EUROPEAN UNION
MINISTRY OF EDUCATION, YOUTH AND SPORTS
OP Education for Competitivness
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

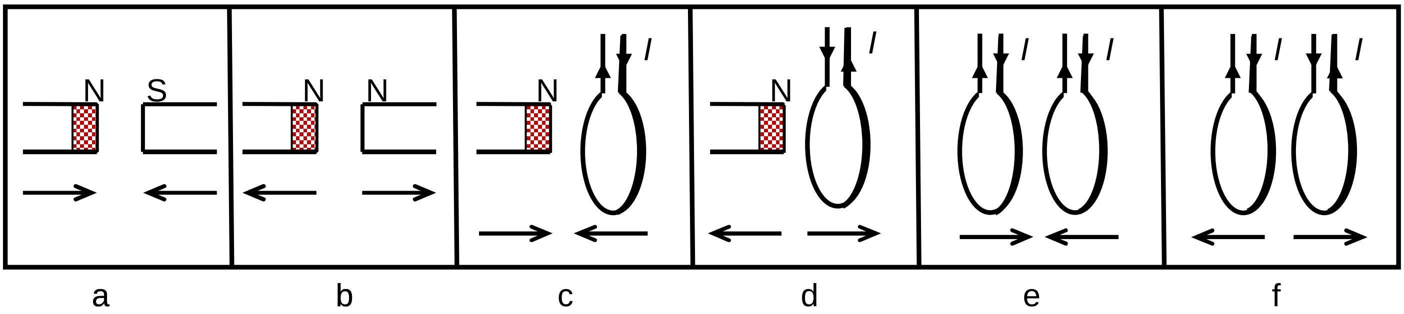
MAGNETIC FIELD

1. Stationary magnetic field

is a part of space where all the quantities which describe the magnetic field do not change with time. It is formed near

- stationary conductors or coils carrying steady currents
- stationary permanent magnets (usually ferrites)

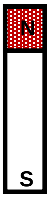
forces between different magnetic fields:



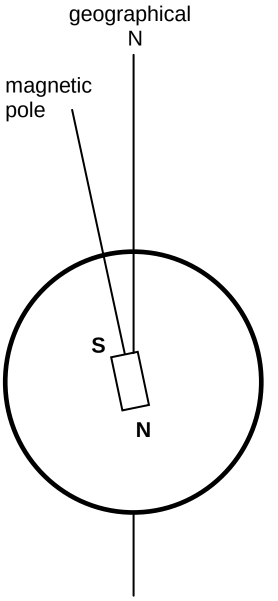
magnetic field lines are the lines in 3dim and the tangents to them represent at any point the direction of a very small plotting compass. Their direction is

- **from N to S pole of a permanent magnet**

  Sketch magnetic field lines:



