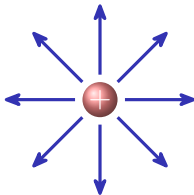


Electric Charges, Fields, & Gauss's Law

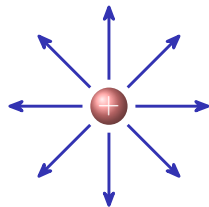
AP Physics C: E&M ■ Unit 8

AP Physics C: E&M



What we will cover

- 1 Charge and Coulomb's law
- 2 The process of charging
- 3 Electric fields and field lines
- 4 Fields of charge distributions
- 5 Electric flux
- 6 Gauss's law



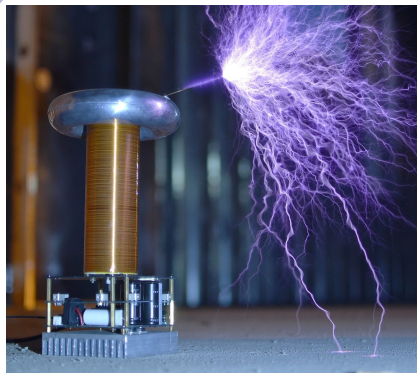
Charge and Coulomb's law

Charge 电荷 is **quantized** 量子化 ($q = ne$)
and **conserved** 守恒:

A vector, inverse-square force

$$\vec{F} = k \frac{q_1 q_2}{r^2} \hat{r}, \quad k = \frac{1}{4\pi\epsilon_0}$$

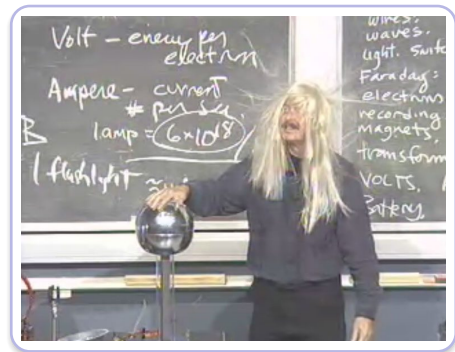
Forces from many charges add by **superposition** 叠加原理 – the vector sum.



tesla Coil Discharge

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 rubbed across
- **conduction** 传导起电 – touch: **same** sign
- **induction** 感应起电 – near + **ground** 接地: **opposite** sign



van De Graaff

Electric fields and field lines

The **electric field** 电场 is force per unit positive **test charge** 检验电荷:

Field of a point charge

$$\vec{E} = \frac{\vec{F}}{q_0}, \quad \vec{E} = k \frac{q}{r^2} \hat{r}$$

- lines leave +, enter -; denser = stronger
- lines never cross; $\vec{F} = q\vec{E}$ on any charge



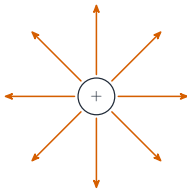
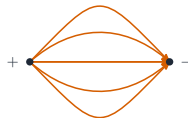
dipole field

Electric fields and field lines

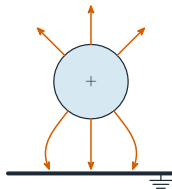
a) parallel plates (uniform field)



b) dipole (+ and -)



c) point charge (radial)



d) sphere above earthed plate

Fields of charge distributions

Split a spread-out charge into pieces dq and **integrate**:

Continuous superposition

$$\vec{E} = \int k \frac{dq}{r^2} \hat{r}$$

Densities 电荷密度: $\lambda = \frac{dq}{d\ell}$, $\sigma = \frac{dq}{dA}$, $\rho = \frac{dq}{dV}$.

Use **symmetry** 对称性 to cancel components.

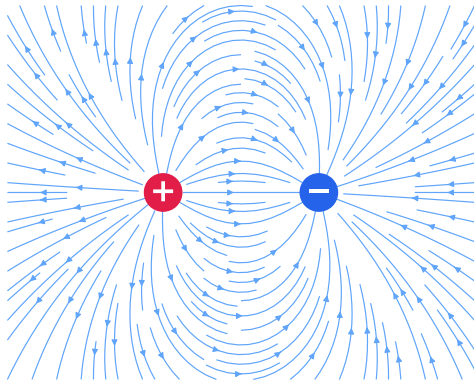
Two standard results

$$\text{ring (axis)} : E = \frac{kQx}{(x^2 + a^2)^{3/2}}$$

$$\text{infinite line} : E = \frac{2k\lambda}{r}$$

Point $\sim 1/r^2$, line $\sim 1/r$, sheet $\sim$ uniform.

Fields of charge distributions



Electric flux

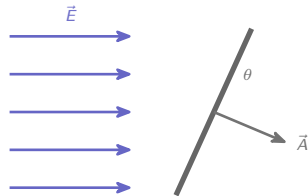
Electric flux 电通量 counts the field lines through a surface:

Uniform, then general

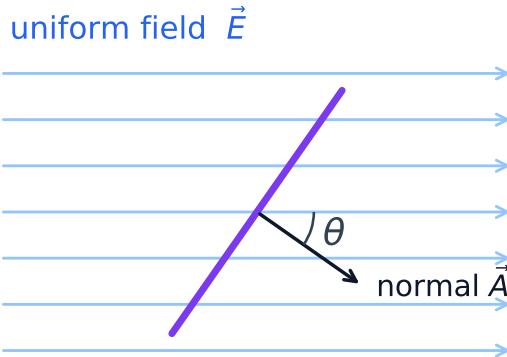
$$\Phi_E = \vec{E} \cdot \vec{A} = EA \cos \theta$$

$$\Phi_E = \oint \vec{E} \cdot d\vec{A}$$

Largest when $\vec{E} \perp$ the surface ($\theta = 0$); zero when parallel.



Electric flux



$$\Phi_E = \vec{E} \cdot \vec{A} = EA \cos \theta$$

Gauss's law

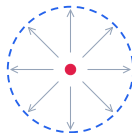
One of Maxwell's equations – flux out of a closed surface reveals the charge inside:

Gauss's law

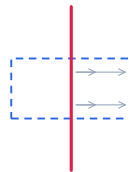
$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{enc}}{\epsilon_0}$$

Choose a **Gaussian surface** 高斯面 matching the **symmetry** so E comes out of the integral.

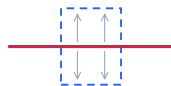
Spherical
(point / sphere)



Cylindrical
(line / cylinder)



Planar
(sheet / pillbox)



Sphere, cylinder, or pillbox – matched to the symmetry.

Unit 8 – key takeaways

1

Coulomb

$$\vec{F} = kq_1q_2\hat{r}/r^2; \text{ superpose vectors}$$

2

Field

$$\vec{E} = kq\hat{r}/r^2; \text{ integrate } \int k dq\hat{r}/r^2 \text{ for distributions}$$

3

Flux

$$\Phi_E = \oint \vec{E} \cdot d\vec{A}; \text{ lines through a surface}$$

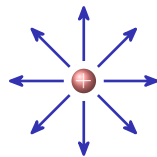
4

Gauss

$$\oint \vec{E} \cdot d\vec{A} = q_{enc}/\epsilon_0; \text{ use symmetry}$$

Check yourself

- 1 Do charges outside a closed surface contribute net flux through it?
- 2 What integral gives the field of a continuous charge distribution?
- 3 When is the flux through a flat surface zero?
- 4 Where does all excess charge sit on a conductor?



Answers 1. no (zero net) 2. $\int k dq \hat{r}/r^2$ 3. when $\vec{E}$ is parallel to it 4. on its outer surface