Electric and magnetic fields, microwave therapy

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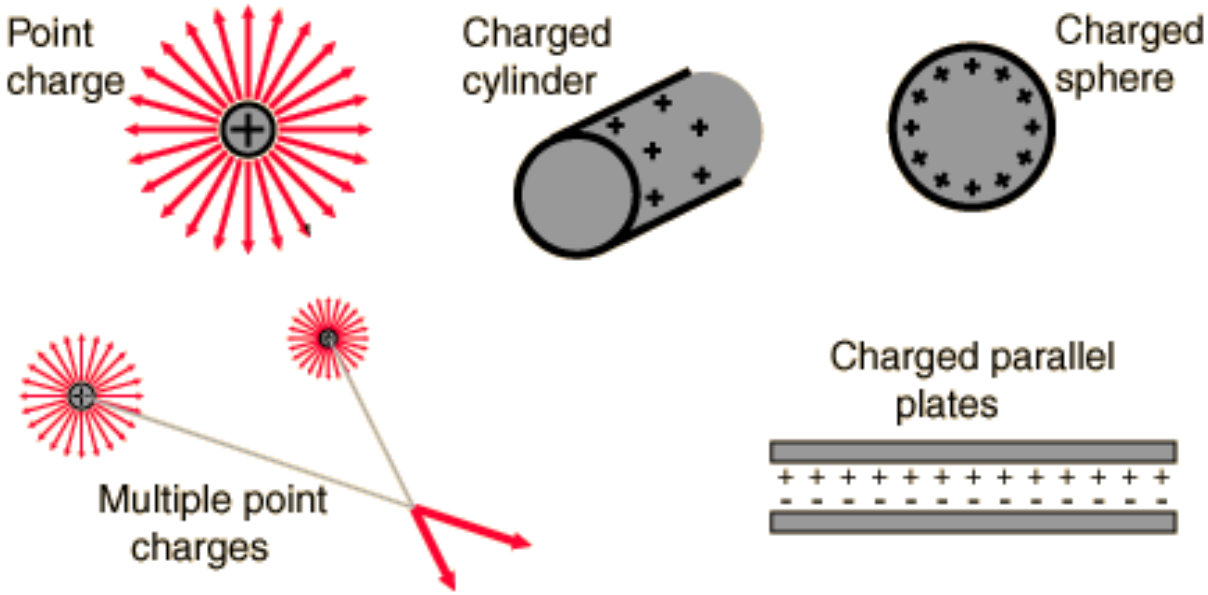
Electric field

the region around the charged body



E – electric field strength = electric force per unit charge

Presentation of electric field

- **vector field** – field lines

in each point of the region, the magnitude and direction of force acting at unit positive charge (test charge)

$$\vec{E} = \vec{F} / q$$

is called strength of electric field

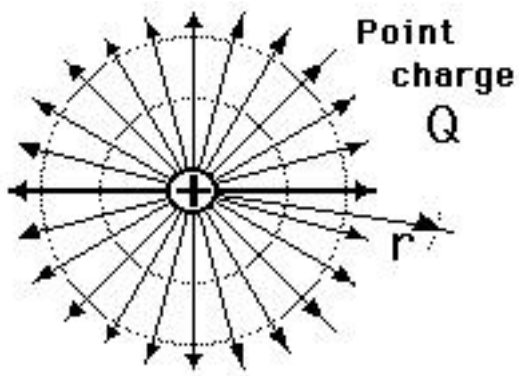
- the electric force changes the energy of the body

- **scalar field** – equipotential surfaces
- in each point of the space the potential energy of the test charge is called electric potential

$$\phi = W / q$$

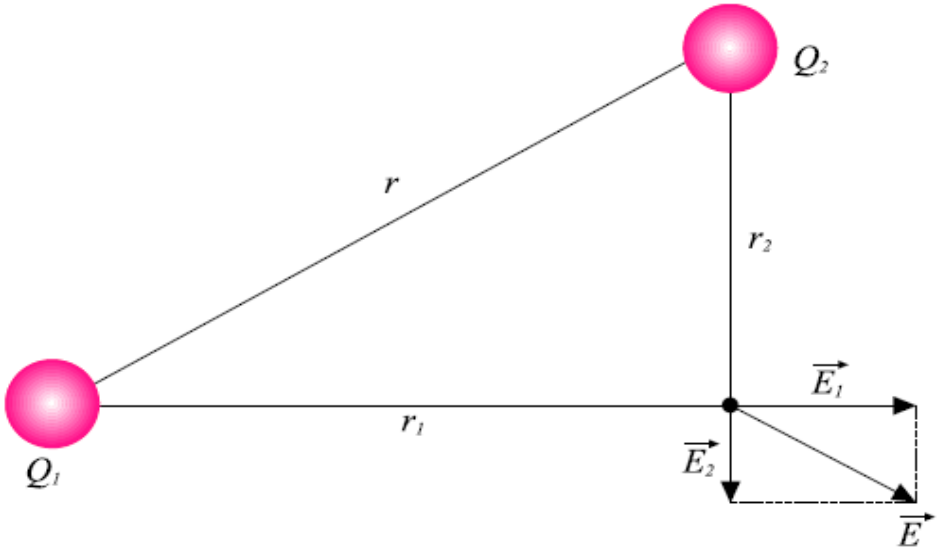
Electric field of the point charge

- inhomogeneous field



- Strength of electric field

$$\vec{E}(r) = \frac{1}{4\pi\varepsilon}\frac{Q}{r^2}\vec{r}_0$$

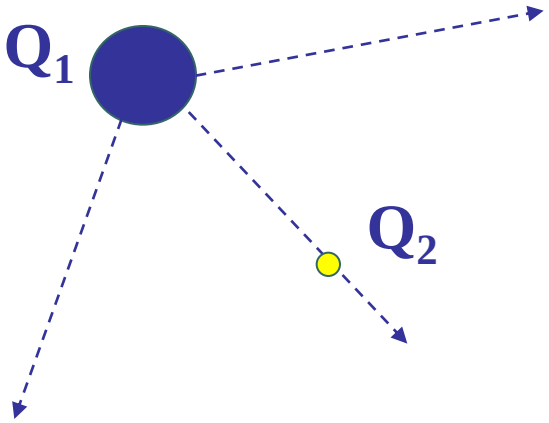


- Principle of superposition

$$\vec{E}(r) = \sum_i \vec{E}_i(r_i) = \sum_i \frac{Q_i}{r_i^2}\vec{r}_{i0}$$

Potential energy in the electric field

- charge Q_2 is in the electric field of charge Q_1, at distance r_A from Q_1. The potential energy is:



