13 Chapter 13: Electric Field

Q01:

Solution:

The relationship is that the force by an electric field on a particle of charge q is $\vec{F}_{\text{by E-field on q}} = q\vec{E}$. The unit of force is newtons (N) and the unit of electric field is newtons per coulomb (N/C).

Q02:

Solution:

(a) At location P, hold the charged object and release it from rest at one end of the meterstick. Watch the direction of motion and then align the meterstick along this direction. Again, release the object from rest from the end of the meterstick. Measure the time elapsed (on the stopwatch) as it travels a small distance along the meterstick. What is small? It depends on the average acceleration of the object. If its acceleration is small, then 1 m will be fine. If its acceleration is large, then perhaps 0.1 m should be used. The astronaut should measure the distance travelled d and the time interval Δt. A good experimentalist will make the measurement for multiple trials and calculate the average time elapsed.

(b) The force on the particle may not be constant (because the electric field at the location of the object may be different as the object moves). However, for a small time interval, we will assume constant force. Define the +x direction to be the direction of motion of the object. Use the following procedure to calculate the electric field:

(1) Use $v_{avg,x} = d/\Delta t$ to calculate the average x-velocity of the object.
(2) Use $v_{avg,x} = (v_i + v_f)/2$ to calculate the final x-velocity of the object.
(3) Use the Momentum Principle to calculate the net force on the object. $F_x = M\Delta v_x/\Delta t$.
(4) Use $\vec{F} = q\vec{E}$ to calculate the electric field.

Note that this procedure only works for small time interval because we are assuming a constant net force on the object.

Q03:

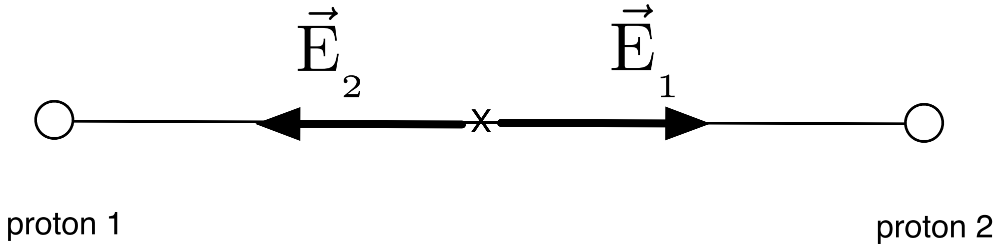
Solution:

A particle cannot exert a force on itself. In the equation $\vec{F} = q\vec{E}$, the electric field at the location of the particle q is due to *other* charges.

Q04:

Solution:

The simplest case is two equally charged particles in opposite directions and equidistant from the point where the net electric field is zero. See the figure below.



Q05:

Solution:

(a) h. For a proton, the force on the proton is in the same direction as the electric field.

(b) d. For an electron, the force on the electron is in the same direction as the electric field.

Q06:

Solution:

Q is the charge of the distant object. q is the magnitude of the charge of each particle of the dipole. s is the distance of separation for the particles that make up the dipole. r is the distance from the center of the dipole to the distant object.

Q07:

Solution:

The formula given in the problem is an approximation for $r >> s$. However, in this case $r = 1.5s$ and therefore the approximation is not valid.

Q08:

Solution:

The E-field vectors shown are for an electric dipole. The longest field vectors shown (on the +y axis, relative to the center of the circle) are for the electric field along the axis of a dipole. They point away from the positive charge and toward the negative charge. Thus, the dipole is oriented "vertically" with the $+q$ along the $+y$ axis and $-q$ along the $-y$ axis, if the origin is defined to be the center of the dipole.

Q09:

Solution:

For all of these answers, I will use the convention $\hat{x}$ to the right, $\hat{y}$ toward the top of the page, and $\hat{z}$ outward perpendicular to the page.

(a) $\hat{E} =< 0, -1, 0 >$. The dipole moment vector $\vec{p}$ points "upward" in the $+y$ direction. Since point A is on the perpendicular bisector of the dipole, the electric field at point A points opposite $\vec{p}$ which is in the $-y$ direction.

(b) $\hat{E} =< 0, 1, 0 >$. Since point B is along the axis of the dipole, the electric field at point B points in the same direction as the dipole moment, in the $+y$ direction.

(c) Because the electron starts from rest, it will move in the direction of the electric force on the electron which is opposite the electric field. Thus, $\hat{F} =< 0, 1, 0 >$.

(d) Because it starts from rest, it will move in the direction of the electric force on the proton which is in the same direction as the electric field. Thus, $\hat{F} =< 0, 1, 0 >$.

(e) The force on the dipole by the electron is opposite the force on the electron by the dipole. Thus the direction of the force on the dipole by the electron is $\hat{F} =< 0, -1, 0 >$. Because the dipole starts from rest, it will begin moving in the direction $< 0, -1, 0 >$.

Q10:

Solution:

1. true
2. true
3. false
4. false
5. true

Q11:
Solution:

Since $d >> s$, then the electric field varies as $1/d^3$. If you triple the distance d, then the electric field changes by a factor $1/3^3 = 1/27$.

Q12:
Solution:

(a) The electric field at the location of Q is due to the dipole, and it remains the same. Since the force on Q due to the field is $F = |q|\,E$, then increasing $|q|$ by 9 will increase the magnitude of the force by a factor of 9; therefore, $F = 9F_0$.

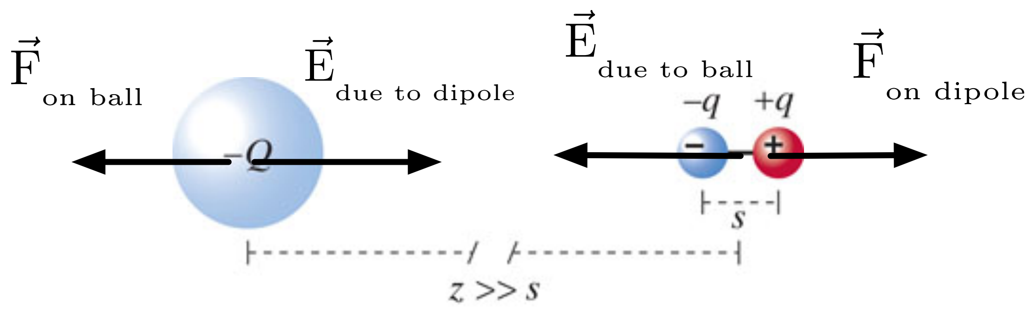
(b) Yes, the force on $-9Q$ is opposite the force on Q and in this case will be in the +x direction.

Q13:
Solution:

Since $d >> s$, then the electric field varies as $1/d^3$. If you change the distance d by 1/2, then the electric field changes by a factor $1/(1/2)^3 = 8$. Thus $F = 8F_0$.

Q14:
Solution:

A sketch of all vectors is shown in the figure below.



(a) The electric field due to the dipole at the location of the ball is in the +x direction, in the same direction as the dipole moment.

(b) Since Q is negative, the force on the ball by the electric field is in the -x direction, opposite the electric field at this location.

(c) The electric field due to the ball at the location of the dipole is in the $-x$ direction, toward the ball, since it is negatively charged.

(d) The force by the ball on the dipole is to the right because the force on $-q$ (which is to the right) is greater than the force on $+q$ (which is to the left). This is consistent with Newton's second law, that in an interaction the objects exert forces on each other that are equal in magnitude and opposite in direction.

