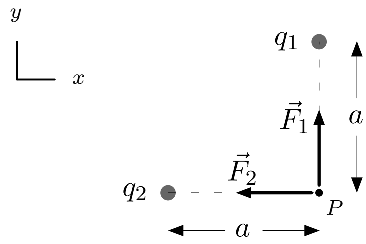
Part I: Problems

Show units.

1. Below, q_1 ($= 2.0\,\mu$C) and q_2 ($= 3.0\,\mu$C) are point charges; $a = 2.0$ mm. Find the y component (in N) of the net electric force on a point charge q ($= -4.0$ nC) at point P.

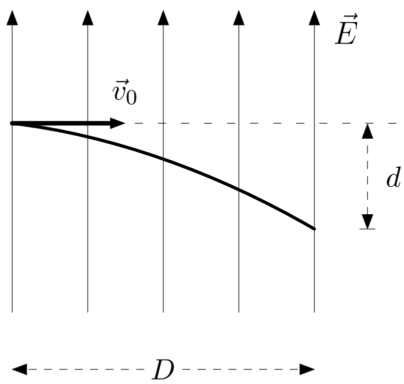
(3 points)



$$F_y = +F_1 = \frac{k|q|q_1}{a^2} = +18\,\mathrm{N}$$

2. The path of a point particle (mass $m = 2.5 \times 10^{-12}$ kg) through the uniform electric field $\vec{E} = (350\,\mathrm{N/C})\,\hat{\jmath}$ is shown below; $D = 0.40$ m and $d = 14$ cm. Find the charge q (in C) of the particle if the velocity $\vec{v}_0 = (2.0\,\mathrm{km/s})\,\hat{\imath}$. *(Give a reason for your choice of sign of q.)*

(5 points)



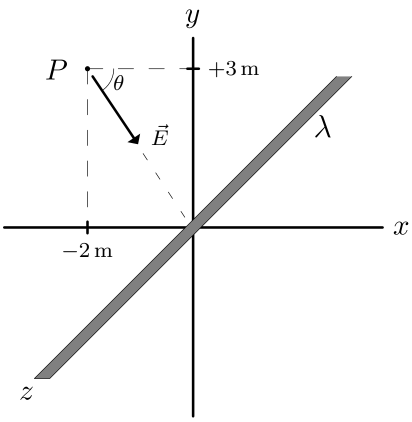
$$\left.\begin{array}{l}\Delta x = v_0 t \\ \Delta y = \frac{1}{2} a_y t^2\end{array}\right\} \xrightarrow{\Delta x = +D,\,\Delta y = -d} \quad a_y = -\frac{2d}{t^2} = -2d\left(\frac{v_0}{D}\right)^2 = -7.0 \times 10^{+6}\,\mathrm{m/s^2}$$

$$a_y = \frac{q}{m} E_y \quad \Longrightarrow \quad q = m\frac{a_y}{E_y} = -5.0 \times 10^{-8}\,\mathrm{C}$$

$$(\vec{a} \text{ opposite to } \vec{E} \Longrightarrow q < 0)$$

3. An infinite line of charge (of constant linear charge density $\lambda = -0.25\,\text{nC/m}$) lies on the z-axis below. Find the x component E_x (in N/C) of the electric field at the point P with coordinates $x = -2\,\text{m}$, $y = +3\,\text{m}$ and $z = 0\,\text{m}$. (*Define any angles you use in a diagram.*)

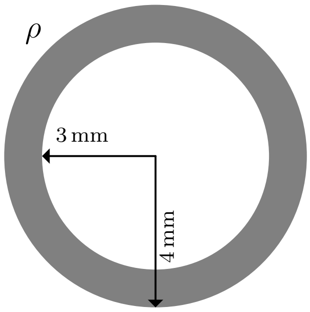
(4 points)



$$E_x = +|\vec{E}|\cos\theta = \frac{2k|\lambda|}{r}\cos\theta = \frac{2k|\lambda|}{\sqrt{13}}\frac{2}{\sqrt{13}} = 0.69\,\text{N/C}$$

4. The spherical shell of charge shown in cross-section below (of uniform volume density $\rho = 8.85 \times 10^{-6}\text{C/m}^3$) has an inner radius of 3.0 mm and an outer radius of 4.0 mm. Find the magnitude (in N/C) of the electric field 6.0 mm from the center of the shell.

