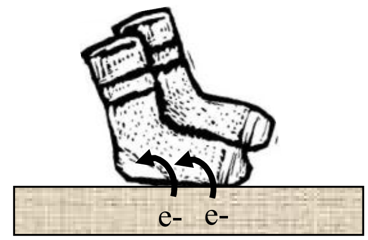
UNIT 2 REVIEW #1: ELECTRIC FIELDS AND FORCES (SOLUTIONS)

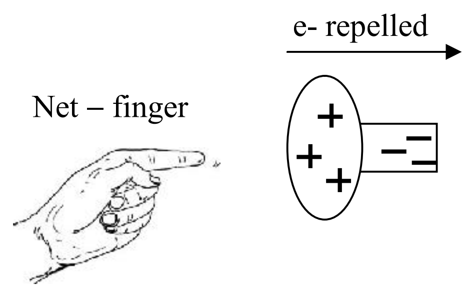
1. a) Charging by friction



When the person drags his socks across the rug, friction creates heat energy. This excites the electrons in the socks and the rug, which makes them easier to remove from the atoms. The socks must be higher on the electrostatic series, which means that the sock material has a stronger hold on the electrons than the rug material does. As a result, the socks strip the excited electrons from the rug, thereby gaining a net negative charge.

The electrons then travel (conduct) from socks and through the rest of the body. In this way, the body gains a net negative charge.

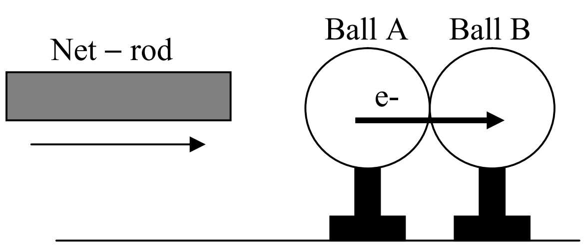
b) Induced separation of charge

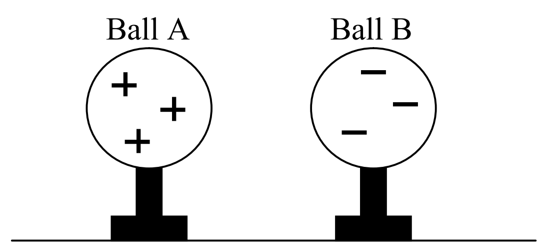


When the net negative finger is brought close to the handle, it repels the electrons inside the handle (due to like charges). This induces a net positive charge in the part of the handle that is closest to the finger. Due to the strong attraction between the finger and the handle (opposite charges), the electrons conduct through the air from the finger into the handle. This is called an electrical discharge.

The resulting flow of electrons (i.e. current) through the finger is painful, which leads to the feeling of being shocked.

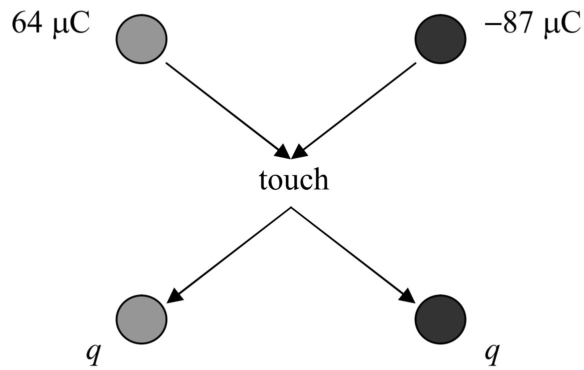
2. When the net negative rod is brought near, electrons are repelled by it (like charges). Thus, electrons travel from Ball A into Ball B.





Thus, ball A gains a net positive charge by induction, since the net negative rod never came into contact with it (Note: Ball B acts like a ground).
Ball B gains a net negative charge by conduction, since electrons conducted from ball A into Ball B.

3. Since the spheres are identical, when they touch, they will achieve balanced (equal) charges.



Conservation of charge

$$q_{Ti} = q_{Tf}$$

$$q_1 + q_2 = 2q$$

$$q = \frac{q_1 + q_2}{2}$$

$$= \frac{64\mu C + (-87\mu C)}{2} = -11.5\ \mu C$$

Since they are like charges, they will repel.

