Dielectric properties

- A dielectric material is an insulating material which can separate positive and negative charged entities

- Used in capacitors to store electrical energy or charge

- Capacitance is given by $C = \frac{Q}{V}$ Q is the charge stored between two oppositely charged layers subjected to voltage V

- If the two parallel plated are separated by a distance l in vacuum $C = \epsilon_0 \frac{A}{l}$

- If the plates are separated by a dielectric material $C = \epsilon \frac{A}{l}$

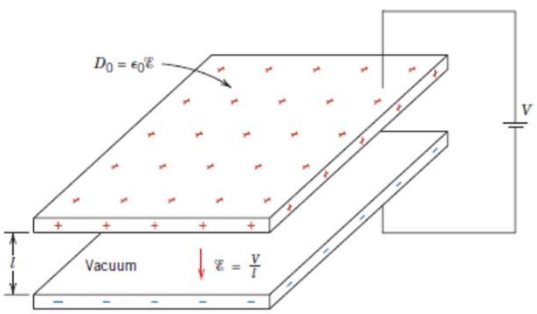
- ε_0 is permittivity of vacuum and $\varepsilon$is permittivity of the material

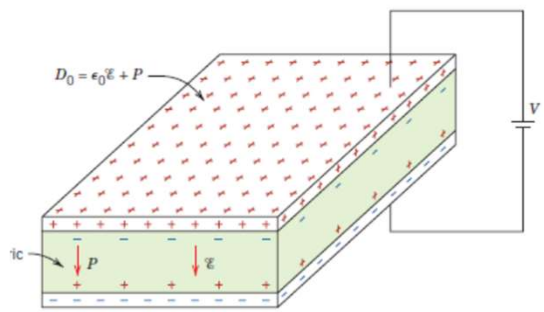
- $\varepsilon_0 = 8.85 \times 10^{-12}\ m^{-3}kg^{-1}s^{4}A^{2}\ (Fm^{-1})$

- Farad named after Michael Faraday, is the SI derived unit of capacitance describing the ability of a body to store charge

- Relative permittivity or dielectric constant

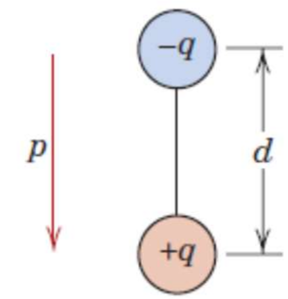
$$\epsilon_r = \frac{\epsilon}{\epsilon_0}$$





Capacitance and Polarization

- A pair of +ve and -ve charge gives rise to an electric dipole



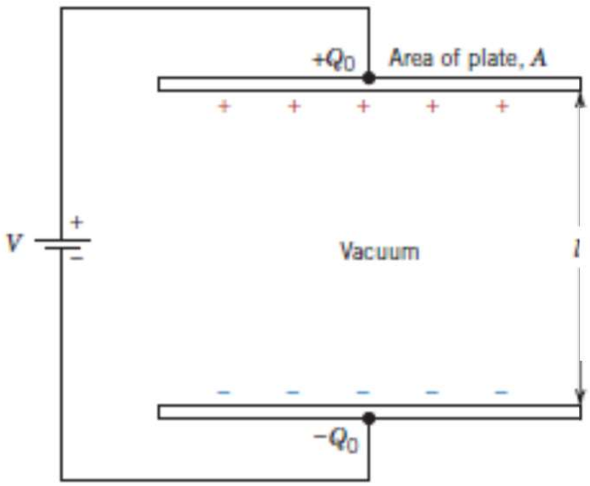
- Orientation of a dipole along the electric field is called polarization

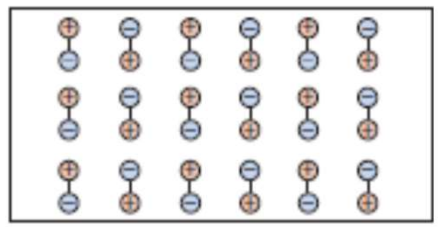
- It causes increase in charge density

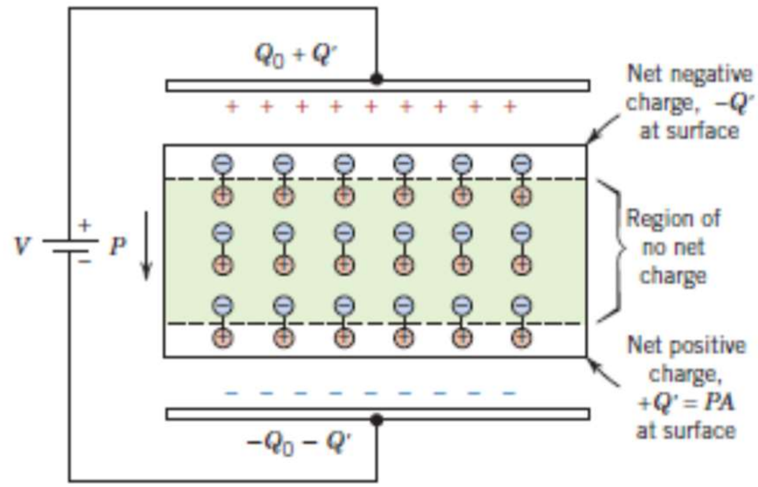
- D is surface charge density of a capacitor also known as dielectric displacement

