Block 09 - Force on Charges and electric Field Strength

Student Group

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Block 09 - Force on Charges and electric Field Strength

Learning objectives

By the end of this section, you will be able to:

- Distinguish **charge** Q (source) from **electric field** $\vec{E}$ (effect in space) and **force** $\vec{F}$ on a test charge q; use formula for Coulomb force with correct vector directions and units ($1~{\rm N/C}=1~{\rm V/m}$).
- Explain and apply the **superposition principle** for forces and fields from multiple charges.
- Compute $|\vec{E}|$ for a **point charge** (Coulomb force), identify ε and check dimensions.
- Determine the force on a charge in an electrostatic field by applying Coulomb's law. Specifically:
    - The force vector in coordinate representation
    - The magnitude of the force vector
    - The angle of the force vector
    - The direction of the force
- Determine a force vector by superimposing several force vectors using vector calculus.

Preparation at Home

And again:

- Please read through the following chapter.
- Also here, there are some clips for more clarification under 'Embedded resources'.

For checking your understanding please do the following exercise:

- 1.2.3

90-minute plan

1. Warm-up (8–10 min):
    1. Quick recall quiz: units of Q, $\vec{E}$, $\vec{F}$; passive sign convention for forces on a **positive** test charge.
    2. Dimensions check: show $1~{\rm N/C}=1~{\rm V/m}$.
2. Concept build & demonstrations (35–40 min):
    1. Cause–field–effect chain: charges $\Rightarrow \vec{E}(\vec{x}) \Rightarrow \vec{F}=q\,\vec{E}$.
    2. Coulomb law $\Rightarrow$ point-charge field magnitude and direction.

    3. **Superposition** for two/three charges; vector addition.
    4. **Field lines**: definition, drawing rules, sources/sinks, no intersections; relate density to magnitude.
    5. **Homogeneous vs. inhomogeneous** fields; conductor boundary facts (perpendicular $\vec{E}$, interior field-free).
3. Guided simulation (20–25 min)
    1. Place single and multiple charges; measure $\vec{E}$ at points.
4. Practice (10–15 min)
    1. net field on-axis of two charges; quick peer check.
5. Wrap-up (5 min):
    1. Summary map: charges → $\vec{E}$ → $\vec{F}$; key properties and units.

Conceptual overview

1. **Fields separate cause and effect**: charges set up a state in space (the field) that exists whether or not a test charge is present.
2. **Coulomb field of a point charge:** $\displaystyle \vec{E}(\vec{r})=\frac{1}{4\pi\varepsilon}\frac{Q}{r^2}\,\vec{e}_{\rm r}$ (radial; outward for $Q>0$, inward for $Q<0$). Magnitude $|\vec{E}|$ follows the inverse-square law.
3. The **electric field** is a **vector field** $\vec{E}(\vec{x})$; its **direction** is the direction of the force on a *positive* test charge; its **magnitude** is given by the actinv force and the charge with units $1~{\rm N/C}=1~{\rm V/m}$.
4. **Point charge** model: inverse-square law; direction is radial, outward for $Q>0$, inward for $Q<0$.
5. **Superposition** holds: for multiple sources, $\vec{E}_{\rm total}=\sum_k \vec{E}_k$ (vector sum at the same point).

Core content

Electric Effects

Every day life teaches us that there are various charges and their effects. The image figure 1 depicts a chargeable body that can be charged through charge separation between the sole and the floor. The movement of the foot generates a negative surplus charge in the body, which progressively spreads throughout the body. A current can flow even through the air if a pointed portion of the body (e.g., a finger) is brought into close proximity to a charge reservoir with no extra charges.

Fig. 1: John Tra-Voltage

First, we shall define certain terms:

1. **Electricity** is a catch-all term for any occurrences involving moving and resting charges.

2. **Electrostatics** is the study of charges at rest and consequently electric fields that do not vary over time. As a result, the electrical quantities have no temporal dependence.
   For any function of the electric quantities, ${{{\rm d} f}\over{{\rm d} t}}=0$ holds mathematically.
3. **Electrodynamics** describes the behavior of moving charges. Hence, electrodynamics covers both changing electric fields and magnetic fields.
   For the time being, the simple explanation will be that magnetic fields are dependent on current or charge flow.
   It is no longer true in electrodynamics that the derivative is always necessary for any function of electric values.

