Materials Properties

- Electrical properties
- Magnetic properties
- Optical properties

Electrical properties

- Ohm's law
- Resistance, resistivity, conductivity

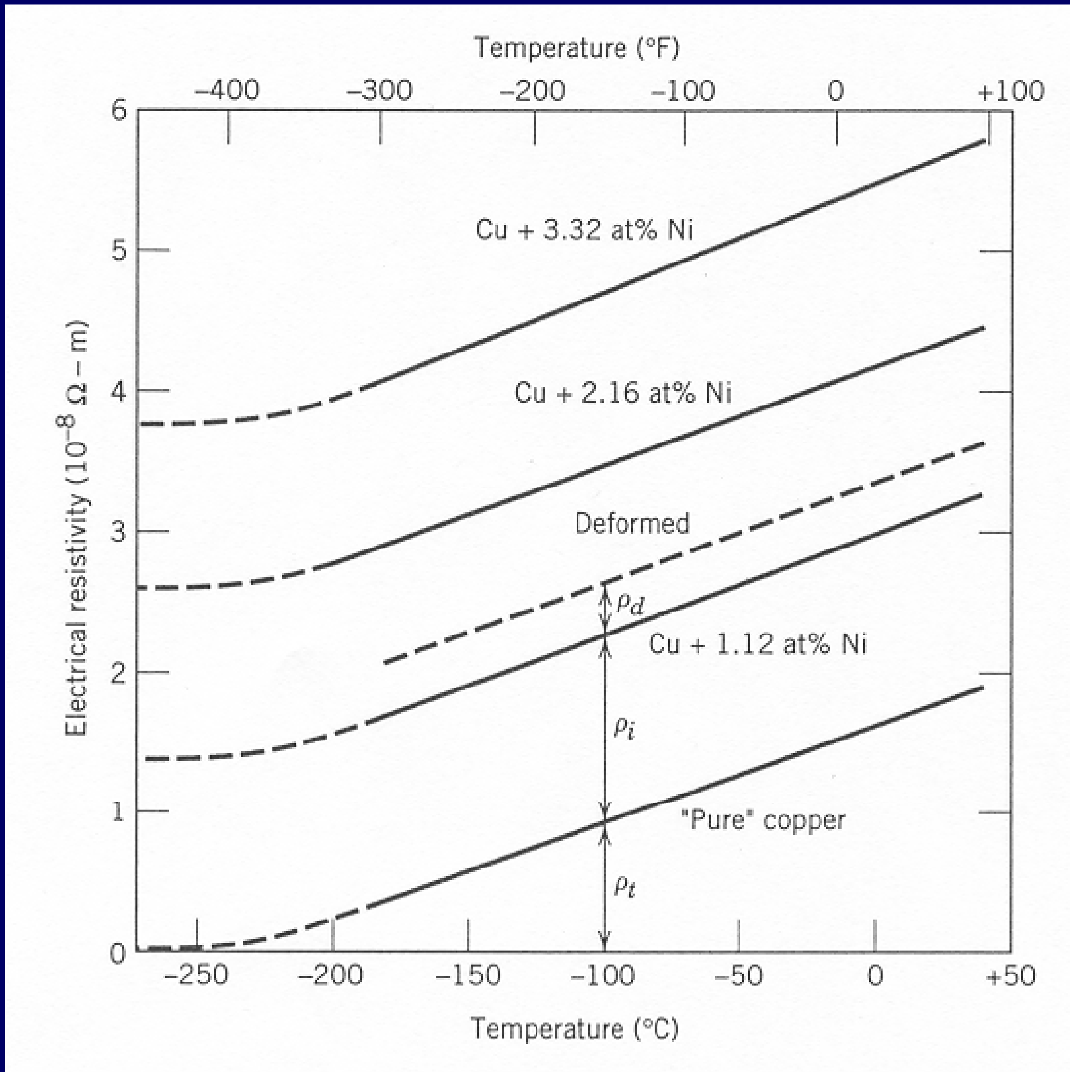
$$V = IR$$

$$\rho = \frac{RA}{l} \qquad \sigma = \frac{1}{\rho}$$

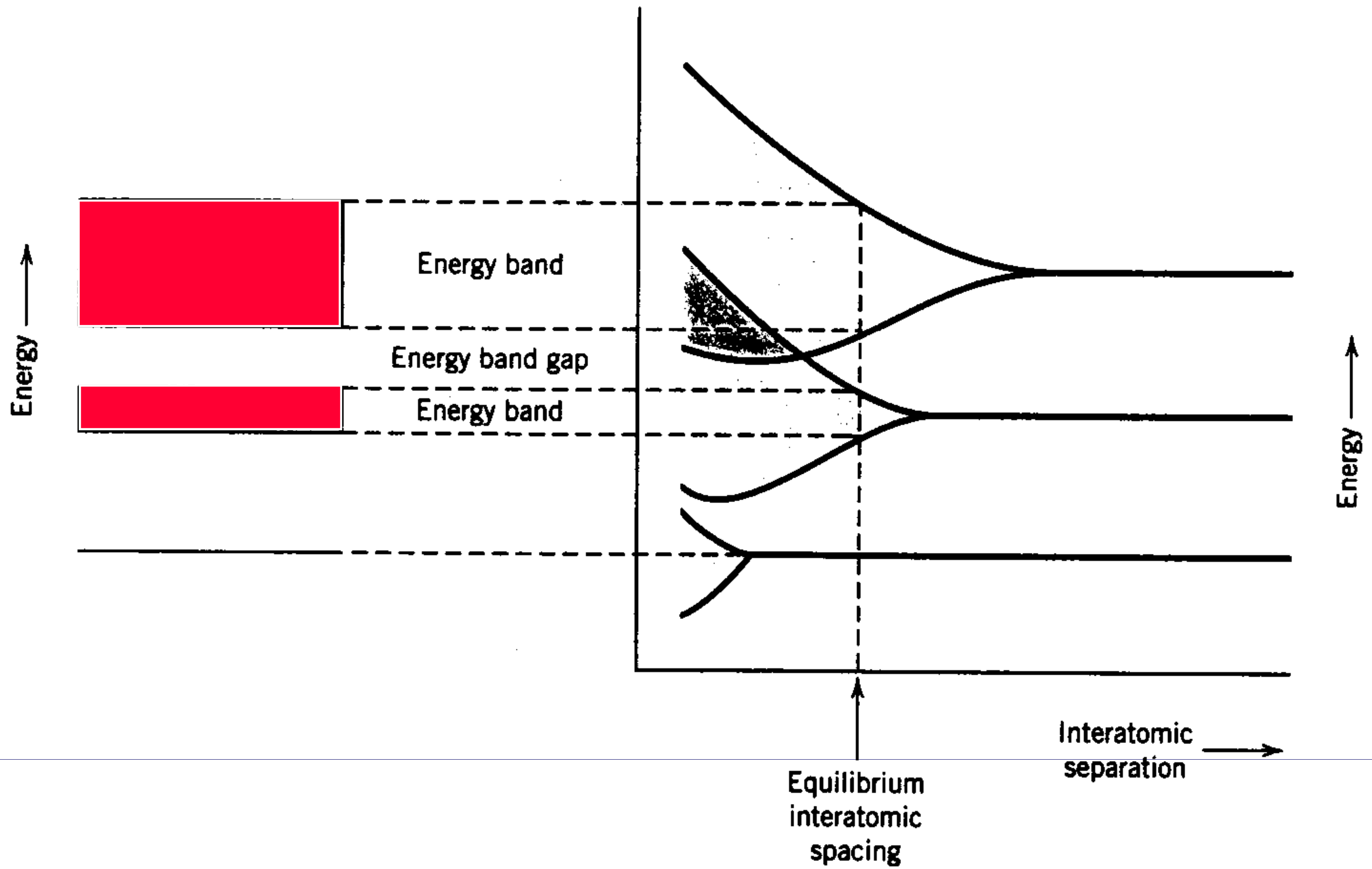
- Matthiessen's rule

$$\rho_{total} = \rho_{thermal} + \rho_{impurity} + \rho_{deformation}$$