$$F_e = \frac{k\, q_1 q_2}{r^2} = \frac{k\, q^2}{r^2}$$

$$= \frac{(8.99\times10^9\ Nm^2/C^2)(11.5\times10^{-6}\ C)^2}{(0.148\ m)^2}$$

$$= 54.3\ \text{N (away from each other)}$$

4. Let $q,\ 6q$ be the two charges

$$F_e = \frac{k\, q_1 q_2}{r^2} = \frac{k\, q\,(6q)}{r^2} = \frac{6k\, q^2}{r^2}$$

$$F_e\, r^2 = 6k\, q^2 \qquad q^2 = \frac{F_e\, r^2}{6k} \qquad q = \sqrt{\frac{F_e\, r^2}{6k}}$$

$$q = \sqrt{\frac{(8.15\times10^{-6}\ N)(72.0\times10^{-3}\ C)^2}{6\,(8.99\times10^9\ Nm^2/C^2)}} = 8.85\times10^{-10}\ \text{C}$$

Then, $q_2 = 6q = 6\,(8.85\times10^{-10}\ \text{C}) = 5.31\times10^{-9}\ \text{C}$

5. Method 1: Using proportions and $F_e = \dfrac{k\,q_1 q_2}{r^2}$

$F_e \propto q$: If $q_1 \times 2$, then $F_e \times 2$; If $q_2 \times 2$, then $F_e \times 2$

$F_e \propto \dfrac{1}{r^2}$: If $r \times 3$, then $F_e \times \dfrac{1}{3^2}$

So, the new electric force would be $F \times 2 \times 2 \times \dfrac{1}{3^2} = \dfrac{4}{9}F$

Method 2: Let the original electric force be $F = \dfrac{k\,q_1 q_2}{r^2}$

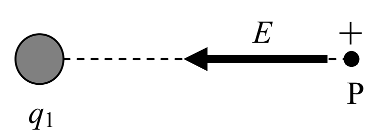
Then, the new electric force would be

$$F_e = \frac{k(2q_1)(2q_2)}{(3r)^2} = \frac{4}{9}\cdot\frac{k\,q_1 q_2}{r^2} = \frac{4}{9}F$$

6. Magnitude:

$$\left|\vec{E}\right| = \frac{kq_1}{r^2} \qquad \left|\vec{E}\right| r^2 = k\,q_1 \qquad q_1 = \frac{\left|\vec{E}\right| r^2}{k}$$

$$q_1 = \frac{(4.18\times10^3\,N/C)(0.735\,m)^2}{8.99\times10^9\ Nm^2/C^2} = 2.51 \times 10^{-7}\ \text{C}$$



Nature of charge:

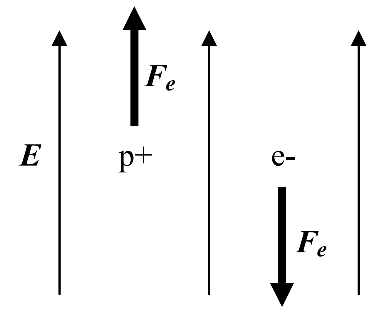
Electric field goes towards a negative central charge
(thus attracting a positive test charge). Thus, the central charge is negative.

Therefore, the central charge is -2.51×10^{-7} C.

7. Proton

Since a proton has a positive charge, the electric field goes in the same direction as the electric force.

$$\left|\vec{E}\right| = \frac{F_e}{q} = \frac{8.35\times10^{-7}\,N}{1.60\times10^{-19}\,C} = 5.219 \times 10^{12}\ \text{N/C}$$

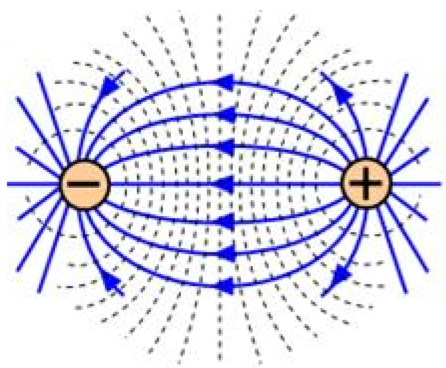


Electron

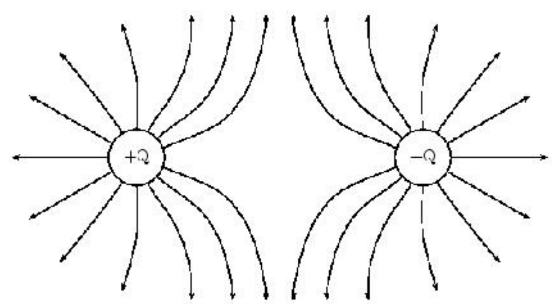
When you place an electron at the same location, the electric field does not change. However, since the electron has a negative charge, the electric force will be n the opposite direction to the electric field. So, the electric force is towards the South.

