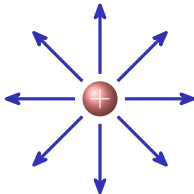


Electric Force, Field, and Potential

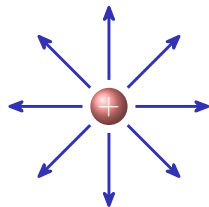
AP Physics 2 ■ Unit 10

AP Physics 2



What we will cover

- 1 Electric charge and Coulomb's law
- 2 The process of charging
- 3 Electric fields and field lines
- 4 Electric potential energy
- 5 Electric potential (voltage)
- 6 Capacitors
- 7 Conservation of electric energy





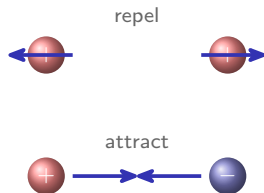
Electric charge and Coulomb's law

Electric charge comes in two kinds; it is **conserved** and **quantized** ($q = ne$).

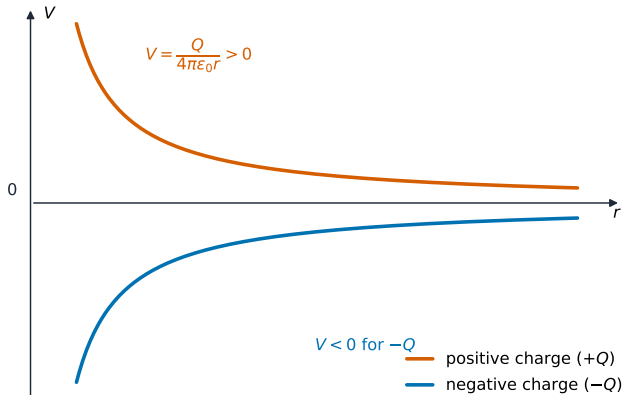
Coulomb's law

$$F = k \frac{q_1 q_2}{r^2}$$

An **inverse-square** law – double r , quarter the force.



The potential near a point charge varies as $1/r$

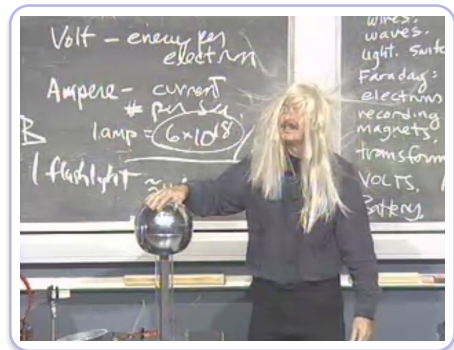


The potential near a point charge varies as $1/r$



The process of charging

- a **conductor** lets charge move; an **insulator** holds it fixed
- **friction** – electrons scraped across
- **conduction** – touch: **same** sign
- **induction** – near + ground: **opposite** sign



Static charge can be stored and transferred

Permittivity, and the three ways to charge something

the constant k

$k = \frac{1}{4\pi\epsilon_0}$ – it hides a property of the medium, the **permittivity**

free space

has the fixed value $\epsilon_0 = 8.85 \times 10^{-12}$ F/m; a material's is larger

the consequence

the same two charges attract **less strongly** in water than in air

friction

rubbing transfers electrons between two materials

conduction

contact with a charged body – the result has the **same** sign

induction

a nearby charge **rearranges** charge in a neutral object, which can then be grounded and left with the **opposite** sign

Induction needs **no contact**. That is what makes it the one method that can charge an object without touching it, and it gives the opposite sign.



Electric fields and field lines

The **electric field** is force per unit positive charge:

Field of a point charge

$$\vec{E} = \frac{\vec{F}}{q}, \quad E = k \frac{q}{r^2}$$

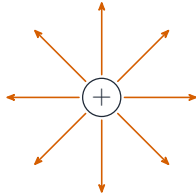
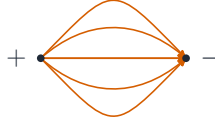
- lines leave +, enter -; denser = stronger
- a **uniform field** sits between parallel plates



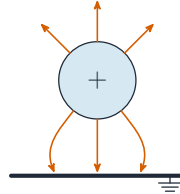
Charges create electric fields in space

Electric field-line patterns for parallel plates

a) parallel plates (uniform field) b) dipole (+ and -)



c) point charge (radial)



d) sphere above earthed plate

Electric field-line patterns for parallel plates, a dipole, and a point charge



Energy, potential, and voltage

Potential energy of a pair

$$U = k \frac{q_1 q_2}{r}$$

Like charges: $U > 0$ (fly apart). Unlike: $U < 0$ (bound). Note r , not r^2 .

Potential (voltage)

$$V = \frac{U}{q} = k \frac{q}{r}$$

A **scalar** – just add the numbers.

