

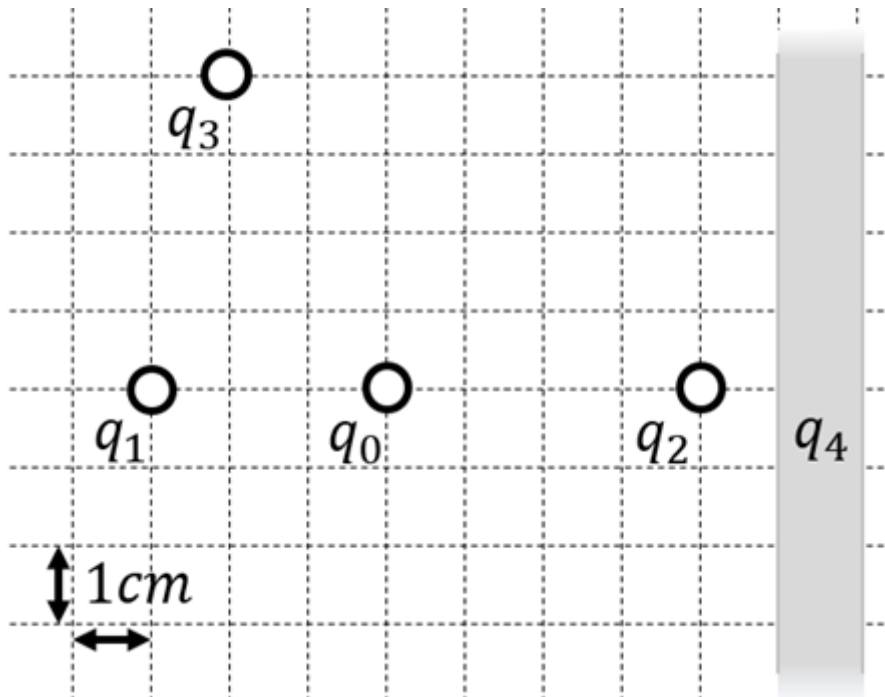
Exam Summer Semester 2022

Student Group

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1. Calculate the single forces $\vec{F}_{01}$, $\vec{F}_{02}$, $\vec{F}_{03}$, on the charge q_0 !

Path

First, calculate the magnitude of the forces, like $\vec{F}_{01}$.

The force $\vec{F}_{01}$ is purely on the x -axis and therefore equal to

$$\begin{aligned} F_{01,x} &= \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 \cdot q_0}{r_{01}^2} = \\ &= \frac{1}{4\pi \cdot 8.854 \cdot 10^{-12} \text{ As/Vm}} \cdot \frac{1 \cdot 10^{-9} \text{ C} \cdot 2 \cdot 10^{-9} \text{ C}}{(3 \cdot 10^{-2} \text{ m})^2} = 19.97... \cdot 10^{-6} \text{ Nm} \\ &= 19.97... \cdot 10^{-6} \text{ Nm} \quad \text{(to the right)} \end{aligned}$$

Similarly, we get for $\vec{F}_{02}$ and $\vec{F}_{03}$

$$\begin{aligned} \vec{F}_{02} &= F_{02,x} = -28.09... \text{ Nm} \quad \text{(to the right)} \\ \vec{F}_{03} &= -22.47... \text{ Nm} \quad \text{(to the top left)} \end{aligned}$$

For $\vec{F}_{03}$, we have to calculate the x - and y -component.

This is possible, by using the angle α between the line through q_0 and q_3 and the positive x -axis (pointing to the right).

So, α has to be between 90° and 180° . It can be calculated by:

$$\begin{aligned} \alpha &= \arctan\left(\frac{-4 \text{ cm}}{+2 \text{ cm}}\right) = \pi - 1.1071... \\ &= 180^\circ - 63.4...^\circ = 116.6...^\circ \end{aligned}$$

Based on this, the x - and y -component is:

$$\begin{aligned} |\vec{F}_{03}| \cdot \cos \alpha &= 10.05... \text{ Nm} \quad \text{(to the left)} \\ F_{03,y} &= |\vec{F}_{03}| \cdot \sin \alpha = 20.10... \text{ Nm} \quad \text{(to the top)} \end{aligned}$$

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top)} \\ \end{align*}
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Exercise E4 Electrostatics II

(written test, approx. 10 % of a 120-minute written test, SS2022)

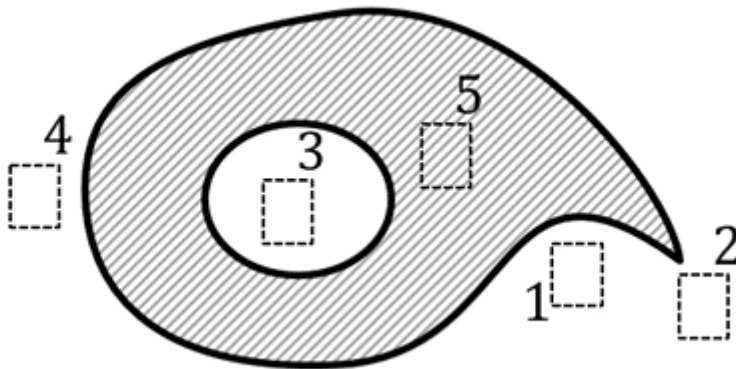
The figure below shows an arrangement of ideal metallic conductors (gray hatched) charged up to $q = +1 \text{ nC}$.

