Chapter 22 Electric Fields

Chap. 22-1 The Electric Field
Chap. 22-2 The Electric Field Due to a Charged Particle
Chap. 22-3 The Electric Field Due to a Dipole
Chap. 22-4 The Electric Field Due to a Line of Charge
Chap. 22-5 The Electric Field Due to a Charged Disk
Chap. 22-6 A Point Charge in an Electric Field
Chap. 22-7 A Dipole in an Electric Field

Chap. 22-1 The Electric Field

How does particle 1 “know” of the presence of particle 2? That is, since the particles do not touch, how can particle 2 push on particle 1—how can ther e be such an action at a distance?

Chap. 22-1 The Electric Field

두 전하 q_1과 q_2가 있을 때, $q_2(q_1)$가 어떻게 $q_1(q_2)$이 있음을 알아서 힘을 받게 되는가?

$q_1(q_2)$이 주위의 공간에 전기장(벡터)을 만들고,
$q_2(q_1)$는 이 전기장과 작용하게 되어 힘을 받는다.

q_1 이 움직이면 q_2 가 받는 힘도 즉시 달라지는가?

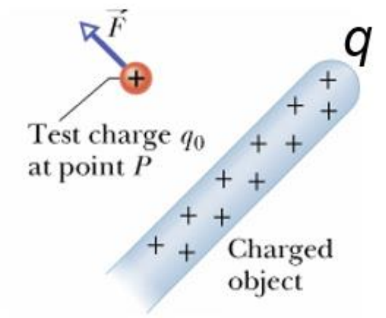
q_1 의 움직임에 관한 정보는 전자기파로서 빛의 속도로 전파되며,
그 것이 q_2 에 이를 때 비로소 q_2 가 받는 힘도 달라진다.

Chap. 22-1 The Electric Field

Electric Field (전기장)

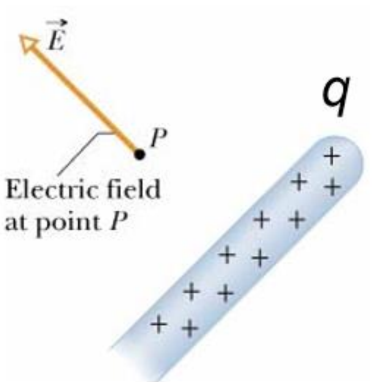
전하 q_0가 받는 정전기력 F 를 전하량으로 나눈 벡터 E

$$\vec{E} = \frac{\vec{F}}{q_o} \quad [\mathrm{N/C}]$$



몇 가지 상황에서 전기장의 세기

상황	전기장 (N/C)
우라늄핵 표면	3×10^{21}
수소원자 속, 보어 반지름 5.29×10^{-11} m 인 곳	5×10^{11}
대기중 방전이 일어나는 조건	3×10^{6}
복사기의 전하를 띤 원통 근처	10^{5}
전하를 띤 플라스틱 빗	10^{3}
대기 저층부	10^{2}
가전제품 구리도선 속	10^{-2}

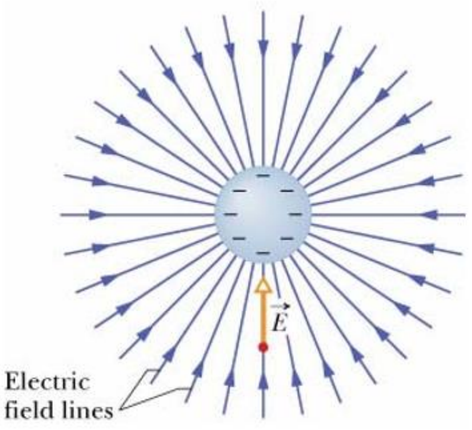


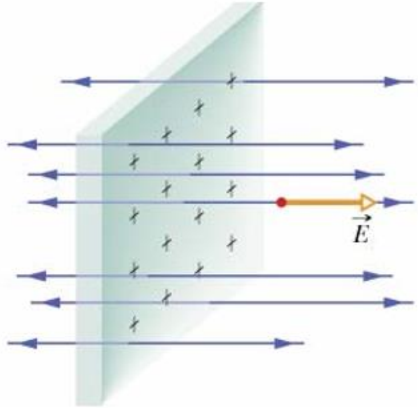
Electric Field Lines(전기장선)