Q15:

Solution:

The force on the ball by the dipole is directly proportional to the electric field created by the dipole. The electric field by the dipole depends on $1/r^3$, for $r >> s$. If the distance r is doubled, then the electric field changes by a factor $1/2^3 = 1/8$. Therefore the force also changes by 1/8.

P16:

Solution:

$$\begin{aligned} \left|\vec{F}\right| &= |q|\left|\vec{E}\right| \\ \left|\vec{E}\right| &= \frac{3.8\times 10^{-16}\text{ N}}{1.602\times 10^{-19}\text{ C}} \\ &= 2375\text{ N/C} \end{aligned}$$

P17:

Solution:

$$\begin{aligned} \vec{F} &= q\vec{E} \\ &= (1.602\times 10^{-19}\text{ C})(< 0, -280, 0 > \text{ N/C}) \\ &= < 0, -4.48\times 10^{-17}, 0 > \text{ N} \end{aligned}$$

P18:

Solution:

$$\begin{aligned} \left|\vec{F}\right| &= |q|\left|\vec{E}\right| \\ \left|\vec{E}\right| &= \frac{3.7\times 10^{-19}\text{ N}}{1.602\times 10^{-19}\text{ C}} \\ &= 2.31\text{ N/C} \end{aligned}$$

P19:

Solution:

$$\begin{aligned} \vec{F} &= q\vec{E} \\ &= (1.602\times 10^{-19}\text{ C})(< 2\times 10^4, 2\times 10^4, 0 > \text{ N/C}) \\ &= < 3.2\times 10^{-15}, 3.2\times 10^{-15}, 0 > \text{ N} \end{aligned}$$

P20:

Solution:

$$\begin{aligned}\vec{F} &= q\vec{E} \\ \vec{E} &= \frac{< 8\times 10^{-17}, -3.2\times 10^{-16}, -4.8\times 10^{-16} > \text{ N}}{-1.602\times 10^{-19} \text{ C}} \\ &= < -500, 2000, 3000 > \text{ N/C}\end{aligned}$$

P21:

Solution:

(a) It is negative since the electric field vectors point toward the charged particle.

(b) The force on the particle at point B is opposite the electric field at point B and thus points down and to the left, radially away from the particle within the dashed circle.

(c)

$$\begin{aligned}\hat{E} &= \frac{\vec{E}}{\left|\vec{E}\right|} \\ &= \frac{< 2000, 2000, > \text{ N/C}}{\sqrt{(2000\text{ N/C})^2 + (2000\text{ N/C})^2 + (0\text{ N/C})^2}} \\ &= < 0.707, 0.707, 0 >\end{aligned}$$

Note that you can determine the answer without doing a calculation because the angle of the vector with respect to the x-axis (or y-axis) is 45°. As a result the unit vector is $< \cos 45, \cos 45, 0 >$.

(d)

$$\begin{aligned}\vec{F} &= q\vec{E} \\ &= (-7\times 10^{-9} \text{ C})(< 2000, 2000, > \text{ N/C}) \\ &= < -1.4\times 10^{-5}, -1.4\times 10^{-5}, 0 > \text{ N}\end{aligned}$$

(e) It is opposite the unit vector for the electric field. Thus, $\hat{F} =< -0.707, -0.707, 0 >$. Note that this is down and to the left as predicted in part (b).

P22:

Solution:

(a) h, because $\vec{E}$ and $\vec{F}$ are in the same direction for a positively charged particle.

(b) (Note: that there likely an error in the exponent for the y-component of the force vector. Also, the signs of the given force do not match the picture. The solution below uses $\vec{F} =< -4\times 10^{-5}, 4\times 10^{-5}, 0 >$ N.)

$$\begin{aligned}\vec{F} &= q\vec{E} \\ \vec{E} &= \frac{< -4\times 10^{-5}, 4\times 10^{-5}, 0 > \text{ N}}{5\times 10^{-9} \text{ C}} \\ &= < -8000, 8000, 0 > \text{ N/C}\end{aligned}$$

(c) $\left|\vec{E}\right| = \sqrt{(-8000 \text{ N/C})^2 + (8000 \text{ N/C})^2 + (0 \text{ N/C})^2} = 1.13 \times 10^4 \text{ N/C}$

(d) d, because $\vec{E}$ and $\vec{F}$ are in the opposite direction for a negatively charged particle.

(e)

$$\begin{aligned} \vec{F} &= q\vec{E} \\ \vec{F} &= (-6 \times 10^{-9} \text{ C})(< -8000, 8000, 0 > \text{ N/C}) \\ &= < 4.8 \times 10^{-5}, -4.8 \times 10^{-5}, 0 > \text{ N} \end{aligned}$$

(f) The electric field points "upward" and to the left (arrow h). Since it points toward a negatively charged (source) particle, then the negatively charged (source) particle must be at location 1.

P23:

Solution:

A particle accelerates in the direction of the (net) force on the particle; therefore, the force on the particle is in the +z direction. Since the particle is negatively charged, the force on the particle is in the opposite direction of the electric field, so the electric field at the location of the particle is in the -z direction. Use Newton's second law (the Momentum Principle) to calculate the force on the electron, and use $\vec{F} = q\vec{E}$ to calculate the electric field at the location of the electron.

$$\begin{aligned} \vec{F}_{\text{net}} &= \frac{d\vec{p}}{dt} \\ \vec{F}_{\text{by E-field}} &= m\vec{a} \\ &= (9.109 \times 10^{-31} \text{ kg})(< 0, 0, 1.6 \times 10^{16} > \text{ m/s}^2) \\ &= < 0, 0, 1.46 \times 10^{-14} \text{ N} > \end{aligned}$$

$$\begin{aligned} \vec{F} &= q\vec{E} \\ \vec{E} &= \frac{\vec{F}}{q} \\ &= \frac{< 0, 0, 1.46 \times 10^{-14} \text{ N} >}{-1.602 \times 10^{-19} \text{ C}} \\ &= < 0, 0, -9.13 \times 10^4 > \text{ N/C} \end{aligned}$$

P24:

Solution:

The net force on the object is

$$\begin{aligned}
\vec{F}_{net} &= \vec{F}_{grav} + \vec{F}_{elec} \\
&= m\vec{g} + q\vec{E} \\
&= (0.3 \text{ kg}) < 0, 5, 0 > \text{ N/kg} + (-4 \times 10^{-8} \text{ C}) < 2 \times 10^{7}, 0, 0 > \text{ N/C} \\
&= < 0, 1.5, 0 > \text{ N} + < -0.8, 0, 0 > \text{ N} \\
&= < -0.8, 1.5, 0 > \text{ N}
\end{aligned}$$

P25:

Solution:

$$\begin{aligned}
\left|\vec{F}_{net}\right| &= \left|\frac{d\vec{p}}{dt}\right| \\
\left|\vec{F}_{\text{by E-field}}\right| &= m\left|\vec{a}\right| \\
&= (1.673 \times 10^{-27} \text{ kg})(9 \times 10^{11} \text{ m/s}^2) \\
&= 1.50 \times 10^{-15} \text{ N}
\end{aligned}$$

$$\begin{aligned}
\left|\vec{F}\right| &= |q|\left|\vec{E}\right| \\
\left|\vec{E}\right| &= \frac{\left|\vec{F}\right|}{|q|} \\
&= \frac{1.50 \times 10^{-15} \text{ N}}{1.602 \times 10^{-19} \text{ C}} \\
&= 9.38 \times 10^{3} \text{ N/C}
\end{aligned}$$

P26:

Solution:

(a) The electric field at B due to the proton at A is the same (because the source of the field did not change). So, the field is $\vec{E}_1$.

