Name: Answers

Practice – 18.1 Static Electricity and Charge: Conservation of Charge

1. There are very large numbers of charged particles in most objects. Why, then, don't most objects exhibit static electricity?

The numbers of positive and negative charges are usually equal and equally distributed!

2. Why do most objects tend to contain nearly equal numbers of positive and negative charges?

An imbalance of charge will create a force to attract the missing charge.

3. Common static electricity involves charges ranging from nanocoulombs to microcoulombs.

A. How many electrons are needed to form a charge of –2.00 nC?

$$-2.00\,nC = -2.00\times10^{-9}\,C\left(\frac{1\ \text{electron}}{-1.6\times10^{-19}\,C}\right) = 1.25\times10^{10}\ \text{electrons}$$

B. How many electrons must be removed from a neutral object to leave a net charge of 0.500 μC ?

$$0.500\,\mu C = 0.5\times10^{-6}\,C\left(\frac{1\ \text{electron removed}}{-1.6\times10^{-19}\,C\ \text{charge added}}\right) = 3.13\times10^{-12}\ \text{electrons}$$

4. If 1.80 x $10^{20}$ electrons move through a pocket calculator during a full day's operation, how many coulombs of charge moved through it?

$$\left(1.8\times10^{20}\ \text{electron}\right)\left(\frac{-1.6\times10^{-19}\,C}{\text{electron}}\right) = -28.8\,C$$

5. To start a car engine, the car battery moves $3.75 \times 10^{21}$ electrons through the starter motor. How many coulombs of charge were moved?

$$3.75 \times 10^{21} e \left( \frac{-1.6 \times 10^{-19} C}{e} \right) = -600 C$$

6. A certain lightning bolt moves 40.0 C of charge. How many fundamental units of charge $|q_e|$ is this?

$$40 C \left( \frac{q_e}{1.6 \times 10^{-19} C} \right) = 2.5 \times 10^{20} q_e$$

**Solutions**:

3. A. $1.25 \times 10^{10}$ $e^-$ B. $3.13 \times 10^{12}$ $e^-$
4. 28.8 C
5. $-6.00 \times 10^2$ C
6. $2.50 \times 10^{20}$ $q_e$

Name Answers
Physics 200

Essex High School
April 5, 2017

Simulation: John Travoltage

Access: Go to http://phet.colorado.edu, click on "Play with Sims", then choose "Electricity, Magnets, and Circuits" simulation. Click on "John Travoltage" and click on "Run Now".

1) Use the mouse to rub his foot on the carpet. What do you observe?

Electrons enter his foot and spread throughout his body.

2) Why do the charges spread out?

They are all negative, so they repel one another

3) Use the mouse to bring his hand close to the door knob. What do you observe?

The electrons flow out of John and into the doorknob

4) Are the charges attracted to the doorknob? Why or why not?

The doorknob has a more positive charge and even though electrons are passing into the knob, they are spreading out evenly through the entire Earth, so the negative charge located in the knob does not build up.

5) Rub his foot on the carpet again. Why don't the charges leak back to the ground through his feet?

The soles of his shoes are insulators.

*Charges will leak out, but it's relatively slow

[When he first rubs his foot on the floor, there must be a high enough concentration of charge for electrons to flow from his soles to his feet.]

Name Answers
Physics 200

Essex High School
April 5, 2017

Simulation: Balloons and Static Electricity

Access: Go to http://phet.colorado.edu, click on "Play with Sims", then choose "Electricity, Magnets, and Circuits" simulation. Click on "Balloons and Static Electricity" and click on "Run Now". Uncheck the box that says "Ignore Initial Balloon Charge".

1) Does the balloon have a net charge? How do you know?

Not in the beginning. It has equal numbers of positive and negative charges.

2) Does the sweater have a net charge? How do you know?

0 net charge. + charges = − charges

3) Use the mouse to rub the balloon on the sweater. What is the net charge on each object?

Balloon ⇒ negative
Sweater ⇒ positive

4) Use the mouse to move the balloon away from the sweater and release it. What happens? Why?

The balloon is attracted to the sweater because they have opposite net charges.

