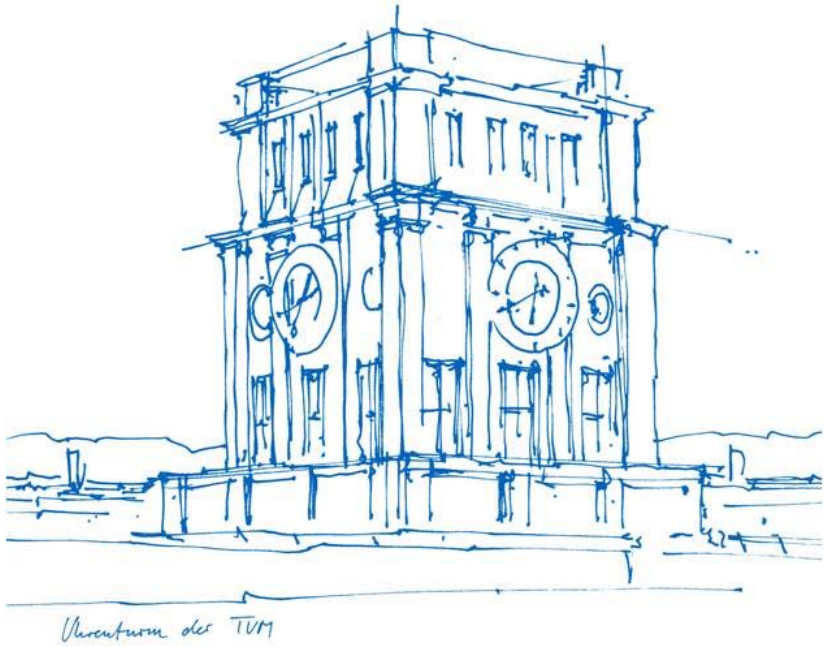
Some questions on electricity and magnetism

(Without any claim to completeness ;-))



- Do two negative charges repel or attract each other?

  repel each other

- Give the force between two point charges q_1 und q_2.

$$\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0\varepsilon_r} \frac{q_1 q_2 (\vec{r}_2 - \vec{r}_1)}{|\vec{r}_2 - \vec{r}_1|^3}$$ Coulomb force

- The force between two point charges is
  - is ……smaller……for larger distance
  - is ……smaller…… If magnitudes of q_1 /q_2 are smaller
  - Is parallel to …… $(\vec{r}_2 - \vec{r}_1)$ = distant vector ……

- How can Coulomb's law for two point charges be generalized to N charges and what is the underlying principle?

Superposition principle ⇒ sum up forces of all N charges

$$\vec{F}_q = \frac{q}{4\pi\varepsilon_0} \sum_i^n \frac{q_i(\vec{r} - \vec{r}_i)}{|\vec{r} - \vec{r}_i|^3}$$

- What is the definition of the electric field and what is its unit?

$$\vec{E} = \frac{\vec{F}}{q} \qquad \text{unit of } \vec{E} = [|\vec{E}|] = \left[\frac{V}{m}\right] = \left[\frac{N}{C}\right]$$

- How do you generally calculate work in a force field, such as electrical work (in an electrostatic field)?

$$W = \int_{P_1}^{P_2} \vec{F}\, d\vec{r} = \int_{P_1}^{P_2} q \cdot \vec{E}\, d\vec{r}$$

- How is the electrical voltage defined?

$$U_{12} = \int_{P_2}^{P_1} \vec{E}\, d\vec{r}$$

- What does it mean for a vector field if the integration path does not play a role?

Vector field is Conservative (potential field)

- What is the basic law of electrostatics? How do you check it (which criteria apply)? Electrostatic field is Conservative

(i) $\int_{P_1}^{P_2} \vec{E}\, d\vec{r}$ is independent of path

(ii) $\text{Curl}\, \vec{E} = 0$

(iii) $\oint \vec{E}\, d\vec{r} = 0$

- Is the electric potential a scalar field or a vector field?

Scalar $\quad \phi(r) = \phi_0 - \int_{P_0}^{P} \vec{E}\, d\vec{r} \qquad P = P(r)$

- Why must a reference potential be defined?

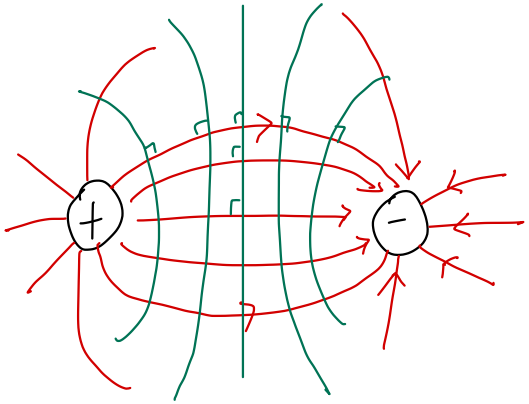
$\vec{E} = -\text{grad}\,\phi \qquad \phi \sim \int \vec{E}\,d\vec{r}$

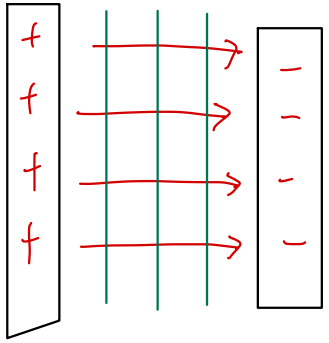
↳ Integration constant has to be defined

- What do equipotential planes mean in terms of electrical work?