(b) The force on the lithium nucleus is $3\vec{F}_1$ since $\vec{F} = q\vec{E}$.

(c) It'll change the force, but not the E-field.

(d) The electric field at B due to the proton at A is the same (because the source of the field did not change). So, the field is $\vec{E}_1$.

(e) The force on the electron is $\left|\vec{F}_1\right|$ since the electron and (original) proton have the same magnitude charge.

(f) f, because the electron is negatively charged so $\vec{F}$ is opposite $\vec{E}$.

P27:

Solution:

(a) $\vec{r}_{particle} = \langle -0.6, -0.7, -0.2\rangle$ m

(b) $\vec{r}_{observation\ location} = \langle 0.5, -0.1, -0.5\rangle$ m

(c)

$$\begin{aligned}\vec{r} &= \langle 0.5, -0.1, -0.5\rangle\,\mathrm{m} - \langle -0.6, -0.7, -0.2\rangle\,\mathrm{m} \\ &= \langle 1.1, 0.6, -0.3\rangle\,\mathrm{m}\end{aligned}$$

(d) $|\vec{r}| = \left(\sqrt{(1.1)^2 + (0.6)^2 + (-0.3)^2}\right)$ m $= 1.29$ m

(e)

$$\begin{aligned}\hat{r} &= \frac{\vec{r}}{|\vec{r}|} \\ &= < 0.854, 0.466, -0.233 >\end{aligned}$$

(f)

$$\begin{aligned}\left|\vec{E}\right| &= \left(9\times 10^{9}\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}\right)\frac{(9\times 10^{-9}\ \mathrm{C})}{(1.29\ \mathrm{m})^2} \\ &= 48.8\ \mathrm{N/C}\end{aligned}$$

$$\frac{1}{4\pi\varepsilon_o}\frac{q}{|\vec{r}|^2} = 48.8\ \mathrm{N/C}$$

(g)

$$\begin{aligned}\vec{E} &= \frac{1}{4\pi\varepsilon_o}\frac{q}{|\vec{r}|^2}\hat{r} \\ &= (48.8\ \mathrm{N/C}) < 0.854, 0.466, -0.233 > \\ &= \langle 41.7, 22.7, -11.4\rangle\ \mathrm{N/C}\end{aligned}$$

P28:

Solution:

$$\vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{q}{|\vec{r}|^2}\hat{r}$$

Note that $\vec{r} = \vec{r}_{location} - \vec{r}_{particle}$. In this case, the particle is at the origin, so $\vec{r} = \vec{r}_{location}$.

$$\begin{aligned}\vec{E} &= \left(9\times 10^{9}\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}\right)\frac{(5\times 10^{-9}\ \mathrm{C})}{(0.4\ \mathrm{m})^2} < 1, 0, 0 > \\ &= \langle 281, 0, 0\rangle\ \mathrm{N/C}\end{aligned}$$

P29:

Solution:

$$\vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{q}{|\vec{r}|^2}\hat{r}$$

Note that $\vec{r} = \vec{r}_{location} - \vec{r}_{particle}$. In this case, the particle is at the origin, so $\vec{r} = \vec{r}_{location}$.

$$\begin{aligned}|\vec{r}| &= \left(\sqrt{(-0.1)^2 + (-0.1)^2 + (0)^2}\right) \text{ m} \\ &= 0.141 \text{ m} \\ \hat{r} &= \frac{\vec{r}}{|\vec{r}|} \\ &= < -0.707, -0.707, 0 >\end{aligned}$$

$$\begin{aligned}\vec{E} &= \left(9\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(4\times10^{-9}\text{ C})}{(0.1\text{ m})^2} < -0.707, -0.707, 0 > \\ &= \langle -2550, -2550, 0\rangle \text{ N/C}\end{aligned}$$

P30:

Solution:

$$\begin{aligned}\left|\vec{E}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2} \\ &= \left(9\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{1.602\times10^{-19}\text{ C}}{(0.5\times10^{-10}\text{ m})^2} \\ &= 5.76\times10^{11}\text{ N/C}\end{aligned}$$

P31:

Solution:

(a) The electric field outside the sphere is the same as if the sphere is a point particle at its center. Thus,

$$\begin{aligned}\left|\vec{E}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2} \\ &= \left(9\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{2\times10^{-9}\text{ C}}{(0.04\text{ m})^2} \\ &= 1.13\times10^{4}\text{ N/C}\end{aligned}$$

P32:

Solution:

The force by the particle on the sphere is equal in magnitude and opposite in direction to the force by the sphere on the particle. Thus, find the force by the sphere on the particle. The electric field outside the sphere is the same as if the sphere is a point particle at its center. Call the charge of the sphere Q and the charge of the particle q. The magnitude of the force on the particle by the sphere is

$$\begin{aligned}
\left|\vec{\mathrm{F}}_{\text{on particle by sphere}}\right| &= |q|\left|\vec{\mathrm{E}}_{\text{sphere}}\right| \\
&= |q|\frac{|Q|}{r^2} \\
&= |Q|\frac{|q|}{r^2} \\
&= |Q|\left|\vec{\mathrm{E}}_{\text{particle}}\right| \\
&= \left(9\times10^{-10}\ \mathrm{C}\right)(470\ \mathrm{N/C}) \\
&= 4.23\times10^{-7}\ \mathrm{N}
\end{aligned}$$

P33:

Solution:

$$\vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{q}{|\vec{\mathrm{r}}|^2}\hat{\mathrm{r}}$$

Note that $\vec{\mathrm{r}} = \vec{\mathrm{r}}_{\text{observation location}} - \vec{\mathrm{r}}_{\text{particle}}$.

$$\begin{aligned}
\vec{\mathrm{r}} &= \langle 0.2, 0, 0\rangle\ \mathrm{m} - \langle 0.4, 0, 0\rangle\ \mathrm{m} \\
&= \langle -0.2, 0, 0\rangle\ \mathrm{m} \\
|\vec{\mathrm{r}}| &= 0.2\ \mathrm{m} \\
\hat{\mathrm{r}} &= \frac{\vec{\mathrm{r}}}{|\vec{\mathrm{r}}|} \\
&= < -1, 0, 0 >
\end{aligned}$$

$$\begin{aligned}
\vec{E} &= \left(9\times10^{9}\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}\right)\frac{(1\times10^{-9}\ \mathrm{C})}{(0.2\ \mathrm{m})^2} < -1, 0, 0 > \\
&= \langle -225, 0, 0\rangle\ \mathrm{N/C}
\end{aligned}$$

P34:

Solution:

Treat the sphere as a particle.

$$\left|\vec{F}_{\text{on sphere by particle}}\right| = \left(-8\times10^{-10}\text{ C}\right)(500\text{ N/C}) \approx 4\times10^{-7}\text{ N}$$

P35:

Solution:

(a) $\vec{r}_{\text{particle}} = \langle 0.8, 0.7, -0.8\rangle$ m

(b) $\vec{r}_{\text{observation location}} = \langle 0.5, 1, -0.5\rangle$ m

(c)

$$\begin{aligned}\vec{r} &= \vec{r}_{\text{observation location}} - \vec{r}_{\text{particle}}\\ &= \langle 0.5, 1, -0.5\rangle\text{ m} - \langle 0.8, 0.7, -0.8\rangle\text{ m}\\ &= \langle -0.3, 0.3, 0.3\rangle\text{ m}\end{aligned}$$