$$D = \epsilon \mathscr{E}$$

$$D_0 = \epsilon_0 \mathscr{E}$$







(c)

$$D_0 = \epsilon_0 \mathscr{E}$$

$$D = \epsilon \mathscr{E}$$

$$D = \epsilon_0 \mathscr{E} + P$$

$$P = \epsilon_0(\epsilon_r - 1)\mathscr{E}$$

Types of Polarization

- Electronic polarization due to displacement of centre of electron cloud around the nucleus under the applied field

- Ionic polarization due to opposite displacement of anions and cations in the electric field

- Orientation polarization in materials with permanent dipole moment

- Space charge polarization at interfaces of heterogeneous materials

Table 18.5 Dielectric Constants and Strengths for Some Dielectric Materials

Material	*Dielectric Constant* 60 Hz	*Dielectric Constant* 1 MHz	*Dielectric Strength (V/mil)*[a]
		Ceramics	
Titanate ceramics	—	15–10,000	50–300
Mica	—	5.4–8.7	1000–2000
Steatite (MgO–SiO_2)	—	5.5–7.5	200–350
Soda–lime glass	6.9	6.9	250
Porcelain	6.0	6.0	40–400
Fused silica	4.0	3.8	250
		Polymers	
Phenol-formaldehyde	5.3	4.8	300–400
Nylon 6,6	4.0	3.6	400
Polystyrene	2.6	2.6	500–700
Polyethylene	2.3	2.3	450–500
Polytetrafluoroethylene	2.1	2.1	400–500

[a] One mil = 0.001 in. These values of dielectric strength are average ones, the magnitude being dependent on specimen thickness and geometry, as well as the rate of application and duration of the applied electric field.

Ferroelectric properties

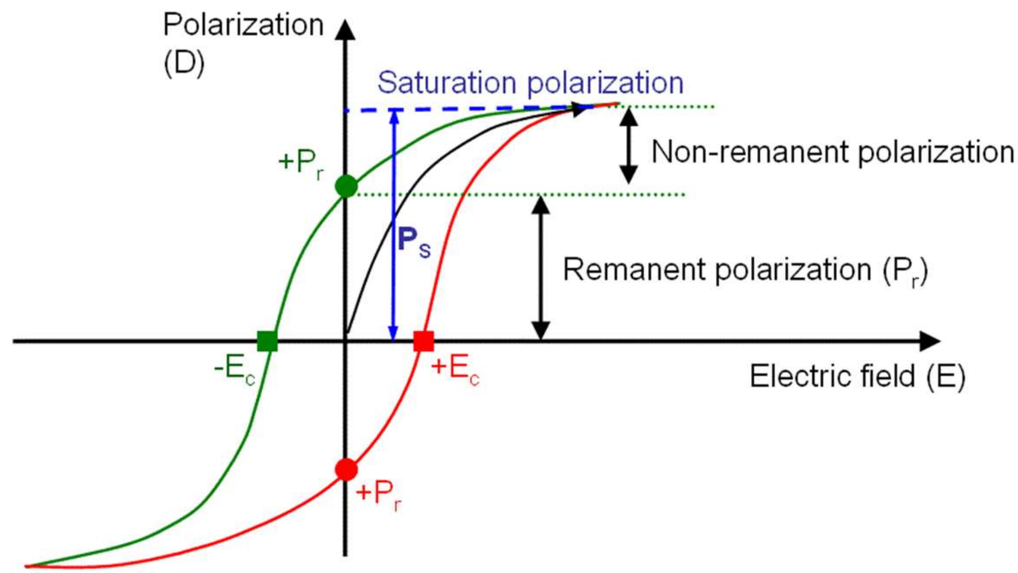
- A **ferroelectric** material is a polar dielectric for which a spontaneous dipole polarization can be switched between two or more equilibrium symmetry equivalent states by the application of an appropriate electric field.