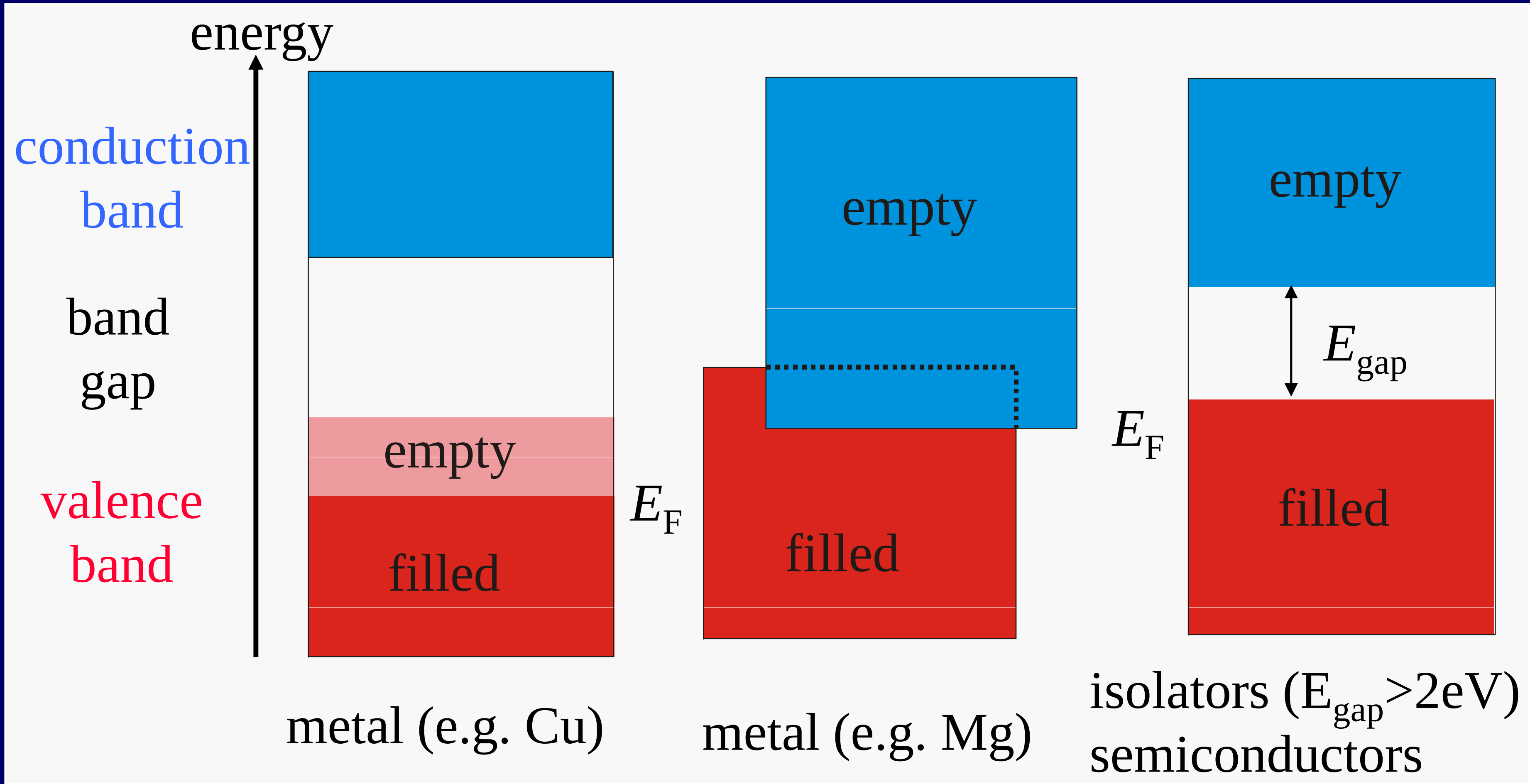
Electrical resistivity



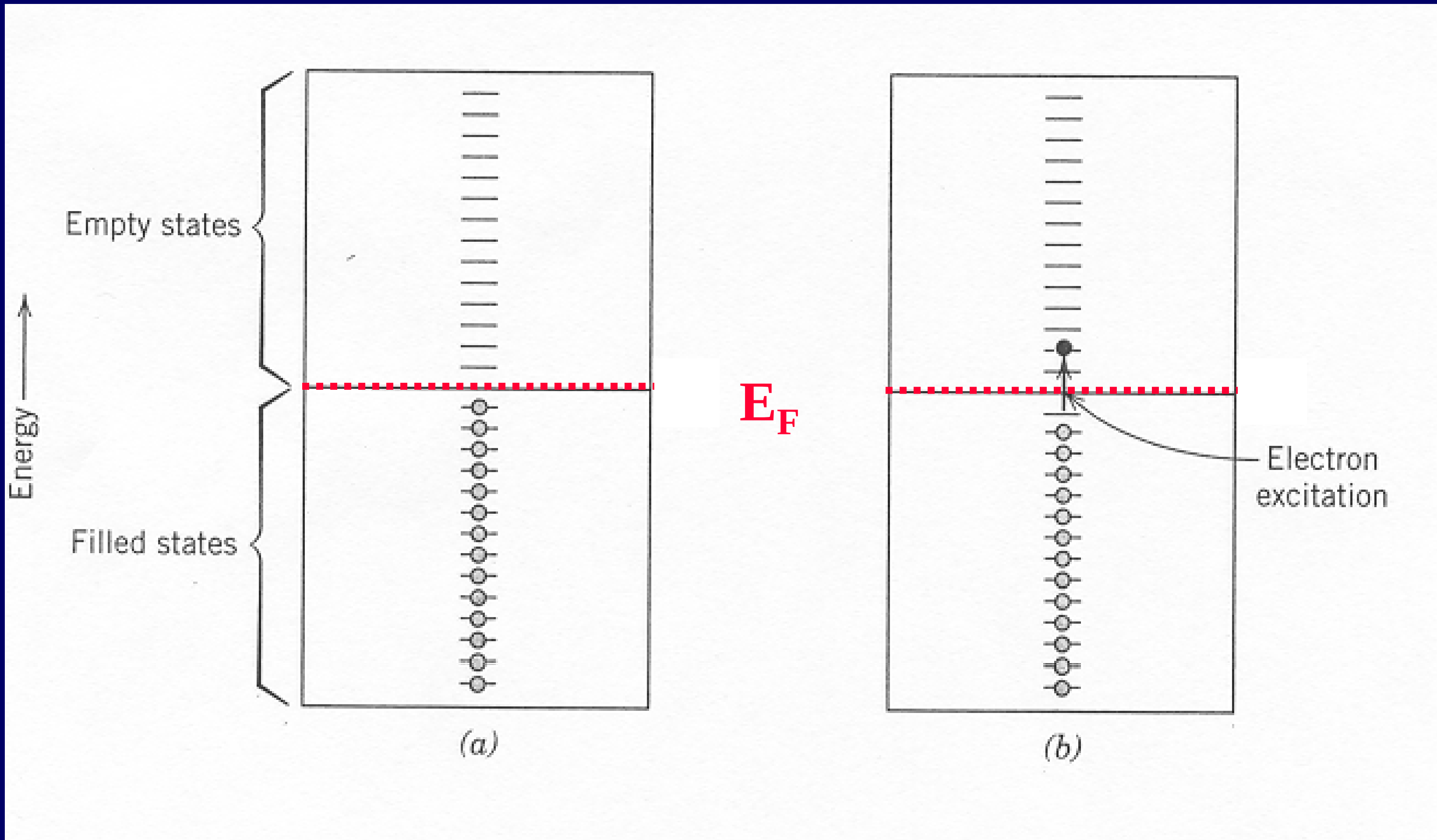
Energy bands



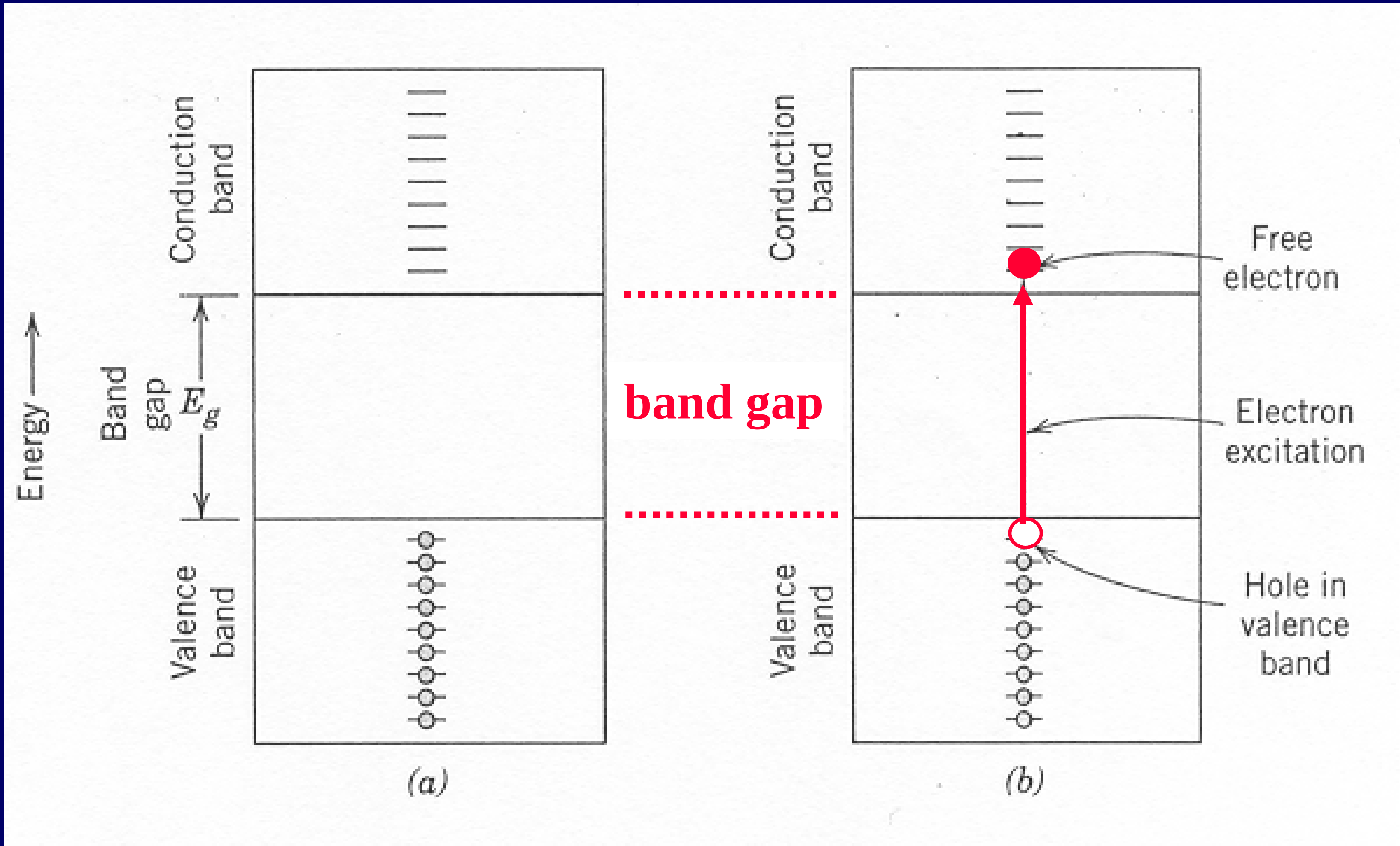
Electron Band Structures



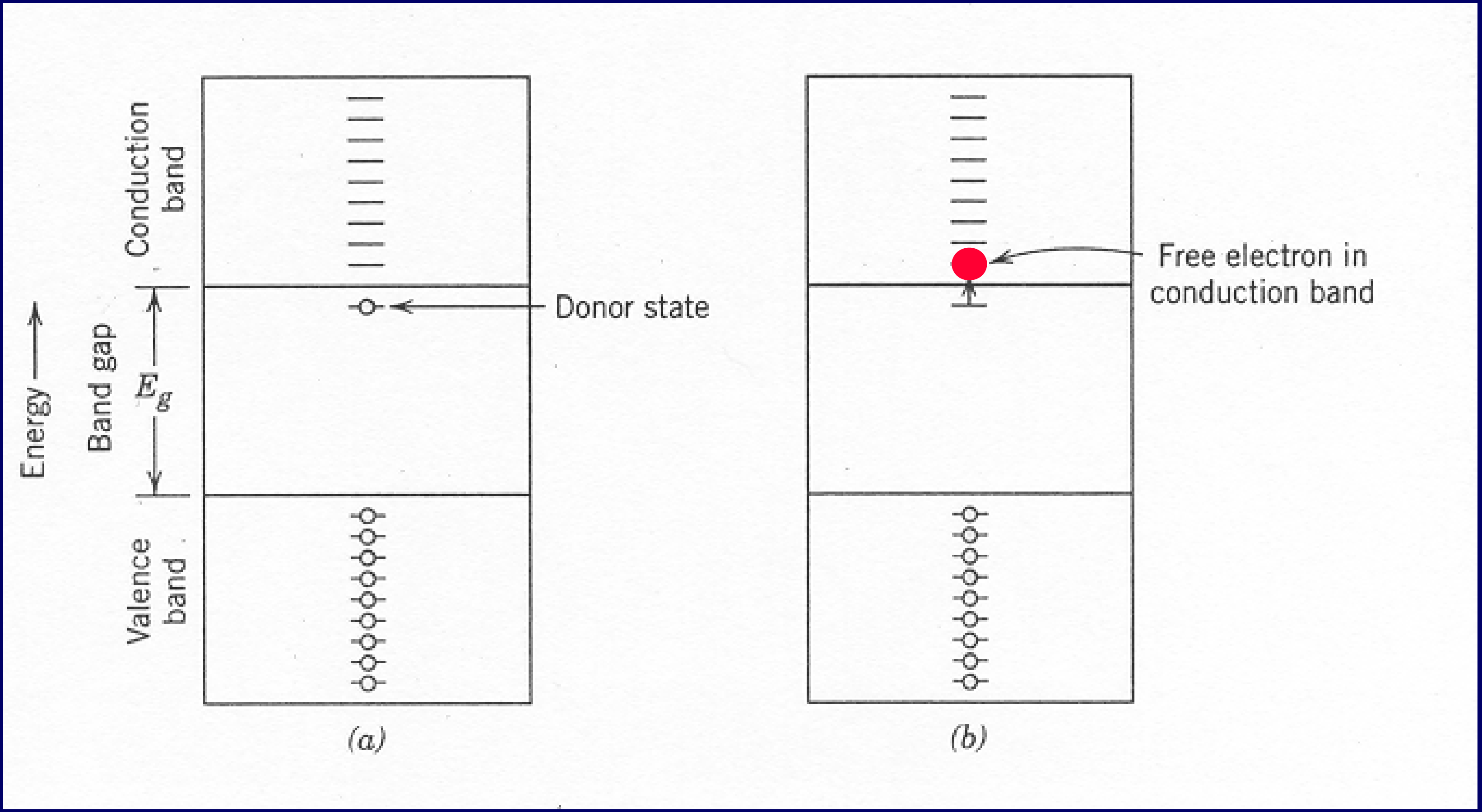
Conductors


Empty states
Energy
Filled states
(a)
E_F
Electron excitation
(b)

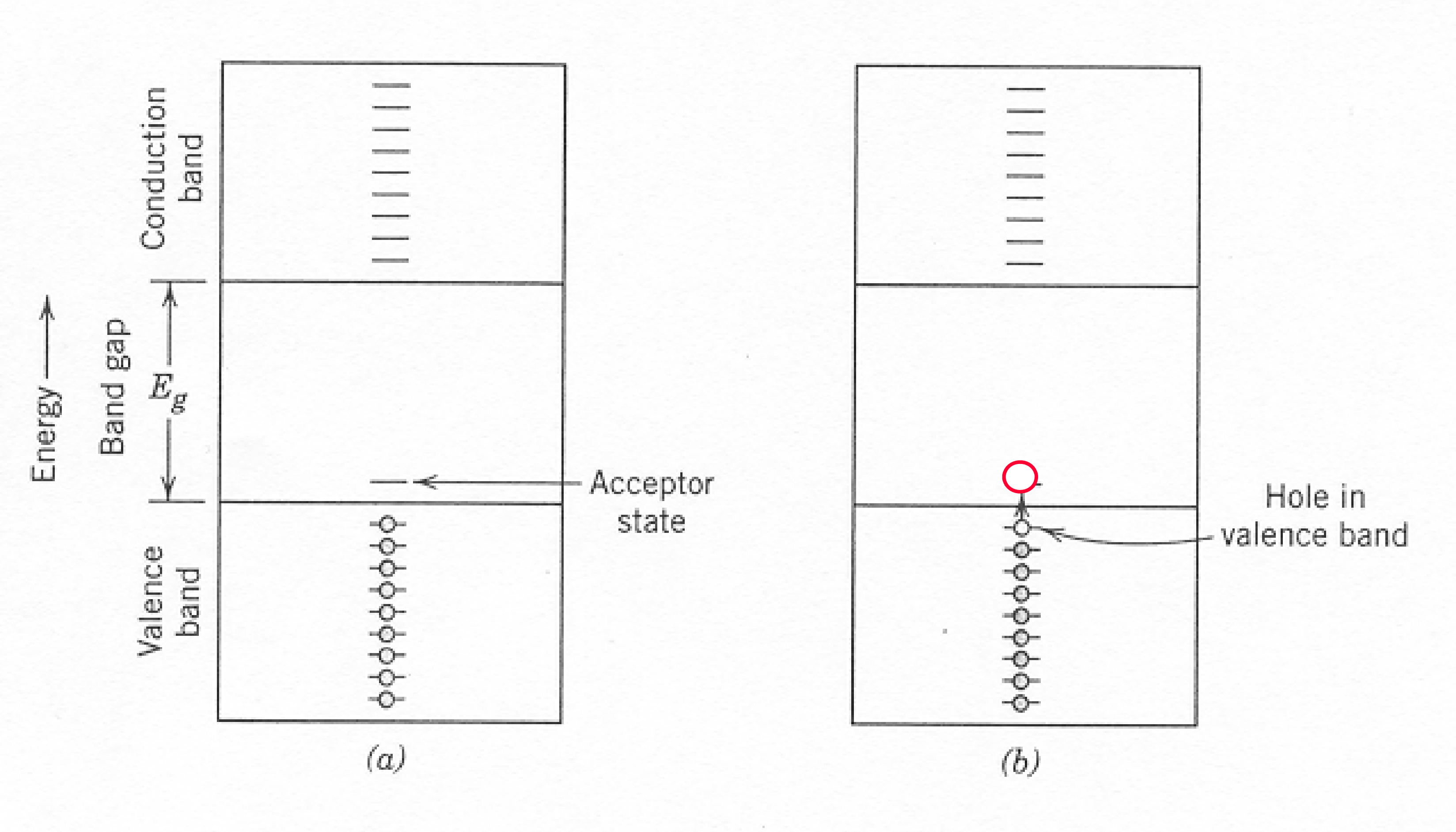
Semiconductors (intrinsic)



