2장 쿨롱의 법칙과 전계세기

2.1 쿨롱의 실험법칙

•두 개의 물체 사이에 작용하는 전기적 힘

$$F \propto \frac{Q_1 Q_2}{R^2}$$

$$F = k\frac{Q_1 Q_2}{R^2} = \frac{1}{4\pi\epsilon_0}\frac{Q_1 Q_2}{R^2}$$

여기서, $k = \dfrac{1}{4\pi\epsilon_0}$, $\epsilon_0 = 8.854\times 10^{-12} \approx \dfrac{1}{36\pi}\times 10^{-9}$ F/m

; 자유공간의 유전율(permittivity)

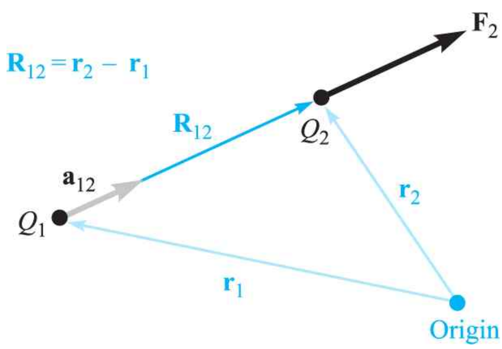
•전하의 단위; C(쿨롱, Coulomb)

전자의 전하량 $e = -1.602\times 10^{-19}$ C

$1\text{C} = -6\times 10^{18} e\ \text{C} = (6\times 10^{18})(1.602\times 10^{-19})\text{C}$

$$F = \frac{1}{4\pi\epsilon_0}\frac{1\text{C}\times 1\text{C}}{(1\text{m})^2} = 9\times 10^9\text{N} \approx 100\text{만톤}$$

•전기력의 벡터표시; 그림 2.1



$$\boldsymbol{F}_2 = \frac{1}{4\pi\epsilon_0}\frac{Q_1 Q_2}{R_{12}^2}\boldsymbol{a}_{12}$$

여기서, $\boldsymbol{a}_{12} = \dfrac{\boldsymbol{R}_{12}}{|\boldsymbol{R}_{12}|} = \dfrac{\boldsymbol{R}_{12}}{R_{12}} = \dfrac{\boldsymbol{r}_2 - \boldsymbol{r}_1}{|\boldsymbol{r}_2 - \boldsymbol{r}_1|}$

$$\boldsymbol{F}_1 = \frac{1}{4\pi\epsilon_0}\frac{Q_1 Q_2}{R_{21}^2}\boldsymbol{a}_{21}$$

$$= \frac{1}{4\pi\epsilon_0}\frac{Q_1 Q_2}{R_{12}^2}(-\boldsymbol{a}_{12})$$

$$= -\boldsymbol{F}_2$$

(예제 2.1) $Q_1 = 3\times10^{-4}\text{C}$ at $M(1,\ 2,\ 3)$, $Q_2 = -10^{-4}\text{C}$ at $N(2,\ 0,\ 5)$

$\rightarrow\ \boldsymbol{F}_2 = ?$

$$\boldsymbol{R}_{12} = \boldsymbol{r}_2 - \boldsymbol{r}_1 = \boldsymbol{a}_x - 2\boldsymbol{a}_y + 2\boldsymbol{a}_z$$

$$\boldsymbol{a}_{12} = \frac{\boldsymbol{R}_{12}}{R_{12}} = \frac{\boldsymbol{a}_x - 2\boldsymbol{a}_y + 2\boldsymbol{a}_z}{\sqrt{1^2 + (-2)^2 + 2^2}} = \frac{\boldsymbol{a}_x - 2\boldsymbol{a}_y + 2\boldsymbol{a}_z}{3}$$

$$\therefore\ \boldsymbol{F}_2 = \frac{Q_1 Q_2}{4\pi\epsilon_0 R_{12}^2}\boldsymbol{a}_{12} = \frac{3\times10^{-4}(-10^{-4})}{4\pi(1/36\pi)10^{-9}\times9}\left(\frac{\boldsymbol{a}_x - 2\boldsymbol{a}_y + 2\boldsymbol{a}_z}{3}\right)\ \text{N}$$

$$= -30\left(\frac{\boldsymbol{a}_x - 2\boldsymbol{a}_y + 2\boldsymbol{a}_z}{3}\right)\ \text{N}$$

$$\boldsymbol{F}_1 = -\boldsymbol{F}_2 = \frac{Q_1 Q_2}{4\pi\epsilon_0 R_{21}^2}\boldsymbol{a}_{21} = -\frac{Q_1 Q_2}{4\pi\epsilon_0 R_{12}^2}\boldsymbol{a}_{12}$$