5) Move the balloon against the wall. Why does the balloon stick to the wall?

The negative balloon induces polarity in the wall. Electrons move into the wall, leaving the outside positive, so that it attracts the balloon.

6) Did the charge on the wall change?

Net charge did not change. The total number of positive and negative charges remained constant.

7) How do you think dryer sheets reduce static cling?

They distribute positive ions which stick to negatively charged clothing, canceling charge.

Name: Answers

# Practice – 18.2 Conductors and Insulators

1. A 50.0 g ball of copper has a net charge of 2.00 μC. What fraction of the copper's electrons has been removed? (Each copper atom has 29 protons, and copper has an atomic mass of 63.5.)

$-2.00\mu C$ = charge removed

$$-2.00^{-6} C \left(\frac{1\ e}{-1.6\times10^{-19}}\right) = 1.25\times10^{13} \text{ electrons removed}$$

$$\frac{1\text{ mole}}{63.5\text{ g}}(50\text{ g})\left(\frac{6.02\times10^{23}\text{ atoms}}{\text{mole}}\right)\left(\frac{29e}{\text{atom}}\right) = 1.38\times10^{25}\ e \text{ total}$$

$$\left(\frac{e\text{ removed}}{\text{total } e}\right)\left(\frac{1.25\times10^{13}\ e}{1.38\times10^{25}\ e}\right) = 9.09\times10^{-13}$$

2. What net charge would you place on a 100 g piece of sulfur if you put an extra electron on 1 in $10^{12}$ of its atoms? (Sulfur has an atomic mass of 32.1.)

$$\left(\frac{1\ e\text{ added}}{10^{12}\text{ atoms}}\right)\left(\frac{-1.6\times10^{-19} C}{e\text{ added}}\right)\left(\frac{6.02\times10^{23}\text{ atoms}}{32.1\text{ g}}\right)(100\text{ g})$$

Charge $= -3.01\times10^{-7}$ C

3. How many coulombs of positive charge are there in 4.00 kg of plutonium, given its atomic mass is 244 and that each plutonium atom has 94 protons?

$$\left(\frac{4\times10^3 g}{}\right)\left(\frac{1 \text{ mole}}{244 g}\right)\left(\frac{6.02\times10^{23} \text{ atoms}}{\text{mole}}\right)\left(\frac{94 \text{ protons}}{\text{atom}}\right)\left(\frac{1.6\times10^{-19} C}{\text{Proton}}\right)$$

$$= 1.48\times10^{8} C$$

**Solutions**:

1. $9.09 \times 10^{-13}$
2. $3.00 \times 10^{-7}$ C
3. $1.48 \times 10^{8}$ C

Name: Answers

Practice – 18.3 Coulomb's Law

1. What is the repulsive force between two pith balls that are 8.00 cm apart and have equal charges of –30.0 nC?

$$F = k\frac{q_1 q_2}{r^2} = 8.99\times10^{9}\frac{Nm^2}{C^2}\frac{(-30.0\times10^{-9}C)(-30.0\times10^{-9}C)}{(0.08m)^2}$$

$$F = 1.26\times^{-3} N$$

2. Two point charges exert a 5.00 N force on each other. What will the force become if the distance between them is increased by a factor of three?

Old Force → $5.00N = \frac{kq_1q_2}{r^2}$ New Force $= \frac{kq_1q_2}{(3r)^2} = \frac{kq_1q_2}{9r^2} = \frac{kq_1q_2}{r^2}\left(\frac{1}{9}\right) = \frac{5N}{9}$

new dist = 3r

3. Two point charges are brought closer together, increasing the force between them by a factor of 25. By what factor was their separation decreased?