(d) $|\vec{r}| = \left(\sqrt{(-0.3)^2+(0.3)^2+(0.3)^2}\right)\text{ m} = 0.520\text{ m}$

(e)

$$\begin{aligned}\hat{r} &= \frac{\vec{r}}{|\vec{r}|}\\ &= < -0.577, 0.577, 0.577 >\end{aligned}$$

(f)

$$\begin{aligned}\left|\vec{E}\right| &= \left(9\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left|-1.602\times10^{-19}\text{ C}\right|}{(0.52\text{ m})^2}\\ &= 5.33\times10^{-9}\text{ N/C}\end{aligned}$$

$$\frac{1}{4\pi\varepsilon_o}\frac{q}{|\vec{r}|^2} = -5.33\times10^{-9}\text{ N/C}$$

(g)

$$\begin{aligned}\vec{E} &= \frac{1}{4\pi\varepsilon_o}\frac{q}{|\vec{r}|^2}\hat{r}\\ &= (-5.33\times10^{-9}\text{ N/C}) < -0.577, 0.577, 0.577 >\\ &= \left\langle 3.08\times10^{-9}, -3.08\times10^{-9}, -3.08\times10^{-9}\right\rangle\text{ N/C}\end{aligned}$$

P36:

Solution:

$$\begin{aligned}\left|\vec{E}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2}\\ 1.2\times10^3\ \text{N/C} &= \left(9\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{|q|}{(0.12\ \text{m})^2}\\ |q| &= 1.92\times10^{-9}\ \text{C}\end{aligned}$$

The electric field points toward the charged particle; therefore, the particle is negatively charged and $q = -1.92\times10^{-9}$ C.

P37:

Solution:

The electric field points in the +x direction and points toward a negative charge. Thus the charged particle must be to the right, in the +x direction, from the point where the electric field is measured.

$$\begin{aligned}\left|\vec{E}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2}\\ 1\times10^3\ \text{N/C} &= \left(9\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{1\times10^{-6}\ \text{C}}{|\vec{r}|^2}\\ |\vec{r}| &= 3\ \text{m}\end{aligned}$$

The electric field points toward the charged particle; therefore, the position of the particle is to the right and $\vec{r} = <3, 0, 0>$ m from the location where the electric field is measured.

P38:

Solution:

(a) The electric field points in the +y direction and points away from a positive charge. Thus the charged particle must be "below" point C in the $-y$ direction from point C.

$$\begin{aligned}\left|\vec{E}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2}\\ 1\times10^6\ \text{N/C} &= \left(9\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{1.602\times10^{-19}\ \text{C}}{|\vec{r}|^2}\\ |\vec{r}| &= 3.79\times10^{-8}\ \text{m}\end{aligned}$$

The electric field points away from the positively charged particle; therefore, the position of the particle is $\vec{r} = <0, -3.79\times10^{-8}, 0>$ m.

(b) The electric field points toward the negatively charged particle, so the particle must be "above" point C, in the $+y$ direction from point C. Thus, $\vec{r} = <0, 3.79\times10^{-8}, 0>$ m.

(c) If the electron is "above" point C, on the +y axis, and the proton is "below" point C on the $-y$ axis, then the superposition of the electric field due to each particle yields a net electric field that is twice the electric field due to just one of the particles. Since $E \propto 1/r^2$, then r must be increased by $\sqrt{2}$ in order to counteract the doubling of the field. So, the proton is at $\vec{r} =< 0, -5.36 \times 10^{-8}, 0 >$ m, and the electron is at $\vec{r} =< 0, 5.36 \times 10^{-8}, 0 >$ m. Use these distances to calculate the electric field due to each particle, and then sum the fields. You should find that the net E-field is 1×10^6 N/C in the +y direction.

P39:

Solution:

(a) The electric field points in the +y direction and points away from a proton. Thus the proton must be "below" this point, in the $-y$ direction.

$$\left|\vec{E}\right| = \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2}$$
$$4104\ \text{N/C} = \left(9 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{1.602 \times 10^{-19}\ \text{C}}{|\vec{r}|^2}$$
$$|\vec{r}| = 5.92 \times 10^{-7}\ \text{m}$$

The electric field points away from the proton; therefore, the position of the proton is $\vec{r} =< 0, -5.92 \times 10^{-7}, 0 >$ m.

(b) The electric field points toward an electron, so the electron must be "above" the origin, in the $+y$ direction. Thus, $\vec{r} =< 0, 5.92 \times 10^{-7}, 0 >$ m.

P40:

Solution:

(a)

$$\vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{q}{|\vec{r}|^2}\hat{r}$$

The particle is at $\vec{r}_{\text{particle}} = \left\langle 7 \times 10^{-9}, -4 \times 10^{-9}, -5 \times 10^{-9}\right\rangle$ m, and the observation location is at $\vec{r}_{\text{observation location}} = \left\langle -5 \times 10^{-9}, 5 \times 10^{-9}, 4 \times 10^{-9}\right\rangle$ m.

The position of the observation location relative to the particle is

$$\begin{aligned}\vec{r} &= \vec{r}_{\text{observation location}} - \vec{r}_{\text{particle}} \\ &= \left\langle -5 \times 10^{-9}, 5 \times 10^{-9}, 4 \times 10^{-9}\right\rangle \text{m} - \left\langle 7 \times 10^{-9}, -4 \times 10^{-9}, -5 \times 10^{-9}\right\rangle \text{m} \\ &= \left\langle -12 \times 10^{-9}, 9 \times 10^{-9}, 9 \times 10^{-9}\right\rangle \text{m}\end{aligned}$$

$$\begin{aligned}|\vec{r}| &= \left(\sqrt{(12)^2 + (9)^2 + (9)^2}\right) \times 10^{-9}\ \text{m} \\ &= 1.75 \times 10^{-8}\ \text{m}\end{aligned}$$

$$\begin{aligned}\hat{r} &= \frac{\vec{r}}{|\vec{r}|}\\ &= <-0.686, 0.514, 0.514>\end{aligned}$$

$$\begin{aligned}\vec{E} &= \frac{1}{4\pi\varepsilon_o}\frac{q}{|\vec{r}|^2}\hat{r}\\ &= \left(9\times10^{9}\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}\right)\frac{\left(-1.602\times10^{-19}\ \mathrm{C}\right)}{(1.75\times10^{-8}\ \mathrm{m})^2} <-0.686, 0.514, 0.514>\\ &= (-4.70\times10^6\ \mathrm{N/C}) <-0.686, 0.514, 0.514>\\ &= \left\langle 3.23\times10^6, -2.42\times10^6, -2.42\times10^6\right\rangle\ \mathrm{N/C}\end{aligned}$$

(b)

$$\begin{aligned}\vec{F} &= q_{antiproton}\vec{E}\\ &= (1.602\times10^{-19}\ \mathrm{C})(\left\langle 3.23\times10^6, -2.42\times10^6, -2.42\times10^6\right\rangle\ \mathrm{N/C})\\ &= <5.17\times10^{-13}, -3.87\times10^{-13}, -3.87\times10^{-13}>\ \mathrm{N}\end{aligned}$$

P41:

Solution:

$$\vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{q}{|\vec{r}|^2}\hat{r}$$