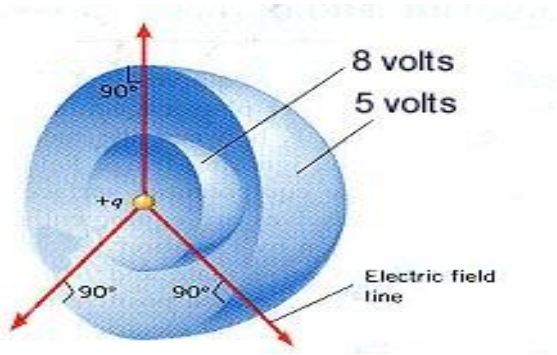
$$E_{pot}(r_A) = \frac{1}{4\pi\varepsilon}\frac{Q_1 Q_2}{r_A} = W_{\infty A}$$

- potential energy of unit charge at point A is **electric potential:**

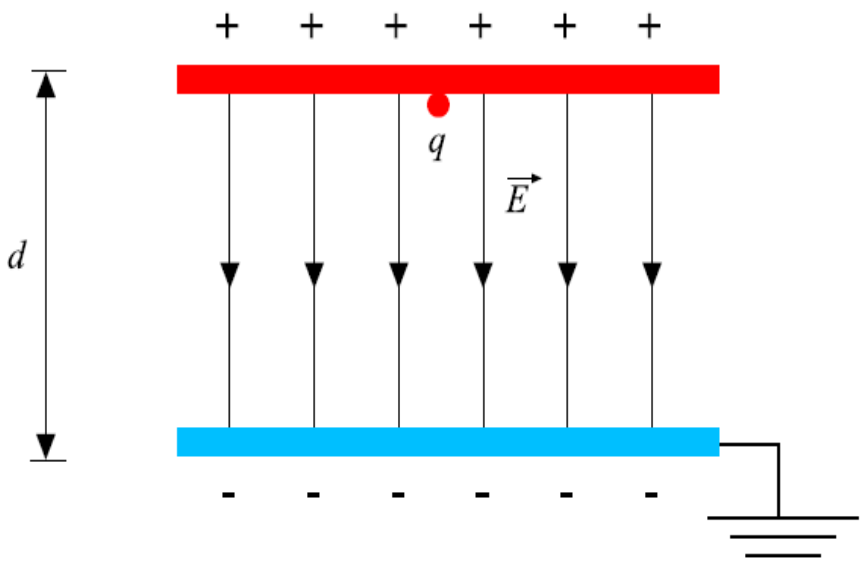
$$\phi(r_A) = \frac{E_{pot}(r_A)}{q} = \frac{1}{4\pi\varepsilon}\frac{Q_1}{r_A}$$