Only electrostatics is discussed in this chapter. For the time being, magnetic fields are thus excluded. Furthermore, electrodynamics is not covered in this chapter and is provided in further detail in subsequent chapters.

Fields

The concept of a field will now be briefly discussed in more detail.

1. The introduction of the field distinguishes the cause from the effect.
   1. The field in space is caused by the charge Q.
   2. As a result of the field, the charge q in space feels a force.
   3. This distinction is brought up again in this chapter.
      It is also fairly obvious in electrodynamics at high frequencies: the field corresponds to photons, i.e. to a transmission of effects with a finite (light)speed c.
2. There are different-dimensional fields, just like physical quantities:
   1. In a **scalar field**, each point in space is assigned a single number.
      For example,
      1. a temperature field $T(\vec{x})$ on a weather map or in an object
      2. a pressure field $p(\vec{x})$
   2. Each point in space in a **vector field** is assigned several numbers in the form of a vector.
      This reflects the action as it occurs along the spatial coordinates.
      As an example.
      1. gravitational field $\vec{g}(\vec{x})$ pointing to the object's center of mass.
      2. electric field $\vec{E}(\vec{x})$
      3. magnetic field $\vec{H}(\vec{x})$
3. A tensor field is one in which each point in space is associated with a two- or more-dimensional physical quantity - that is, a tensor. Tensor fields are useful in mechanics (for example, the stress tensor), but they are not required in electrical engineering.

Vector fields are defined as follows:

1. Effects along spatial axes x, y and z (Cartesian coordinate system).
2. Effect in magnitude and direction vector (polar coordinate system)

educational Task

Place a negative charge Q in the middle of the simulation and turn off the electric field. The latter is accomplished by using the hook on the right. The situation is now close to reality because a charge appears to have no effect at first glance.

A sample charge q is placed near the existing charge Q for impact analysis (in the simulation, the sample charge is called “sensors”). The charge Q is observed to affect a force on the sample charge. At any point in space, the magnitude and direction of this force can be determined. In space, the force behaves similarly to gravity. A field serves to describe the condition space changed by the charge Q.

Fig. 2: setup for own experiments
Take a charge ($+1~{ \rm nC}$) and position it.
Measure the field across a sample charge (a sensor).

Note:

1. Fields describe a physical state of space.
2. Here, a physical quantity is assigned to each point in space.
3. The electrostatic field is described by a vector field.

The electric Field

We had already considered the charge as the central quantity of electricity in block02 and recognized it as a multiple of the elementary charge. Now, we want to determine the electric field of charges. For this, a measurement of its magnitude and direction is now required. The **Coulomb force** between two charges Q_1 and Q_2 is:

\begin{align*} F_C = {{{1} \over {4\pi\cdot\varepsilon}} \cdot {{Q_1 \cdot Q_2} \over {r^2}}} \end{align*}

The force on a (fictitious) sample charge q is now considered to obtain a measure of the magnitude of the electric field.

\begin{align*} F_C &= {{{1} \over {4\pi\cdot\varepsilon}} \cdot {{Q_1 \cdot q} \over {r^2}}} \\ &= \underbrace{{{1} \over {4\pi\cdot\varepsilon}} \cdot {{Q_1} \over {r^2}}}_\text{=independent of q} \cdot q \\ \end{align*}

As a result, the left part is a measure of the magnitude of the field, independent of the size of the sample charge q. Thus, the magnitude of the electric field is given by

$E = {{1} \over {4\pi\cdot\varepsilon}} \cdot {{Q_1} \over {r^2}} \quad$ with $[E]={{[F]}\over{[q]}}=1 ~{ \rm {N}\over{As}}=1 ~{ \rm {N\cdot m}\over{As \cdot m}} = 1 ~{ \rm {V \cdot A \cdot s}\over{As \cdot m}} = 1 ~{ \rm {V}\over{m}}$

The result is therefore \begin{align*} \boxed{F_C = E \cdot q} \end{align*}

The unit of E is $\rm 1 {{N}\over{As}} = 1 {{V}\over{m}} $

Note:

1. The test charge q is always considered to be posi**t**ive (mnemonic: t = +). It is only used as a thought experiment and has no retroactive effect on the sampled charge Q.
2. The sampled charge here is always a point charge.

