

Exam Summer Semester 2022

Student Group

First Name	Surname	Matrikel Nr.

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Exam Summer Semester 2022

Additional permitted Aids

- non-programmable calculator,
- formulary (4 one-sided DIN A4 pages)

Hits

- The duration of the exam is 120 min.
- Attempts to cheat will lead to exclusion and failure of the exam.
- Withdrawal is no longer possible after these exam has been handed out.
- Please write down intermediate calculations and results on the assignment sheet. (when more space is needed also on the reverse side. In this case: Mark it clearly).
- Always use units in the calculation.
- Use a document-proof, non-red pen.

Only EEE1-relevant Part

This part is only for about 40 minutes !

Exercise E1 Electrostatics I

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

Given is the arrangement of three charges on the x-axis as shown in the picture below. The charges of the previous exercise are $q_1 = 1.97 \cdot 10^{-9} \text{ As/Vm}$. Which value needs E_4 to have to get a resulting force of 0 N on q_0 ?

Path: $q_0 = -1 \text{ nC}$

- $q_1 = -2 \text{ nC}$

Path: $E_4 = 230.97 \text{ V/m}$

$$\vec{F}_{01} = \left(\begin{array}{c} 19.97 \\ 0 \\ 0 \end{array} \right) \cdot \mu N$$

In the x -direction we can calculate the resulting magnitude of the force F_{01} .

$$F_{01} = \left(\begin{array}{c} 19.97 \\ 0 \\ 0 \end{array} \right) \cdot \mu N$$

Here, this force F_{01} is the force F_{01} from q_1 on q_0 .

$$|\vec{F}_{01}| = |E_4| \cdot |q_0| \Rightarrow E_4 = \frac{|\vec{F}_{01}|}{|q_0|} = \frac{19.97 \cdot 10^{-6} \text{ N}}{1 \cdot 10^{-9} \text{ C}} = 19.97 \cdot 10^3 \text{ V/m} = 19.97 \text{ kV/m}$$

$$E_4 = 19.97 \cdot 10^3 \text{ V/m} = 19.97 \text{ kV/m}$$

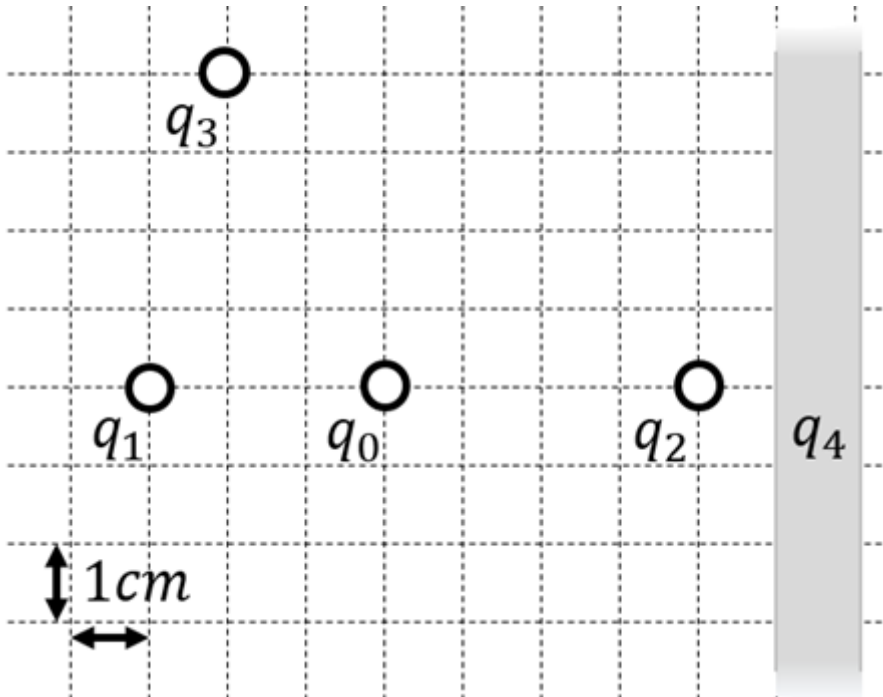
$$E_4 = 19.97 \cdot 10^3 \text{ V/m} = 19.97 \text{ kV/m}$$