(ex 1) $Q_1 = 2\text{mC}$ at $P_1(3,\ -2,\ -4)$, $Q_2 = -5\mu\text{C}$ at $P_2(1,\ -4,\ 2)$

(a) $\boldsymbol{R}_{12}$ (b) $|\boldsymbol{F}_1|$

(a) $\boldsymbol{R}_{12} = \boldsymbol{r}_2 - \boldsymbol{r}_1 = -2\boldsymbol{a}_x - 2\boldsymbol{a}_y + 6\boldsymbol{a}_z$

$$\boldsymbol{a}_{12} = \frac{\boldsymbol{R}_{12}}{R_{12}} = \frac{-2\boldsymbol{a}_x - 2\boldsymbol{a}_y + 6\boldsymbol{a}_z}{\sqrt{(-2)^2 + (-2)^2 + 6^2}} = \frac{-2\boldsymbol{a}_x - 2\boldsymbol{a}_y + 6\boldsymbol{a}_z}{\sqrt{44}}$$

$$\therefore\ \boldsymbol{F}_2 = \frac{Q_1 Q_2}{4\pi\epsilon_0 R_{12}^2}\boldsymbol{a}_{12}\ [\text{N}]$$

$$= \frac{2\times10^{-3}\times(-5)\times10^{-6}}{4\pi(1/36\pi)10^{-9}\times44}\frac{-2\boldsymbol{a}_x - 2\boldsymbol{a}_y + 6\boldsymbol{a}_z}{\sqrt{44}}\ \text{N}$$

$$= 2.045\ \frac{2\boldsymbol{a}_x + 2\boldsymbol{a}_y - 6\boldsymbol{a}_z}{\sqrt{44}}\ \text{N}$$

$$= 0.616\boldsymbol{a}_x + 0.616\boldsymbol{a}_y - 1.848\boldsymbol{a}_z\ \text{N}$$

(b) $|\boldsymbol{F}_1| = |\boldsymbol{F}_2| = \sqrt{0.616^2 + 0.616^2 + (-1.848)^2} = 2.04\ \text{N}$

(응용예제 2.1) $Q_A = 20\mu\text{C}$ at $A(-6,\ 4,\ 7)$, $Q_B = 50\mu\text{C}$ at $B(5,\ 8,\ -2)$

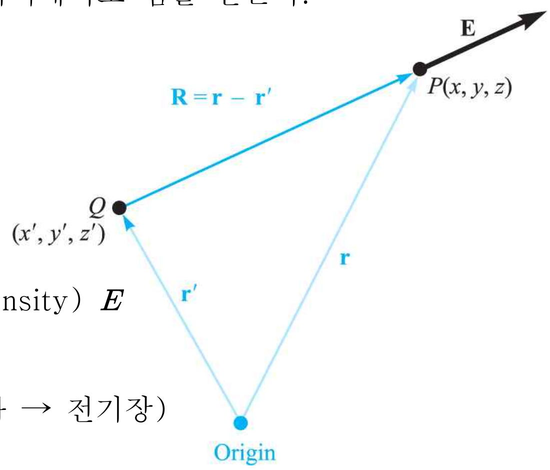
(a) $\boldsymbol{R}_{AB}$ (b) R_{AB} (c) $\boldsymbol{F}_A$

2.2 전계의 세기

•전하 Q_1의 위치를 고정하면 제2의 전하 Q_2는 어떠한 위치에서도 힘을 받는다.

→ Q_1에 의한 힘의 장(계)(force field)이 존재

→ Q_2를 Q_t로 대체하면 $F_t = \dfrac{Q_1 Q_t}{4\pi\epsilon_0 R_{1t}^2} a_{1t}$



•시험전하의 단위전하당 작용하는 힘

$$\frac{F_t}{Q_t} = \frac{Q_1}{4\pi\epsilon_0 R_{1t}^2} a_{1t} \rightarrow \text{전계세기(electric field intensity)}\ E$$

$$\therefore\ E = \frac{F_t}{Q_t} = \frac{Q_1}{4\pi\epsilon_0 R_{1t}^2} a_{1t} = \frac{Q}{4\pi\epsilon_0 R^2} a_R \ \text{V/m (전하 → 전기장)}$$

