

Charging objects and the force between charges

AP Physics 2 (algebra-based) · Lesson

Quick answer: Electric charge comes in positive and negative kinds, is conserved and is quantised in units of $e = 1.60 \times 10^{-19}$ C. Objects charge by friction, conduction or induction. Charges exert forces of size $F = k|q_1q_2|/r^2$, attractive for unlike charges and repulsive for like charges.

Level: AP Physics 2 (algebra-based) · **Curriculum:** AP P2 Unit 10

What is electric charge?

Electric charge is a property of matter that makes some particles push or pull on each other. There are two kinds. Protons carry positive charge, electrons carry negative charge, and neutrons carry none. Most objects are neutral because they hold equal numbers of protons and electrons. Charging an object means moving electrons on or off it, because protons stay locked in the nucleus.

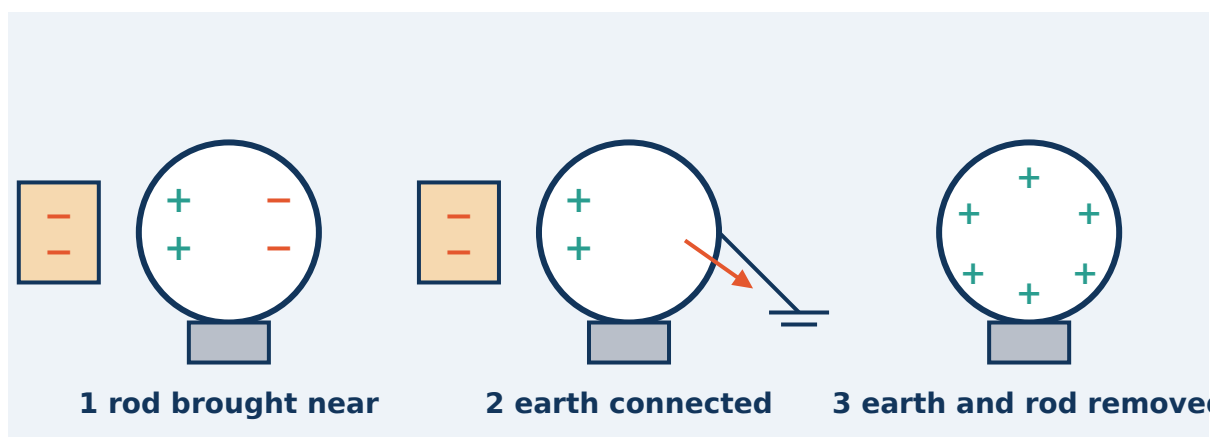
Definition

Charge Q is measured in coulombs (C). It is **quantised**: every charge is a whole-number multiple of the elementary charge $e = 1.60 \times 10^{-19}$ C, so $Q = Ne$. It is also **conserved**: the total charge of an isolated system never changes.

How do objects become charged?

Rubbing a plastic ruler with wool moves electrons from the wool to the ruler. The ruler gains a negative charge and the wool gains the same amount of positive charge, so the total stays zero. This is charging by friction. Touching a charged metal object to another conductor lets electrons flow between them, which is charging by conduction. A third method needs no contact at all.

In a conductor, electrons are free to move. In an insulator they stay close to their own atoms. If a negative rod is brought near a neutral metal sphere, electrons move away from the rod and leave the near side positive. Connecting the sphere to the earth lets those electrons escape. Removing the earth first and then the rod leaves a net positive charge spread over the sphere. This is charging by **induction**.



Charging by induction. The sphere never touches the rod, yet it ends with the opposite charge.

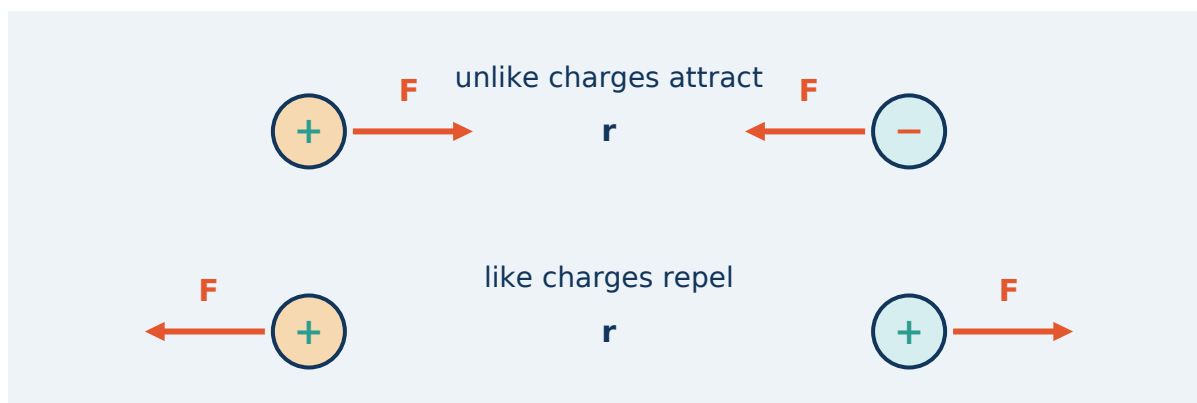
How does Coulomb's law work?

Charles Coulomb measured the force between small charged spheres and found that it grows with the product of the charges and falls with the square of their separation. Like charges repel, unlike charges attract, and by Newton's third law the two forces are equal in size and opposite in direction.