The position of the observation location relative to the particle is

$$\begin{aligned}\vec{r} &= \vec{r}_{\text{observation location}} - \vec{r}_{\text{particle}}\\ &= \langle -0.1, -0.1, 0\rangle\,\mathrm{m} - <0,0,0>\\ &= \langle -0.1, -0.1, 0\rangle\,\mathrm{m}\end{aligned}$$

$$\begin{aligned}|\vec{r}| &= \left(\sqrt{(0.1)^2 + (0.1)^2 + (0)^2}\right)\ \mathrm{m}\\ &= 0.141\ \mathrm{m}\end{aligned}$$

$$\begin{aligned}\hat{r} &= \frac{\vec{r}}{|\vec{r}|}\\ &= <-0.707, -0.707, 0>\end{aligned}$$

$$
\begin{aligned}
\vec{E} &= \frac{1}{4\pi\varepsilon_o}\frac{q}{|\vec{r}|^2}\hat{r} \\
&= \left(9\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(3\times10^{-9}\ \text{C})}{(0.141\ \text{m})^2} < -0.707, -0.707, 0 > \\
&= (1360\ \text{N/C}) < -0.707, -0.707, 0 > \\
&= \langle -960, -960, 0\rangle\ \text{N/C}
\end{aligned}
$$

P42:

Solution:

The electric field points in the +x direction. If it is due to a positively charged particle, then it points away from the particle, and the charged particle must be to the left, in the $-x$ direction, from the point where the electric field is measured. Both q and $|\vec{r}|$ are unknowns, so you must simply choose a value for one of these variables. Suppose we use $q = q_{\text{proton}}$. Then, the particle must be at a distance

$$
\begin{aligned}
\left|\vec{E}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2} \\
1\times10^3\ \text{N/C} &= \left(9\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left|-1.602\times10^{-19}\ \text{C}\right|}{|\vec{r}|^2} \\
|\vec{r}| &= 1.2\times10^{-6}\ \text{m}
\end{aligned}
$$

The electric field points away from the charged particle; therefore, the position of the particle is to the left and $\vec{r} =< -1.2\times10^{-6}, 0, 0 >$ m.

If the field is due to a negatively charged particle, like an electron for example, then the electron must be to the right of the point where we calculate the field since the field points toward the particle. In this case, using $q = q_{\text{electron}}$, $\vec{r} =< 1.2\times10^{-6}, 0, 0 >$ m.

P43:

Solution:

The electric field points in the +y direction. Since it points toward an electron, then the electron must be in the $+y$ direction from the point where the electric field is measured. The electron must be at a distance given by

$$
\begin{aligned}
\left|\vec{E}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2} \\
160\ \text{N/C} &= \left(9\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left|-1.602\times10^{-19}\ \text{C}\right|}{|\vec{r}|^2} \\
|\vec{r}| &= 3\times10^{-6}\ \text{m}
\end{aligned}
$$

The electric field points toward the electron; therefore, the position of the electron is "upward," and $\vec{r} =< 0, 3\times10^{-6}, 0 >$ m.

P44:

Solution:

Let's define $\hat{x}$ to the East ("to the right") and $\hat{y}$ to the North ("up").

(a) The electric field points in the $-x$ direction and points away from a positive charge. Thus the proton must be to the right of point C in the $+x$ direction from point C.

$$\begin{aligned} \left|\vec{\mathrm{E}}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{\mathrm{r}}|^2} \\ 2\times 10^6\ \mathrm{N/C} &= \left(9\times 10^{9}\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}\right)\frac{1.602\times 10^{-19}\ \mathrm{C}}{|\vec{\mathrm{r}}|^2} \\ |\vec{\mathrm{r}}| &= 2.68\times 10^{-8}\ \mathrm{m} \end{aligned}$$

The electric field points away from the positively charged particle; therefore, the position of the particle is $\vec{\mathrm{r}} =< 2.68\times 10^{-8}, 0, 0 >$ m, relative to location C.

(b) The electric field points toward the negatively charged particle, so the electron must be to the left of point C, in the $-x$ direction from point C. Thus, $\vec{\mathrm{r}} =< -2.68\times 10^{-8}, 0, 0 >$ m, relative to point C.

(c) If the electron is to the left of point C, on the $-x$ axis, and the proton is to the right of point C on the $+x$ axis, then the superposition of the electric field due to each particle yields a net electric field that is twice the electric field due to just one of the particles. Since $E \propto 1/r^2$, then r must be increased by $\sqrt{2}$ in order to counteract the doubling of the field. So, the proton is at $\vec{\mathrm{r}} = \sqrt{2} < 2.68\times 10^{-8}, 0, 0 >$ m $=< 3.79\times 10^{-8}, -, 0 >$ m, and the electron is at $\vec{\mathrm{r}} =< -3.79\times 10^{-8}, 0, 0 >$ m. To check your answer, use these distances to calculate the electric field due to each particle, and then sum the fields. You should find that the net E-field is 2×10^6 N/C in the $-x$ direction.

P45:

Solution:

(a) A lithium nucleus accelerates in the direction of the (net) force on the particle; therefore, the force on the particle (by the electric field) is in the +x direction. Since the nucleus is positively charged, the force on the particle is in the same direction of the electric field, so the electric field at the location of the nucleus is in the +x direction.

(b) Use Newton's second law (the Momentum Principle) to calculate the force on the nucleus, and use $\vec{F} = q\vec{E}$ to calculate the electric field at the location of the nucleus. Note that the mass of a proton and the mass of a neutron are nearly equal (to 3 significant figures).

$$\begin{aligned} \vec{\mathrm{F}}_{\mathrm{net}} &= \frac{d\vec{\mathrm{p}}}{dt} \\ \vec{\mathrm{F}}_{\mathrm{by\ E\text{-}field}} &= m\vec{\mathrm{a}} \\ &= 7(1.673\times 10^{-27}\ \mathrm{kg})(< 3\times 10^{13}, 0, 0 >\ \mathrm{m/s^2}) \\ &= < 3.51\times 10^{-13}, 0, 0 >\ \mathrm{N} \end{aligned}$$

$$\begin{aligned}\vec{F} &= q\vec{E} \\ \vec{E} &= \frac{\vec{F}}{q} \\ &= \frac{< 3.51 \times 10^{-13}, 0, 0 > \text{ N}}{3(1.602 \times 10^{-19} \text{ C})} \\ &= < 7.31 \times 10^{5}, 0, 0 > \text{ N/C}\end{aligned}$$

So the magnitude of the field is $\left|\vec{E}\right| = 7.31 \times 10^5$ N/C.

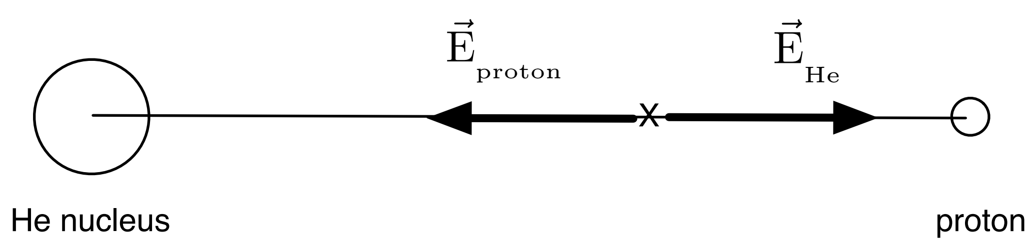
(c) If the electric field is due to the positively charged helium nucleus, then it points away from the nucleus. This means that the helium nucleus is to the left of the lithium nucleus, in the $-x$ direction. It is at a distance given by

$$\begin{aligned}\left|\vec{E}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2} \\ 7.31 \times 10^5 \text{ N/C} &= \left(9 \times 10^{9} \frac{\text{N} \cdot \text{m}^2}{\text{C}^2}\right)\frac{3(1.602 \times 10^{-19} \text{ C})}{|\vec{r}|^2} \\ |\vec{r}| &= 7.69 \times 10^{-8} \text{ m}\end{aligned}$$

The helium nucleus is to the left of the lithium nucleus at the location $\vec{r} = -7.69 \times 10^{-8}$ m relative to the lithium nucleus.