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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

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

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

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

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:

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

top)} \\ \end{align*}

Exercise E2 Electrostatics II
(written test, approx. 10 % of a 120-minute written test, SS2022)

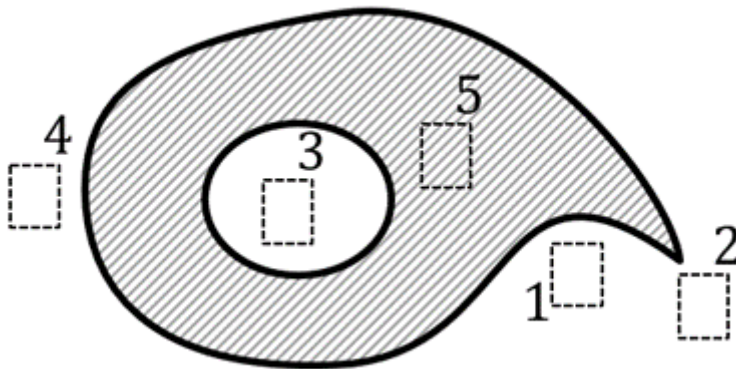
The figure below shows an arrangement of ideal metallic conductors (gray hatched) charged up to $q = +1 \text{ nC}$.

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 E2 Capacitor
(written test, approx. 7 % of a 120-minute written test, SS2022)

Given the parallel plate capacitor shown in the left side of the figure with the following dimensions: $d = 0.1 \text{ mm}$ of air ($\epsilon_r = 1$), while the thickness of the dielectric material remains the same.
 Length of layer overlap: $l = 1.5 \text{ mm}$
 Path

What is the new capacitance C if $d=1.0 \text{ nm}$?

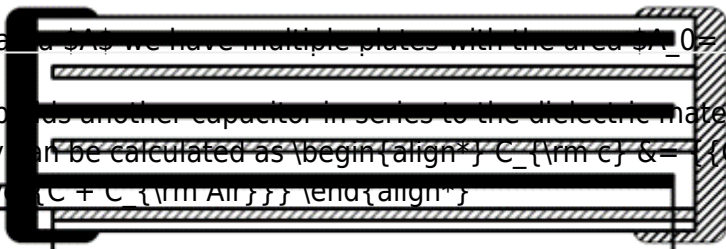
The dielectric constant is $\epsilon_r = 3$.

The number of layers is $N=5$.

Path

For the area A we have multiple plates with the area $A_0 = l \cdot w$ facing each other.

The air is another capacitor in series to the dielectric material. Therefore, the capacity can be calculated as $C_{\text{Air}} = \frac{\epsilon_0 \cdot A_0}{d_{\text{Air}}}$



The capacity of air is $C_{\text{Air}} = \frac{\epsilon_0 \cdot N \cdot l \cdot w}{d_{\text{Air}}}$ $\approx 8.854 \cdot 10^{-12} \text{ As/Vm} \cdot 1 \cdot 1.5 \cdot 10^{-3} \cdot 0.7 \cdot 10^{-3} / 0.1 \cdot 10^{-6} \approx 0.465 \text{ nF}$

The material shall have a dielectric permittivity of $\epsilon_r = 3$.

For this, we have to count facing areas A_0 . There are $N \cdot A_0$.

$\epsilon_0 = 8.854 \cdot 10^{-12} \text{ As/Vm}$

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

Path

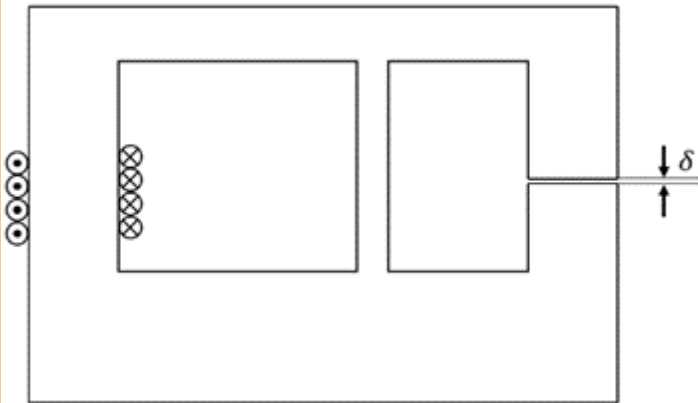
The electric field strength E is given by: $E = \frac{U}{d} = \frac{6.3 \text{ V}}{1 \cdot 10^{-6} \text{ m}}$