Note:

At a measuring point P, a charge Q produces an electric field $\vec{E}(Q)$. This electric field is given by

1. the magnitude $|\vec{E}|=\Bigl| {{1} \over {4\pi\cdot\varepsilon}} \cdot {{Q_1} \over {r^2}} \Bigl| $ and
2. the direction of the force $\vec{F_C}$ experienced by a sample charge on the measurement point P. This direction is indicated by the unit vector $\vec{e_{ \rm r}}={{\vec{F_C}}\over{|F_C|}}$ in that direction.

Be aware that in English courses and literature $\vec{E} $ is simply referred to as the electric field, and the electric field strength is the magnitude $|\vec{E}|$. In German notation, the *Elektrische Feldstärke* refers to $\vec{E}$ (magnitude and direction), and the *Elektrische Feld* denotes the general presence of an electrostatic interaction (often without considering exact magnitude).

The direction of the electric field is switchable in figure 2 via the “Electric Field” option on the right.

Direction of the Coulomb force and Superposition

In the case of the force, only the direction has been considered so far, e.g., direction towards the sample charge. For future explanations, it is important to include the cause and effect in the naming. This is done by giving the correct labeling of the subscript of the force. In figure 3 (a) and (b), the convention is shown: A force $\vec{F}_{21}$ acts on charge Q_2 and is caused by charge Q_1. As a mnemonic, you can remember “tip-to-tail” (first the effect, then the cause).

Furthermore, several forces on a charge can be superimposed, resulting in a single, equivalent force. Strictly speaking, it must hold that ε is constant in the structure. For example, the resultant force in figure 3 Fig. (c) on Q_3 becomes equal to: $\vec{F_3}= \vec{F_{31}}+\vec{F_{32}}$.
figure 3 Fig. (d) shows that for a charged surface, the force on a charge on top of this surface is always perpendicular to the surface itself.

Fig. 3: direction of coulomb force

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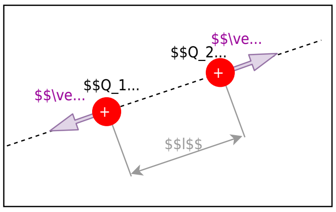
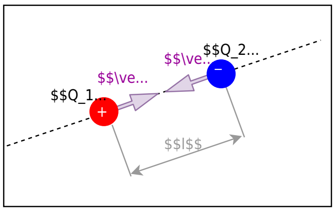




Energy required to Displace a Charge in the electric Field

Now we want to see, whether we can derive the required energy to displace a charge in the electric field.

Since we know the force on a charge in an electrical field $\vec{E}$ (= Coulomb-Force $\vec{F}_C = q \cdot \vec{E} $), we can borrow some relationships from mechanics for the energy ΔW:

$$\begin{align*} \Delta W = \int \vec{F} d\vec{r} = q \int \vec{E} d\vec{r} \end{align*}$$

Looks familiar? Maybe not on the first sight. But we already had defined the fraction of the energy difference per charge ${{\Delta W}\over{q}}$ as voltage U!
Therefore:

$$\boxed{U = \int \vec{E} d\vec{r} }$$

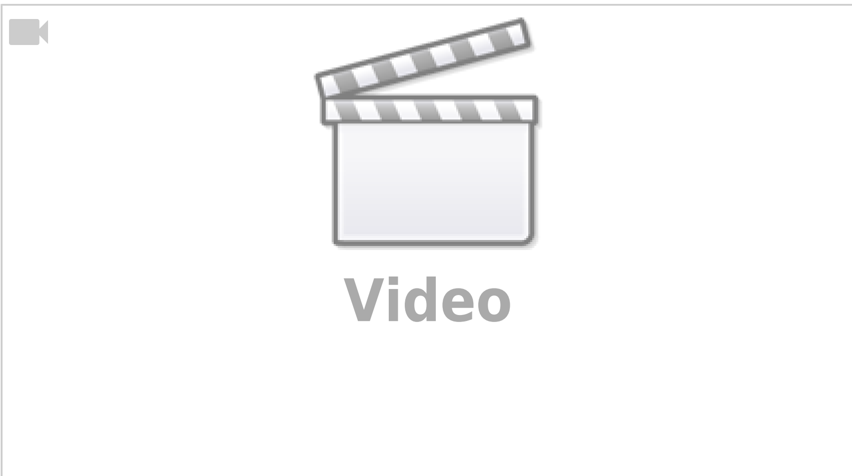
We will apply this relationship in multiple of the upcoming blocks.