$F = \frac{kq_1q_2}{r^2}$, so → $25F = \frac{kq_1q_2}{\frac{1}{25}(r^2)} = \frac{kq_1q_2}{\left(\frac{r}{5}\right)^2}$ r is divided by 5

4. How far apart must two point charges of 75.0 nC (typical of static electricity) be to have a force of 1.00 N between them?

$$1.00N = 8.99\times10^{9}\frac{Nm^2}{C^2}\left(\frac{(75\times10^{-9}C)^2}{r^2}\right)$$

$$r = 7.11\times10^{-3} m$$

5. If two equal charges each of 1.00 C each are separated in air by a distance of 1.00 km, what is the magnitude of the force acting between them? You will see that even at a distance as large as 1 km, the repulsive force is substantial because 1 C is a very significant amount of charge.

$$F = 8.99\times10^{9}\,\frac{Nm^2}{C^2}\left(\frac{(1C)^2}{(10^3 m)^2}\right) = 8.99\times10^{3}\,N$$

6. A test charge of +2.00 μC is placed halfway between a charge of +6.00 μC and another of +4.00 μC separated by 10.0 cm. What is the magnitude and direction of the force on the test charge?

+4μC ○ $F_1\rightarrow$ +2μC ○ $\leftarrow F_2$ ○ +6μC

$$\Sigma F = F_2 - F_1 = k\left(\frac{(6\mu C)(2\mu C)}{r^2}\right) - k\left(\frac{(4\mu C)(2\mu C)}{r^2}\right)$$

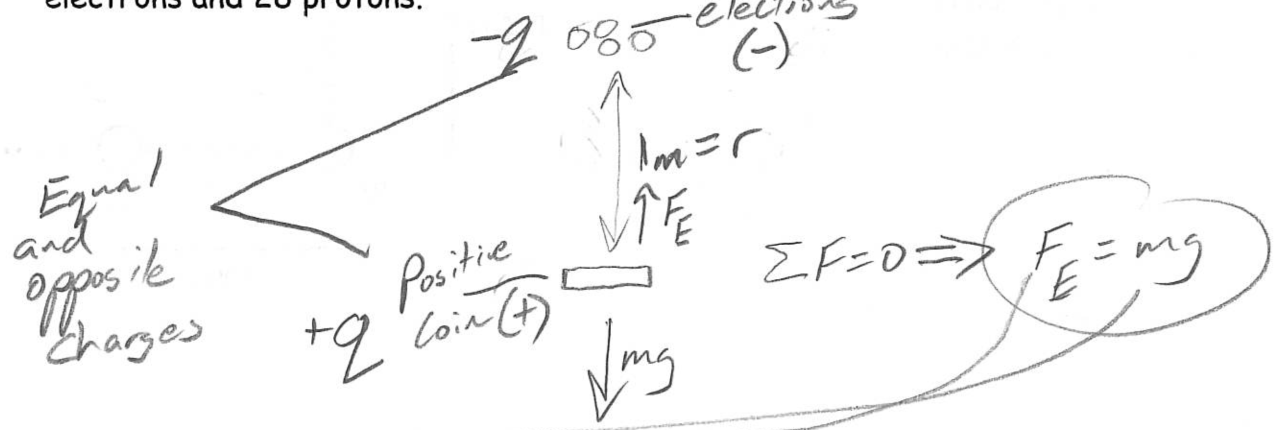
$$= 8.99\times10^{9}\,\frac{Nm^2}{C^2}\left(\frac{4\times10^{-12}C}{(0.05m)^2}\right) = 14.4N \text{ toward the } 4\mu C \text{ charge}$$

7. Find the ratio of the electrostatic to gravitational force between two electrons. $m_e = 9.11 \times 10^{-31}$ kg.

$$\frac{F_E}{F_g} = \frac{k\,q_1 q_2 / r^2}{G\,m_1 m_2 / r^2} = \frac{(8.99\times10^{9})(1.6\times10^{-19}C)(1.6\times10^{-19}C)}{(6.67\times10^{-11})(9.11\times10^{-31}kg)(9.11\times10^{-31}kg)}$$

$$0.0416\times10^{44} = 4.16\times10^{42}$$

8. A certain five cent coin contains 5.00 g of nickel. What fraction of the nickel atoms' electrons, removed and placed 1.00 m above it, would support the weight of this coin? The atomic mass of nickel is 58.7, and each nickel atom contains 28 electrons and 28 protons.




