Pearson Physics Level 30
Unit VI Forces and Fields: Chapter 10
Solutions

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Concept Check

1. It is easier for ebonite to remove electrons from fur than from silk.
2. Ebonite acquires a negative charge when rubbed with fur.

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Concept Check

If you bring the balloon near a wall, atoms on the surface of the wall experience charge separation through the process of induction. As a result, the surface of the wall closest to the balloon is oppositely charged and attraction occurs. Since the balloon and the wall are insulators, the transfer of charge while they are in contact is difficult and occurs very slowly. The balloon will stick to the wall for a long time until enough charge has leaked from the balloon to the wall. Then repulsion will occur because the balloon and the wall are now similarly charged.

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10.1 Check and Reflect

Knowledge

1. Electrostatics is the study of electric charges at rest or stationary charges.
2. A simple experiment would involve testing different objects to see if they either attracted or repelled each other. The fact that there were two possible actions was evidence that there were two different types of effects. This led scientists to conclude that there must be two different types of charges.
3. **(a)** Similarities:
Both display attraction or repulsion.
There must be two different types of electric charges and two different types of magnetic poles. They both affect objects at a distance.
(b) Differences:
Electric objects must be rubbed before any effects are observed.
Magnetic objects affect only certain other objects.
Magnetic effects seem to originate from two poles while electric effects do not.
4. **(a)** Electrical conductivity depends on how tightly the nucleus of an atom holds onto the atom's outer electrons.
(b) Insulator, semiconductor, conductor, superconductor
(c) Students' answers may vary. The following are examples of possible answers:
Insulator—glass
Semiconductor—selenium

Conductor—copper
Superconductor—copper oxide alloys

(d) Selenium is an insulator in the dark and a conductor when exposed to light.

Applications

5. (a) The object nearer the top of the chart will become negatively charged since it has a greater affinity for electrons.

(b) The greater the separation of two objects in the chart, the easier the transfer of charge.

6. (a) To charge the glass sphere positively by friction, rub the glass rod with silk.

(b) To charge the glass sphere positively by conduction, touch the glass sphere with a positively charged object.

(c) To charge the glass sphere positively by induction, bring a negatively charged object near the glass sphere. Ground the glass sphere, and then remove the negatively charged object. The glass sphere will now have a positive charge.

7. To charge the sphere negatively by induction, bring a positively charged object near the sphere. Ground the sphere. Remove the grounding source, and then remove the positively charged object. The sphere will now have a negative charge.

8.(a) As a negatively charged rod approaches a neutral pith ball, electrons in the pith ball are repelled and shift to the other side of the atoms, causing the atoms to become polarized. Since the positive nuclei are closer to the negatively charged rod than the negative electrons, there will be a net force of attraction and the pith ball will swing toward the negatively charged rod.

(b) After they touch, the pith ball will become negatively charged by conduction. There will be a net force of repulsion between the two objects and the pith ball will swing away from the negatively charged rod.

9. (a) Both objects will become negatively charged by conduction. However, since aluminium is a conductor, the charges redistribute evenly throughout the surface of the aluminium and since glass is an insulator, the charges remain on the surface of the glass at the point of contact with the negatively charged object.

(b) When a negatively charged small metal sphere touches a larger metal sphere, electrons transfer from the smaller metal sphere to the larger metal sphere, and the larger metal sphere will become charged by conduction. Since it is larger, it will now have a larger negative charge than the smaller metal sphere.

10. (a) When a negatively charged object is held near the knob of an electroscope, electrons in the knob are repelled and move to the leaves. The leaves diverge, indicating that they are now charged with negative charges.

(b) When the knob is grounded, the excess electrons in the leaves are removed to the ground. The leaves will now return to their original neutral position.

(c) The charging rod holds the charges in the knob in place. If the charging rod is removed before the ground, then the knob will become grounded, and there will be no residual charge on the electroscope.

Extensions

11. Student answers may vary. One example procedure would be:
Rub the ebonite rod with fur. The ebonite is now charged negatively.
Touch the ebonite rod to charge the electroscope negatively by conduction.
Bring the electroscope near the unknown charge.

If the unknown sphere is negatively charged, the electroscope leaves should diverge further.
If the unknown sphere is positively charged, the leaves on the electroscope would converge.

12. Charging an object by friction involves a transfer of electrons from one object to another. No new charge has been produced. The net positive charge on the glass rod will equal the net negative charge on the silk, as would be predicted by the law of conservation of charge.

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Example 10.1 Practice Problem

1. ***Given***

$q_1 = -1.60 \times 10^{-19}$ C

$q_2 = +1.60 \times 10^{-19}$ C

$r = 5.29 \times 10^{-11}$ m

Required

magnitude of the electrostatic force acting on the two charges ($\left|\vec{F}_{\mathrm{e}}\right|$)

Analysis and Solution

According to Newton's third law, the electrostatic forces acting on the two charges are the same in magnitude but opposite in direction.
To calculate the magnitude of the electrostatic force acting on the two charges, use

$$\left|\vec{F}_{\mathrm{e}}\right| = k\frac{q_1 q_2}{r^2}$$

The negative and the positive signs for the charges are only used in the final answer to indicate if the electrostatic force is attractive or repulsive.
Coulomb's constant is $k = 8.99 \times 10^9$ N•m^2/C^2.
The electrostatic force is attractive because the charges are opposite to each other.

$$\begin{aligned}\left|\vec{F}_{\mathrm{e}}\right| &= k\frac{q_1 q_2}{r^2}\\ &= \frac{\left(8.99 \times 10^9\ \frac{\mathrm{N \cdot m^2}}{\cancel{\mathrm{C}^2}}\right)(1.60 \times 10^{-19}\ \cancel{\mathrm{C}})(1.60 \times 10^{-19}\ \cancel{\mathrm{C}})}{(5.29 \times 10^{-11}\ \mathrm{m})^2}\\ &= 8.22 \times 10^{-8}\ \mathrm{N}\end{aligned}$$

Paraphrase

The electrostatic force acting on the two charges is 8.22×10^{-8} N. Since one charge is negative and the other is positive, the electrostatic force is attractive.

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Example 10.2 Practice Problem

1. ***Given***

$q_1 = -3.00 \times 10^{-6}$ C

$q_2 = +2.00 \times 10^{-6}$ C

$r = 12.0$ cm or 1.20×10^{-1} m

Required

magnitude of the electrostatic force acting on the two spheres after they have touched one another and separated ($|\vec{F}_e|$)

Analysis and Solution

According to Newton's third law, the electrostatic forces acting on the two spheres are the same in magnitude but opposite in direction.

When the two spheres momentarily touch one another, the resulting net charge is divided equally between them. When a sphere with a negative charge of 3.00×10^{-6} C momentarily touches a sphere with a positive charge of 2.00×10^{-6} C, then -2.00×10^{-6} C is removed from the first sphere to neutralize the $+2.00\times 10^{-6}$ C of the second sphere. This leaves a negative charge of -1.00×10^{-6} C on the first sphere, divided equally between the two spheres. Each sphere now has a negative charge of -0.500×10^{-6} C.

To calculate the magnitude of the electrostatic force acting on the two spheres, use:

$$|\vec{F}_e| = k\frac{q_1 q_2}{r^2}$$

Coulomb's constant is $k = 8.99 \times 10^9$ N•m²/C².

