RC circuits

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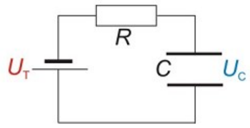
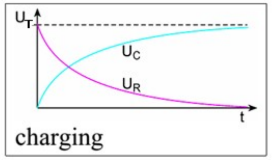
Charging the RC circuit



RC circuit: an electrical circuit consisting of an ohmic resistor and a capacitor
(in series, in our case)

Kirchhoff's voltage law (Kirchhoff's loop law, Kirchhoff's second law): as a result of conservation of energy, the directed sum (considering the signs) of voltages of electrical components along a loop within an electrical circuit is zero.



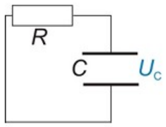
From Kirchhoff's 2nd law: $U_T = U_R + U_C$

$\mathbf{U_c = C \cdot q}$

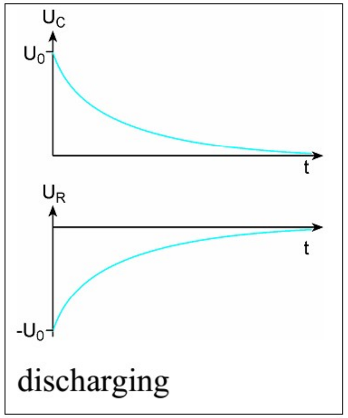
$$U_C = U_T \cdot \left(1 - e^{-\frac{t}{R \cdot C}}\right)$$

RC = τ time constant

Discharging the RC circuit

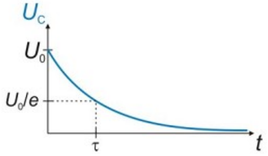


From Kirchhoff's 2nd law:
$U_R + U_C = 0$
$U_C = -U_R$



$$U_C = U_0 e^{-\frac{t}{RC}}$$

Note!
Meaning of time constant:



Capacitor in alternating current circuits

Alternating current circuit (**AC circuit**): current and voltage changes periodically following a sine function:

$$I = I_{max} \sin \omega t \quad \text{and} \quad U = U_{max} \sin(\omega t + \varphi)$$

In an AC circuit the capacitor has a finite "resistance" called **capacitive reactance (symbol: Xc)**.
Unit of capacitive reactance: **Ω (ohm)**.
The alternating current keeps charging and discharging the capacitor , then again charging with the opposite polarity and again discharging and so forth.

$$X_C = \frac{1}{\omega C}$$

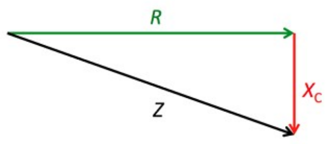
$\omega = 2\pi f$ is the angular frequency of the AC circuit

Impedance

If an AC circuit contains both resistors and capacitors, the total "resistance" of the whole circuit is called **impedance** . Usual symbol: Z; unit: Ω (ohm).

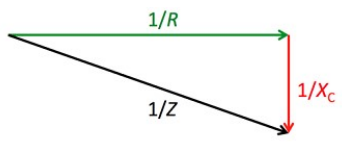
Because of the phase shift between U and I in case of capacitors, the two quantities have to be considered perpendicular vectors which will define a right triangle: impedance will be related to the hypotenuse of this triangle.

Impedance of a series RC circuit



$$R^2 + (X_C)^2 = Z^2$$

Impedance of a parallel RC circuit



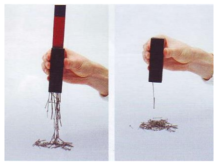
$$\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_C}\right)^2 = \left(\frac{1}{Z}\right)^2$$

Note! Pythagorean theorem: $a^2 + b^2 = c^2$ (where c is the hypotenuse)

Magnetism and Electromagnetic Induction

Magnet: a body with a special magnetic property

- **permanent magnets**
  - special ores (early observation in ancient times near to *Magnesia*)
  - Earth
  - elementary particles of atom (electron, proton, neutron)
- **non-permanent magnets**
  - ferromagnetic materials (iron, cobalt, nickel)

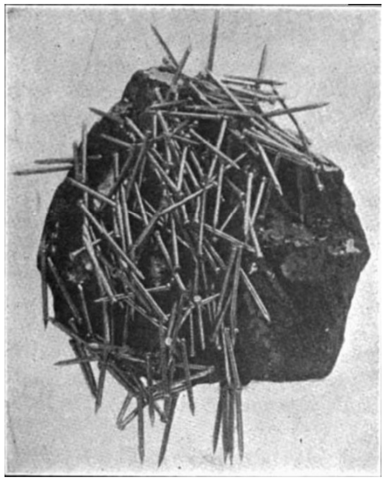


Magnetic effect of electric current: moving charges induce magnetic field

electromagnets

The strength of the magnet is given by the **magnetic moment** (Symbol: m or μ)