$$mg = \frac{k\,(-q)(+q)}{(r)^2}$$

$$(0.005\,kg)(9.8\,m/s^2) = 8.99\times10^{9}\,\frac{Nm^2}{C^2}\left(\frac{(-q)(q)}{(1m)^2}\right)$$

$$q = 2.33\times10^{-6}\,C$$

Charge removed

$$-2.33\times10^{-6}\,C\left(\frac{1\ \text{electron}}{-1.6\times10^{-19}\,C}\right) = 1.46\times10^{13}\ \text{electrons}$$

$$\left(\frac{28\ \text{electrons}}{\text{atom}}\right)\left(\frac{6.02\times10^{23}\ \text{atoms}}{\text{mole}}\right)\left(\frac{1\ \text{mole}}{58.7\,g}\right)(5.00\,g) = 1.44\times10^{24}\ \text{electrons total}$$

$$\text{Fraction} = \frac{e}{e_{total}} = 1.01\times10^{-11}$$

9. What is the net force (magnitude and direction) on $q_2$?

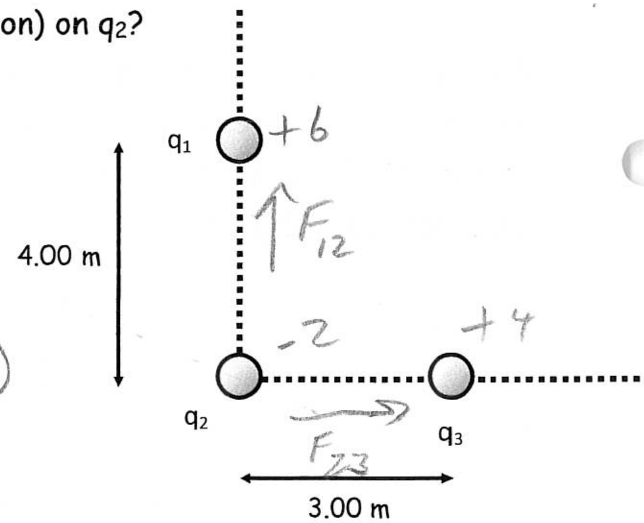
$q_1 = +6.00\ \mu C$

$q_2 = -2.00\ \mu C$

$q_3 = +4.00\ \mu C$

$r_{12} = 4.00$ m

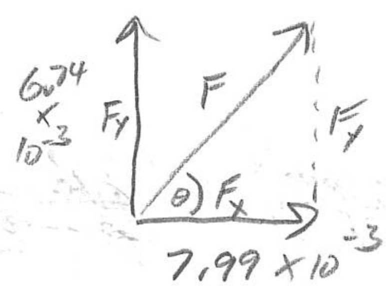
$r_{32} = 3.00$ m




$$F_y = F_{12} = 8.99\times10^{9}\,\frac{Nm^2}{C^2}\left(\frac{(6\times10^{-6}\,C)(-2\times10^{-6}\,C)}{(4m)^2}\right)$$

$$= -6.74\times10^{-3}\,N$$

$$F_x = F_{23} = 8.99\times10^{9}\,\frac{Nm^2}{C^2}\left(\frac{(2\times10^{-6}\,C)(4\times10^{-6}\,C)}{(3m)^2}\right) = -7.99\times10^{-3}\,N$$



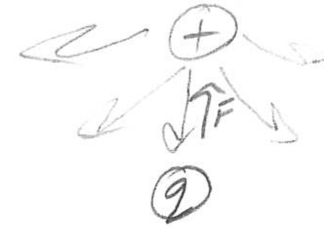

$$F = \sqrt{(6.74\times10^{-3}\,N)^2 + (7.99\times10^{-3}\,N)^2} = 1.05\times10^{-2}\,N$$

$$\tan^{-1}\left(\frac{6.74\times10^{-3}}{7.99\times10^{-3}}\right) = 40.1^\circ$$

**Solutions**:

1. $1.26 \times 10^{-3}$ N
2. 0.556 N
3. 5
4. $7.11 \times 10^{-3}$ m
5. $8.99 \times 10^{3}$ N
6. 14.4 N
7. $4.16 \times 10^{42}$
8. $1.02 \times 10^{-11}$
9. $1.05 \times 10^{-2}$ N @ 40.2°