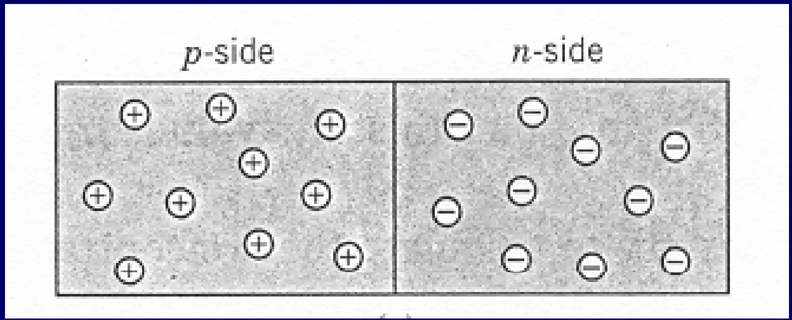
n-type Extrinsic Semiconductor



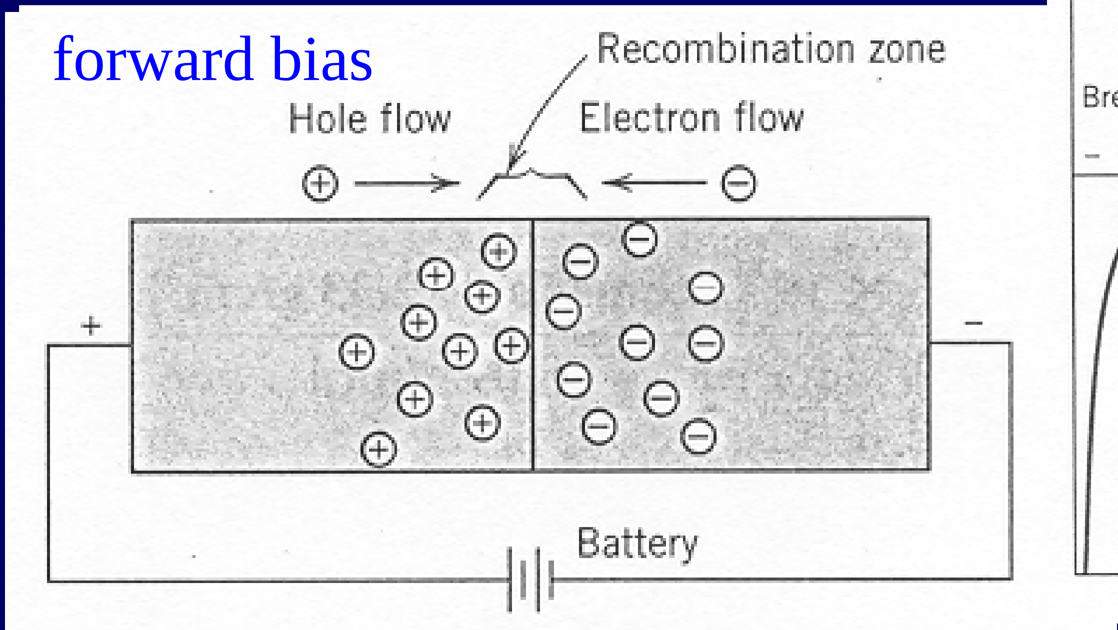
p-type Extrinsic Semiconductor



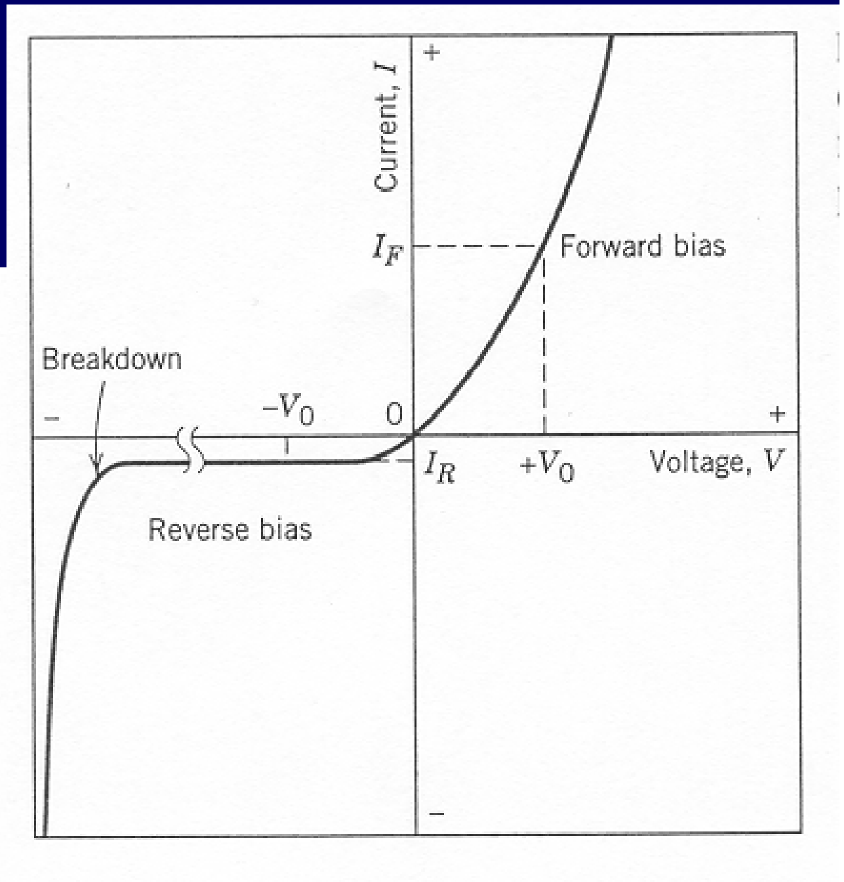
The p-n Diode



p-side
n-side



forward bias
Recombination zone
Hole flow
Electron flow
+
−
Battery



Current, I
+
I_F
Forward bias
Breakdown
−
$-V_0$
0
+
I_R
$+V_0$
Voltage, V
Reverse bias
−

