Block 02 — Electric Charge, Current, Voltage

Student Group

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Block 02 — Electric charge and current

Learning objectives

- Define electric charge Q and explain its quantization in multiples of the elementary charge e.
- Distinguish positive and negative charges, their interactions, and typical carriers (electrons, ions).
- Define electric current I as rate of charge flow; relate I to moving charge via $I = \frac{{\rm d}Q}{{\rm d}t}$.
- Apply the unit check for $1~\rm A = 1~C/s$ and recall typical current magnitudes (pA … kA).
- Explain and consistently use the **conventional current direction**.
- Identify and sketch the symbols of the **ideal current and voltage source**.

90-minute plan

1. Warm-up (5–10 min): Recall of SI units from Block 01; estimate "How many electrons per second flow at $1~\rm A$?"
2. Core concepts & derivations (60–70 min):
    1. Electric charge: definition, elementary charge, Coulomb's law (overview only).
    2. Charge carriers in metals vs. electrolytes.
    3. Electric current: definition, instantaneous and average values, unit check.
    4. Typical magnitudes; conventional vs. electron flow.
    5. Ideal current source, symbol, and U–I diagram.
3. Practice (10–20 min): Quick calculations and sim-based exercises.
4. Wrap-up (5 min): Summary and pitfalls.

Conceptual overview

1. **Charge Q** is the fundamental "substance" of electricity, always in multiples of the elementary charge.
2. **Like charges repel, unlike charges attract**; forces are described by Coulomb's law (detail in Block 09).
3. **Current I** quantifies *how fast* charge moves: $1~\rm A$ = $1~C/s$.
4. Convention: we follow **conventional current direction** (positive charge motion, from $+$ to $-$), even though in metals electrons move oppositely.
5. Ideal current sources deliver a fixed current regardless of load voltage — a useful abstraction for circuit analysis.
6. This block connects Block 01 (units) to Block 03 (voltage and resistance), and prepares for Kirchhoff's laws in Block 04.

Core content

Electric charge

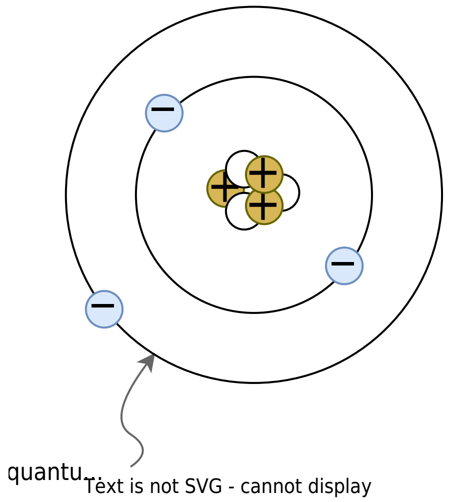


Fig. ##: Atomic model according to Bohr / Sommerfeld

- Electric charge Q is a physical quantity indicating the amount of excess or deficit of electrons or ions.
- the charge is based on the electron shell and the atomic nucleus, see the atomic model of Bohr and Sommerfeld in figure ##
- Due to the electrons and protons it is **quantized** in multiples of the elementary charge:

\begin{align*} e &= 1.602 \cdot 10^{-19}~\rm C \\ Q &= n \cdot e \end{align*}

with $n \in \mathbb{Z}$.

* Positive charge: deficiency of electrons (e.g. ionized atoms). * Negative charge: excess electrons.

\begin{align*} [Q] = 1~\rm C = 1~A \cdot s \end{align*}

Example / micro-exercise

How many electrons correspond to a charge of $1~\rm C$? \begin{align*} n = \frac{Q}{e} = \frac{1~\rm C}{1.602\cdot 10^{-19}~\rm C} \approx 6.24 \cdot 10^{18} \end{align*}

Electric current

An **electric current** arises when charges move in a preferred direction. The instantaneous current is defined as

\begin{align*} i(t) = \frac{{\rm d}Q}{{\rm d}t} \end{align*}

Unit check:

\begin{align*} [i] &= \frac{[Q]}{[t]} = \frac{1~\rm C}{1~\rm s} = 1~\rm A \end{align*}

* In metals: flow of electrons. * In electrolytes: movement of ions. * In semiconductors: electrons and

holes.

Convention

In this course, we always use the **conventional current direction**: positive from $+$ to $-$. Electron flow is opposite.

Typical current magnitudes

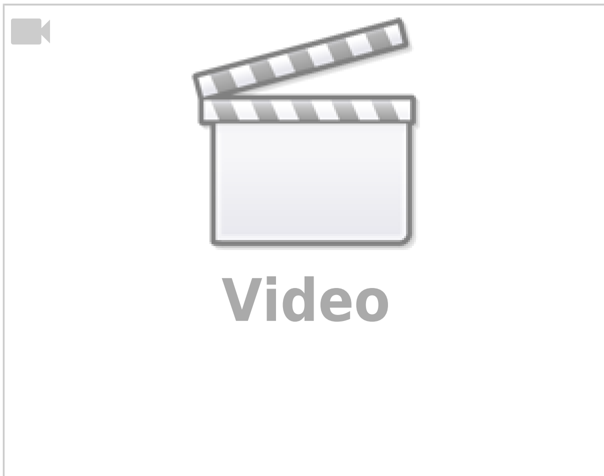
- $10~\rm pA$ — control current in a FET gate
- $10~\rm \mu A$ — sensitive sensor output
- $10~\rm mA$ — LED or small sensor supply
- $10~\rm A$ — heating device
- $10~\rm kA$ — large generator output

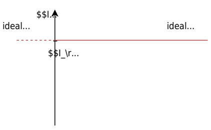
Ideal current source

From circuit theory, we abstract the **ideal current source**:

- Delivers a fixed current I_s, independent of load voltage.
- Symbol: circle with arrow.
- U–I characteristic: vertical line at $I = I_s$.

