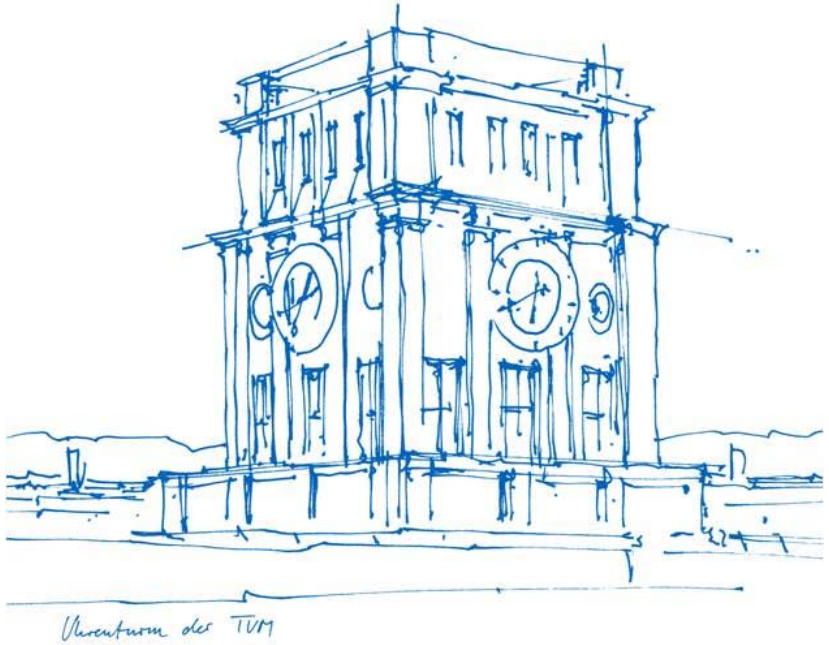
Lecture

Electricity and Magnetism

Chapter 1 Electrostatics – 1.1. Electric Charge

- Introduction
- Electric Charge



1.1. Electric Charge - Introduction

The Greek discovered already 550 B.C.:

- Amber attracts small and light things like leaves or feathers, if it is rubbed with a tissue
- This is called triboelectric effect Triboelectricity
- Amber = Greek: ελεκτρον

electron

Charges:

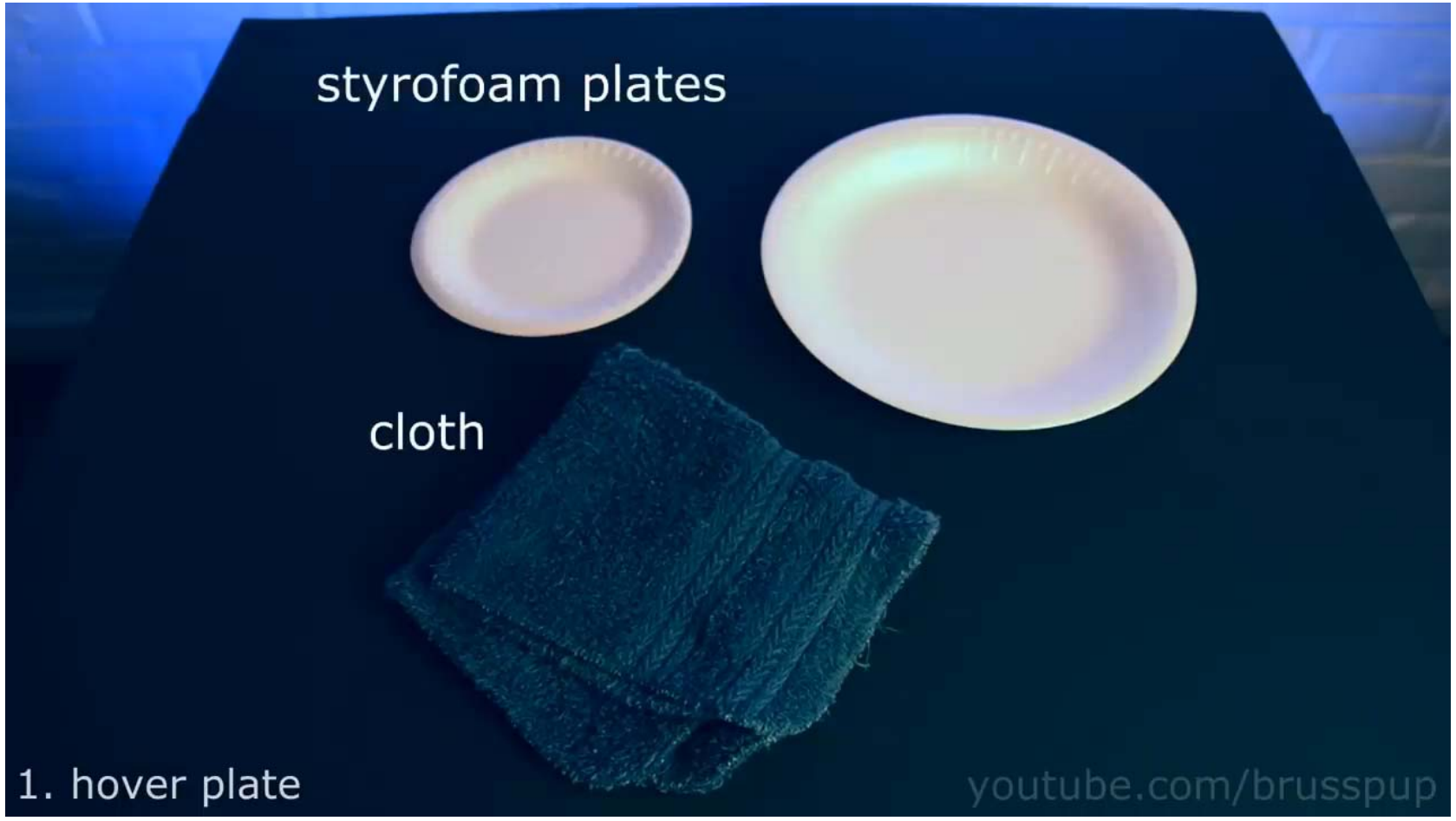
- Not visible, but impact and effect observable