In white a dielectric (e.g. vacuum) is shown.

Several designated areas are shown by dashed frames and numbers x , which are partly inside the object.

Arrange the designated areas clearly according to ascending field strengths $|\vec{E}_x|$ (absolute magnitude)!

Indicate also, if designated areas have quantitatively the same field strength.



Result

$$|E_3| = |E_5| = 0 < |E_1| < |E_4| < |E_2|$$

Exercise E6 Electron Velocity in Semiconductors

(written test, approx. 6 % of a 120-minute written test, SS2022)

A current of $I = 1 \text{ mA}$ flows through a cross-sectional area $A = 10 \text{ } \mu\text{m}^2$ in a semiconductor.

The electron density in the semiconductor is given by the number of dopant atoms per

volume.

The doping shall provide 5 donor atoms per silicon atom. The elementary charge is $e_0 = 1.602 \cdot 10^{-19} \text{ As}$.
 The molar volume of silicon is $V_{\text{mol,Si}} = 12 \cdot 10^{-6} \text{ m}^3/\text{mol}$, with $N_{\text{A}} = 6.022 \cdot 10^{23}$ silicon atoms per 1 mol .

The elementary charge is given as: $e_0 = 1.602 \cdot 10^{-19} \text{ As}$

What is the average electron velocity v_e in this semiconductor?

Path

The following formula gives the speed, where n_e is the number of electrons per volume.

$$v_e = \frac{I}{n_e \cdot e_0 \cdot A}$$

n_e can be derived from the overall number of Si-atoms per volume ($\frac{N_{\text{A}}}{V_{\text{mol,Si}}}$) and the fraction k_{Donators} of these atoms, which got substituted by donators.

$$v_e = \frac{I}{\left(\frac{N_{\text{A}}}{V_{\text{mol,Si}}} \cdot k_{\text{Donators}} \cdot e_0 \cdot A \right)}$$

Putting in the numbers:

$$v_e = \frac{1 \cdot 10^{-3} \text{ As}}{\left(\frac{6.022 \cdot 10^{23} \text{ 1/mol}}{12 \cdot 10^{-6} \text{ m}^3/\text{mol}} \cdot 10^{-10} \cdot 1.602 \cdot 10^{-19} \text{ As} \cdot 10^{-6} \text{ m}^2 \right)}$$

Exercise E8 Capacitor

(written test, approx. 7 % of a 120-minute written test, SS2022)

Given the multiplication factor $\epsilon_r = 5$ in the left side layer, with the following dimensions: $\epsilon_0 = 0.1 \text{ mm}$

Result: ϵ_r of air ($\epsilon_{\text{r,Air}} = 1$), while the thickness of the dielectric material

remains the same: $l = 1.5 \text{ mm}$

Path: Distance between single layers: $d = 1.0 \text{ mm}$

- Depth of component: $w = 0.7 \text{ mm}$

Number of layers (from the picture): 3 left-side and 3 right-side layers.

Path

The capacity can be derived from the geometry by:

$$C = \epsilon_0 \epsilon_r \frac{A}{d}$$

The air band is another capacitor in series to the dielectric material. Therefore, the capacity can be calculated as:

$$C_{\text{Air}} = \epsilon_0 \epsilon_{\text{r,Air}} \frac{A}{d}$$

The capacity of air is:

$$C_{\text{Air}} = \epsilon_0 \epsilon_{\text{r,Air}} \frac{N \cdot l \cdot w}{d} = 8.854 \cdot 10^{-12} \text{ As/Vm} \cdot 1 \cdot \{5 \cdot 1.5 \cdot 10^{-3}\} \cdot 0.7 \cdot 10^{-3}$$

The material has a total dielectric permittivity of $\epsilon = \epsilon_0 \epsilon_r = 3 \epsilon_0$.

The following calculations shall ignore boundary effects on the end of the layers.

By this the overall capacity is
$$C_{\text{c}} = \left\{ \frac{0.139 \dots \text{ nF} \cdot 0.465 \dots \text{ nF}}{0.139 \dots \text{ nF} + 0.465 \dots \text{ nF}} \right\}$$

.. What is the field strength in the dielectric material between the layer, when a voltage of $U = 6.3 \text{ V}$ is applied?

How many “multiple plates” N do we have to consider?

For this, we have to count facing areas A_0 . There are $N = 5$.

