

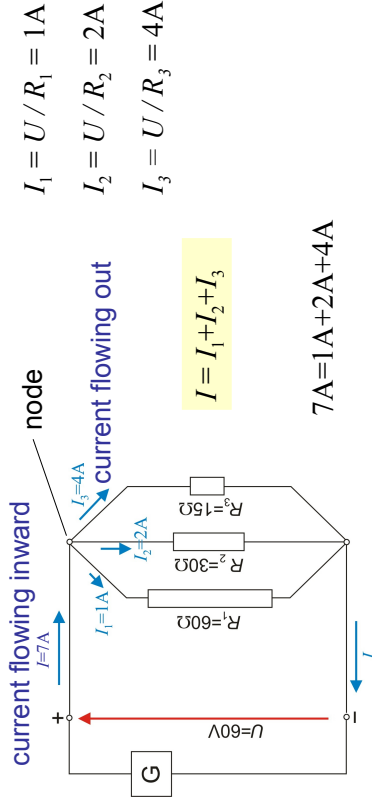
Electromagnetism II

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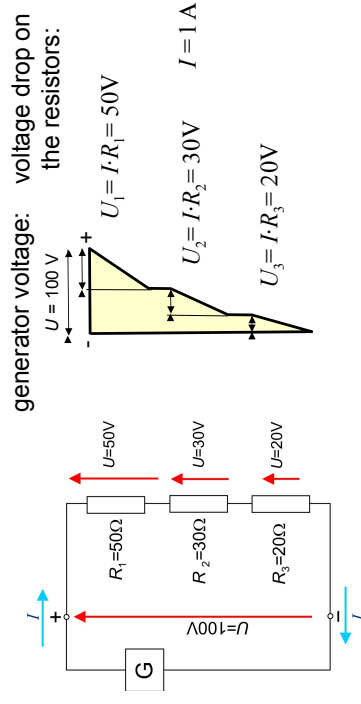
Kirchhoff's current law (Kirchhoff's first law)

The **conservation of charge** implies that: at any node, the sum of currents flowing into the node is equal to the sum of currents flowing out of that node.



Kirchhoff's voltage law (Kirchhoff's second law)

The **conservation of energy** implies that: the sum of the electron motive forces in any closed loop is equivalent to the sum of the potential drops in that loop.



$$U = U_1 + U_2 + U_3$$

$$100V = 50V + 30V + 20V$$

Voltage source

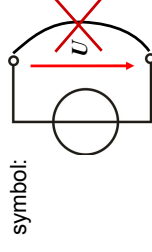
An ideal voltage source is a circuit element that generates constant voltage independently of the load current through it.

e.g.: $U = 10V = \text{constant}$

If $R = 1\Omega$, then $I = U/R = 10A$.

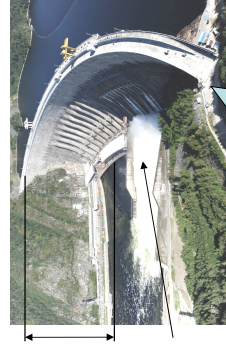
If $R = 10\Omega$, then $I = U/R = 1A$.

A voltage source has very small (ideally zero) internal resistance. It is forbidden to short it!



$$(R=0): I = U/R = \infty$$

In practice most electric power sources can be considered voltage source.



constant difference of level, constant pressure difference

different loads means different flow rates

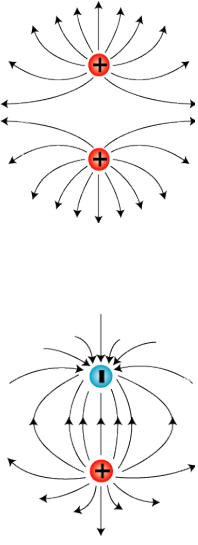


short = dam break!