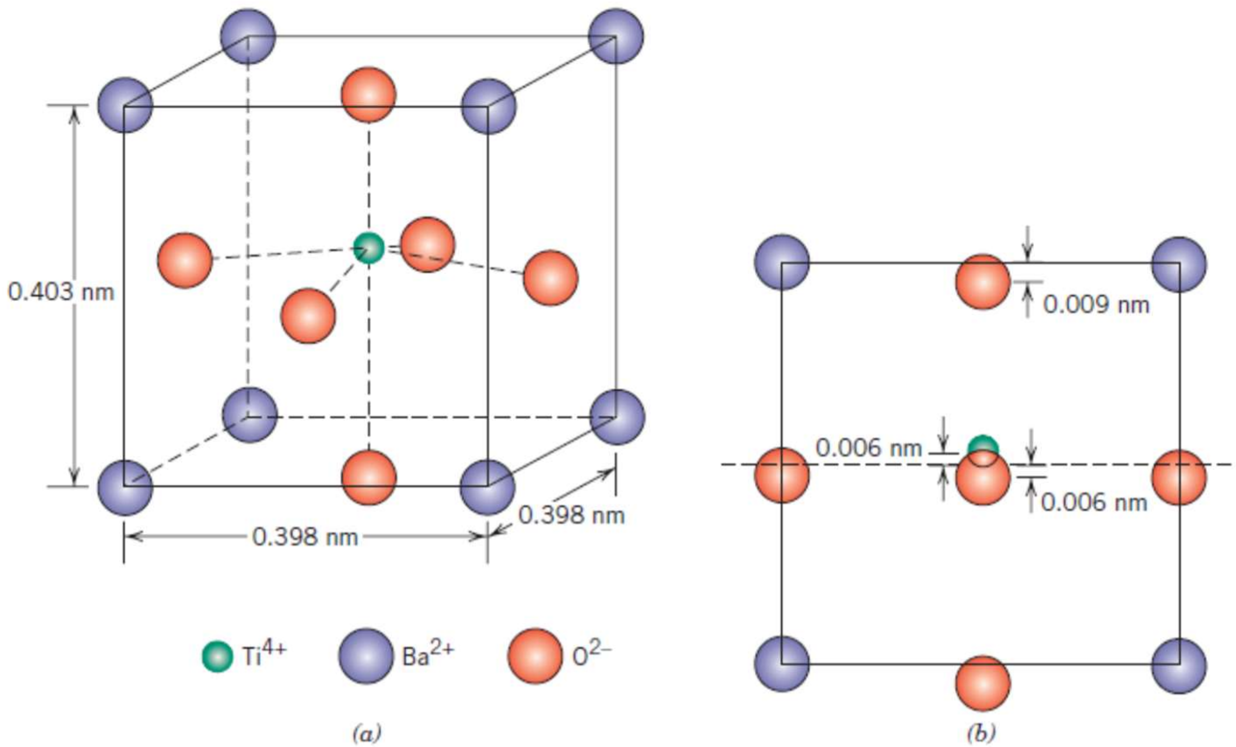
- Barium titanate, PZT

- Electric dipole and domain

- Ferroelectric RAM and RFID

- All ferroelectric materials are pyroelectric





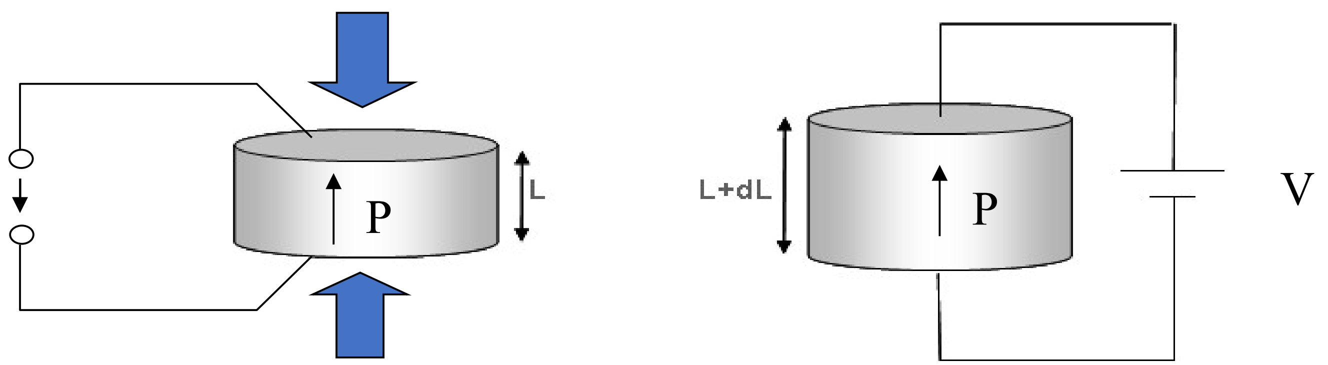
0.403 nm
0.398 nm
0.398 nm
Ti4+
Ba2+
O2–
(a)
0.009 nm
0.006 nm
0.006 nm
(b)

Pyroelectric materials

- Pyroelectricity can be described as the ability of certain materials to generate a temporary voltage when they are heated or cooled.
- The change in temperature modifies the positions of the atoms slightly within the crystal structure, such that the polarization of the material changes. This polarization change gives rise to a voltage across the crystal.
- Pyroelectric coefficient is the change in spontaneous polarization vector with temperature
- Electromagnetic radiation detection sensors $\boldsymbol{\rho_i = \frac{\partial P_{S,i}}{T}}$
- Not to be confused with thermoelectric effect that converts temperature change wrt distance not time to potential.

Piezoelectric properties

- Certain crystalline ionic materials when under mechanical stress leads to the formation of dipoles in the bulk giving rise to polarization charges on the external surface of this crystal (positive on one surface and negative on opposite surface) . This charge leads to development of voltage difference across the two surfaces.
- The reverse is also true for these crystals, i.e. if external bias is applied across it's two surfaces, there develops strain in the crystal, though very small.
- These two effects collectively define **Piezoelectricity**.