$$\left|\vec{E}\right| = \frac{F_e}{q} \qquad F_e = q\left|\vec{E}\right| = (1.60 \times 10^{-19}\ \text{C})\,(5.219 \times 10^{12}\ \text{N/C}) = 8.35 \times 10^{-7}\ \text{N}$$

8. a)



b)

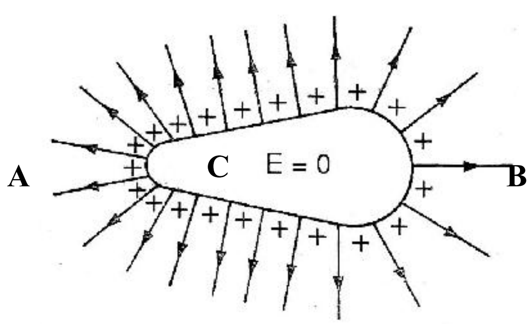


Electric field goes away from the positive charge and towards the negative charge.

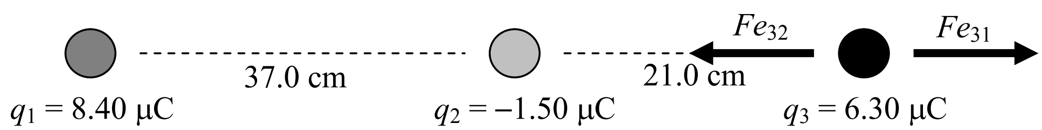
9. At location A, the electric field is directed outward and perpendicular to the surface. Since the charge is more concentrated here (at a point), the electric field is stronger.

At location B, the field is still perpendicular to the surface, but the concentration of charge would be less, and so, the electric field would be weaker than A.

At location C, there no electric field (inside a hollow metal container).



10.



Since q_1 has the same charge as q_3, it will repel q_3. The distance between q_1 and q_3 is 58.0 cm.

$$Fe_{31} = \frac{k\,q_3 q_1}{r_{31}^2} = \frac{(8.99\times10^9\,Nm^2/C^2)(6.30\times10^{-6}\,C)(8.40\times10^{-6}\,C)}{(0.580\,m)^2} = 1.4142\text{ N (right)}$$

Since q_2 has the opposite charge as q_3, it will attract q_3. The distance between q_2 and q_3 is 21.0 cm.

$$Fe_{32} = \frac{k\,q_3 q_2}{r_{32}^2} = \frac{(8.99\times10^9\,Nm^2/C^2)(6.30\times10^{-6}\,C)(1.50\times10^{-6}\,C)}{(0.210\,m)^2} = 1.9264\text{ N (left)}$$

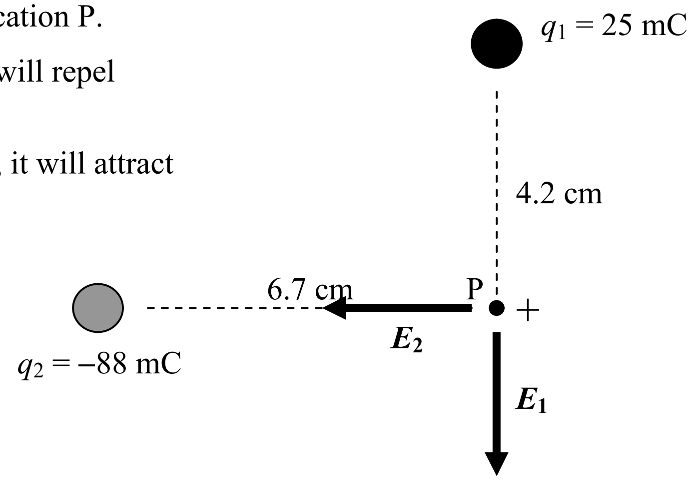
The net force is the vector sum: (Ref: Right +, Left −)

$$net\,\vec{F}_e = \vec{F}e_{31} + \vec{F}e_{32} = (+1.4142\text{ N}) + (-1.9264\text{ N}) = -0.512\text{ N} = 0.512\text{ N left}$$

11. Place a positive test charge at location P.

Since q_1 has the same charge, it will repel the positive test charge.

