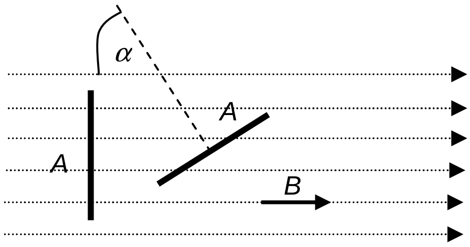
ELECTROMAGNETIC INDUCTION

1. Magnetic flux (Φ), non-stationary magnetic field

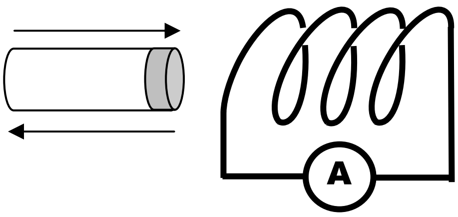
Magnetic flux is a new physical quantity needed to describe the CHANGES of the magnetic field (non-stationary magnetic field) related to a certain area. Sometimes even the field can in fact stay the same, but it changes if the area e.g. rotates in it.



when $A \perp \vec{B}$: $\Phi = BA$
for any α : $\Phi = BA\cos\alpha$
for $\alpha = \omega t$: $\Phi = BA\cos\omega t$
(regularly rotating area)

$[\Phi] = \mathrm{T} \cdot \mathrm{m}^2 = \mathrm{Wb}$ (weber)

2. Phenomenon of electromagnetic induction



changes of the magnetic field $\Rightarrow$

induced electric field or voltage,
induced el. current flows if possible

(1831 Faraday in E, Henry in USA)

3. Faraday's law of electromagnetic induction

The rate of change of flux linkage or flux is directly proportional to the electromotive force induced

flux linkage = $N\Phi$ when the coil in the magnetic field has *N* loops(turns), the flux changes in each of them so that the voltage induced must be *N*-times bigger

$$U_i \propto \frac{\mathrm{d}(N\Phi)}{\mathrm{d}t}$$

$$U_i \propto \frac{N\Delta\Phi}{\Delta t}$$ for regular changes of flux during t

E.g. when the flux in a single-turn coil changes by 1Wb during 1s, the voltage induced is 1V.

TENTO PROJEKT JE SPOLUFINANCOVÁN EVROPSKÝM SOCIÁLNÍM FONDEM A STÁTNÍM ROZPOČTEM ČESKÉ REPUBLIKY

4. Lenz's law

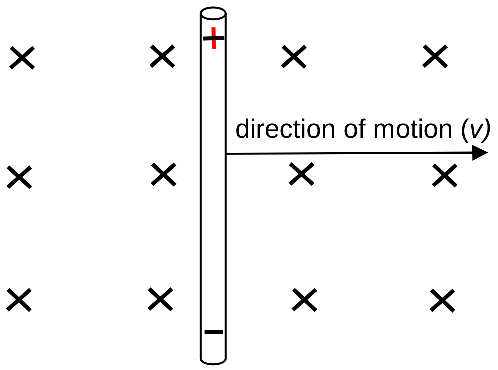
The direction of the electromotive force is such that it tends to oppose the flux change causing it and it does oppose if an induced current flows.

$$U_i = -\frac{\mathrm{d}(N\Phi)}{\mathrm{d}t}$$

$$U_i = -\frac{N\Delta\Phi}{\Delta t}$$ for regular changes of flux during t

- voltage induced when a conductor moves in a magnetic field

Electrons in a conductor move in the outer magnetic field (v), therefore there is a magnetic force which pushes them towards one end of the conductor ($F_m = Bev$). They move until the electric force equals the magnetic one.



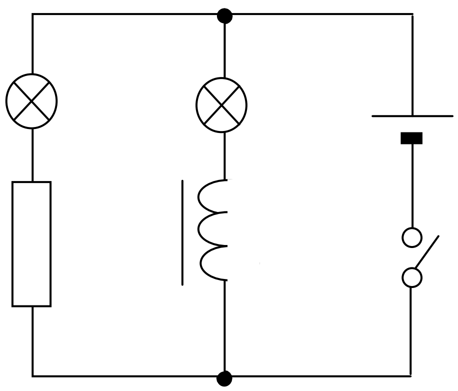
its electric field strength $E_i = \frac{F_m}{e} = Bv$

voltage induced across a moving conductor

$$U_i = E_i l = Bvl$$

5. Self-induction

is a phenomenon present when the changing current in the coil produces a changing magnetic field around it which then affects the coil back as if there are the changes of another „outer“ magnetic field.



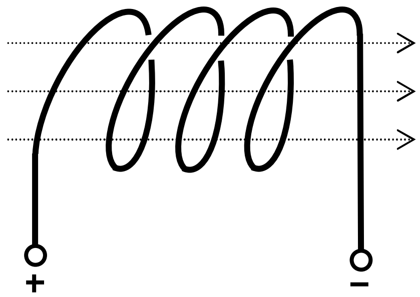
Do any of the bulbs light later when we switch on the circuit? Explain.