(ex 2) Q_1 at $O(r=0,\ \theta=0,\ \phi=0)$ → $r = r_1$인 곳에서의 E?

$$E = \frac{Q}{4\pi\epsilon_0 R^2} a_R = \frac{Q_1}{4\pi\varepsilon_0 r_1{}^2} a_r$$

(ex 3) Q at $O(x=0,\ y=0,\ z=0)$ → $P(x=x_1,\ y=y_1,\ z=z_1)$에서의 E ?

$$R = x_1 a_x + y_1 a_y + z_1 a_z$$

$$a_R = \frac{x_1 a_x + y_1 a_y + z_1 a_z}{\sqrt{x_1^2 + y_1^2 + z_1^2}}$$

$$\therefore\ E = \frac{Q}{4\pi\epsilon_0 R^2} a_R = \frac{Q}{4\pi\epsilon_0 (x_1^2 + y_1^2 + z_1^2)} \frac{x_1 a_x + y_1 a_y + z_1 a_z}{\sqrt{x_1^2 + y_1^2 + z_1^2}}$$

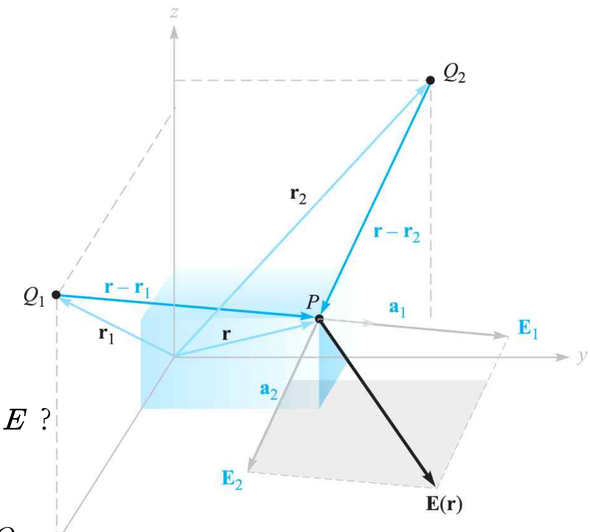
(ex 4) Q at $O(x',\ y',\ z')$ → $P(x,\ y,\ z)$에서의 E?

$$R = r_P - r_O = (x-x')a_x + (y-y')a_y + (z-z')a_z$$

$$a_R = \frac{R}{R} = \frac{(x-x')a_x + (y-y')a_y + (z-z')a_z}{\sqrt{(x-x')^2 + (y-y')^2 + (z-z')^2}}$$

$$\therefore\ E = \frac{Q}{4\pi\epsilon_0 R^2} a_R = \frac{Q}{4\pi\epsilon_0 R^3} R$$

$$= \frac{Q\,[(x-x')a_x + (y-y')a_y + (z-z')a_z]}{4\pi\epsilon_0 [(x-x')^2 + (y-y')^2 + (z-z')^2]^{3/2}}$$



(ex 5) Q_1 at r_1, Q_2 at r_2 → r에서의 $\boldsymbol{E}$?

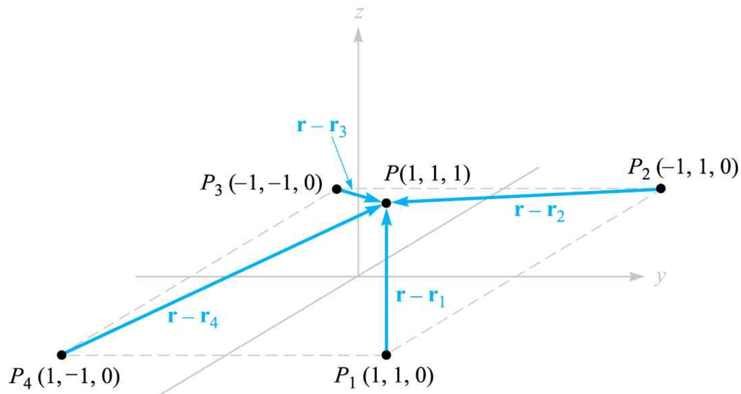
$$\boldsymbol{E} = \boldsymbol{E}_1 + \boldsymbol{E}_2 = \frac{Q_1}{4\pi\epsilon_0 |\boldsymbol{r}-\boldsymbol{r}_1|^2}\boldsymbol{a}_1 + \frac{Q_2}{4\pi\epsilon_0 |\boldsymbol{r}-\boldsymbol{r}_2|^2}\boldsymbol{a}_2$$

(ex 6) Q_1 at r_1, Q_2 at r_2, ⋯, Q_n at r_n → r인 곳에서의 $\boldsymbol{E}$?