Common pitfalls

- Treating **force** and **field** as the same thing; forgetting $\vec{F}=q\,\vec{E}$ and the positive-test-charge convention.
- Mixing units (${\rm N}$, ${\rm C}$, ${\rm V}$, ${\rm m}$): not recognizing $1~{\rm N/C}=1~{\rm V/m}$.
- Drawing **field lines** as closed loops or allowing them to **intersect** (source field: start at $+$, end at $-$; no crossings).
- Ignoring **vector addition** in superposition (adding magnitudes instead of vectors).
- Assuming field exists **only** when a test charge is present; the field is a property of space due to sources.
- Using point-charge formulas too near extended objects; not identifying **homogeneous vs. inhomogeneous** regions.
- Forgetting conductor boundary facts: lines must be **perpendicular** to ideal conducting surfaces; interior **$|\vec{E}|=0$** in electrostatics.

Exercises

Task 1.1.1 simple task with charges



Task 1.2.1 Multiple Forces on a Charge I (exam task, ca 8% of a 60-minute exam, WS2020)

Given is the arrangement of electric charges in the picture on the right.
The following force effects result:
$F_{01}=-5 ~\rm{N}$
$F_{02}=-6 ~\rm{N}$
$F_{03}=+3 ~\rm{N}$

Calculate the magnitude of the resulting force.

Tips for the Solution

- How have the forces be prepared, to add them correctly?

Solution

$$\begin{align*} F_0 &= |\vec{F_0}| \quad \quad \text{ with } \vec{F_0} = \left(\begin{matrix}{F_{x,0}}\\ {F_{y,0}} \end{matrix} \right) = \left(\begin{matrix} \sum\limits_{n} F_{x,0n} \\ \sum\limits_{n} F_{y,0n} \end{matrix} \right) \\ F_0 &= \sqrt{ \left(\sum\limits_{n} F_{x,0n} \right)^2 + \left(\sum\limits_{n} F_{y,0n} \right)^2 } \\ \end{align*}$$

The forces have to be resolved into coordinates. Here, it is recommended to use an orthogonal coordinate system (x and y).
The coordinate system shall be in such a way, that the origin lies in Q_0, the x-axis is directed towards Q_3 and the y-axis is orthogonal to it.
For the resolution of the coordinates, it is necessary to get the angles α_{0n} of the forces with respect to the x-axis.

In the chosen coordinate system this leads to: $\alpha_{0n} = \arctan(\frac{\Delta y}{\Delta x})$
$\alpha_{01} = \arctan(\frac{3}{1})= 1.249 = 71.6°$
$\alpha_{02} = \arctan(\frac{4}{3})= 0.927 = 53.1°$
$\alpha_{03} = \arctan(\frac{0}{3})= 0= 0°$

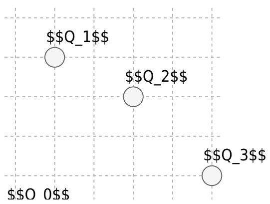
Consequently, the resolved forces are:

$$\begin{align*} F_{x,0} &= F_{x,01} + F_{x,02} + F_{x,03} && | \quad \text{with } F_{x,0n} = F_{0n} \cdot \cos(\alpha_{0n}) \\ F_{x,0} &= (-5~\rm{N}) \cdot \cos(71.6°) + (-6~\rm{N}) \cdot \cos(53.1°) + (+3~\rm{N}) \cdot \cos(0°) \\ F_{x,0} &= -9.54 ~\rm{N} \\ \\ F_{y,0} &= F_{y,01} + F_{y,02} + F_{y,03} && | \quad \text{with } F_{y,0n} = F_{0n} \cdot \sin(\alpha_{0n}) \\ F_{y,0} &= (-5~\rm{N}) \cdot \sin(71.6°) + (-6~\rm{N}) \cdot \sin(53.1°) + (+3~\rm{N}) \cdot \sin(0°) \\ F_{y,0} &= -2.18 ~\rm{N} \\ \\ \end{align*}$$