Since q_2 has the opposite charge, it will attract the positive test charge.



$$|\vec{E}_1| = \frac{k\,q_1}{r_1^2} = \frac{(8.99\times10^9\,Nm^2/C^2)(25\times10^{-3}\,C)}{(0.042\,m)^2} = 1.274\times10^{11}\text{ N/C (South)}$$

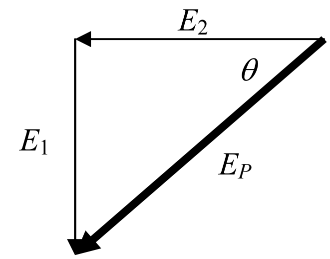
$$|\vec{E}_2| = \frac{k\,q_2}{r_2^2} = \frac{(8.99\times10^9\,Nm^2/C^2)(88\times10^{-3}\,C)}{(0.067\,m)^2} = 1.762\times10^{11}\text{ N/C (West)}$$

Solving the vector triangle,

$$\left|\vec{E}_P\right| = \sqrt{E_1^2 + E_2^2}$$

$$= \sqrt{\left(1.274\times10^{11}\,N/C\right)^2 + \left(1.762\times10^{11}\,N/C\right)^2}$$

$$= 2.2 \times 10^{11}\text{ N/C}$$



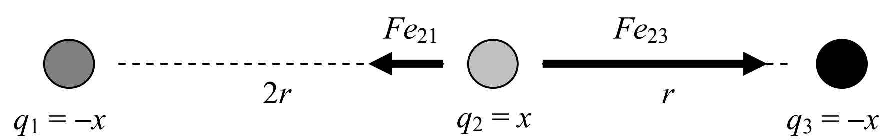
$$\tan\theta = \frac{E_1}{E_2} = \frac{1.274\times10^{11}}{1.762\times10^{11}}$$

$$\theta = \tan^{-1}(0.723) = 36°\text{ S of W (or 54° W of S)}$$

12. a) Based on $F_e = \dfrac{k\,q_1 q_2}{r^2}$, $F_e \propto \dfrac{1}{r^2}$. So, if $r \times 2$, then $F_e \times \dfrac{1}{2^2}$.

Thus, since the charges for q_1 and q_3 are the same, Fe_{21} will be 1/4 the magnitude of Fe_{23}.

Since they both have opposite charges with q2, they will both atttract.

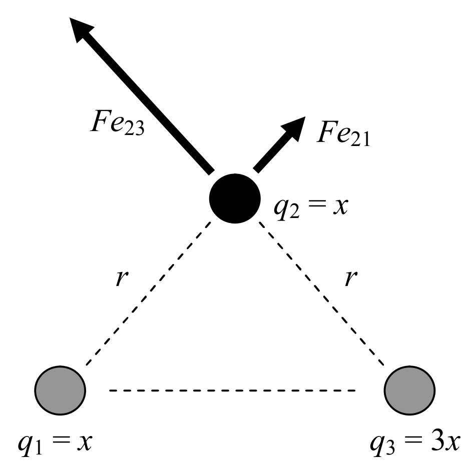


b) Based on $F_e = \dfrac{k\,q_1 q_2}{r^2}$, $F_e \propto q$.

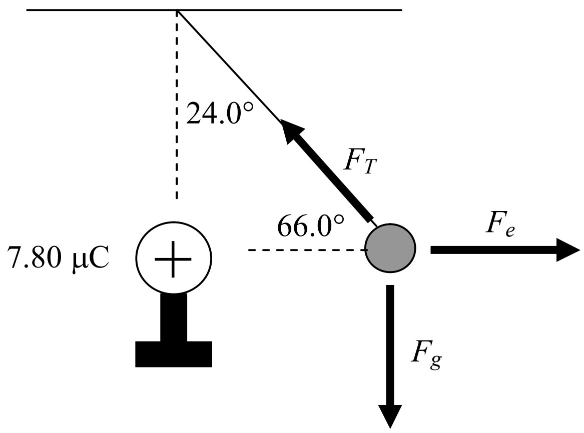
So, if $q \times 3$, then $F_e \times 3$.

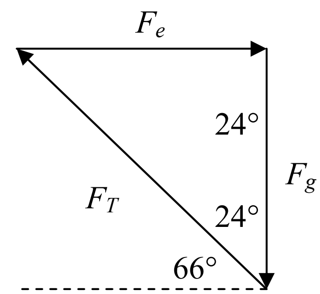
Thus, since the distances from each are the same, Fe_{23} will be 3 times larger than Fe_{21}.

Also, since they both have the same charge as q_2, they will both repel q_2.



13. a)





b) Since the pith ball is suspended, then the **forces must be balanced** (i.e. the net force is zero).