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

$$= \frac{Q_1}{4\pi\epsilon_0 |\boldsymbol{r}-\boldsymbol{r}_1|^2}\boldsymbol{a}_1 + \frac{Q_2}{4\pi\epsilon_0 |\boldsymbol{r}-\boldsymbol{r}_2|^2}\boldsymbol{a}_2 + \cdots + \frac{Q_n}{4\pi\epsilon_0 |\boldsymbol{r}-\boldsymbol{r}_n|^2}\boldsymbol{a}_n$$

$$= \sum_{m=1}^{n} \frac{Q_m}{4\pi\epsilon_0 |\boldsymbol{r}-\boldsymbol{r}_m|^2}\boldsymbol{a}_m$$



(예제 2.2) 3 nC at $P_1(1,\ 1,\ 0)$, 3 nC at $P_2(-1,\ 1,\ 0)$,

3 nC at $P_3(-1,\ -1,\ 0)$, 3 nC at $P_4(1,\ -1,\ 0)$,

→ $\boldsymbol{E}=$? at $P(1,\ 1,\ 1)$

$$\boldsymbol{E} = \sum_{m=1}^{4}\boldsymbol{E}_m = \sum_{m=1}^{4}\frac{Q_m}{4\pi\epsilon_0|\boldsymbol{r}-\boldsymbol{r}_m|^2}\boldsymbol{a}_m$$

$$= \sum_{m=1}^{4}\frac{Q_m}{4\pi\epsilon_0|\boldsymbol{r}-\boldsymbol{r}_m|^2}\frac{\boldsymbol{r}-\boldsymbol{r}_m}{|\boldsymbol{r}-\boldsymbol{r}_m|} = \sum_{m=1}^{4}\frac{Q_m}{4\pi\epsilon_0}\frac{\boldsymbol{r}-\boldsymbol{r}_m}{|\boldsymbol{r}-\boldsymbol{r}_m|^3}$$

$$= \frac{Q}{4\pi\epsilon_0}\left[\frac{\boldsymbol{r}-\boldsymbol{r}_1}{|\boldsymbol{r}-\boldsymbol{r}_1|^3} + \frac{\boldsymbol{r}-\boldsymbol{r}_2}{|\boldsymbol{r}-\boldsymbol{r}_2|^3} + \frac{\boldsymbol{r}-\boldsymbol{r}_3}{|\boldsymbol{r}-\boldsymbol{r}_3|^3} + \frac{\boldsymbol{r}-\boldsymbol{r}_4}{|\boldsymbol{r}-\boldsymbol{r}_4|^3}\right]$$

where, $\boldsymbol{r}-\boldsymbol{r}_1 = \boldsymbol{a}_z$ $\qquad |\boldsymbol{r}-\boldsymbol{r}_1| = 1$

$\boldsymbol{r}-\boldsymbol{r}_2 = 2\boldsymbol{a}_x + \boldsymbol{a}_z$ $\qquad |\boldsymbol{r}-\boldsymbol{r}_2| = \sqrt{2^2+1^2} = \sqrt{5}$

$\boldsymbol{r}-\boldsymbol{r}_3 = 2\boldsymbol{a}_x + 2\boldsymbol{a}_y + \boldsymbol{a}_z$ $\qquad |\boldsymbol{r}-\boldsymbol{r}_1| = \sqrt{2^2+2^2+1^2} = 3$

$\boldsymbol{r}-\boldsymbol{r}_4 = 2\boldsymbol{a}_y + \boldsymbol{a}_z$ $\qquad |\boldsymbol{r}-\boldsymbol{r}_1| = \sqrt{2^2+1^2} = \sqrt{5}$

$$\therefore\ \boldsymbol{E} = \frac{3\times10^{-9}}{4\pi\times8.854\times10^{-12}}\left[\frac{\boldsymbol{a}_z}{1^3} + \frac{2\boldsymbol{a}_x+\boldsymbol{a}_z}{\sqrt{5}^3} + \frac{2\boldsymbol{a}_x+2\boldsymbol{a}_y+\boldsymbol{a}_z}{3^3} + \frac{2\boldsymbol{a}_y+\boldsymbol{a}_z}{\sqrt{5}^3}\right]$$

$$= 6.82\boldsymbol{a}_x + 6.82\boldsymbol{a}_y + 32.8\boldsymbol{a}_z \ \text{V/m}$$

(ex 7) $\boldsymbol{E}$ at $M(3,\ -4,\ 2)$?

