Static Electricity (Part I) In class assignment

Due: 11:59pm on Sunday, July 31, 2022

You will receive no credit for items you complete after the assignment is due. Grading Policy

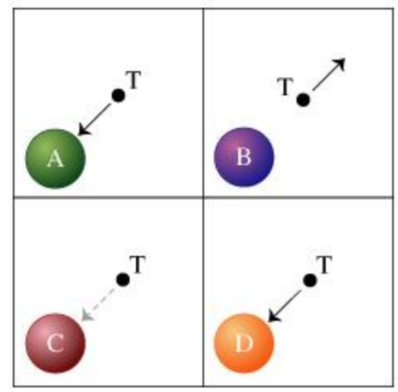
A Test Charge Determines Charge on Insulating and Conducting Balls

Learning Goal:
To understand the electric force between charged and uncharged conductors and insulators.

When a test charge is brought near a charged object, we know from Coulomb's law that it will experience a net force (either attractive or repulsive, depending on the nature of the object's charge). A test charge may also experience an electric force when brought near a *neutral* object. Any attraction of a neutral insulator or neutral conductor to a test charge must occur through induced polarization. In an insulator, the electrons are bound to their molecules. Though they cannot move freely throughout the insulator, they can shift slightly, creating a rather weak net attraction to a test charge that is brought close to the insulator's surface. In a conductor, free electrons will accumulate on the surface of the conductor nearest the positive test charge. This will create a strong attractive force if the test charge is placed very close to the conductor's surface.

Consider three plastic balls (A, B, and C), each carrying a uniformly distributed charge equal to either $+Q$, $-Q$ or zero, and an uncharged copper ball (D). A positive test charge (T) experiences the forces shown in the figure when brought very near to the individual balls. The test charge T is strongly attracted to A, strongly repelled from B, *weakly* attracted to C, and strongly attracted to D.

Assume throughout this problem that the balls are brought very close together.



Part A

What is the nature of the force between balls A and B?

Hint 1. What is the net charge on ball A?

Since the test charge is positively charged, and there is a strongly attractive force between ball A and the test charge, what must be the nature of the net charge of ball A?

ANSWER:

- positive
- negative
- zero

Hint 2. What is the net charge on ball B?

Since the test charge is positively charged, and there is a strongly repulsive force between ball B and the test charge, what must be the nature of the net charge of ball B?

ANSWER:

- positive
- negative
- zero

ANSWER:

- (selected) strongly attractive
- strongly repulsive
- weakly attractive
- neither attractive nor repulsive

Correct

Part B

What is the nature of the force between balls A and C?

Hint 1. What is the charge on ball C?

Recall that ball C is composed of insulating material, which means that it can be polarized, but the charges inside are otherwise not free to move around inside the ball. Since the test charge experiences only a weak force due to ball C, if we compare to ball A we conclude that the charge on ball C must be

ANSWER:

- $+Q$
- $-Q$
- (selected) zero

ANSWER:

- strongly attractive
- strongly repulsive
- (selected) weakly attractive
- neither attractive nor repulsive

Correct

Recall that ball C is composed of insulating material, which can be polarized in the presence of an external charged object such as ball A. Once polarized, there will be a weak attraction between balls A and C, because the positive and negative charges in ball C are at slightly different average distances from ball A. If ball C had a very small negative charge the test charge would have the same response (weakly attractive) but it would have a weak repulsive interaction with ball A. However, a smaller negative charge is not one of the options.

Part C

What is the nature of the force between balls A and D?

Hint 1. What are the surface charges on ball D?

Recall that copper is a conductor, in which charges can freely flow. When ball D is brought close to ball A, what will be the nature of the surface charge density on the side of ball D that is closest to ball A?

ANSWER:

- (selected) positive
- negative
- zero

ANSWER:

- (selected) attractive
- repulsive
- neither attractive nor repulsive

Correct

Part D

What is the nature of the force between balls D and C?

ANSWER:

- attractive
- repulsive
- (selected) neither attractive nor repulsive

Correct
Because the test charge T is neither strongly attracted to nor repelled from ball C, ball C must have zero net charge. Since ball D also has zero net charge, there will not be any force between the two balls.

± PSS 21.1 Coulomb's Law

Learning Goal:
To practice Problem-Solving Strategy 21.1 Coulomb's Law.

Three charged particles are placed at each of three corners of an equilateral triangle whose sides are of length 2.3 cm . Two of the particles have a negative charge: q_1 = -7.2 nC and q_2 = -14.4 nC . The remaining particle has a positive charge, q_3 = 8.0 nC . What is the net electric force acting on particle 3 due to particle 1 and particle 2?

Problem-Solving Strategy: Coulomb's law

IDENTIFY *the relevant concepts:*
Coulomb's law comes into play whenever you need to know the electric force acting between charged particles.

SET UP *the problem using the following steps:*

1. Make a drawing showing the locations of the charged particles, and label each particle with its charge.
2. If three or more particles are present and they do not all lie on the same line, set up an *xy* coordinate system.
3. Often you will need to find the electric force on just one particle. If so, identify that particle.

EXECUTE *the solution as follows:*

1. For each particle that exerts a force on the particle of interest, calculate the magnitude of that force using $F = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2}$.
2. Sketch a free-body diagram showing the electric force vectors acting on the particle(s) of interest due to each of the other particles. Recall that the force exerted by particle 1 on particle 2 points from particle 2 toward particle 1 if the two charges have opposite signs, but points

from particle 2 directly away from particle 1 if the charges have the same sign.
3. Calculate the total electric force on the particle(s) of interest. Recall that the electric force, like any force, is a vector.
4. As always, using consistent units is essential. If you are given non-SI units, don't forget to convert!
5. If there is a continuous distribution of charge along a line or over a surface, divide the total charge distribution into infinitesimal pieces, use Coulomb's law for each piece, and then integrate to find the vector sum.
6. In many situations, the charge distribution will be *symmetrical*. Whenever possible, exploit any symmetries to simplify the problem-solving process.

EVALUATE *your answer:*
Check whether your numerical results are reasonable, and confirm that the direction of the net electric force agrees with the principle that like charges repel and opposite charges attract.

IDENTIFY the relevant concepts

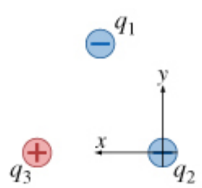
To determine the angle of the force vector on a single charged particle, you will need to calculate the vector sum of all the forces on that particle due to the presence of other charged particles. To do this, you will need to use Coulomb's law.

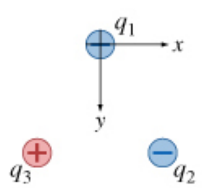
SET UP the problem using the following steps

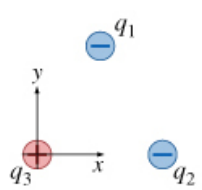
Part A

Identify the most appropriate *xy* coordinate system.

ANSWER:







Correct
You are asked to find the net force acting on particle 3. Centering the *xy* coordinate system on particle 3 will make this easier.

EXECUTE the solution as follows

Part B

Find the net force $\Sigma\vec{F}_3$ acting on particle 3 due to the presence of the other two particles. Report you answer as a magnitude ΣF_3 and a direction θ measured from the positive *x* axis.

Express the magnitude in newtons and the direction in degrees to three significant figures.