Bar magnet



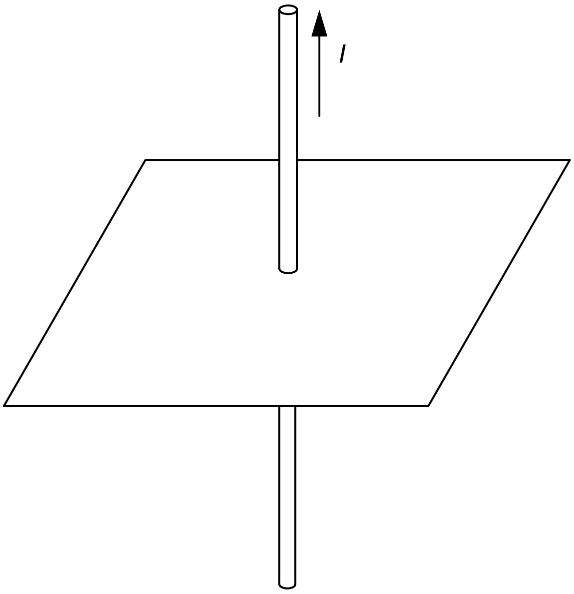
The Earth´s magnetic field

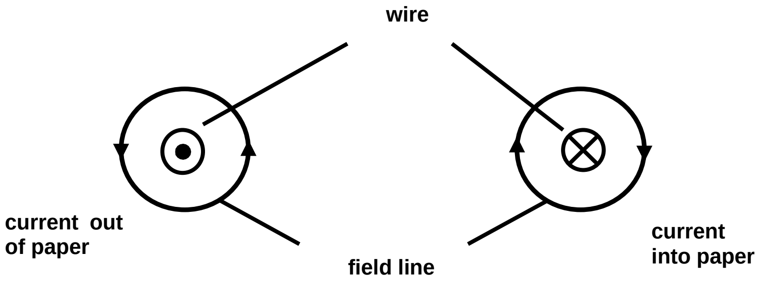
- **for a straight conductor:**

Ampere’s right-hand-grip rule: thumb in the direction of current, fingers show the direction of field lines

right-hand screw rule (see additional materials): if a right-handed screw moves forward in the direction of the current, then the direction of rotation of the screw gives the direction of the magnetic field lines

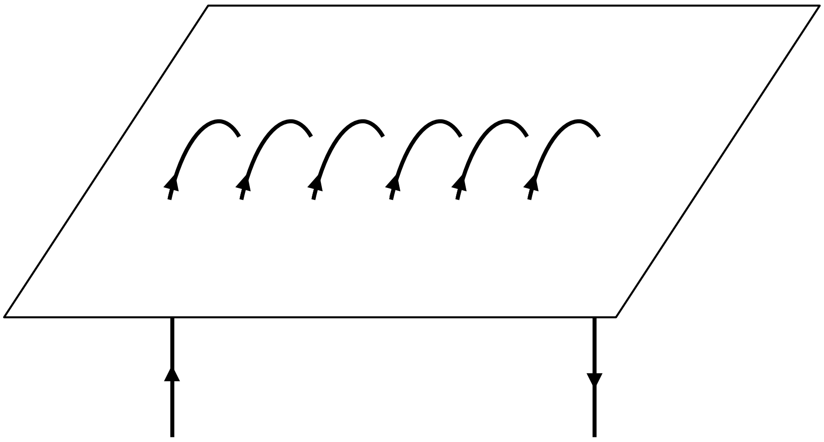
Sketch magnetic field lines:



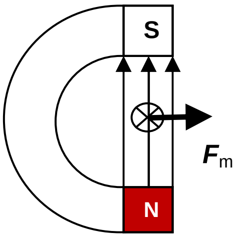


- **for a coil:**
  Ampere’s right-hand-grip rule: grip the coil - fingers in the direction of the conventional current, thumb shows the north pole

Sketch magnetic field lines:



2. Magnetic force on a conductor in a magnetic field



- magnets are affected by magnetic force when placed in the outer magnetic field
- conductors carrying currents are surrounded by magnetic field ⇒ can behave like “magnets“

  when placed in another outer magnetic field
  - are affected by magnetic force

- <u>Fleming’s LEFT hand (motor) rule:</u> when conductor ⊥ to the field lines

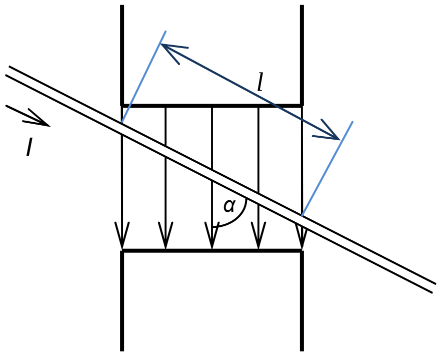
CZ:	E:
field lines into the palm	first finger in the direction of the field
fingers in the dir. of the current	second finger in the direction of the current
thumb shows the direction of the force F_m	thumb shows the thrust (= force)

(See additional materials)