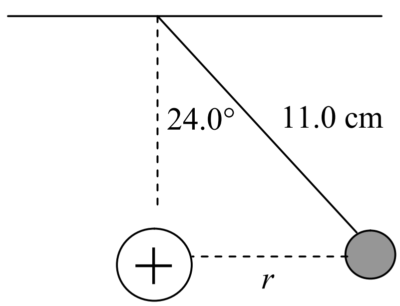
$$\vec{F}_{net} = \vec{F}_e + \vec{F}_g + \vec{F}_T = 0$$

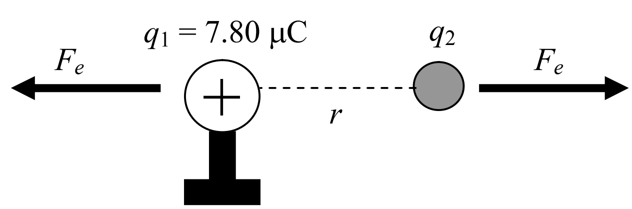
This leads to the vector triangle shown above right.

$$F_g = mg \;=\; (0.038 \text{ kg})\,(9.81 \text{ N/kg}) \;=\; 0.37278 \text{ N}$$

$$\tan 24° = \frac{F_e}{F_g} \qquad F_e = F_g \tan 24° \;=\; (0.37278 \text{ N}) \tan 24° \;=\; 0.166 \text{ N}$$

c)





$$\sin 24° = \frac{r}{11} \qquad r = 11 \sin 24° \;=\; 4.474 \text{ cm}$$

$$F_e = \frac{k\,q_1 q_2}{r^2} \qquad F_e r^2 = k\,q_1 q_2 \qquad q_2 = \frac{F_e r^2}{kq_1}$$

$$q_2 = \frac{(0.166\,N)(0.0474\,m)^2}{(8.99\times10^9\,Nm^2/C^2)(7.80\times10^{-6}\,C)} \;=\; 5.32\times10^{-9} \text{ C}$$

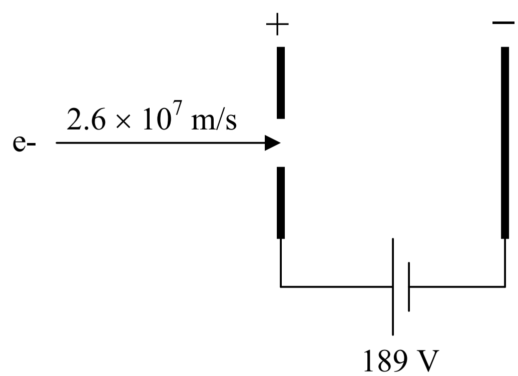
14. a) $\Delta V = \dfrac{\Delta E}{q}$ The change in kinetic energy is negative, since it is decreasing.

$\Delta E_k = -q\,\Delta V$ $\qquad$ $\cancel{E_{kf}} - E_{ki} = -q\,\Delta V$ $\qquad$ $-E_{ki} = -q\,\Delta V$

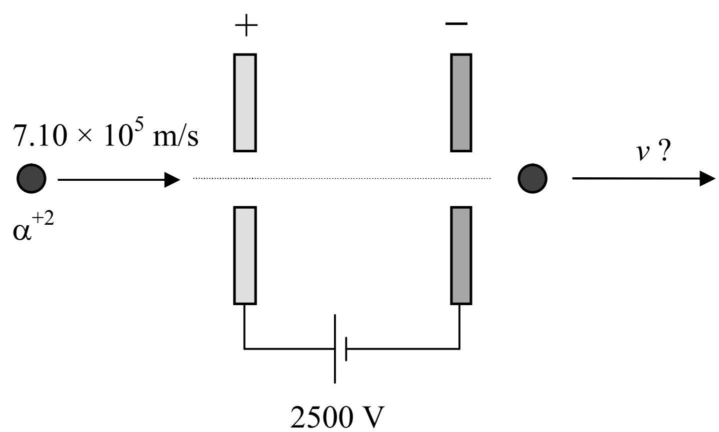
$E_{ki} = q\,\Delta V$ $\qquad$ $\dfrac{1}{2}mv^2 = q\,\Delta V$ $\qquad$ $\Delta V = \dfrac{mv^2}{2q}$

$$\Delta V = \frac{(9.11\times10^{-31}\,kg)(8.15\times10^{6}\,m/s)^2}{2\,(1.60\times10^{-19}\,C)} \quad = \quad 189\text{ V}$$

b) The far plate must be negative, so that it will repel the electron (like charges).