Hint 1. How to approach the problem

To calculate the electric force acting on particle 3, you should begin by drawing a free-body diagram indicating the forces acting on particle 3 due to particle 1 and particle 2. You know that

$$\Sigma\vec{F}_3 = \vec{F}_{1\text{ on }3} + \vec{F}_{2\text{ on }3}.$$

Use Coulomb's law to calculate the magnitude of each of these forces. Apply vector algebra to find the component forces in the x and the y directions. Then, sum the component forces for each direction:

$$\begin{aligned}(\Sigma F_3)_x &= (F_{1\text{ on }3})_x + (F_{2\text{ on }3})_x \\ (\Sigma F_3)_y &= (F_{1\text{ on }3})_y + (F_{2\text{ on }3})_y\end{aligned}.$$

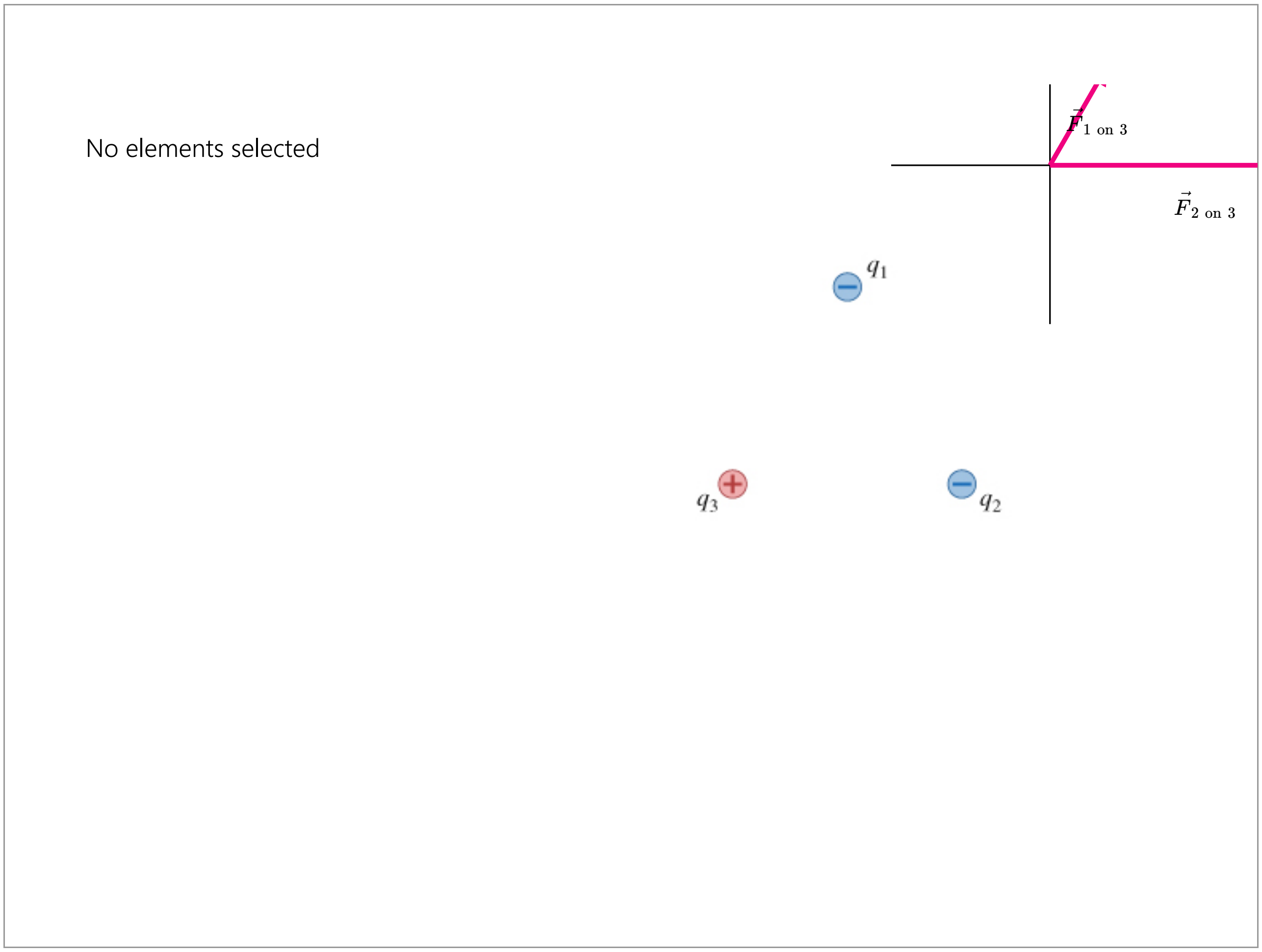
From $(\Sigma F_3)_x$ and $(\Sigma F_3)_y$ you can find the magnitude and direction of the resulting electric force vector.

Hint 2. Draw a free-body diagram

Identify the forces on the positively charged particle 3.

Draw your vectors starting at the origin. The orientation of your vectors will be graded but their precise length will not.

ANSWER:



Hint 3. Calculate the force on particle 3 due to particle 1

Using the equation for Coulomb's law, calculate the magnitude of the force on particle 3 due to particle 1. Keep in mind that

$$\frac{1}{4\pi\epsilon_0} = 8.988 \times 10^9 \ \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}.$$

Express your answer in newtons using three significant figures.

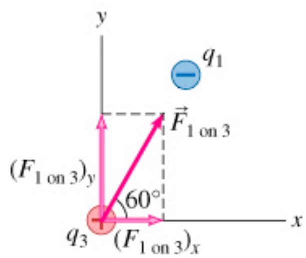
ANSWER:

$F_{1 \text{ on } 3}$ = 9.79×10^{-4} N

Correct
Use the same method to calculate the force on particle 3 due to particle 2.

Hint 4. Calculate the component forces on particle 3 due to particle 1

Calculate the *x* component and the *y* component forces acting on particle 3 due to particle 1, using simple trigonometry. The angle between particle 1 and particle 3 is 60°:



Enter the components of the force in newtons separated by a comma.

ANSWER:

$(F_{1 \text{ on } 3})_x, (F_{1 \text{ on } 3})_y$ = 4.89×10^{-4},8.48×10^{-4} N, N

Correct
Use the same method to calculate the component force on particle 3 due to particle 2. The sum of all the components in each direction

$$\begin{aligned}(\Sigma F_3)_x &= (F_{1 \text{ on } 3})_x + (F_{2 \text{ on } 3})_x \\ (\Sigma F_3)_y &= (F_{1 \text{ on } 3})_y + (F_{2 \text{ on } 3})_y\end{aligned}$$

will provide you with the information needed to calculate the magnitude and direction of the net force on particle 3.

Hint 5. How to calculate the component forces on particle 3 due to particle 2

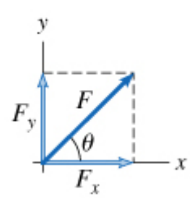
Because particles 2 and 3 both lie on the *x* axis, there will be no *y* component to calculate. The *x* component of force will therefore be equal to the value calculated from Coulomb's law, and the *y* component will be zero.

Hint 6. How to determine the magnitude and direction of a vector from its components

If a vector $\vec{F}$ has components F_x and F_y, the magnitude F and direction θ are given by

$$\begin{aligned}F &= \sqrt{(F_x)^2 + (F_y)^2} \\ \theta &= \arctan(F_y/F_x)\end{aligned},$$

where



ANSWER:

ΣF_3, θ = 2.59×10^{-3},19.1 N, °

All attempts used; correct answer displayed

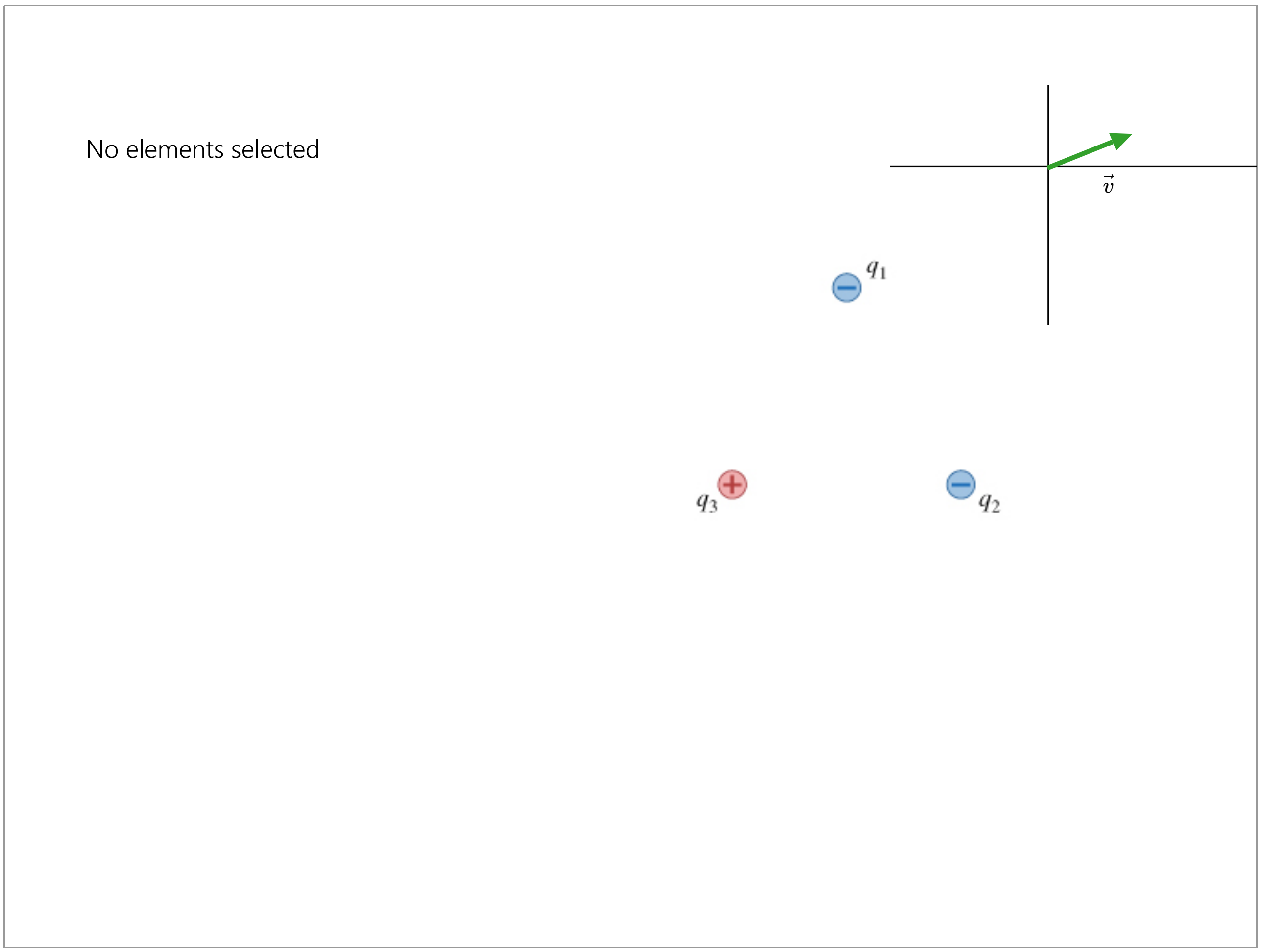
EVALUATE your answer

Part C

Assume that particle 3 is no longer fixed to a corner of the triangle and is now allowed to move. In what direction would particle 3 move the instant after being released?

Draw the velocity vector for particle 3 below. The orientation of your vector will be graded, but not its length.

ANSWER:



Correct

Specifically, from Newton's 2nd law, $\vec{F} = m\vec{a}$, you know that a mass accelerates in the same direction as the net force acting upon it. Therefore, at the instant after being released, particle 3 accelerates in the same direction as $\Sigma\vec{F}_3$. Moreover, since particle 3 starts from rest, its velocity at that instant will be $\vec{v} = \vec{a}t$. In other words, the initial direction of particle 3 is the same direction as its acceleration, and therefore the same direction as the applied net force.

Let us interpret this result in terms of electric forces. In general, like charges repel and unlike charges attract. If particle 3 were free to move, it would move toward the negative charges q_1 and q_2. If q_1 and q_2 were the same size, particle 3 would start to move toward them along a direction equidistant from each charge, that is, at an angle of 30° from the positive *x* axis. Instead, $|q_2| > |q_1|$, so particle 3 will be more strongly attracted toward particle 2 and will move off in a direction less than 30°.

Exercise 21.7

An average human weighs about 650 N .

Part A

If two such generic humans each carried 1.5 coulomb of excess charge, one positive and one negative, how far apart would they have to be for the electric attraction between them to equal their 650 N weight?

Express your answer using two significant figures.

ANSWER:

r = 5.6 km

Correct

Coulomb's Law Tutorial

Learning Goal:
To understand how to calculate forces between charged particles, particularly the dependence on the sign of the charges and the distance between them.

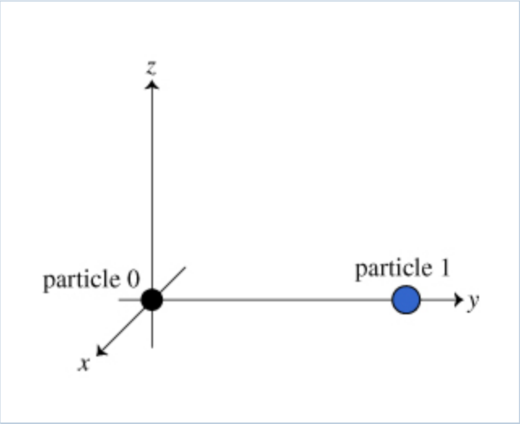
Coulomb's law describes the force that two charged particles exert on each other (by Newton's third law, those two forces must be equal and opposite). The force F_{21} exerted *by* particle 2 (with charge q_2) *on* particle 1 (with charge q_1) is proportional to the charge of each particle and inversely proportional to the square of the distance r between them:

$$\vec{F}_{21} = \frac{k\, q_2\, q_1}{r^2}\,\hat{r}_{21},$$

where $k = \frac{1}{4\pi\epsilon_0}$ and $\hat{r}_{21}$ is the unit vector pointing *from* particle 2 *to* particle 1. The force vector will be parallel or antiparallel to the direction of $\hat{r}_{21}$, parallel if the product $q_1\, q_2 > 0$ and antiparallel if $q_1\, q_2 < 0$; the force is *attractive* if the charges are of opposite sign and *repulsive* if the charges are of the same sign.

Part A

Consider two positively charged particles, one of charge q_0 (particle 0) fixed at the origin, and another of charge q_1 (particle 1) fixed on the *y*-axis at $(0,\ d_1,\ 0)$. What is the net force $\vec{F}$ *on* particle 0 *due to* particle 1?



Express your answer (a vector) using any or all of k, q_0, q_1, d_1, $\hat{i}$, $\hat{j}$, and $\hat{k}$.

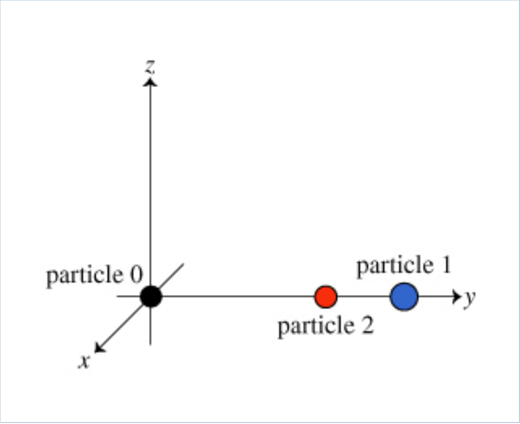
ANSWER:

$\vec{F}$ = $-\frac{kq_0q_1}{(d_1)^2}\hat{j}$

Correct

Part B

Now add a third, negatively charged, particle, whose charge is $-q_2$ (particle 2). Particle 2 fixed on the *y*-axis at position $(0,\ d_2,\ 0)$. What is the new net force *on* particle 0, *from* particle 1 and particle 2?



Express your answer (a vector) using any or all of k, q_0, q_1, q_2, d_1, d_2, $\hat{i}$, $\hat{j}$, and $\hat{k}$.

ANSWER:

$\vec{F}$ = $\frac{-(kq_1q_0)}{(d_1)^2}\hat{j}+\frac{kq_2q_0}{(d_2)^2}\hat{j}$

Correct

Part C

Particle 0 experiences a repulsion *from* particle 1 and an attraction *toward* particle 2. For certain values of d_1 and d_2, the repulsion and attraction should balance each other, resulting in no net force. For what ratio d_1/d_2 is there no net force on particle 0?

Express your answer in terms of any or all of the following variables: k, q_0, q_1, q_2.

ANSWER:

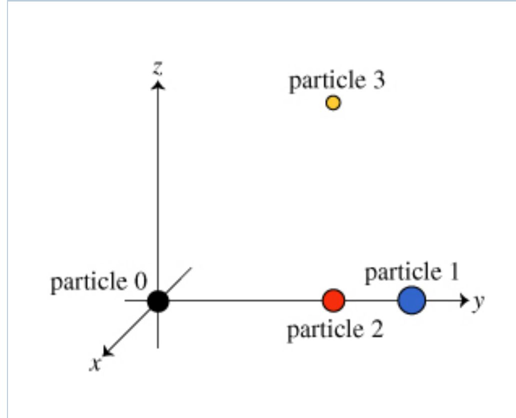
d_1/d_2 = $\sqrt{\frac{q_1}{q_2}}$

Correct

Part D

Now add a fourth charged particle, particle 3, with positive charge q_3, fixed in the *yz*-plane at $(0,\ d_2,\ d_2)$. What is the net force $\vec{F}$ on particle 0 due *solely* to this charge?