(a) $Q_1 = 2\mu\text{C}$ at $P_1(0,\ 0,\ 0)$

$$r_M - r_1 = 3a_x - 4a_y + 2a_z$$

$$|r_M - r_1| = \sqrt{3^2 + (-4)^2 + 2^2} = \sqrt{29}$$

$$\therefore\ E_{1M} = \frac{Q}{4\pi\epsilon_0 R_{1M}^2} a_R = \frac{Q_1}{4\pi\varepsilon_0 |\boldsymbol{r}_M - \boldsymbol{r}_1|^2} \frac{\boldsymbol{r}_M - \boldsymbol{r}_1}{|\boldsymbol{r}_M - \boldsymbol{r}_1|}$$

$$= \frac{2\times 10^{-6}}{4\pi \cdot 8.854\times 10^{-12} \cdot 29} \frac{3a_x - 4a_y + 2a_z}{\sqrt{29}}$$

$$= 620 \frac{3a_x - 4a_y + 2a_z}{\sqrt{29}}\ \text{V/m}$$

$$= 345a_x - 460a_y + 230a_z\ \text{V/m}$$

(b) $Q_2 = 3\mu\text{C}$ at $P_2(-1,\ 2,\ 3)$

$$r_M - r_2 = 4a_x - 6a_y - a_z$$

$$|r_M - r_2| = \sqrt{4^2 + (-6)^2 + (-1)^2} = \sqrt{53}$$

$$\therefore\ E_{2M} = \frac{Q}{4\pi\epsilon_0 R_{2M}^2} a_R = \frac{Q_1}{4\pi\epsilon_0 |r_M - r_2|^2} \frac{r_M - r_2}{|r_M - r_2|}$$

$$= \frac{3\times 10^{-6}}{4\pi \cdot 8.854\times 10^{-12} \cdot 53} \frac{4a_x - 6a_y - a_z}{\sqrt{53}}$$

$$= 509 \frac{4a_x - 6a_y - a_z}{\sqrt{53}}\ \text{V/m}$$

$$= 280a_x - 419a_y - 69.9a_z\ \text{V/m}$$

(c) $Q_1 = 2\mu\text{C}$ at $P_1(0,\ 0,\ 0)$ and $Q_2 = 3\mu\text{C}$ at $P_2(-1,\ 2,\ 3)$

$$E_M = E_{1M} + E_{2M}$$

$$= (345a_x - 460a_y + 230a_z) + (280a_x - 419a_y - 69.9a_z)$$

$$= 625a_x - 879a_y + 160.1a_z\ \text{V/m}$$

(응용예제 2.2) $Q_A = -0.3\mu\text{C}$ at $A(25,\ -30,\ 15)$㎝,

$Q_B = 0.5\mu\text{C}$ at $B(-10,\ 8,\ 12)$㎝,

$\boldsymbol{E} = ?$ at (a) 원점 (b) $P(15,\ 20,\ 50)$㎝

(응용예제 2.3)

(a) $\displaystyle\sum_{m=0}^{5} \frac{1+(-1)^m}{m^2+1}$ (b) $\displaystyle\sum_{m=1}^{4} \frac{(0.1)^m+1}{(4+m^2)^{1.5}}$

2.3 연속적인 체적전하분포에 의한 전계

•전하가 점이 아닌 부피를 가지고 분포 → 체적전하밀도(ρ_v C/m^3)로 표시

$$\rho_v = \frac{Q}{v} \rightarrow \rho_v = \frac{\Delta Q}{\Delta v} \rightarrow \rho_v = \lim_{\Delta v \to 0} \frac{\Delta Q}{\Delta v} = \frac{dQ}{dv}$$

$$\therefore\ Q = \int_{vol} dQ = \int_{vol} \rho_v dv$$

$$\rightarrow\ \boldsymbol{E} = \frac{Q}{4\pi\epsilon_0 R^2}\boldsymbol{a_r}$$

$$= \frac{Q}{4\pi\epsilon_0 |\boldsymbol{r}-\boldsymbol{r}'|^2} \frac{\boldsymbol{r}-\boldsymbol{r}'}{|\boldsymbol{r}-\boldsymbol{r}'|}$$