Therefore, the formula is $C = \frac{\epsilon_0 \cdot \epsilon_r \cdot N \cdot l \cdot w}{d} = 8.854 \cdot 10^{-12} \text{ As/Vm} \cdot 3 \cdot 1.5 \cdot 10^{-3} \cdot 0.7 \cdot 10^{-3} / 1 \cdot 10^{-6} \approx 0.465 \text{ nF}$

Exercise E7 Magnetic Circuit
(written test, approx. 7 % of a 120-minute written test, SS2022)

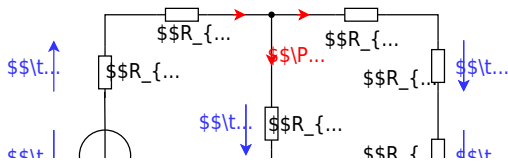
The magnetic setup below shall be given. Draw the equivalent magnetic circuit to represent the setup fully. Name all the necessary magnetic resistances, fluxes, and voltages. The components shall be designed in such a way, that the magnetic resistance is constant in it.

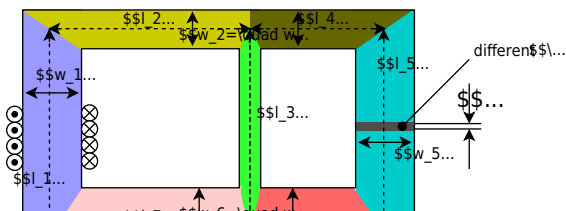
Formulas are not necessary.



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".

$$R_{\text{m}} = \frac{1}{\mu_0 \mu_r} \frac{l}{w \cdot h}$$




Full Exam

Here is only a part of the exam in more details given.
 The full results can be found in [ILIAS](#)

Full exam

Exercise E1 Electrostatics I

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

2. What is the charge Q_2 of the rod that is in the area $0 \leq x \leq 4$ m. The value of the electric field of E_4 . Which value needs E_4 to have to get a resulting force of 0 N on q_0 ?
 Path: $q_0 = -1 \text{ nC}$

- $q_1 = -2 \text{ nC}$

Path: $E_4 = 2310,97 \frac{\text{N}}{\text{m}}$

- $\vec{F}_{01} = \left(\begin{array}{c} 19,97 \\ 0 \\ 0 \end{array} \right) \cdot 10^{-6} \text{ N}$

With the q_1 and q_2 we can calculate the resulting magnitude

- $F = \sqrt{F_x^2 + F_y^2} = \sqrt{19,97^2 + 0^2} = 19,97 \text{ nN}$

As $\vec{F}_{01} = \left(\begin{array}{c} 19,97 \\ 0 \\ 0 \end{array} \right) \text{ nN}$ and $\vec{F}_{02} = \left(\begin{array}{c} 0 \\ 0 \\ 0 \end{array} \right) \text{ nN}$