1) 전기장의 특성을 그림으로 이해할 수 있게 도입한 개념

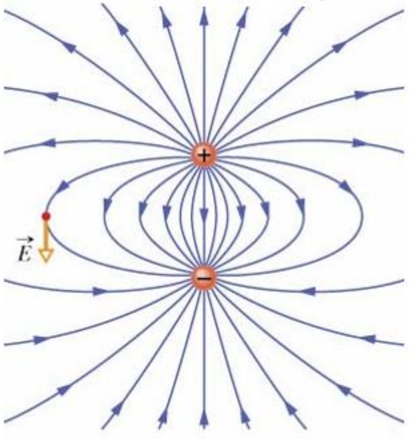
2) 전기장선은 양전하에서 뻗어 나와 음전하로 들어간다.

① 전기장의 방향 = 전기장선의 접선방향
② 전기장의 세기 = 전기장선의 밀도에 비례





전기 쌍극자
(electric dipole)



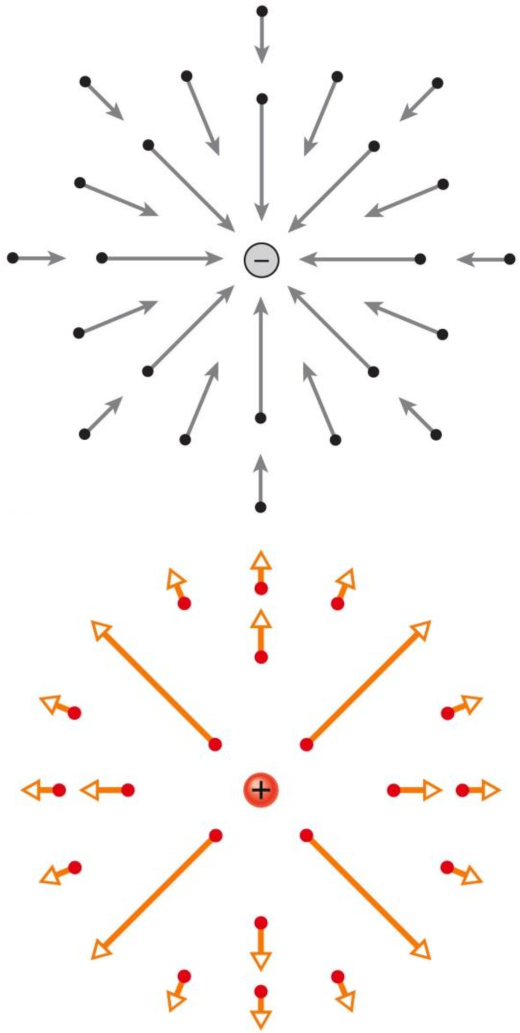
Fields of Point Charges and Charge Distributions

- The field of a point charge is radial, outward for a positive charge and inward for a negative charge.

$$\vec{E}_{\text{point charge}} = \frac{kq}{r^2}\hat{r}$$

- The superposition principle shows that the field du e to a charge distribution is the vector sum of the fi elds of the individual charges.

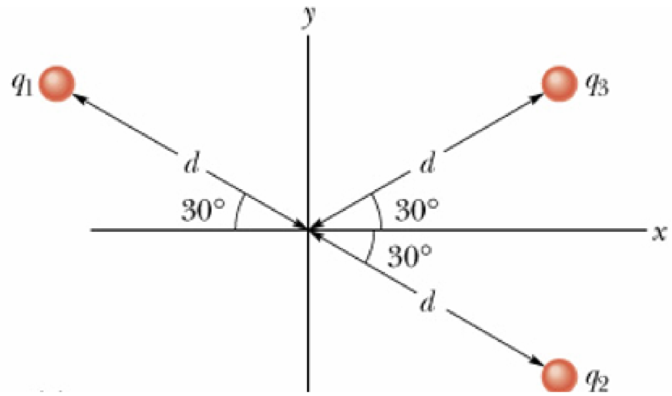
$$\vec{E} = \sum \vec{E}_i = \sum \frac{kq_i}{r_i^2}\hat{r}_i$$