Result

$$\begin{align*} F_0 &= \sqrt{ (-9.54 ~\rm{N})^2 + (-2.18 ~\rm{N})^2} = 9.79 ~\rm{N} \rightarrow 9.8 ~\rm{N} \\ \end{align*}$$

Task 1.2.2 Variation: Multiple Forces on a Charge II (exam task, ca 8% of a 60 minute exam, WS2020)



Given is the arrangement of electric charges in the picture on the right.
The following force effects result:

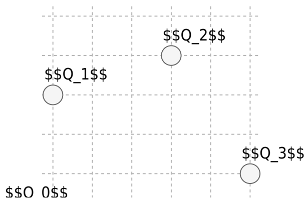
$F_{01}=-5 ~\rm{N}$
$F_{02}=-6 ~\rm{N}$
$F_{03}=+3 ~\rm{N}$

Calculate the magnitude of the resulting force.

Result

\begin{align*} |F_0| &= \sqrt{ (-0.418 ~\rm{N})^2 + (-9.264 ~\rm{N})^2 } = 9.274 ~\rm{N} \rightarrow 9.3 ~\rm{N} \\ \end{align*}

Task 1.2.3 Variation: Multiple Forces on a Charge II (exam task, ca 8% of a 60 minute exam, WS2020)



Given is the arrangement of electric charges in the picture on the right.
The following force effects result:
$F_{01}=+2 ~\rm{N}$
$F_{02}=-3 ~\rm{N}$
$F_{03}=+4 ~\rm{N}$

Calculate the magnitude of the resulting force.

Result

\begin{align*} |F_0| &= \sqrt{ (2.12 ~\rm{N})^2 + (0.38 ~\rm{N})^2 } = 2.16 ~\rm{N} \rightarrow 2.2 ~\rm{N}\\ \end{align*}

Exercise E1 Electrostatics I
(written test, approx. 10 % of a 120-minute written test, SS2022)

Given is the arrangement of electric charges in the picture below. The values of the point charges are:

- $q_0=-1 ~\rm nC$
- $q_1=-2 ~\rm nC$
- $q_3= [illegible] ~\rm nC$

In the beginning, the area charge is $q_4=0 ~\rm nC$.

The permittivity is $\varepsilon_0 = 8.854 \cdot 10^{-12} ~\rm As/Vm$

- $\vec{F}_{01} = \left({\begin{array}{cccc} 19.97 {~\rm \mu N} \\ 0 \\ \end{array} } \right)$
- $\vec{F}_{02} = \left({\begin{array}{cccc} 28.09 {~\rm \mu N} \\ 0 \\ \end{array} } \right)$
- $\vec{F}_{03} = \left({\begin{array}{cccc} 10.05 {~\rm \mu N} \\ 20.10 {~\rm \mu N} \\ \end{array} } \right)$

2. What is the magnitude of the resulting force?

Result

Path

With all the x and y components, we can calculate the resulting magnitude of the force with the Pythagorean Theorem:

$$\begin{align*} F = |\vec{F}| &= \sqrt{\left(\sum_i F_{i,x} \right)^2 + \left(\sum_i F_{i,y} \right)^2} \\ &= \sqrt{\left(19.97 {~\rm \mu N} + 28.09 {~\rm \mu N} - 10.05 {~\rm \mu N} \right)^2 + \left(20.10 {~\rm \mu N} \right)^2} \\ &= 42.99... {~\rm \mu N} \end{align*}$$

3. Now the charge q_2 is set to 0. The area charge q_4 generates a homogenous field E_4. Which value needs E_4 to have to get a resulting force of $0 ~\rm N$ on q_0?

