Chapter 13

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 $< 0, -1, 0 >$.

P22:

Solution:

(a) h, because $\vec{\mathrm{E}}$ and $\vec{\mathrm{F}}$ 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 $\vec{\mathrm{F}} =< -4 \times 10^{-5}, 4 \times 10^{-5}, 0 >$ N.)

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

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

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

(e)

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

(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.

P27:

Solution:

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

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

(c)

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

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

(e)

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

(f)

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

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

(g)

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

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.

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

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

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

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

$$\begin{aligned} \left|\vec{E}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2} \\ &= \frac{1}{4\pi\varepsilon_o}\frac{1.602\times 10^{-19}\ \mathrm{C}}{(100\times 10^{-9}\ \mathrm{m})^2} \\ &= 1.44\times 10^5\ \mathrm{N/C} \end{aligned}$$

So, the E-field vector is $\vec{E}_{Cl} =< 1.44\times 10^5, 0, 0 >$ N/C. The electric field due to Fe^{3+} at the location A points in the $+x$ direction. Its magnitude is

$$\begin{aligned} \left|\vec{E}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2} \\ &= \frac{1}{4\pi\varepsilon_o}\frac{3(1.602\times 10^{-19}\ \mathrm{C})}{(300\times 10^{-9}\ \mathrm{m})^2} \\ &= 4.8\times 10^4\ \mathrm{N/C} \end{aligned}$$

So, the E-field vector is $\vec{E}_{Fe} =< 4.80\times 10^4, 0, 0 >$ N/C. This gives a net electric field of

$$\begin{aligned} \vec{E}_{net,\ A} &= < 1.44\times 10^5, 0, 0 >\ \mathrm{N/C} + < 4.80\times 10^4, 0, 0 >\ \mathrm{N/C} \\ &= < 1.92\times 10^5, 0, 0 >\ \mathrm{N/C} \end{aligned}$$

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

$$\begin{aligned} \left|\vec{E}\right| &= \frac{1}{4\pi\varepsilon_o}\frac{|q|}{|\vec{r}|^2} \\ &= \frac{1}{4\pi\varepsilon_o}\frac{3(1.602\times 10^{-19}\ \mathrm{C})}{(500\times 10^{-9}\ \mathrm{m})^2} \\ &= 1.73\times 10^4\ \mathrm{N/C} \end{aligned}$$

So, the E-field vector is $\vec{E}_{Fe} =< 1.73\times 10^4, 0, 0 >$ N/C. This gives a net electric field of

$$\begin{aligned} \vec{E}_{net,\ B} &= < -1.44\times 10^5, 0, 0 >\ \mathrm{N/C} + < 1.73\times 10^4, 0, 0 >\ \mathrm{N/C} \\ &= < -1.27\times 10^5, 0, 0 >\ \mathrm{N/C} \end{aligned}$$

(c)

$$\begin{aligned} \vec{F} &= q\vec{E} \\ &= (-1.602\times 10^{-19}\ \mathrm{C})(< 1.92\times 10^5, 0, 0 >\ \mathrm{N/C}) \\ &= < -3.07\times 10^{-14}, 0, 0 >\ \mathrm{N} \end{aligned}$$

P58:

Solution:

(a)

$$\begin{aligned}
\vec{E}_{\text{dipole}} &\approx \left\langle 0, -\frac{1}{4\pi\varepsilon_o}\frac{4\,|e|\,s}{|\vec{r}|^3}, 0 \right\rangle \\
\vec{F}_{\text{proton by dipole}} &\approx \left\langle 0, -\frac{1}{4\pi\varepsilon_o}\frac{4\,|e|^2\,s}{|\vec{r}|^3}, 0 \right\rangle \\
&\approx \left\langle 0, -\left(9\times 10^{9}\ \frac{\mathrm{N}\cdot\mathrm{m}^2}{\mathrm{C}^2}\right)\frac{4\left(1.602\times 10^{-19}\ \mathrm{C}\right)^2\left(7\times 10^{-10}\ \mathrm{m}\right)}{\left(3\times 10^{-8}\ \mathrm{m}\right)^3}, 0 \right\rangle \\
&\approx \left\langle 0, -2.40\times 10^{-14}, 0 \right\rangle\ \mathrm{N}
\end{aligned}$$