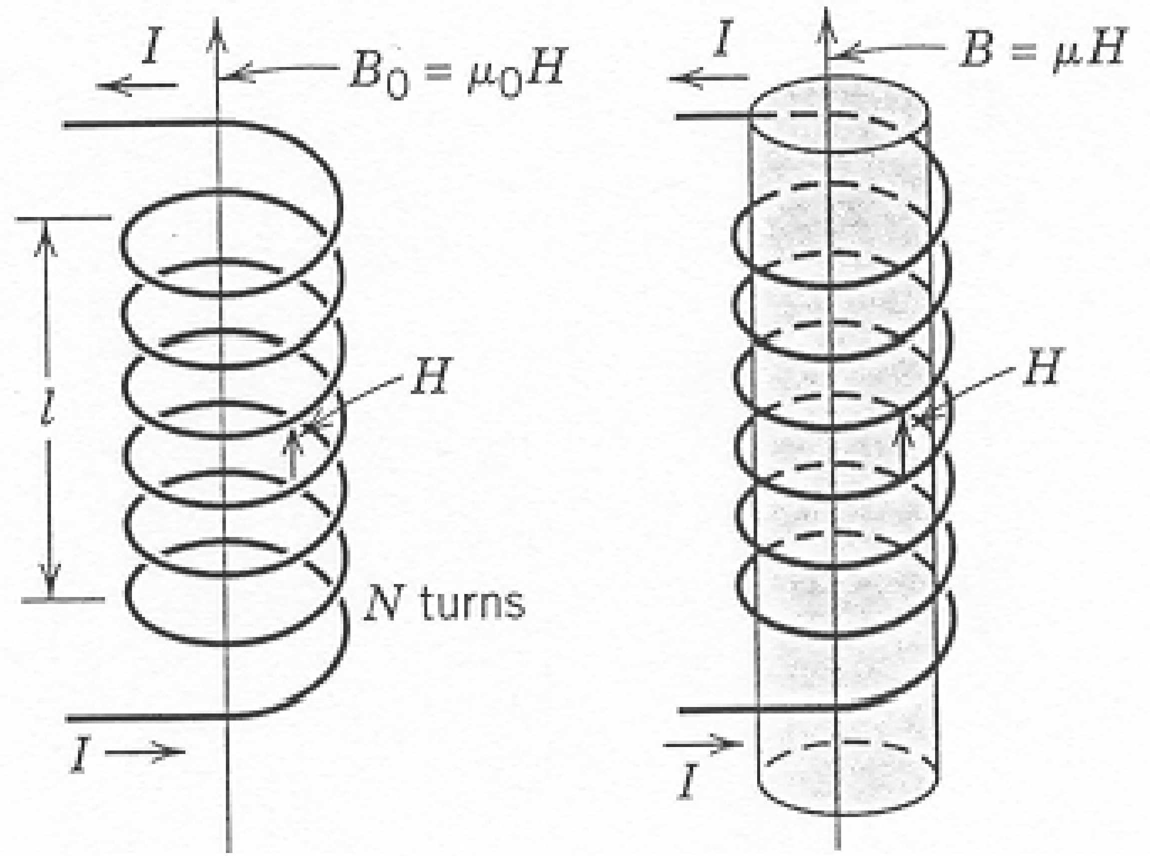
Magnetic properties

- Magnetic field strength, magnetic flux density, magnetization, permeability, and magnetic susceptibility

$$B = \mu H \qquad \mu_r = \frac{\mu}{\mu_0}$$

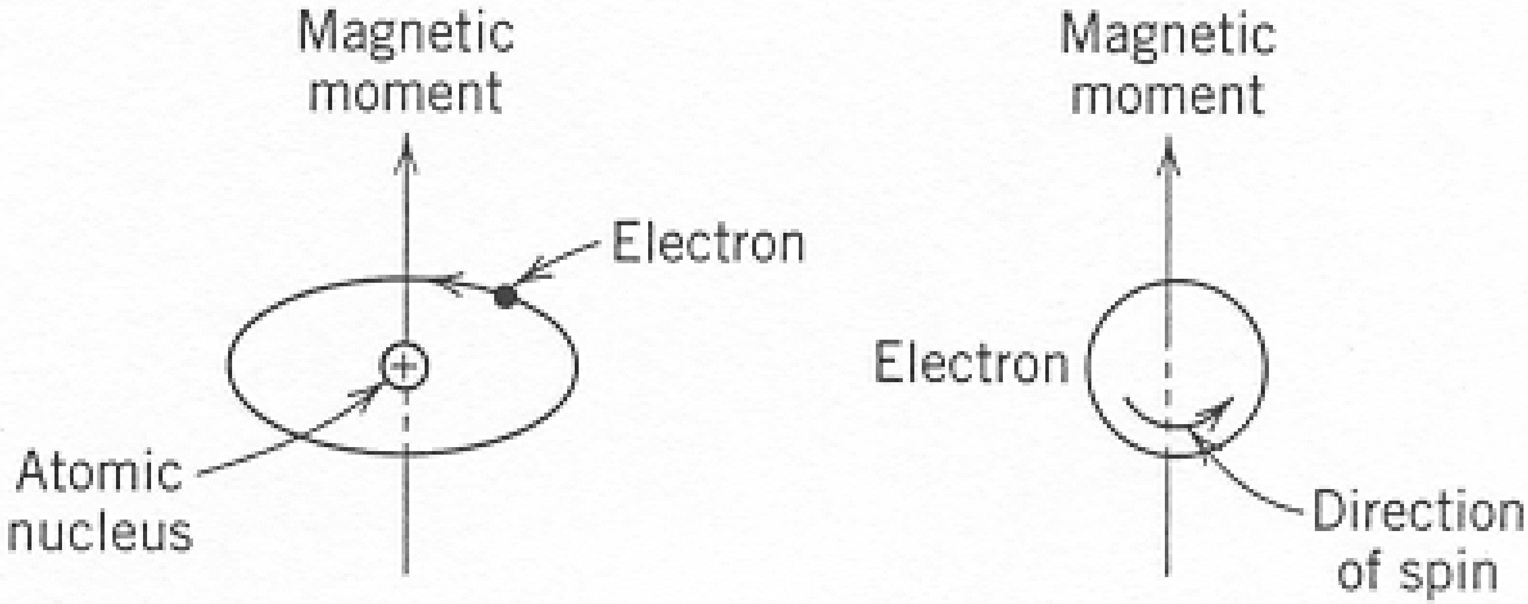
$$B = \mu_0 H + \mu_0 M \qquad M = \chi_m H \qquad \chi_m = \mu_r - 1$$

