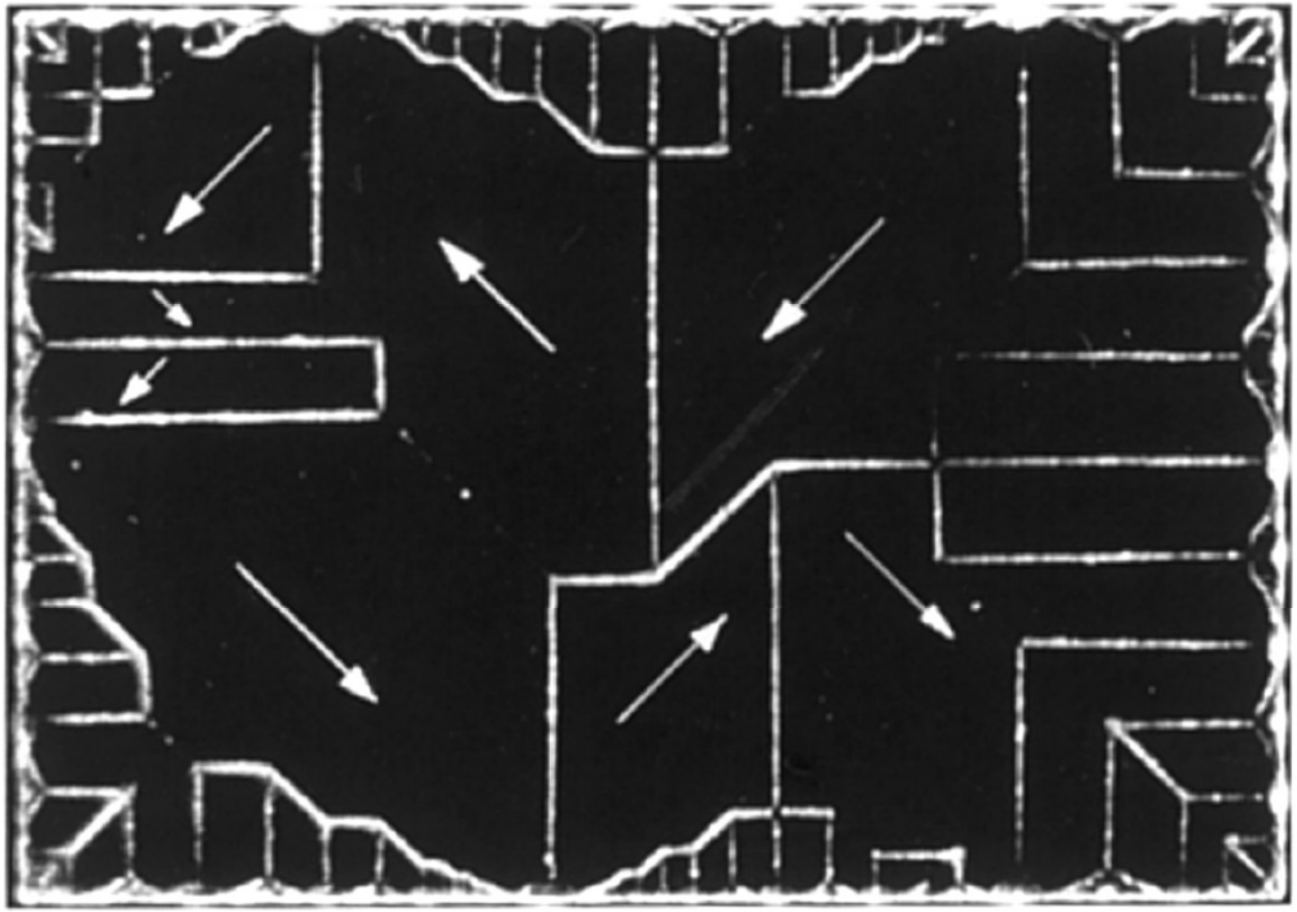
Magnetism of matter



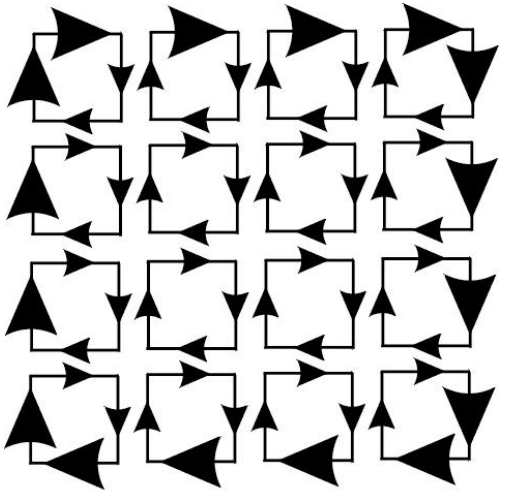
Magnetism of matter:

strongly attractive **feromagnetic**

slightly attractive **paramagnetic**

repulsive **diamagnetic**

magnetization $\vec{M} = \frac{\sum \vec{m}}{V}$ $\vec{M} = \frac{d\vec{m}}{dV}$



Ampère's hypothesis:
atomic and molecular currents

All magnetic phenomena, whether produced by magnets, currents, or the Earth, could be explained by a general law of electric current (even hypothetic) passing through the loop.

Susceptibility and Permeability of matter

$$\vec{B} = \vec{B}_0 + \vec{B}_M$$

$$B_0 = \mu_0 \frac{IN}{l} \qquad B_M = \frac{\mu_0 N_M I_M}{l}$$

$$M = \frac{N_M I_M S}{V} = \frac{N_M I_M}{l} \qquad \vec{B}_M = \mu_0 \vec{M}$$

$$\oint_C \left(\frac{\vec{B} - \mu_0 \vec{M}}{\mu_0} \right) \cdot d\vec{l} = I \qquad \vec{H} = \frac{\vec{B} - \mu_0 \vec{M}}{\mu_0}$$

$$\oint_C \vec{H} \cdot d\vec{l} = I$$

$\vec{M} = \chi_m \vec{H}$ magnetic susceptibility

$$\vec{B} = \mu_0 \left(\vec{H} + \vec{M} \right) = \mu_0 \left(1 + \chi_m \right) \vec{H} = \mu_0 \mu_r \vec{H}$$

Diamagnetism

inert gases, metals, organic matters, water

$\chi_m < 0$ $\mu_r \doteq 1$

- all common matters
- slight effect: masked by para- or ferromagnetism
- Langevin's theory:
  In an external magnetic field, the velocity of electrons changes and the magnetic moment is developed in a direction opposite to that of the applied magnetic

$|\chi_m| < 10^{-6}$ bismuth: $\chi_m = -14 \cdot 10^{-6}$

P. Curie: susceptibility of a diamagnetic matter is independent of the temperature

Paramagnetism

oxygen, natrium, aluminium, platinum

$\chi_m > 0$ $\mu_r \doteq 1$

$$\chi_m = \frac{C}{T}$$ Curie law

- Each atom of such a material has a permanent resultant magnetic dipole moment, but the moments are randomly oriented in the material and the material as a whole lacks a net magnetic field.

- an external magnetic field can partially align the atomic magnetic dipole moments to give the material a net magnetic field

- slightly attractive

$\chi_m \geq 10^{-6}$; někdy $\chi_m \approx 10^{-3}$

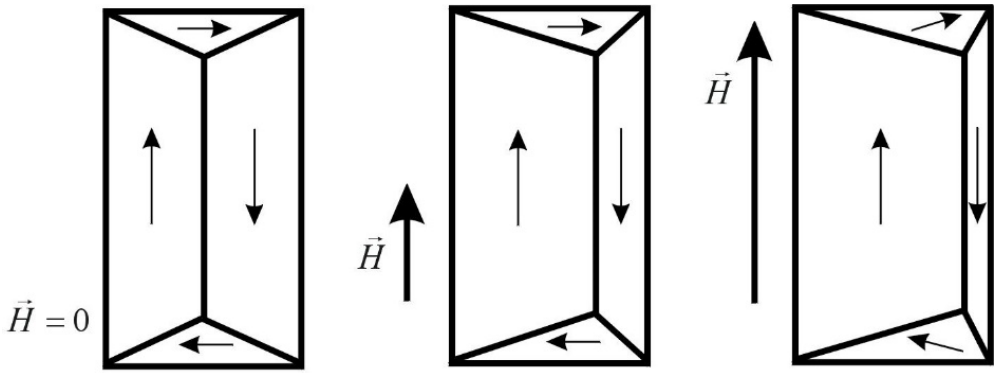
Liquid oxygen is suspended between the two pole faces of a magnet because the liquid is paramagnetic and is magnetically attracted to the magnet.