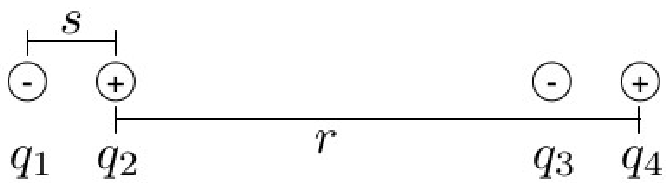
(b)

$$\begin{aligned}
\vec{E}_{\text{dipole}} &\approx \left\langle 0, \frac{1}{4\pi\varepsilon_o}\frac{2\,|e|\,s}{|\vec{r}|^3}, 0 \right\rangle \\
\vec{F}_{\text{electron by dipole}} &\approx \left\langle 0, -\frac{1}{4\pi\varepsilon_o}\frac{2\,|e|^2\,s}{|\vec{r}|^3}, 0 \right\rangle \\
&\approx \left\langle 0, -\left(9\times 10^{9}\ \frac{\mathrm{N}\cdot\mathrm{m}^2}{\mathrm{C}^2}\right)\frac{2\left(1.602\times 10^{-19}\ \mathrm{C}\right)^2\left(7\times 10^{-10}\ \mathrm{m}\right)}{\left(3\times 10^{-8}\ \mathrm{m}\right)^3}, 0 \right\rangle \\
&\approx \left\langle 0, -1.20\times 10^{-14}, 0 \right\rangle\ \mathrm{N}
\end{aligned}$$

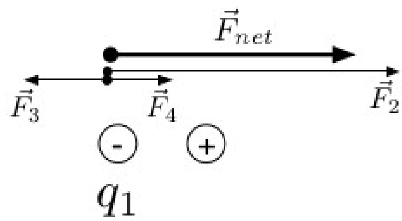
P63:

Solution:

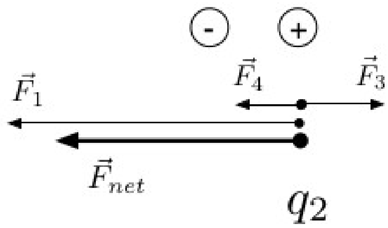
First, sketch a picture of the system and label each particle, starting with the particle on the left.



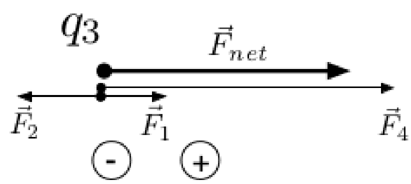
(a) Here are the forces (and net force) acting on particle 1.



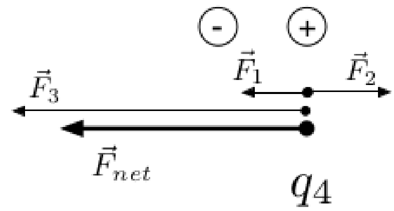
Here are the forces (and net force) acting on particle 2.



Here are the forces (and net force) acting on particle 3.

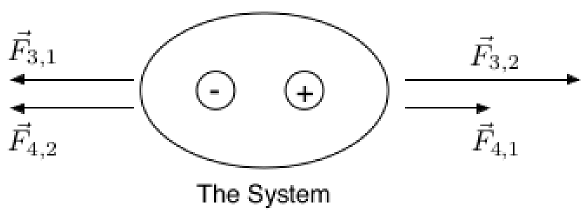


Here are the forces (and net force) acting on particle 4.



(b) Since we want to calculate the net force by one dipole on the other dipole, let's define a single dipole as the system. In this case, I will choose particles 1 and 2 to be the system. Let's use the naming convention $\vec{F}_{3,1}$ to mean "the force by particle 3 on particle 1." Because we define particles 1 and 2 as the system, the force by particle 1 on particle 2 and the force by particle 2 on particle 1 are internal to the system and are therefore not external forces.

Sketch a free-body diagram showing external forces on the system.