Express your answer (a vector) using k, q_0, q_3, d_2, $\hat{i}$, $\hat{j}$, and $\hat{k}$. Include only the force caused by particle 3.



Hint 1. Find the magnitude of force from particle 3

What is the magnitude of the force on particle 0 from particle 3, fixed at $(0,\ d_2,\ d_2)$?

Express your answer using k, q_0, q_3, d_2.

Hint 1. Distance to particle 3

Use the Pythagorean theorem to find the straight line distance between the origin and $(0,\ d_2,\ d_2)$.

ANSWER:

$F_3 = \frac{kq_0q_3}{2{d_2}^2}$

Hint 2. Vector components

The force vector points from q_3 to q_0. Because q_3 is symmetrically located between the *y*-axis and the *z*-axis, the angle between $\hat{r}_{30}$, the unit vector pointing *from* particle 3 *to* particle 0, and the *y*-axis is $\pi/4$ radians. You have already calculated the magnitude of the vector above. Now break up the force vector into its *y* and *z* components.

ANSWER:

$\vec{F} = -\frac{kq_0q_3}{2(d_2)^2}\frac{\sqrt{2}}{2}\left(\hat{j}+\hat{k}\right)$

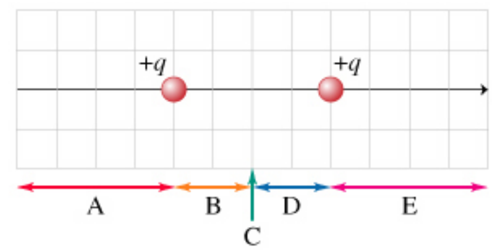
Correct

Electric Field Conceptual Question

Part A

For the charge distribution provided, indicate the region (A to E) along the horizontal axis where a point exists at which the net electric field is zero.

If no such region exists on the horizontal axis choose the last option (nowhere).



Hint 1. Zeros of the electric field

The net electric field can only be zero if the electric fields due to the two charges point in opposite directions and have equal magnitudes. Therefore, first determine the region(s) where the two constituent electric fields point in opposite directions. Then, in each region determine whether a point exists where the fields have equal magnitude. If there is such a point, then select that region.

ANSWER:

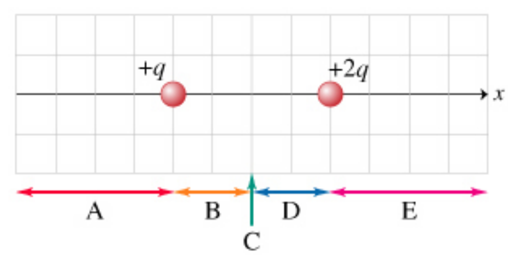
- A
- B
- C (selected)
- D
- E
- nowhere

Correct

Part B

For the charge distribution provided, indicate the region (A to E) along the horizontal axis where a point exists at which the net electric field is zero.

If no such region exists on the horizontal axis choose the last option (nowhere).



Hint 1. Zeros of the electric field

The net electric field can only be zero if the electric fields due to the two charges point in opposite directions and have equal magnitudes. Therefore, first determine the region(s) where the two constituent electric fields point in opposite directions. Then, in each region determine whether a point exists where the fields have equal magnitude. If there is such a point, then select that region.

Hint 2. Determine the regions where the electric fields could cancel

In which region(s) do the electric fields from the two source charges point in opposite directions?

List all the correct answers in alphabetical order.

ANSWER:

BCD

Hint 3. Consider the magnitude of the electric field

For each of the three regions found in the previous hint, determine whether it is possible for the magnitudes to be equal. As an example, consider the point directly between the two charges. Which charge produces the largest magnitude field directly between the two charges?

ANSWER:

- (selected) the charge on the right
- the charge on the left
- neither, because they have the same magnitude

ANSWER:

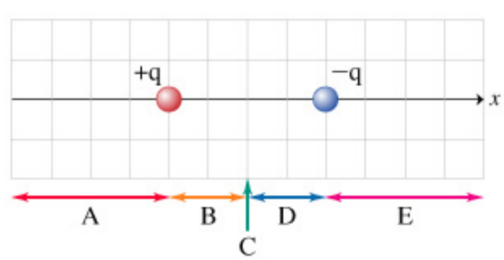
- A
- (selected) B
- C
- D
- E
- nowhere

Correct

Part C

For the charge distribution provided, indicate the region (A to E) along the horizontal axis where a point exists at which the net electric field is zero.

If no such region exists on the horizontal axis choose the last option (nowhere).



Hint 1. Zeros of the electric field

The net electric field can only be zero if the electric fields due to the two charges point in opposite directions and have equal magnitudes. Therefore, first determine the region(s) where the two constituent electric fields point in opposite directions. Then, in each region determine whether a point exists where the fields have equal magnitude. If there is such a point, then select that region.

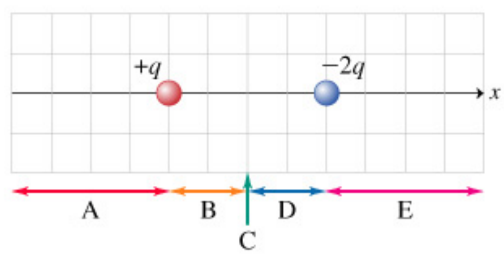
ANSWER:

- A
- B
- C
- D
- E
- nowhere

Correct

Part D

For the charge distribution provided, indicate the region (A to E) along the horizontal axis where a point exists at which the net electric field is zero.



Hint 1. Zeros of the electric field

The net electric field can only be zero if the electric fields due to the two charges point in opposite directions and have equal magnitudes. Therefore, first determine the region(s) where the two constituent electric fields point in opposite directions. Then, in each region determine whether a point exists where the fields have equal magnitude. If there is such a point, then select that region.

ANSWER:

- A
- B
- C
- D
- E
- Nowhere along the finite *x* axis

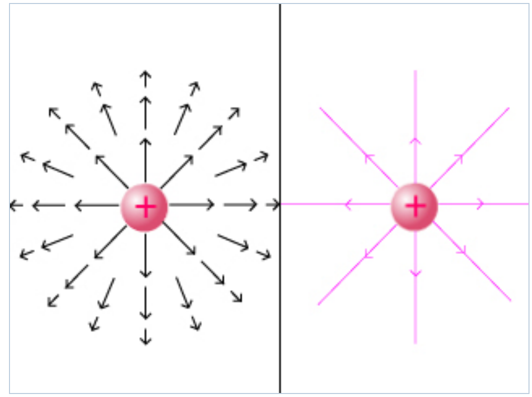
Correct

Visualizing Electric Fields

Learning Goal:
To understand the nature of electric fields and how to draw field lines.

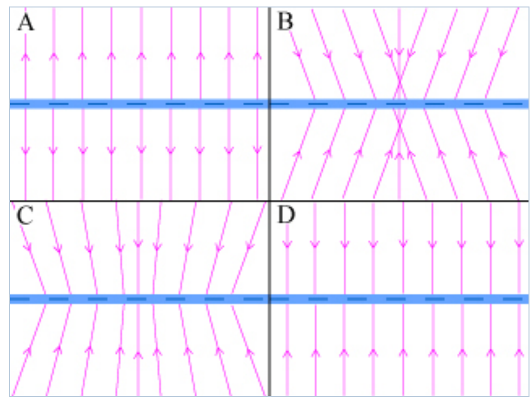
Electric field lines are a tool used to visualize electric fields. A field line is drawn beginning at a positive charge and ending at a negative charge. Field lines may also appear from the edge of a picture or disappear at the edge of the picture. Such lines are said to begin or end *at infinity*. The field lines are directed so that the electric field at any point is tangent to the field line at that point.

shows two different ways to visualize an electric field. On the left, vectors are drawn at various points to show the direction and magnitude of the electric field. On the right, electric field lines depict the same situation. Notice that, as stated above, the electric field lines are drawn such that their tangents point in the same direction as the electric field vectors on the left. Because of the nature of electric fields, field lines never cross. Also, the vectors shrink as you move away from the charge, and the electric field lines spread out as you move away from the charge. The spacing between electric field lines indicates the strength of the electric field, just as the length of vectors indicates the strength of the electric field. The greater the spacing between field lines, the weaker the electric field. Although the advantage of field lines over field vectors may not be apparent in the case of a single charge, electric field lines present a much less cluttered and more intuitive picture of more complicated charge arrangements.



