PHYS143
Physics for Engineers
Tutorial - Chapter 23 - Solutions

Question 1

An electron with a speed of 3.00×10^6 m/s moves into a uniform electric field of magnitude 1.00×10^3 N/C. The field lines are parallel to the electron's velocity and pointing in the same direction as the velocity. How far does the electron travel before it is brought to rest?

The electric force is opposite to the field direction, so it is opposite to the velocity of the electron. From Newton's second law, the acceleration the electron will be

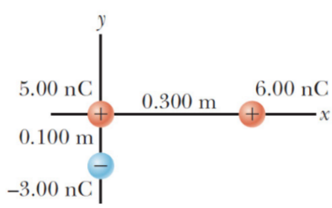
$$a_x = \frac{F_x}{m} = \frac{qE_x}{m} = \frac{(-1.60\times10^{-19}\ \text{C})(1.00\times10^{3}\ \text{N/C})}{9.11\times10^{-31}\ \text{kg}}$$
$$= -1.76\times10^{14}\ \text{m/s}^2$$

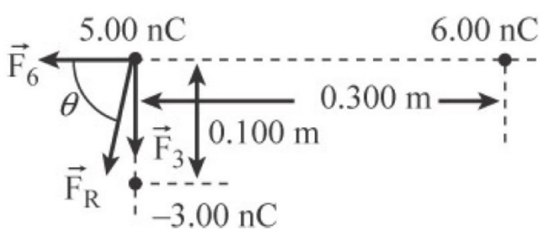
The kinematics equation $v_x^2 = v_{0x}^2 + 2a_x(\Delta x)$, with $v_x = 0$, gives the stopping distance as

$$\Delta x = \frac{-v_{0x}^2}{2a_x} = \frac{-(3.00\times10^{6}\ \text{m/s})^2}{2(-1.76\times10^{14}\ \text{m/s}^2)} = 2.56\times10^{-2}\ \text{m} = 2.56\ \text{cm}$$

Question 2

Three point charges are arranged as shown in the Figure. Find (a) the magnitude and (b) the direction of the electric force on the particle at the origin.





The particle at the origin carries a positive charge of 5.00 nC. The electric force between this particle and the –3.00-nC particle located on the $-y$ axis will be attractive and point toward the $-y$ direction and is shown with $\vec{F}_3$ in the diagram, while the electric force between this particle and the 6.00-nC particle located on the x axis will be repulsive and point toward the $-x$ direction, shown with $\vec{\mathbf{F}}_6$ in the diagram. The resultant force should point toward the third quadrant, as shown in the diagram with $\vec{\mathbf{F}}_R$. Although the charge on the x axis is greater in magnitude, its distance from the origin is three times larger than the –3.00-nC charge. We expect the resultant force to make a small angle with the $-y$ axis and be approximately equal in magnitude with F_3.

From the diagram above, the two forces are perpendicular, and the components of the resultant force are

$$F_x = -F_6 = -\left(8.99\times10^9\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}\right)\frac{(6.00\times10^{-9}\ \mathrm{C})(5.00\times10^{-9}\ \mathrm{C})}{(0.300\ \mathrm{m})^2}$$

$$= -3.00\times10^{-6}\ \mathrm{N}\quad(\text{to the left})$$

$$F_y = -F_3 = -\left(8.99\times10^9\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}\right)\frac{(3.00\times10^{-9}\ \mathrm{C})(5.00\times10^{-9}\ \mathrm{C})}{(0.100\ \mathrm{m})^2}$$

$$= -1.35\times10^{-5}\ \mathrm{N}\quad(\text{downward})$$

(a) The forces are perpendicular, so the magnitude of the resultant is

$$F_R = \sqrt{(F_6)^2 + (F_3)^2} = \boxed{1.38\times10^{-5}\ \mathrm{N}}$$

(b) The magnitude of the angle of the resultant is

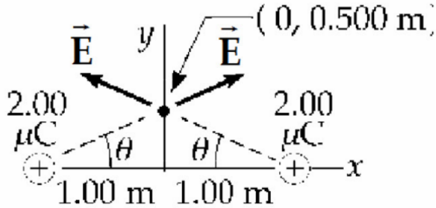
$$\theta = \tan^{-1}\left(\frac{F_3}{F_6}\right) = 77.5^\circ$$

The resultant force is in the third quadrant, so the direction is

$$\boxed{77.5^\circ\ \text{below}\ -x\ \text{axis}}$$

Question 3

Two 2.00-μC point charges are located on the x axis. One is at x = 1.00 m, and the other is at x = -1.00 m. (a) Determine the electric field on the y axis at y = 0.500 m. (b) Calculate the electric force on a (-3.00-μC) charge placed on the y axis at y = 0.500 m.



(a) The distance from each charge to the point at y = 0.500 m is

$$d = \sqrt{(1.00\text{ m})^2 + (0.500\text{ m})^2} = 1.12\text{ m}$$

the magnitude of the electric field from each charge at that point is then given by

$$E = \frac{k_e q}{r^2} = \frac{(8.99 \times 10^9\text{ N}\cdot\text{m}^2/\text{C}^2)(2.00 \times 10^{-6}\text{ C})}{(1.12\text{ m})^2} = 14\,400\text{ N/C}$$

The x components of the two fields cancel and the y components add, giving

$$E_x = 0 \text{ and } \quad E_y = 2(14\,400\text{ N/C})\sin 26.6° = 1.29 \times 10^4\text{ N/C}$$

so $\boxed{\vec{\mathbf{E}} = 1.29 \times 10^4\,\hat{\mathbf{j}}\text{ N/C}}$.

(b) The electric force at this point is given by

$$\vec{\mathbf{F}} = q\vec{\mathbf{E}} = (-3.00 \times 10^{-6}\text{ C})(1.29 \times 10^4\text{ N/C}\hat{\mathbf{j}})$$

$$= \boxed{-3.86 \times 10^{-2}\,\hat{\mathbf{j}}\text{ N}}$$

Question 4

A proton accelerates from rest in a uniform electric field of 640 N/C. At one later moment, its speed is 1.20 Mm/s (nonrelativistic because v is much less than the speed of light). (a) Find the acceleration of the proton. (b) Over what time interval does the proton reach this speed? (c) How far does it move in this time interval?

(a) We obtain the acceleration of the proton from the particle under a net force model, with $F = qE$ representing the electric force:

$$a = \frac{F}{m} = \frac{qE}{m} = \frac{(1.602 \times 10^{-19}\text{ C})(640\text{ N/C})}{1.67 \times 10^{-27}\text{ kg}} = \boxed{6.14 \times 10^{10}\text{ m/s}^2}$$

(b) The particle under constant acceleration model gives us $v_f = v_i + at$, from which we obtain

$$t = \frac{v_f - 0}{a} = \frac{1.20 \times 10^6\text{ m/s}}{6.14 \times 10^{10}\text{ m/s}^2} = \boxed{19.5\ \mu\text{s}}$$

(c) Again, from the particle under constant acceleration model,

$$\Delta x = v_i t + \frac{1}{2}at^2 = 0 + \frac{1}{2}(6.14 \times 10^{10}\text{ m/s}^2)(19.5 \times 10^{-6}\text{ s})^2$$

$$= \boxed{11.7\text{ m}}$$