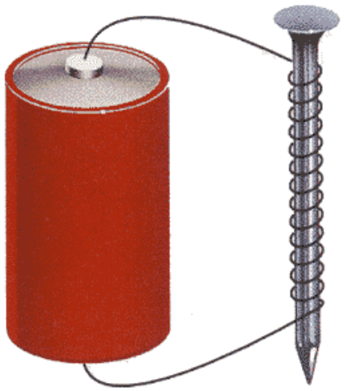
# Matter in external magnetic field

http://www.ru.nl/hfml/research/levitation/diamagnetic/

April, 2018

Sanja Dolanski Babić

$B = B_0 + B'$



$B_0$ – external magnetic field
$B'$ – induced magnetic field

relative magnetic permeability: $\mu_r = B / B_0$

# Matter in external magnetic field

relative magnetic permeability: $\mu_r = B/\,B_0$

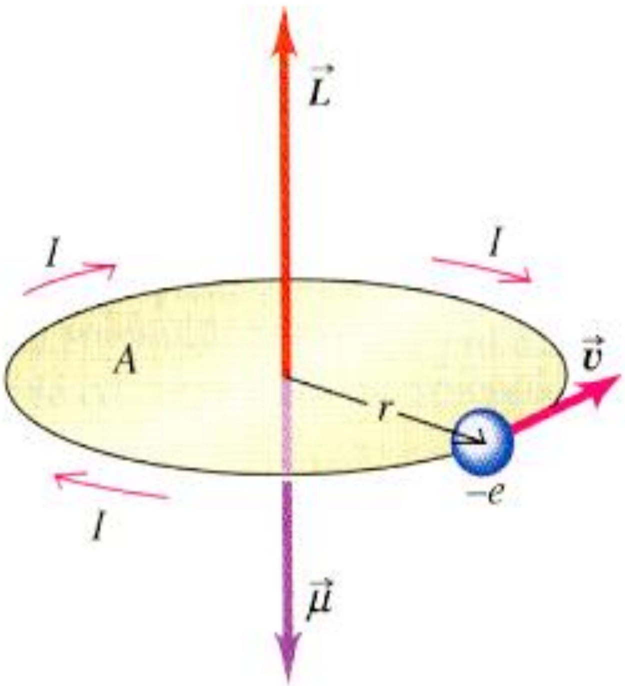
$\mu_r \geq 1,\ B \approx B_0\,(1+10^{-4})$ paramagnetics

$\mu_r \leq 1,\ B \approx B_0\,(1-10^{-6})$ diamagnetics

$\mu_r >> 1,\ B \approx B_0 \cdot 10^{3}$ feromagnetics

# Magnetic properties of atom

- Classical model of atom: electrons rotate around nucleus
- magnetic field is induced by “microcurrents”
- nucleus can has spin magnetic moment
- electron can has spin magnetic moment and orbital magnetic moment
- Classical model is not satisfactory




Angular moment: $\vec{L} = m\,\vec{r} \times \vec{v}$

Orbital magnetic moment:

$$\vec{\mu_l} = \frac{-e}{2m}\vec{L}$$

Spin magnetic moment:

$$\vec{\mu_s} = \frac{-e}{2m}\vec{S}$$

For simplicity: spin magnetic moment of nucleus is neglected.

# Diamagnetism

- All types of matter have the property of diamagnetism.
- Dominant property of matter where molecules have paired electronic spins (no net spin) – only magnetic moment from orbital motion is in interaction with the field.
- When external magnetic field is switched on – induces change in orbital and magnetic moment of electron.
- Induced magnetic field is in opposite direction of external field (Lentz's rule)