The new electrostatic force will be repulsive because both charges are negative:

$$\begin{aligned}|\vec{F}_e| &= k\frac{q_1 q_2}{r^2}\\ &= \frac{\left(8.99 \times 10^9 \ \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(0.500 \times 10^{-6}\ \cancel{\text{C}})(0.500 \times 10^{-6}\ \cancel{\text{C}})}{(1.20 \times 10^{-1}\ \text{m})^2}\\ &= 1.56 \times 10^{-1}\ \text{N}\end{aligned}$$

Paraphrase

The electrostatic force acting on the two charges is 1.56×10^{-1} N. Since both spheres have a negative charge, the electrostatic force is repulsive.

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Concept Check

Similarities:

• Both forces vary with $\frac{1}{r^2}$.

• Both forces are action-at-a-distance forces.

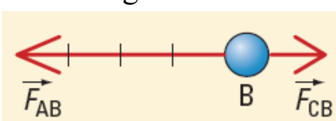
• Both forces have similar equations.

Differences:
• Electrostatic forces are much greater.
• Electrostatic forces can be attractive or repulsive.
• Gravitational forces are only attractive.

Example 10.3 Practice Problems

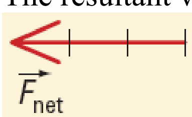
1. ***Analysis and Solution***

The electrostatic force of charge A on charge B is attractive to the left, and the electrostatic force of charge C on charge B is attractive to the right.
The product of the charges is the same for both forces.
The only factor affecting the magnitudes of the forces of charges A and C on B is distance, where $\left|\vec{F}_{\text{e}}\right| \propto \frac{1}{r^2}$.
Since the distance between charges A and B is one-half the distance between charges C and B, then $\left|\vec{F}_{\text{CB}}\right|$ is $\left(\frac{1}{2}\right)^2$ or $\frac{1}{4}\left|\vec{F}_{\text{AB}}\right|$.
The vector diagram is shown below. The vector to the left represents $\vec{F}_{\text{AB}}$. It is four times longer than the vector to the right, which represents $\vec{F}_{\text{CB}}$.



2. ***Analysis and Solution***

The two electrostatic forces are vectors along the same line, so the net force can be determined by adding the vectors in the solution to Practice Problem 1.
The resultant vector is shown below.



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Example 10.4 Practice Problems

1. ***Given***

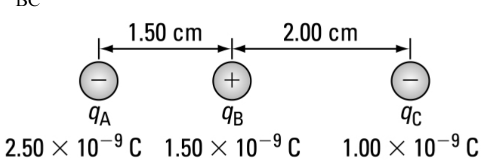
$q_{\text{A}} = -2.50 \times 10^{-9}$ C

$q_{\text{B}} = +1.50 \times 10^{-9}$ C

$q_{\text{C}} = -1.00 \times 10^{-9}$ C

$r_{\text{AB}} = 1.50$ cm or 1.50×10^{-2} m

$r_{\text{BC}} = 2.00$ cm or 2.00×10^{-2} m



Required
net electrostatic force on sphere B $(\vec{F}_{\text{net}})$
Analysis and Solution
The electrostatic force of q_A on q_B is an attractive force to the left.
The electrostatic force of q_C on q_B is an attractive force to the right.
Since the two electrostatic forces are vectors along the same line, the net force can be determined by adding the vectors.

$$\vec{F}_{\text{net}} = \vec{F}_{\text{AB}} + \vec{F}_{\text{CB}}$$

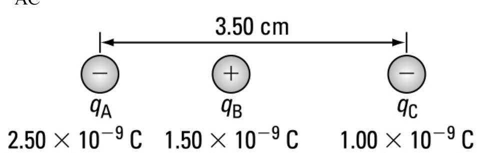
Use the following convention for vector addition: Vectors directed to the right are positive. Vectors directed to the left are negative.

$$\begin{aligned}
\vec{F}_{\text{net}} &= \vec{F}_{\text{AB}} + \vec{F}_{\text{CB}} \\
&= -\left(\frac{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.50\times10^{-9}\ \cancel{\text{C}})(1.50\times10^{-9}\ \cancel{\text{C}})}{(1.50\times10^{-2}\ \text{m})^2}\right) + \left(\frac{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(1.50\times10^{-9}\ \cancel{\text{C}})(1.00\times10^{-9}\ \cancel{\text{C}})}{(2.00\times10^{-2}\ \text{m})^2}\right) \\
&= -1.498\times10^{-4}\ \text{N} + 3.371\times10^{-5}\ \text{N} \\
&= -1.16\times10^{-4}\ \text{N}
\end{aligned}$$

Paraphrase
The net electrostatic force on the second charge is 1.16×10^{-4} N toward the -2.50×10^{-9} C charge or left.

2. ***Given***

$$\begin{aligned}
q_A &= -2.50\times10^{-9}\ \text{C} \\
q_B &= +1.50\times10^{-9}\ \text{C} \\
q_C &= -1.00\times10^{-9}\ \text{C} \\
r_{AC} &= 3.50\ \text{cm or } 3.50\times10^{-2}\ \text{m}
\end{aligned}$$



Required
position of the second sphere so that the net electrostatic force on it is zero (r_{AB})
Analysis and Solution
The distance of the second charge from the first charge is r_{AB}.
The distance of the second charge from the third charge is (3.50×10^{-2} cm $- r_{AB}$).
The electrostatic force of q_A on q_B is an attractive force to the left.
The electrostatic force of q_C on q_B is an attractive force to the right.
Since the two electrostatic forces are force vectors along the same line, the net force can be determined by adding the vectors.

$$\vec{F}_{\text{net}} = \vec{F}_{\text{AB}} + \vec{F}_{\text{CB}}$$

Use the following convention for vector addition: Vectors directed to the right are positive. Vectors directed to the left are negative.
If the $\vec{F}_{\text{net}} = 0$, then:

$$0 = \vec{F}_{AB} + \vec{F}_{CB}$$

$$= -\left(\frac{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.50\times10^{-9}\ \cancel{\text{C}})(1.50\times10^{-9}\ \cancel{\text{C}})}{(r_{AB})^2}\right) + \left(\frac{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(1.50\times10^{-9}\ \cancel{\text{C}})(1.00\times10^{-9}\ \cancel{\text{C}})}{(3.50\times10^{-2} - r_{AB})^2}\right)$$

$$\left(\frac{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.50\times10^{-9}\ \cancel{\text{C}})(1.50\times10^{-9}\ \cancel{\text{C}})}{(r_{AB})^2}\right) = \left(\frac{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(1.50\times10^{-9}\ \cancel{\text{C}})(1.00\times10^{-9}\ \cancel{\text{C}})}{(3.50\times10^{-2} - r_{AB})^2}\right)$$

$$\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.50\times10^{-9}\ \cancel{\text{C}})(1.50\times10^{-9}\ \cancel{\text{C}}) = (r_{AB})^2\left(\frac{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(1.50\times10^{-9}\ \cancel{\text{C}})(1.00\times10^{-9}\ \cancel{\text{C}})}{(3.50\times10^{-2} - r_{AB})^2}\right)$$

$$\frac{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.50\times10^{-9}\ \cancel{\text{C}})(1.50\times10^{-9}\ \cancel{\text{C}})}{\left(8.99\times10^{9}\ \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(1.50\times10^{-9}\ \cancel{\text{C}})(1.00\times10^{-9}\ \cancel{\text{C}})} = \frac{(r_{AB})^2}{(3.50\times10^{-2} - r_{AB})^2}$$

$$\sqrt{2.5} = \frac{r_{AB}}{3.50\times10^{-2} - r_{AB}}$$

$$(3.50\times10^{-2} - r_{AB})(\sqrt{2.5}) = r_{AB}$$

$$(3.50\times10^{-2})(\sqrt{2.5}) - (r_{AB})(\sqrt{2.5}) = r_{AB}$$

$$(3.50\times10^{-2})(\sqrt{2.5}) = r_{AB}(1+\sqrt{2.5})$$

$$r_{AB} = 2.14\times10^{-2}\ \text{m}$$

Paraphrase

The net electrostatic force on the second charge is 0 N when the second charge is placed 2.14×10^{-2} m to the right of the first charge.