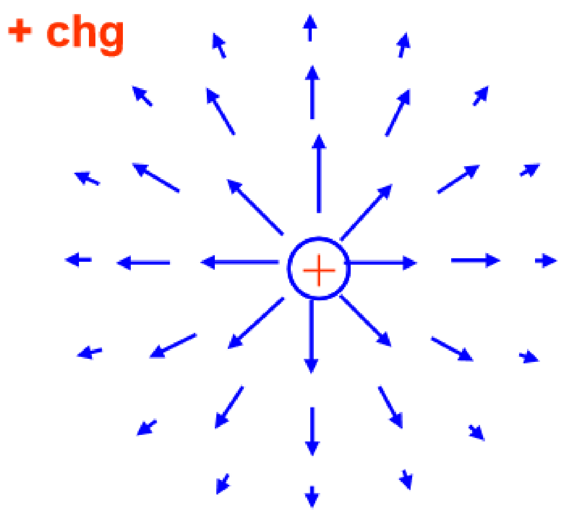
Chap. 22-2 The Electric Field Due to a Charged Particle

$$\left|\vec{E}\right| = \frac{\left|\vec{F}\right|}{q_o} = \frac{1}{4\pi\varepsilon_o}\frac{|q|}{r^2}$$

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \cdots + \vec{E}_n$$



vector map



화살표 방향 = 전기장 방향

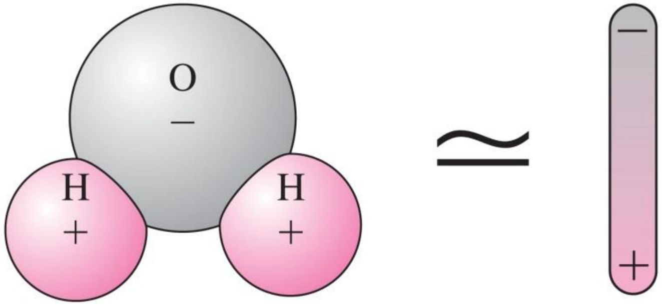
화살표 길이 = 전기장 세기

보기문제 22.01

Electric Dipole (전기 쌍극자)

An electric dipole consists of two particles with charges of equal magnitude *q* but opposite signs, separated by a small distance *d*.

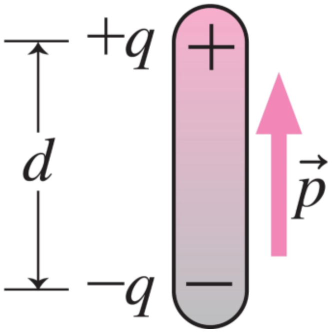
→ 크기가 같고 부호가 반대인 두 전하가 가까이 놓인 것



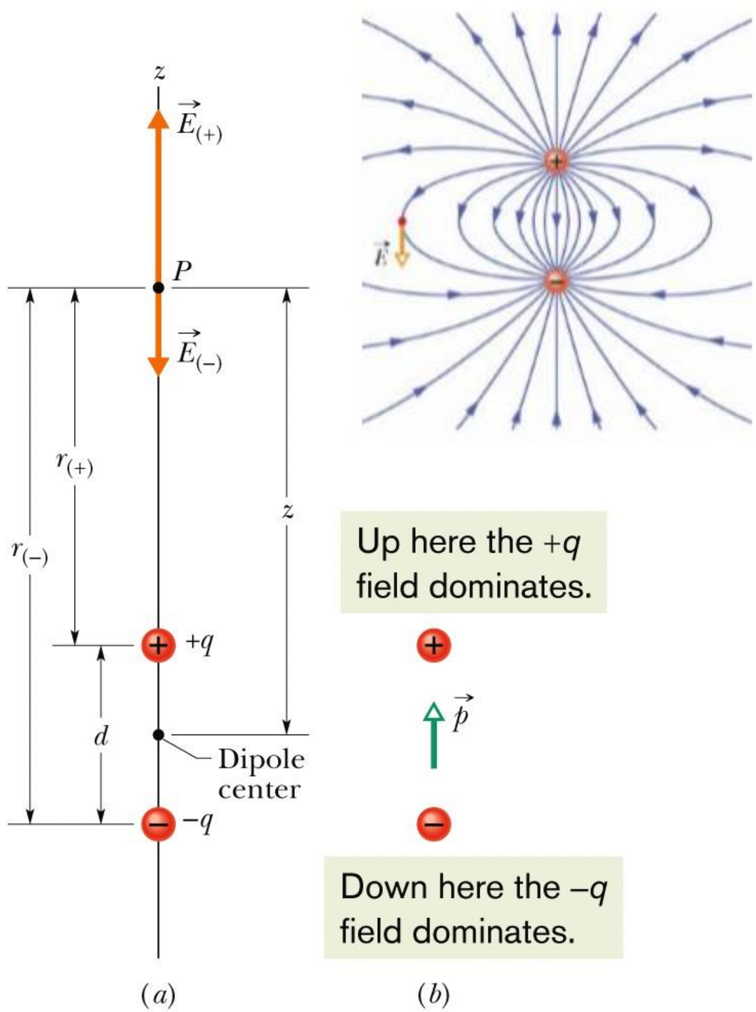
- The dipole is electrically neutral, but the separation of its charges results in an electric field.
- Many charge distributions, especially molecules, behave like electric dipoles.
- The product of the charge and separation is the **electric dipole moment:**