Path

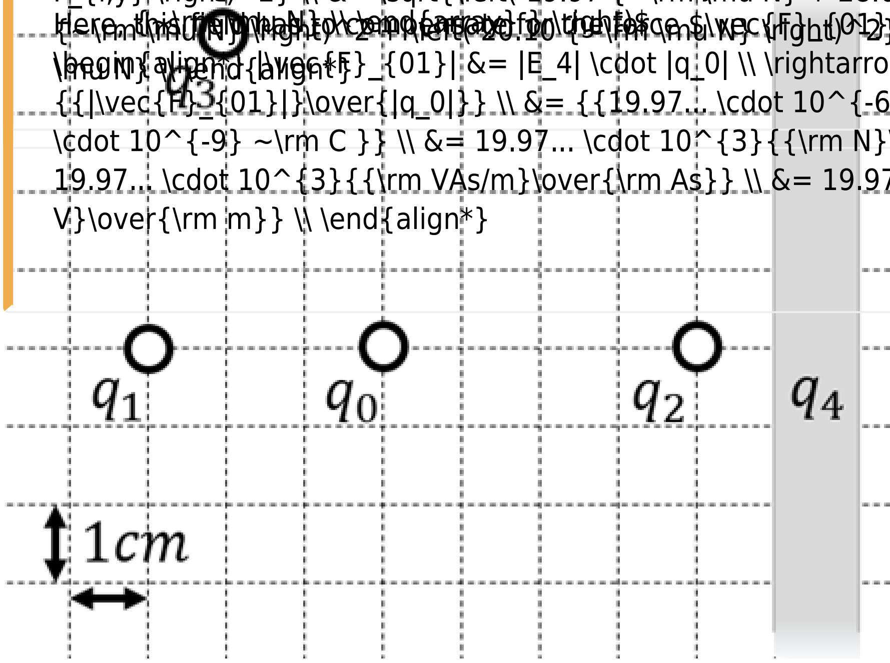
In the homogenous field the force is [illegible]

Here, this field has to compensate for the force $\vec{F}_{01}$ from q_1 on q_0:

$$\begin{align*} |\vec{F}_{01}| &= |E_4| \cdot |q_0| \\ \rightarrow E_4 &= {{|\vec{F}_{01}|}\over{|q_0|}} \\ &= {{19.97... \cdot 10^{-6} {~\rm N}}\over{1 \cdot 10^{-9} ~\rm C }} \\ &= 19.97... \cdot 10^{3}{{\rm N}\over{\rm C}} \\ &= 19.97... \cdot 10^{3}{{\rm VAs/m}\over{\rm As}} \\ &= 19.97... \cdot 10^{3}{{\rm V}\over{\rm m}} \\ \end{align*}$$

Result

$E_4 = 19.97 {{\rm kV}\over{\rm m}}$



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 $F_{01,x}$.

$$\begin{align*} \vec{F}_{01} = F_{01,x} &= {{1}\over{4\pi\varepsilon}}\cdot {{q_1\cdot q_0}\over{r^2_{01}}} \\ &= {{1}\over{4\pi\cdot 8.854 \cdot 10^{-12} ~\rm As/Vm}}\cdot {{1 \cdot 10^{-9} ~\rm C \cdot 2 \cdot 10^{-9} ~\rm C}\over{(3 \cdot 10^{-2} ~\rm m)^2}} \\ &= 19.97... \cdot 10^{-6} {\rm {{(As)^2 \cdot Vm}\over{As \cdot m^2}}} = 19.97... \cdot 10^{-6} {\rm {{VAs}\over{m}}} = 19.97... \cdot 10^{-6} {\rm {{Ws}\over{m}}} \\ &= 19.97... {\rm \mu N} \quad \text{(to the right)} \end{align*}$$

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

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

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{align*} \alpha = \arctan(\rm {{-4~cm}\over{+2~cm}}) = \pi - 1.1071... = 180° - 63.4...° = 116.6...° \end{align*}

Based on this, the x- and y-component is: \begin{align*} F_{03,x} &= |\vec{F}_{03}| \cdot \cos \alpha = 10.05... {~\rm \mu N} \text{(to the left)} \\ F_{03,y} &= |\vec{F}_{03}| \cdot \sin \alpha = 20.10... {~\rm \mu N} \text{(to the top)} \\ \end{align*}

Exercise E2 Electrostatics I
(written test, approx. 8 % of a 120-minute written test, SS2024)

Given is the arrangement of the electric charges in the picture below. The values of the point charges are:

- $q_0=-1 ~\rm nC$
- $q_1=-5 ~\rm nC$

In the beginning, the area charge is $q_4=0 ~\rm nC$.
The permittivity is $\varepsilon_0 = 8.854 \cdot 10^{-12} ~\rm As/Vm$