Electric field, Coulomb's law

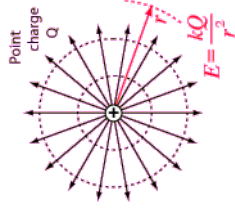
An electric field surrounds electric charges and time-varying magnetic fields. This electric field exerts a force on other electrically charged objects.

Electric field lines can be used to represent the electric field.



Electric field strength around a point charge

Charges are the source of the electric field lines. Electric field lines do not appear from nowhere, and do not disappear to nowhere.



$$F = k \frac{Q \cdot q}{r^2}$$

$$E = F/q$$

Electric field strength

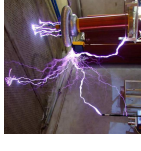
The electric field strength at a given point is defined as the force that would be exerted on a positive test charge of 1 coulomb placed at that point.

symbol: E

unit: V/m

$$E = F/Q$$

$$N / C = (J/m) / C = V \cdot A \cdot s / m \cdot A \cdot s = V/m$$



examples for field strengths

break down limit in air: $3 \cdot 10^6 V/m$

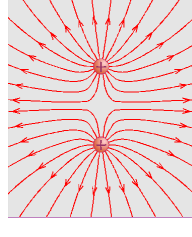


radio waves in the antenna: $1-100 \propto V/m$

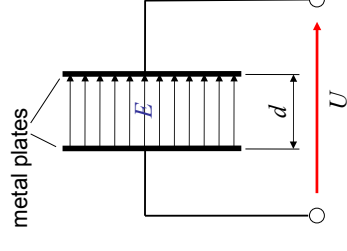


across the cell membrane: $\sim 10^7 V/m$

Inhomogeneous and homogeneous electric fields



The density of the field lines is different in every point of space \longrightarrow inhomogeneous field



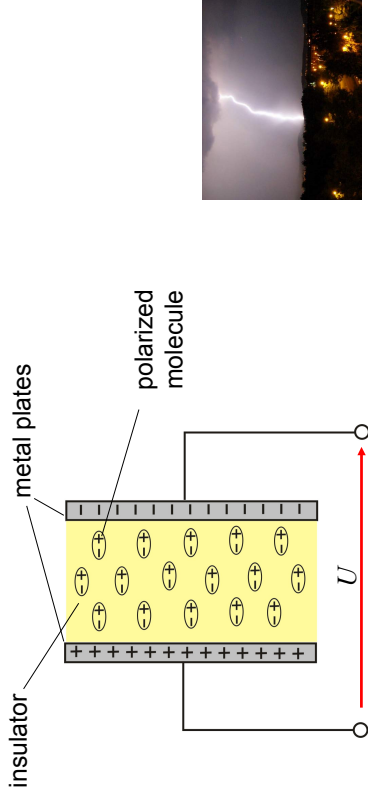
Between two parallel charged metal plates the electric field is homogeneous.

$$E \sim U \quad E \sim 1/d$$

$$E = U/d$$

Dielectric polarization

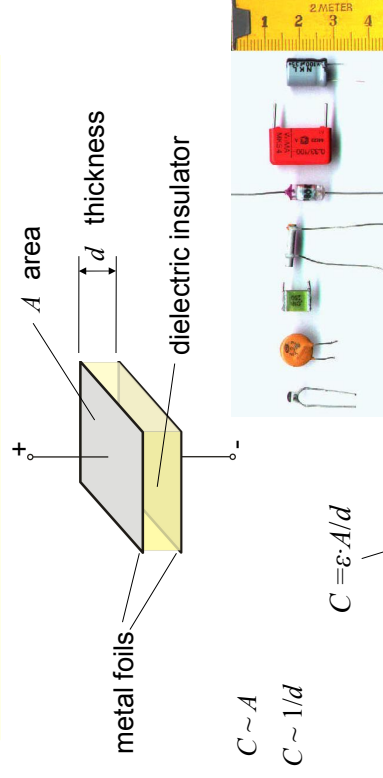
The atoms and molecules of insulators are deformed in electric field. Charges separate, the particle is polarized.