- Electric displacement D that is electrical flux density is related to strain by direct piezoelectric coefficient

$$D = \varepsilon E \ or \ D_i = d_{ijk} \, \varepsilon_{jk}$$

- 20 out of 21 non centrosymmetric point groups out of the total 32 point groups exhibit piezoelectricity

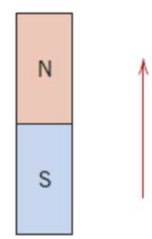
- Example include quartz, lead zirconate titanate (PZT)

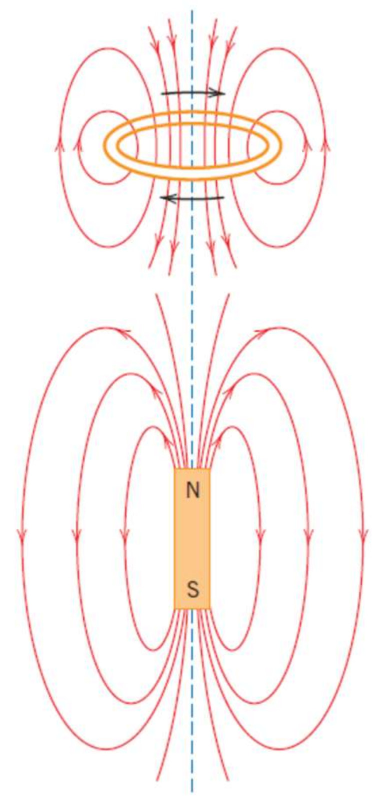
- Application in touch screen of devices, green energy generation in gym, lighter for ignition, pressure sensors

Magnetic properties

- Phenomenon of attraction or repulsion between objects
- Physical origins of magnetism is complex
- From motors to transformers to computers anc magnetic materials are everywhere
- Magnetic dipole comprising of north and soutl
- Magnetic field vector
- Magnetic field strength

$$H = \frac{NI}{l}$$





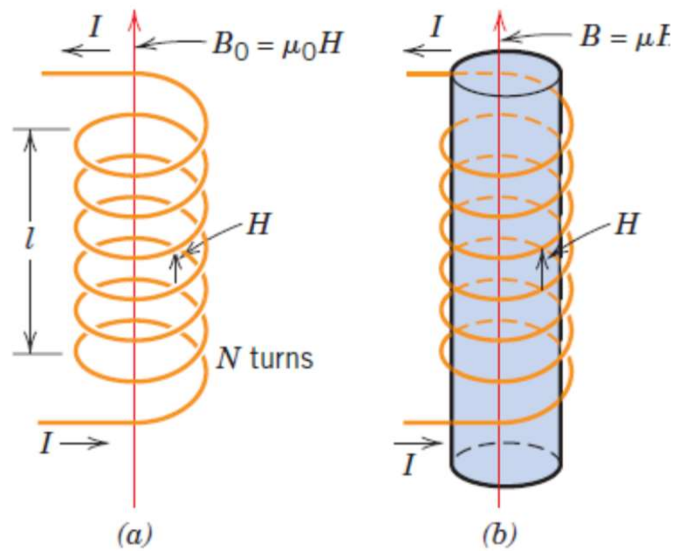
Permiability and Susceptibility

- Magnetic field strength and flux density are related by

$$B = \mu H$$

- In vacuum, $$B_0 = \mu_0 H$$

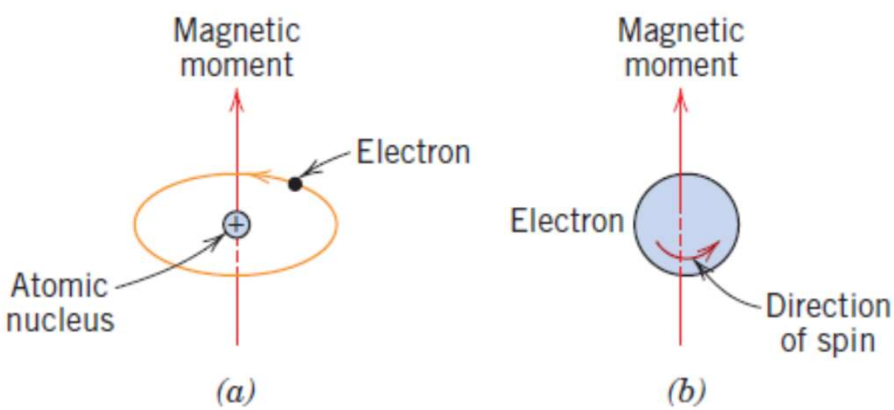
- Relative permeability $$\mu_r = \frac{\mu}{\mu_0}$$