1.1. Electric Charge - Introduction

In daily life

1.1. Electric Charge - Introduction

Experiments, in which we can observe the existence of electric charge (can be reproduce at home without any danger ;-)):



1.1. Electric Charge - Introduction

Electrostatics in nature:

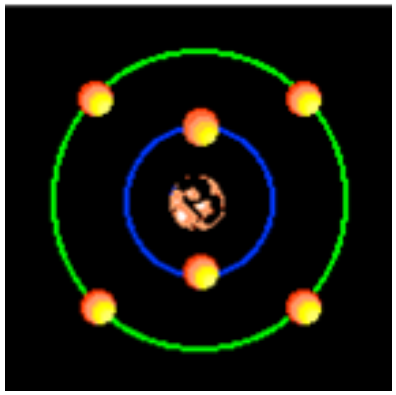
Lightning from thunderclouds = best known and most dramatic natural electrical phenomenon

Some other effects in nature:

- Electric eels use quasi-static electric fields for navigation purposes and protection against predators
- Bees and bumble bees feel electric charges from flowers
- Electrical discharges in clouds from volcanic eruptions

1.1. Electric Charge - Introduction

Electrical Structure of Matter: Electrical Charges – Atoms and Ions



Atoms consist of

- **a nucleus (protons and neutrons)**
- **and the respective number of electrons**

Atoms are netural:

number of electrons = number of protons

Electrons are bound to the nucleus by electric Coulomb forces.

- One or more electrons removed → positively charged ion
- One or more additional electron → negatively charged ion

1.1. Electric Charge

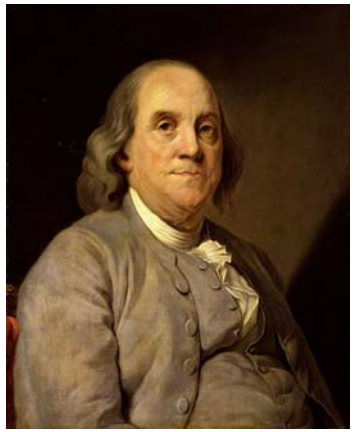
From experimental observation/from experience we can deduce the following fundamental properties: Charge is

- fundamental property of all elementary particles (comparable to mass)
- source for electro(magnetic) interaction (as one of the four fundamental interactions in physics, such as, e.g. gravitation)

i. Benjamin Franklin (1760): from „Experiments & observations on electricity“

➢ Found out that charge is like a particle;

There are two flavors/classes of charges: positive and negative



ii. Total charge in a closed system is conserved

➢ only pairwise generation or nihilation of positive and negative charge

1.1. Electric Charge

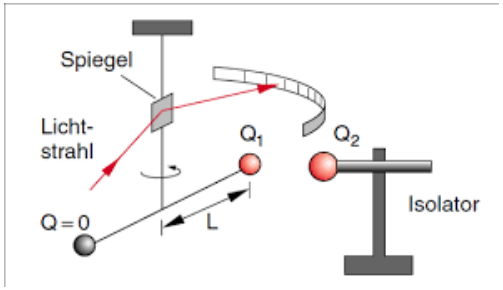
iii. C.A. Coulomb (1785):