$$\vec{p} = q\vec{d}.$$

- Far from the dipole, its electric field falls off as the inverse cube of the distance.



Chap. 22-3 The Electric Field Due to a Dipole



$$E = E_{(+)} + E_{(-)}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{(+q)}{r_{(+)}{}^2} + \frac{1}{4\pi\varepsilon_0}\frac{(-q)}{r_{(-)}{}^2}$$

$$= \frac{q}{4\pi\varepsilon_0}\left\{\frac{1}{\left(z-\frac{1}{2}d\right)^2} - \frac{1}{\left(z+\frac{1}{2}d\right)^2}\right\}$$

$$\frac{1}{\left(z\pm\frac{1}{2}d\right)^2} = \left(z\pm\frac{d}{2}\right)^{-2} = z^{-2}\left(1\pm\frac{d}{2z}\right)^{-2}$$

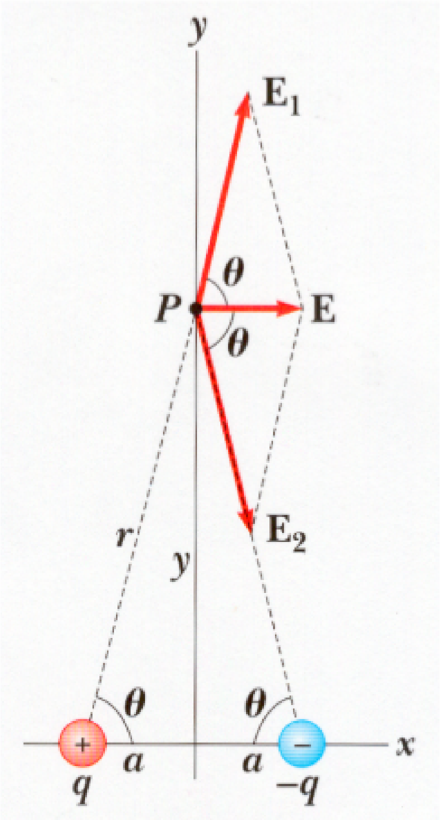
$$= z^{-2}\left[1+\frac{(-2)}{1!}\left(\pm\frac{d}{2z}\right)+\cdots\right]$$

$$\approx z^{-2}\left(1\mp\frac{d}{z}\right)$$

$$E \approx \frac{1}{2\pi\varepsilon_0}\frac{qd}{z^3} = \frac{1}{2\pi\varepsilon_0}\left(\frac{p}{z^3}\right)$$

$\vec{p} = q\vec{d}$ 전기 쌍극자 모멘트 (electric dipole moment)

Chap. 22-3 The Electric Field Due to a Dipole



$$\vec{E} = \vec{E}_1 + \vec{E}_2 = k_e \frac{q}{r^2}\hat{r}_1 - k_e \frac{q}{r^2}\hat{r}_2$$

$$|E_1| = |E_2|$$

$$E_y = E_1 \sin\theta + E_2 \sin(-\theta) = E_1 \sin\theta - E_1 \sin\theta = 0$$

$$E_x = E = E_1 \cos\theta + E_2 \cos\theta = 2E_1 \cos\theta$$

$$E = 2k_e \frac{q}{r^2}\cos\theta = 2k_e \frac{q}{(y^2 + a^2)} \cdot \frac{a}{(y^2 + a^2)^{1/2}}$$