3. Magnetic flux density ($\vec{B}$)

represents the “strength” of the magnetic field (sometimes called magnetic field strength)

(See additional materials)



- $F_m \propto l, I, B, \alpha$

$$F_m = BIl\sin\alpha$$

$F_m = BIl$ ... for the conductor ⊥ to the field lines

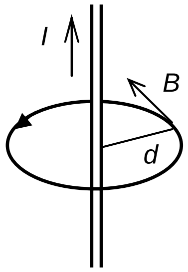
$$B = \frac{F_m}{Il}$$

$[B] = \frac{\mathrm{N}}{\mathrm{A \cdot m}} = \mathrm{T}$ (tesla)

Questions:

L5/251-259, 262, x263-5

4. Magnetic field of two parallel current carrying conductors



- **$\vec{B}$ near a straight wire**

size: $B = \mu \frac{I}{2\pi d}$

dir.: tangent to the field lines

- μ ... permeability of the medium around the wire, material constant

  $\mu = \mu_r \mu_0$

  μ_r ... relative permeability – in the book of data

  μ_0 ... permeability of vacuum

  $\mu_0 = 4\pi 10^{-7}\ \mathrm{N \cdot A^{-2}}$

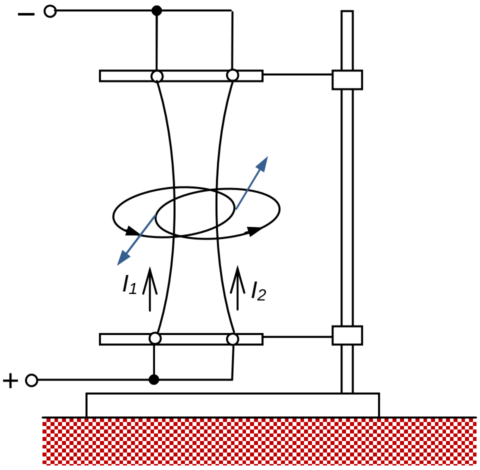
- **magnetic field of two conductors**

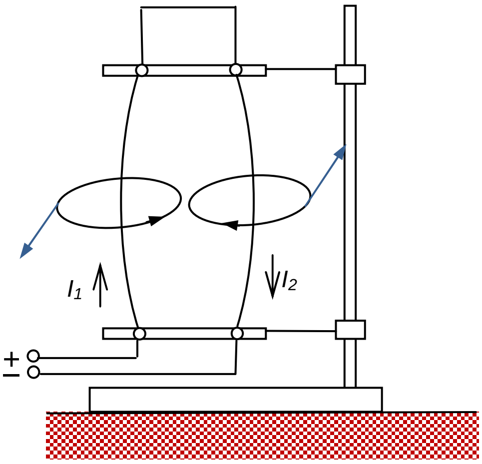
$$\text{size: } F_m = B I_2 l = \mu \frac{I_1}{2\pi d} I_2 l$$

$$\text{size: } F_m = \frac{\mu}{2\pi} \frac{I_1 I_2}{d} l$$

dir.: attraction when I_1, I_2 in the same dir.
repulsion when I_1, I_2 in opposite dir.

Finish pictures (label magnetic flux density, mark forces):

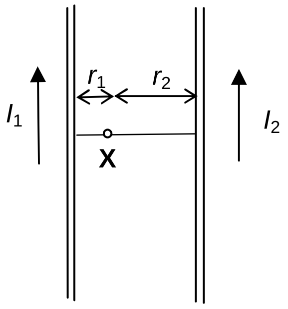




Definition of 1 A: when 2 parallel ∞long wires in vacuum 1 m apart carry 1 A each, the force per 1 m of their common length is 2×10^{-7} N.