Ferromagnetism

iron, nickel, dysprosium and alloys

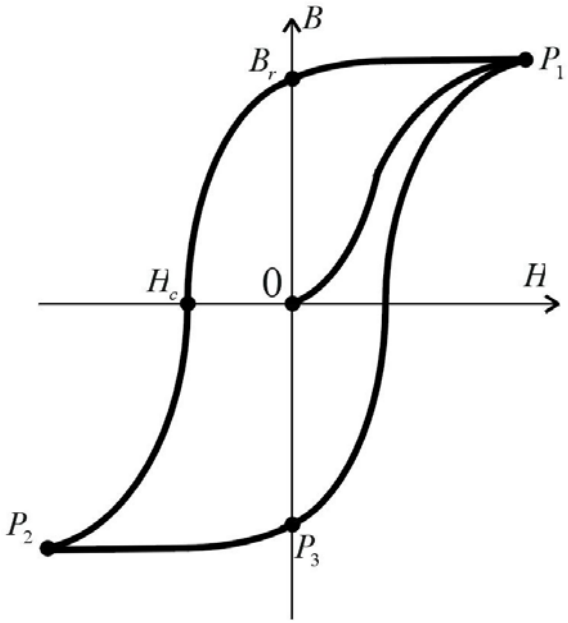
$\chi_m \gg 1$ $\mu_r \gg 1$

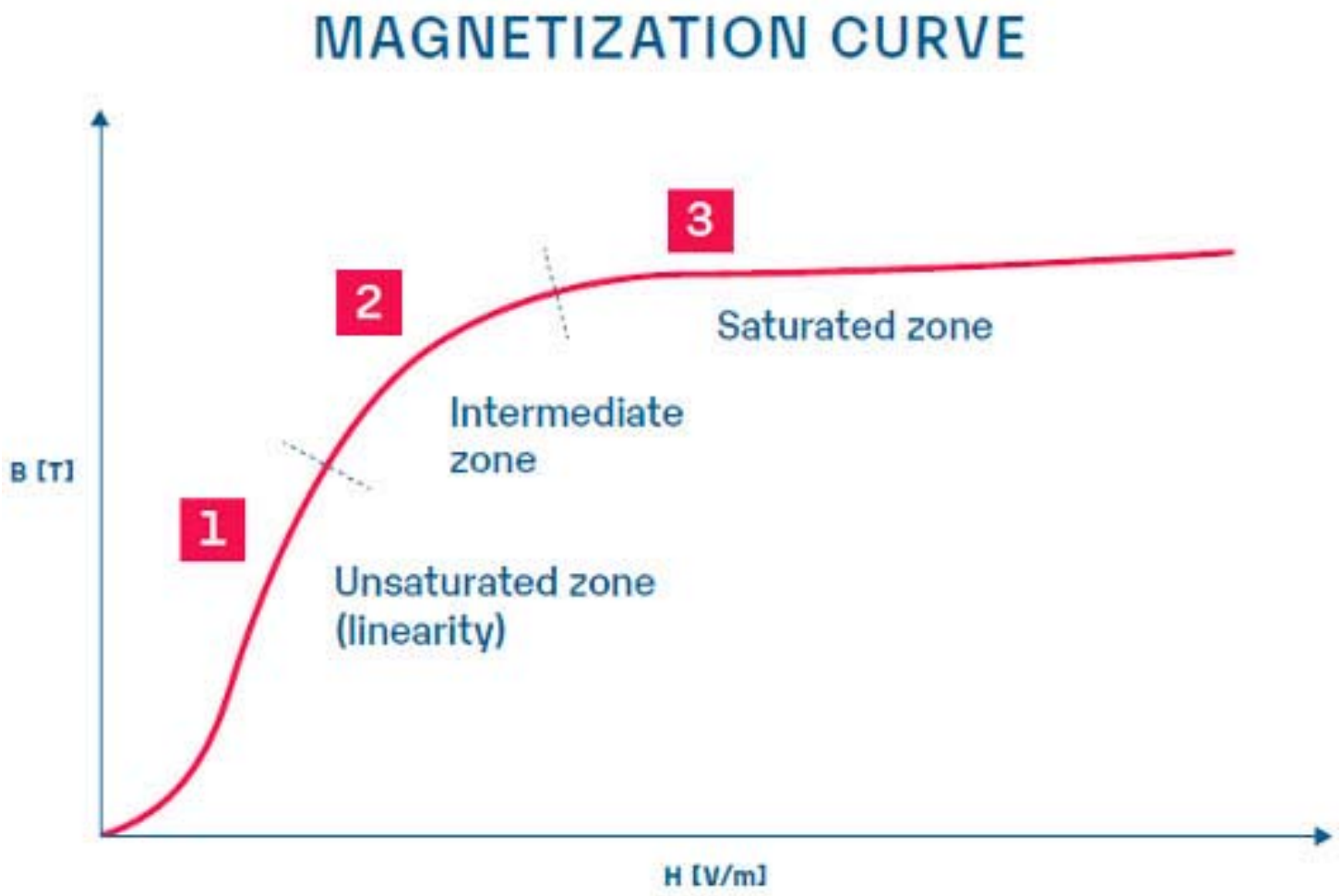
$\mu > \mu_0$

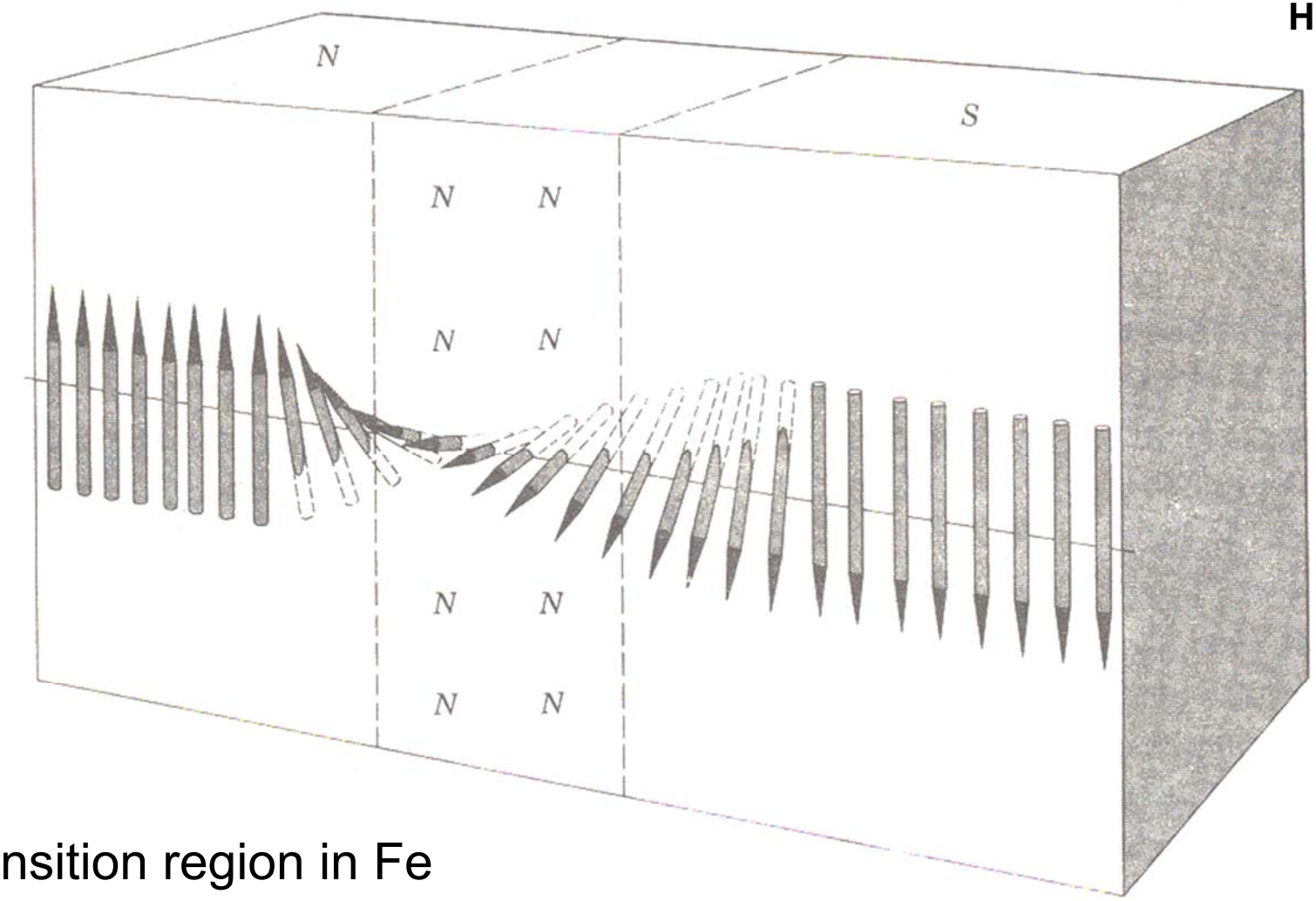


domains, Bloch walls

hysteresis




MAGNETIZATION CURVE
B [T]
H [V/m]
1
2
3
Unsaturated zone
(linearity)
Intermediate
zone
Saturated zone



Transition region in Fe

≈ 300 a

bcc: a = 0,287 nm

300 a ≈ **85 nm**

Charles Kittel: Introduction to Solid State Physics