2. What is the magnitude of the resulting force?

Result

Path

- $\vec{F}_{01} = \left({\begin{array}{cccc} +917 {~\rm \mu N} \\ 0 \\ \end{array} } \right)$
- $\vec{F}_{02} = \left({\begin{array}{cccc} -1997 {~\rm \mu N} \\ 0 \\ \end{array} } \right)$
- $\vec{F}_{03} = \left({\begin{array}{cccc} 0 {~\rm \mu N} \\ -1123 {~\rm \mu N} \\ \end{array} } \right)$

With all the x and y components, we can calculate the resulting magnitude of the force with the Pythagorean Theorem:
\begin{align*} F = |\vec{F}| &= \sqrt{\left(\sum_i F_{i,x} \right)^2 + \left(\sum_i F_{i,y} \right)^2} \\ &= \sqrt{\left(+917 {~\rm \mu N} - 1997 {~\rm \mu N} \right)^2 + \left(-1123 {~\rm \mu N} \right)^2} \\ &= 1560.\;.\!.\!.\! {~\rm \mu N} \\ \end{align*}

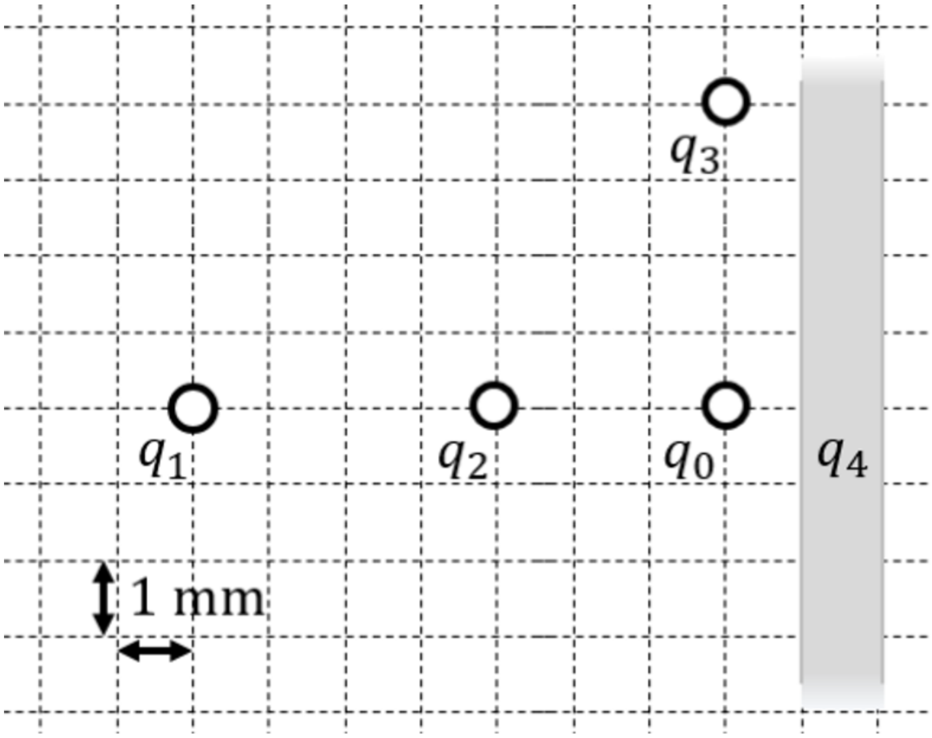
3. Now the charge q_2 ... the area charge q_4 generates a homogenous field E_4. Which value needs E_4 to have to get a resulting force of $0 ~\rm N$ on q_0?

