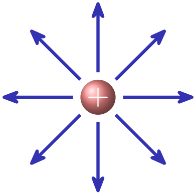
Electric Force, Field, and Potential

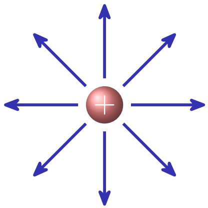
AP Physics 2 ▪ Unit 10

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



1 Charge & Coulomb

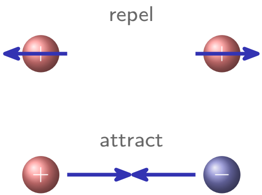
Electric charge and Coulomb's law

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

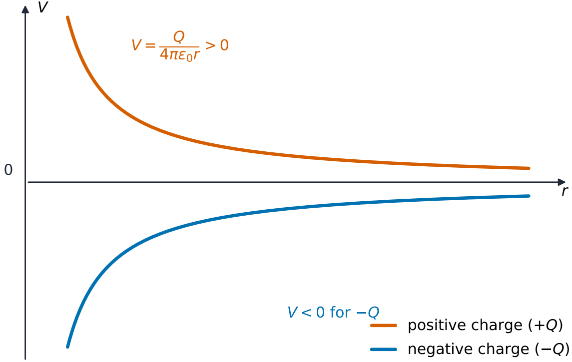
Coulomb's law

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

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



The potential near a point charge varies as 1/r

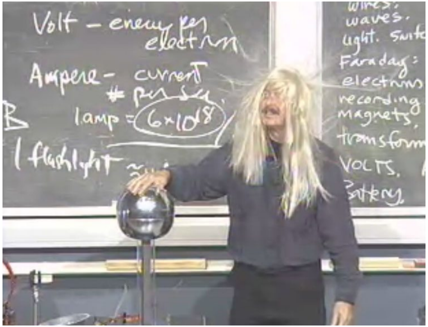


The potential near a point charge varies as 1/r

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	$k = \dfrac{1}{4\pi\varepsilon_0}$ – 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:

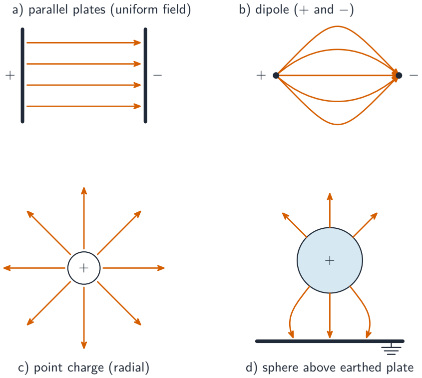
Field of a point charge

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

- 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.

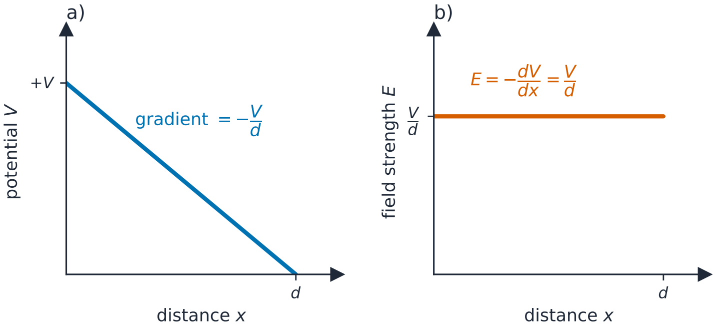
The field points downhill on the potential – toward lower V.

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

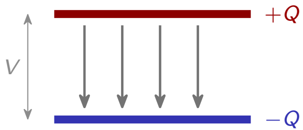
Capacitors

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

Capacitance and stored energy

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

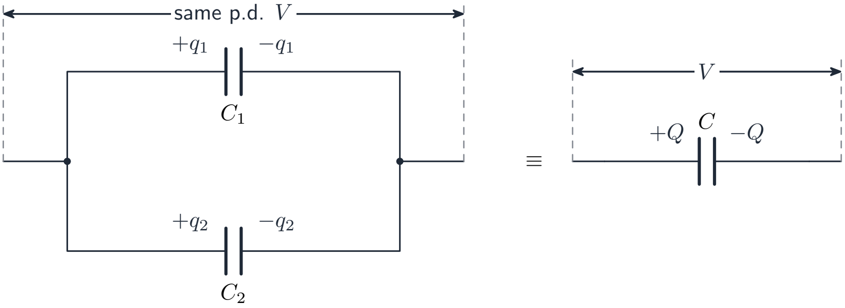
> Bigger plates or a smaller gap $\Rightarrow$ more capacitance. Energy $\propto V^2$.



$2\,\mu\mathrm{F}$ at $12\,\mathrm{V}$:

$Q = 24\,\mu\mathrm{C}.$

Capacitors in parallel share the same p.d



$Q = q_1 + q_2$

$C = C_1 + C_2$

> 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 $200\,\mathrm{V}$:

$$\Delta KE = (1.6 \times 10^{-19})(200)$$

$$= 3.2 \times 10^{-17}\,\mathrm{J}$$

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

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

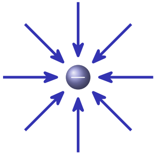
$V = U/q = kq/r$, a scalar; $E = \Delta V/d$

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