P46:
Solution:

(a) Sketch the He nucleus and proton along the +x axis as shown in the figure below. Place the point X at the origin. The He nucleus is to the left of the origin and the proton is to the right of the origin. The position vector for the helium nucleus is $\vec{r} = -1 \times 10^{-10}$ m.

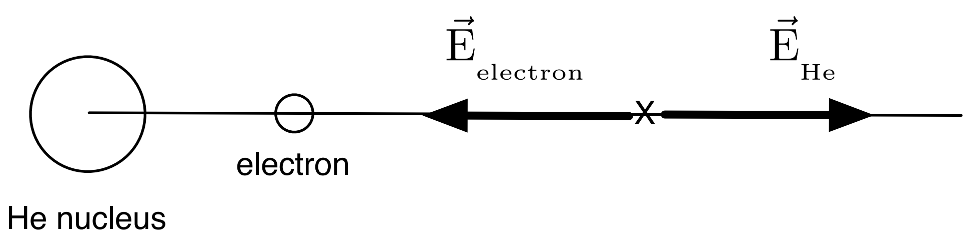


The electric field due to the helium nucleus at point X is to the right. The E-field due to the proton at point X is to the left. They sum to zero to give zero net electric field. The field due to each particle is equal in magnitude, and they are opposite in direction. Thus,

$$\begin{aligned}
\left|\vec{E}_{He}\right| &= \left|\vec{E}_{proton}\right| \\
\frac{1}{4\pi\varepsilon_o}\frac{q_{He}}{\left|\vec{r}_{He}\right|^2} &= \frac{1}{4\pi\varepsilon_o}\frac{q_{proton}}{\left|\vec{r}_{proton}\right|^2} \\
\frac{1}{4\pi\varepsilon_o}\frac{2q_{proton}}{\left|\vec{r}_{He}\right|^2} &= \frac{1}{4\pi\varepsilon_o}\frac{q_{proton}}{\left|\vec{r}_{proton}\right|^2} \\
\left|\vec{r}_{proton}\right|^2 &= \frac{\left|\vec{r}_{He}\right|^2}{2} \\
\left|\vec{r}_{proton}\right| &= \frac{\left|\vec{r}_{He}\right|}{\sqrt{2}} \\
&= 7.07\times10^{-11}\text{ m}
\end{aligned}$$

Since the proton is to the right of the origin, then its position is $\vec{r} =< 7.07\times10^{-11}, 0, 0 >$ m.

(b) The electron must be on the same side of the origin as the helium nucleus, so that it creates a field at the origin that is to the left in order to balance the E-field due to the helium nucleus and give a zero net field. (See the figure below.) Since its charge is the same as the proton, it will be the same distance from the origin as the proton in part (a). Thus, its position is $\vec{r} =< -7.07\times10^{-11}, 0, 0 >$ m.



P47:
Solution:

(a)

$$\vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{q}{|\vec{r}|^2}\hat{r}$$

Q_1 is at $\vec{r}_{particle} = \langle 0, 0.03, 0\rangle$ m, and the observation location is at the location of Q_3 which is $\vec{r}_{observation\ location} = \langle 0.04, 0, 0\rangle$ m.

The position of the observation location relative to the particle is

$$\begin{aligned}
\vec{r} &= \vec{r}_{observation\ location} - \vec{r}_{particle} \\
&= \langle 0.04, 0, 0\rangle\text{ m} - \langle 0, 0.03, 0\rangle\text{ m} \\
&= \langle 0.04, -0.03, 0\rangle\text{ m}
\end{aligned}$$

$$|\vec{r}| = \left(\sqrt{(0.04)^2 + (0.03)^2 + (0)^2}\right)\text{ m}$$
$$= 0.05\text{ m}$$

$$\hat{r} = \frac{\vec{r}}{|\vec{r}|}$$
$$= < 0.8, -0.6, 0 >$$

$$\vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{Q_1}{|\vec{r}|^2}\hat{r}$$
$$= \left(9\times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(-4\times 10^{-6}\text{ C}\right)}{(0.05\text{ m})^2} < 0.8, -0.6, 0 >$$
$$= (-1.44\times 10^7\text{ N/C}) < 0.8, -0.6, 0 >$$
$$= \left\langle -1.15\times 10^7, 8.64\times 10^6, 0\right\rangle\text{ N/C}$$

(b) The electric field due to Q_2 at the location of Q_3 points in the $-y$ direction. Its magnitude is

$$\left|\vec{E}\right| = \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2}$$
$$= \frac{1}{4\pi\varepsilon_o}\frac{3\times 10^{-6}\text{ C}}{(0.03\text{ m})^2}$$
$$= 3\times 10^7\text{ N/C}$$

So, the E-field vector is $\vec{E} =< 0, -3\times 10^7, 0 >$ N/C.

(c) Sum the electric fields due to Q_1 and Q_3.

$$\vec{E}_{net} = \left\langle -1.15\times 10^7, 8.64\times 10^6, 0\right\rangle\text{ N/C} + < 0, -3\times 10^7, 0 >\text{ N/C}$$
$$= \left\langle -1.15\times 10^7, -2.13\times 10^7, 0\right\rangle\text{ N/C}$$

(d)

$$\vec{F}_{net} = Q_3\vec{E}$$
$$= \left(-2\times 10^{-6}\text{ C}\right)(\left\langle -1.15\times 10^7, -2.13\times 10^7, 0\right\rangle\text{ N/C})$$
$$= \langle 23.0, 42.6, 0\rangle\text{ N/C}$$

(e) The electric field due to Q_1 at the location of A points in the $+y$ direction. Its magnitude is

$$\left|\vec{E}_1\right| = \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2}$$
$$= \frac{1}{4\pi\varepsilon_o}\frac{4\times 10^{-6}\text{ C}}{(0.03\text{ m})^2}$$
$$= 4\times 10^7\text{ N/C}$$

So, the E-field vector is $\vec{E}_1 =< 0, 4\times10^7, 0 >$ N/C.