Questions:

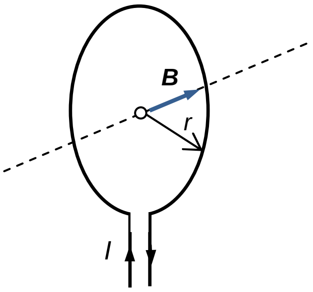
1. State the magnitude and the direction of magnetic flux density at the point X (see the figure). $I_1 = 50$ A, $I_2 = 10$ A, $r_1 = 5$ cm, $r_2 = 15$ cm, permeability of vacuum is $4\pi\cdot10^{-7}\ \mathrm{N\cdot A^{-1}}$.

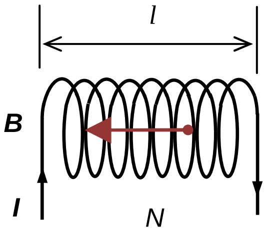


5. Magnetic fields of coils

- direction – tangent to the field lines
- size in the centre:

of a single loop	of a long solenoid or toroid
$B = \dfrac{\mu I}{2r}$	$B = \dfrac{\mu N I}{l}$ N ... number of loops

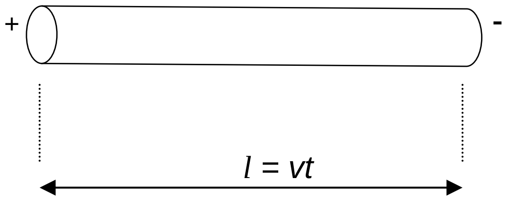




Questions:
2. A solenoid has the length 40 cm and 500 loops of a densely reeled wire. Relative permeability of the steel core is 1200 and the current passing through is 0.1 A. Stipulate *B* in the middle of the solenoid with and without the core.

L5/267-271

6. Charged particle in a magnetic field



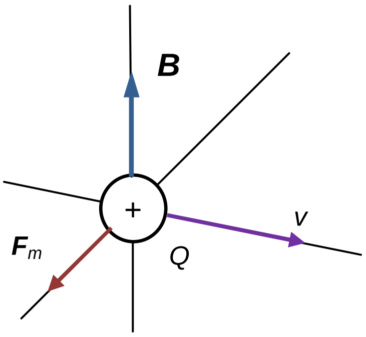
$$I = \frac{Q}{t} = \frac{Ne}{\frac{l}{v}} = \frac{Nev}{l}$$

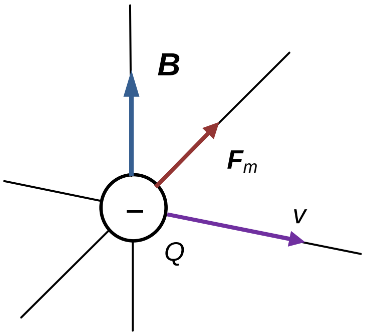
when the conductor is $\perp$ to $\vec{B}$, the size of the force on N electrons: $F_m = BIl = BNev$

size of the force on ONE electron $\vec{v} \perp \vec{B}$: $F_\mathrm{m} = Bev$

size of the force on a moving charge q, $\vec{v} \perp \vec{B}$: $F_\mathrm{m} = Bqv$

direction of the force: Fleming's left hand rule (for + charge!!!)





trajectory of the particle

$\vec{v} \perp \vec{B}$ ... a circle when the field is large enough, if not – just a part of it

$\vec{v}$ not $\perp \vec{B}$ ... a helix

$$F_\mathrm{m} = F_\mathrm{C}$$
$$Bev = \frac{mv^2}{r}$$
$$\frac{e}{m} = \frac{v}{Br}$$

