Block 09 - Force on Charges and electric Field Strength

Student Group

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Table of Contents

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Learning objectives

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

1. Know that an electric field is formed around a charge.
2. Sketch the field lines of electric fields.
3. Represent the field vectors in a sketch when given several charges.
4. Determine the resulting field vector by superimposing several field vectors using vector calculus.
5. Determine the force on a charge in an electrostatic field by applying Coulomb's law. Specifically:
    1. The force vector in coordinate representation
    2. The magnitude of the force vector
    3. The angle of the force vector

90-minute plan

1. Warm-up (5–10 min):
    1. Recall / Quick quiz …
2. Core concepts & derivations (60–70 min):
    1. …
3. Practice (10–20 min): …
4. Wrap-up (5 min): …

Conceptual overview

1. …

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

We had already considered the charge as the central quantity of electricity in the first chapter of the previous semester and recognized it as a multiple of the elementary charge. There was already a mutual force action (the Coulomb-force) derived. This will be more fully explained.

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

To determine the electric field, a measurement of its magnitude and direction is now required. The Coulomb force between two charges Q_1 and Q_2 is known from the first chapter of the previous semester:

\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*}

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.

Common pitfalls

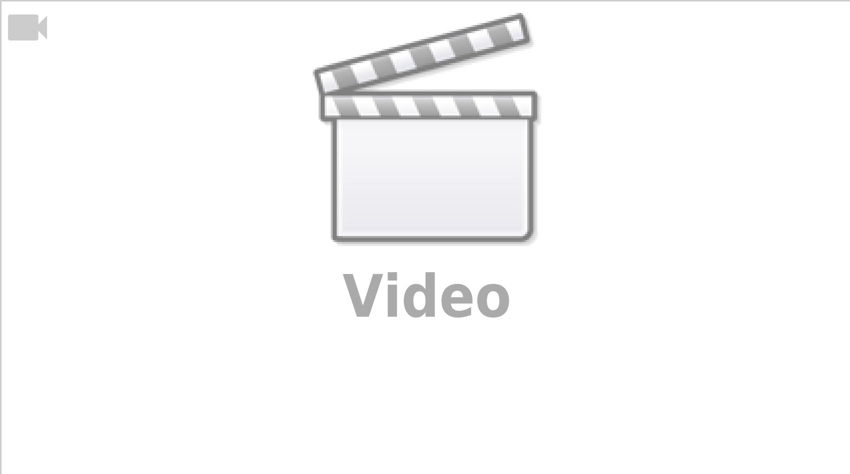
- …

…

Exercises

Quick checks

Task 1.1.1 simple task with charges



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