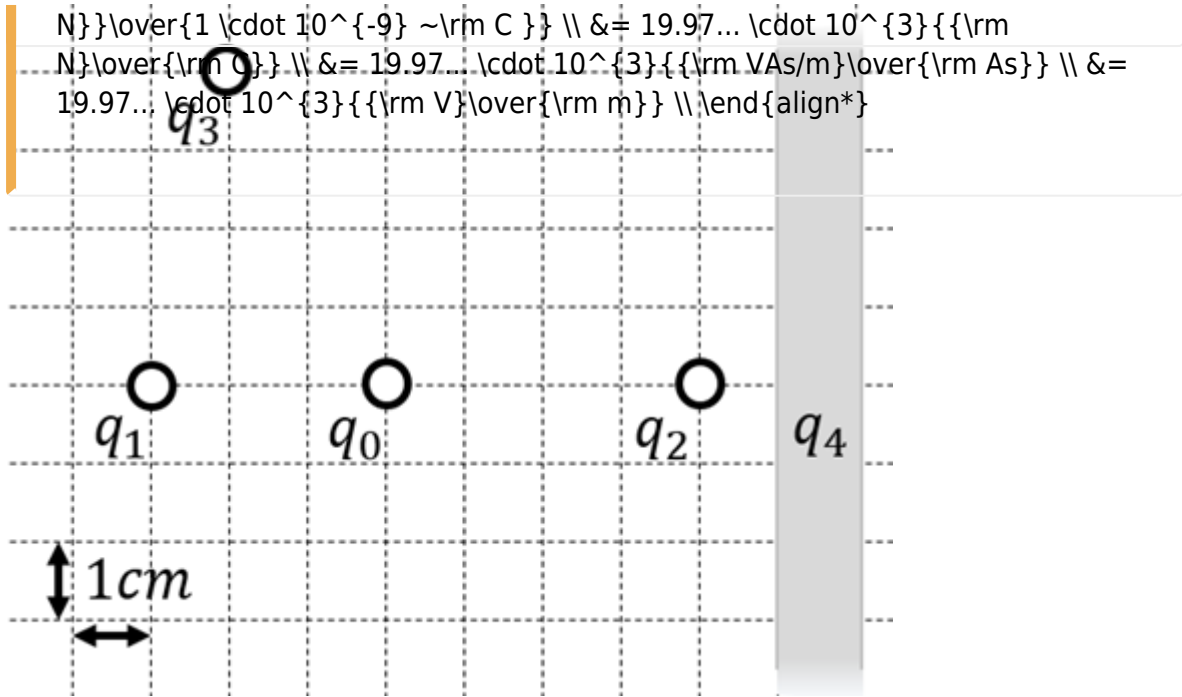
Here we find the magnitude of the force $F = 19,97 \text{ nN}$

$q_0 = -1 \text{ nC}$ and $q_1 = -2 \text{ nC}$

$E_4 = 2310,97 \frac{\text{N}}{\text{m}}$

$F = |q_0| \cdot E_4 = 1 \cdot 10^{-9} \cdot 2310,97 = 2,31097 \cdot 10^{-6} \text{ N}$

$F = 2,31097 \cdot 10^{-6} \text{ N}$



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 $F_{01,x}$.
$$\vec{F}_{01} = F_{01,x} \hat{x} = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 \cdot q_0}{r_{01}^2} \hat{x} = \frac{1}{4\pi \cdot 8.854 \cdot 10^{-12} \sim \text{As/Vm}} \cdot \frac{1 \cdot 1 \cdot 10^{-9} \sim \text{C} \cdot 2 \cdot 10^{-9} \sim \text{C}}{(3 \cdot 10^{-2} \sim \text{m})^2} \hat{x} = 19.97... \cdot 10^{-6} \{ \text{As}^2 \cdot \text{Vm} \} \over \{ \text{As} \cdot \text{m}^2 \} \} = 19.97... \cdot 10^{-6} \{ \text{Vs} \} \over \{ \text{m} \} \} = 19.97... \cdot 10^{-6} \{ \text{Ws} \} \over \{ \text{m} \} \} \parallel \&= 19.97... \{ \text{m} \mu \text{N} \} \quad \text{(to the right)}$$

Similarly, we get for \vec{F}_{02} and \vec{F}_{03}
$$\vec{F}_{02} = F_{02,x} \hat{x} = -28.09... \{ \text{m} \mu \text{N} \} \quad \text{(to the right)}$$

$$\vec{F}_{03} = -22.47... \{ \text{m} \mu \text{N} \} \quad \text{(to the top left)}$$

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

Based on this, the x - and y -component is:
$$F_{03,x} =$$

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

[electrical_engineering_and_electronics:task_dtoqvpvrbdtdcozfk_with_calculation](#)
[electrostatic](#), [field lines](#), [exam ee2 ss2022](#)

