Applied Physics BS 101
Homework (BS-SE-1 AB)

The Electric Field

Problem 1: An object having a net charge of 24μC is placed in a uniform electric field of 610 N/C directed vertically. What is the mass of this object if it "floats'' in the field?

P23.14 $\sum F_y = 0 : \; QE\hat{\mathbf{j}} + mg(-\hat{\mathbf{j}}) = 0$

$$\therefore m = \frac{QE}{g} = \frac{(24.0 \times 10^{-6}\ \text{C})(610\ \text{N/C})}{9.80\ \text{m/s}^2} = \boxed{1.49\ \text{grams}}$$

Ans.: 1.49g

Problem 2: Two point charges are located on the x axis. The first is a charge $+Q$ at x=-a. The second is an unknown charge located at x=3a. The net electric field these charges produce at the origin has a magnitude of $2kQ/a^2$. What are the two possible values of the unknown charge?

*P23.17 The first charge creates at the origin field $\frac{k_e Q}{a^2}$ to the right.

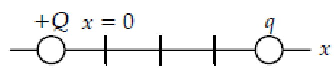


FIG. P23.17

Suppose the total field at the origin is to the right. Then q must be negative:

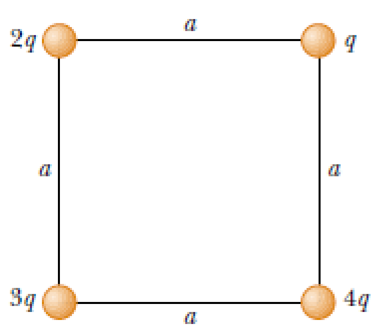
$$\frac{k_e Q}{a^2}\hat{\mathbf{i}} + \frac{k_e q}{(3a)^2}(-\hat{\mathbf{i}}) = \frac{2k_e Q}{a^2}\hat{\mathbf{i}} \qquad \boxed{q = -9Q}.$$

In the alternative, the total field at the origin is to the left:

$$\frac{k_e Q}{a^2}\hat{\mathbf{i}} + \frac{k_e q}{9a^2}(-\hat{\mathbf{i}}) = \frac{2k_e Q}{a^2}(-\hat{\mathbf{i}}) \qquad \boxed{q = +27Q}.$$

Ans.: **(**a) q=-9Q if field is towards right and q=+27Q if if field is towards left.

Problem 3: Four point charges are at the corners of a square of side a as shown in Figure.
(a) Determine the magnitude and direction of the electric field at the location of charge q.
(b) What is the resultant force on q?



P23.21 (a) $$\mathbf{E}=\frac{k_e q_1}{r_1^2}\hat{\mathbf{r}}_1+\frac{k_e q_2}{r_2^2}\hat{\mathbf{r}}_2+\frac{k_e q_3}{r_3^2}\hat{\mathbf{r}}_3=\frac{k_e(2q)}{a^2}\hat{\mathbf{i}}+\frac{k_e(3q)}{2a^2}\left(\hat{\mathbf{i}}\cos 45.0°+\hat{\mathbf{j}}\sin 45.0°\right)+\frac{k_e(4q)}{a^2}\hat{\mathbf{j}}$$

$$\mathbf{E}=3.06\frac{k_e q}{a^2}\hat{\mathbf{i}}+5.06\frac{k_e q}{a^2}\hat{\mathbf{j}}=\boxed{5.91\frac{k_e q}{a^2}\text{ at }58.8°}$$

(b) $$\mathbf{F}=q\mathbf{E}=\boxed{5.91\frac{k_e q^2}{a^2}\text{ at }58.8°}$$

Ans.: $E=3.06\frac{kq}{a^2}i+5.06\frac{kq}{a^2}j,\ \ F=3.06\frac{kq^2}{a^2}i+5.06\frac{kq^2}{a^2}j$

Problem 4: An electron and a proton are each placed at rest in an electric field of 520 N/C. Calculate the speed of each particle 48.0 ns after being released.

P23.42 $F=qE=ma \qquad a=\frac{qE}{m}$

$v_f=v_i+at \qquad v_f=\frac{qEt}{m}$

electron: $$v_e=\frac{\left(1.602\times10^{-19}\right)(520)\left(48.0\times10^{-9}\right)}{9.11\times10^{-31}}=\boxed{4.39\times10^{6}\ \text{m/s}}$$

in a direction opposite to the field

proton: $$v_p=\frac{\left(1.602\times10^{-19}\right)(520)\left(48.0\times10^{-9}\right)}{1.67\times10^{-27}}=\boxed{2.39\times10^{3}\ \text{m/s}}$$

in the same direction as the field

Ans.: Electron; $4.39\times10^6\ m/s$, **Proton;** $2.39\times10^3\ m/s$

Problem 5: A proton accelerates from rest in a uniform electric field of 640 N/C. At some later time, its speed is $1.2\times10^6\ m/s$ (nonrelativistic, because v is much less than the speed of light). (a) Find the acceleration of the proton. (b) How long does it take the proton to reach this speed? (c) How far has it moved in this time? (d) What is its kinetic energy at this time?