$$E_{pot}(r_A) = Q_2\,\phi(r_A)$$

- points of equal potential build the **equipotential surface**



Charge in homogeneous field

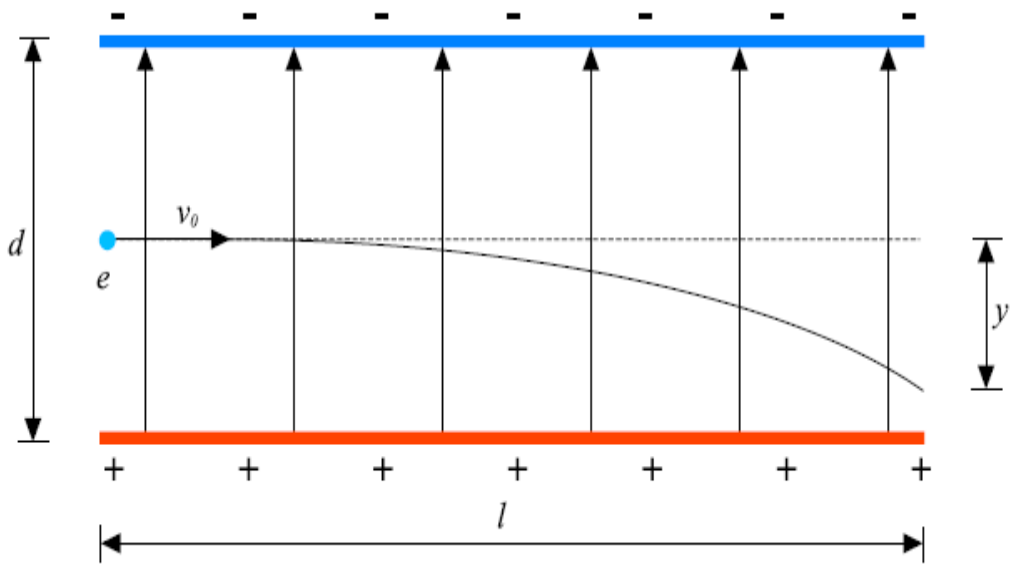


electric field of capacitor

$$E = \frac{U}{d}$$

$$\vec{F} = \vec{E}\,q$$

Charge in homogeneous field

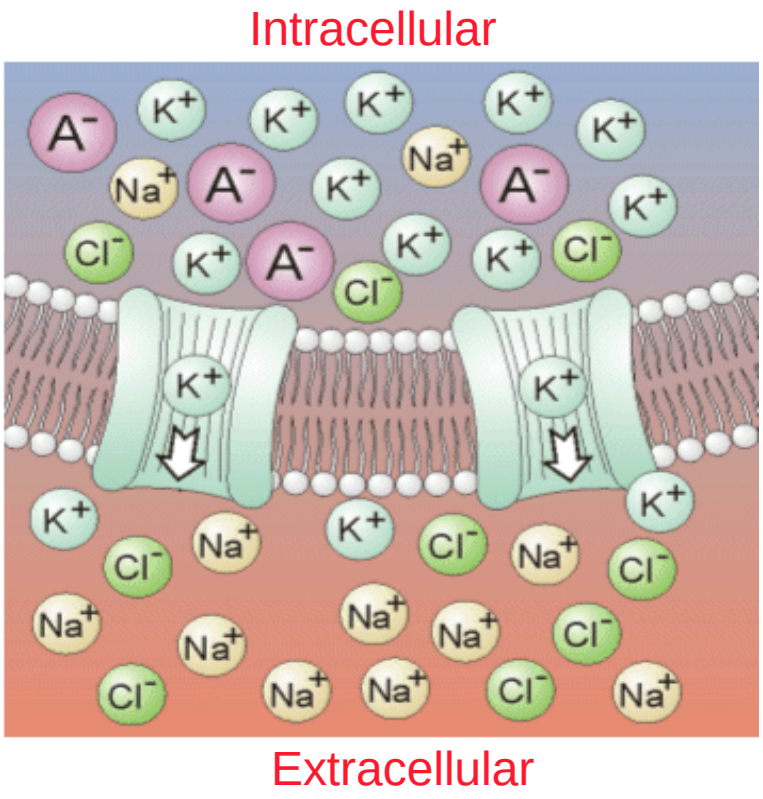


$$\Delta E_{kin} = W$$
$$W = Q \cdot U$$

- electric field always act by electric force to charge and always change amount of speed

http://magnetizam.ifs.hr/

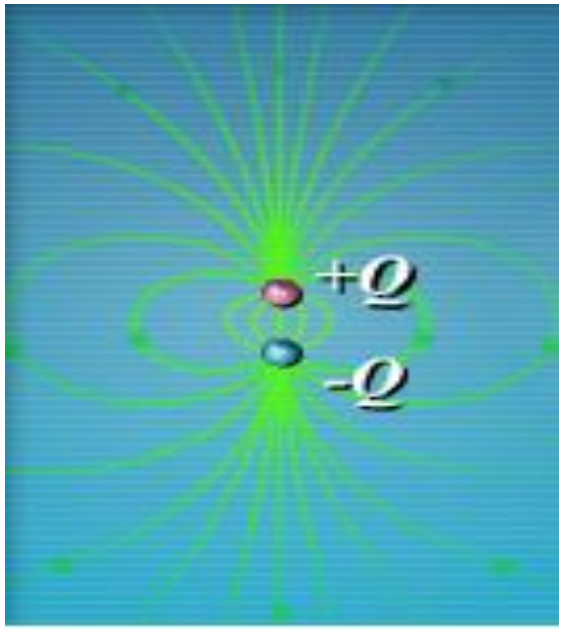
Cell membrane as capacitor

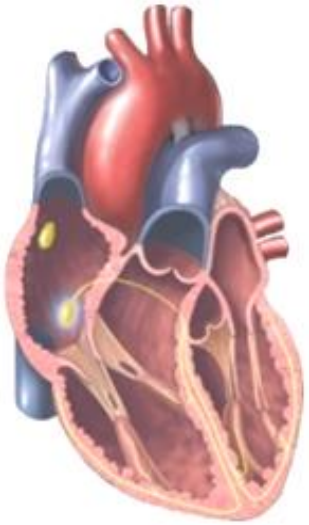


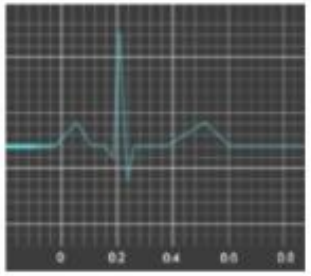
$$E = \frac{U}{d}$$

$$E \approx \frac{60mV}{6nm} = \frac{60 \cdot 10^{-3} V}{6 \cdot 10^{-9} m} = 10^{7} V/m$$

Electric dipole → model for electrical activity of the heart







- electric dipole is a pair of opposite charges q at distance ℓ; it has a **dipole moment**

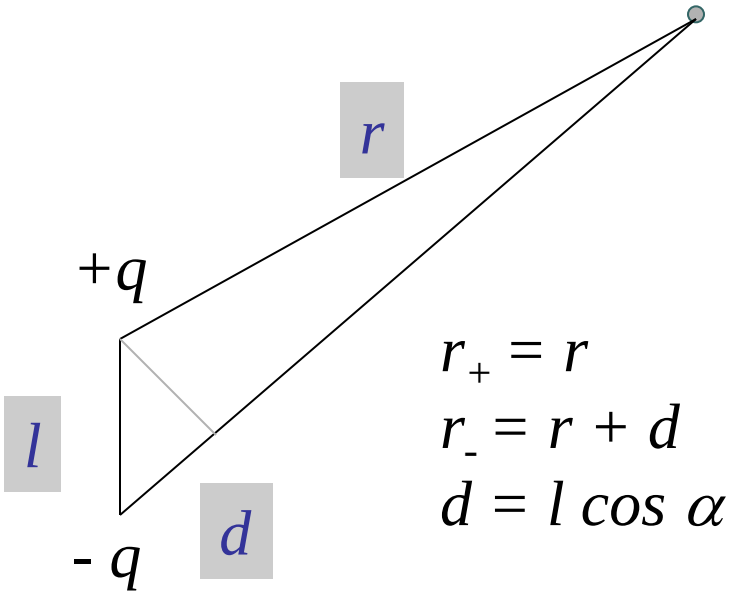
$$\vec{p} = q\vec{l}$$

(p ~ 10^{-30} C m)

$$\vec{p} = \sum_i q_i \cdot \vec{l}_i$$

- for more dipoles the net dipole moment is vector sum of individual contributions - situation in the heart