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Example 10.5 Practice Problems

1. ***Given***

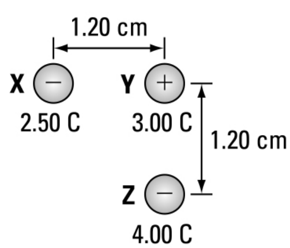
$q_X = -2.50$ C

$q_Y = +3.00$ C

$q_Z = +4.00$ C

$r_{XY} = 1.20\times10^{-2}$ m

$r_{ZY} = 1.20\times10^{-2}$ m



Required

net electrostatic force on charge Y ($\vec{F}_{net}$)

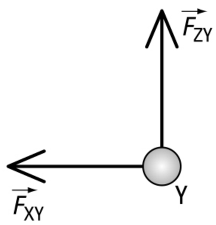
Analysis and Solution

The electrostatic force of q_X on q_Y is an attractive force ($\vec{F}_{XY}$) on a line from charge Y toward charge X.

The electrostatic force of q_Z on q_Y is a repulsive force ($\vec{F}_{ZY}$) directly upward from charge Y.

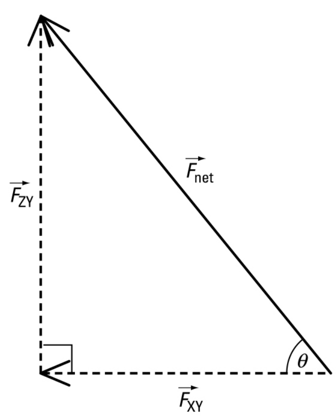
To calculate the electrostatic force of q_X on q_Y use: $\left|\vec{F}_{XY}\right| = k\frac{q_X q_Y}{r_{XY}^2}$

Draw a free-body diagram of the electrostatic forces on charge Y:



$$\left|\vec{F}_{XY}\right| = k\frac{q_X q_Y}{r_{XY}^2}$$
$$= \frac{\left(8.99 \times 10^9 \frac{\mathrm{N}\cdot\cancel{\mathrm{m}^2}}{\cancel{\mathrm{C}^2}}\right)(2.50\ \cancel{\mathrm{C}})(3.00\ \cancel{\mathrm{C}})}{(1.20 \times 10^{-2}\ \mathrm{m})^2}$$
$$= 4.682 \times 10^{14}\ \mathrm{N}$$

$$\left|\vec{F}_{ZY}\right| = k\frac{q_Z q_Y}{r_{ZY}^2}$$
$$= \frac{\left(8.99 \times 10^9 \frac{\mathrm{N}\cdot\cancel{\mathrm{m}^2}}{\cancel{\mathrm{C}^2}}\right)(4.00\ \cancel{\mathrm{C}})(3.00\ \cancel{\mathrm{C}})}{(1.20 \times 10^{-2}\ \mathrm{m})^2}$$
$$= 7.492 \times 10^{14}\ \mathrm{N}$$



Determine the magnitude of the force using the Pythagorean theorem:

$$\left|\vec{F}_{net}\right| = \sqrt{(7.492 \times 10^{14}\ \mathrm{N})^2 + (4.682 \times 10^{14}\ \mathrm{N})^2}$$
$$= 8.83 \times 10^{14}\ \mathrm{N}$$

Determine the angle θ:

$$\tan\theta = \frac{7.492 \times 10^{14}\ \mathrm{N}}{4.682 \times 10^{14}\ \mathrm{N}}$$
$$\theta = 58°$$

From the vector diagram, this angle is [58° N of W]. Using the Cartesian method, this angle is 180° – 58° = 122°.

Paraphrase

The net electrostatic force on charge Y is 8.83×10^{14} N [122°].

2. ***Given***

$q_A = -2.00\ \mu C$

$q_B = +1.00\ \mu C$

$q_C = -2.00\ \mu C$

$r_{AB} = 1.00 \times 10^{-2}$ m

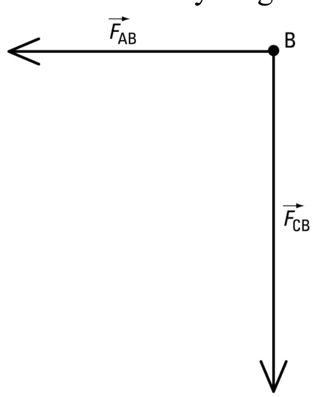
$r_{BC} = 1.00 \times 10^{-2}$ m

Required

net electrostatic force on charge B ($\vec{F}_{net}$)

Analysis and Solution

Draw a free-body diagram of the electrostatic forces on charge B:



Determine the electrostatic force of charge A on charge B (attraction toward A):

$$\left|\vec{F}_{AB}\right| = k\frac{q_A q_B}{r_{AB}^2}$$

$$= \frac{\left(8.99 \times 10^9 \frac{N \cdot \cancel{m^2}}{\cancel{C^2}}\right)(2.00 \times 10^{-6}\ \cancel{C})(1.00 \times 10^{-6}\ \cancel{C})}{(1.00 \times 10^{-2}\ m)^2}$$

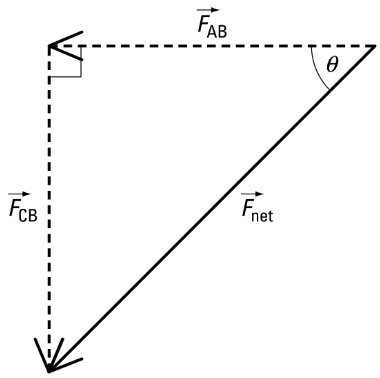
$$= 1.798 \times 10^2\ N$$

Determine the electrostatic force of charge C on charge B (attraction toward C):

$$\left|\vec{F}_{CB}\right| = k\frac{q_C q_B}{r_{CB}^2}$$

$$= \frac{\left(8.99 \times 10^9 \frac{N \cdot \cancel{m^2}}{\cancel{C^2}}\right)(2.00 \times 10^{-6}\ \cancel{C})(1.00 \times 10^{-6}\ \cancel{C})}{(1.00 \times 10^{-2}\ m)^2}$$

$$= 1.798 \times 10^2\ N$$



Determine the magnitude of the net force using the Pythagorean theorem:

$$\left|\vec{F}_{net}\right| = \sqrt{(1.798 \times 10^2 \text{ N})^2 + (1.798 \times 10^2 \text{ N})^2}$$
$$= 2.54 \times 10^2 \text{ N}$$

Determine the angle θ:

$$\tan\theta = \frac{1.798 \times 10^2 \text{ N}}{1.798 \times 10^2 \text{ N}}$$
$$\theta = 45.0°$$

From the vector diagram, the direction of the net force is [45.0° S of W] or [225°].

Paraphrase

The net electrostatic force on charge B is 2.54×10^2 N [45.0° S of W] or [225°].