At the break down electric field strength the positive and negative charges separate, and the material becomes conductive (spark, lightning).

Capacitor, electric permittivity

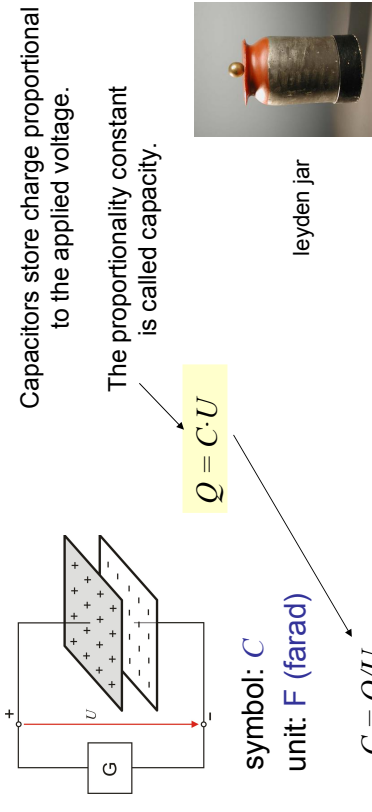
Capacitors are usually built of two metal foils separated by an insulator dielectric layer.



The proportionality constant ϵ is called electric permittivity.

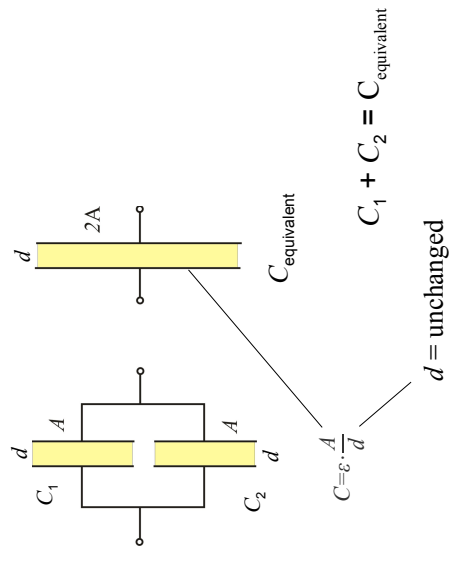
Capacitor, capacity

The capacitor consists of two conductor plates separated by an insulator layer.

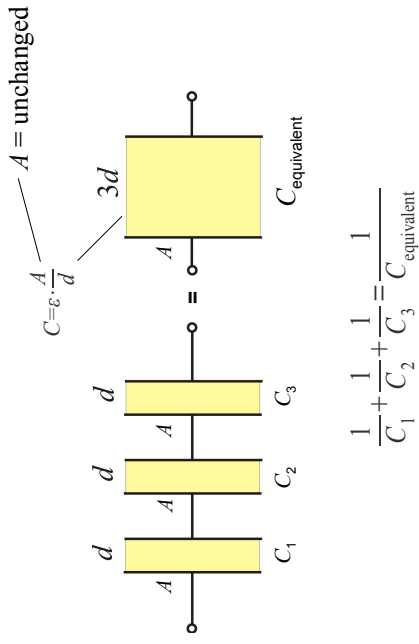


1F is the capacity of a capacitor that stores 1C charge when it is charged to 1 V.