Permeability and Susceptibility

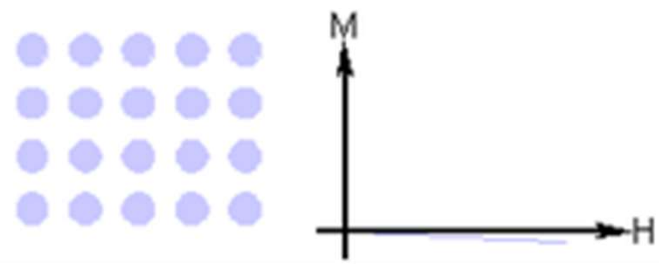
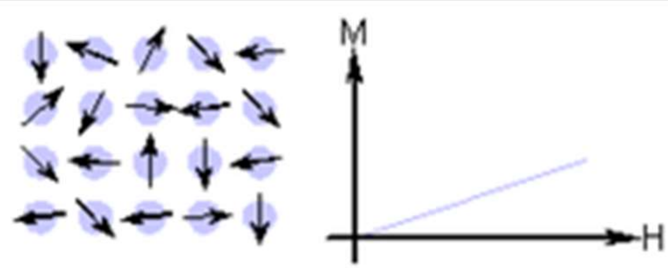
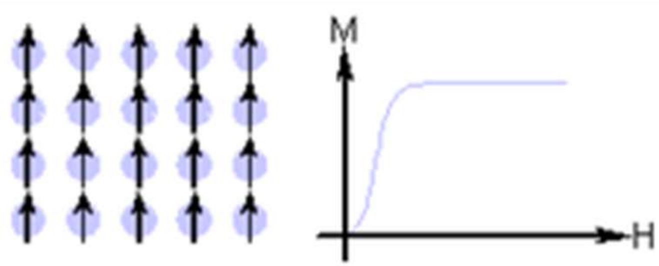
- Magnetization is defined as $$B = \mu_0 H + \mu_0 M$$
- Contribution from magnetic moment inside the material
- Magnetic susceptibility links M and H $$M = \chi_m H$$
- Relation between permeability and susceptibility

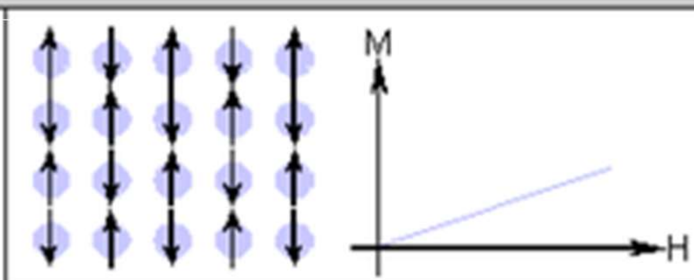
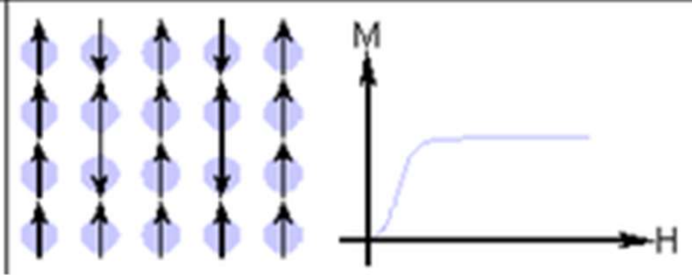
$$\chi_m = \mu_r - 1$$



Origin of magnetism

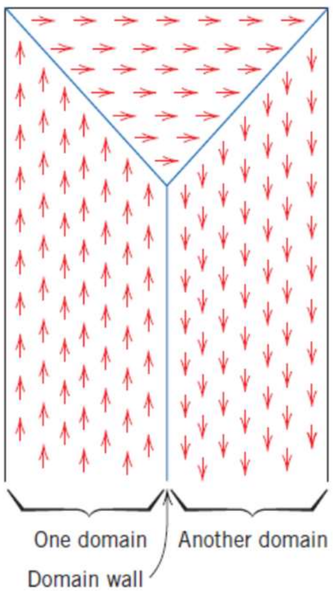
Type of magnetism

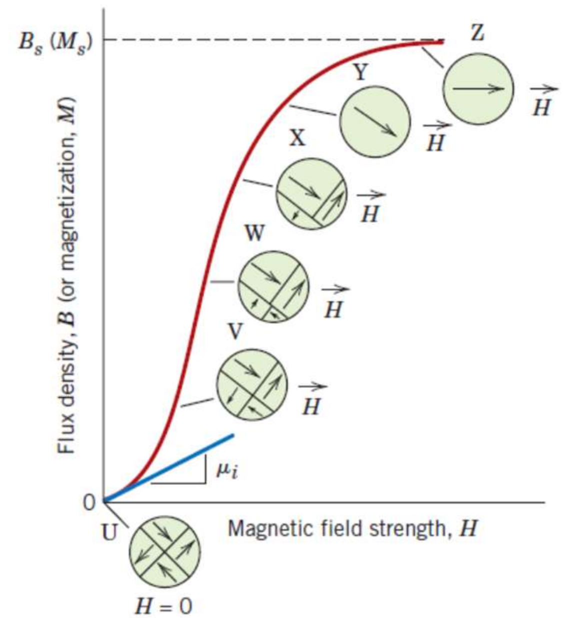
Type of Magnetism	Susceptibility	Atomic / Magnetic Behaviour		Example / Susceptibility	
Diamagnetism	Small & negative.	Atoms have no magnetic moment		Au Cu	-2.74×10^{-6} -0.77×10^{-6}
Paramagnetism	Small & positive.	Atoms have randomly oriented magnetic moments		β-Sn Pt Mn	0.19×10^{-6} 21.04×10^{-6} 66.10×10^{-6}
Ferromagnetism	Large & positive, function of applied field, microstructure dependent.	Atoms have parallel aligned magnetic moments		Fe	~100,000