Wehnelt's tube

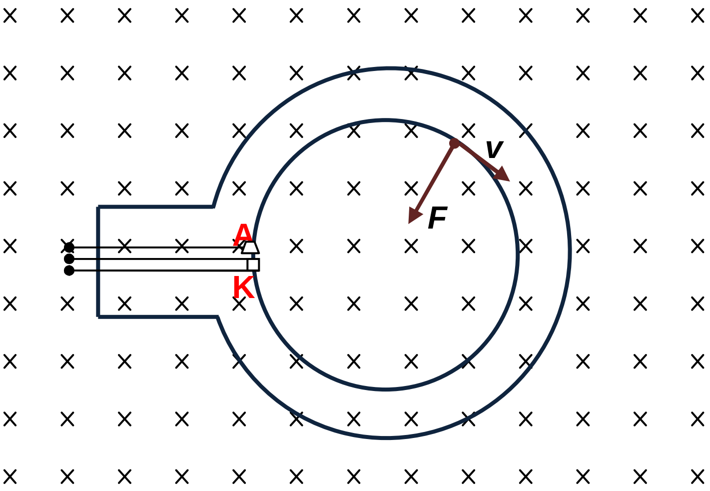
(See additional materials)

Lorentz´s force: *A charged particle moving in both electric and magnetic fields is affected simultaneously by electric and magnetic force. Their result is Lorentz´s force which determines the direction and type of motion of the particle.*

$\boldsymbol{F}_{\mathrm{L}} = \boldsymbol{F}_{\mathrm{e}} + \boldsymbol{F}_{\mathrm{m}}$

Questions:

3\. An electron enters the uniform magnetic field of $B = 2.5 \times 10^{-3}$ T at speed $v = 10^{6}$ m·s^{-1} perpendicularly to magnetic field lines. Find the radius of the circle – trajectory of the electron.
$e = 1.602\times10^{-19}$ C, $m_e = 9.109\times10^{-31}$ kg
Then calculate the radius in case of α-particle whose charge is 2e and mass $6\cdot10^{-27}$ kg.



4\. A solenoid with 1000 loops and of length 0.1 m is lined up so that its axis is parallel to the Earth´s field lines. The magnetic flux density is 70 μT at the position of the solenoid. Calculate the current in the solenoid which will create a magnetic field of the same strength as the Earth´s field. Assume permeability of vacuum $4\pi\cdot10^{-7}$ N·A^{-1}.

L5/272-284

7. Magnetic properties of materials

Magnetic properties of different materials are described as relative permeability μ_r . Big relative permeability means that the material can reinforce the strength of the outer magnetic field. Such materials can be used e.g. for cores of electromagnets, where they make the electromagnet μ_r -times “stronger“.

- **diamagnetic materials**
  - μ_r is slightly less than 1 (e.g. 0.99999), so they make the outer magnetic field slightly weaker than it would be in a vacuum
  - noble gases, gold, copper, mercury, ...

- **paramagnetic materials**
  - μ_r is slightly more than 1 (e.g. 1.000023 for Al), so they make the outer magnetic field slightly stronger
  - sodium, potassium, aluminium, ...

- **ferromagnetic materials**
  - μ_r from about 100 to 100 000, so they reinforce the outer magnetic field a lot

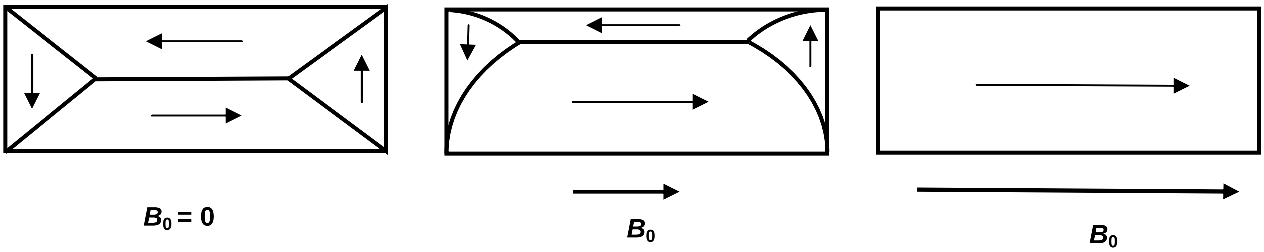
  - soft - do not keep the magnetic properties when the outer field is removed or change with it quickly, used e.g. for cores of electromagnets
  - hard – are more difficult to magnetise, but they keep their magnetism even when removed from the outer magnetic field, e.g. ferrites – made from iron oxide combined with other metal oxides (Mn, Ba), used for permanent magnets