15. The alpha particle is attracted to the negative plate. Thus, it speeds up, which means that its kinetic energy is increasing (positive change).



$\Delta V = \dfrac{\Delta E}{q}$

$\Delta E_k = +q\,\Delta V$

$E_{kf} - E_{ki} = q\,\Delta V$

$E_{kf} = E_{ki} + q\,\Delta V \quad = \quad \dfrac{1}{2}mv_i^2 + q\,\Delta V$

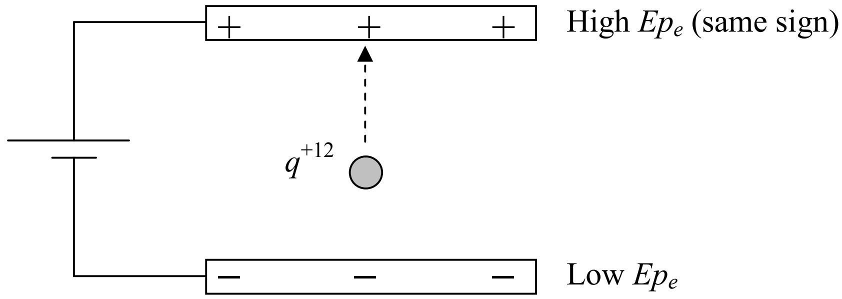
$= 0.5\,(6.65\times10^{-27}\text{ kg})\,(7.10\times10^{5}\text{ m/s})^2 + 2\,(1.60\times10^{-19}\text{ C})\,(2500\text{ V})$

$= 2.476\times10^{-15}\text{ J}$

Then, $E_{kf} = \dfrac{1}{2}mv^2$ $\qquad$ $v^2 = \dfrac{2E_{kf}}{m}$ $\qquad$ $v = \sqrt{\dfrac{2E_{kf}}{m}}$

$$v = \sqrt{\frac{2\,(2.476\times10^{-15}\,J)}{6.65\times10^{-27}\,kg}} \quad = \quad 8.63\times10^{5}\text{ m/s}$$

16. a)

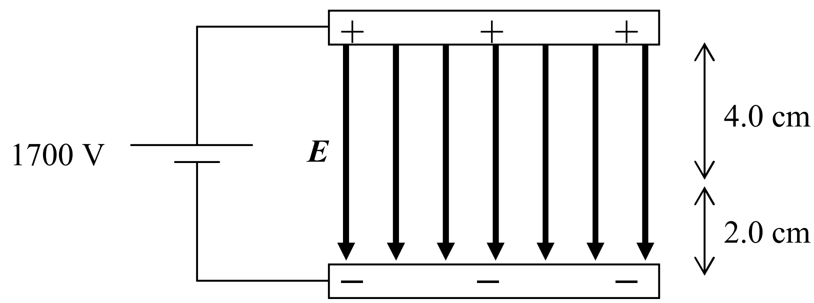


Since the object has 12 electrons in deficit, it has a positive charge (specifically, $+12e$).

A charge has high electric potential energy when it is near a plate with the same sign. Since this positive charge is moving towards the positive plate, it is gaining electric potential energy.

b) Direction:

The electric field is a uniform field that goes from the positive plate to the negative plate.



Magnitude:

If you use the full 1700 V, then you must use the full distance between the plates.

$$\left|\vec{E}\right| = \frac{\Delta V}{\Delta d} = \frac{1700\,V}{0.060\,m} = 2.8 \times 10^{4} \text{ V/m}$$

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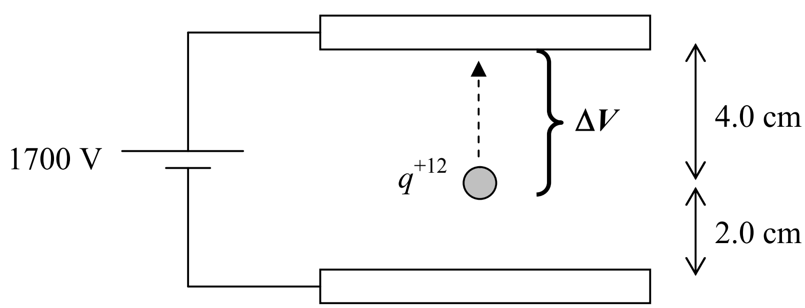
c) Method 1: Energetics