$$= k_e \frac{2qa}{(y^2 + a^2)^{3/2}}$$

$$k_e = \frac{1}{4\pi\varepsilon_o}$$

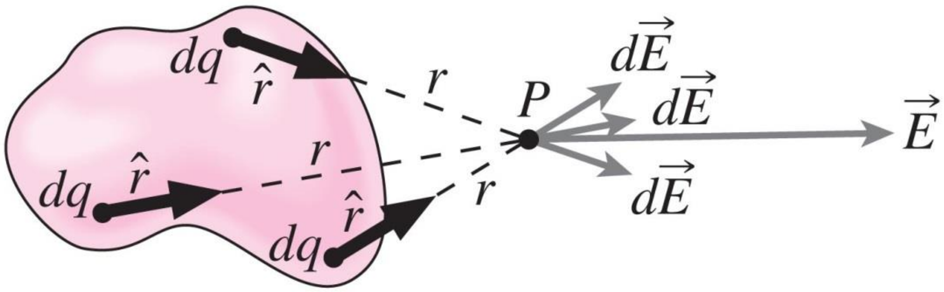
For $r >> a$: $$E = k_e \frac{2qa}{y^3} \quad \propto \frac{1}{r^3}$$

Chap. 22-4 The Electric Field Due to a line of charge

연속적인 전하분포를 가진 물체가 만드는 전기장 (선, 면 부피)

- Charge ultimately resides on individual particles, but it's often convenient to consider it distributed continuously on a line, over an area, or throughout space.

- The electric field of a charge distribution follows by summing—that is, integrating—the fields of individual charge elements *dq*, each treated as a point charge:



Charge distribution

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

Chap. 22-4 The Electric Field Due to a line of charge

- *Charge Density (전하밀도) for uniform distributions*

  - *Volume charge density,* ρ *: Charge per unit volumes*

$$\rho \equiv \frac{Q_{tot}}{V}, \qquad \vec{E} = k_e \int \frac{\rho dV}{r^2} \hat{r}$$

  - *Surface charge density,* σ *: Charge per unit area*

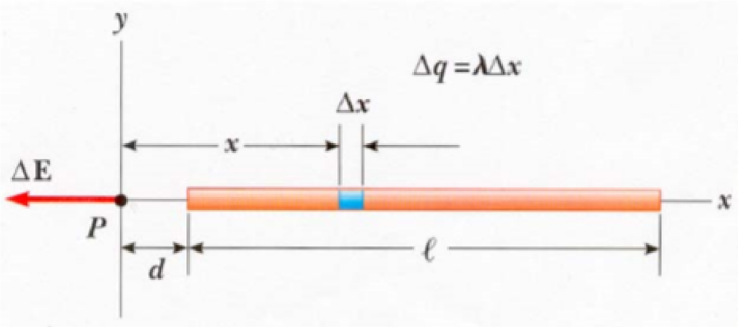
$$\sigma \equiv \frac{Q_{tot}}{A}, \qquad \vec{E} = k_e \int \frac{\sigma dS}{r^2} \hat{r}$$

  - *Linear charge density,* λ *: Charge per unit length*

$$\lambda \equiv \frac{Q_{tot}}{L}, \qquad \vec{E} = k_e \int \frac{\lambda dl}{r^2} \hat{r}$$

Chap. 22-4 The Electric Field Due to a line of charge

직선 전하가 만드는 전기장



Total Charge Q

Linear charge density (선 전하 밀도)

$$\lambda = \frac{Q}{l}$$

$$E = k_e \int \frac{\lambda dl}{r^2} = k_e \int_d^{d+l} \frac{\lambda dx}{x^2}$$

$$= k_e \lambda \left[-\frac{1}{x} \right]_{x=d}^{x=l+d} = k_e \lambda \left(\frac{1}{d} - \frac{1}{l+d} \right) = \frac{k_e \lambda l}{d(l+d)}$$