  - they have the property only when
    - in crystalline, not liquid or amorphous state
    - their temperature does not exceed Curie’s temperature – material property, for Fe 770 °C

    if not – they become paramagnetic

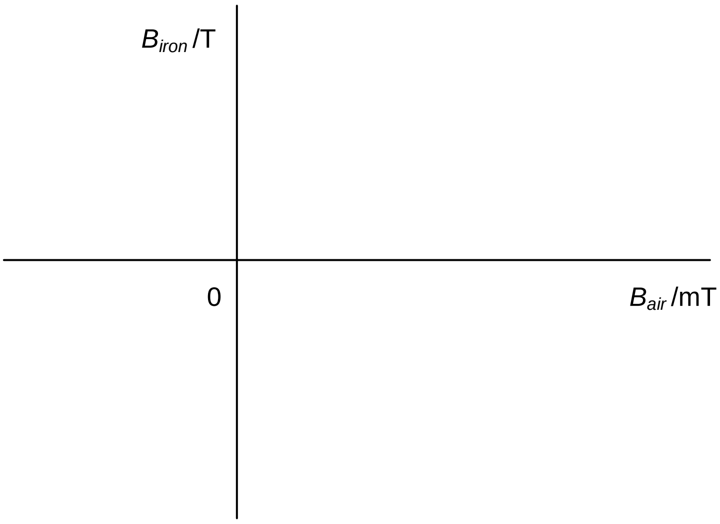
Domain theory of magnetism

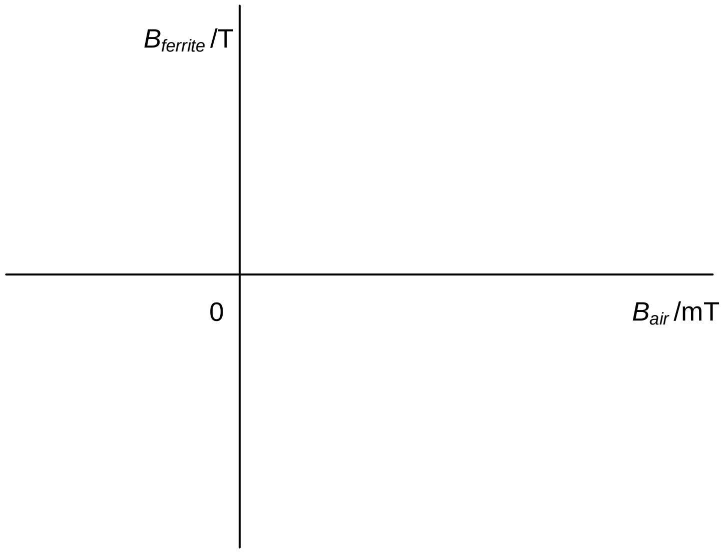
Magnetic domains are formed spontaneously within the material – volume about 10^{-3} mm^3 to 10 mm^3. Within these domains electrons revolve in similar directions – “tiny magnets“. When outer magnetic field is applied – domains tend to be lined up. When the outer magnetic flux density rises, more and more domains do that until all of them are lined up. We call this situation magnetic saturation.



Hysteresis loop describes the magnetic flux density in the material (***B***) when placed in the outer magnetic field (***B*₀**). Area inside is proportional to the energy needed to complete one “cycle of magnetisation and demagnetisation“ so heat is formed as well during the process.

Sketch the picture of a hysteresis loop to the coordinate system:





8. Uses of electromagnets

Sketch pictures according to additional materials:

<u>relay</u>

<u>moving-coil galvanometer</u>

moving-coil loudspeaker

Questions:

L5/287-290

Answers:

1. 187 μT
2. 0.189 T, 1.57×10^{-4} T
3. 2.27 mm, 7.49 m
4. 5.6×10^{-3} A

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