Part A -

Which of the following panels (labelled A, B, C, and D) in correctly depicts the field lines from an infinite uniformly negatively charged sheet? Note that the sheet is being viewed edge-on in all pictures.



Hint 1. Description of the field

Recall that the field around an infinite charged sheet is always perpendicular to the sheet and that the field strength does not change, regardless of distance from the sheet.

ANSWER:

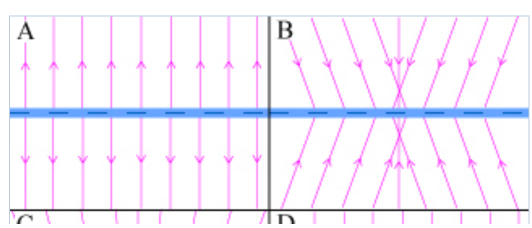
- A
- B
- C
- D (selected)

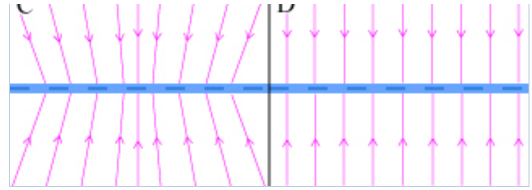
Correct

Part B

In , what is wrong with panel B? (Pick only those statements that apply to panel B.)

Check all that apply.





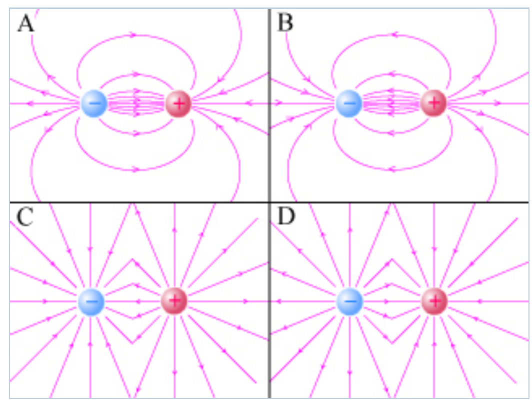
ANSWER:

- [x] Field lines cannot cross each other.
- [x] The field lines should be parallel because of the sheet's symmetry.
- [ ] The field lines should spread apart as they leave the sheet to indicate the weakening of the field with distance.
- [ ] The field lines should always end on negative charges or at infinity.

Correct

Part C -

Which of the following panels (labelled A, B, C, and D) in shows the correct electric field lines for an electric dipole?



ANSWER:

- ○ A
- ◉ B
- ○ C
- ○ D

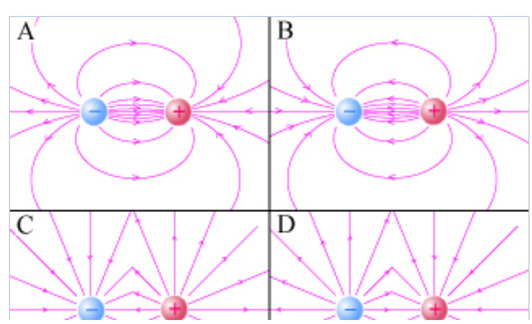
Correct

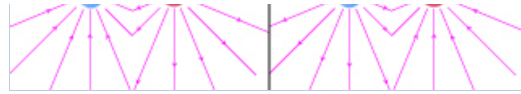
This applet shows two charges. You can alter the charge on each independently or alter the distance between them. You should try to get a feeling for how altering the charges or the distance affects the field lines.

Part D

In , what is wrong with panel D? (Pick only those statements that apply to panel D.)

Check all that apply.

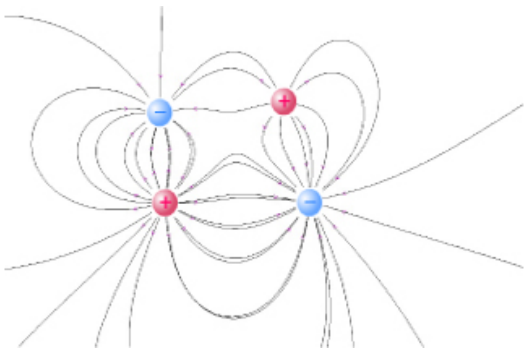




ANSWER:

- [ ] Field lines cannot cross each other.
- [ ] The field lines should turn sharply as you move from one charge to the other.
- [x] The field lines should be smooth curves.
- [x] The field lines should always end on negative charges or at infinity.

Correct

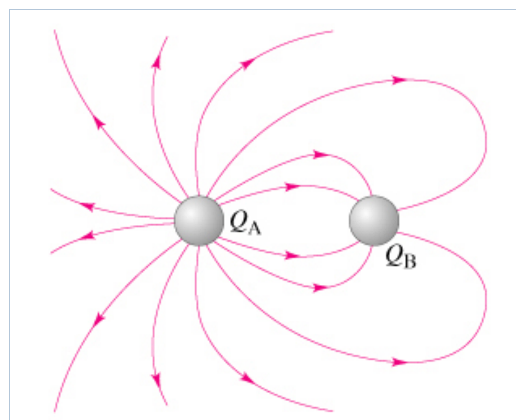


Even in relatively simple setups as in the figure shown, electric field lines are quite helpful for understanding the field qualitatively (understanding the general direction in which a certain charge will move from a specific position, identifying locations where the field is roughly zero or where the field points a specific direction, etc.). A good figure with electric field lines can help you to organize your thoughts as well as check your calculations to see whether they make sense.

Part E

In , the electric field lines are shown for a system of two point charges, $Q_{\rm A}$ and $Q_{\rm B}$. Which of the following could represent the magnitudes and signs of $Q_{\rm A}$ and $Q_{\rm B}$?

In the following, take q to be a positive quantity.



ANSWER:

- ○ $Q_{\rm A} = +q$, $Q_{\rm B} = -q$
- ◉ $Q_{\rm A} = +7q$, $Q_{\rm B} = -3q$
- ○ $Q_{\rm A} = +3q$, $Q_{\rm B} = -7q$
- ○ $Q_{\rm A} = -3q$, $Q_{\rm B} = +7q$
- ○ $Q_{\rm A} = -7q$, $Q_{\rm B} = +3q$

Correct

Very far from the two charges, the system looks like a single charge with value $Q_{\mathrm{A}} + Q_{\mathrm{B}} = +4q$. At large enough distances, the field lines will be indistinguishable from the field lines due to a single point charge $+4q$.

Electric Field Vector Drawing

Each of the four parts of this problem depicts a motion diagram showing the position and velocity of a charged particle at equal time intervals as it moves through a region of uniform electric field. For each part, draw a vector representing the direction of the electric field.

Part A

Draw a vector representing the direction of the electric field. The orientation of the vector will be graded. The location and length of the vector will not be graded.