Formula

$$F = k|q_1q_2| / r^2$$

F is the force on each charge (N), q_1 and q_2 are the charges (C), r is the distance between their centres (m) and $k = 8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$. Use absolute values for the size, then decide the direction from the signs.



The two forces in each pair are equal in size and opposite in direction.

Worked example

Chiamaka holds a $+3.0 \mu\text{C}$ sphere 0.30 m from a $-5.0 \mu\text{C}$ sphere. Find the force.

$F = (8.99 \times 10^9)(3.0 \times 10^{-6})(5.0 \times 10^{-6}) / (0.30)^2 = 0.1349 / 0.090 = \mathbf{1.5 \text{ N}}$, attractive on both spheres.

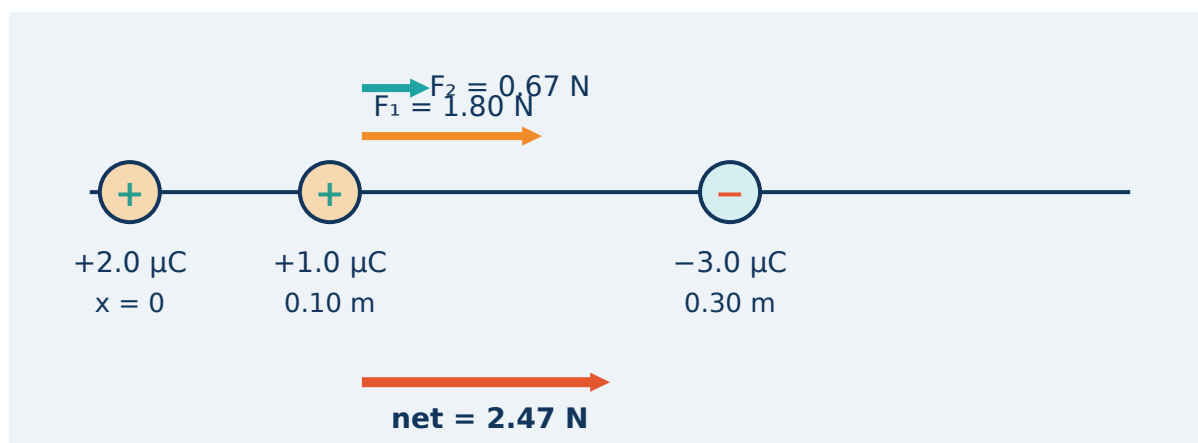
Change in distance r	Force multiplier
half as far ($r/2$)	$\times 4$

Change in distance r	Force multiplier
unchanged	$\times 1$
twice as far ($2r$)	$\times \frac{1}{4}$
three times as far ($3r$)	$\times \frac{1}{9}$
four times as far ($4r$)	$\times \frac{1}{16}$

The table shows the inverse-square law at work. Moving a charge twice as far makes the force four times smaller, which is why static effects fade quickly with distance.

How do you add forces from several charges?

Electric forces obey superposition. The net force on a charge is the vector sum of the forces from each other charge, found as if the others were absent. On a straight line, give each force a sign for its direction and add.



Forces on the middle charge add as vectors. Here both point to the right, so the sizes add.

Worked example

A +2.0 μC charge sits at $x = 0$ and a -3.0 μC charge at $x = 0.30$ m. Find the force on a +1.0 μC charge at $x = 0.10$ m.

From the first charge (repulsion, towards $+x$): $F_1 = (8.99 \times 10^9)(2.0 \times 10^{-6})(1.0 \times 10^{-6}) / (0.10)^2 = 1.80$ N. From the second (attraction, also towards $+x$, distance 0.20 m): $F_2 = (8.99 \times 10^9)(3.0 \times 10^{-6})(1.0 \times 10^{-6}) / (0.20)^2 = 0.67$ N. Net force = $1.80 + 0.67 = \mathbf{2.5}$ N towards $+x$.

Common mistake

Do not put the sign of a charge into the formula and then call a negative answer a repulsion by accident. Calculate the size with absolute values, then decide attract or repel from the signs. Also convert μC to C and cm to m before substituting.

Lina's tip

Draw the charges on a line, add a small arrow for each force on your chosen charge, and say attract or repel out loud before you calculate anything. Then you know which way each

number points.

Key points to remember

- Elementary charge $e = 1.60 \times 10^{-19} \text{ C}$; total charge is conserved
- Coulomb's law: $F = k|q_1q_2|/r^2$, with $k = 8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$
- Doubling the distance cuts the force to one quarter (inverse square)
- Forces from several charges add as vectors (superposition)
- Induction charges an object with no contact: it ends with the opposite sign to the rod

Charging objects and the force between charges: frequently asked questions

What does conservation of charge mean?

Charge is never created or destroyed, only moved from one object to another. When a ruler gains 8.0 nC by friction, the wool gains exactly +8.0 nC, so the total remains zero.

Why does a charged comb attract small pieces of neutral paper?

The comb polarises the paper by shifting charge slightly inside each atom. The opposite charge in the paper is nearer the comb than the like charge, so the attraction beats the repulsion.

How is Coulomb's law similar to Newton's law of gravitation?

Both forces fall with the square of the distance and rise with the product of two properties, charge or mass. The electric force can attract or repel, while gravity only attracts.

What is the difference between charging by conduction and by induction?

In conduction the objects touch and the second object gets the same sign of charge. In induction there is no contact, and the object ends with the opposite sign to the charged rod.

Why must charges be in coulombs and distances in metres?

The constant $k = 8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$ is defined with SI units. Using μC or cm without conversion gives answers wrong by large powers of ten.