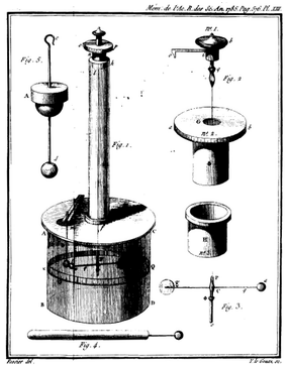
- ➢ Force between charges depending on location and distance (see 1.2.).
- Source of electro(magnetic) interaction (as one of the four fundamental interactions in physics, such as, e.g. gravitation)
- ➢ Like charges repel each other, unlike charges attract each other

B.t.w.: He also did research on

- friction in viscous fluids
- stiction friction
- electrostatic forces

(Coulomb's force = one of the fundamental forces in physics)





Coulomb's balance (left) and reproduction in „Deutsches Museum" Munich" (right)

1.1. Electric Charge

iv. Charge has a „radius of action“, i.e. charges are influenced by other charges, even if they are far away

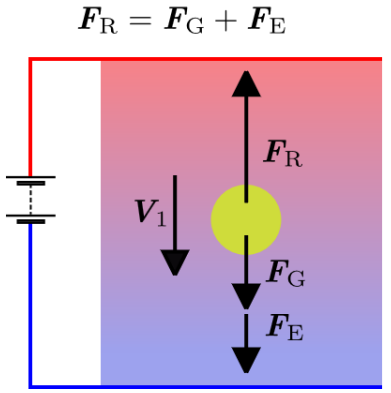
- ➢ M. Faraday (ca. 1830): effect can be described by a force field (see 1.3.)

v. Charge is quantized -> minimun charge quantum = elementary charge
Thomson (1897, emission of electrons by cathodes), Millikan (1910, measured charge carried by droplets of oil):

- ➢ Elementary charge: $q_{el} = e = 1{,}602e^{-19}$ C ; $[q_{el}]$= 1 C = 1 Coulomb = 1 As
- ➢ All separable charged particles carry a multiple of this elementary charge

cathode beam

Millikan experiment: working principle



1.1. Electric Charge

Elementary charge e_0 : $e_0 = 1{,}602... \cdot 10^{-19}\,C$

Physical unit of electric charges: Coulomb C,

$$[e_0] = [q] = [Q] = C = A \cdot s$$

$Q = Z \cdot e_0$ mit $Z \in \mathbb{Z}$

-		+
$Z \in \mathbb{Z}_-$	$Z = 0$	$Z \in \mathbb{N}, \mathbb{Z}_+$
$Q < 0C$	$Q = 0C$	$Q > 0C$
negative charges	neutral	positive charges

Exception: Quarks with charges of $\pm\frac{1}{3}e_0$ or $\pm\frac{2}{3}e_0$

1.1. Electric Charge

Properties of Electrical Charges

- Electron
  - Negative elementary charge q_e=-1.602 … · 10^{-19} C
  - Electron mass m_e = 9,109 383 … · 10^{-31} kg
  - Diameter < 10^{-20} m
  - Discovered in 1897 by J.J. Thompson

- Proton
  - Positive elementary charge q_p=+1.602 … · 10^{-19} C
  - Proton mass m_p = 1,672 621 … · 10^{-27} kg
  - Diameter ≈ 1.7 · 10^{-15} m = 1.7 fm
  - Discovered in 1919 by E. Rutherford

1.1. Electric Charge

Summary - Properties of Electrical Charges

- fundamental property of all elementary particles
- charge is like a particle
- there are two flavors/classes of charges: positive and negative
- Total charge in a closed system is conserved (pairwise generation)
- Force between charges depends on location and distance (Coulomb force)
- Like charges repel, unlike charges attract each other
- Charge has a „radius of action“ (force field = electric field)
- Charge is quantized = elementary charge

1.1. Electric Charge

The concept of point charges: What is is and why do we introduce it? What are the consequences?

We introduce and use in the following sections (until further notice) point charges, which are a theoretical concept that is

- charge has no geometrical extension
- location of charge is exactly determined/fixed

Advantages:

- Derivation of fundamental relations and equations simplified
- Nature of physics allows for generalization of simplified fundamental equations for more complex, real configurations (see 1.2. superposition principle and 1.6. continuous charge distributions)

Disadvantages:

Concept itself is „unrealistic“ and at most valid for charge particles with finite extension; leads to non-physical (theoretical) singularities in equations

- Photos of researchers, Coulomb-Charge balance, Milikan experiment: Wikipedia
- Millikan experiment: Dirk Hünninger - https://commons.wikimedia.org/wiki/File:ForcesInMilikanExperimentWithSinkingOilDrop.svg, CC BY 3.0,
- Videos:
  9 Awesome scientific tricks using static electricity, youtube
  https://www.youtube.com/watch?v=ViZNgU-Yt-Y
  Static Hair kid: youtube, https://www.youtube.com/watch?v=mC975kz_CmU