

# 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  $I = \frac{dQ}{dt}$ .
- Apply the unit check for  $I \sim \text{A} = 1 \sim \text{C/s}$  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  $1 \sim \text{A}$ ?”
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:  $I \sim \text{A} = 1 \sim \text{C/s}$ .
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

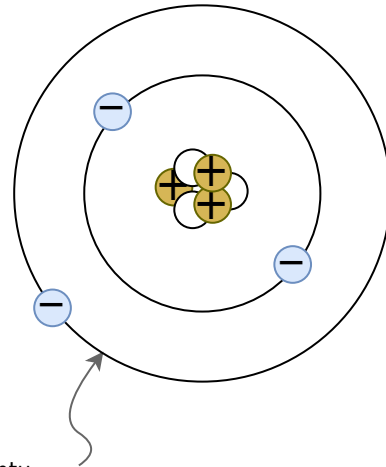


Fig. ##: Atomic model according to Bohr / Sommerfeld <sup>quantu</sup>Text is not SVG - cannot display

- 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:

$$\begin{aligned} e &= 1.602 \cdot 10^{-19} \text{~}\text{r}\text{m C} \\ Q &= n \cdot e \end{aligned}$$

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

- Positive charge: deficiency of electrons generates an excess of positive charges (e.g. ionized atoms).
- Negative charge: excess electrons overcompensates the positive charges.
- charges with different signs attract each other. Charges with similar sign repel each other

$$\begin{aligned} [Q] &= 1 \text{~}\text{r}\text{m C} = 1 \text{~}\text{A} \cdot \text{s} \end{aligned}$$

### Example / micro-exercise

How many electrons correspond to a charge of  $1 \text{~}\text{r}\text{m C}$ ? 
$$n = \frac{Q}{e} = \frac{1 \text{~}\text{r}\text{m C}}{1.602 \cdot 10^{-19} \text{~}\text{r}\text{m C}} \approx 6.24 \cdot 10^{18}$$

## Electric current

An **electric current** arises when charges move in a preferred direction, e.g. by attraction and repulsion. The current is defined as

$$\begin{aligned} I &= \frac{Q}{t} \end{aligned}$$

The instantaneous current is defined as

$$i(t) = \frac{dQ}{dt}$$

Unit check:

$$i = \frac{Q}{t} = \frac{1 \text{ C}}{1 \text{ s}} = 1 \text{ A}$$

\* 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

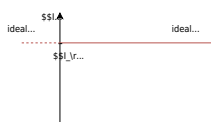
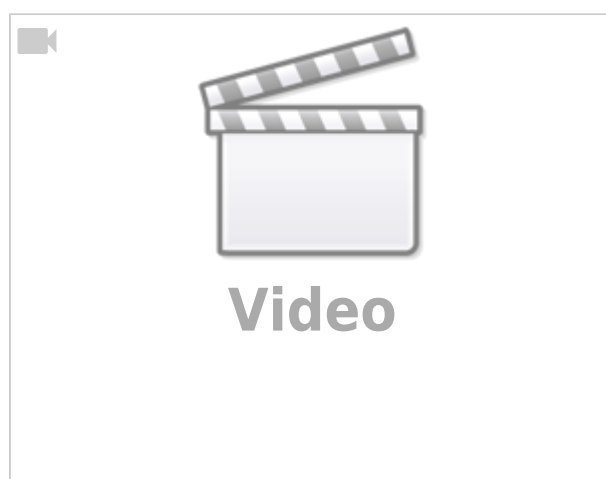
- $10 \text{ pA}$  — control current in a FET gate
- $10 \text{ }\mu\text{A}$  — sensitive sensor output
- $10 \text{ mA}$  — LED or small sensor supply
- $10 \text{ A}$  — heating device
- $10 \text{ kA}$  — large generator output

### 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  $Q=7\text{ nC}$  on its surface.

**Result** How many additional electrons are on the balloon?

Solution

$$43.7 \cdot 10^9 \text{ electrons}$$

$$Q = 7 \text{ nC} = 7 \cdot 10^{-9} \text{ C} \quad n_{\text{e}} = \frac{7 \cdot 10^{-9} \text{ C}}{1.6022 \cdot 10^{-19} \text{ C/electron}} = 43.7 \cdot 10^9 \text{ electrons}$$

### Exercise E14 Charges on a Ballon

A balloon has a charge of  $Q=7\text{ nC}$  on its surface.