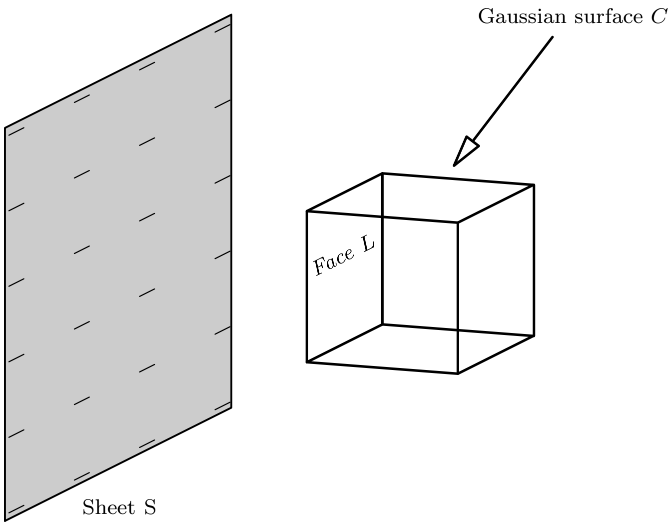
(3 points)



$$\left.\begin{aligned} |\vec{E}| &= +\frac{k|Q_{\text{encl}}|}{r^2} \\ Q_{\text{encl}} &= \rho\frac{4\pi}{3}\left[(4\,\text{mm})^3 - (3\,\text{mm})^3\right] \end{aligned}\right\} \overset{r=6\,\text{mm}}{\Longrightarrow} \quad |\vec{E}| = 3.4 \times 10^2\,\text{N/C}$$

5. Below, the left face L of the cube C (with sides of length $a = 2.0\,\text{cm}$) is parallel to a large plane sheet S of charge (with uniform surface charge density $\sigma = -4.5\,\text{nC/m}^2$). Find the electric flux Φ (in V·m) through the left face of C.

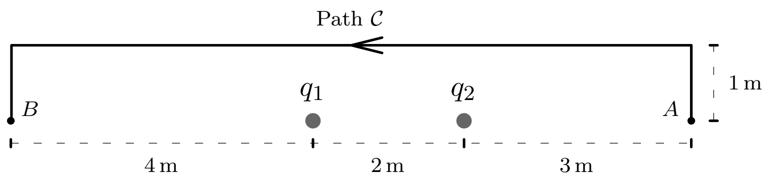
(3 points)



$$\left.\begin{aligned} E_\perp &= +|\vec{E}| = +\frac{|\sigma|}{2\epsilon_0} \\ \Phi &= E_\perp A \end{aligned}\right\} \xRightarrow{A=a^2} \quad \Phi = 0.10\,\text{V·m}$$

6. When a test charge q is moved from A to B along path $\mathcal{C}$ below, no net work is done by the electric field of point charges q_1 and q_2. Find q_2/q_1.

(4 points)



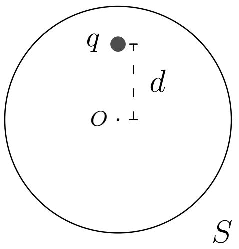
$$0 = W_{\text{Electric Field}} = -q\Delta V \quad \Longrightarrow \quad V_A = V_B$$

$$\Longrightarrow \quad k\left(\frac{q_1}{5} + \frac{q_2}{3}\right) = k\left(\frac{q_1}{4} + \frac{q_2}{6}\right)$$

$$\Longrightarrow \quad \left(\frac{1}{3} - \frac{1}{6}\right) q_2 = \left(\frac{1}{4} - \frac{1}{5}\right) q_1 \quad \Longrightarrow \frac{q_2}{q_1} = \frac{3}{10}$$

7. The point charge q below is at a distance $d = 0.20\,\text{m}$ from the center O of a spherical gaussian surface S; the flux through S is $480\,\text{V·m}$. Find the value (in V) at O of the potential of q (relative to its value at infinity).

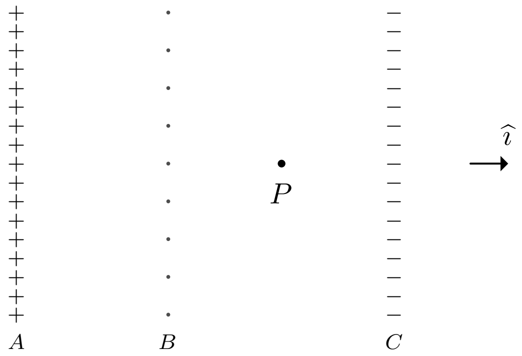
(3 points)



$$\left.\begin{array}{l} q = \epsilon_0 \Phi \\ \\ V = k\dfrac{q}{d} \end{array}\right\} \overset{k=1/(4\pi\epsilon_0)}{\Longrightarrow} \quad V = \underbrace{\frac{\Phi}{4\pi d} = 190\,\text{V}}_{\Phi = 480\,\text{V·m}}$$

8. Below, A, B and C are three large parallel sheets of charge; A and C have uniform surface charge densities of $\sigma_A = +17.7\,\text{nC/m}^2$ and $\sigma_C = -17.7\,\text{nC/m}^2$. At point P, the net electric field $\vec{E} = (1250\,\text{V/m})\,\hat{\imath}$. Find the uniform surface charge density σ_B (in C/m^2) of sheet B.