Capacitors connected in parallel

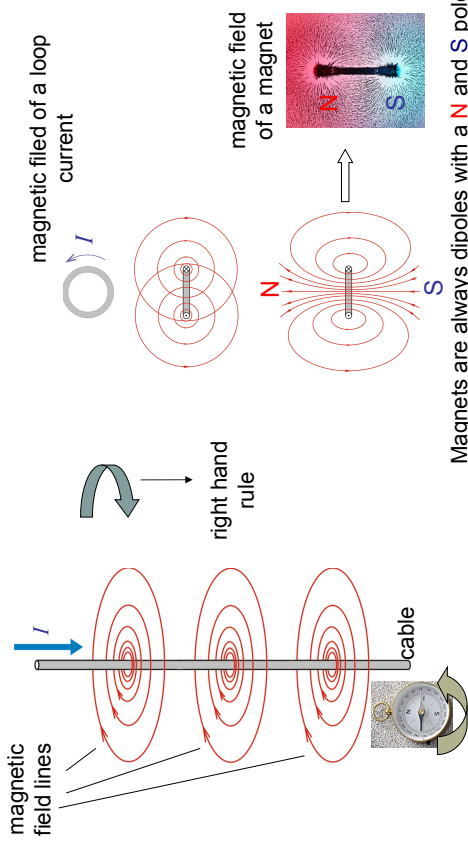


Capacitors connected in series



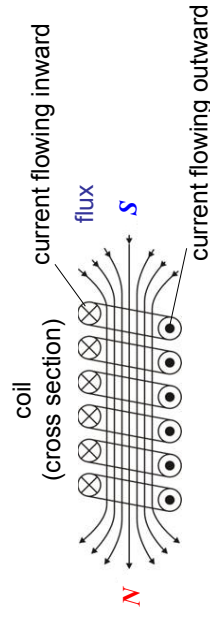
Magnetic field

A magnetic field is a force field produced by ferromagnetic materials, moving charges, and changing electric fields.



Magnetic flux

Flux is the total number of magnetic force field lines passing through a specified area.



symbol: Φ
unit: weber, Wb

Magnetic induction

Magnetic induction (flux density) is the flux that crosses unit area perpendicularly.

symbol: B
unit: T (tesla)

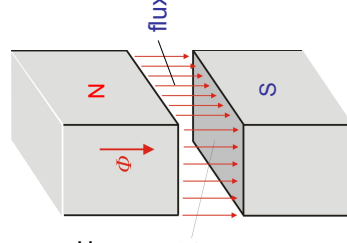
$$\frac{\text{Wb}}{\text{m}^2} = \text{T}$$

In homogeneous magnetic field:

$$B \sim \Phi$$

$$B \sim \Phi / A$$

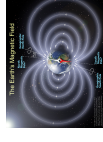
$$B = \frac{\Phi}{A}$$



magnetic induction inside an MRI: $\sim 1\text{ T}$

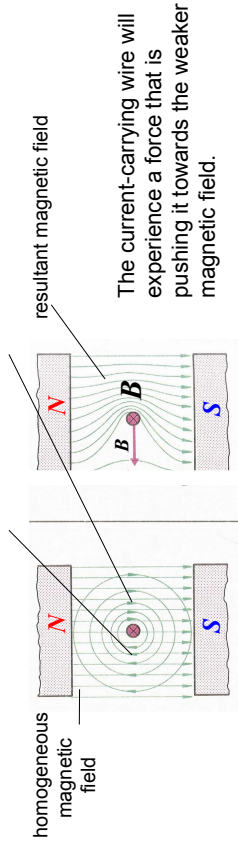


the magnetic induction of the Earth in Hungary: $\sim 50 \mu\text{T}$



Forces in magnetic fields

The magnetic field of the electric current and the static magnetic field superimpose. In some places they **weaken**, in others they **strengthen** each other.



induction $F \sim B$

current intensity $F \sim I$

length of the wire $F \sim l$

force $F = B \cdot I \cdot l$

Lorenz force

Lorenz force: is the force acting on a charge Q moving with velocity v in a static magnetic field.

$$F = B \cdot I \cdot l$$

$$I = \frac{Q}{t}$$

$$l = \frac{l}{t} \Rightarrow v$$

$$F = B \cdot \frac{Q}{t} \cdot l = B \cdot Q \cdot v$$

$$B \perp v \perp F$$

F will be a centripetal force

the charge will move on a circular path

