

Electrostatic Force And The Electric Field

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Electric Charge

Experiments show that there are two types of charge, positive and negative.

Like charges repel and unlike charges attract.

Generally, matter has equal amount of positive charge and negative charge.

When objects have net positive/negative charge, then there is interaction by the electrostatic force.

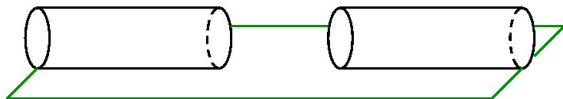
Objects become *electrically charged* when negative charge is transferred from one object to another.

Glass Rods And Silk

Consider (electrically neutral) two glass rods.



The rods neither attract nor repel each other.
The rods are both rubbed with silk.



Glass Rods And Silk

The rods become positively charged, and hence repel each other.



How did the glass rods become positively charged?

Where do the negative charges (electrons) transfer to?

The silk gains negative charges and hence ends up with a net negative charge.

The glass rods lose negative charge (an equal amount to the negative charges gained by the silk). The rods are left with a net positive charge.

Electric Charge

The fundamental unit of charge e is 1.60×10^{-19} C.

The proton has a charge of $+e$; the electron has a charge of $-e$.

All charge quantities occur in discrete quantities - multiples of e .

Since an electron has a charge of -1.60×10^{-19} C, it would take

$$\frac{1}{e} = \frac{1}{1.60 \times 10^{-19}} = 6.25 \times 10^{18}$$

electrons to make up a charge of -1.00 C.

How do charges interact?

Coulomb's Law

The magnitude of the electrostatic force, F , between two charges q_1 and q_2 , a distance r from one another, is

$$F_{12} = k_e \frac{|q_1||q_2|}{r^2}$$

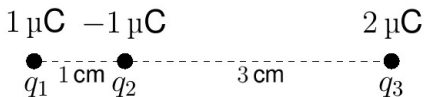
The proportionality constant k_e is the Coulomb constant.

$$k_e = \frac{1}{4\pi\epsilon_0} \approx 9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

The SI unit of charge is the Coulomb, C.

Superposition Theorem

Charges lie in a vacuum on a line, as shown below. Find the force on the $1\ \mu\text{C}$ charge (i.e. the force on q_1).

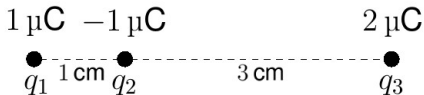


The total force on q_1 depends on the contributions of the force on q_1 due to q_2 and the force on q_1 due to q_3 .

This is called the principle of superposition, which applies to Coulomb's Law.

Superposition Theorem

Charges lie in a vacuum on a line, as shown below. Find the force on the $1 \mu\text{C}$ charge (i.e. the force on q_1).



The total force F on q_1 is given by

$$\mathbf{F} = \mathbf{F}_{21} + \mathbf{F}_{31}$$

Superposition Theorem

In which direction are each of the forces on q_1 ?



The magnitude of the total force F on q_1 is given by

$$\begin{aligned} F &= F_{21} - F_{31} \\ &= k_e \frac{(1 \times 10^{-6}) \times (1 \times 10^{-6})}{(0.01)^2} - k_e \frac{(1 \times 10^{-6}) \times (2 \times 10^{-6})}{(0.04)^2} \end{aligned}$$

Action At A Distance

Contact forces, as the name implies, are forces between two or more objects that are in contact with one another.

Gravity is an example of a force that acts on an object whether it is in contact with another object or not (an example is the gravitational force on the moon, due to the earth).

Newton called this "action at a distance."

Michael Faraday introduced the concept of a *field* - an invisible influence spreading out over all space.

The sun creates a gravitational field, due to its mass. The earth, which has mass, interacts with the sun's gravitational field (not directly with the sun).