It does not go through the full 1700 V. In fact,

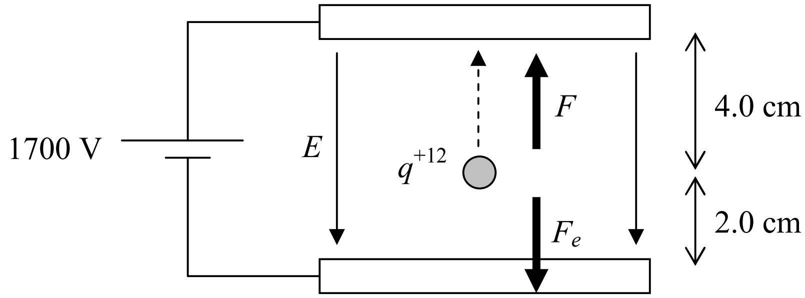


$$\Delta V = \frac{4}{6}(1700\,V)$$
$$= 1133.33 \text{ V}$$

Then, the minimum work would be

$$W = \Delta E = q\Delta V$$
$$= 12\,(1.60 \times 10^{-19}\text{ C})\;(1133.33\text{ V})$$
$$= 2.2 \times 10^{-15}\text{ J}$$

Method 2: Dynamics



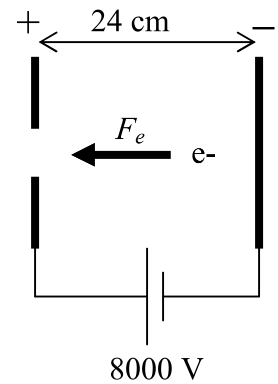
If it is minimum work, then the charge is moving in uniform motion (balanced forces). This means that the applied force must be equal and opposite to the electric force.

$$F = F_e = q|\vec{E}| = 12\,(1.60 \times 10^{-19}\text{ C})\ (2833.33\text{ N/C}) = 5.44 \times 10^{-14}\text{ N}$$

The charge is moved through a displacement of 4.0 cm, so

$$W = F \cdot d = (5.44 \times 10^{-14}\text{ N})\,(0.040\text{ m}) = 2.2 \times 10^{-15}\text{ J}$$

17. a) Direction:



The negative plate will repel the electron (like charges). Thus, the electric force will act towards the left.

Since the electric force is the only force, the acceleration will also be to the left.

Magnitude:

The electric field between the plates would be

$$|\vec{E}| = \frac{\Delta V}{\Delta d} = \frac{8000\,V}{0.24\,m} = 33{,}333\text{ V/m}$$

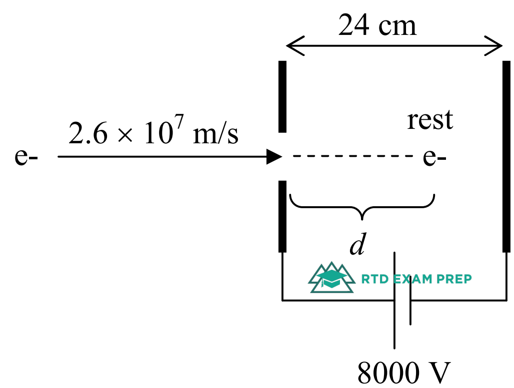
Uniform acceleration (unbalanced forces)

$$|\vec{a}| = \frac{|\vec{F}_{net}|}{m} = \frac{F_e}{m} = \frac{q|\vec{E}|}{m}$$

$$= \frac{(1.60 \times 10^{-19}\,C)(33{,}333\,N/C)}{9.11 \times 10^{-31}\,kg} = 5.85 \times 10^{15}\text{ m/s}^2$$

b) At the point where it gets closest, it comes to rest.

Ref: Right +, left –



$\vec{v}_i = +2.6 \times 10^7$ m/s ; $\vec{v}_f = 0$

$\vec{a} = -5.8544 \times 10^{15}$ m/s^2 ; $\vec{d}$?

$$v_f^2 = v_i^2 + 2ad \qquad d = \frac{v_f^2 - v_i^2}{2a}$$

$$d = \frac{0 - (2.6 \times 10^7\, m/s)^2}{2\left(-5.844 \times 10^{15}\, m/s^2\right)} = 0.0577 \text{ m} = 5.77 \text{ cm}$$

Then, the distance to the right plate would be

24 cm – 5.77 cm = 18 cm

18. a) Horizontal (x): The electron moves with a **constant horizontal velocity** of 3.80×10^6 m/s for a horizontal displacement of 40.0 cm – 15.0 cm = 25.0 cm.