$$\boxed{E = \frac{k_e Q}{d(l+d)}}$$

If $d >> l$, $\quad E \approx \dfrac{k_e Q}{d^2}$ *: like a point charge*

고리선 전하가 만드는 전기장

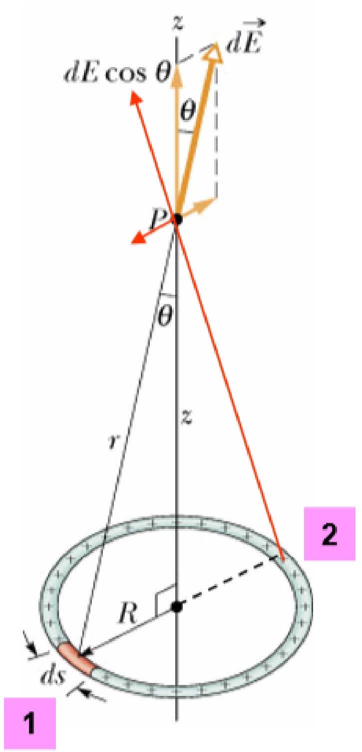
Total Charge Q *Linear charge density* $\lambda = \dfrac{Q}{2\pi R}$

$$\vec{E} = \int d\vec{E} = k_e \int \frac{\lambda dl}{r^2}\hat{r}$$

$$dE_{1\perp} = -dE_{2\perp}, \quad dE_{1z} = dE_{2z}$$

$$dE_z = k_e \frac{dq}{r^2}\cos\theta = \frac{k_e dq}{\left(z^2+R^2\right)} \cdot \frac{z}{\left(z^2+R^2\right)^{1/2}} = \frac{k_e z dq}{\left(z^2+R^2\right)^{3/2}}$$

$$\left|\vec{E}\right| = E_z = \frac{k_e z}{\left(z^2+R^2\right)^{3/2}}\int dq = \frac{Qz}{4\pi\varepsilon_o\left(z^2+R^2\right)^{3/2}}$$



If $z = 0, \ E = 0.$

If $z >> R, \quad E \approx \dfrac{Q}{4\pi\varepsilon_o z^2}$ *: like a point charge*

Chap. 22-5 The Electric Field Due to a Charged Disk

대전된 원판이 만드는 전기장

Total Charge Q *Surface charge density* $\sigma = \dfrac{Q}{\pi R^2}$

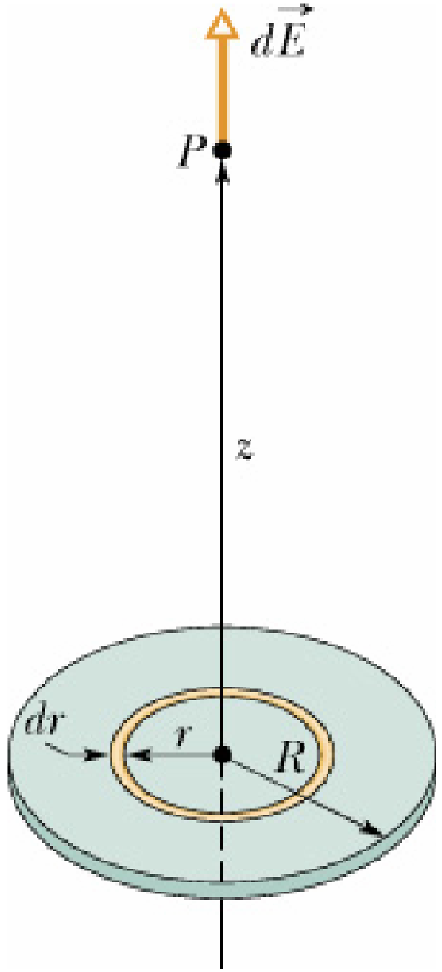
$$dq = \sigma dA = \sigma(2\pi r dr)$$

$$\left|d\vec{E}\right| = dE_z = \frac{z}{4\pi\varepsilon_o\left(z^2+r^2\right)^{3/2}}dq$$

$$\left|\vec{E}\right| = E_z = \frac{\sigma z}{4\varepsilon_o}\int_0^R \frac{2r}{\left(z^2+r^2\right)^{3/2}}dr$$

$$= \frac{\sigma}{2\varepsilon_o}\left(1-\frac{z}{\sqrt{z^2+R^2}}\right)$$

If $R \rightarrow$ *infinite,* $E \approx \dfrac{\sigma}{2\varepsilon_o}$



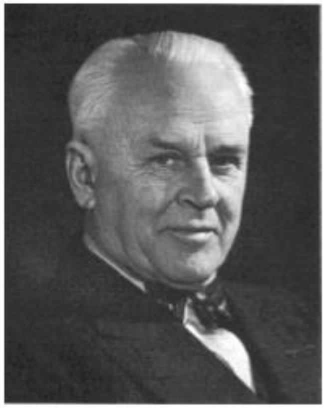
Chap. 22-6 A Point Charge in an Electric Field

