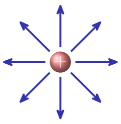
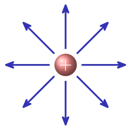
Electric Force, Field, and Potential

AP Physics 2 ▪ Unit 10

AP Physics 2



What we will cover



1 Charge & Coulomb

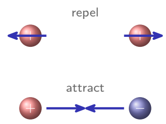
Electric charge and Coulomb's law

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

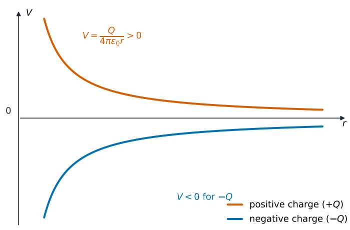
Coulomb's law

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

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



The potential near a point charge varies as 1/r

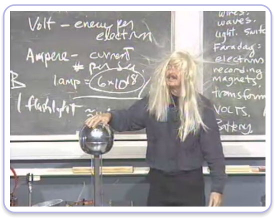


The potential near a point charge varies as $1/r$

2 Charging

The process of charging

- a **conductor** 导体 lets charge move; an **insulator** 绝缘体 holds it fixed
- **friction** 摩擦起电 – electrons scraped across
- **conduction** 传导 – touch: same sign
- **induction** 感应起电 – near + ground: opposite sign



Static charge can be stored and transferred

Permittivity, and the three ways to charge something

the constant k	$k = \frac{1}{4\pi\varepsilon_0}$ – it hides a property of the medium, the **permittivity** 介电常数
free space	has the fixed value $\varepsilon_0 = 8.85 \times 10^{-12}$ 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 感应起电	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.

3 Fields

Electric fields and field lines

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

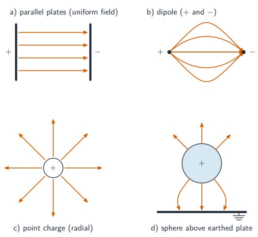
Field of a point charge

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

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

Charges create electric fields in space

Electric field-line patterns for parallel plates



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

4 Potential energy & potential

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.

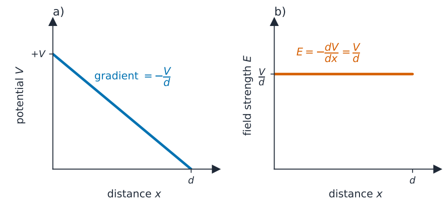
The field points downhill on the potential – toward lower V.

Between parallel plates

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

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

Electric Potential Energy



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

5 Capacitors

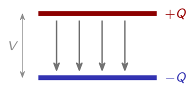
Capacitors

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

Capacitance and stored energy

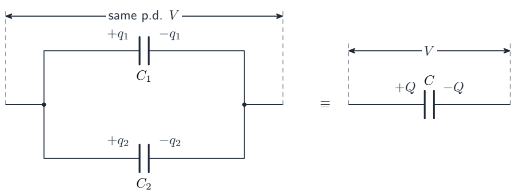
$$C = \frac{Q}{V} = \frac{\varepsilon_0 A}{d}, \qquad U = \tfrac{1}{2} C V^2$$

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



$2\,\mu\mathrm{F}$ at $12\,\mathrm{V}$: $Q = 24\,\mu\mathrm{C}$.

Capacitors in parallel share the same p.d



$Q = q_1 + q_2$ $\qquad$ $C = C_1 + C_2$

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

6 Conservation

Conservation of electric energy

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

Accelerating a charge

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

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

Worked example

An electron through $200\,\mathrm{V}$:

$$\Delta KE = (1.6\times10^{-19})(200)$$

$$= 3.2\times10^{-17}\,\mathrm{J}$$

$$v = \sqrt{\tfrac{2\,\Delta KE}{m}} \approx 8.4\times10^{6}\,\mathrm{m/s}$$

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 $U = \frac{1}{2}CV^2$.

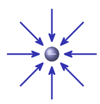
7 Recap

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