The Magnetic Field



vacuum atmosphere/material

The Magnetic Moment

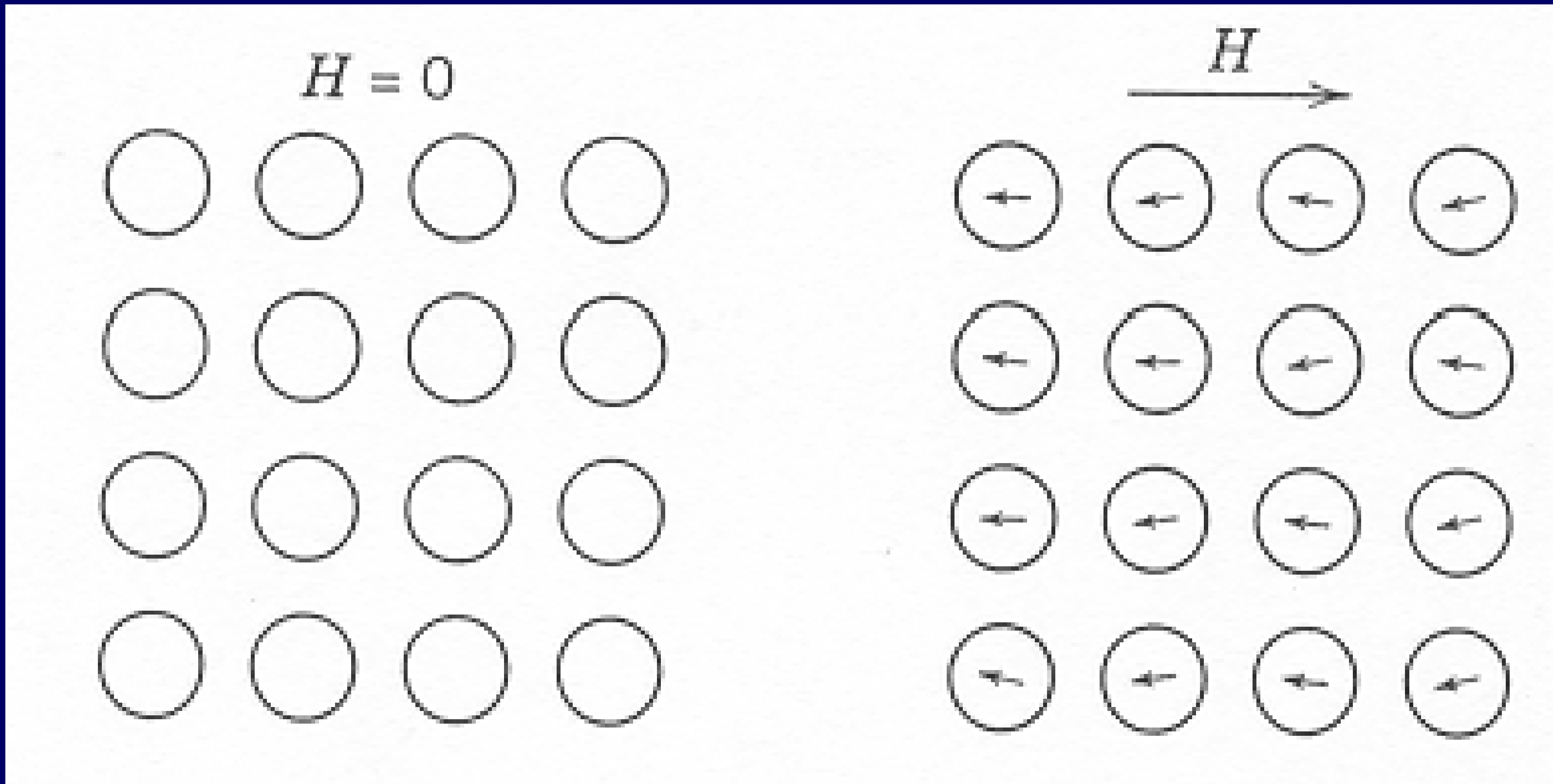


orbital contribution
=> $m_l \mu_B$

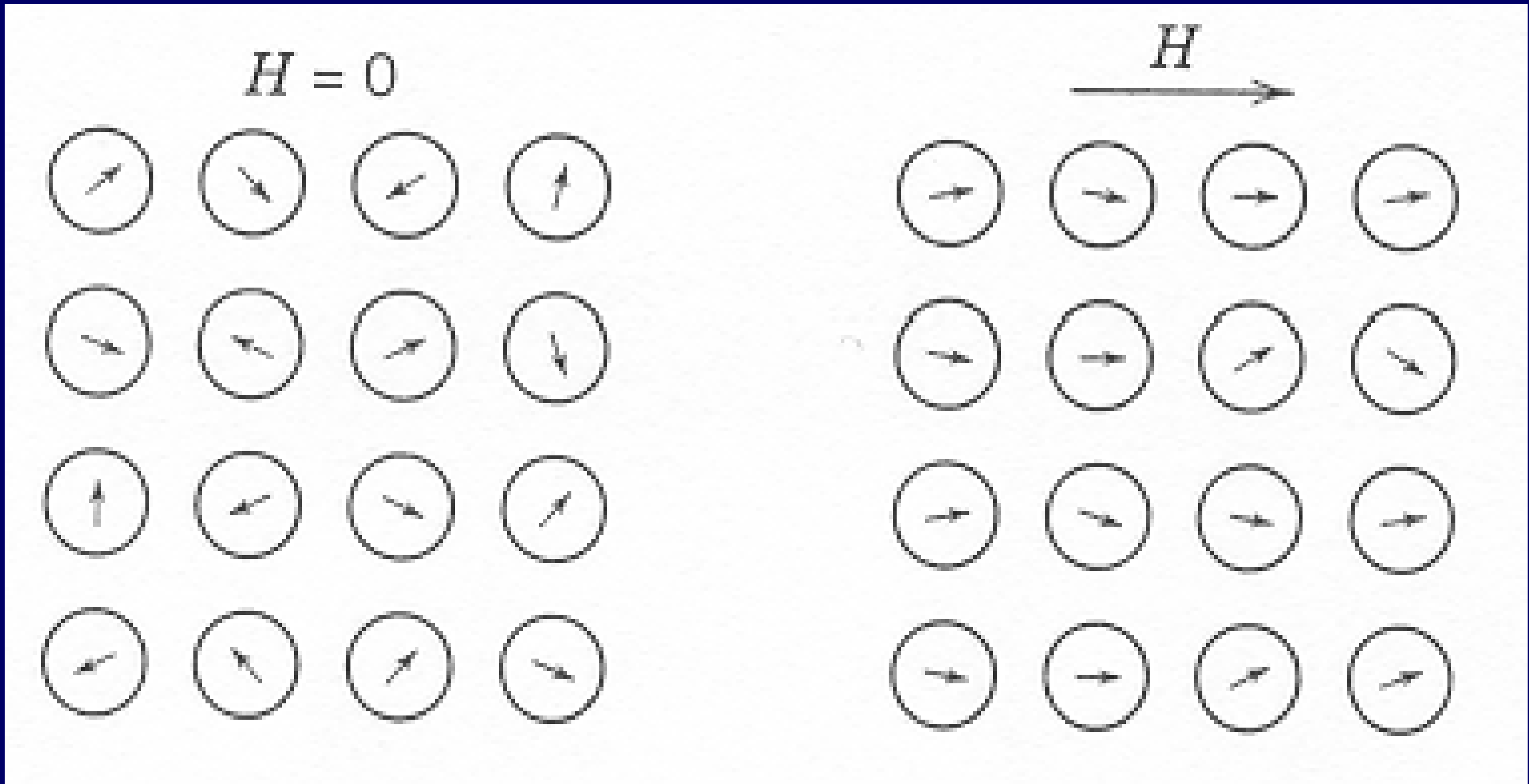
spin contribution
=> $+/- \mu_B$

Bohr magneton: $\mu_B = 9.27 \times 10^{-24}$ Am²

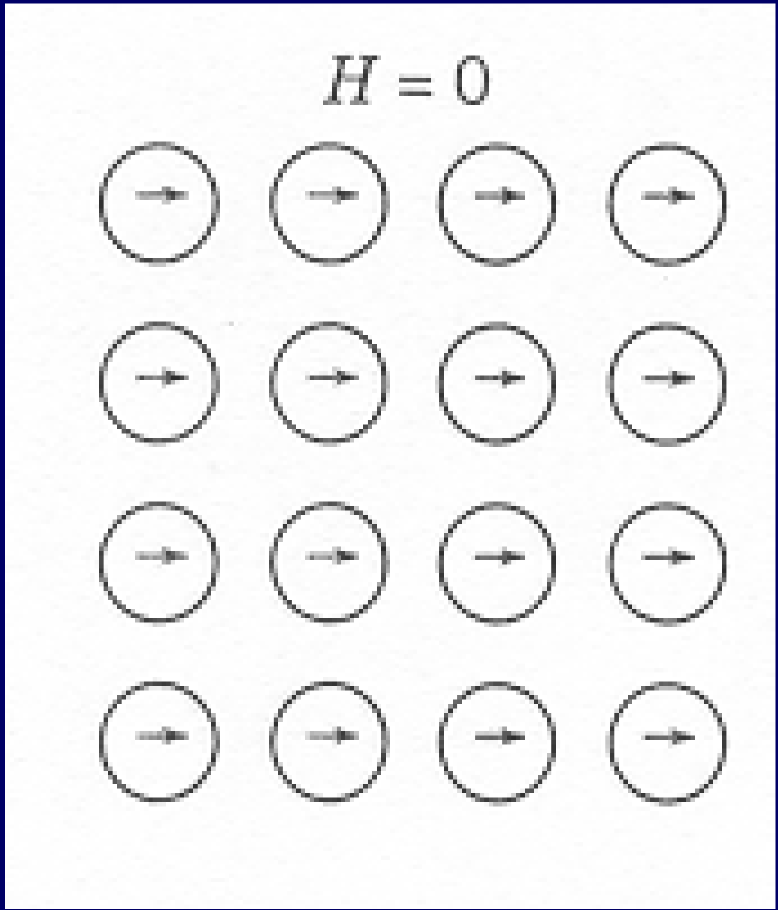
Diamagnetic Materials

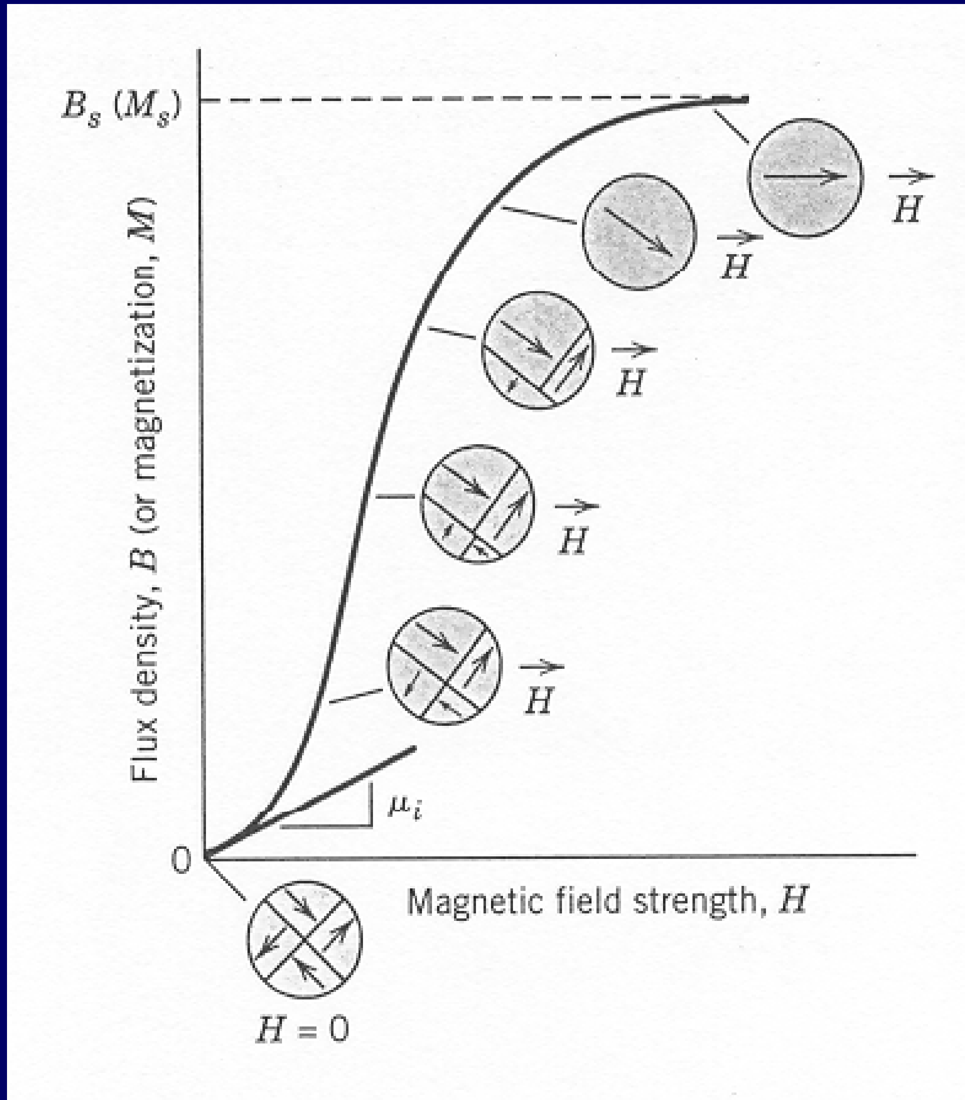


Paramagnetic Materials

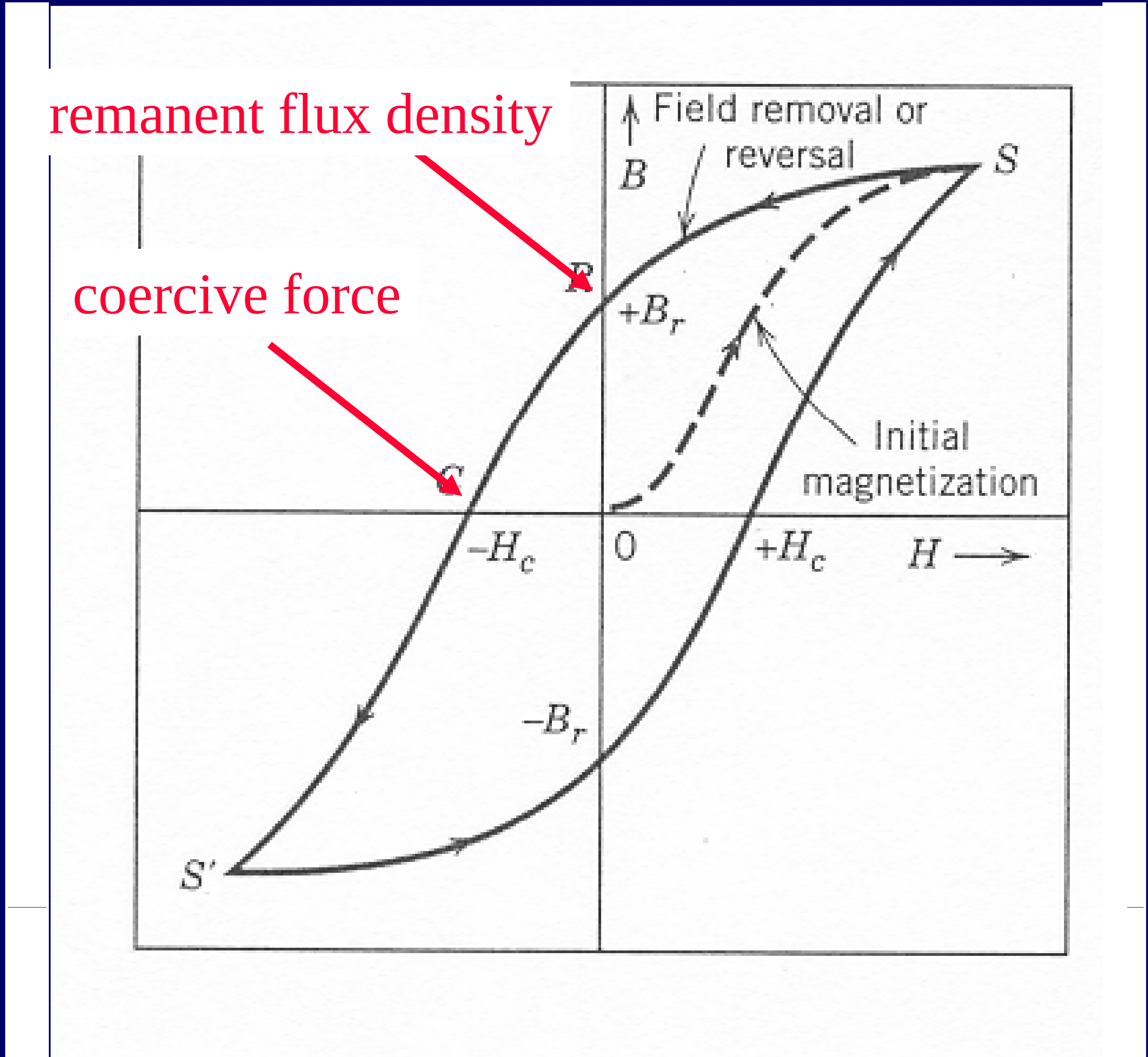


Ferromagnetic Materials





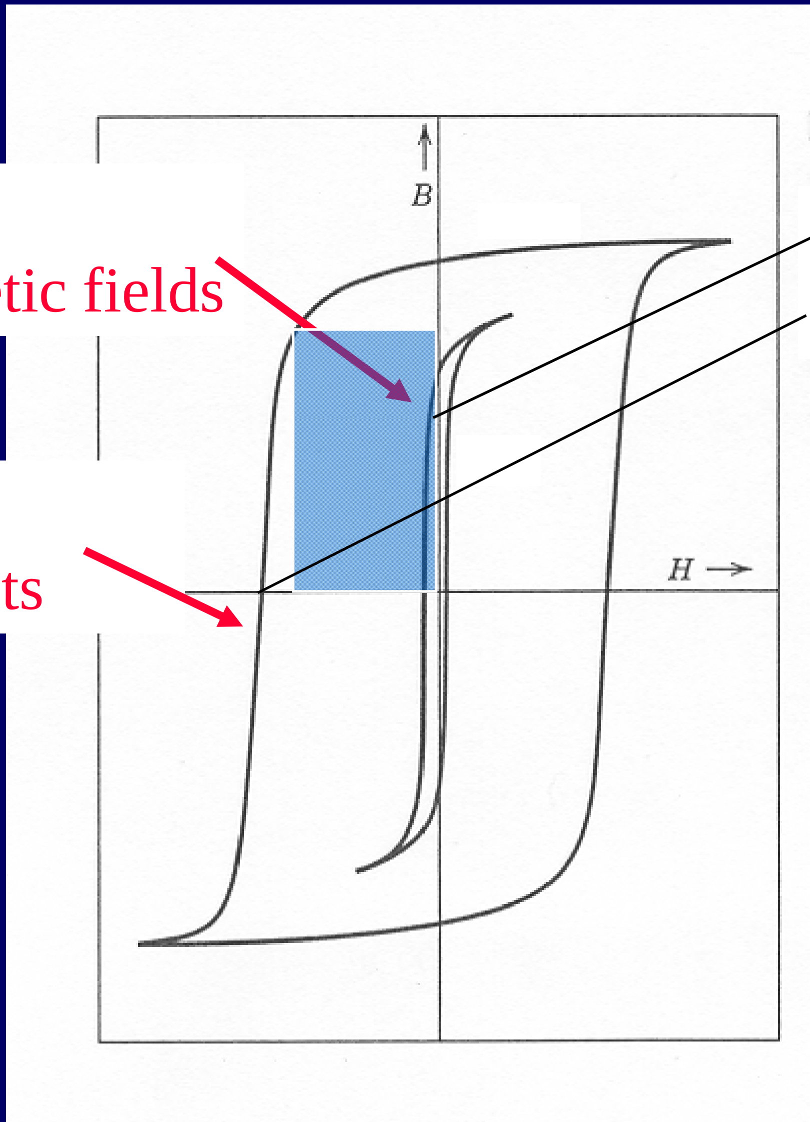