Hint 1. Relationship between electric field and electric force

The relationship between the electric force that acts on a particle and the electric field at the location of the particle is

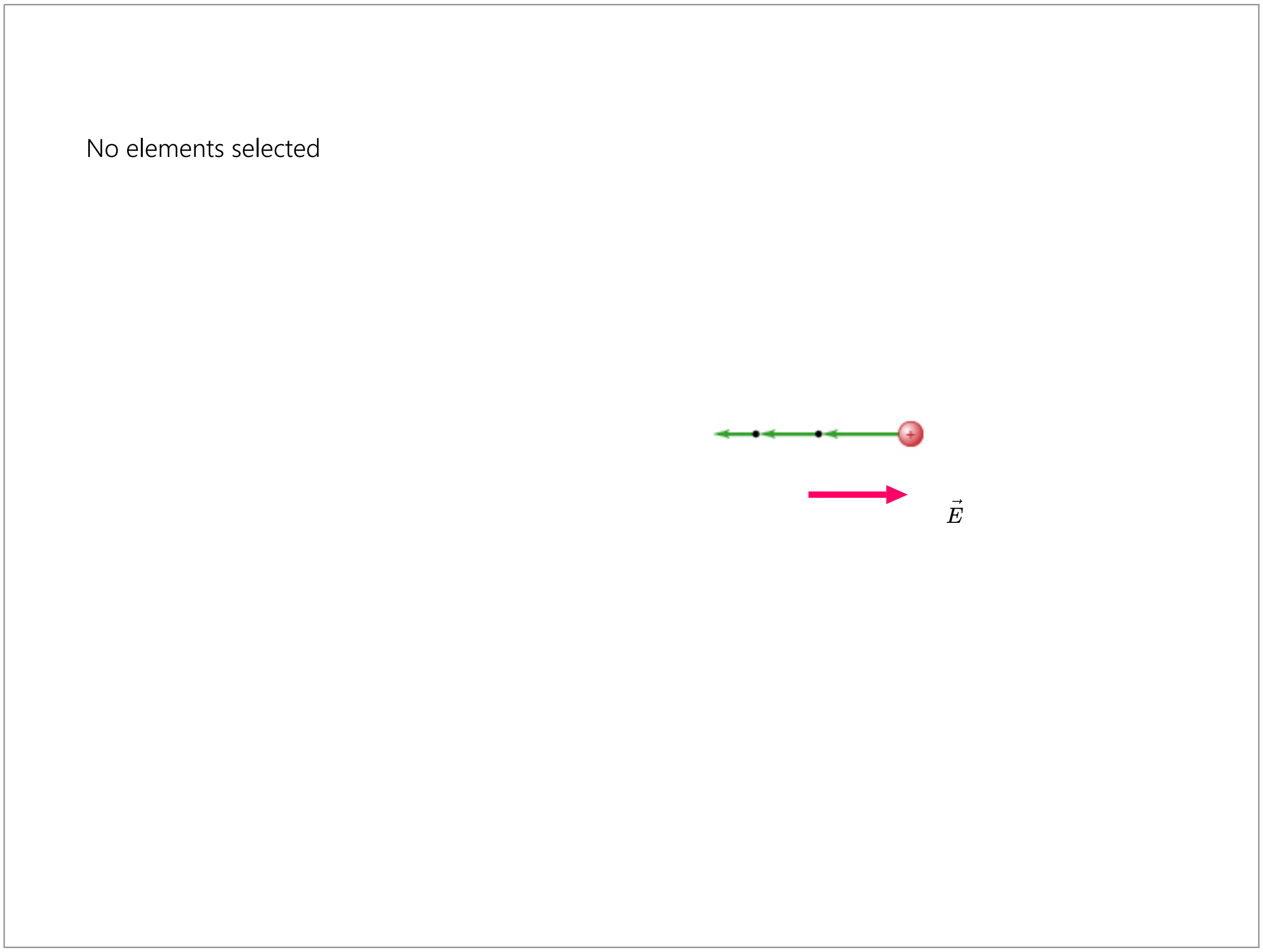
$$\vec{F} = q\vec{E}.$$

This formula indicates that the force and the electric field point in the same direction for a positively charged particle, and in opposite directions for a negatively charged particle.

Hint 2. Determining the direction of the electric field

The acceleration of the particle can be determined from the change in its velocity. By Newton’s 2nd law, the force acting on the particle is parallel to its acceleration. Finally, since this is a positively charged particle, the electric field is parallel to the force. Putting this all together results in an electric field that is parallel to the particle’s acceleration.

ANSWER:



Correct

The motion diagram shows that the particle's acceleration points to the right. Because the particle has positive charge, the electric field should point to the right.

Part B

Draw a vector representing the direction of the electric field. The orientation of the vector will be graded. The location and length of the vector will not be graded.

Hint 1. Relationship between electric field and electric force

The relationship between the electric force that acts on a particle and the electric field at the location of the particle is

$$\vec{F} = q\vec{E}.$$

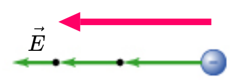
This formula indicates that the force and the electric field point in the same direction for a positively charged particle, and in opposite directions for a negatively charged particle.

Hint 2. Determining the direction of the electric field

The acceleration of the particle can be determined from the change in its velocity. By Newton’s 2nd law, the force acting on the particle is parallel to its acceleration. Finally, since this is a negatively charged particle, the electric field is directed opposite to the force. Putting this all together results in an electric field that is directed opposite to the particle’s acceleration.

ANSWER:

No elements selected



Correct

The motion diagram shows that the particle's acceleration points to the right. Because the particle has negative charge, the electric field should point to the left.

Part C

Draw a vector representing the direction of the electric field. The orientation of the vector will be graded. The location and length of the vector will not be graded.

Hint 1. Relationship between electric field and electric force

The relationship between the electric force that acts on a particle and the electric field at the location of the particle is

$$\vec{F} = q\vec{E}.$$

This formula indicates that the force and the electric field point in the same direction for a positively charged particle, and in opposite directions for a negatively charged particle.

Hint 2. Determining the direction of the electric field

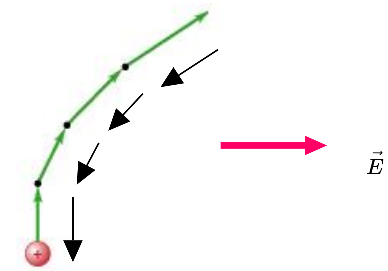
The acceleration of the particle can be determined from the change in its velocity. By Newton's 2nd law, the force acting on the particle is parallel to its acceleration. Finally, since this is a positively charged particle, the electric field is parallel to the force. Putting this all together results in an electric field that is parallel to the particle's acceleration.

Because the electric field is uniform, you can find the direction of the particle's acceleration by subtracting any two consecutive velocity vectors graphically. If $\vec{v}_\mathrm{i}$ and $\vec{v}_\mathrm{f}$ are any two consecutive velocities, you can subtract $\vec{v}_\mathrm{i}$ from $\vec{v}_\mathrm{f}$ by placing $-\vec{v}_\mathrm{i}$ at the tip of $\vec{v}_\mathrm{f}$. $\vec{v}_\mathrm{f} - \vec{v}_\mathrm{i}$ is the vector that starts at the tail of $\vec{v}_\mathrm{f}$ and ends at the tip of $\vec{v}_\mathrm{i}$.

To find the direction of the particle's acceleration graphically, use two unlabeled vectors to represent $-\vec{v}_\mathrm{i}$ and $\vec{v}_\mathrm{f} - \vec{v}_\mathrm{i}$. Pick any two vectors $\vec{v}_\mathrm{i}$ and $\vec{v}_f$ that would make your subtraction easier; you can verify your result by subtracting any other pair of consecutive vectors.

ANSWER:

No elements selected



Correct

Part D

Draw a vector representing the direction of the electric field. The orientation of the vector will be graded. The location and length of the vector will not be graded.

Hint 1. Relationship between electric field and electric force

The relationship between the electric force that acts on a particle and the electric field at the location of the particle is

$$\vec{F} = q\vec{E}.$$

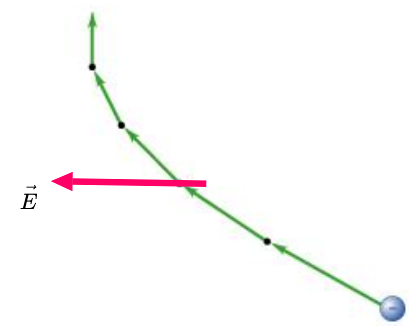
This formula indicates that the force and the electric field point in the same direction for a positively charged particle, and in opposite directions for a negatively charged particle.

Hint 2. Determining the direction of the electric field

The acceleration of the particle can be determined from the change in the illustrated velocity vectors. By Newton's 2nd law, the force acting on the particle is parallel to its acceleration. Finally, since this is a negatively charged particle, the electric field is directed opposite to the electric force. Putting this all together results in an electric field that is directed opposite to the particle's acceleration.
Because the electric field is uniform, you can find the direction of the particle's acceleration by subtracting any two consecutive velocity vectors graphically. If $\vec{v}_{\rm i}$ and $\vec{v}_{\rm f}$ are any two consecutive velocities, you can subtract $\vec{v}_{\rm i}$ from $\vec{v}_{\rm f}$ by placing $-\vec{v}_{\rm i}$ at the tip of $\vec{v}_{\rm f}$. $\vec{v}_{\rm f} - \vec{v}_{\rm i}$ is the vector that starts at the tail of $\vec{v}_{\rm f}$ and ends at the tip of $\vec{v}_{\rm i}$.
To find the direction of the particle's acceleration graphically, use two unlabeled vectors to represent $-\vec{v}_{\rm i}$ and $\vec{v}_{\rm f} - \vec{v}_{\rm i}$. Pick any two vectors $\vec{v}_{\rm i}$ and $\vec{v}_f$ that would make your subtraction easier; you can verify your result by subtracting any other pair of consecutive vectors.