Because of the distances between the particles,

$$
\begin{aligned}
\left|\vec{F}_{3,2}\right| &> \left|\vec{F}_{4,1}\right| \\
\left|\vec{F}_{3,1}\right| &= \left|\vec{F}_{4,2}\right| \\
\left|\vec{F}_{3,2}\right| &> \left|\vec{F}_{3,1}\right|
\end{aligned}
$$

Apply the Principle of Superposition to the system.

$$
\begin{aligned}
\vec{F}_{net} &= \vec{F}_{3,2} + \vec{F}_{4,1} + \vec{F}_{3,1} + \vec{F}_{4,2} \\
&= \vec{F}_{3,2} + \vec{F}_{4,1} + 2\vec{F}_{3,1}
\end{aligned}
$$

Define $\hat{r}$ to point to the right along the axis between the dipoles. Then substitute for each electric force on the system.

$$
\begin{aligned}
\vec{F}_{net} &= \vec{F}_{3,2} + \vec{F}_{4,2} + 2\vec{F}_{3,1} \\
&= \frac{1}{4\pi\varepsilon_o}\frac{q^2}{(r-s)^2}\hat{r} + \frac{1}{4\pi\varepsilon_o}\frac{q^2}{(r+s)^2}\hat{r} + 2\left(\frac{1}{4\pi\varepsilon_o}\frac{q^2}{r^2}\right)(-\hat{r}) \\
&= \frac{1}{4\pi\varepsilon_o}\frac{q^2}{(r-s)^2}\hat{r} + \frac{1}{4\pi\varepsilon_o}\frac{q^2}{(r+s)^2}\hat{r} - 2\left(\frac{1}{4\pi\varepsilon_o}\frac{q^2}{r^2}\right)\hat{r} \\
&= \frac{1}{4\pi\varepsilon_o}q^2\left[\frac{1}{(r-s)^2} + \frac{1}{(r+s)^2} - \frac{2}{r^2}\right]\hat{r}
\end{aligned}
$$

Combine terms by finding common denominators. Use algebra to simplify the expression. Start with the first two terms.

$$
\begin{aligned}
\vec{F}_{net} &= \frac{1}{4\pi\varepsilon_o}q^2\left[\frac{(r+s)^2+(r-s)^2}{(r-s)^2(r+s)^2} - \frac{2}{r^2}\right]\hat{r} \\
&= \frac{1}{4\pi\varepsilon_o}q^2\left[\frac{r^2+s^2+\cancel{2rs}+r^2+s^2-\cancel{2rs}}{(r^2-s^2)^2} - \frac{2}{r^2}\right]\hat{r} \\
&= \frac{1}{4\pi\varepsilon_o}q^2\left[\frac{2(r^2+s^2)}{(r^2-s^2)^2} - \frac{2}{r^2}\right]\hat{r} \\
&= 2\frac{1}{4\pi\varepsilon_o}q^2\left[\frac{(r^2+s^2)r^2-(r^2-s^2)}{r^2(r^2-s^2)^2}\right]\hat{r} \\
&= 2\frac{1}{4\pi\varepsilon_o}q^2\left[\frac{\cancel{r^4}+r^2s^2-\cancel{r^4}-s^4+2s^2r^2}{r^2(r^2-s^2)^2}\right]\hat{r} \\
&= 2\frac{1}{4\pi\varepsilon_o}q^2\left[\frac{3s^2r^2-s^4}{r^2(r^2-s^2)^2}\right]\hat{r}
\end{aligned}
$$

Because $r >> s$, then $s^4 \approx 0$ and $r^2 - s^2 \approx r^2$. Then

$$
\begin{aligned}
\vec{F}_{net} &= 2\frac{1}{4\pi\varepsilon_o}q^2\left[\frac{3s^2r^2}{r^6}\right]\hat{r} \\
&= 2\frac{1}{4\pi\varepsilon_o}q^2\left[\frac{3s^2}{r^4}\right]\hat{r} \\
&= \frac{1}{4\pi\varepsilon_o}\left(\frac{6q^2s^2}{r^4}\right)\hat{r}
\end{aligned}
$$

Thus the magnitude of the net force on the dipole by the other dipole is

$$
\left|\vec{F}_{net}\right| = \frac{1}{4\pi\varepsilon_o}\frac{6q^2s^2}{r^4}
$$

Chapter 14

Q10:

Solution:

Atoms inside the plastic block become induced dipoles with the negative side of the dipoles on the right and the positive side of the dipoles on the left.