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Example 10.6 Practice Problems

1. ***Given***

$q_X = -2.50$ C

$q_Y = +3.00$ C

$q_Z = +4.00$ C

$r_{XY} = 1.20 \times 10^{-2}$ m

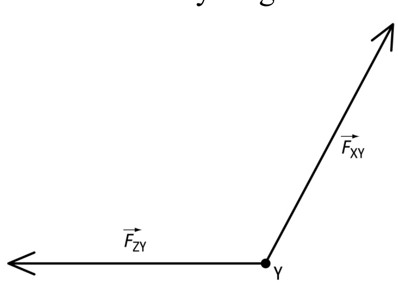
$r_{ZY} = 1.20 \times 10^{-2}$ m

Required

net electrostatic force on charge Y ($\vec{F}_{net}$)

Analysis and Solution

Draw a free-body diagram of the electrostatic forces on charge Y (see below).



Determine the electrostatic force of charge X on charge Y (attraction toward X):

$$\left|\vec{F}_{XY}\right| = k\frac{q_X q_Y}{r_{XY}^2}$$

$$= \frac{\left(8.99 \times 10^9 \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.50\ \cancel{\text{C}})(3.00\ \cancel{\text{C}})}{(1.20 \times 10^{-2}\ \cancel{\text{m}})^2}$$

$$= 4.682 \times 10^{14}\ \text{N}$$

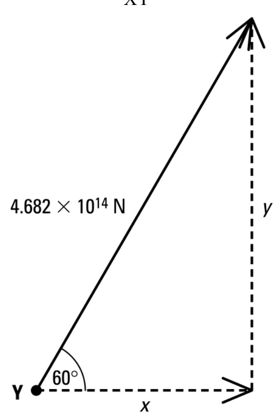
Determine the electrostatic force of charge Z on charge Y (repulsion away from Z):

$$\left|\vec{F}_{ZY}\right| = k\frac{q_Z q_Y}{r_{ZY}^2}$$

$$= \frac{\left(8.99 \times 10^9 \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(4.00\ \cancel{\text{C}})(3.00\ \cancel{\text{C}})}{(1.20 \times 10^{-2}\ \cancel{\text{m}})^2}$$

$$= 7.492 \times 10^{14}\ \text{N}$$

Resolve $\vec{F}_{XY}$ into x and y components as shown below:



$$F_{XY_x} = (4.682 \times 10^{14}\ \text{N})(\cos 60.0°)$$
$$= 2.341 \times 10^{14}\ \text{N}$$

$$F_{XY_y} = (4.682 \times 10^{14}\ \text{N})(\sin 60.0°)$$
$$= 4.055 \times 10^{14}\ \text{N}$$

The electrostatic force of charge Z on charge Y has only an x component.

$$F_{ZY_x} = -7.492 \times 10^{14}\ \text{N}$$

$$F_{ZY_y} = 0\ \ \text{N}$$

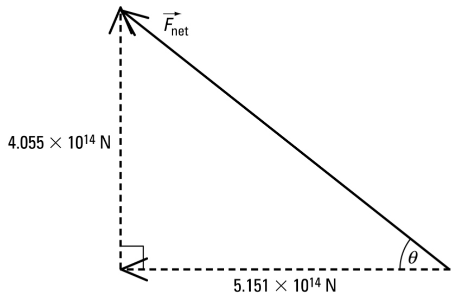
Find the sum of the x and y components.

$$\vec{F}_{\text{net}} = \vec{F}_{XY} + \vec{F}_{ZY}$$

$$F_{\text{net}_x} = F_{XY_x} + F_{ZY_x}$$
$$= 2.341 \times 10^{14}\ \text{N} + (-7.492 \times 10^{14}\ \text{N})$$
$$= -5.151 \times 10^{14}\ \text{N}$$

$$F_{\text{net}_y} = F_{\text{XY}_y} + F_{\text{ZY}_y}$$
$$= 4.055 \times 10^{14}\ \text{N} + 0\ \text{N}$$
$$= 4.055 \times 10^{14}\ \text{N}$$

Use trigonometry to determine the direction and magnitude of the net electrostatic force on charge Y, as shown below.



Determine the magnitude of the force using the Pythagorean theorem:

$$\left|\vec{F}_{\text{net}}\right| = \sqrt{(5.151 \times 10^{14}\ \text{N})^2 + (4.055 \times 10^{14}\ \text{N})^2}$$
$$= 6.56 \times 10^{14}\ \text{N}$$

Determine the angle θ using the tangent function:

$$\tan\theta = \frac{4.055 \times 10^{14}\ \text{N}}{5.151 \times 10^{14}\ \text{N}}$$
$$\theta = 38.2°$$

From the diagram, this angle is N of W.

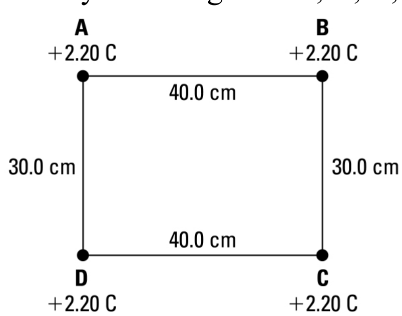
The direction of the net force is [38.2° N of W] or [142°].

Paraphrase

The net electrostatic force on charge Y is 6.56×10^{14} N [142°].

2. ***Given***

Identify the charges as A, B, C, and D as shown in the diagram.



$q_A = +2.20\ \text{C}$

$q_B = +2.20\ \text{C}$

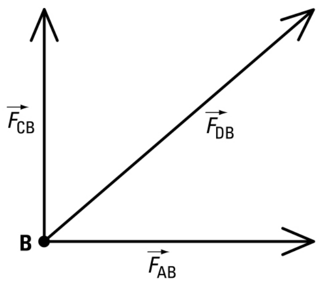
$q_C = +2.20\ \text{C}$

$q_D = +2.20\ \text{C}$

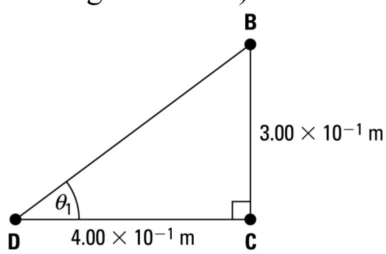
$r_{AB} = 4.00 \times 10^{-1}\ \text{m}$

$r_{CB} = 3.00 \times 10^{-1}\ \text{m}$

Required
net electrostatic force on charge B ($\vec{F}_{\text{net}}$)
Analysis and Solution
Draw a free-body diagram of the electrostatic forces on charge B like the one below:



Determine the distance between charges B and D by using the Pythagorean theorem (see diagram below).



$$r_{\text{DB}} = \sqrt{(3.00 \times 10^{-1}\text{ m})^2 + (4.00 \times 10^{-1}\text{ m})^2}$$
$$= 5.00 \times 10^{-1}\text{ m}$$

Determine the electrostatic force of charge A on charge B (repulsion away from A):

$$\left|\vec{F}_{\text{AB}}\right| = k\frac{q_{\text{A}}q_{\text{B}}}{r_{\text{AB}}^2}$$
$$= \frac{\left(8.99 \times 10^9 \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.20\ \cancel{\text{C}})(2.20\ \cancel{\text{C}})}{(4.00 \times 10^{-1}\text{ m})^2}$$
$$= 2.719\times10^{11}\ \text{N}$$

Determine the electrostatic force of charge C on charge B (repulsion away from C):

$$\left|\vec{F}_{\text{CB}}\right| = k\frac{q_{\text{C}}q_{\text{B}}}{r_{\text{CB}}^2}$$
$$= \frac{\left(8.99 \times 10^9 \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.20\ \cancel{\text{C}})(2.20\ \cancel{\text{C}})}{(3.00 \times 10^{-1}\ \cancel{\text{m}})^2}$$
$$= 4.835 \times 10^{11}\ \text{N}$$