ANSWER:

No elements selected



Correct

Electric Fields and Forces

Learning Goal:
To understand Coulomb's law, electric fields, and the connection between the electric field and the electric force.

Coulomb's law gives the electrostatic force $\vec{F}$ acting between two charges. The magnitude F of the force between two charges q_1 and q_2 depends on the product of the charges and the square of the distance r between the charges:

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

where $k = 1/(4\pi\epsilon_0) = 8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}$. The direction of the force is along the line connecting the two charges. If the charges have the same sign, the force will be repulsive. If the charges have opposite signs, the force will be attractive. In other words, opposite charges attract and like charges repel.

Because the charges are not in contact with each other, there must be an intermediate mechanism to cause the force. This mechanism is the electric field. The electric field at any location is equal to the force per unit charge experienced by a charge placed at that location. In other words, if a charge q experiences a force $\vec{F}$, the electric field $\vec{E}$ at that point is

$$\vec{E} = \frac{\vec{F}}{q}.$$

The electric field vector has the same direction as the force vector on a positive charge and the opposite direction to that of the force vector on a negative charge.

An electric field can be created by a single charge or a distribution of charges. The electric field a distance r from a point charge q' has magnitude

$$E = k\frac{|q'|}{r^2}.$$

The electric field points away from positive charges and toward negative charges. A distribution of charges creates an electric field that can be found by taking the vector sum of the fields created by individual point charges. Note that if a charge q is placed in an electric field created by q', q will not significantly affect the electric field if it is small compared to q'.

Imagine an isolated positive point charge with a charge Q (many times larger than the charge on a single electron).

Part A

There is a single electron at a distance from the point charge. On which of the following quantities does the force on the electron depend?

Check all that apply.

ANSWER:

- [x] the distance between the positive charge and the electron
- [x] the charge on the electron
- [ ] the mass of the electron
- [x] the charge of the positive charge
- [ ] the mass of the positive charge
- [ ] the radius of the positive charge
- [ ] the radius of the electron

Correct
According to Coulomb's law, the force between two particles depends on the charge on each of them and the distance between them.

Part B

For the same situation as in Part A, on which of the following quantities does the electric field at the electron's position depend?

Check all that apply.

ANSWER:

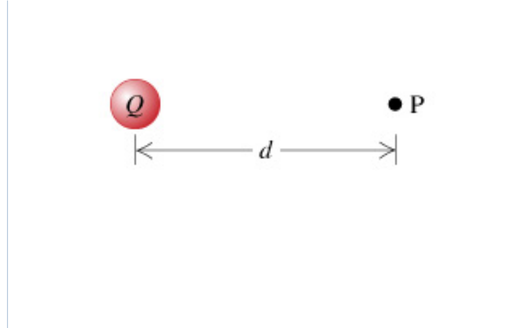
- [x] the distance between the positive charge and the electron
- [ ] the charge on the electron
- [ ] the mass of the electron
- [x] the charge of the positive charge
- [ ] the mass of the positive charge
- [ ] the radius of the positive charge
- [ ] the radius of the electron

Correct
The electrostatic force cannot exist unless two charges are present. The electric field, on the other hand, can be created by only one charge. The value of the electric field depends only on the charge producing the electric field and the distance from that charge.

Part C

If the total positive charge is Q = 1.62×10^{-6} C , what is the magnitude of the electric field caused by this charge at point P, a distance d = 1.53 m from the charge?

Enter your answer numerically in newtons per coulomb.



ANSWER:

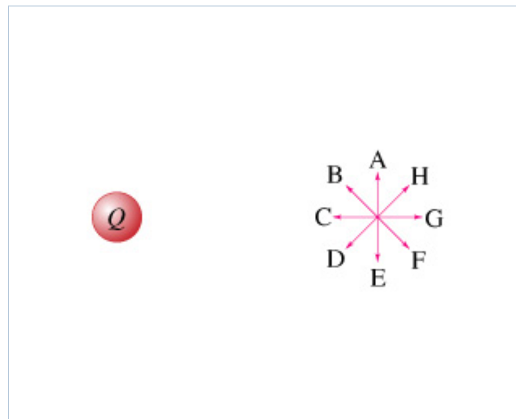
E_{P} = 6220 $\mathrm{N/C}$

Correct

Part D

What is the direction of the electric field at point P?

Enter the letter of the vector that represents the direction of $\vec{E}_{\mathrm{P}}$.



ANSWER:

G

Correct

Part E

Now find the magnitude of the force on an electron placed at point P. Recall that the charge on an electron has magnitude $e = 1.60 \times 10^{-19}\ \mathrm{C}$.

Enter your answer numerically in newtons.

Hint 1. Determine how to approach the problem

What strategy can you use to calculate the force between the positive charge and the electron?

ANSWER:

- ○ Use Coulomb's law.
- ○ Multiply the electric field due to the positive charge by the charge on the electron.
- ◉ Do either of the above.
- ○ Do neither of the above.

ANSWER:

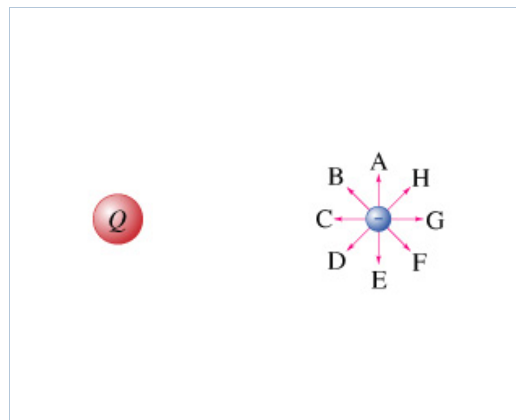
F = 9.95×10^{-16} N

Correct

Part F

What is the direction of the force on an electron placed at point P?

Enter the letter of the vector that represents the direction of $\vec{F}$.



ANSWER:

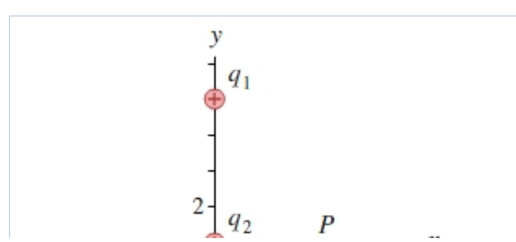
C

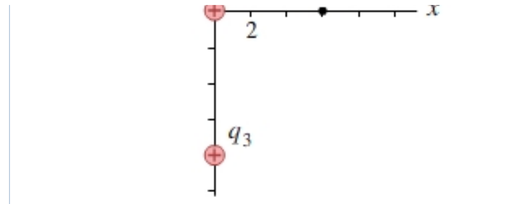
Correct

± PSS 21.2 Electric-Field Calculations

Learning Goal:
To practice Problem-Solving Strategy 21.2 Electric-Field Calculations.

Three positive point charges are spaced equally along the *y* axis ($x = 0$), q_1 = 4.50 nC at $y = +8.00\ \mathrm{cm}$, q_2 = 4.50 nC at $y = 0$, and q_3 = 4.50 nC at $y = -8.00\ \mathrm{cm}$. Find the *x* and *y* components of the total electric field E_x and E_y at point P, which is located on the *x* axis at $x = 6.00\ \mathrm{cm}$.





Problem Solving Strategy 21.2: Electric-Field Calculations

IDENTIFY *the relevant concepts:*
Use the principle of superposition whenever you need to calculate the electric field due to a charge distribution (two or more point charges, a distribution over a line, surface, or volume, or a combination of these).

SET UP *the problem* using the following steps:

1. Make a drawing that clearly shows the locations of the charges and your choice of coordinate axes.
2. On your drawing, indicate the position of the *field point* (the point at which you want to calculate the electric field $\vec{E}$).