$$= \frac{\int_{vol} \rho_v(\boldsymbol{r}')dv'}{4\pi\epsilon_0 |\boldsymbol{r}-\boldsymbol{r}'|^2} \frac{\boldsymbol{r}-\boldsymbol{r}'}{|\boldsymbol{r}-\boldsymbol{r}'|}$$

$$= \int_{vol} \frac{\rho_v(\boldsymbol{r}')dv'(\boldsymbol{r}-\boldsymbol{r}')}{4\pi\epsilon_0 |\boldsymbol{r}-\boldsymbol{r}'|^3}$$

(예제 2.3) 그림 2.5와 같이 체적전하밀도가 $\rho_v = -5\times 10^{-6} e^{-10^5 \rho z}$ C/m^{3}이고, 길이 2 cm, 반지름 1 cm인 전자빔의 총전하량 Q?

$$Q = \int_{vol} dQ = \int_{vol} \rho_v dv$$

$$= \int_{vol} -5\times 10^{-6} e^{-10^5 \rho z} \rho d\rho d\phi dz$$

$$= \int_{z=0.02}^{z=0.04} \int_{\phi=0}^{\phi=2\pi} \int_{\rho=0}^{\rho=0.01} -5\times 10^{-6} e^{-10^5 \rho z} \rho d\rho d\phi dz$$

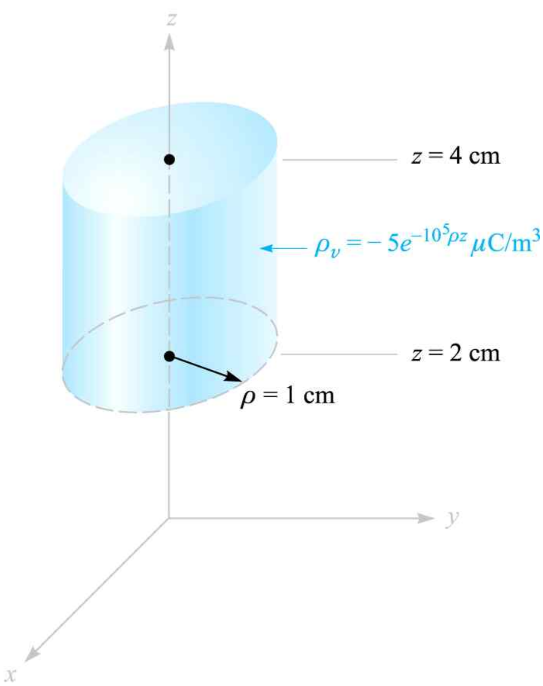
$$= -5\times 10^{-6} \int_{z=0.02}^{z=0.04} \int_{\rho=0}^{\rho=0.01} e^{-10^5 \rho z} \rho d\rho \left(\int_{\phi=0}^{\phi=2\pi} d\phi \right) dz$$

$$= -5\times 10^{-6} \int_{z=0.02}^{z=0.04} \int_{\rho=0}^{\rho=0.01} e^{-10^5 \rho z} \cdot 2\pi\ \rho d\rho dz$$

$$= -10^{-5}\pi \int_{\rho=0}^{\rho=0.01} \rho \left(\int_{z=0.02}^{z=0.04} e^{-10^5 \rho z} \right) dz d\rho$$

$$= -10^{-5}\pi \int_{\rho=0}^{\rho=0.01} \rho \left[\frac{1}{-10^5 \rho} e^{-10^5 \rho z} \right]_{z=0.02}^{z=0.04} d\rho$$

$$= 10^{-10}\pi \int_{\rho=0}^{\rho=0.01} \left(e^{-4000\rho} - e^{-2000\rho} \right) d\rho$$



$$=10^{-10}\pi\left[\frac{e^{-4000\rho}}{-4000}-\frac{e^{-2000\rho}}{-2000}\right]_{\rho=0}^{\rho=0.01}$$

$$=10^{-10}\pi\left\{\left(\frac{e^{-40}}{-4000}-\frac{e^{-20}}{-2000}\right)-\left(\frac{1}{-4000}-\frac{1}{-2000}\right)\right\}$$