Name: Answers



Practice – 18.4 Electric Field

1. What is the magnitude and direction of an electric field that exerts a $2.00 \times 10^{-5}$ N upward force on a –1.75 μC charge?

$$E = \frac{F}{q} = \frac{2 \times 10^{-5} N}{-1.75 \times 10^{-6} C} = 11.4 \times 10 \frac{N}{C} \text{ Downward}$$

2. What is the magnitude and direction of the force exerted on a 3.50 μC charge by a 250 N/C electric field that points due east?

$$F = qE = 3.5 \times 10^{-6} C \left(250 \frac{N}{C}\right) = 8.75 \times 10^{-4} N \text{ Eastward}$$

3. Calculate the magnitude of the electric field 2.00 m from a point charge of 5.00 mC (such as found on the terminal of a Van de Graaff).

$$E = \frac{kQ}{r^2} = 8.99 \times 10^{9} \frac{Nm^2}{C^2} \left(\frac{5 \times 10^{-3} C}{(2.00 m)^2}\right) = 1.12 \times 10^{7} \frac{N}{C}$$

4. What magnitude point charge creates a 10,000 N/C electric field at a distance of 0.250 m?

$$Q = \frac{Er^2}{k} = \frac{10{,}000 N/C \,(0.250 m)^2}{8.99 \times 10^{9} \frac{Nm^2}{C^2}} = 6.95 \times 10^{-8} C$$

5. Calculate the initial (from rest) acceleration of a proton in a $5.00 \times 10^{6}$ N/C electric field. $m_p = 1.67 \times 10^{-27}$ kg

$$F = qE = 1.6 \times 10^{-19} C \left(5 \times 10^{6} \frac{N}{C}\right) = 8 \times 10^{-13} N$$

$$F = ma \Rightarrow 8 \times 10^{-13} N = 1.67 \times 10^{-27} kg \,(a)$$

$$a = 4.79 \times 10^{14} m/s^2$$

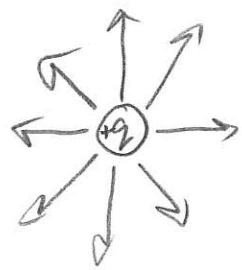
**Solutions**:

1. 11.4 N/C downward
2. $8.75 \times 10^{-4}$ N east
3. $1.12 \times 10^{7}$ N/C
4. $6.95 \times 10^{-8}$ C
5. $4.79 \times 10^{14}$ m/s$^2$

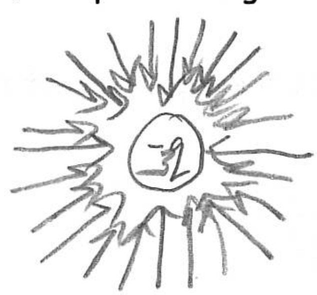
Name: Answers

Practice – 18.5 Electric Field Lines: Multiple Charges

1. A. Sketch the electric field lines near a point charge +q.



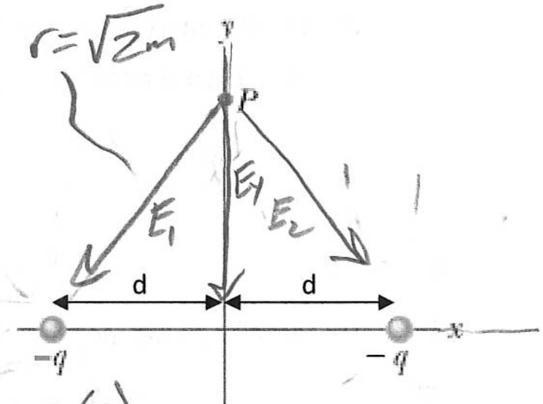

B. Do the same for a point charge -3.00q.




3X as many lines as

2. A. In what direction does the electric field point at Point P?

B. If d = 1.00 m, -q = -4.00 μC and the distance from Point P to the x-axis is 1.00 m, what is the magnitude of the electric field at Point P?