The B-H Hysteresis



Hard and Soft Magnetic Materials

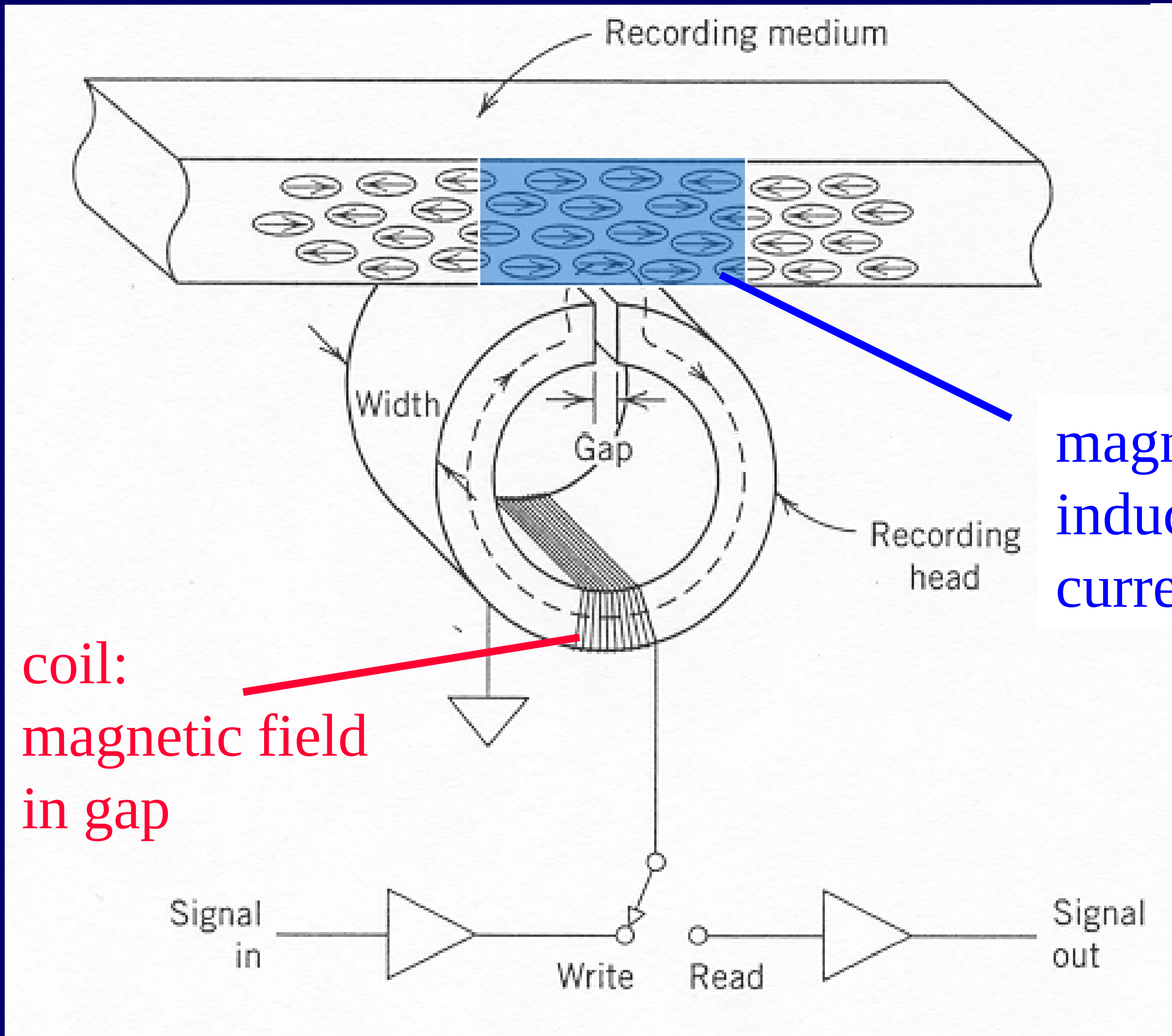
soft:
alternating magnetic fields

hard:
permanent magnets



energy product
coercivity

Magnetic Storage



magnetic field: induces electric current

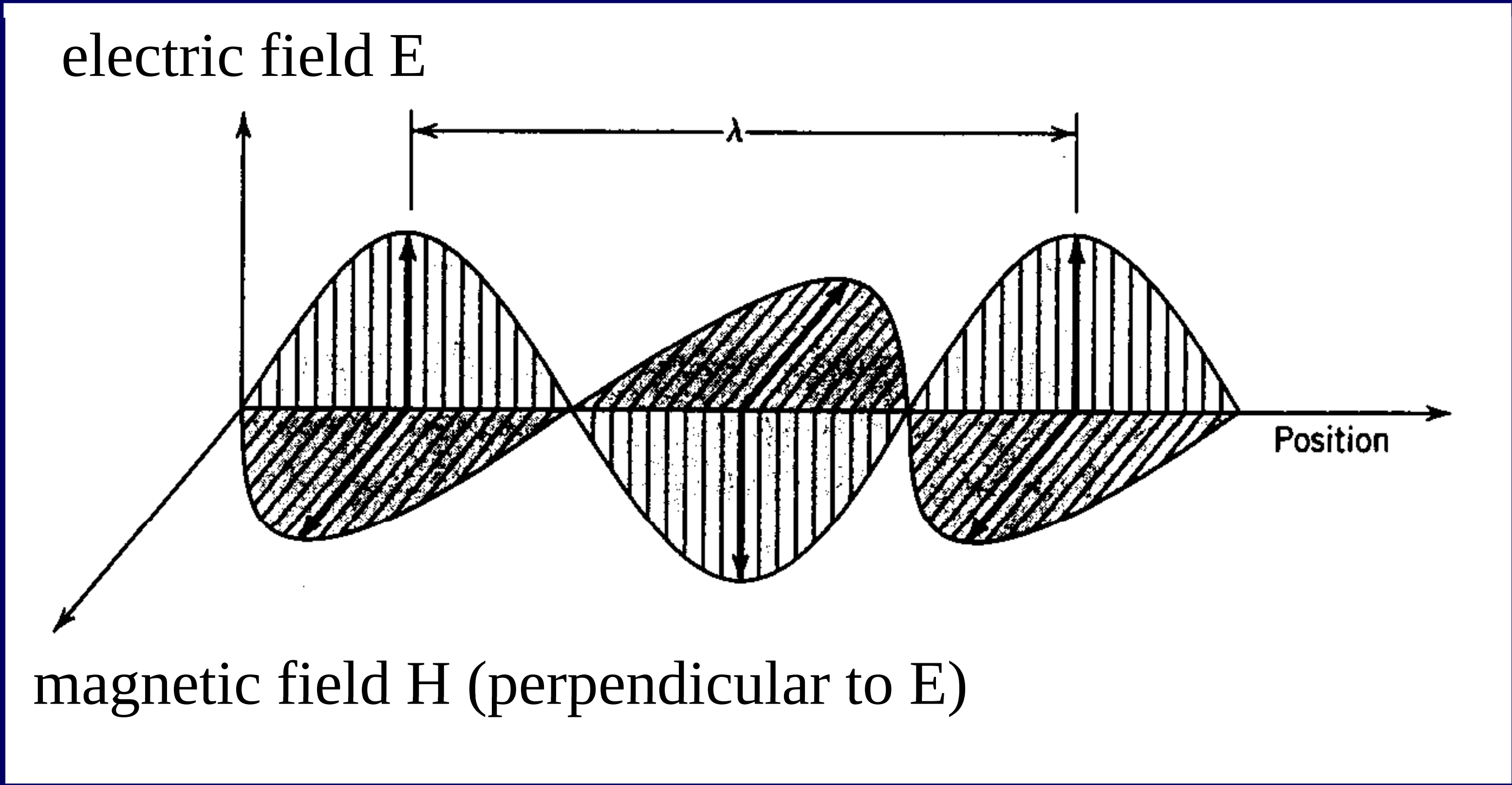
coil: magnetic field in gap

Optical properties

- Transmission
- Refraction
- Absorption

Electro magnetic waves

light = electromagnetic wave



wave: $c=\lambda\nu$ (const. light velocity in vacuum=300,000 km/s)
photons: $E=h\nu$ (Planck constant, 6.63 x 10^{-34} J/s)