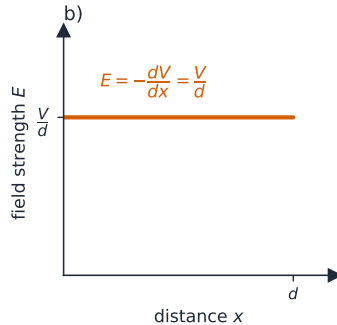
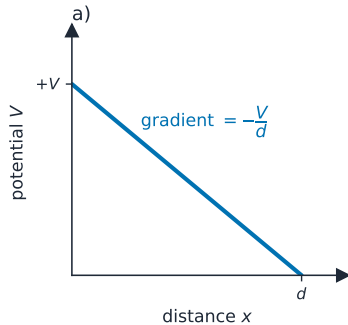
The field points **downhill** on the potential – toward lower V .

Between parallel plates

$$E = \frac{\Delta V}{d}, \quad W = q \Delta V$$

100 V over 0.02 m: $E = 5000 \text{ V/m}$.

Electric Potential Energy



In a uniform field the potential falls steadily with distance, so E relates to V



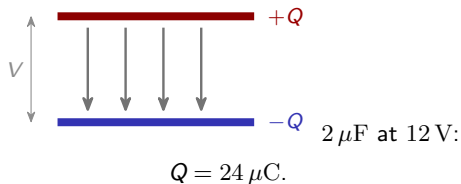
Capacitors

A **capacitor** stores charge on two plates ($+Q$ and $-Q$).

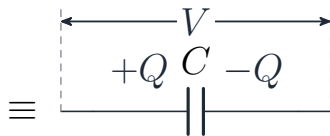
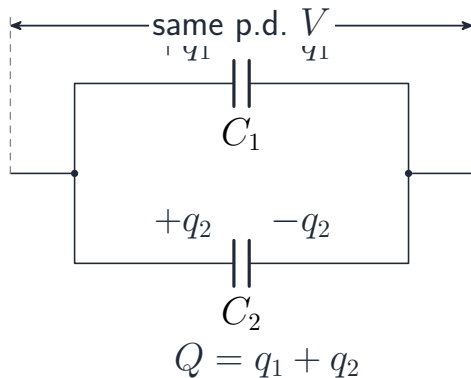
Capacitance and stored energy

$$C = \frac{Q}{V} = \frac{\epsilon_0 A}{d}, \quad U = \frac{1}{2} CV^2$$

Bigger plates or a smaller gap $\Rightarrow$ more capacitance. Energy $\propto V^2$.



Capacitors in parallel share the same p.d



$$C = C_1 + C_2$$

Capacitors in parallel share the same p.d., and their charges add



Conservation of electric energy

A charge **accelerated** through a potential difference turns field work into kinetic energy:

Accelerating a charge

$$\Delta KE = q \Delta V = \frac{1}{2}mv^2$$

A capacitor stores $\frac{1}{2}CV^2$, then hands it back – energy borrowed, not lost.

Worked example

An electron through 200 V:

$$\begin{aligned}\Delta KE &= (1.6 \times 10^{-19})(200) \\ &= 3.2 \times 10^{-17} \text{ J}\end{aligned}$$

$$v = \sqrt{\frac{2\Delta KE}{m}} \approx 8.4 \times 10^6 \text{ m/s}$$

Exam tips

- **Coulomb's law** and the point-charge field are **inverse-square** – doubling the separation makes the force (or field) four times smaller.
- Use magnitudes for the size of a force and decide direction from the **signs**; the field points the way a **positive** test charge would move.
- **Potential (V) is a scalar so potentials from several charges simply add; the field (E) is a vector** and must be added by direction.
- For a charge accelerated through a voltage use energy conservation $qV = \frac{1}{2}mv^2$.
- Capacitor relations: $C = Q/V$ (capacitance is fixed by geometry) and energy $U = \frac{1}{2}CV^2$.



Unit 10 – key takeaways

1

Coulomb

$F = kq_1q_2/r^2$; like repel, unlike attract

2

Field

$E = F/q = kq/r^2$; lines leave +, enter –

3

Potential

$V = U/q = kq/r$, a scalar; $E = \Delta V/d$

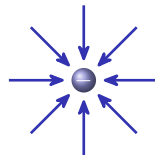
4

Capacitor

$C = Q/V$; stores $U = \frac{1}{2}CV^2$

Check yourself

- 1 Double the distance between two charges – what happens to the force?
- 2 Which way do field lines point around a negative charge?
- 3 Is electric potential a scalar or a vector?
- 4 Double a capacitor's voltage – what happens to its stored energy?



Answers 1. it drops to one quarter 2. inward (toward the charge) 3. a scalar 4. it quadruples