Note: for point charge $\phi \sim 1/r$; $E \sim 1/r^2$



$r_+ = r$

$r_- = r + d$

$d = l \cos \alpha$

$r >> l$

potential of a dipole

$$\phi = \phi(+q) + \phi(-q)$$

$$\phi = \frac{q}{4\pi\varepsilon r} - \frac{q}{4\pi\varepsilon(r + l\cos\alpha)}$$

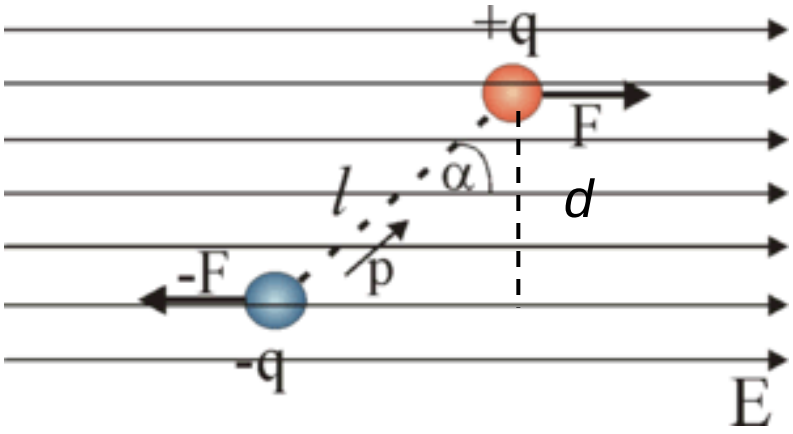
$r\, l \cos\alpha << r^2$

$$\phi(r,\alpha) = \frac{1}{4\pi\varepsilon}\frac{\vec{p}\cdot\vec{r}_0}{r^2}$$

- **electric field of a dipole**

$$E = \frac{1}{4\pi\varepsilon}\frac{\vec{p}\cdot\vec{r}_0}{r^3}$$

Electric dipole in the external electric field



$$\vec{M} = \vec{d} \times \vec{F}$$

$$M = l \sin\alpha \, q \, E$$

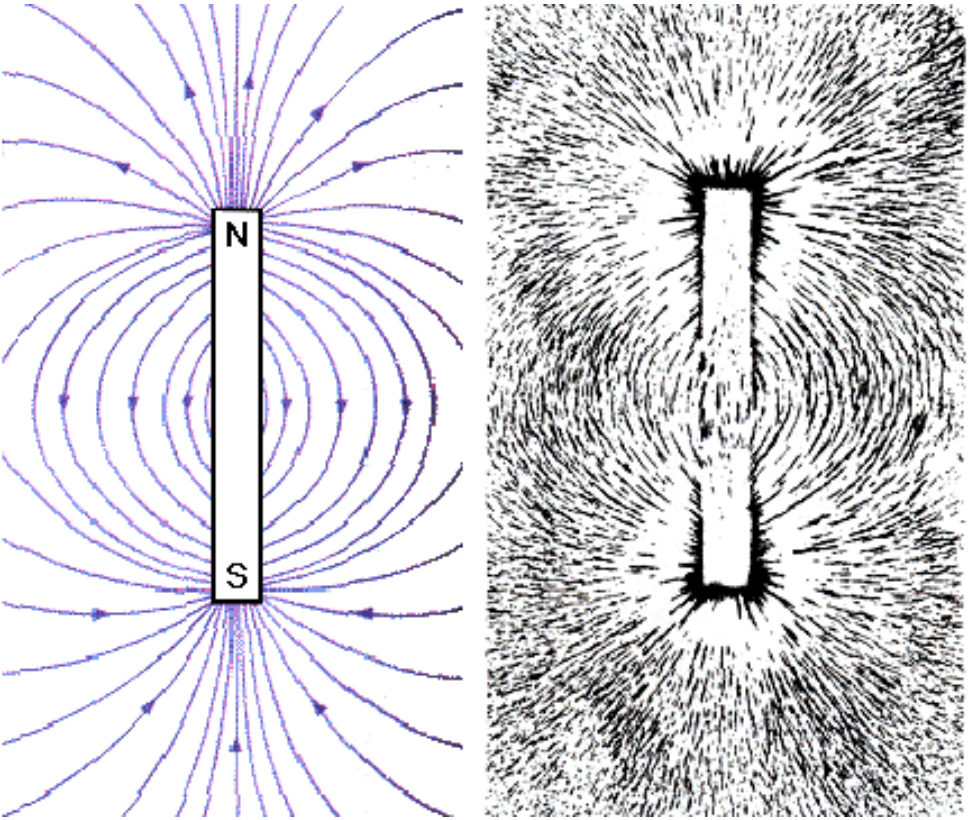