**Result** How many additional electrons are on the balloon?

Solution

$$43.7 \cdot 10^9 \text{ electrons}$$

$$Q = 7 \text{ nC} = 7 \cdot 10^{-9} \text{ C} \quad n_{\text{e}} = \frac{7 \cdot 10^{-9} \text{ C}}{1.6022 \cdot 10^{-19} \text{ C/electron}} = 43.7 \cdot 10^9 \text{ electrons}$$

### 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  $1.6022 \cdot 10^{-19} \text{ C}$ , what is the charge on the surface if there are  $8 \cdot 10^{22}$  ions added?

$$12.818 \text{ C}$$

Solution

$$\begin{aligned} 8 * 10^{22} \cdot 1.6022 * 10^{-19} \text{~}\{\text{r m C}\} &= 12'817.6 \text{~}\{\text{r m C}\} \\ \end{aligned}$$

### 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  $1.6022 \cdot 10^{-19} \text{~}\{\text{r m C}\}$ , what is the charge on the surface if there are  $8 \cdot 10^{22} \text{~}\{\text{r m ions}\}$  added?

$$\begin{aligned} 12'818 \text{~}\{\text{r m C}\} \end{aligned}$$

Solution

$$\begin{aligned} 8 * 10^{22} \cdot 1.6022 * 10^{-19} \text{~}\{\text{r m C}\} &= 12'817.6 \text{~}\{\text{r m C}\} \\ \end{aligned}$$

### Task 2.1: Counting charges in a current

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

Strategy

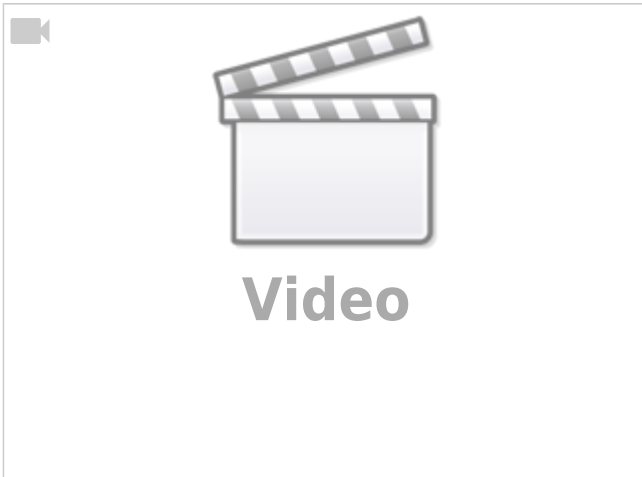
Use  $n = \frac{I \cdot t}{e}$  with  $t=1 \text{~}\{\text{r m s}\}$ .

Solution

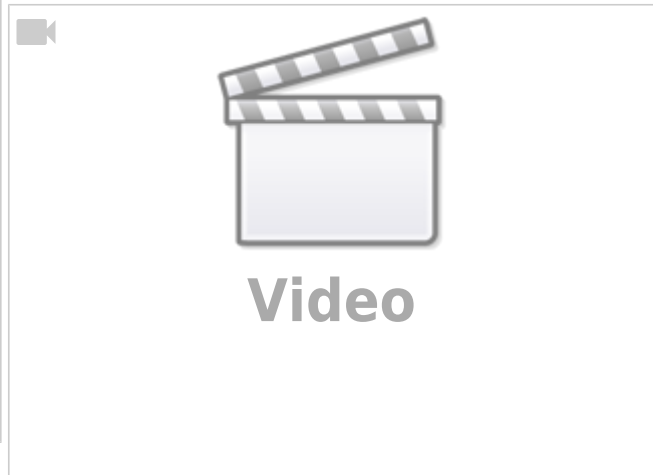
$$\begin{aligned} n &= \frac{0.25 \text{~}\{\text{r m C}\}}{1.602 \cdot 10^{-19} \text{~}\{\text{r m C}\}} \approx 1.6 \cdot 10^{18} \\ \end{aligned}$$

## Embedded resources

## Charge in Matter



## What is Electric Charge and How Electricity Works



## Summary & checklist

1. Electric charge  $Q$  is quantized in multiples of  $e=1.602 \cdot 10^{-19} \text{ C}$ .
2. Current  $I = \frac{dQ}{dt}$ ;  $1 \text{ A} = 1 \text{ C/s}$ .
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 ( $\text{A} = \text{C/s}$ ).
  - Misinterpreting current as “speed” rather than rate of charge flow.

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Last update: **2025/09/27 15:57**