Light Interaction with Solid

$$I_0 = I_{transmitted} + I_{absorbed} + I_{reflected}$$

transparent
translucent
opaque

heat

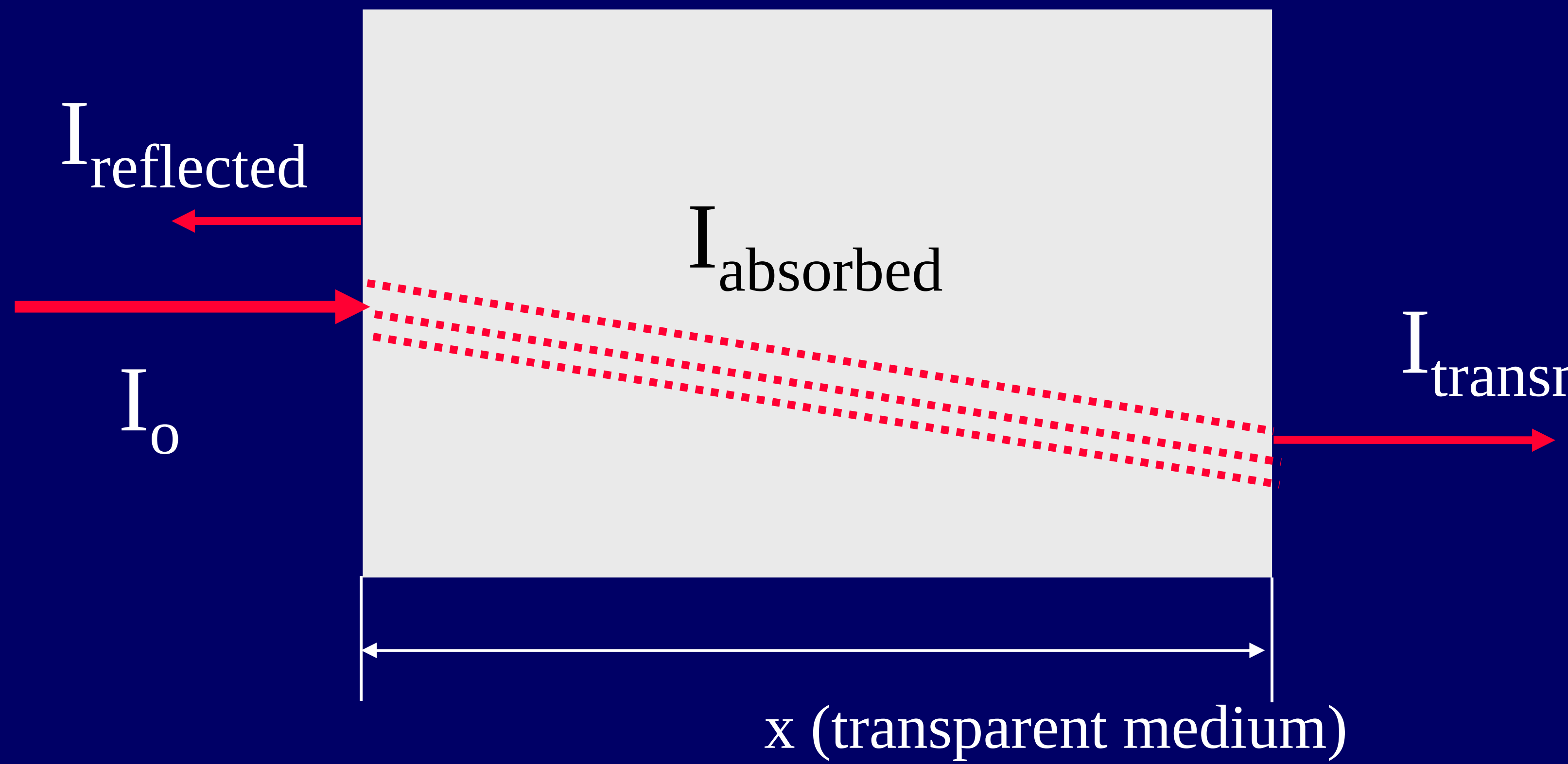
reflection (metals):
absorption (electrons excitation by ΔE) => re-emission of photons
color (e.g. Au, Cu => only partial re-emission)

refraction:
transmission into transparent material
=> decrease in v ($n=c/v$), bending at interface

Absorption

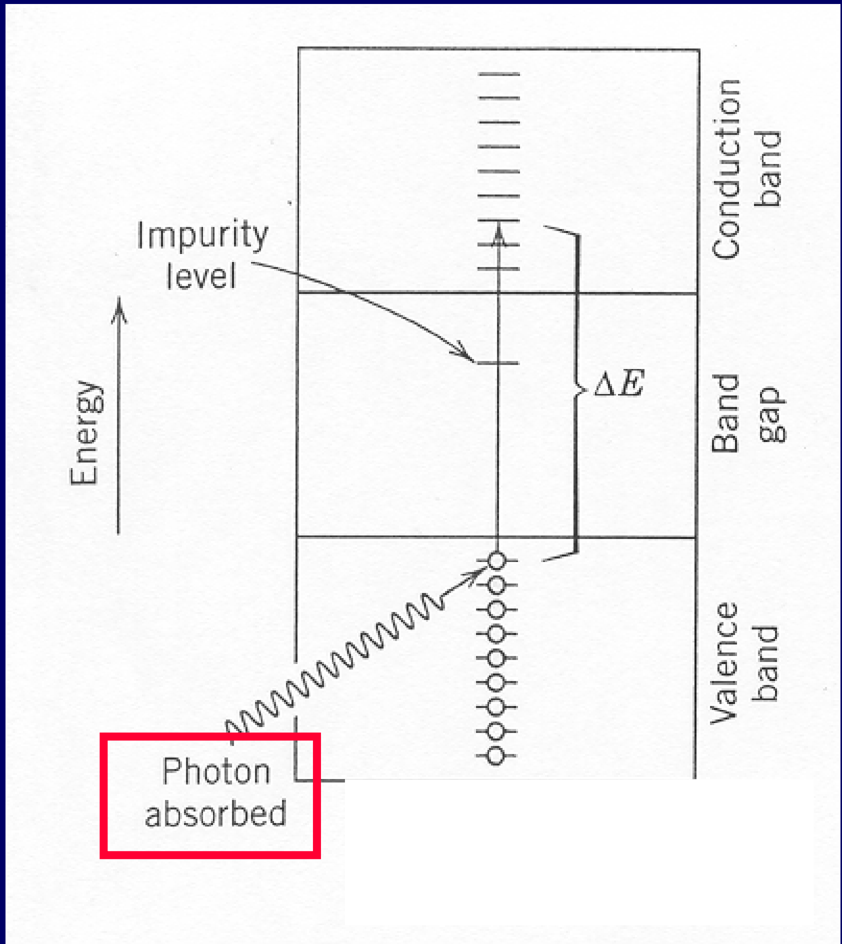
$$I_{transmitted}=I_0(1-R)^2\exp(-\beta x)$$

