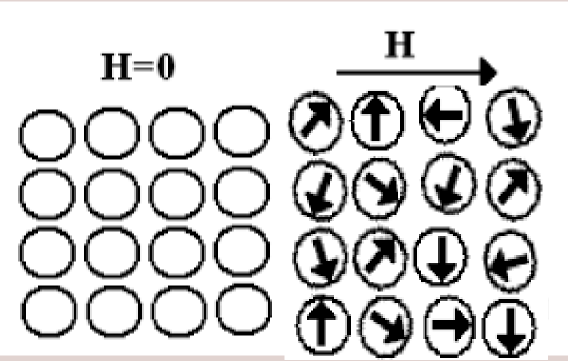
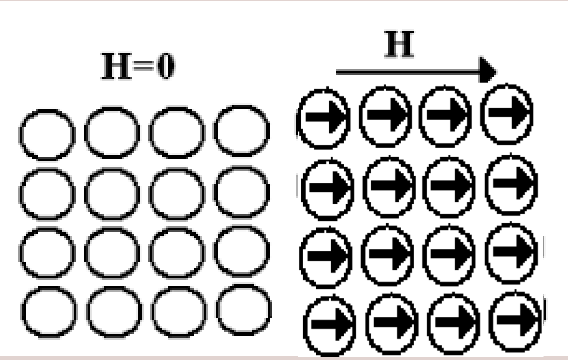
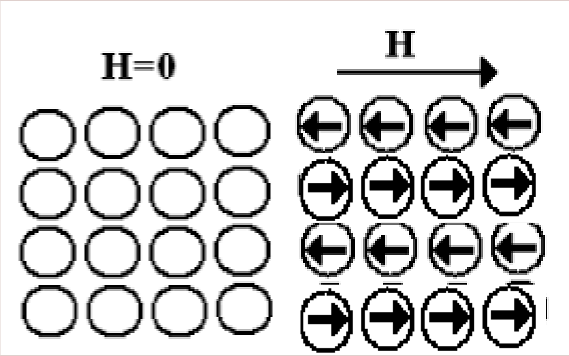
$$B = \frac{kg \cdot m}{s^2 \cdot A^2} \times \frac{A}{m} = \frac{kg}{s^2 A} = \mathrm{T} = \frac{A \cdot H}{m^2}$$

$$M = \frac{\#\frac{at}{uc}\left(\#\frac{Magneton}{at}\right)\mu_B}{a_0^3}$$

$$M = \frac{\#\frac{at}{uc}\left(\#\frac{Magneton}{at}\right)\frac{A \cdot m^2}{magneton}}{\frac{m^3}{uc}} = \frac{A}{m}$$

Classification: Magnetic RESPONSE

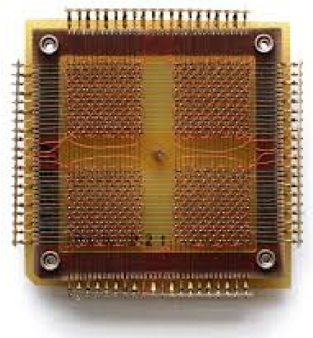
Curie Temperature: T at which ferromagnetic become paramagnetic.
Above this temperature, ferrimagnetic become paramagnetic

Diamagnetism	Paramagnetism	Ferromagnetism	Ferrimagnetism
Induced opposite magnetic dipole	Induced random magnetic dipole	Induced magnetic dipole	Induced magnetic dipole both parallel and opposite
Opposing magnetic fields	No interaction among dipoles	Amplify magnetic field	Amplify magnetic field
			
Gold, silver, copper, mercury	Calcium, aluminum, chromium	Iron, Cobalt	Zinc, Nickel and ceramics

Application: Soft magnets

Field of application	Products	Requirements	Materials
Power conversion electrical - mechanical	Motors Generators Electromagnets	Large **M** Small **H** Low losses = small conductivity low	**Fe** based materials, e.g. **Fe + Si** **Fe + Co**
Power adaption	(Power) Transformers		
Signal transfer	Transformer ("Überträger")	Linear **M - H** curve	

Application: HARD MAGNETS



Field of application	Products	Requirements	Materials
<u>Permanent magnets</u>	Loudspeaker Small generators Small motors Sensors	Large H_C (and M_R)	**Fe/Co/Ni/Al/Cu** $\mathbf{SmCo_5}$ $\mathbf{Sm_2Co_{17}}$
<u>Data storage analog</u>	Video tape Audio tape	Medium H_C(and M_R), hystereses loop as rectangular as possible	**NiCo, CuNiFe,** $\mathbf{CrO_2}$ $\mathbf{Fe_2O_3}$
Data storage digital	Ferrite core memory Drum		