Gravitational And Electric Field

NII states that a net force on an object results in an acceleration. From a gravitational point of view, a mass m experiences a weight, \mathbf{W} , in the presence of a gravitational field, \mathbf{g} .

$$\mathbf{W} = m\mathbf{g}$$

(Remember, this is valid for objects near the earth's surface.) An electric field, \mathbf{E} , exists in the region around a charge. Any other charge within the field experiences a force due to the electric field.

$$\mathbf{F} = q\mathbf{E}$$

Definition Of The Electric Field

The electric field \mathbf{E} at a point is defined as the force per unit charge experienced by a *stationary* charge q , which is situated at that point.

$$\mathbf{E} = \frac{\mathbf{F}}{q}$$

The SI unit for the electric field is N C^{-1} .

Note:

- the charge q is not the charge that creates the field - it is a test charge situated at the point where the electric field is being measured/calculated.
- the charge q must be stationary, since moving charges lead to a magnetic interaction.
- Conceptually, the charge q (sometimes called the test charge q_0) is very small to not affect the charge creating the electric field \mathbf{E} .

Electric Field

The electric field is a vector quantity, so it has direction!

The direction of the electric field is found using a *positive* test charge.

For a positive test charge q_0 , the electric field \mathbf{E} at a point is given by

$$\mathbf{E} = \frac{\mathbf{F}}{q_0}$$

The electric field, at the point where q_0 is situated, points in the same direction as the force \mathbf{F} .

Electric Field

Consider a charge Q at some point in a vacuum. Find the electric field at some particular point in the vicinity of Q .

Place a positive test charge q_0 at the point where the electric field is to be found.



What is the direction of the force \mathbf{F} acting on q_0 ?

Electric Field

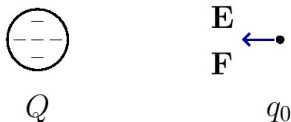
The direction of the force acting on q_0 depends on the sign of Q . When Q is a positive charge, the force \mathbf{F} on the test charge q_0 must point away from Q , since like charges repel.



The electric field points in the same direction as the force (for a positive test charge), and therefore points away from Q .

Electric Field

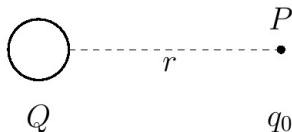
When Q is a negative charge, the force \mathbf{F} on the test charge q_0 must point towards Q , since unlike charges attract.



The electric field points in the same direction as the force (for a positive test charge), and therefore points towards Q .

Electrostatic Force And The Electric Field

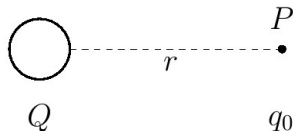
Consider, again, a point charge Q . Find the electric field at a point P , at a distance r away from Q .



The force that the test charge q_0 experiences due to Q is given by

$$\mathbf{F} = k_e \frac{Qq_0}{r^2} \hat{\mathbf{r}}$$

Electrostatic Force And The Electric Field



The electric field at P is

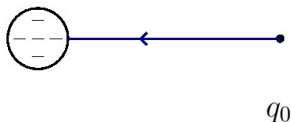
$$\mathbf{E} = \frac{\mathbf{F}}{q_0} = k_e \frac{1}{q_0} \frac{Qq_0}{r^2} \hat{\mathbf{r}} = k_e \frac{Q}{r^2} \hat{\mathbf{r}}$$

Note that the electric field \mathbf{E} depends only on the source of the field, namely Q .

An electric field exists at P whether a test charge is placed there or not.

Visualising The Electric Field

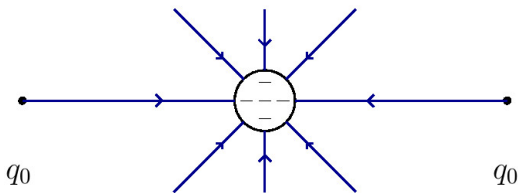
Faraday introduced electric field lines to help visualise the electric field. For a positive test charge near a negative charge, the electric field points towards the negative charge (since there is a force of attraction).



What is the direction of the electric at some other point close to the negative charge?

Electric Field Lines

By placing test charges at various points around the negative charge, the electric field created by the negative charge can be seen.



The direction of the electric field is tangent to the electric field line at each point. (Electric field lines need not be straight lines).

The number of field lines per unit area (perpendicular to the field) is proportional to the strength of the field.