For the copper block, the sea of electrons shifts to the left, toward the positively charged particle. As a result, the surface of the block on the left becomes negatively charged, and the surface of the block on the right becomes positively charged.

P37:

Solution:

(a) The force by the polarized carbon atom on the electron has a magnitude

$$F = \left(\frac{1}{4\pi\varepsilon_o}\right)^2 \frac{2\alpha e^2}{r^5}$$

According to the Momentum Principle, $\vec{F}_{net} = m\vec{a}$. Assume that the only force on the electron is that of the carbon atom.

$$\begin{aligned} \left|\vec{F}\right| &= m\left|\vec{a}\right| \\ \left|\vec{a}\right| &= \frac{\left|\vec{F}\right|}{m} \\ &= \left(\frac{1}{4\pi\varepsilon_o}\right)^2 \frac{2\alpha e^2}{mr^5} \end{aligned}$$

Substitute constants to calculate a.

$$\begin{aligned} a &= \left(9\times 10^9\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}\right)^2 \frac{2\left(1.96\times 10^{-40}\ \mathrm{C\cdot m/(N/C)}\right)\left(1.602\times 10^{-19}\ \mathrm{C}\right)^2}{(9.11\times 10^{-31}\ \mathrm{kg})(1\times 10^{-6}\ \mathrm{m})^5} \\ &\approx 894\ \mathrm{m/s^2} \end{aligned}$$

(b) Since $a \propto 1/r^5$, then doubling the initial distance will change the initial acceleration by a factor $1/2^5 = 1/32$.

P42:

Solution:

(a) c. The electric field along the perpendicular bisector of the dipole is opposite its dipole moment.

(b) c.

(c) 1.

(d) 1.

(e) 2 and 4.

(f) c.

(g) g.

(h) c. The net electric field is slightly less than the electric field due to the dipole.

(i) 1.

(j) 3.

P43:

Solution:

$$u = 5.2 \times 10^{-8}\ \frac{\text{m/s}}{\text{N/C}}$$
$$|\vec{v}| = u\left|\vec{E}\right| = \left(5.2 \times 10^{-8}\ \frac{\text{m/s}}{\text{N/C}}\right)\left(2.4 \times 10^{3}\ \text{N/C}\right)$$
$$|\vec{v}| = 1.25 \times 10^{-4}\ \text{m/s}$$

P56:

Solution:

Calculate the electric field of the point charge at the location inside the metal sphere.

$$\begin{aligned}
\vec{r} &= \vec{r}_{obs} - \vec{r}_{source} = \langle 0, 0.07, 0\rangle\ \text{m} - \langle -0.3, 0, 0\rangle\ \text{m} \\
|\vec{r}| &= 0.308\ \text{m} \\
\hat{r} &= \frac{\vec{r}}{|\vec{r}|} = \langle 0.974, 0.227, 0\rangle \\
\vec{E}_{charge} &= \frac{1}{4\pi\varepsilon_o}\frac{Q}{|\vec{r}|^2} \\
&= \left(9 \times 10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{\left(6 \times 10^{-8}\ \text{C}\right)}{(0.308\ \text{m})^2}\langle 0.974, 0.227, 0\rangle \\
&= \langle 5541.35, 1292.98, 0\rangle\ \text{N/C}
\end{aligned}$$

Because everything is stationary, the net field inside the metal sphere must be zero at every point. That means that the field due to the charges must be the opposite of the field due to the point charge, at every point inside the sphere.

$$\therefore \vec{E}_{charges} = \langle -5541.35, -1292.98, 0\rangle\ \text{N/C}$$

P64:

Solution:

(a) O because any excess charge spreads over your body and the net charge on the sphere is nearly zero.

(b) N.

In 6, the sphere must be negatively charged because the sphere and rod repel. In 5, the block must be negatively charged because the sphere and block repel. In 4, the sphere became negatively charged because it touched the block. In 3, the sphere was attracted to the block because at this moment, the sphere was neutral. The reason that the sphere is attracted to the negatively charged block is that the sphere becomes polarized when the negatively charged electron sea shifts away from the block.

(c) K. The sphere is negatively charged. However, the charge is mobile; therefore, there is a greater density of negative charge away from the negatively charged block.

(d) K. The reason is similar to part (c).