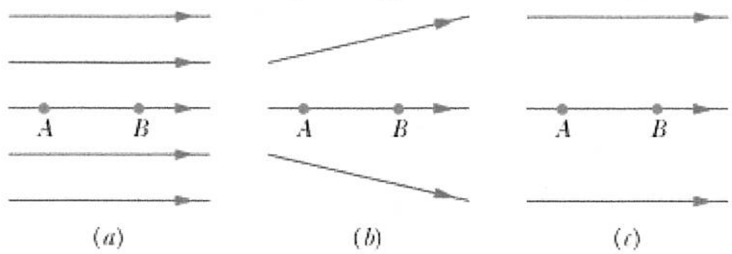

$$E_1 = E_2 = \frac{k(q)}{r^2} = 8.99\times10^9\frac{Nm^2}{C^2}\left(\frac{4\times10^{-6}C}{(\sqrt{2}m)^2}\right) = 1.80\times10^4\frac{N}{C}$$

$$\Sigma E = 2E_y = 2\left(\frac{E_2}{\sqrt{2}}\right) = \sqrt{2}\,E_2 = \sqrt{2}\left(1.8\times10^4 N/C\right)$$

$$= 2.5\times10^4 N/C$$

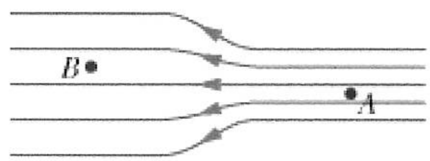
3. Three arrangements of electric field lines are shown below. In each arrangement, a proton is released from rest at point A and is then accelerated through point B by the electric field. Points A and B have equal separations in the three arrangements. Rank the arrangements according to the linear momentum of the proton at point B, greatest first?

Large E    E large→small    Small E




1    2    3

4. The electric field lines on the left have twice the separation of those on the right.




A. If the magnitude of the field at A is 40.0 N/C, what is the magnitude of the force on a proton at A?

$$E_A = 40\frac{N}{C}(1.6\times10^{-19}C) = 6.4\times10^{-18}N$$

B. What is the magnitude of the field at B?

20 N/C

5. The nucleus of a plutonium-239 atom contains 94 protons. Assume that the nucleus is a sphere with radius 6.64 fm (1 fm = $10^{-15}$ m) and with the charge of the protons uniformly spread through the sphere. At the nucleus surface, what are the magnitude and direction (radially inward or outward) of the electric field produced by the protons?

$$E = \frac{kQ}{r^2} = \frac{\left(8.99\times10^9\frac{Nm^2}{C^2}\right)(94\,\text{protons})\left(\frac{1.6\times10^{-19}C}{\text{proton}}\right)}{(6.64\times10^{-15}m)^2}$$

$E = 3.07\times10^{21}\frac{N}{C}$ outward

6. What is the magnitude of a point charge whose electric field 50.0 cm away has the magnitude 2.00 N/C?

$$q = \frac{Er^2}{k} = \frac{(2.00\ N/C)(0.5m)^2}{8.99\times10^9\ Nm^2/C^2} = 5.56\times10^{-11}\ C$$

**Solutions**:

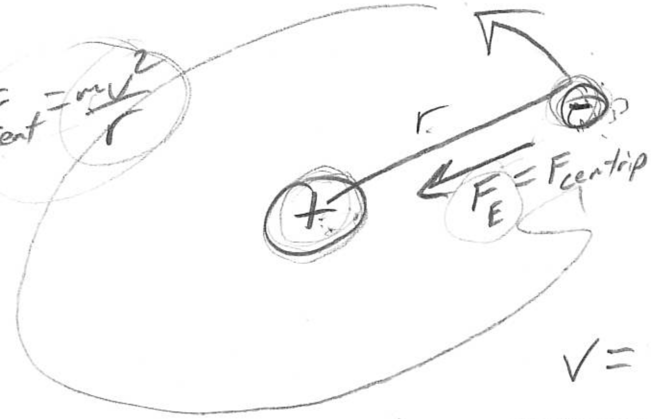
2. A. downward B. $2.54 \times 10^4$ N/C
3. a, b, c
4. A. $6.40 \times 10^{-18}$ N B. 20.0 N/C
5. $3.07 \times 10^{21}$ N/C, radially outward
6. $5.56 \times 10^{-11}$ C