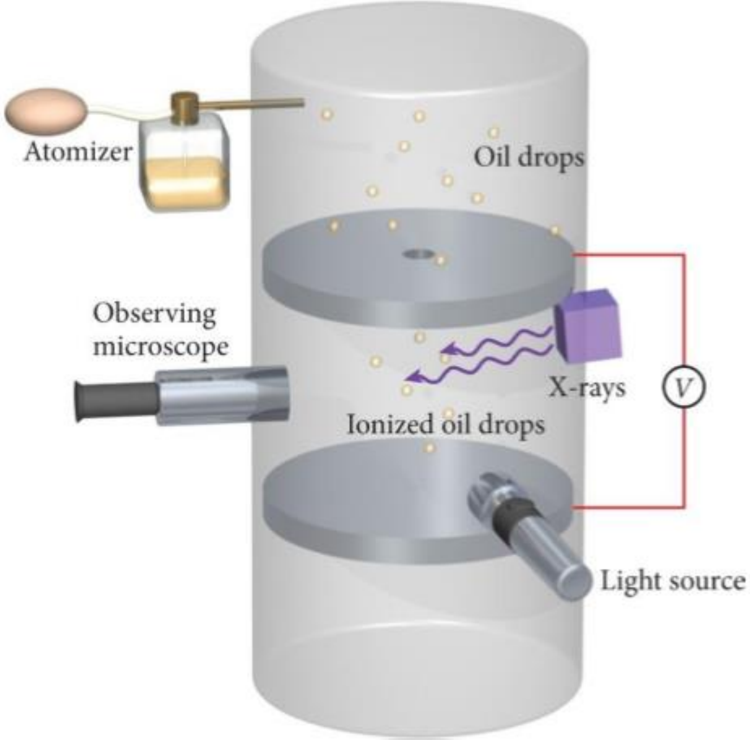
- **기본전하**

전하의 양자화
전하량은 **최소 크기**(전자/양성자의 전하량)의 정수배로만 주어진다.

$$e = 1.602176487(40) \times 10^{-19}\ \mathrm{C}$$

밀리칸 기름방울 실험
전하가 양자화되어 있다는 것을 밝힌 실험이다.





$$q = ne, n = 0, \pm 1, \pm 2, \pm 3, \ldots .$$

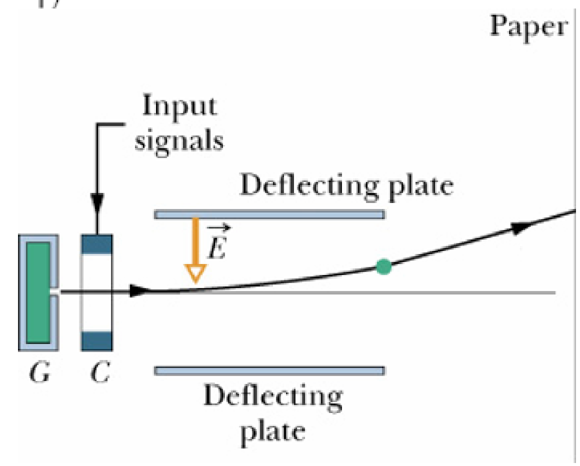
Chap. 22-6 A Point Charge in an Electric Field

전기장 안의 점전하

입자가 받는 힘: $\mathrm{F} = q\,\mathrm{E}$ (정전기력)

운동방정식: $q\,\mathrm{E} = m\dfrac{d\mathrm{v}}{dt}$ (뉴턴의 운동방정식)

보기문제 22.04 전기장에서의 대전입자의 운동



판을 지나오는 순간의 수직이동거리?