Determine the electrostatic force of charge D on charge B:

$$\left|\vec{F}_{\text{DB}}\right| = k\frac{q_{\text{D}}q_{\text{B}}}{r_{\text{DB}}^2}$$

$$= \frac{\left(8.99 \times 10^9 \ \frac{\text{N} \cdot \text{m}^2}{\cancel{\text{C}^2}}\right)(2.20 \ \cancel{\text{C}})(2.20 \ \cancel{\text{C}})}{(5.00 \times 10^{-1} \ \cancel{\text{m}})^2}$$

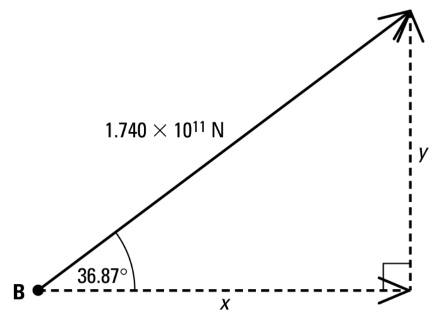
$$= 1.740 \times 10^{11} \text{ N}$$

Use trigonometry to determine the angle θ_1 of the diagonal line from D to B.

$$\tan\theta_1 = \frac{3.00 \times 10^{-1} \text{ m}}{4.00 \times 10^{-1} \text{ m}}$$

$$\theta_1 = 36.87°$$

Then resolve $\vec{F}_{\text{DB}}$ into x and y components.



$$F_{\text{DB}_x} = (1.740 \times 10^{11} \text{N})(\cos 36.87°)$$

$$= 1.392 \times 10^{11} \text{ N}$$

$$F_{\text{DB}_y} = (1.740 \times 10^{11} \text{N})(\sin 36.87°)$$

$$= 1.044 \times 10^{11} \text{ N}$$

$$\vec{F}_{\text{net}} = \vec{F}_{\text{AB}} + \vec{F}_{\text{CB}} + \vec{F}_{\text{DB}}$$

$$F_{\text{net}_x} = F_{\text{AB}_x} + F_{\text{CB}_x} + F_{\text{DB}_x}$$

$$= 2.719 \times 10^{11} \text{ N} + 0 \text{ N} + 1.392 \times 10^{11} \text{ N}$$

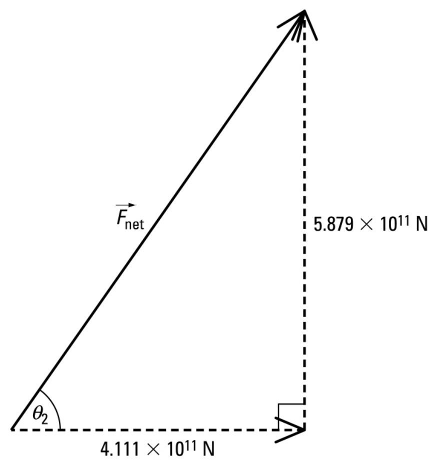
$$= 4.111 \times 10^{11} \text{ N}$$

$$F_{\text{net}_y} = F_{\text{AB}_y} + F_{\text{CB}_y} + F_{\text{DB}_y}$$

$$= 0 \text{ N} + 4.835 \times 10^{11} \text{ N} + 1.044 \times 10^{11} \text{ N}$$

$$= 5.879 \times 10^{11} \text{ N}$$

Use trigonometry to determine the net electrostatic force on charge B, as shown in the following diagram.



Determine the magnitude of the net force using the Pythagorean theorem:

$$\left|\vec{F}_{net}\right| = \sqrt{(5.879 \times 10^{11}\ \text{N})^2 + (4.111 \times 10^{11}\ \text{N})^2}$$

$$= 7.17 \times 10^{11}\ \text{N}$$

Determine the angle θ_2 using the tangent function:

$$\tan\theta_2 = \frac{5.879 \times 10^{11}\ \text{N}}{4.111 \times 10^{11}\ \text{N}}$$

$$\theta_2 = 55.0°$$

From the diagram, the direction of the net force is [55.0°].

Paraphrase

The net electrostatic force on charge B is 7.17×10^{11} N [55.0°] by the Cartesian method.

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10.2 Check and Reflect

Knowledge

1. The two factors that affect the electrostatic force are the amount of each charge and the distance between the centres of the charges. The mathematical relationships are:

$\vec{F}_e \propto \frac{1}{r^2}$ and $\vec{F}_e \propto q_1 q_2$.

2. Coulomb reasoned that since there appeared to be symmetry in nature, the electrostatic forces should vary according to the inverse square law that explained gravitational forces.

3. The smallest unit of charge is one electron. It has a charge of 1.60×10^{-19} C, which was determined experimentally by Millikan.

4. Coulomb would touch the two objects together, reasoning that charge would be divided equally each time they were in contact.

Applications

5. (a) If $\vec{F}_e \propto q_1 q_2$, doubling one charge doubles the force, which would be 20 N.

(b) If $\vec{F}_e \propto q_1 q_2$, doubling both charges quadruples the force, which would be 40 N.

6. (a) Attaining a large charge on objects is difficult because of the large forces of repulsion: the object loses this charge to the surroundings.

(b) $$\frac{-5.0\times10^{-9}\ \cancel{C}}{-1.60\times10^{-19}\ \frac{\cancel{C}}{e^-}} = 3.1\times10^{10}\ e^-$$

The object gained 3.1×10^{10} electrons.

7. ***Given***

$q_1 = 5.00 \times 10^{-5}$ C

$q_2 = 6.00 \times 10^{-5}$ C

$r = 2.00$ m

Required

(a) electrostatic force ($\vec{F}_e$)

(b) new electrostatic force ($\vec{F}_e$)

Analysis and Solution

(a) According to Newton's third law, the electrostatic forces acting on the two spheres are the same in magnitude but opposite in direction. Thus, it is only necessary to calculate the magnitude of the forces.

$$\begin{aligned}\left|\vec{F}_e\right| &= k\frac{q_1q_2}{r^2}\\ &= \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(5.00\times10^{-5}\ \cancel{\text{C}})(6.00\times10^{-5}\ \cancel{\text{C}})}{(2.00\ \text{m})^2}\\ &= 6.74\ \text{N}\end{aligned}$$

(b) When a sphere with a charge of 5.00×10^{-5} C momentarily touches a sphere with a charge of 6.00×10^{-5} C, this leaves a charge of 11.0×10^{-5} C, divided equally between the two spheres. Each sphere now has a charge of 5.50×10^{-5} C.
The new electrostatic force will be repulsive because both spheres have like charges:

$$\begin{aligned}\left|\vec{F}_e\right| &= k\frac{q_1q_2}{r^2}\\ &= \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(5.50\times10^{-5}\ \cancel{\text{C}})(5.50\times10^{-5}\ \cancel{\text{C}})}{(2.00\ \text{m})^2}\\ &= 6.80\ \text{N}\end{aligned}$$

Paraphrase

(a) The electrostatic force acting on the two charges is 6.74 N. Since the charges are like charges, the electrostatic force is repulsive.

(b) The electrostatic force acting on the two charges is 6.80 N. Since the spheres have like charges, the electrostatic force is repulsive.