Name: Answers

Practice – 18.7 Conductors and Electric Fields in Static Equilibrium

1. Calculate the linear velocity and the angular velocity ω of an electron assuming it orbits a proton (even though technically it does not) in the hydrogen atom, given the radius of the orbit is 0.530 x $10^{-10}$ m. You may assume that the proton is stationary and the centripetal force is supplied by Coulomb attraction. $m_e$ = 9.11 x $10^{-31}$ kg

$\sum F = F_{cent} = \frac{mv^2}{r}$




$\frac{kqQ}{r^2} = \frac{mv^2}{r}$

$v = \sqrt{\frac{kqQ}{mr}}$

$v = \sqrt{\frac{8.99\times10^{9}\frac{Nm^2}{C^2}(1.6\times10^{-19}C)(1.6\times10^{-19}C)}{9.11\times10^{-31}kg\,(0.53\times10^{-10}m)}}$

$v = 2.18\times10^{6}\,m/s$

$\omega = \frac{v}{r} = 4.11\times10^{16}\,rad/s$

$\sqrt{\frac{kqQ}{mr}} = \sqrt{\frac{mv^2}{m}} = v$

2. An electron has an initial velocity of $5.00 \times 10^6$ m/s in a uniform $2.00 \times 10^5$ N/C strength electric field. The field accelerates the electron in the direction opposite to its initial velocity.

A. What is the direction of the electric field?

Rightward (Pos direction)
(same as V of electron)


B. How far does the electron travel before coming to rest?

$M_{electron} = 9.11 \times 10^{-31}$ Kg

$F = Eq = 2.00 \times 10^5 \, N/C \, (1.6 \times 10^{-19} C) = 3.2 \times 10^{-14} N$

$F = ma \quad a = \frac{F}{m} = \frac{3.2 \times 10^{-14} N}{9.11 \times 10^{-31} Kg} = -3.5 \times 10^{16} m/s^2$

$V^2 = V_0^2 + 2a\Delta x$

$0 = (5 \times 10^6 m/s)^2 + 2(-3.5 \times 10^{16} m/s^2)(\Delta x)$

$\Delta x = 3.57 \times 10^{-14} m$

C. How long does it take the electron to come to rest?

$V = V_0 + at$

$0 = (5 \times 10^6 m/s) + (-3.5 \times 10^{16} m/s^2)(t)$

$t = 1.42 \times 10^{-10} s$

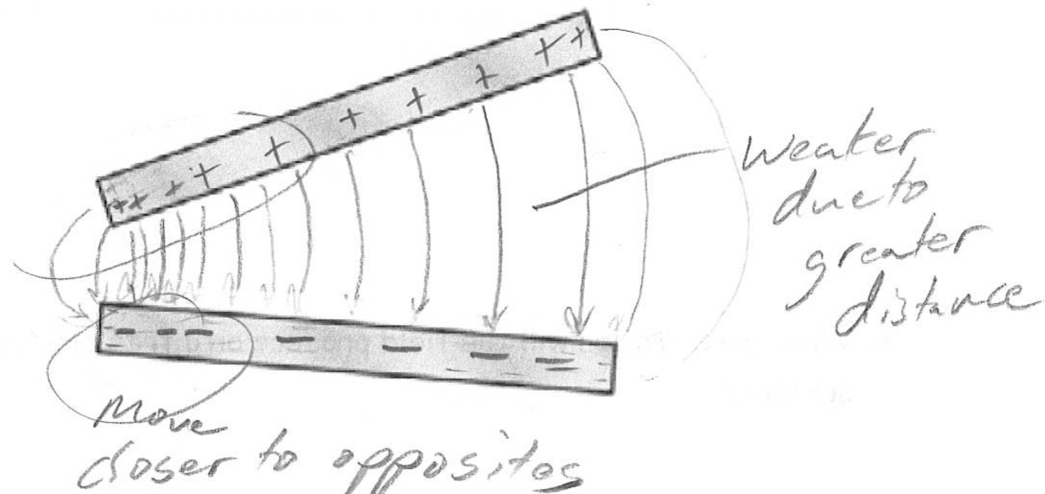
**Solutions**:

1. $2.18 \times 10^6$ m/s, $4.12 \times 10^{16}$ rad/s
2. A. In the direction of the electron's initial velocity
   B. $3.56 \times 10^{-4}$ m
   C. $1.42 \times 10^{-10}$ s

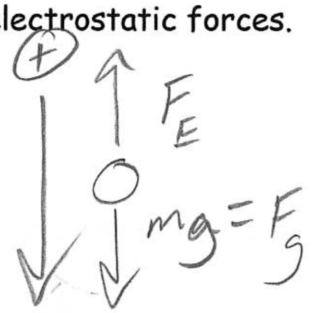
Name: Answers

Practice – 18.8 Electrostatic Applications

1. Sketch the electric field between the two conducting plates shown below using the principles of electric fields and charges in and around conductors. Assume the top plate is positive and an equal amount of negative charge is on the bottom plate. Also indicate the distribution of charge on the plates.




2. What is the direction and magnitude of an electric field that supports the weight of a free electron ($m_e = 9.11 \times 10^{-31}$ kg) near the surface of Earth? Discuss what the small value for this field implies regarding the relative strength of the gravitational and electrostatic forces.




$F_E = Eq$

$mg = Eq$

$(9.11 \times 10^{-31} \text{ kg})(9.8 \text{ m/s}^2) = E(1.6 \times 10^{-19} \text{ C})$

$E = 5.58 \times 10^{-11} \text{ N/C}$

Toward Earth's Surface

3. Earth has a net charge that produces an electric field of approximately 150 N/C downward at its surface.

A. What is the magnitude and sign of the excess charge, noting the electric field of a conducting sphere is equivalent to a point charge at its center? $R_{Earth}$ = 6371 km

$$E = \frac{kQ}{r^2} \qquad 150\,\frac{N}{C} = \frac{\left(8.99\times10^9\,\frac{Nm^2}{C^2}\right)(Q)}{(6.371\times10^6\,m)^2}$$

$$Q = -6.77\times10^5\,C$$

B. What acceleration will the field produce on a free electron near Earth's surface?

$$a = \frac{F}{m} = \frac{(1.6\times10^{-19}\,C)(150\,\frac{N}{C})}{9.11\times10^{-31}\,kg}$$

$$a = 2.63\times10^{13}\,m/s^2 \text{ upward}$$

C. What mass object with a single extra electron will have its weight supported by this field?

$$F_E = mg$$

$$m = \frac{F_E}{g} = \frac{(1.6\times10^{-19}\,C)(150\,N/C)}{9.8\,m/s^2}$$

$$m = 2.44\times10^{-18}\,kg$$

4. The practical limit to an electric field in air is about 3.00 x $10^6$ N/C. Above this strength, sparking takes place because air begins to ionize and charges flow, reducing the field.

   A. Calculate the distance a free proton must travel in this field to reach 3.00% of the speed of light, starting from rest. $m_p$ = 1.67 x $10^{27}$ kg, c = 3.00 x $10^8$ m/s

$$v^2 = v_0^2 + 2a\Delta x$$

$$\Delta x = \frac{v^2}{2a} = \frac{\left[(0.03)(3\times10^8\ m/s)\right]^2}{2\left[\frac{(3\times10^6\ N/C)(1.6\times10^{-19}\ C)}{1.67\times10^{-27}\ kg}\right]}$$

$$a = \frac{F_E}{m} = \frac{Eq}{m}$$

$$= \frac{8.1\times10^{13}\ m^2/s^2}{5.75\times10^{-40}\ N/kg} = 0.141\ m$$

   B. Is this practical in air, or must it occur in a vacuum?

**Solutions**:

2. 5.58 x $10^{-11}$ N/C toward the Earth's surface

3. A. -6.77 x $10^5$ C    B. 2.63 x $10^{13}$ m/$s^2$ upwards    C. 2.45 x $10^{-18}$ kg

4. A. 0.141 m