EXECUTE *the solution* as follows:

1. Be sure to use a consistent set of units. Distances must be in meters and charge must be in coulombs.
2. When adding up the electric fields caused by different parts of the charge distribution, remember that electric field is a vector, so you *must* use vector addition.
3. Take advantage of any symmetries in the charge distribution to simplify your calculations.
4. Most often you will use components to compute vector sums. Be certain the components are consistent with your choice of coordinate axes.
5. The field produced by a point charge always points from source point to field point if the charge is positive; it points in the opposite direction if the charge is negative.
6. In some situations you will have a continuous distribution of charge along a line, over a surface, or through a volume. Then you must define a small element of charge that can be considered as a point, find its electric field at point P and find a way to add the fields of all the charge elements.

EVALUATE *your answer:*
Check that the direction of $\vec{E}$ is reasonable. If your result for the electric-field magnitude E is a function of position (say, the coordinate *x*), check your result in any limits for which you know what the magnitude should be. When possible, check your answer by calculating it in a different way.

IDENTIFY the relevant concepts

The target variables are the *x* and *y* components of the electric field, E_x and E_y, at point P due to the three point charge configuration.

SET UP the problem using the following steps

Part A

Classify these (*x*,*y*) coordinate pairs as a source point or a field point.

Drag the appropriate items to their respective bins.

ANSWER:

Reset Help

Field point(s)	Source point(s)
(6,0)	(0,0) (0,-8) (0,8)

Correct

The source points are the three point charges along the *y* axis, representing where the electric field emanates. The field point is located at point P, and represents the location where you will need to calculate the *x* and *y* components of $\vec{E}$.

EXECUTE the solution as follows

Part B

Find the *x* and *y* components of the total electric field at point P, which is located on the *x* axis at $x = 6.00\ \mathrm{cm}$.

Enter the values for E_x and E_y in newtons per coulomb separated by commas.

Hint 1. How to approach the problem

Use the equation for an electric field $\vec{E}$ due to a point charge and the geometry of the charge distribution to solve for the *x* and *y* components of the individual electric fields produced by each point charge. Finally, make use of the superposition principle of electric fields

$$E_x = E_{1x} + E_{2x} + E_{3x}$$
$$E_y = E_{1y} + E_{2y} + E_{3y}$$

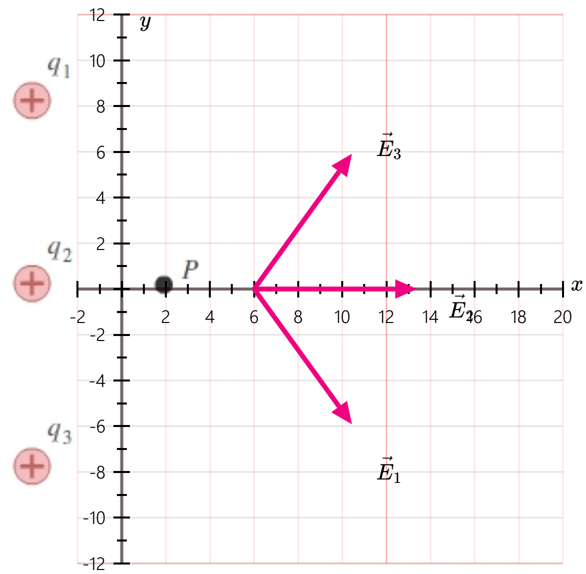
to calculate the total electric field components $\vec{E}_x$ and $\vec{E}_y$ at the field point P due to the three charges. Identifying any symmetry in the problem can reduce the number of steps to the solution.

Hint 2. Sketch the electric field vectors at P

On the graph below, adjust the angles of $\vec{E}_1$, $\vec{E}_2$, and $\vec{E}_3$ to match the relative electric field vectors produced at point P by the corresponding point charge. Note that you will not be graded explicitly on vector lengths since the graph is set in units of distance. However when adjusting the relative lengths of the vectors, electric fields with equal magnitudes should have equal lengths.

ANSWER:

No elements selected



Incorrect; Try Again; 3 attempts remaining

Hint 3. Identify any symmetry

Choose the appropriate statement concerning any symmetry present in the components of the electric field vectors $\vec{E}_1$, $\vec{E}_2$, and $\vec{E}_3$ about point P, where symmetry implies equal magnitudes but opposite directions in similar components of two vectors.

ANSWER:

- ○ There is symmetry in the *x* components of $\vec{E}_1$ and $\vec{E}_2$ about point P.
- ○ There is symmetry in the *x* components of $\vec{E}_1$ and $\vec{E}_3$ about point P.
- ◉ There is symmetry in the *y* components of $\vec{E}_1$ and $\vec{E}_3$ through point P.
- ○ There is no symmetry present about point P.

Correct

There is a symmetry in the *y* components of $\vec{E}_1$ and $\vec{E}_3$, such that the are equal in magnitude but opposite in direction. Thus, you only have to be concerned with the *x* components of $\vec{E}_1$ and $\vec{E}_3$ contributing to the final electric field.

Hint 4. Calculate E_{1x}

Calculate the *x* component of the electric field $\vec{E}_1$ at point P due to q_1.

Express your answer in units of newtons per coulomb

Hint 1. Determine $|\vec{E}|$ due to a point charge

Write the expression for the magnitude of an electric field $\vec{E}$ due to a point charge. Express your answer in terms of the charge q, the distance from the charge r, and the constant k, where $k = 1/(4\pi\epsilon_0)$.

Express your answer in terms of q, r, and k.

ANSWER:

E = $\frac{kq}{r^2}$

Answer Requested

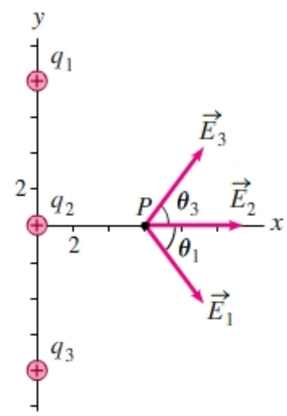
Each of the three point charges q_1, q_2, and q_3 is a source of an electric field, which in vector notation is given by

$$\vec{E} = k\frac{q}{r^2}\hat{r}.$$

The total electric field at point P will then be the result of the vector sum of the individual electric fields.

Hint 2. Determine the expression for E_{1x}

Enter the expression to determine the *x* component of $\vec{E}_1$, using the magnitude E_1 and angle from the *x* axis θ_1.



Express your answer in terms of E_1 and θ_1.

ANSWER:

E_{1x} = $E_1 \cos(\theta_1)$

Answer Requested

Hint 3. Calculating the angles θ_1 and θ_3

Calculate the angles θ_1 and θ_3, where θ_1 is the angle between the *x* axis, point P, and $\vec{E}_1$ and θ_3 is the angle between the *x* axis, point P, and $\vec{E}_3$. Use the convention that angles measured counterclockwise are positive and angles measured clockwise are negative.

Enter the values for θ_1 and θ_3 in degrees separated by commas

ANSWER:

θ_1, θ_3 = -53.1,53.1 degrees

Answer Requested

ANSWER:

E_{1x} = 2430 $\mathrm{N/C}$

Answer Requested

ANSWER:

E_x, E_y = 1.61×10^4,0 $\mathrm{N/C}$

Correct

EVALUATE your answer

Part C

Due to the symmetry in the *y* components of $\vec{E}_1$ and $\vec{E}_3$, this problem essentially reduced to a one dimensional problem in the *x* direction. What would the affect be on the *y* component of the total electric field E_y at P if the charge on q_3 is increased?

ANSWER:

- ○ E_y would have be **unchanged** (i.e., $E_{\mathrm{y}} = 0$).
- ◉ E_y would have a **positive** value.
- ○ E_y would have a **negative** value.
- ○ The affect on E_y **cannot be determined**, because more information is needed.

Correct
The electric field is directly dependent upon charge. If charge increases, then the magnitude of the electric field due to that charge will increase also. An increase in q_3 results in an increase in $\vec{E}_3$, losing the symmetry in the *y* components of $\vec{E}_1$ and $\vec{E}_3$. Thus, the total electric field at P will have a net *y* component in the positive *y* direction.

Score Summary:

Your score on this assignment is 96.2%.
You received 96.18 out of a possible total of 100 points.