Type of Magnetism	Susceptibility	Atomic / Magnetic Behaviour		Example / Susceptibility	
Antiferromagnetism	Small & positive.	Atoms have mixed parallel and anti-parallel aligned magnetic moments		Cr	$3.6x10^{-6}$
Ferrimagnetism	Large & positive, function of applied field, microstructure dependent	Atoms have anti-parallel aligned magnetic moments		Ba ferrite	~3

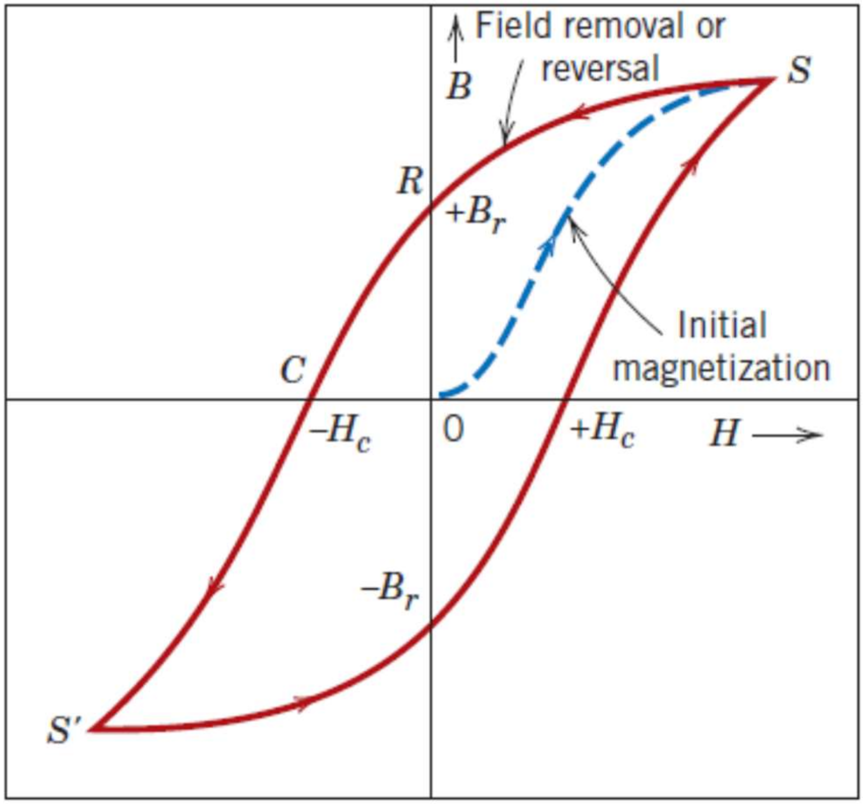
Magnetic domain

- Domain and domain walls
- Arrangement of atomic dipoles
- Neutron diffraction as electrons do not interact with nucleus
- Origins of magnetism in the nucleus