(f) The electric field due to Q_2 at the location of A is given by

$$\begin{aligned}\vec{r} &= \vec{r}_{\text{observation location}} - \vec{r}_{\text{particle}}\\ &= \langle -0.04, -0.03, 0\rangle \text{ m}\end{aligned}$$

$$\begin{aligned}|\vec{r}| &= \left(\sqrt{(0.04)^2 + (0.03)^2 + (0)^2}\right) \text{ m}\\ &= 0.05 \text{ m}\end{aligned}$$

$$\begin{aligned}\hat{r} &= \frac{\vec{r}}{|\vec{r}|}\\ &= < -0.8, -0.6, 0 >\end{aligned}$$

$$\begin{aligned}\vec{E}_2 &= \frac{1}{4\pi\varepsilon_o}\frac{Q_2}{|\vec{r}|^2}\hat{r}\\ &= \left(9\times10^9 \ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(3\times10^{-6}\text{ C})}{(0.05\text{ m})^2} < -0.8, -0.6, 0 >\\ &= (1.08\times10^7 \text{ N/C}) < -0.8, -0.6, 0 >\\ &= \left\langle -8.64\times10^6, -6.48\times10^6, 0\right\rangle \text{ N/C}\end{aligned}$$

(g) The electric field due to Q_3 at the location of A points in the $+x$ direction. Its magnitude is

$$\begin{aligned}\left|\vec{E}_3\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|Q_3|}{|\vec{r}|^2}\\ &= \frac{1}{4\pi\varepsilon_o}\frac{2\times10^{-6}\text{ C}}{(0.04\text{ m})^2}\\ &= 1.125\times10^7 \text{ N/C}\end{aligned}$$

So, the E-field vector is $\vec{E}_3 =< 1.125\times10^7, 0, 0 >$ N/C.

(h) Sum the electric fields due to Q_1, Q_2, and Q_3.

$$\begin{aligned}\vec{E}_{\text{net}} &= < 0, 4\times10^7, 0 > \text{ N/C} + \left\langle -8.64\times10^6, -6.48\times10^6, 0\right\rangle \text{ N/C} + < 1.125\times10^7, 0, 0 > \text{ N/C}\\ &= \left\langle 2.61\times10^6, 3.35\times10^7, 0\right\rangle \text{ N/C}\end{aligned}$$

(i)

$$\begin{aligned}\vec{F} &= q\vec{E}\\ &= (-3\times10^{-9}\text{ C})(\left\langle 2.61\times10^6, 3.35\times10^7, 0\right\rangle \text{ N/C})\\ &= \left\langle -7.83\times10^{-3}, -0.101, 0\right\rangle \text{ N/C}\end{aligned}$$

P48:

Solution:

(a)

$$\vec{E}_2 = \left\langle 0, \frac{1}{4\pi\varepsilon_o}\frac{|Q_2|}{|\vec{r}_{12}|^2}, 0\right\rangle$$

$$\approx \left\langle 0, \left(9\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(8\times10^{-6}\ \text{C}\right)}{\left(4\times10^{-2}\ \text{m}\right)^2}, 0\right\rangle \approx \left\langle 0, 4.5\times10^7, 0\right\rangle\ \text{N/C}$$

$$\vec{E}_3 = \frac{1}{4\pi\varepsilon_o}\frac{|Q_3|}{|\vec{r}_{13}|^2}\left\langle \frac{3}{5}, -\frac{4}{5}, 0\right\rangle$$

$$\approx \left(9\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(5\times10^{-6}\ \text{C}\right)}{\left(5\times10^{-2}\ \text{m}\right)^2}\left\langle \frac{3}{5}, -\frac{4}{5}, 0\right\rangle \approx \left\langle 1.08\times10^7, -1.44\times10^7, 0\right\rangle\ \text{N/C}$$

$$\vec{E}_{net} = \vec{E}_2 + \vec{E}_3 \approx \left\langle 1.08\times10^7, 3.06\times10^7, 0\right\rangle\ \text{N/C}$$

(b)

$$\vec{F}_{1,23} = Q_1\vec{E}_{net}$$

$$\approx \left(3\times10^{-6}\ \text{C}\right)\left\langle 1.08\times10^7, 3.06\times10^7, 0\right\rangle\ \text{N/C}$$

$$\approx \langle 32.4, 91.8, 0\rangle\ \text{N}$$

(c)

$$\vec{E}_1 = \left\langle \frac{1}{4\pi\varepsilon_o}\frac{|Q_1|}{|\vec{r}_1|^2}, 0, 0\right\rangle$$

$$\approx \left\langle \left(9\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(3\times10^{-6}\ \text{C}\right)}{\left(3\times10^{-2}\ \text{m}\right)^2}, 0, 0\right\rangle$$

$$\approx \left\langle 3\times10^7, 0, 0\right\rangle\ \text{N/C}$$

$$\vec{E}_2 = \frac{1}{4\pi\varepsilon_o}\frac{|Q_2|}{|\vec{r}_2|^2}\left\langle \frac{3}{5}, \frac{4}{5}, 0\right\rangle$$

$$\approx \left(9\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(8\times10^{-6}\ \text{C}\right)}{\left(5\times10^{-2}\ \text{m}\right)^2}\left\langle \frac{3}{5}, \frac{4}{5}, 0\right\rangle$$

$$\approx \left\langle 1.73\times10^7, 2.30\times10^7, 0\right\rangle\ \text{N/C}$$

$$\vec{E}_3 = \left\langle 0, -\frac{1}{4\pi\varepsilon_o}\frac{|Q_3|}{|\vec{r}_3|^2}, 0\right\rangle$$

$$\approx \left\langle 0, -\left(9\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(5\times10^{-6}\ \text{C}\right)}{\left(4\times10^{-2}\ \text{m}\right)^2}, 0\right\rangle$$

$$\approx \left\langle 0, -2.81\times10^7, 0\right\rangle\ \text{N/C}$$

$$\vec{E}_{net} \approx \left\langle 4.73\times10^7, -0.51\times10^7, 0\right\rangle\ \text{N/C}$$

(d)

$$\begin{aligned}\vec{F}_{\alpha} &= (2e)\,\vec{E}_{net}\\ &\approx 2\left(1.602\times10^{-19}\text{ C}\right)\left\langle 4.73\times10^{7}, -0.51\times10^{7}, 0\right\rangle \text{ N/C}\\ &\approx \left\langle 1.52\times10^{-11}, -1.63\times10^{-12}, 0\right\rangle \text{ N/C}\end{aligned}$$

P49:

Solution:

(a) The net electric field is $\vec{E} = \vec{E}_{Cl} + \vec{E}_{Fe}$. Find the E-field due to each ion and sum them.

The electric field due to Cl^- at the location A points in the $+x$ direction. Its magnitude is

$$\begin{aligned}\left|\vec{E}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2}\\ &= \frac{1}{4\pi\varepsilon_o}\frac{1.602\times10^{-19}\text{ C}}{(100\times10^{-9}\text{ m})^2}\\ &= 1.44\times10^{5}\text{ N/C}\end{aligned}$$

So, the E-field vector is $\vec{E}_{Cl} =< 1.44\times10^5, 0, 0 >$ N/C. The electric field due to Fe^{3+} at the location A points in the $+x$ direction. Its magnitude is

$$\begin{aligned}\left|\vec{E}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2}\\ &= \frac{1}{4\pi\varepsilon_o}\frac{3(1.602\times10^{-19}\text{ C})}{(300\times10^{-9}\text{ m})^2}\\ &= 4.8\times10^{4}\text{ N/C}\end{aligned}$$

So, the E-field vector is $\vec{E}_{Fe} =< 4.80\times10^4, 0, 0 >$ N/C. This gives a net electric field of

$$\begin{aligned}\vec{E}_{net,\,A} &= < 1.44\times10^5, 0, 0 > \text{ N/C} + < 4.80\times10^4, 0, 0 > \text{ N/C}\\ &= < 1.92\times10^5, 0, 0 > \text{ N/C}\end{aligned}$$

(b) At point B, $\vec{E}_{Cl}$ has the same magnitude but points in the $-x$ direction. $\vec{E}_{Fe}$ is

$$\begin{aligned}\left|\vec{E}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2}\\ &= \frac{1}{4\pi\varepsilon_o}\frac{3(1.602\times10^{-19}\text{ C})}{(500\times10^{-9}\text{ m})^2}\\ &= 1.73\times10^{4}\text{ N/C}\end{aligned}$$

So, the E-field vector is $\vec{E}_{Fe} =< 1.73\times10^4, 0, 0 >$ N/C. This gives a net electric field of

$$\begin{aligned}\vec{E}_{net,\,B} &= <-1.44\times10^{5},0,0>\ \text{N/C}+<1.73\times10^{4},0,0>\ \text{N/C}\\ &= <-1.27\times10^{5},0,0>\ \text{N/C}\end{aligned}$$

(c)

$$\begin{aligned}\vec{F} &= q\vec{E}\\ &= (-1.602\times10^{-19}\ \text{C})(<1.92\times10^{5},0,0>\ \text{N/C})\\ &= <-3.07\times10^{-14},0,0>\ \text{N}\end{aligned}$$

P50:

Solution:

Outside the ball, treat the ball as a particle. Inside the ball, the electric field due to the charge **on the ball** is zero.