Result

$E_4 = 917 {{\rm kV}\over{\rm m}}$

Path

In the homogenous field the force is calculated by $F = E \cdot q$.
Here, this field has to compensate for the force $\vec{F}_{01}$ from q_1 on q_0:
\begin{align*} |\vec{F}_{01}| &= |E_4| \cdot |q_0| \\ \rightarrow E_4 &= {{|\vec{F}_{01}|}\over{|q_0|}} \\ &= {{917.\;.\!.\!.\! \cdot 10^{-6} {~\rm N}}\over{1 \cdot 10^{-9} ~\rm C }} \\ &= 917.\;.\!.\!.\! \cdot 10^{3}{{\rm N}\over{\rm C}} \\ &= 917.\;.\!.\!.\! \cdot 10^{3}{{\rm VAs/m}\over{\rm As}} \\ &= 917.\;.\!.\!.\! \cdot 10^{3}{{\rm V}\over{\rm m}} \\ \end{align*}



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

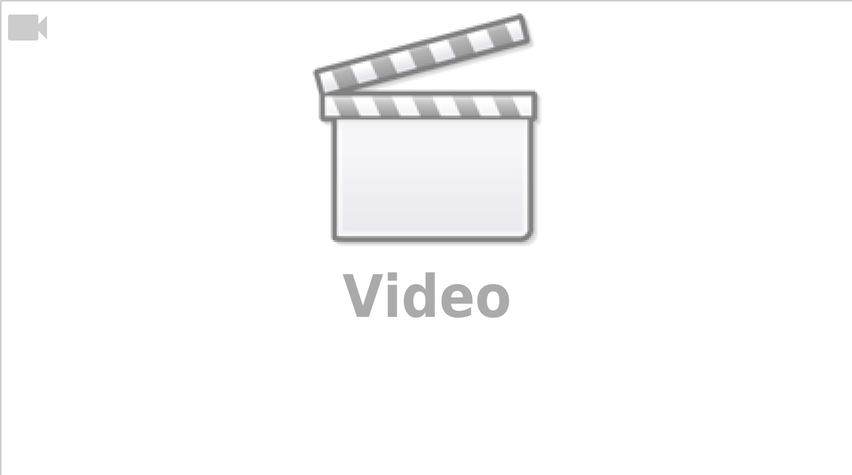
Path

First, set up a coordinate system. Here, I choose x pointing to the right (positive values to the right) and y pointing upwards (positive values upwards).

Then, calculate the magnitude of the forces, like $\vec{F}_{01}$ (force on q_0 from q_1).
The force $\vec{F}_{01}$ is purely on the x-axis and therefore equal to $F_{01,x}$. \begin{align*} \vec{F}_{01} = F_{01,x} &= {{1}\over{4\pi\varepsilon}}\cdot {{q_1\cdot q_0}\over{r^2_{01}}} \\ &= {{1}\over{4\pi\cdot 8.854 \cdot 10^{-12} ~\rm As/Vm}}\cdot {{1 \cdot 10^{-9} ~\rm C \cdot 5 \cdot 10^{-9} ~\rm C}\over{(7 \cdot 10^{-3} ~\rm m)^2}} \\ &= 917.\;.\!.\!.\! \cdot 10^{-6} {\rm {{(As)^2 \cdot Vm}\over{As \cdot m^2}}} = 917.\;.\!.\!.\! \cdot 10^{-6} {\rm {{VAs}\over{m}}} = 917.\;.\!.\!.\! \cdot 10^{-6} {\rm {{Ws}\over{m}}} \\ &= +917.\;.\!.\!.\! {\rm \mu N} \end{align*} Since both q_0 and q_1 have the same sign for their charges, they are repelling each other. Therefore, The force $\vec{F}_{01}$ points to the right (positive value).

Similarly, we get for $\vec{F}_{02}$ and $\vec{F}_{03}$ \begin{align*} \vec{F}_{02} = F_{02,x} &= -1997.\;.\!.\!.\! {\rm \mu N} \\ \vec{F}_{03} = F_{03,y} &= -1123.\;.\!.\!.\! {\rm \mu N} \\ \end{align*} Since q_0 and q_2 have the different sign for their charges, they are attract each other. Therefore, The force $\vec{F}_{02}$ points to the left (negative value).
Since q_0 and q_3 have the different sign for their charges, they are attract each other. Therefore, The force $\vec{F}_{03}$ points downwards (negative value).

Task 1.2.4 Superposition of Charges in 1D



Embedded resources

The online book 'University Physics II' is strongly recommended as a reference for this chapter. Especially the following chapters:

- Chapter 5. Electric Charges and Fields
- Chapter 6. Gauss's Law
- Chapter 7. Electrical Potential
- Chapter 8. Capacitance

Intro into electric field