$$v_x = \frac{d_x}{t} \qquad d_x = v_x t \qquad t = \frac{d_x}{v_x}$$

$$t = \frac{0.25\, m}{3.80 \times 10^6\, m/s} = 6.58 \times 10^{-8} \text{ s}$$

b) Vertical (y): The electron experiences a **constant vertical acceleration** over a displacement of 12.0 cm. (Ref: Down +, Up –)

$\vec{v}_{iy} = 0$; $\vec{a}_y$? ; $\vec{d}_y = 0.120$ m ; $t = 6.57895 \times 10^{-8}$ s

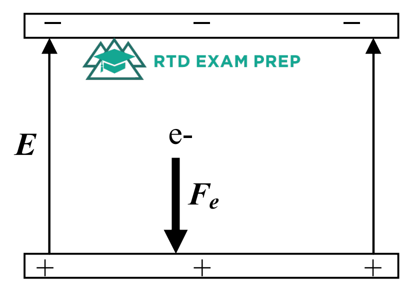
$$\vec{d}_y = \cancel{\vec{v}_{iy}} t + \frac{1}{2}\vec{a}_y t^2 \qquad d_y = \frac{1}{2} a_y t^2 \qquad a = \frac{2d_y}{t^2}$$

$$a = \frac{2\,(0.12\, m)}{(6.57895 \times 10^{-8}\, s)^2} = 5.55 \times 10^{13} \text{ m/s}^2 \text{ (downward)}$$

c) Direction:

If the electron is deflecting downward, then the electric force must be downward as well. Since an electron has a negative charge, electric field and electric force go in opposite directions.

Thus, the electric field is upward (from positive plate to negative plate)

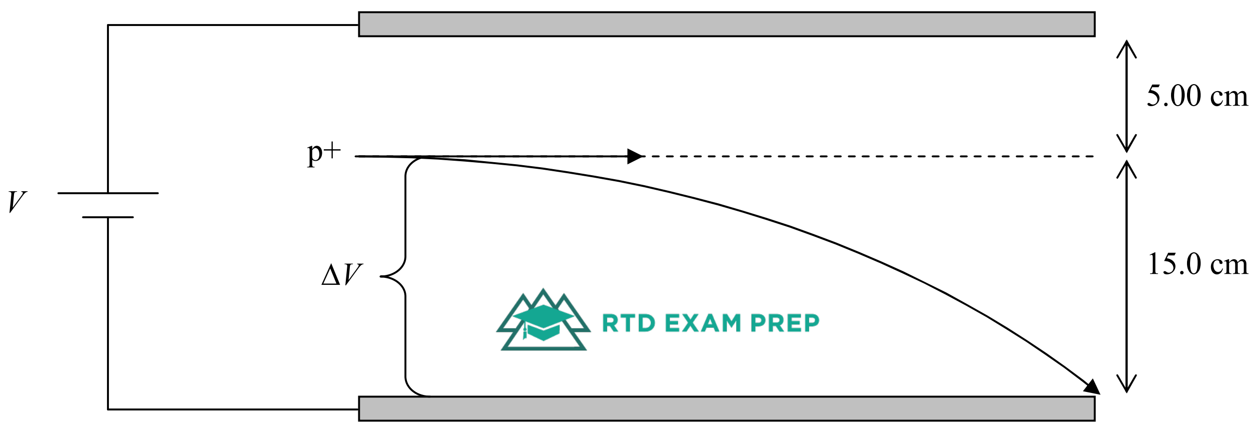


Magnitude: Uniform acceleration (unbalanced forces)

$$\left|\vec{F}_{net}\right| = m\left|\vec{a}\right| \qquad F_e = ma \qquad q\left|\vec{E}\right| = ma$$

$$\left|\vec{E}\right| = \frac{ma}{q} = \frac{(9.11\times10^{-31}\,kg)(5.545\times10^{15}\,m/s^2)}{1.60\times10^{-19}\,C} = 316 \text{ N/C}$$

19.



$$W = \Delta E = 4.80 \times 10^{-15} \text{ J}$$

$$\Delta V = \frac{\Delta E}{q} = \frac{4.80\times10^{-15}\,J}{1.60\times10^{-19}\,C} = 30{,}000 \text{ V}$$

Finally, as you can see in the diagram,

$$\Delta V = \frac{15}{20}\cdot V \qquad \Delta V = \frac{3}{4}\cdot V \qquad V = \frac{4}{3}\cdot\Delta V$$

$$V = \frac{4}{3}(30{,}000\,V) = 40{,}000 \text{ V} = 4.00 \times 10^4 \text{ V}$$