P23.43 (a) $$a=\frac{qE}{m}=\frac{1.602\times10^{-19}(640)}{1.67\times10^{-27}}=\boxed{6.14\times10^{10}\ \text{m/s}^2}$$

(b) $v_f=v_i+at \qquad 1.20\times10^6=\left(6.14\times10^{10}\right)t \qquad t=\boxed{1.95\times10^{-5}\ \text{s}}$

(c) $x_f-x_i=\frac{1}{2}\left(v_i+v_f\right)t \qquad x_f=\frac{1}{2}\left(1.20\times10^6\right)\left(1.95\times10^{-5}\right)=\boxed{11.7\ \text{m}}$

(d) $$K=\frac{1}{2}mv^2=\frac{1}{2}\left(1.67\times10^{-27}\ \text{kg}\right)\left(1.20\times10^6\ \text{m/s}\right)^2=\boxed{1.20\times10^{-15}\ \text{J}}$$

Ans.: $(a) 6.14 \times \frac{10^{10} m}{s^2}, (b) 1.95 \times 10^{-5} s, (c) 11.7m, (d) 1.2 \times 10^{-15} J$

Problem 6: A dipole with charge 6.0μC and separation 4.0 mm is immersed in an *E*-field of strength $3.0 \times 10^6 N/C$. Calculate the maximum torque.

Solution: $\tau_{max} = 2aqE = 2 \cdot 4.0 \times 10^{-3}\,\text{m} \cdot 6.0 \times 10^{-6}\,\text{C} \cdot 3.0 \times 10^6\,\text{N/C} = 144 \times 10^{-3}\,\text{Nm}$

Ans.: $\tau = 72 \times 10^{-3} Nm$

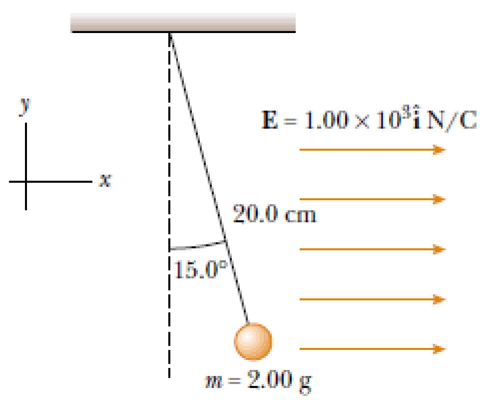
Problem 7: A dipole with charge 6.0μC and separation 4.0 mm is immersed in an *E*-field of strength $3.0 \times 10^6 N/C$ such that angle between dipole moment and electric field is 70. Calculate the work required to rotate the dipole moment in the orientation where energy of the system (electric field +dipole) is minimum.

Solution: $W = -pE\cos\theta\Big|_{70^o}^{20^o} = 0.144\,\text{N}\cdot\text{m}(\cos 70^o - \cos 20^o) = -0.086\,\text{J}$

The electric field has done 0.086J of work on the dipole, and this is the amount of energy stored in the dipole-field system.

Ans.: $W = -0.046J$

Problem 8: A small, 2g plastic ball is suspended by a 20.cm-long string in a uniform electric field as shown in Figure. If the ball is in equilibrium when the string makes a 15.0° angle with the vertical, what is the net charge on the ball?



P23.54 From the free-body diagram shown,

$\sum F_y = 0$: $T\cos 15.0° = 1.96 \times 10^{-2}\ \text{N}$.

So $T = 2.03 \times 10^{-2}\ \text{N}$.

From $\sum F_x = 0$, we have $qE = T\sin 15.0°$

or $q = \frac{T\sin 15.0°}{E} = \frac{(2.03 \times 10^{-2}\ \text{N})\sin 15.0°}{1.00 \times 10^3\ \text{N/C}} = 5.25 \times 10^{-6}\ \text{C} = \boxed{5.25\ \mu\text{C}}$.

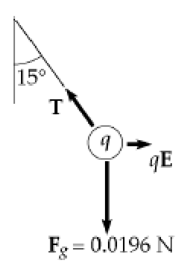
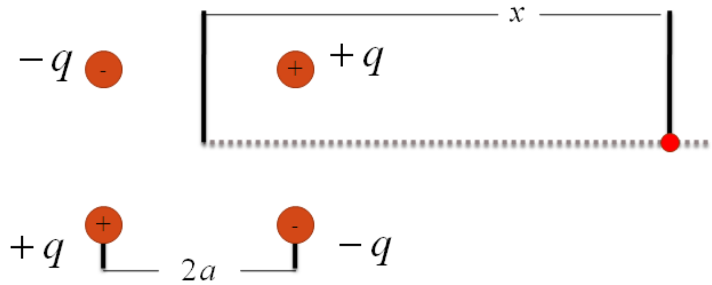


FIG. P23.54

Ans.: $q = 5.25\mu C$

Problem 9: If x >> a for electrical quadrupole shown below, show that electric field at point P is given by

$$E = \frac{3(2qa^2)}{2\pi\varepsilon_0 x^4}$$



Problem 10: If z >> d for electrical quadrupole shown below, show that electric field at point P is given by

$$E = \frac{3(2qd^2)}{4\pi\varepsilon_0 z^4}$$