No work is done, when moving along them

- Draw the equipotential surfaces of an electric dipole field and inside a plate capacitor

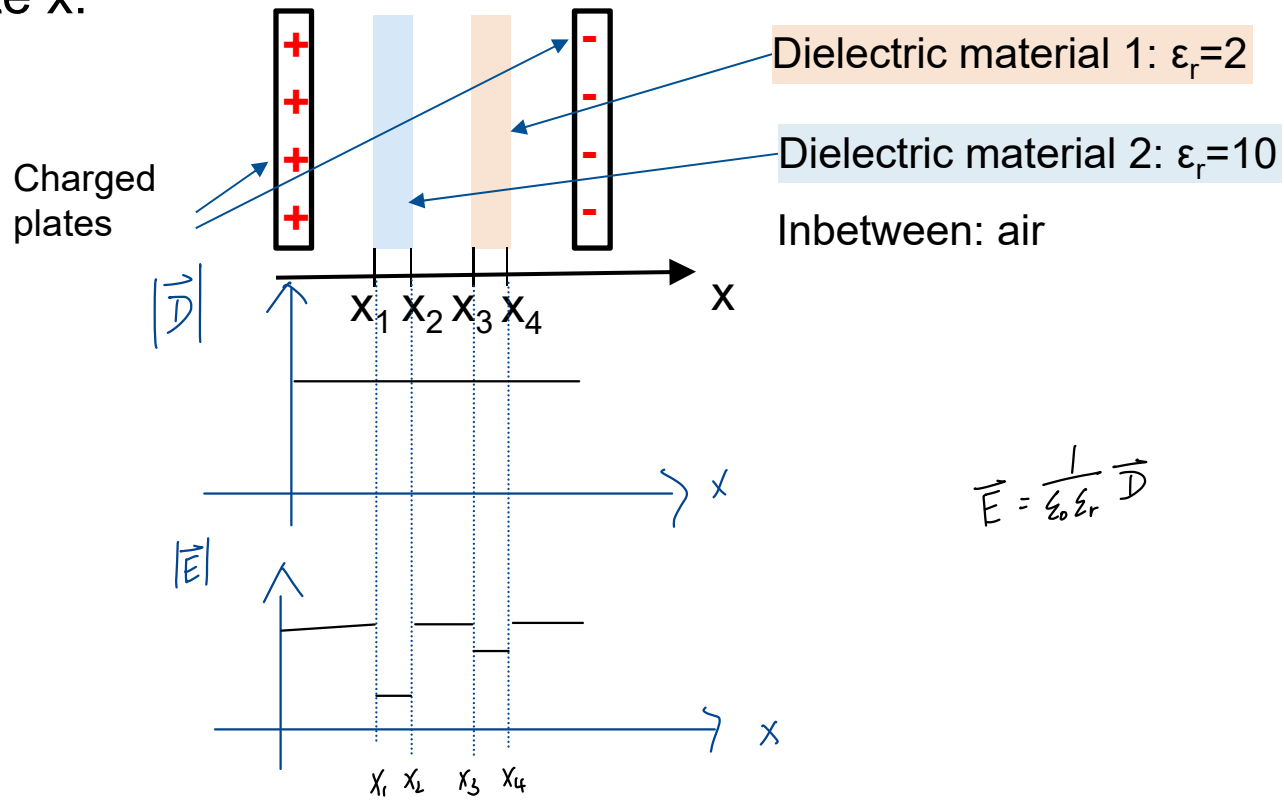




- How is the dielectric displacement density defined?

$\vec{D} = \varepsilon_0 \varepsilon_r \vec{E}$

- Sketch the course of the magnitude of the electric field and the dielectric displacement field for the following arrangement as a function of the coordinate x:



$\vec{E} = \frac{1}{\varepsilon_0 \varepsilon_r} \vec{D}$

- How is the space charge density defined?

$$\rho(\vec{r}) = \lim_{\Delta V \to 0} \frac{\Delta Q}{\Delta V}$$ (Charge per volume)

- How is the surface charge density defined?

$$\sigma(\vec{r}) = \lim_{\Delta A \to 0} \frac{\Delta Q}{\Delta A}$$ (Charge per area/surface)

- What is Gauss's law in general form and how is it related to space charge density?

$$\oint_{\partial V} \vec{D} \cdot d\vec{a} = Q(V(\vec{r})) = \int_V \rho(\vec{r})\, dV$$

- How is the dielectric displacement field at the surface of an electrical conductor calculated?

$$\vec{D} \cdot \vec{N} = \sigma \qquad |\vec{D}| = \sigma$$

- What is the charge distribution in an electrical conductor that is in an electric field? And what is this phenomenon called?

electric induction

Charges are attracted to surface $\Rightarrow \sigma$ at surface of the Conductor ; σ is homogeneous

- How large is the electric field in an electric conductor? What does this mean for the electric potential in electrically conductive media?