$$\approx 10^{-10}\pi\left(\frac{1}{4000}-\frac{1}{2000}\right)$$

$$=10^{-10}\pi\cdot\left(-\frac{1}{4000}\right)$$

$$=-\frac{\pi}{40}10^{-12}$$

$$=-\frac{\pi}{40}\ \mathrm{pC}$$

$$=-0.0785\ pC$$

(응용예제 2.4) $Q=?$

(a) $0.1 \leqq |x|, |y|, |z| \leqq 0.2$; $\rho_v = \dfrac{1}{x^3y^3z^3}$

(b) $0 \leqq \rho \leqq 0.1$, $0 \leqq \phi \leqq \pi$, $2 \leqq \rho \leqq 4$; $\rho_v = \rho^2 z^2 \sin 0.6\phi$

(c) 우주; $\rho_v = \dfrac{e^{-2r}}{r^2}$

2.4 선전하에 의한 전계

•전하가 점이 아닌 라인 위에 분포 → 선전하밀도(ρ_L C/m)로 표시

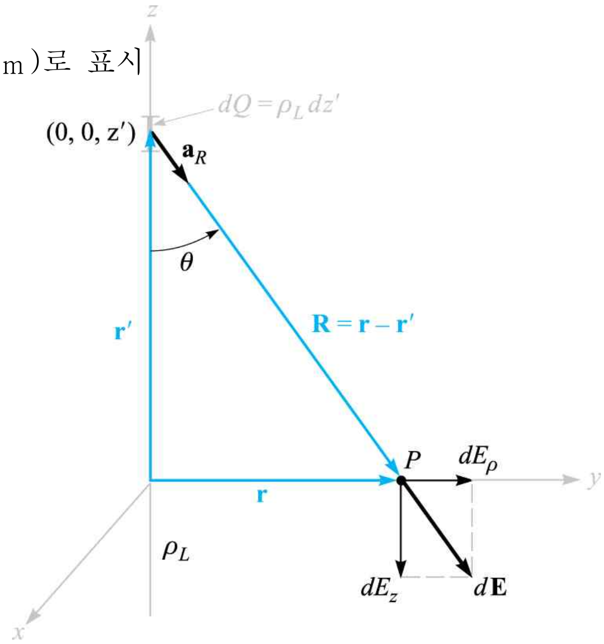
$$\rho_L = \frac{Q}{l} \rightarrow \rho_L = \frac{\Delta Q}{\Delta l} \rightarrow \rho_L = \lim_{\Delta l \to 0} \frac{\Delta Q}{\Delta l} = \frac{dQ}{dl}$$

$$\therefore\ Q = \int_l dQ = \int_l \rho_L dl$$

$$\rightarrow E = \frac{Q}{4\pi\epsilon_0 R^2} a_r = \frac{Q}{4\pi\epsilon_0 |r - r'|^2} \frac{r - r'}{|r - r'|}$$

$$= \frac{\int_l \rho_L(r') dl'}{4\pi\epsilon_0 |r - r'|^2} \frac{r - r'}{|r - r'|}$$

$$= \int_l \frac{\rho_L(r') dl' (r - r')}{4\pi\epsilon_0 |r - r'|^3}$$



(ex 8) z축의 $-\infty$에서 $+\infty$까지 선전하밀도 ρ_L의 전하가 균일하게 분포되어 있을 때, z 축에서 ρ만큼 떨어진 곳에서의 전계세기=?(그림 2.6)

$r = \rho a_\rho$

$r' = z' a_z$

$R = r - r' = \rho a_\rho - z' a_z$

$R = \sqrt{\rho^2 + z'^2}$

$$\therefore\ E = \int_l \frac{\rho_L(r') dl' (r - r')}{4\pi\epsilon_0 |r - r'|^3}$$

$$= \int_{-\infty}^{+\infty} \frac{\rho_L dz' (\rho a_\rho - z' a_{z'})}{4\pi\epsilon_0 (\rho^2 + z'^2)^{3/2}}$$

$$= \int_{-\infty}^{+\infty} \frac{\rho_L \rho dz'}{4\pi\epsilon_0 (\rho^2 + z'^2)^{3/2}} a_\rho \qquad <- \ E_z = 0$$