Fig. ##: ideal current source





Exercises

Exercise E13 Charges on a Ballon

A balloon has a charge of $Q=7~{\rm nC}$ on its surface.
How many additional electrons are on the balloon?

Result

$$\begin{align*} 43.7*10^{9}~{\rm electrons} \end{align*}$$

Solution

$$\begin{align*} Q &= 7~{\rm nC} = 7\cdot 10^{-9}~{\rm C} \\ n_{\rm e} &= {{7*10^{-9}~{\rm C}}\over{1.6022*10^{-19}~{\rm C/electron}}} = 43.7*10^{9}~{\rm electrons} \end{align*}$$

Exercise E14 Charges on a Ballon

A balloon has a charge of $Q=7~{\rm nC}$ on its surface.
How many additional electrons are on the balloon?

Result

$$\begin{align*} 43.7*10^{9}~{\rm electrons} \end{align*}$$

Solution

$$\begin{align*} Q &= 7~{\rm nC} = 7\cdot 10^{-9}~{\rm C} \\ n_{\rm e} &= {{7*10^{-9}~{\rm C}}\over{1.6022*10^{-19}~{\rm C/electron}}} = 43.7*10^{9}~{\rm electrons} \end{align*}$$

Exercise E15 Charges in Electroplating

To get a different metal coating onto a surface, often Electroplating is used. In this process, the surface is located in a liquid, which contains metal ions of the coating.
In the following, a copper coating (e.g. for corrosion resistance) shall be looked on. The charge of one copper ion is around $1.6022 \cdot 10^{-19}~{\rm C}$, what is the charge on the surface if there are $8 \cdot 10^{22}~{\rm ions}$ added?

Result

$$\begin{align*} 12'818~{\rm C} \end{align*}$$

Solution

$$\begin{align*} 8 * 10^{22} \cdot 1.6022 *10^{-19}~{\rm C} = 12'817.6~{\rm C}$$

\end{align*}

Exercise E16 Charges in Electroplating

To get a different metal coating onto a surface, often Electroplating is used. In this process, the surface is located in a liquid, which contains metal ions of the coating.
In the following, a copper coating (e.g. for corrosion resistance) shall be looked on. The charge of one copper ion is around $1.6022 \cdot 10^{-19}~{\rm C}$, what is the charge on the surface if there are $8 \cdot 10^{22}~{\rm ions}$ added?

Result

\begin{align*} 12'818~{\rm C} \end{align*}

Solution

\begin{align*} 8 * 10^{22} \cdot 1.6022 *10^{-19}~{\rm C} = 12'817.6~{\rm C} \end{align*}

Task 2.1: Counting charges in a current

A flashlight bulb is supplied with $I=0.25~\rm A$. How many electrons pass through the filament in one second?

Strategy

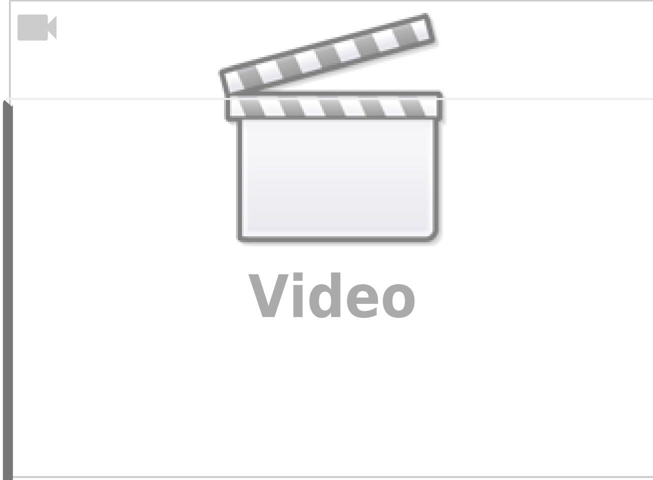
Use $n=\frac{I \cdot t}{e}$ with $t=1~\rm s$.

Solution

\begin{align*} n = \frac{0.25~\rm C}{1.602 \cdot 10^{-19}~\rm C} \approx 1.6 \cdot 10^{18} \end{align*}

Embedded resources

Charge in Matter



Summary & checklist

1. Electric charge Q is quantized in multiples of $e=1.602\cdot 10^{-19}~\rm C$.
2. Current $I = \frac{{\rm d}Q}{{\rm d}t}$; $1~\rm A = 1~C/s$.
3. **Conventional current direction** runs from $+$ to $-$. Electron flow is opposite.
4. Typical currents range from pA (sensors) to kA (power generators).
5. Ideal current sources supply fixed current independent of load.
6. Pitfalls:
   - Mixing electron flow vs. conventional current.
   - Forgetting unit checks ($\rm A = C/s$).
   - Misinterpreting current as “speed” rather than rate of charge flow.