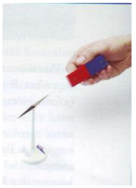
Natural magnets



Lodestone

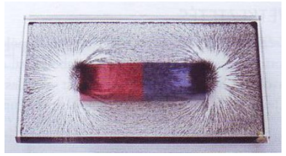
Magnetite (Fe_3O_4)

Magnetic interaction

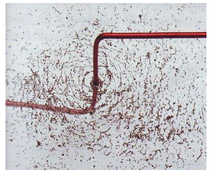


Electric phenomenon	Magnetic phenomenon
Two types of charges: positive and negative	Two types of poles: north pole and south pole
Like charges repel, the unlike charges attract each other	Like poles repel, the unlike pole attract each other
There are individual charges	There is no „one-polar” magnet (poles can not be separated)
Electric field	Magnetic field

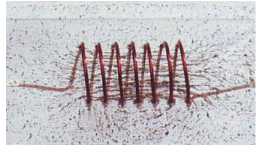
Magnetic field



Magnetic field of a magnet



Magnetic field of electric current flowing in a straight wire

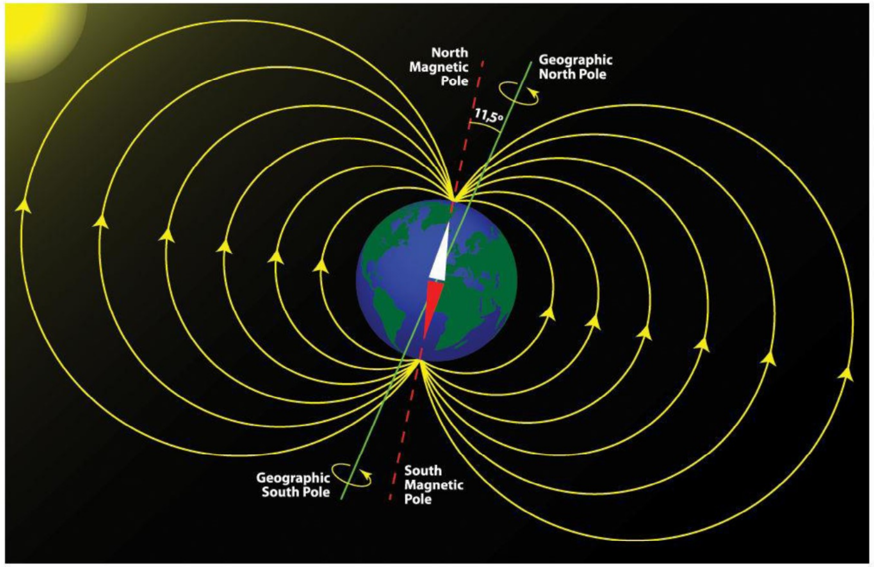


Magnetic field of electric current flowing in an electromagnet

Strength of the magnetic field is characterized by:
Magnetic flux density
Symbol: B ; unit: T (tesla)

The structure, direction and strength of a magnetic field is visualized by **field lines**

Magnetic field of the Earth



Some examples…

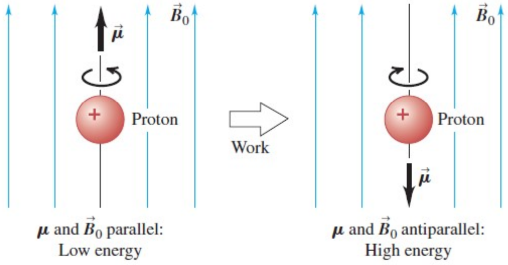
Magnetic flux density of the Earth	0,03-0,06 mT
Magnetic flux densitiy of fridge magnet	~ 10 mT
magnetic flux density used in MRI appliances	1-10 T

Generally:
Magnetic flux density of electromagnets:

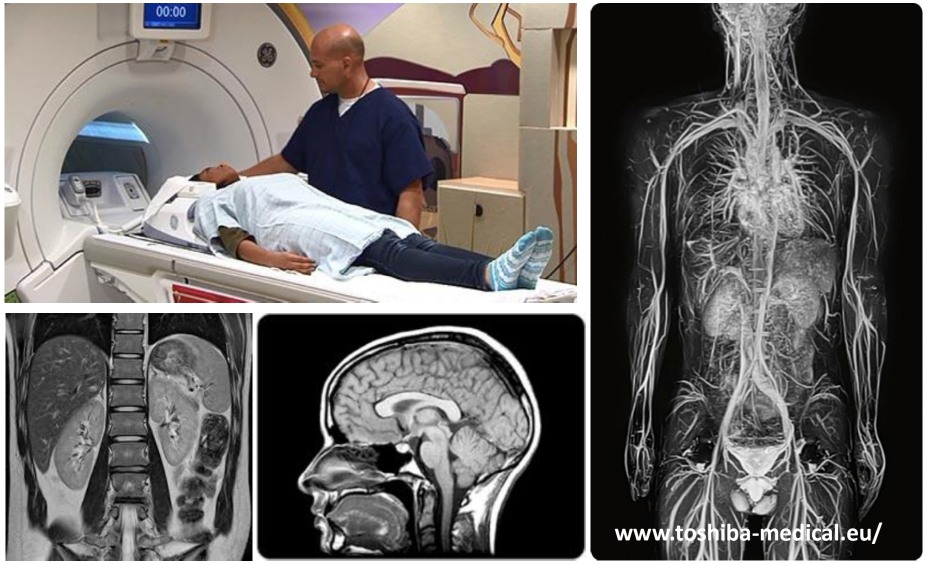
B ~ N·I

where **N** is the number of turns of the coil,
I is the current intensity

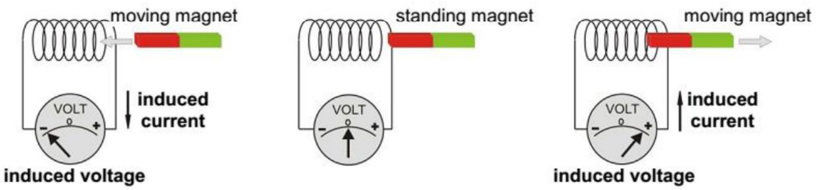
Interaction between a magnet and an external magnetic fields



Magnetic Resonance Imaging (MRI)



Electromagnetic induction

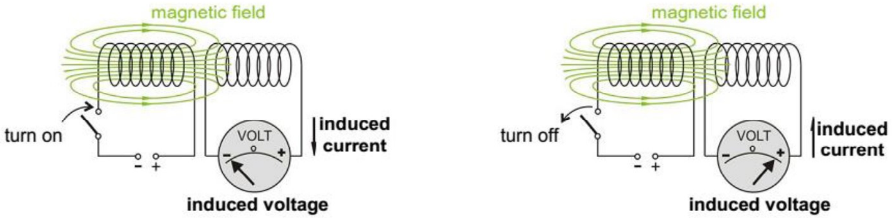


The magnetic field change caused by moving the magnet induces electric field, voltage, and current in the coil.

The faster the magnet moves, the higher the voltage.

Lenz's law: the induced voltage and current will act against the phenomenon creating it.

Electromagnetic induction



In the moment of switching the voltage source on or off the magnetic field changes: it will build up and break down, respectively.

During the change of the magnetic field , voltage is induced in the second coil.

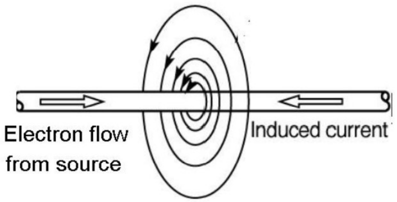
Generally: the faster and greater the change in the magnetic field, the greater the induced voltage.

Self-induction

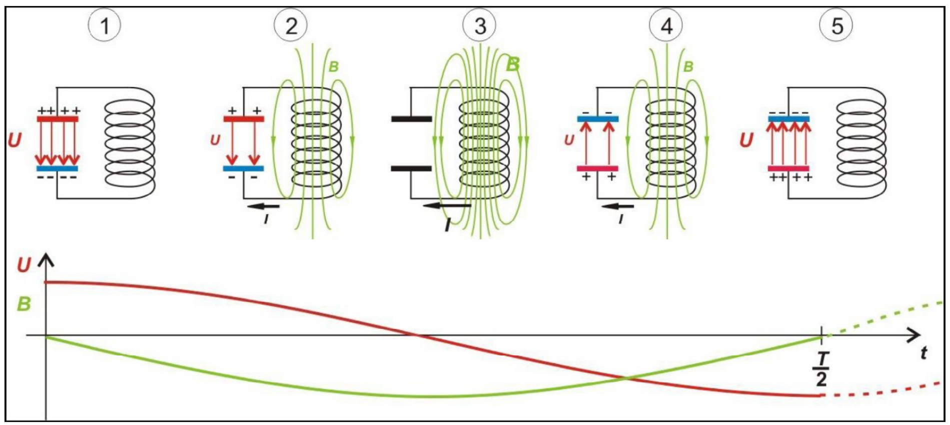
Self-induction: induction of voltage in the same coil – or, in general, any kind of conductor – in which the current change causes change in the magnetic field.

Self-induction occurs any time a circuit is switched on or off.

Lenz's law



LC circuit (resonant circuit)



Electric and magnetic oscillations are going on linked to each other

↓

electromagnetic oscillation