$$= \ldots$$

$$= \frac{\rho_L}{2\pi\epsilon_0 \rho} a_\rho$$

점전하에 의한 전계의 세기는 거리의 제곱에 반비례하는데 반하여, 선전하의 경우에는 거리에 반비례

(응용예제 2.5) $\rho_L = 5\text{nC/m}$ at x축 & y축

$\boldsymbol{E} = ?$ at (a) $P_A(0,\ 0,\ 4)$ (b) $P_B(0,\ 3,\ 4)$

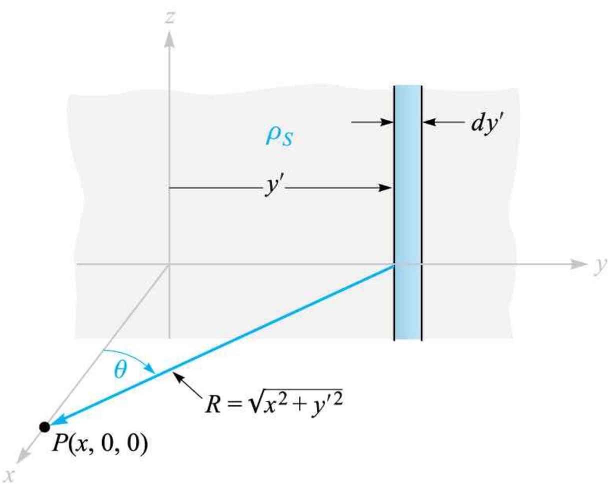
2.5 면전하(판전하)에 의한 전계

•전하가 점이 아닌 판에 분포 → 면적전하밀도(ρ_S C/m^2)로 표시

$$\rho_S = \frac{Q}{S} \rightarrow \rho_S = \frac{\Delta Q}{\Delta S} \rightarrow \rho_S = \lim_{\Delta l \to 0}\frac{\Delta Q}{\Delta S} = \frac{dQ}{dS}$$

$$\therefore\ Q = \int_S dQ = \int_S \rho_S dS$$

$$\rightarrow \boldsymbol{E} = \frac{Q}{4\pi\epsilon_0 R^2}\boldsymbol{a}_r = \frac{Q}{4\pi\epsilon_0|\boldsymbol{r}-\boldsymbol{r}'|^2}\frac{\boldsymbol{r}-\boldsymbol{r}'}{|\boldsymbol{r}-\boldsymbol{r}'|} = \ldots = \frac{\rho_S}{2\epsilon_0}\boldsymbol{a}_N$$



무한판 전하에 의한 전계의 세기는 어느 곳에서나 그 크기와 방향이 같다.

(응용예제 2.6) $\rho_S = 3\text{nC/m}^2$ at $z=1$ & $\rho_S = -8\text{nC/m}^2$ at $z=4$

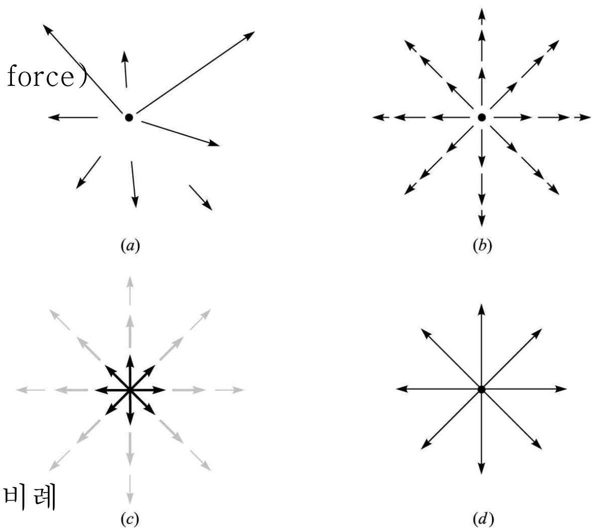
$\boldsymbol{E} = ?$ at (a) $P_A(2,\ 5,\ -5)$ (b) $P_B(4,\ 2,\ -3)$

(c) $P_C(-1,\ -5,\ 2)$ (d) $P_D(-2,\ 4,\ 5)$

2.6 전계의 유선(streamline)과 스케치

전하가 존재하면 주변에 반드시 전기장 존재

•전기장의 선; 전기력선 또는 전력선(lines of electric force)
선속 또는 속선(flux line)
방향선(directional line)
유선(stream line)



•전기력선의 표시방법
+ 전하가 있는 곳으로부터 먼 곳으로 화살표
먼 곳에서 – 전하가 있는 곳으로 화살표
→ 전기력선 사이의 간격과 전기장의 세기는 반비례