Exercise E2 Electrostatics II

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

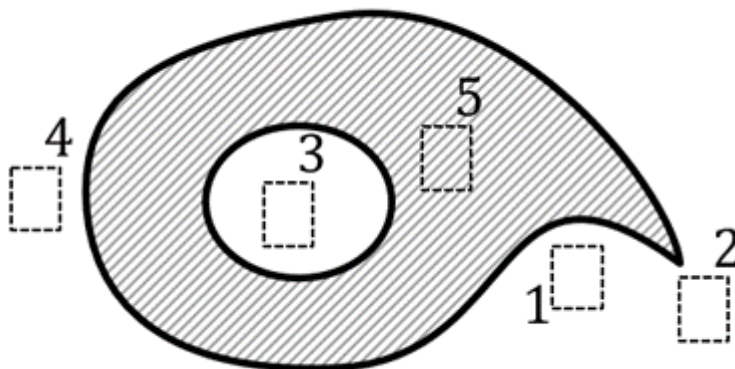
The figure below shows an arrangement of ideal metallic conductors (gray hatched) charged up to $q = +1 \text{ nC}$.

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

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

[electrical_engineering_and_electronics:task_ic9pioiu0notvwfp_with_calculation](#)
[electrostatic](#), [electric field strength](#), [exam ee2 ss2022](#)

Exercise E4 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 1 donor atom (= one electron) per 10^{10} silicon atoms. The molar volume of silicon is $V_{\text{mol,Si}} = 12\text{ }\cdot 10^{-6}\text{ m}^3/\text{mol}$, with $N_{\text{A}} = 6.022\text{ }\cdot 10^{23}$ silicon atoms per 1 mol .

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

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.

$$n_e = \frac{N_{\text{A}}}{V_{\text{mol,Si}}} \cdot k_{\text{Donators}} \cdot e_0 \cdot A$$

Putting in the numbers:

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

[electrical_engineering_and_electronics:task_tx86fewvysrcy8fc_with_calculation](#)
electrostatic, electric field strength, exam ee2 ss2022

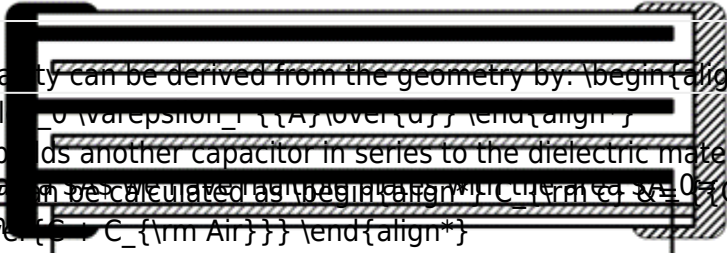
Exercise E2 Capacitor (written test, approx. 7 % of a 120-minute written test, SS2022)

Calculate the capacitance per 1 m^2 of the left-side layer with the following dimensions: $\epsilon_r = 0.1$ and $\epsilon_0 = 8.854\text{ }\cdot 10^{-12}\text{ F/m}$.
Result: $C = 0.1339\text{ nF/m}^2$

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

• 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 adds another capacitor in series to the dielectric material. Therefore, the capacity can be calculated as
$$\frac{1}{C_{\text{total}}} = \frac{1}{C_{\text{dielectric}}} + \frac{1}{C_{\text{air}}}$$

The capacity of air is
$$C_{\text{air}} = \epsilon_0 \frac{N l w}{d_{\text{air}}}$$

The material shall have a dielectric permittivity of $\epsilon_r = 3$

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

By this the overall capacity
$$C_{\text{total}} = \frac{0.139... \text{ nF} \cdot 0.465... \text{ nF}}{0.139... \text{ nF} + 0.465... \text{ nF}}$$

How many "multiple plates", N , do we have to consider?
 .. What is the field strength in the dielectric material between the plates, when a voltage of $U = 6.3 \text{ V}$ is applied?