$$\vec{M} = \vec{p} \times \vec{E}$$

- torque of couple of forces rotates the dipole in external electric field

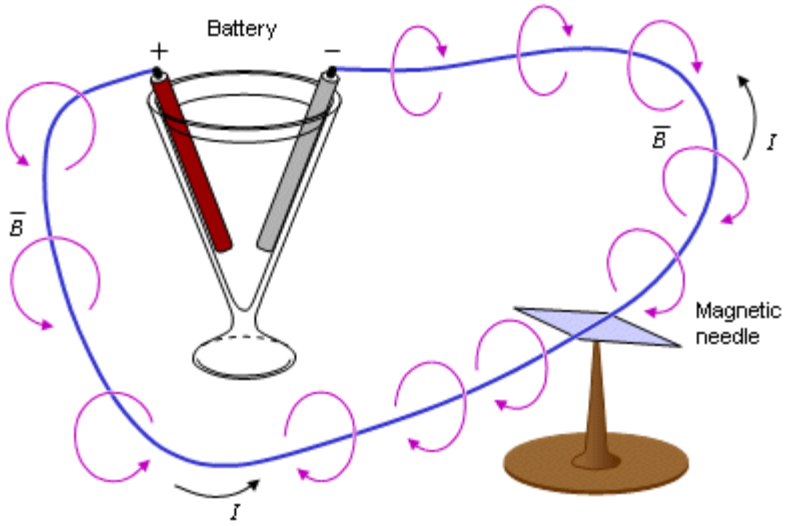
Magnetic field

the region around moving charge or electric current

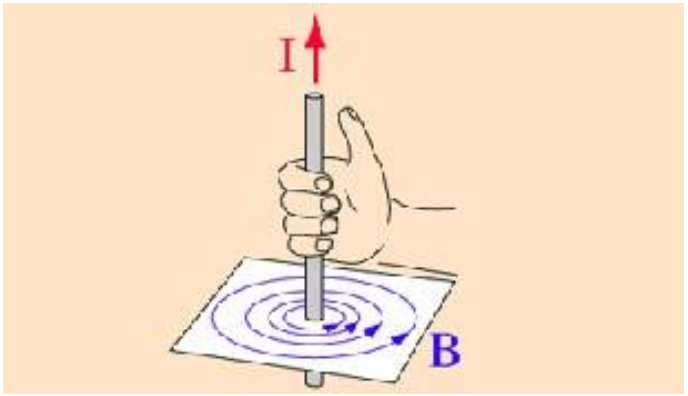
Bar magnets



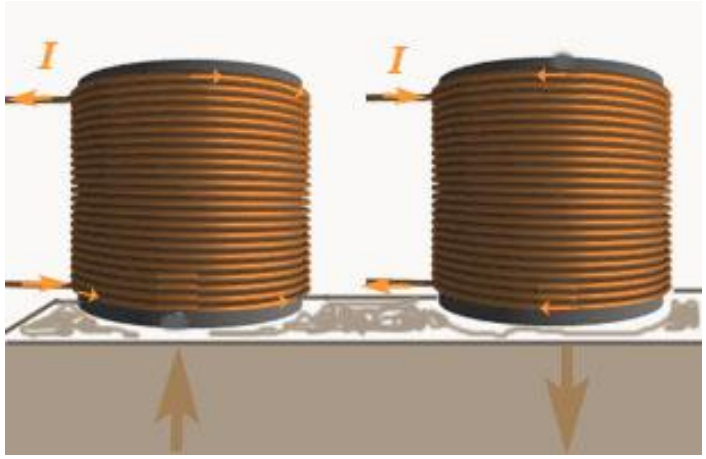
Electromagnets



Magnetic induction



$$B = \mu_0 \mu_r \frac{I}{2r\pi}$$



$$B = \mu_0 \mu_r \frac{IN}{4\pi l}$$

Magnetic induction - *B*

- magnetic field is the vector field - the field lines are closed curves

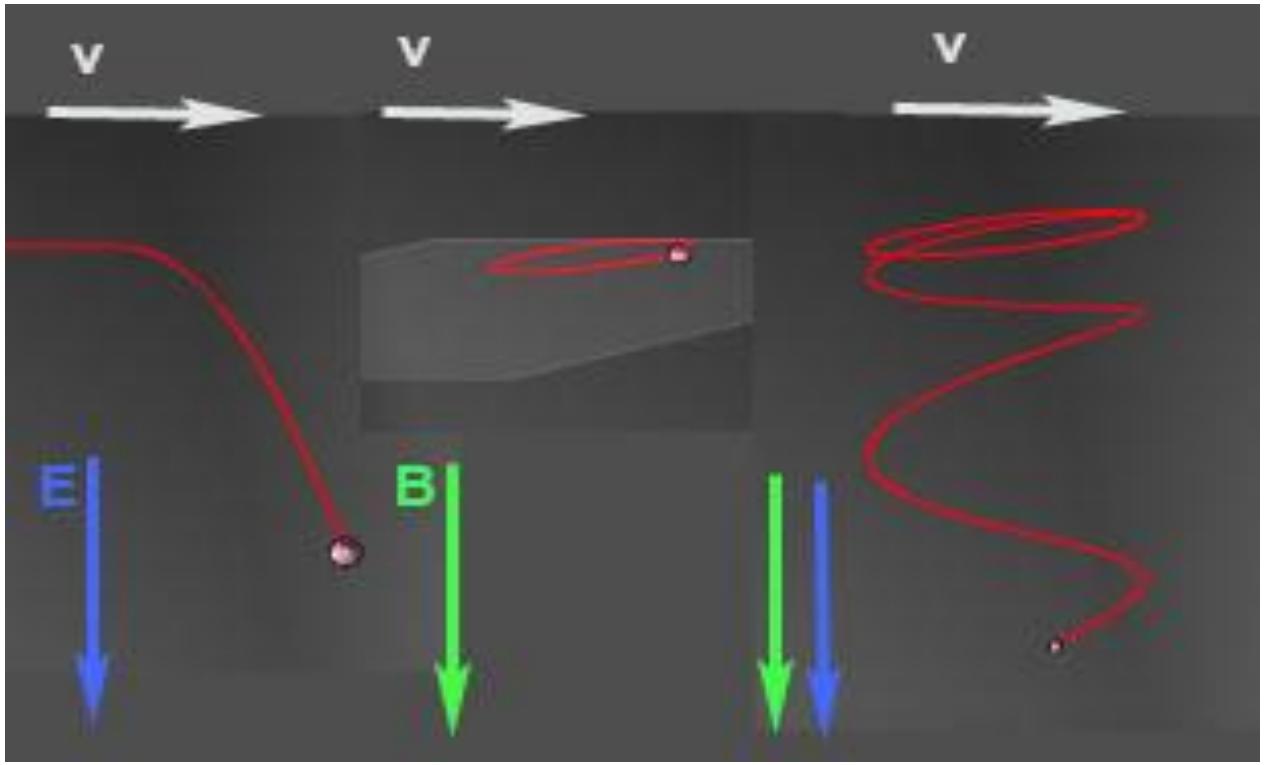
- force between two wires which carry electric currents:

$$F = \frac{\mu}{2\pi}\frac{I_1}{d} I_2 \ell$$

- magnetic induction is force on unit current element ($I_2\ \ell = 1$ Am):

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

Point charge in electric and magnetic field

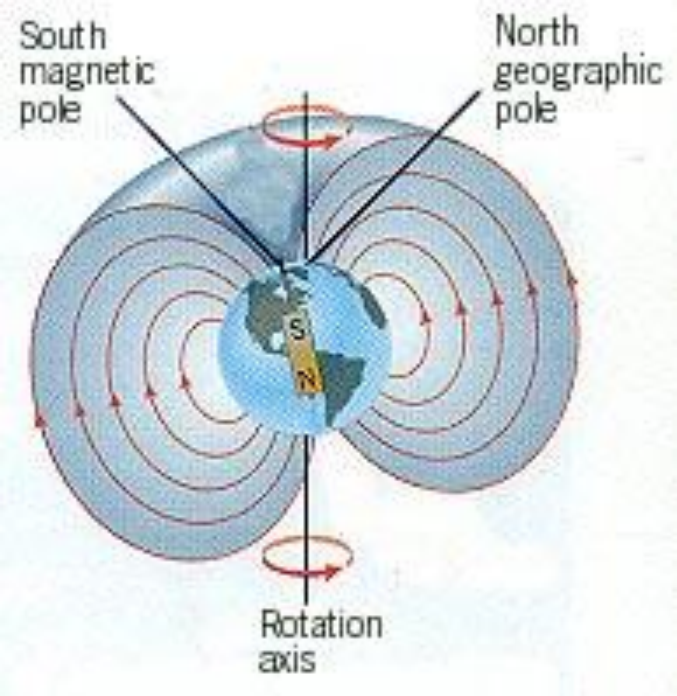


$$\vec{F} = q\vec{v} \times \vec{B} + q\vec{E}$$

Lorentz force

Earth

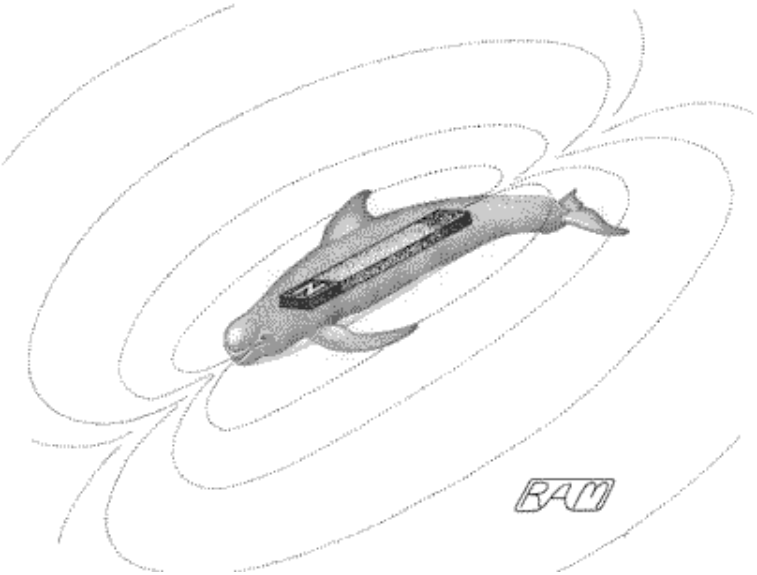
B ~ 50 μT= 0.5 G



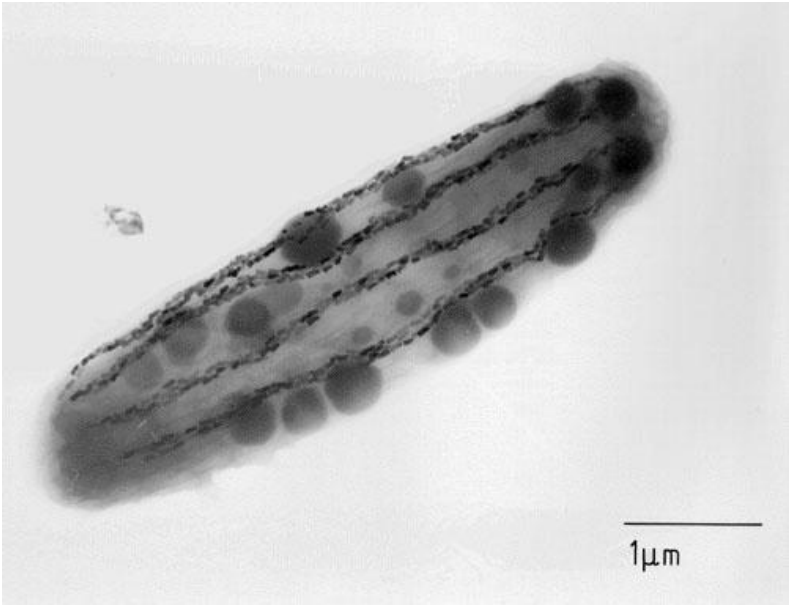
Model of dynamo

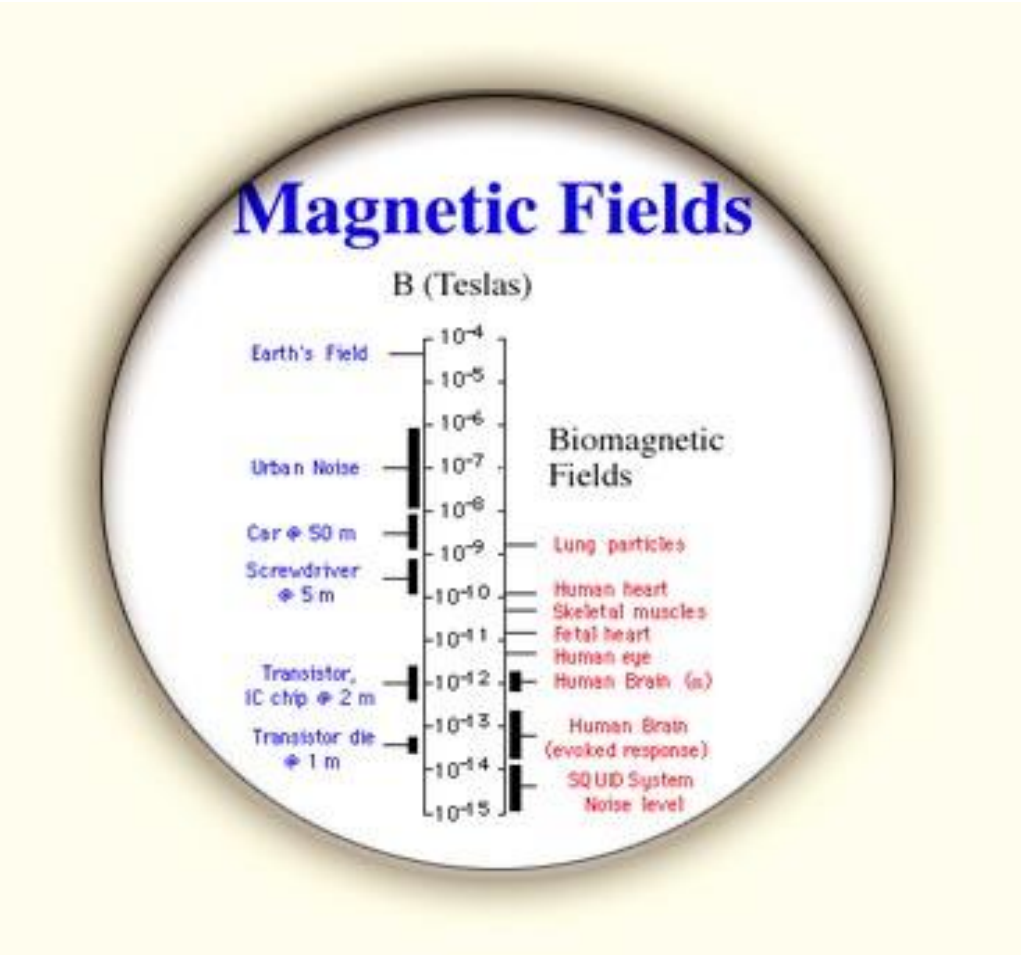
Biomagnetism