8. ***Given***

$q_A = -2.00\,\text{C}$

$q_B = +3.00\,\text{C}$

$q_C = -2.00\,\text{C}$

$r_{AB} = 2.00\,\text{m}$

$r_{BC} = 3.00\,\text{m}$

Required

(a) net electrostatic force on charge A ($\vec{F}_{\text{net}}$)

(b) net electrostatic force on charge B ($\vec{F}_{\text{net}}$)

Analysis and Solution

(a) The distance between q_A and q_C is:

$$\begin{aligned} r_{CA} &= 2.00\text{ m} + 3.00\text{ m} \\ &= 5.00\text{ m} \end{aligned}$$

The electrostatic force of q_B and q_A is an attractive force to the right.
The electrostatic force of q_C and q_A is an repulsive force to the left.
Since the two electrostatic forces are vectors along the same line, the net force can be determined by adding the vectors.

$\vec{F}_{\text{net}} = \vec{F}_{\text{BA}} + \vec{F}_{\text{CA}}$

Consider right to be positive.

$$\begin{aligned} \left|\vec{F}_{\text{net}}\right| &= \left(\frac{\left(8.99\times10^{9}\,\frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.00\,\cancel{\text{C}})(3.00\,\cancel{\text{C}})}{(2.00\text{ m})^2}\right) + \left(-\frac{\left(8.99\times10^{9}\,\frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.00\,\cancel{\text{C}})(2.00\,\cancel{\text{C}})}{(5.00\text{ m})^2}\right) \\ &= 1.349\times10^{10}\text{ N} + (-1.438\times10^{9}\text{ N}) \\ &= 1.21\times10^{10}\text{ N} \end{aligned}$$

(b) The electrostatic force of q_A on q_B is an attractive force to the left.
The electrostatic force of q_C on q_B is an attractive force to the right.
Since the two electrostatic forces are vectors along the same line, the net force on charge B can be determined by adding the vectors.

$\vec{F}_{\text{net}} = \vec{F}_{\text{AB}} + \vec{F}_{\text{CB}}$

$$\begin{aligned} \left|\vec{F}_{\text{net}}\right| &= -\left(\frac{\left(8.99\times10^{9}\,\frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.00\,\cancel{\text{C}})(3.00\,\cancel{\text{C}})}{(2.00\text{ m})^2}\right) + \left(\frac{\left(8.99\times10^{9}\,\frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.00\,\cancel{\text{C}})(3.00\,\cancel{\text{C}})}{(3.00\text{ m})^2}\right) \\ &= -1.349\times10^{10}\text{ N} + 5.993\times10^{9}\text{ N} \\ &= -7.50\times10^{9}\text{ N} \end{aligned}$$

Paraphrase

(a) The net electrostatic force on charge A is 1.21×10^{10} N toward charge B.

(b) The net electrostatic force on charge B is 7.50×10^{9} N toward charge A.

Extensions

9. No. The electrostatic forces are caused by both charges, and according to Newton's third law, each force is equal in magnitude but opposite in direction.

10. There are also forces of electrostatic repulsion acting in your body that balance the attractive forces.

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Chapter 10 Review

Knowledge

1. An electrostatic charge is a charge at rest.

2. They depend on how tightly the atoms of these materials hold onto their outermost electrons.

3. Selenium becomes a good conductor when exposed to light and an insulator when kept in the dark. Materials with this property are called semiconductors.

4. Objects may become charged by friction, conduction, or induction that includes a grounding step.

5. The object made of a material that holds onto electrons more tightly will become negatively charged.

6. These processes are alike in that there is a transfer of electrons through contact. The difference is that friction allows more contact between the two objects.

7. The law of charges states that like charges repel and unlike charges attract.

8. Benjamin Franklin is given credit for naming the charges.

9. The law of conservation of charges states that the total amount of charge in a system must remain the same.

10. Selenium becomes a semiconductor when it is exposed to light, whereas germanium becomes a semiconductor when doped with gallium. For this reason, selenium is used in photocopiers.

11. ***Given***

$q_1 = -3.00 \times 10^{-6}\ \text{C}$

$q_2 = -2.50 \times 10^{-6}\ \text{C}$

$r = 0.200\ \text{m}$

Required

electrostatic force ($\vec{F}_\text{e}$)

Analysis and Solution

According to Newton's third law, the electrostatic forces exerted by the two charges on each other are the same in magnitude but opposite in direction.

$$\begin{aligned}\left|\vec{F}_\text{e}\right| &= k\frac{q_1 q_2}{r^2} \\ &= \frac{\left(8.99 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(3.00\times10^{-6}\ \cancel{\text{C}})(2.50\times10^{-6}\ \cancel{\text{C}})}{(0.200\ \text{m})^2} \\ &= 1.69\ \text{N}\end{aligned}$$

The electrostatic force is repulsive because the charges are the same.

Paraphrase
The electrostatic force acting on the two charges is 1.69 N. Since both charges are negative, the electrostatic force is repulsive.

12. ***Given***

$q_1 = -5.00\text{ C}$

$q_2 = -5.00\text{ C}$

$\left|\vec{F}_{\text{e}}\right| = 5.00 \times 10^3\text{ N}$

Required
distance between the two charges (r)

Analysis and Solution

$$\left|\vec{F}_{\text{e}}\right| = k\frac{q_1 q_2}{r^2}$$

$$r = \sqrt{\frac{kq_1 q_2}{\left|\vec{F}_{\text{e}}\right|}}$$

$$= \sqrt{\frac{\left(8.99 \times 10^9\ \frac{\cancel{\text{N}} \cdot \text{m}^2}{\cancel{\text{C}^2}}\right)(5.00\ \cancel{\text{C}})(5.00\ \cancel{\text{C}})}{(5.00 \times 10^3\ \cancel{\text{N}})}}$$

$$= 6.70 \times 10^3\text{ m}$$

Paraphrase
The distance between the two charges is 6.70×10^3 m.

13. ***Given***

$q_{\text{A}} = -2.50\text{ C}$

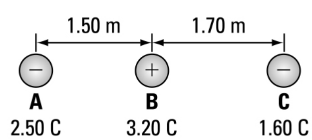
$q_{\text{B}} = +3.20\text{ C}$

$q_{\text{C}} = -1.60\text{ C}$

$r_{\text{AB}} = 1.50\text{ m}$

$r_{\text{CB}} = 1.70\text{ m}$

$r_{\text{AC}} = 3.20\text{ m}$



Required
(a) net electrostatic force on charge B ($\vec{F}_{\text{net}}$)
(b) net electrostatic force on charge C ($\vec{F}_{\text{net}}$)

Analysis and Solution
(a) The electrostatic force of q_{A} on q_{B} is an attractive force to the left.
The electrostatic force of q_{C} on q_{B} is an attractive force to the right.
Since the two electrostatic forces are vectors along the same line, the net force on q_{B} can be determined by adding the vectors.

$$\vec{F}_{\text{net}} = \vec{F}_{\text{AB}} + \vec{F}_{\text{CB}}$$

Choose right to be positive.

$$\left|\vec{F}_{\text{net}}\right| = -\left(\frac{\left(8.99\times10^{9}\,\frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.50\,\cancel{\text{C}})(3.20\,\cancel{\text{C}})}{(1.50\text{ m})^2}\right) + \left(\frac{\left(8.99\times10^{9}\,\frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(1.60\,\cancel{\text{C}})(3.20\,\cancel{\text{C}})}{(1.70\text{ m})^2}\right)$$

$$= -3.196\times10^{10}\text{ N} + 1.593\times10^{10}\text{ N}$$

$$= -1.60\times10^{10}\text{ N}$$

(b) The electrostatic force of q_A on q_C is a repulsive force to the right.
The electrostatic force of q_C on q_B is an attractive force to the left.
Since the two electrostatic forces are vectors along the same line, the net force can be determined by adding the vectors.