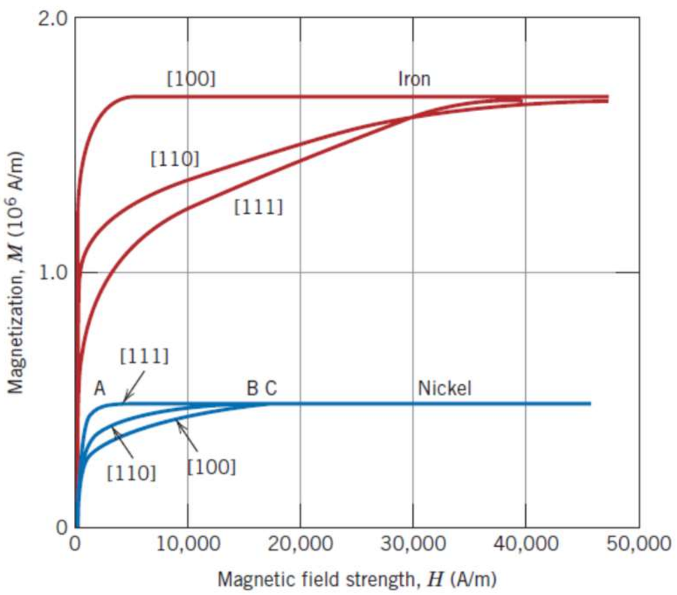
B-H loop

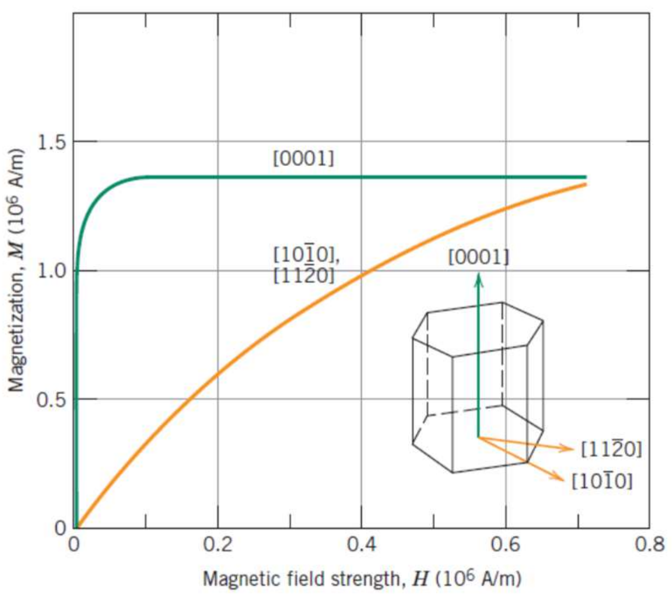


Field removal or reversal
B
S
R
$+B_r$
Initial magnetization
C
$-H_c$
0
$+H_c$
H
$-B_r$
S′

Magnetocrystalline anisotropy

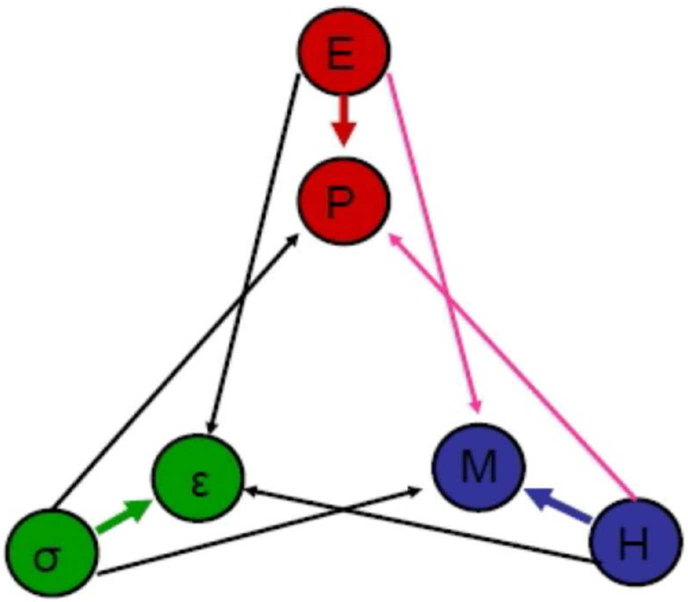
- Permeability is tensorial
- Directional dependence
- Higher anisotropy for hexagonal compared to cubic





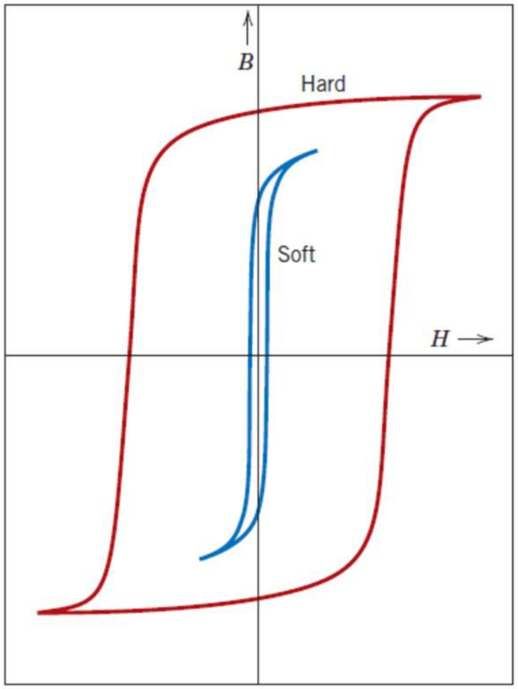
Multiferroics

- Cross coupling of cause and effect
- Materials that exhibit both ferroelectric and ferromagnetic behaviour
- Spontaneous electric and magnetic dipole movement
- Multistate data storage
- $BiFeO_3$



Soft and Hard magnet

- Easy magnetization and demagnetization in soft magnets
- Hard magnets are permanent magnets
- Transformer core Fe-Si alloy is soft magnet with 110 texture or preferred orientation