Some organisms use the Earth's geomagnetic field for the orientation and navigation.



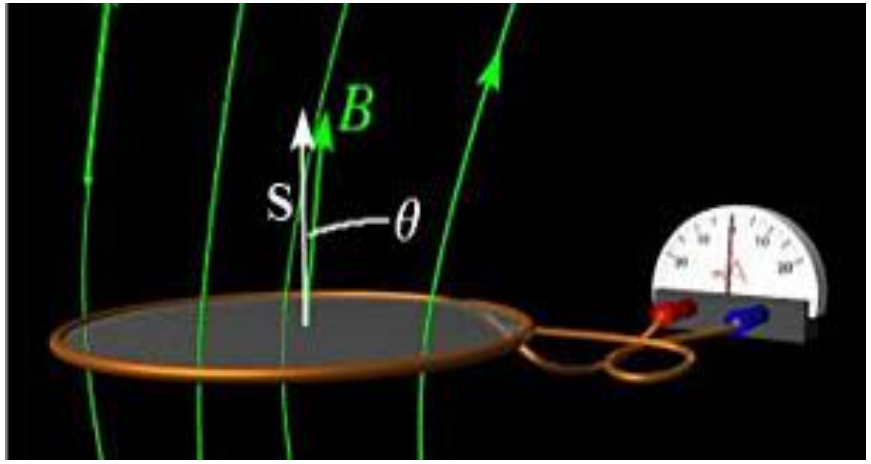
Magnetotactic bacteria produce tiny magnetite particles (Fe_3O_4), the clearest in nature.





Source	Magnetic induction (T)
Human brain	~ 10^{-13}
Urban noise	~ 10^{-7}
Earth's field	0.5· 10^{-4}
Bar magnet	0.001-1
Electromagnet	< 16

Electromagnetic induction



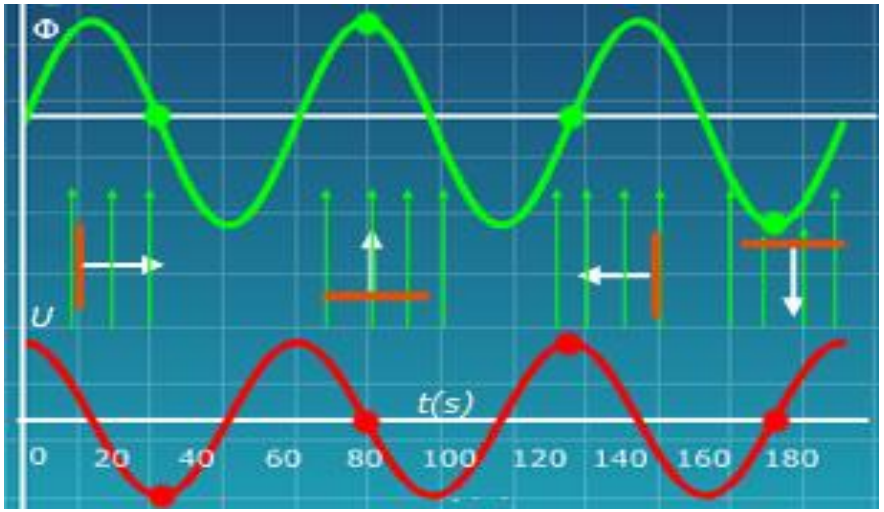
If the flux of magnetic field through the coil is time dependent, the voltage will be generated in the coil.