$\mu_r \leq 1$, $B \approx B_0\,(1\text{-}10^{-6})$ diamagnetics

# Diamagnetism

$B' \approx 10^{-6} B_0$

diamagnetics: noble gases, nitrogen, hydrogen, cooper, grafit, gold

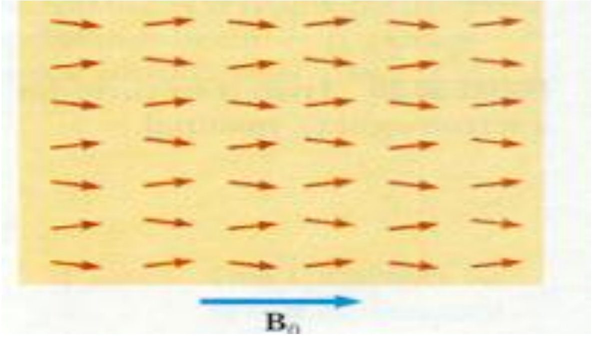
http://www.youtube.com/watch?v=A1vyB-O5i6E&feature=rellist&playnext=1&list=PL8E7ED16454FE1C63tation/diamagnetic/

# Paramagnetism

- magnetic dipole moment: orbital and spin

- out of field spin magnetic moments are oriented randomly (chaotic)

- In the magnetic field they will tend to orientate in the direction parallel to field lines



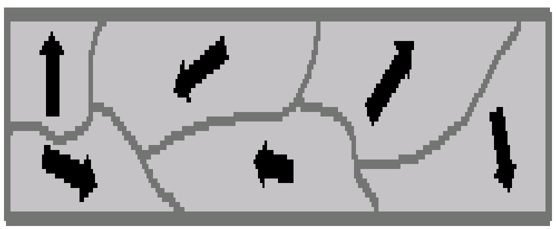

$B' \approx 10^{-4} B_0$

Paramagnetics: aluminium, manganese, sodium, potassium, free radicals

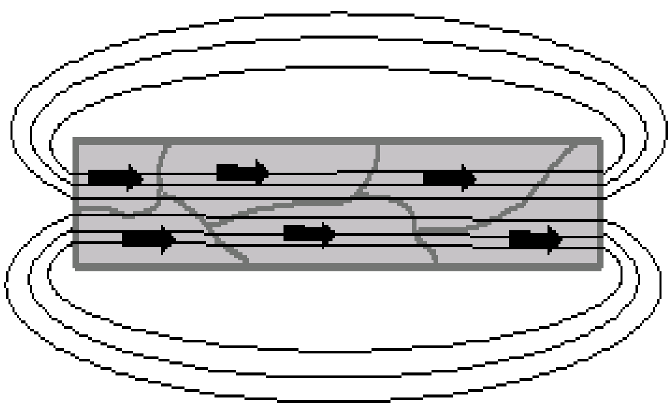
$\mu_r \geq 1$, $B \approx B_0 (1+10^{-4})$ paramagnetics

# Feromagnetism

- Inside particular magnetic domain, spin magnetic moments are mutually parallel



- Orientation of different domains is not the same before first magnetization; when the magnetic field is applied, spin magnetic moments in amm domains tend to align along a field
- When B0 is switched of, ordering of domains (magnetization) remains



$B' \approx 10^3 B_0$

Feromagnetics: metals VIII – X group

$\mu_r >> 1$, $B \approx B_0 \cdot 10^3$ feromagnetics

NATURE | VOL 400 | 22 JULY 1999 | www.nature.com

**Figure 2** Levitation at your fingertips. A strong NdFeB magnet (1.4 tesla) levitates 2.5 metres below a powerful superconducting magnet. The field at the levitation point is about 500 Gauss.

$B = B_0 + B'$

$\mu_r = B / B_0$

$\mu_r \geq 1,\ B \approx B_0\ (1 + 10^{-4})$ paramagnetics

$\mu_r \leq 1,\ B \approx B_0\ (1 - 10^{-6})$ diamagnetics

$\mu_r >> 1,\ B \approx B_0 \cdot 10^3$ feromagnetics

magnetic moment of electron → spin magnetic moment

***para and feromagnetism***

**and/only**

magnetic moment of electron → orbital magnetic moment

***diamagnetism***