The current in the branch with the coil is delayed because of voltage induced against the outer one until the current is steady.

The delay depends on the property of the coil called **inductance (L).**

6. Inductance (*L*)

big $L \longrightarrow$ big voltage induced against the outer when the current changes $\longrightarrow$ big delay in the branch with the coil in the previous experiment



$\Phi = LI$

magnetic flux through the coil depends on
the current passing it
its property is called inductance

X e.g. for a solenoid $L = \dfrac{\mu N^2 A}{l}$

- $U_i = -\dfrac{\Delta \Phi}{\Delta t} = -L\dfrac{\Delta I}{\Delta t}$
- $[L] = \left[\dfrac{U_i \Delta t}{\Delta I}\right] = \dfrac{\mathrm{V \cdot s}}{\mathrm{A}} = \dfrac{\mathrm{Wb}}{\mathrm{A}} = \mathrm{H} \quad (\text{henry})$

The coil has the inductance of 1H when the rate of change of current by 1A per second induces the voltage of 1V.

Questions:

1. Magnetic flux in a 20 turns coil rises during 0.4 s by 80 mWb. What is the voltage induced? What would be changed if the flux decreases?

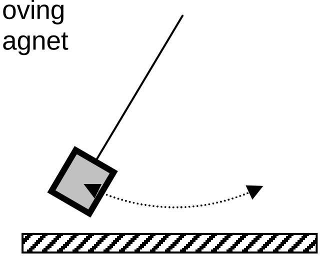
2. A straight conductor of length 0.8 m moves at 0.2 $\mathrm{m \cdot s^{-1}}$ at a right angle to the field lines of magnetic field. When the voltage induced between the ends of the conductor is 50 mV, calculate the magnetic flux density of the field.

L5/291-299, 304, 311-316

7. Eddy currents

are present when a large sample of conducting material is placed into a the changing magnetic field $\rightarrow$ electric field is induced within the sample and induced current can flow when the block is uniform
Experiment 1: What do you feel when the magnet moves above the metal placed on your hand? Explain.

moving
magnet



sheet of conducting material : iron, copper, lead

Experiment 2: Two bits of some material fall through a narrow copper tube. One of the bits is delayed a lot. What is the reason?

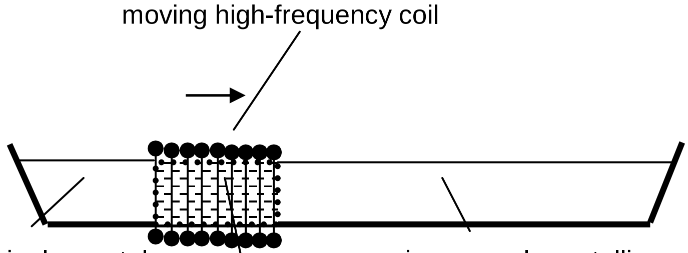
Eddy currents induced against the changes of the outer magnetic field produce a magnetic field which tends to slow down the movement of the magnet – „work against the change“.

Eddy currents can be used in

- <u>paying for electricity</u> – in some of the devices installed in any house to measure the consumption of electrical energy an aluminium disc rotates between the magnets and it keeps rotating when we use the electricity. When all the appliances are off, the eddy currents induced in the disc will stop it (so that inertia of the disc does not affect the measurement and therefore the cost).

- <u>refining metals and manufacture of monocrystals</u>

moving high-frequency coil

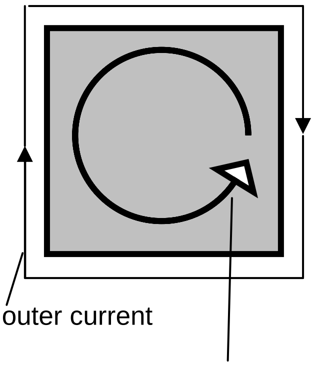


pure single crystal
impure polycrystalline semiconductor or metal
molten zone

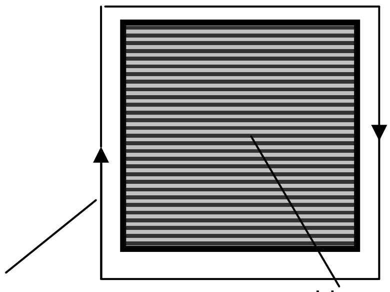
Eddy currents could cause problems in

- <u>cores of transformers</u>

cross-section of ordinary core



cross-section of laminated core



If we allow eddy currents to flow, their magnetic field would reduce the effect of the outer field caused by the current in the coil (bad for induction on the secondary coil) and they can also produce heat!!!

Answers:
1. -4 V
2. 312.5 mT