The electric field strength E is given by:
$$E = \frac{U}{d} = \frac{6.3 \text{ V}}{1 \cdot 10^{-6} \text{ m}}$$

Therefore, the formula is
$$C = \epsilon_0 \epsilon_r \left\{ \frac{N \cdot l \cdot w}{d} \right\} = 8.854 \cdot 10^{-12} \text{ As/Vm} \cdot 3 \cdot \left\{ \frac{5 \cdot 1.5 \cdot 10^{-3} \text{ m} \cdot 0.7 \cdot 10^{-3} \text{ m}}{1 \cdot 10^{-6} \text{ m}} \right\}$$

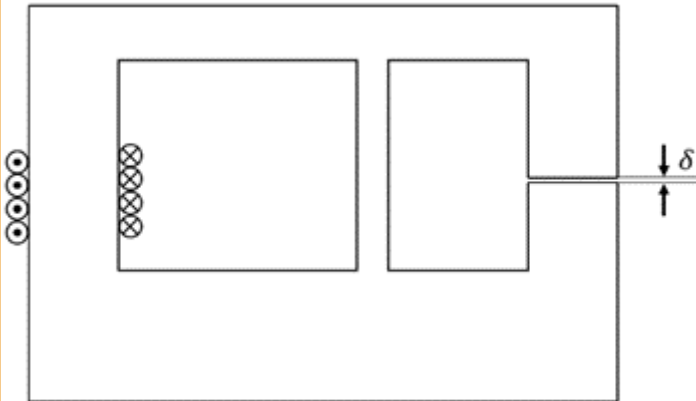
Exercise E10 Magnetic Circuit

(written test, approx. 7 % of a 120-minute written test, SS2022)

The magnetic setup below shall be given. Draw the equivalent magnetic circuit to represent

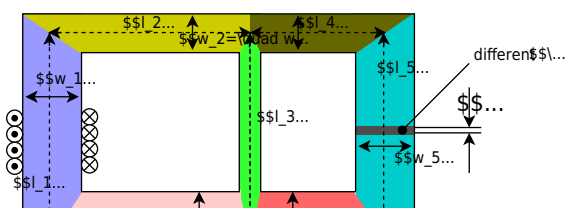
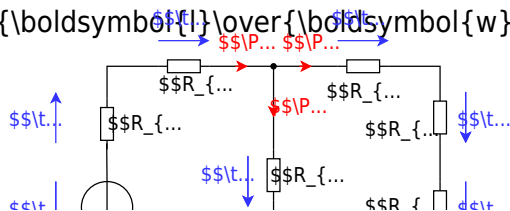
Result
 Setup fully. Name all the necessary magnetic resistances, fluxes, and voltages.
 The components shall be designed in such a way, that the magnetic resistance is constant in it.

Formulas are not necessary.



Path

Watch for parts of the magnetic circuit, where the width and material are constant. These parts represent the magnetic resistors which have to be calculated individually. Be aware, that every junction creates a branch with a new resistor, like for an electrical circuit - there must be a node on each "diversion".

$$R_{\text{m}} = \frac{l}{\mu_0 \mu_r w h}$$


Exercise E12 Self Induction

(written test, approx. 8 % of a 120-minute written test, SS2022)

2. A motor with an inductance of $L = 50 \text{ mH}$, which is connected to a DC voltage source $U = 3150 \text{ V}$, is fused with a circuit breaker.

Sketch the breakers $i(t)$ and $u_{\text{ind}}(t) = 0$ with a percentage of 63% of the induced current in the linearly down to 0 A within 1 ms .

(The inner resistance of the motor shall be neglected.)

$$u_{\text{ind}}(t) = 3150 \text{ V}$$

Path

1. Draw the circuit (the circuit breaker can be drawn as a switch), with all voltage and current arrows.

For the maximum voltage on the circuit breaker one has to consider the following:

Result

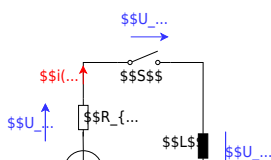
- external voltage of the voltage source U
- voltage $u_{\text{ind}}(t)$ induced by the change of the current

The first one is not given in the exercise, and therefore not considered here.

The induced voltage can be calculated by linearizing the following:

$$u_{\text{ind}}(t) = -L \frac{di}{dt} \rightarrow u_{\text{ind}}(t) = -L \frac{\Delta i}{\Delta t}$$

$$\begin{aligned} \text{With the given details: } u_{\text{ind}}(t) &= -L \frac{0 - I}{t_1 - t_0} \\ &= 50 \cdot 10^{-6} \frac{63 \text{ A}}{1 \cdot 10^{-6} \text{ s}} \\ &= 3150 \frac{\text{Vs}}{\text{A}} \cdot 63 \frac{\text{A}}{\text{s}} \end{aligned}$$




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\begin{align*} \varphi &= \arctan \left( \frac{X_{LC}}{R} \right) \\ &= \arctan \left( \frac{-121.45 \text{ m}\Omega}{88 \text{ m}\Omega} \right) \\ &= -54.07...^\circ \end{align*}
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