잉크방울: 질량 $m = 1.3\times10^{-10}$ kg, 전하 $Q = 1.5\times10^{-13}$ C,

진입속도 $v_x = 18$ m/s

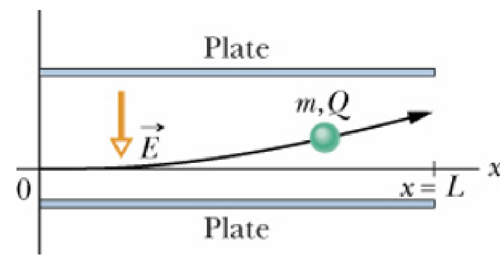
편향판: 길이 $L = 1.6$ cm, 전기장 $E = 1.4\times10^{6}$ N/C

수평방향은 등속운동, 수직방향은 등가속운동

수직방향의 가속도 : $a_y = \dfrac{F}{m} = \dfrac{QE}{m}$

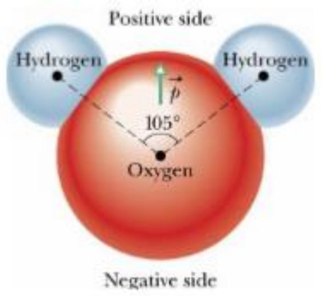
수직방향 이동거리 : $y = \dfrac{1}{2}a_y t^2, \quad t = \dfrac{L}{v_x}$

$$\therefore\ y = \frac{QEL^2}{2mv_x^2} = 0.64\ \mathrm{mm}$$



Chap. 22-7 A Dipole in an Electric Field

전기장 안의 쌍극자

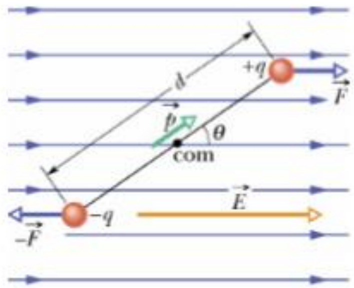


고른 전기장 속에 놓인 전기쌍극자가 받는 돌림힘과 위치에너지

[보기: 고른 전기장 속의 전기쌍극자(예: 물 분자)가 받는 힘]

1. 힘

두 전하 $\pm q$ 가 받는 힘은 각각 $\pm \mathrm{F}$ 로 알짜힘은 0

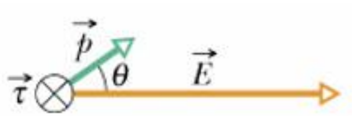


2. 돌림힘

$$\tau = \left[-F\left(\frac{d}{2}\right)\sin\theta\right] + \left[-F\left(\frac{d}{2}\right)\sin\theta\right]$$

$$= -Fd\sin\theta = -qEd\sin\theta$$

$$= -pE\sin\theta \dashrightarrow \vec{\tau} = \vec{p} \times \vec{E} \dashrightarrow$$



3. 회전 위치에너지 **(전기쌍극자의 위치에너지)**

쌍극자가 전기장과 수직인 상태($\theta = 90^o$)를 기준으로 정한다.

$$U = -\int_{90^o}^{\theta} \tau\, d\theta = \int_{90^o}^{\theta} pE\sin\theta\, d\theta = -pE\cos\theta \dashrightarrow U = -\vec{p}\cdot\vec{E}$$

Summary

Definition of Electric Field

- The electric field at any point

$$\vec{E} = \frac{\vec{F}}{q_0}. \qquad \textbf{Eq. 22-1}$$

Electric Field Lines

- provide a means for visualizing th e directions and the magnitudes o f electric fields

Field due to a Point Charge

- The magnitude of the electric field $\boldsymbol{E}$ set up by a point charge q at a d istance r from the charge is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}. \qquad \textbf{Eq. 22-3}$$

Field due to an Electric Dipole

- The magnitude of the electric fiel d set up by the dipole at a dista nt point on the dipole axis is

$$E = \frac{1}{2\pi\varepsilon_0}\frac{p}{z^3} \qquad \textbf{Eq. 22-9}$$

Field due to a Charged Disk

- The electric field magnitude at a point on the central axis thr ough a uniformly charged disk is given by

$$E = \frac{\sigma}{2\varepsilon_0}\left(1 - \frac{z}{\sqrt{z^2 + R^2}}\right) \qquad \textbf{Eq. 22-26}$$

Summary

Force on a Point Charge in an Electric Field

- When a point charge q is placed in an external electric field ***E***

$$\vec{F} = q\vec{E}.$$ **Eq. 22-28**

Dipole in an Electric Field

- The electric field exerts a torque on a dipole

$$\vec{\tau} = \vec{p} \times \vec{E}.$$ **Eq. 22-34**

- The dipole has a potential energy U associated with its orientation in the field

$$U = -\vec{p} \cdot \vec{E}.$$ **Eq. 22-38**