$\vec{E}_i$ (Conductor) = 0

Φ is Constant on electrically Conducting Surfaces (equipotential surfaces)

- How is the electric current I defined and what is the physical unit of I?

$$I = \frac{dQ}{dt}\Big|_A \qquad [I] = 1\,A$$

- What is the relationship between electric current density and electric current I ? Explain qualitatively the difference between the two quantities.

$$I = \int_A \vec{j}\, d\vec{a}$$

I = integral quantity; total current, scalar value

$\vec{j}(\vec{r})$ = "local" quantity, magnitude and direction depends on $\vec{r}$ (vector field)

- How is the electric current density related to microscopic properties such as space charge density, particle number density and charge?

$$\vec{j} = q \cdot n \cdot \vec{v}$$

- What parameters does electrical conductivity depend on?

$\rho = \frac{1}{\sigma}$

$\sigma = q \cdot n \cdot \mu$ → mobility

q: Charge; n: particle density N/V

- State local Ohm's law. Name the quantities contained in it.

$\vec{j} = \sigma \vec{E}$

$\vec{j}$ current density

$\vec{E}$ electric field

σ electric conductivity $[\sigma] = \Omega m$

- State Ohm's law in integral form. Name the quantities contained in it.

$[R] = \Omega$

$U = R \cdot I$

U: Voltage; R: Resistance; I: Current

- How do you calculate the electric power density of a current density ($\vec{j}$) in an electric field? ($\vec{E}$)

P_{el} = Power/volume $= \vec{j} \cdot \vec{E}$

- Why is the power dissipated in Ohmic transport always positive? Explain by giving an equation.

Ohmic transport : $\vec{j} = \sigma \vec{E}$

$P_{el} = \vec{j} \cdot \vec{E} = \sigma \cdot \vec{E}^2 > 0$

- How do you calculate the power dissipated at an ohmic resistor R?

$P = U \cdot I = R \cdot I^2$

- How is electrical capacitance generally defined?

$$C = \frac{Q}{U}$$

- How do you calculate the capacitance of an parallel plate capacitor?

$$C = \varepsilon_0 \cdot \varepsilon_r \cdot \frac{A}{d}$$

- How do you calculate the equivalent capacitance value of N capacitors connected in parallel ?

$$C_{tot} = \sum_{i=1}^{n} C_i$$

- How do you calculate the equivalent capacitance value of N capacitors connected in series?

$$\frac{1}{C_{tot}} = \sum_{i=1}^{n} \frac{1}{C_i} \quad = \quad C_{tot} = \left(\sum_{i=1}^{n} \frac{1}{C_i} \right)^{-1}$$

- How can we see that an external magnetic field is present?

  Moving charge is deflected.

- How is this force termed and how is it calculated?

  Lorentz force $\quad \vec{F}_L = q(\vec{v} \times \vec{B})$

- How is the physical quantity termed that causes this force?

  $\vec{B}$ - field (magnetic induction, magnetic flux density)

Circulation

- Which of the following statements for the gyration of a particle charged with q are correct?
  - If the magnitude of the B-field is larger, the particle rotates at a lower frequency.
  - ~~If the mass of the particle is larger, it rotates at a lower frequency.~~
  - If the mass of the particle is larger, the radius of the gyration is smaller.
  - ~~If the magnetic field is larger, the radius of the particle's gyration is smaller.~~
  - The trajectories of particles with a higher speed have a smaller radius.
  - The gyrational frequency (no) and the radius (yes) of the trajectory both depend on the speed of the particle.

- Give the differential force on an element ds of a conductor through which a current I flows calculated differentially in a constant B-field?

  How do you calculate from this the force on a conductor of length l and cross-section A?

- Which equation describes the solenoidality of the B-field? What does this mean physically? Name three equivalent physical statements/consequences.

- How are magnetostatic fields generated and which law is used to describe this? State this law.

- What is the relationship between B-field and H-field?

- What is the relationship between H-field and magnetization in the simplest case and which material constant describes this?

- Name the three forms of magnetism that occur in magnetizable materials What results for the $\vec{B}$ field inside the three types of material?

- What is hysteresis in context of magnetization and what does remanence magnetization mean? Draw a graph.

- What happens if you heat a permanent magnet above the Curie temperature?

- What is Maxwell's extension of Ampére's circuital law and what is its physical significance?

- What are the two types of induction? How can electric fields be induced?

- How is the magnetic flux Φ defined and how is it calculated?

- How is the induced voltage calculated from the magnetic flux? Does this formula apply to motion induction, rest induction or in general?

- Are induced electric fields conservative? Give a reason to your answer by stating the according Maxwell's equation.