$\vec{F}_{\text{net}} = \vec{F}_{\text{AC}} + \vec{F}_{\text{BC}}$

Choose right to be positive.

$$\left|\vec{F}_{\text{net}}\right| = \left(\frac{\left(8.99\times10^{9}\,\frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.50\,\cancel{\text{C}})(1.60\,\cancel{\text{C}})}{(3.20\text{ m})^2}\right) - \left(\frac{\left(8.99\times10^{9}\,\frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(1.60\,\cancel{\text{C}})(3.20\,\cancel{\text{C}})}{(1.70\text{ m})^2}\right)$$

$$= 3.512\times10^{9}\text{ N} - 1.593\times10^{10}\text{ N}$$

$$= -1.24\times10^{10}\text{ N}$$

Paraphrase

(a) The net electrostatic force on charge B is 1.60×10^{10} N [left].

(b) The net electrostatic force on charge C is 1.24×10^{10} N [left].

Applications

14. As electrons from the CRT strike the screen of the TV, the screen becomes negatively charged and attracts dust particles in the air by induction.

15. In materials with low electrical resistance, very little energy is lost to heat, so they are better conductors of electricity.

16. The flame ionizes the air near the charged rod, allowing electrons from the rod to leak to the charged air molecules.

17. Attraction can occur between a charged object and a neutral object; however, repulsion can occur only if two objects have the same charge.

18. Charges from charged objects will leak into the humid air.

19. Initially, the charged ball attracts the neutral ball through the process of induction. When they touch, the neutral ball acquires a like charge through conduction, and repulsion occurs.

20. Any charge that the rod accumulates through friction with the fur is grounded by your hand, so the rod remains neutral.

21. No. The person will be able to discharge some of the charge from the object only by becoming charged through conduction.

22. (a) The magnitude of the force is proportional to the two charges and the distance between them: $\left|\vec{F}_e\right| \propto q_1 q_2$ and $\left|\vec{F}_e\right| \propto \frac{1}{r^2}$

$$\left|\vec{F}_e\right| \propto \frac{2 \times 2}{\left(\frac{1}{2}\right)^2}$$
$$\propto 16$$

The new electrostatic force will be 16 times greater if the charge on both spheres is doubled and the separation distance is halved.

$$\left|\vec{F}_e\right| = 16 \times 10\ \text{N}$$
$$= 160\ \text{N}$$

The new force is 160 N.

[You can also determine the answer by using the equation $\left|\vec{F}_e\right| = k\frac{q_1q_2}{r^2}$.]

(b) The magnitude of the force is proportional to the two charges and the distance between them: $\left|\vec{F}_e\right| \propto q_1q_2$ and $\left|\vec{F}_e\right| \propto \frac{1}{r^2}$

$$\left|\vec{F}_e\right| \propto \frac{2 \times 3}{3^2}$$
$$\propto \frac{6}{9}$$

The new electrostatic force will be $\frac{6}{9}$ as much.

$$\left|\vec{F}_e\right| = \frac{6}{9} \times 10\ \text{N}$$
$$= 6.7\ \text{N}$$

The new force will be 6.7 N.

[You can also determine the answer by using the equation $\left|\vec{F}_e\right| = k\frac{q_1q_2}{r^2}$.]

23. ***Given***

$q_{e^-} = -1.60 \times 10^{-19}\ \text{C}$

$q_{p^+} = +1.60 \times 10^{-19}\ \text{C}$

$r = 5.29 \times 10^{-11}\ \text{m}$

$m_{e^-} = 9.11 \times 10^{-31}\ \text{kg}$

$m_{p^+} = 1.67 \times 10^{-27}\ \text{kg}$

Required

ratio of the electrostatic force to the gravitational force $\left(\frac{\left|\vec{F}_e\right|}{\left|\vec{F}_g\right|}\right)$

Analysis and Solution

To calculate the magnitude of the electrostatic force acting on the two charges, use:

$$\left|\vec{F}_e\right| = k\frac{q_{e^-}q_{p^+}}{r^2}$$

To calculate the magnitude of the gravitational force on the two masses, use:

$$\left|\vec{F}_g\right| = G\frac{m_{e^-}m_{p^+}}{r^2}$$

Coulomb's constant is $k = 8.99 \times 10^9$ N•m^2/C^2.

The universal gravitation constant is $G = 6.67 \times 10^{-11}$ N•m^2 /kg^2.

$$\frac{\left|\vec{F}_e\right|}{\left|\vec{F}_g\right|} = \frac{k\dfrac{q_{e^-}q_{p^+}}{\cancel{r^2}}}{G\dfrac{m_{e^-}m_{p^+}}{\cancel{r^2}}}$$

$$= \frac{\left(8.99 \times 10^9 \dfrac{\cancel{\text{N}\cdot\text{m}^2}}{\cancel{\text{C}^2}}\right)(1.60 \times 10^{-19}\ \cancel{\text{C}})^2}{\left(6.67 \times 10^{-11} \dfrac{\cancel{\text{N}\cdot\text{m}^2}}{\cancel{\text{kg}^2}}\right)(9.11 \times 10^{-31}\ \cancel{\text{kg}})(1.67 \times 10^{-27}\ \cancel{\text{kg}})}$$

$$= 2.27 \times 10^{39}$$

Paraphrase

The electrostatic force is 2.27×10^{39} times greater than the gravitational force.

24. ***Given***

Draw and label the equilateral triangle with X at the top vertex, Y at the bottom left vertex, and Z at the bottom right.

$q_X = -2.50\text{ C}$

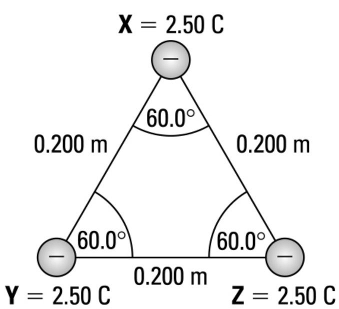
$q_Y = -2.50\text{ C}$

$q_Z = -2.50\text{ C}$

$r_{XY} = 0.200$ m

$r_{ZY} = 0.200$ m

$r_{XZ} = 0.200$ m



Required

net electrostatic force on charge X ($\vec{F}_{net}$)

net electrostatic force on charge Y ($\vec{F}_{net}$)

net electrostatic force on charge Z ($\vec{F}_{net}$)

Analysis and Solution

The angles in an equilateral triangle are all 60.0°.

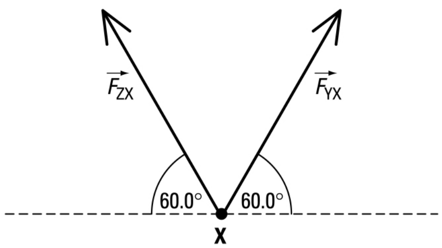
First calculate the net electrostatic force on charge X.

The electrostatic force of q_Y on q_X is a repulsive force 60.0° to the x-axis.

The electrostatic force of q_Z on q_X is a repulsive force 120° to the x-axis.

Since the two electrostatic forces on charge X are vectors that are at an angle, use the component method to determine the net force.

Draw a free-body diagram of the electrostatic forces on charge X:



The magnitude of the electrostatic force of charge Y on charge X (repulsion away from Y) is:

$$\left|\vec{F}_{YX}\right| = k\frac{q_X q_Y}{r_{XY}^2}$$

$$= \frac{\left(8.99 \times 10^9 \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.50\ \cancel{\text{C}})(2.50\ \cancel{\text{C}})}{(0.200\ \text{m})^2}$$

$$= 1.405 \times 10^{12}\ \text{N}$$

The electrostatic force of charge Y on charge X is 1.405×10^{12} N [60.0°].