(4 points)



$$E_{Ax} = +\frac{|\sigma_A|}{2\epsilon_0} = +1000\,\text{V/m}, \qquad E_{Cx} = +\frac{|\sigma_C|}{2\epsilon_0} = +1000\,\text{V/m}$$

$$\Longrightarrow \quad E_{Bx} = E_x - E_{Ax} - E_{Bx} = -750\,\text{V/m}$$

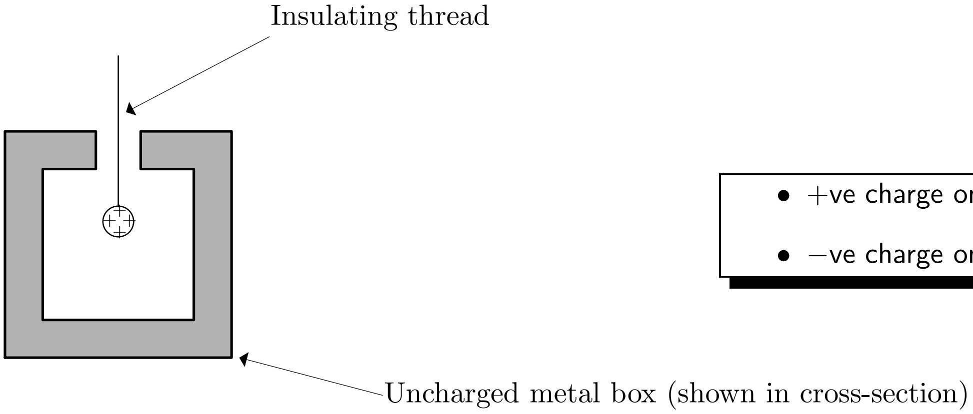
$$\Longrightarrow \quad |\sigma_B| = 2\epsilon_0 |E_{Bx}| = 13.3\,\text{nC/m}^2$$

$E_{Bx} < 0$ at $P \Longrightarrow \vec{E}_B$ pointing *toward* sheet $B \Longrightarrow \sigma_B < 0 \Longrightarrow \sigma_B = -13.3\,\text{nC/m}^2$

Part II: Conceptual Questions

1. You have to draw charge distributions (with + and − signs) in the figures below. [If you think that there are no charges on an object (box or ball), then write this answer down.]

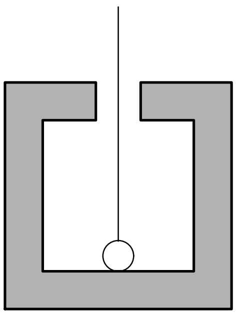
Figure 1: a charged metal ball is lowered into an uncharged metal box. *(1 point)*



- +ve charge on outer surface
- −ve charge on inner surface

Draw the charge distribution (if any) on the metal box.

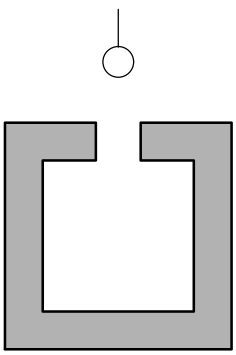
Figure 2: the metal ball is in contact with the metal box for a long time. *(1 point)*



- +ve charge on outer surface of box
- no charge on ball or inner surface of box

Draw the charge distributions (if any) on the metal box *and* on the metal ball.

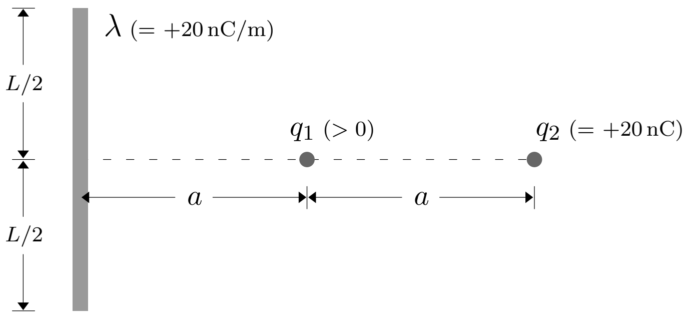
Figure 3: the metal ball is then taken out of the metal box. *(1 point)*



- +ve charge on outer surface of box (and no charge inside)
- −ve charge on side of ball nearest box,
  +ve charge on side furthest from box

Draw the charge distributions (if any) on the metal box *and* on the metal ball.

2. Point charge q_1 below is halfway between a point charge q_2 and a rod of charge of length L $(= 1\,\mathrm{m})$ and constant linear charge density λ.



The questions below are about the net electric force $\vec{F}$ on q_1. **Choose answers from the following list.**

Answers

(a) $\vec{F}$ is bigger and to the left.
(b) $\vec{F}$ is bigger and to the right.
(c) $\vec{F}$ is smaller and to the left.
(d) $\vec{F}$ is smaller and to the right.
(e) $|\vec{F}|$ is the same but the direction is opposite.
(f) $\vec{F}$ does *not* change.
(g) $\vec{F} = 0$.

Questions about $\vec{F}$ (for changes to the ***initial*** set-up shown in the figure).

How does $\vec{F}$ change when:	Answer [eg. (a), (b), ...]
1) **$\boldsymbol{\lambda}$ is made smaller?**	(a)
2) **$\boldsymbol{L}$ is made smaller (but the total charge of the rod is not changed)?**	(c)
3) **$\boldsymbol{q_1}$ is made smaller (but its sign is not changed)?**	(c)
4) **$\boldsymbol{q_2}$ is increased to $+30\,\mathrm{nC}$?**	(a)

(2 points)