minelabs

The Coulomb Force

in collaboration with

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developed by

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imec

A. Electric Charge

From the main room, follow the orange path on the left. Talk to the scientist in the first room to get the charged particles you need for the following tasks.

Task A1 Place the particles on the ground and observe how they interact. Do they push or pull each other? Maybe they don't interact? Based on your observations, group the particles in the table.

Group I	Group II	Group III

Task A2 Based on the groups you defined above, complete the following table about the interactions between particles by putting **'attract'** →←, **'repel'** ←→ or **'no interaction'** ⏸ in the blank fields

Group Name	Interaction	Group Name
I		I
I		II
I		III
II		II
II		III
III		III

The property of the particles that causes the observed movement is called **electric charge.** The electric charge can be positive ⊕, neutral 0 or negative ⊖.

Task A3 Based on the information from the previous sentence, complete the table below by putting **'positive charge'**, **'negative charge'** or **'neutral charge'** into the empty fields with the corresponding groups from *Task A1*. You can deduce which particles are positive or negative by looking at their icons.

Group Name	Charge
Group I	
Group II	
Group III	

Did you know

You may have noticed that the particles not only move, but sometimes they also change or disappear in a flash of light. If you're curious, here is how:

- Some particles are unstable and will transform into different particles over time. When this happens, a weak boson appears. For example, a weak boson is produced when a neutron changes into a proton. This phenomenon is at basis of radioactive decay.
- Every particle has an anti-particle. When the particle meets its anti-particle, they disappear in a flash of light. This process is called 'annihilation'.

B. Visualizing the Force

Talk to the scientist in the second room to collect the items for the following exercises. Below, you can find a summary of the items you will obtain.

Task B1 You can play with the items and check that their behaviour matches the notes listed below.

- An electrically charged particle can move another charged particle from a distance. This force at a distance is called the **Coulomb force.** The first charged particle exerts the Coulomb force on the other particle. This also goes the other way: the other charged particle exerts a force on the first charged particle.
- The **'Force View Toggle'** item allows you to switch the setting for displaying the forces acting on particles.
- The force acting on the particle influences its velocity. When the force view mode is enabled and the force vector is visible, the particle's velocity changes. This change is called **acceleration.** The acceleration can cause the particle to speed up, slow down or change direction.
- When there is no longer any force acting on the particle (force view enabled, but no visible force vector), the velocity of the particle doesn't change. This means that it keeps being **stationary** or it continues moving with a **constant velocity** (depending on the initial velocity). In the game, the particles experience small friction, which means that they will stop after a while when there is no force acting on them.

C. Coulomb Force Equation

Task C1 Use the machines on the sides of the third room to. They allow you to experimenton how a change in the particle's position or charge affects the magnitude of the Coulomb force. Based on your observations, tick the true statements in the table below.

Option A	Option B
☐ The force is inversely proportional to the first charge $F \sim \frac{1}{q_1}$	☐ The force is directly proportional to the first charge $F \sim q_1$
☐ The force is inversely proportional to the second charge $F \sim \frac{1}{q_2}$	☐ The force is directly proportional to the second charge $F \sim q_2$
☐ The force is inversely proportional to the squared distance between charges $F \sim \frac{1}{r^2}$	☐ The force is directly proportional to the squared distance between charges $F \sim r^2$

Did you know

The Coulomb constant k is a value that scales the Coulomb force. It changes based on the medium between the charges (for example air). In vacuum, the Coulomb's constant is:

$$k = 8{,}99 \cdot 10^9 \, \frac{N \cdot m^2}{C^2}$$

Task C2 Based on the note about the Coulomb constant k and your choices from *Task C1*, select the correct equation that describes the Coulomb force.

	Equation
☐	$F = k \cdot q_1 \cdot q_2 \cdot r^2$
☐	$F = k \cdot \frac{q_1 \cdot q_2}{r^2}$
☐	$F = k \cdot \frac{r^2}{q_1 \cdot q_2}$
☐	$F = k \cdot \frac{1}{q_1 \cdot q_2 \cdot r^2}$

D. The Electric Field

Task D1 Observe the exhibition showing various electric fields in the fourth room of the Coulomb Force lesson and talk to the scientist. The scientist will give you some new items. With these items, you can perform experiments that will help you in the next task. Here is a summary on how to use the items.

- The **'Field Visualizer'** is an item that you can place on the ground to show the direction and strength of the electric field. It displays an arrow that represents the vector aligned to the electric field. The arrow gets bigger when the electric field is stronger.
- The **'Time Freeze Block'** is an item that you can place on the ground to stop the movement on nearby particles. You can used it combined with the **'Field Visualizer'** and particles to better study the interactions and the electric field.
- The **'Charged Point'** is an object in the game that can be placed on the ground, similar to particles. Its charge can be modified through interactions with protons and electrons (hold the particle item in your hand and interact with the Charged Point). Protons increase its charge and electrons decrease it. This tool allows you to conduct experiments aimed at examining how different charges interact with the electric field and particles.

Did you know

The Electric Field at a certain position is the Coulomb Force a particle with charge $q_2 = +1$ would observe if it is placed at that position:

$$\vec{F} = q_2\,\vec{E}$$

Task D2 Place a 'Time Freeze Block' and a few 'Charged Point' charges next to it. Use some 'Field visualizer' blocks to show the electric field. Adjust the charges of the 'Charged Point' and observe the changes in the electric field. Based on the observations select the *true* answers in the sentences below.

- The vectors of the electric field point *away* / *towards* negative charges.
- The vectors of the electric field point *away* / *towards* positive charges.
- The vectors of the electric field near a larger charge are *larger* / *smaller* than near a smaller charge.
- Close to a point charge the vector of the electric field is *larger* / *smaller* than far away from it.

Task D3 View the electric field in 3D and sketch the field below in 2D.

Type	Electric Field
Radial	
Dipole	
Electric Wire	
Uniform	

E. Macroscopic Charges

Until now, you have been working with charges at the elemental level, such as the electric charge of a few electrons. However, in everyday life, you encounter charges caused by hundreds of thousands of billions of electrons.

We represent an amount of charge by the quantity Q. The unit of charge is 'Coulomb', denoted by the symbol C.

The charge is quantized. This means that each charge is a multiple of 'the smallest charge that exists'. The electron and proton have the smallest possible charge:

a proton has a charge

$$Q_{\text{proton}} = e \ = +1.60 \cdot 10^{-19}\, C$$

an electron has a charge

$$Q_{\text{electron}} = -e \ = \ -1.60 \cdot 10^{-19}\, C$$

A macroscopic object can become charged when it absorbs electrons from another object. It can also donate or give electrons to another object. For example, if you rub glass with a cloth, electrons move from the glass to the cloth. This makes the glass positively charged and the cloth negatively charged. The charge that the glass receives is of the order of $10^{-6}C$, we call this microcoulomb (μC).

$$1\ \mu C = \ 10^{-6} C$$

Task E1 Fill in the missing parts of the equation below and decide if it is *a lot* or *a few* electrons.

Suppose the cloth has received a charge of $-1\ \mu C$. You can calculate the number of electrons that have jumped from the glass to the cloth by dividing the charge given to the cloth by the charge of one electron

$$n_{\text{electrons}} = \frac{Q_{\text{cloth}}}{Q_{\text{electron}}} = \frac{\qquad\qquad\qquad}{} = \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots,$$

That are *a lot of* / *a few* electrons!