Faraday law:

$$U = -N\frac{\Delta\phi}{\Delta t}$$

$$U = U_0 \sin \omega t$$

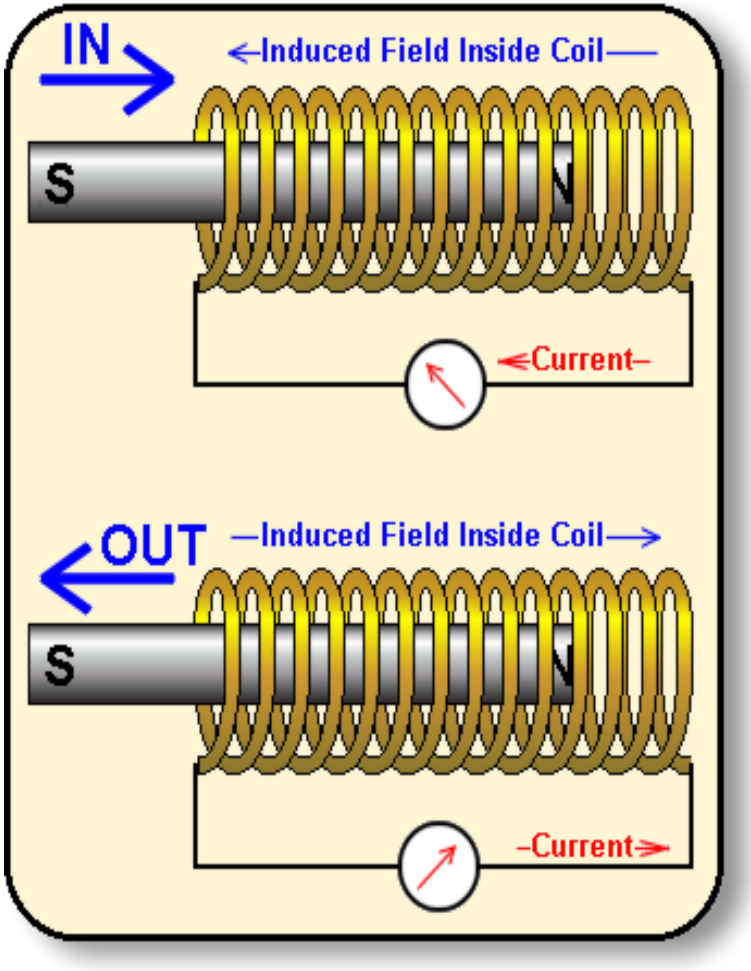
$$I = I_0 \sin \omega t$$



Demonstration of electromagnetic induction

If we insert the magnet into the coil it will cause the change of magnetic field and current flow due electromagnetic induction.

The magnitude of the current depends on speed of magnet motion in or out of the coil, and the number of loops in the coil.



Electromagnetic field

- energy density of electric and magnetic field

$$\frac{E_{pot}}{V} = \frac{1}{2}\varepsilon E^2 + \frac{1}{2}\frac{B^2}{\mu}$$

- electromagnetic wave is transversal – direction of propagation is perpendicular to the planes of oscillation of both fields

- wave velocity depends on substance's properties

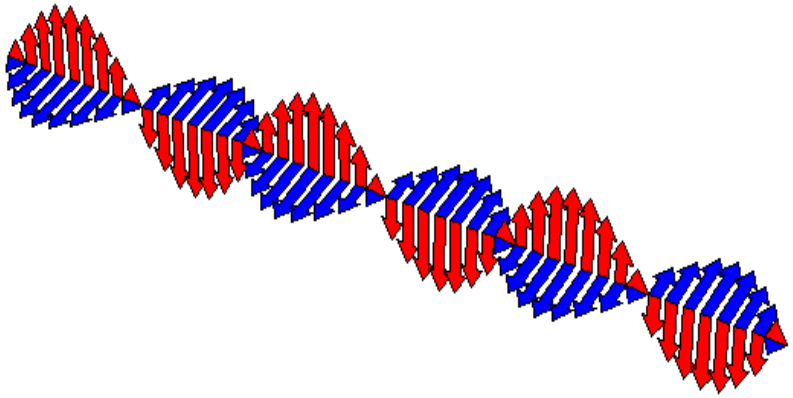
$$v = \frac{1}{\sqrt{\mu\varepsilon}} \qquad c = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$$

- the source of field is oscillating charge

- oscillating fields are mutually perpendicular

$$E = E_0 \sin \omega t$$

$$B = B_0 \sin \omega t$$



Microwave therapy

equipment

types of aerials

- technique of heating biological tissue by electromagnetic radiation
- high frequency oscillations generated in magnetron
- microwave frequencies 1- 3 GHz emitted by dipole aerial

Microwave therapy

Intensity of entranced radiation

- Beer's law:

$$I_t = I_0 \cdot e^{-\alpha x}$$

Intensity of transmitted radiation

- absorption coefficient, α
- the best absorption of microwaves occurs in muscle tissue
- standing waves increase the heating at tissue boundaries