The magnitude of the electrostatic force of charge Z on charge X (repulsion away from Z) is:

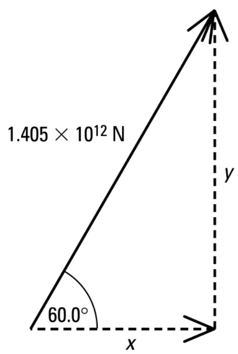
$$\left|\vec{F}_{ZX}\right| = k\frac{q_X q_Z}{r_{XZ}^2}$$

$$= \frac{\left(8.99 \times 10^9 \frac{\text{N}\cdot\text{m}^2}{\cancel{\text{C}^2}}\right)(2.50\ \cancel{\text{C}})(2.50\ \cancel{\text{C}})}{(0.200\ \text{m})^2}$$

$$= 1.405 \times 10^{12}\ \text{N}$$

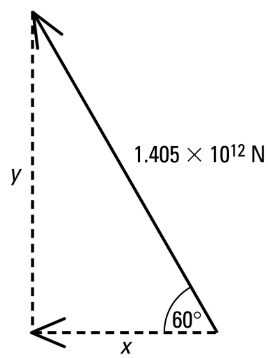
The electrostatic force of charge Z on charge X is 1.405×10^{12} N [120°].

Resolve $\vec{F}_{\text{YX}}$ into x and y components:



$$F_{\text{YX}_x} = (1.405 \times 10^{12}\ \text{N})(\cos 60.0°)$$
$$= 7.025 \times 10^{11}\ \text{N}$$
$$F_{\text{YX}_y} = (1.405 \times 10^{12}\ \text{N})(\sin 60.0°)$$
$$= 1.217 \times 10^{12}\ \text{N}$$

Resolve $\vec{F}_{\text{ZX}}$ into x and y components:

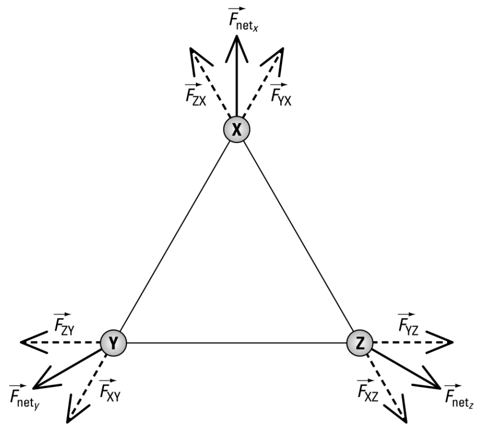


$$F_{\text{ZX}_x} = (1.405 \times 10^{12}\ \text{N})(\cos 60.0°)$$
$$= -7.025 \times 10^{11}\ \text{N}$$
$$F_{\text{ZX}_y} = (1.405 \times 10^{12}\ \text{N})(\sin 60.0°)$$
$$= 1.217 \times 10^{12}\ \text{N}$$
$$F_{\text{net}_x} = -7.025 \times 10^{11}\ \text{N} + 7.025 \times 10^{11}\ \text{N}$$
$$= 0$$
$$F_{\text{net}_y} = 1.217 \times 10^{12}\ \text{N} + 1.217 \times 10^{12}\ \text{N}$$
$$= 2.43 \times 10^{12}\ \text{N}$$

The net electrostatic force on charge X is 2.43×10^{12} N on a line straight upward from X, between charges Y and Z.

Assumption

This triangle is an equilateral triangle, and all the charges are the same. According to Newton's third law, the net force on charge Y and the net force on charge Z should have the same magnitudes as the net force on charge X. The directions of these forces are away from each charge and between the other two charges, as shown in the following diagram.



Paraphrase

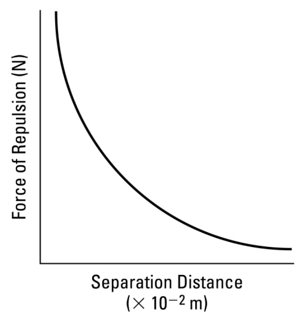
The net forces on the three charges are:

X — 2.43×10^{12} N [90º]

Y — 2.43×10^{12} N [210°]

Z — 2.43×10^{12} N [330°]

25. (a)



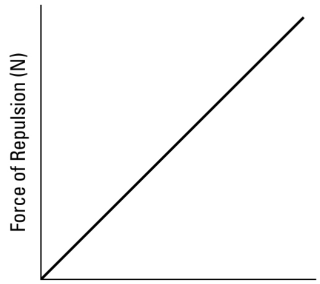
(b) The shape of the graph suggests the following relationship:

$$\left|\vec{F}_e\right| \propto \frac{1}{r} \quad \text{or} \quad \frac{1}{r^2}$$

(c)

Reciprocal of Separation Distance Squared ($1/r^2$) ($\times 10^3/m^2$)	Force of Repulsion ($\left\|\vec{F}_e\right\|$) (N)
10.0	**360.0**
2.50	**89.9**
1.11	**40.0**
0.625	**27.5**
0.400	**14.4**

(d)



(e)

$$\begin{aligned}\text{slope} &= \frac{\text{rise}}{\text{run}}\\ &= \frac{360.0\ \text{N} - 14.4\ \text{N}}{\frac{10\,000}{\text{m}^2} - \frac{400}{\text{m}^2}}\\ &= 0.0360\ \text{N}\cdot\text{m}^2\end{aligned}$$

(f) Since $\left|\vec{F}_\text{e}\right| = k\frac{q_1q_2}{r^2}$ and

$$\begin{aligned}\text{slope} &= \frac{\left|\vec{F}_\text{e}\right|}{\frac{1}{r^2}}\\ &= \left|\vec{F}_\text{e}\right| r^2\end{aligned}$$

then $\text{slope} = kq_1q_2$

(g)

$$\begin{aligned}\text{slope} &= kq_1q_2\\ &= kq^2\\ q &= \sqrt{\frac{\text{slope}}{k}}\\ &= \sqrt{\frac{0.0360\ \cancel{\text{N}\cdot\text{m}^2}}{8.99\times10^9\ \frac{\cancel{\text{N}\cdot\text{m}^2}}{\text{C}^2}}}\\ &= 2.00\times10^{-6}\ \text{C}\end{aligned}$$

Each charge is 2.00×10^{-6} C.

Extensions

26. No. A neutral object has equal numbers of opposite charges.

27. Yes. A single negative charge or electron and a single positive charge or proton can exist.

28. You cannot charge the coin by rubbing it between your fingers because you are grounded.

29. Lightning on Earth is caused by discharges between negatively charged clouds and the positively charged surface of Earth. On Saturn, lightning is caused by discharges between rings with different charges.

30. (a) Connect the two spheres with the conducting wire. Rub the glass rod with the silk to give it a positive charge by friction. Hold the glass rod near one metal sphere. Repulsion of charges will cause charge migration, and, through induction, the sphere closest to the rod will be negatively charged. The other metal sphere will have an equal positive charge.

(b) With the spheres connected by the wire and the rod close to one sphere, ground the two spheres. Then remove the ground and the charged rod. Each sphere will have an equal net negative charge due to the process of induction and grounding.

31. (a) A transfer of electrons has occurred. One strip has acquired a net negative charge, while the other strip has acquired an equal net positive charge, according to the law of conservation of charge. Since they have opposite charges, they attract.

(b) When the two strips are stuck to a table and peeled off, they both acquire the same charge from the table, and so they repel each other.