- Easy magnetization and demagnetization to reduce Eddy current losses

Table 20.5 Typical Properties for Several Soft Magnetic Materials

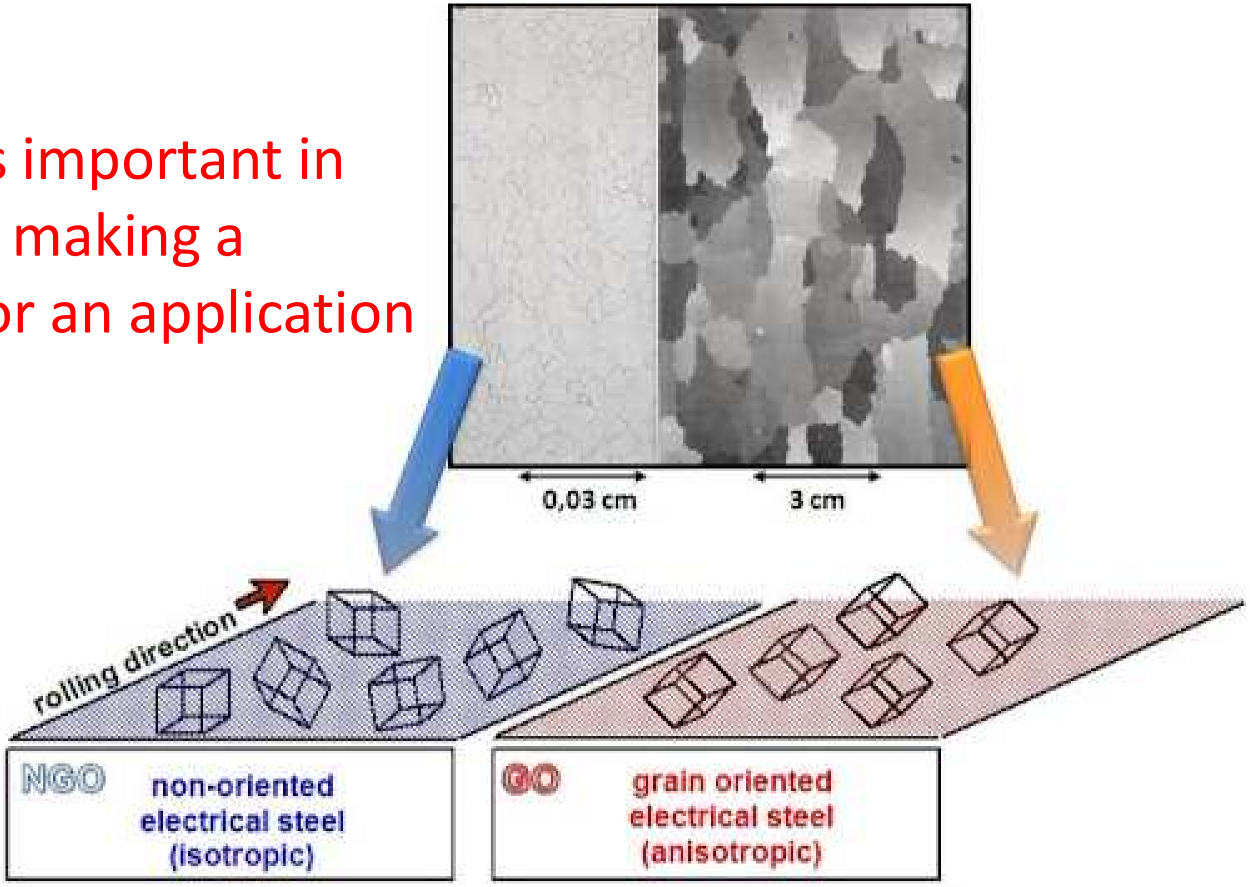
Material	*Composition (wt %)*	*Initial Relative Permeability* μ_i	*Saturation Flux Density* B_s *[tesla (gauss)]*	*Hysteresis Loss/Cycle* $[J/m^3\ (erg/cm^3)]$	*Resistivity* ρ $(\Omega\cdot m)$
Commercial iron ingot	99.95Fe	150	2.14 (21,400)	270 (2700)	1.0×10^{-7}
Silicon–iron (oriented)	97Fe, 3Si	1400	2.01 (20,100)	40 (400)	4.7×10^{-7}
45 Permalloy	55Fe, 45Ni	2500	1.60 (16,000)	120 (1200)	4.5×10^{-7}

Table 20.6 Typical Properties for Several Hard Magnetic Materials

Material	*Composition (wt%)*	*Remanence* B_r *[tesla (gauss)]*	*Coercivity* H_c *[amp-turn/m (Oe)]*	$(BH)_{max}$ $[kJ/m^3$ *(MGOe)]*	*Curie Temperature* T_c *[°C (°F)]*	*Resistivity* ρ $(\Omega\cdot m)$
Tungsten steel	92.8 Fe, 6 W, 0.5 Cr, 0.7 C	0.95 (9500)	5900 (74)	2.6 (0.33)	760 (1400)	3.0×10^{-7}
Cunife	20 Fe, 20 Ni, 60 Cu	0.54 (5400)	44,000 (550)	12 (1.5)	410 (770)	1.8×10^{-7}
Sintered alnico 8	34 Fe, 7 Al, 15 Ni, 35 Co, 4 Cu, 5 Ti	0.76 (7600)	125,000 (1550)	36 (4.5)	860 (1580)	—

Structure-processing-property performance for functional materials

Design is important in terms of making a device for an application



http://www.dierk-raabe.com/electrical-steels-fe-3-si/

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