(a)

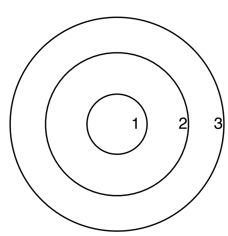
$$\begin{aligned}\text{ball: }\vec{r} &= \vec{r}_{obs}-\vec{r}_{source}\approx\left\langle 3\times10^{-2},6\times10^{-2},0\right\rangle\ \text{m}\\ |\vec{r}| &\approx 6.71\times10^{-2}\ \text{m}\\ \hat{r} &= \langle 0.447,0.894,0\rangle\\ \vec{E}_{ball} &= \frac{1}{4\pi\varepsilon_o}\frac{Q_{ball}}{|\vec{r}|^2}\hat{r}\\ \vec{E}_{ball} &\approx \langle -2683,-5367,0\rangle\ \text{N/C}\\ \text{particle: }\vec{r} &= \vec{r}_{obs}-\vec{r}_{source}\approx\left\langle -4\times10^{-2},6\times10^{-2},0\right\rangle\ \text{m}\\ |\vec{r}| &\approx 7.21\times10^{-2}\ \text{m}\\ \hat{r} &= \langle -0.555,0.832,0\rangle\\ \vec{E}_{particle} &= \frac{1}{4\pi\varepsilon_o}\frac{Q_{particle}}{|\vec{r}|^2}\hat{r}\\ \vec{E}_{particle} &\approx \langle -4800,7200,0\rangle\ \text{N/C}\\ \vec{E}_{net} &\approx \langle -7483,1833,0\rangle\ \text{N/C}\end{aligned}$$

(b) The arrow should point toward the upper right.

P51:

Solution:

Sketch a picture of the spheres. Label them 1, 2, and 3.



The radii and charges are:

$$\begin{aligned} R_1 &= 2 \text{ cm} \\ Q_1 &= 6 \times 10^{-9} \text{ C} \\ R_2 &= 5 \text{ cm} \\ Q_2 &= -4 \times 10^{-9} \text{ C} \\ R_3 &= 10 \text{ cm} \\ Q_3 &= 8 \times 10^{-9} \text{ C} \end{aligned}$$

Note that inside a uniformly charged sphere, the electric field due to the charge on the surface of the sphere is zero. Outside a uniformly charged sphere, the electric field is the same as if the sphere is a charged particle at the center.

(a) $\left|\vec{E}_{net}\right|$ at $r = 1$ cm?

Using the Superposition Principle, the net electric field is the sum of electric field due to each charged sphere.

$$\vec{E}_{net} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3$$

A point at $r = 1$ cm is inside each of the spheres, so the electric field due to each sphere is zero and thus $\vec{E}_{net} = < 0, 0, 0 >$.

(b) $\left|\vec{E}_{net}\right|$ at $r = 4$ cm?

This point is inside sphere 2 and sphere 3; therefore, $\vec{E}_2$ and $\vec{E}_3$ are zero. $\vec{E}_1$ is the electric field due to a charged particle at its center.

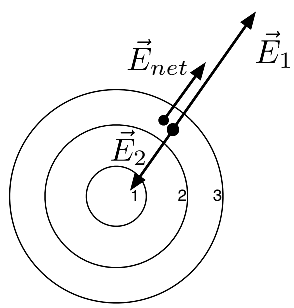
$$\begin{aligned} \vec{E}_{net} &= \vec{E}_1 \\ \left|\vec{E}_1\right| &= \frac{1}{4\pi\varepsilon_o}\frac{Q_1}{r^2} \\ &= \frac{\left(9 \times 10^9 \ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(6 \times 10^{-9} \text{ C})}{(0.04 \text{ m})^2} \\ &= 3.38 \times 10^4 \text{ N/C} \end{aligned}$$

(c) $\left|\vec{E}_{net}\right|$ at $r = 9$ cm?

A point at $r = 9$ cm is inside sphere 3, so the electric field due to sphere 3 is zero and thus $\vec{E}_{net} = \vec{E}_1 + \vec{E}_2$. It's very important to add the vectors before you calculate the magnitude of the net electric field.

$$\begin{aligned}
\vec{E}_{net} &= \vec{E}_1 + \vec{E}_2 \\
&= \frac{1}{4\pi\varepsilon_o}\frac{Q_1}{r^2}\hat{r} + \frac{1}{4\pi\varepsilon_o}\frac{Q_2}{r^2}\hat{r} \\
&= \left(\frac{\left(9\times10^9\ \frac{N\cdot m^2}{C^2}\right)(6\times10^{-9}\ C)}{(0.09\ m)^2}\right)\hat{r} + \left(\frac{\left(9\times10^9\ \frac{N\cdot m^2}{C^2}\right)(-4\times10^{-9}\ C)}{(0.09\ m)^2}\right)\hat{r} \\
&= \left(\frac{\left(9\times10^9\ \frac{N\cdot m^2}{C^2}\right)(2\times10^{-9}\ C)}{(0.09\ m)^2}\right)\hat{r} \\
&= \left(2.22\times10^3\ N/C\right)\hat{r} \\
\left|\vec{E}_{net}\right| &= 2.22\times10^3\ N/C
\end{aligned}$$

Note that $\vec{E}_1$ points away from the center of the sphere, and $\vec{E}_2$ points toward the center of the sphere. The net field is smaller than $\vec{E}_1$ and points away from the center of the spheres. It's a good idea to sketch the vectors. The picture below shows $\vec{E}_1$, $\vec{E}_2$, and $\vec{E}_{net}$. The arrows are not necessarily drawn to scale.



P52:

Solution:

(a) g. The electric field along the axis of the dipole is in the same direction as the dipole moment.

(b) c. The electric field along the axis of the dipole is in the opposite direction as the dipole moment.

P53:

Solution:

The point where the field is calculated is along the perpendicular bisector of the dipole. Since $r >> s$ in this case, calculate the approximate magnitude of E-field at the given point.

$$\begin{aligned}
\left|\vec{E}\right| &\approx \frac{1}{4\pi\varepsilon_o}\frac{qs}{r^3} \\
&\approx \left(9\times10^9\ \frac{N\cdot m^2}{C^2}\right)\frac{(1.602\times10^{-19}\ C)(2\times10^{-10}\ m)}{(3\times10^{-8}\ m)^3} \\
&\approx 1.07\times10^4\ N/C
\end{aligned}$$