Path

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

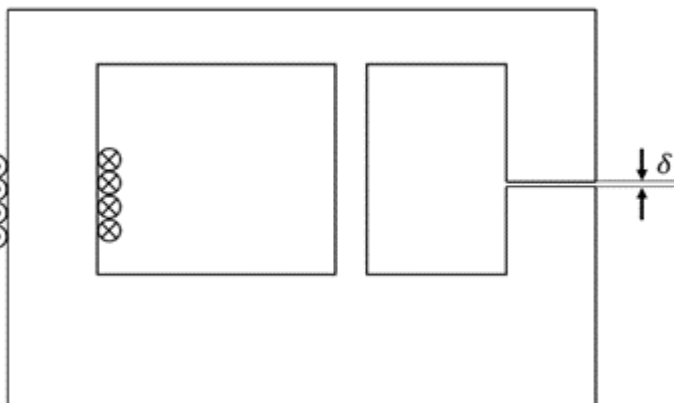
Therefore, the formula is
$$C = \epsilon_0 \epsilon_r \frac{N l w}{d} = 8.854 \cdot 10^{-12} \text{ As/Vm} \cdot 3 \cdot \frac{5 \cdot 1.5 \cdot 10^{-3} \text{ m} \cdot 0.7 \cdot 10^{-3} \text{ m}}{1 \cdot 10^{-6} \text{ m}}$$

electrostatic, capacitor, plate capacitor, capacity, exam ee2 ss2022

Exercise E7 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 the 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.



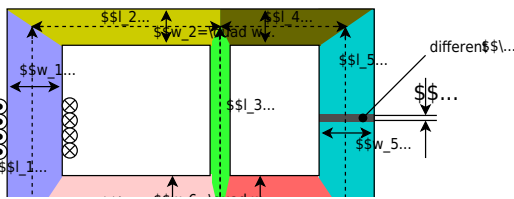
Path

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".

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



electrical_engineering_and_electronics:task_yp4rbdlj8kktyrh_p_with_calculation
magnetic circuit, exam ee2 ss2022

**Exercise E9 Self Induction
(written test, approx. 8 % of a 120-minute written test, SS2022)**

2. A voltage source with a maximum voltage of $U = 50 \text{ V}$, which the circuit breaker has a DC voltage source, which is fused with a circuit breaker.

Sketch the breaker part of the circuit ($i(t) = 0 \text{ A}$) with a current of $I = 0.3 \text{ A}$. The inner resistance of the motor shall be neglected.)

The inner resistance of the motor shall be neglected.)
 $u_{\text{ind}}(t) = 3150 \text{ V}$
 path
 .. 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:

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

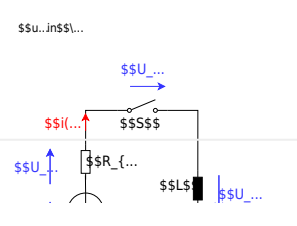
The first one is not given in the exercise, and therefore not considered here.

The induced voltage can be calculated by linearizing the following:

$$\begin{aligned} u_{\text{ind}}(t) &= -L \frac{di}{dt} \end{aligned}$$

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

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



electrical_engineering_and_electronics:task_unkkahm3u0v9azny_with_calculation self induction, induction, exam ee2 ss2022

Exercise E10 Series Resonant Circuit (written test, approx. 10 % of a 120-minute written test, SS2022)

2. What is the resonance frequency of the series RLC circuit shown in the diagram? The circuit parameters are: $R = 10 \text{ } \Omega$, $L = 10 \text{ } \mu\text{H}$, and $C = 10 \text{ nF}$.

In this case, the magnitude of the impedance Z_{RLC} would be $X_{C0} = Z_{\text{RLC}}$. Which value would C_0 have for the given f_0 ?

- Path 1: $C = 10 \text{ nF}$
- Path 2: $C = 100 \text{ nF}$
- Path 3: $C = 10 \text{ } \mu\text{F}$
- Path 4: $C = 100 \text{ } \mu\text{F}$

$$f_{\text{r}} = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{10 \cdot 10^{-6} \cdot 10 \cdot 10^{-9}}} = 100 \text{ kHz}$$

$$Z_{\text{RLC}} = X_{C0} \Rightarrow \frac{1}{\omega C} = R \Rightarrow C = \frac{1}{\omega R} = \frac{1}{2\pi \cdot 100 \cdot 10^3 \cdot 10} = 100 \text{ nF}$$

$$\begin{aligned} C &= \frac{1}{2\pi \cdot 100 \cdot 10^3 \cdot 10} = 100 \text{ nF} \\ \omega &= 2\pi \cdot 100 \cdot 10^3 = 628 \text{ } \Omega \end{aligned}$$

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