reflectivity　　absorption coefficient

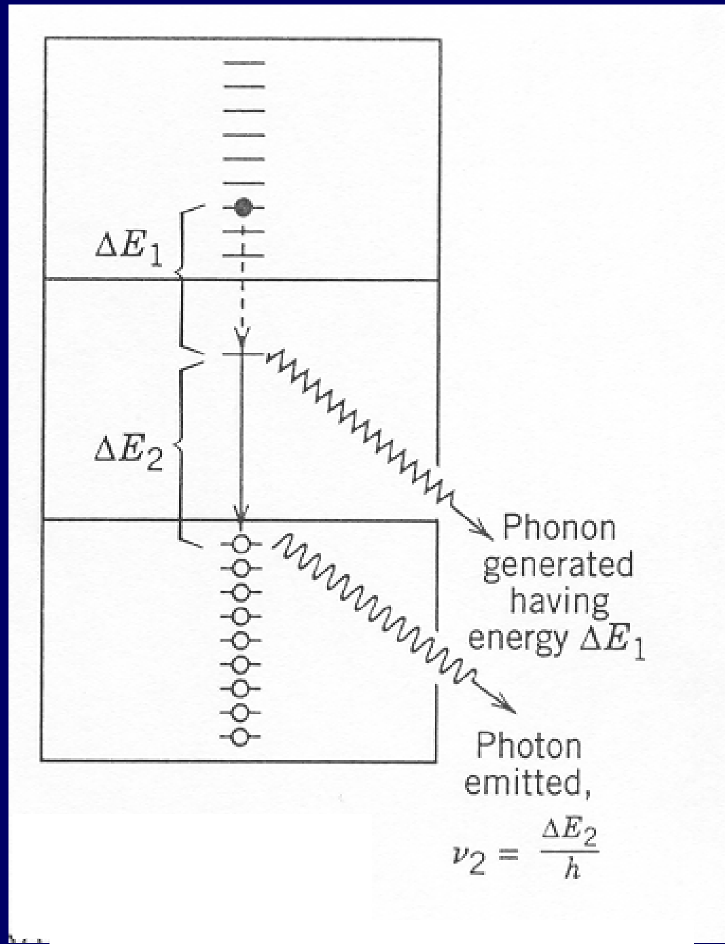


Photon Absorption in a (Semiconducting) Solid

1. hole/electron pair generation



2. hole/electron pair generation



$E_{gap,max}$=hc/λ_{min} (>3.1eV no visible light a

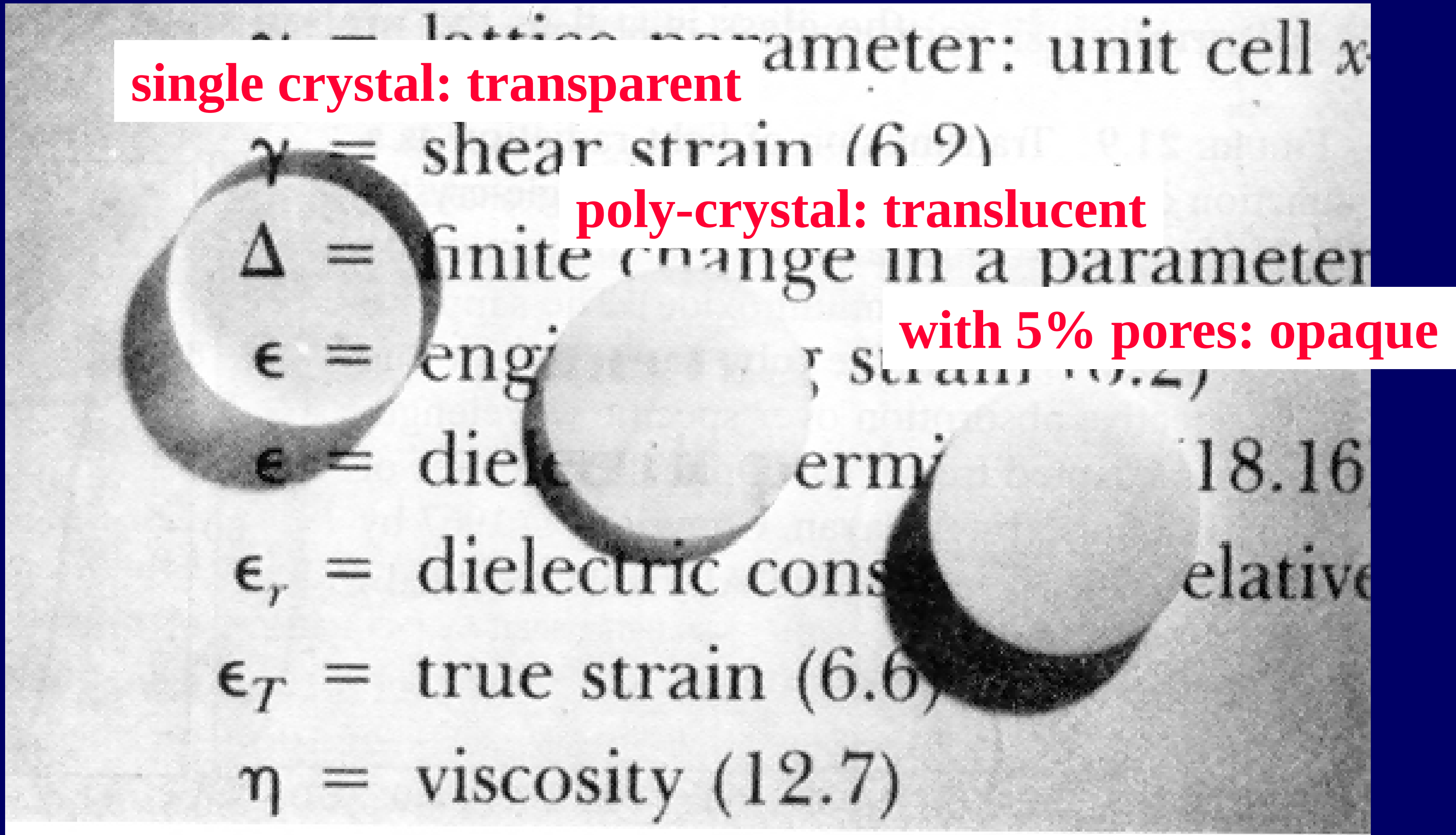
$E_{gap,min}$ ($\lambda_{max,visible}$=700nm) (<1.8eV all vi ... que)

in between colored!!

e.g. red ruby Al_2O_3 with Cr_2O_3

impurity level in the band gap

Light Transmission in Al_2O_3



internal reflection/refraction at grain/phase boundaries – pores
polymers: scattering at boundaries betw. crystalline/amorphous regions

Effects/Applications

luminescence

absorbing energy => re-emitting visible light (1.8eV < hv < 3.1eV)

fluorescence (< 1s)

phosphorescence (> 1s)

e.g. TV (fluoresc. coating) LED (forward bias diode – recombination=> light)

photoconductivity

illumination => generation of charge carriers

e.g. light meters, solar cells

optical fibres

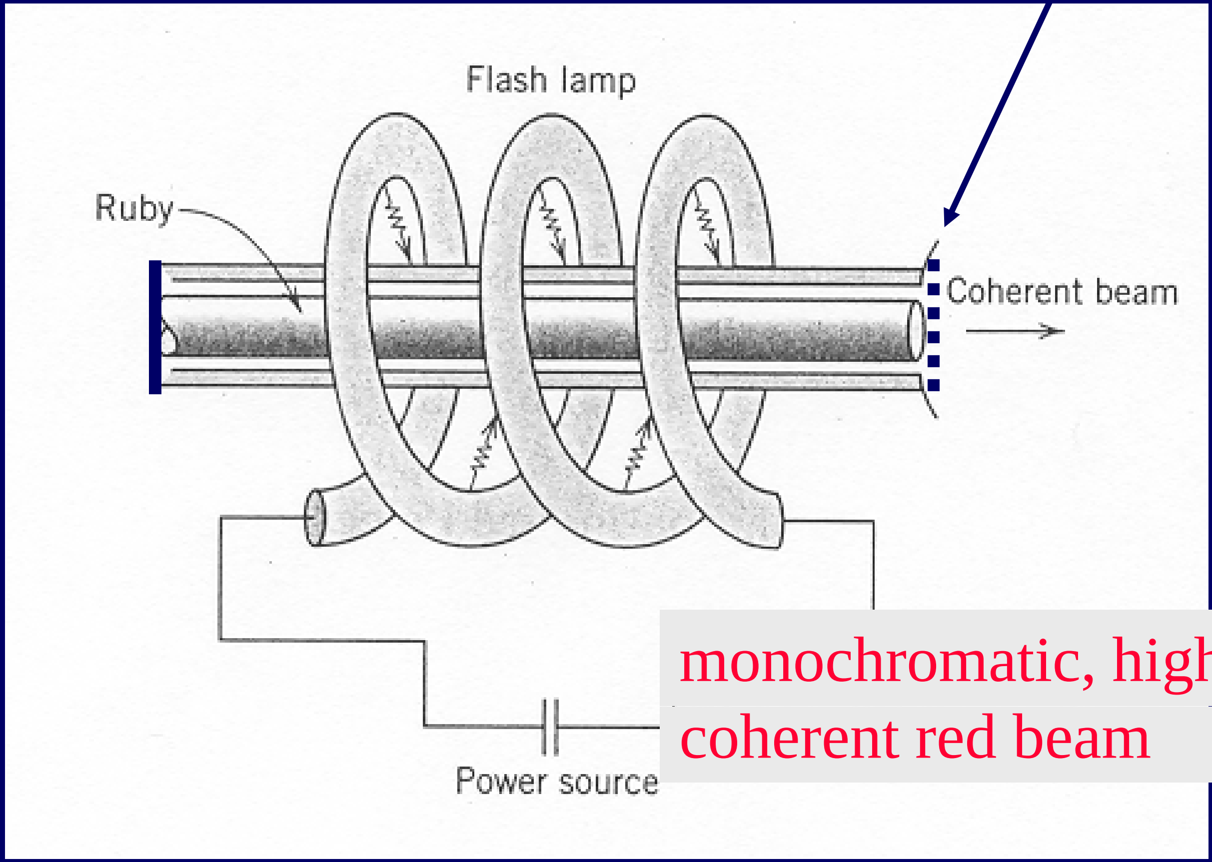
1/0 impulses – high information density 24000 telephone calls by two wires

e.g. 30000kg Cu corresp. to 0.1kg high-purified SiO_2 glass

Laser Concepts

(light amplification by stimulated emission of radiation)

1. Xe flash lamp excite electrons from Cr^{3+} ions
2. large number of electrons falls back to intermediate state
3. after approx. 3ms: spontaneous emission – triggers avalanche of emissions
4. photons parallel to the rod are transmitted to the semi-silvered end



monochromatic, high-intensity
coherent red beam