26 The Electric Field

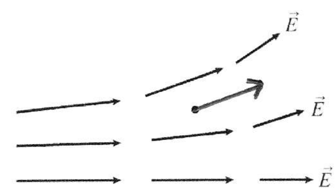
26.1 Electric Field Models

26.2 The Electric Field of Multiple Point Charges

1. You've been assigned the task of determining the magnitude and direction of the electric field at a point in space. Give a step-by-step procedure of how you will do so. List any objects you will use, any measurements you will make, and any calculations you will need to perform. Make sure that your measurements do not disturb the charges that are creating the field.

Place a tiny, positive test charge at the point in space and measure the force on it. From the force measurement and the charge, calculate the electric field using $E = F/q$. The direction of the field is the same as the direction of the force because q is positive.

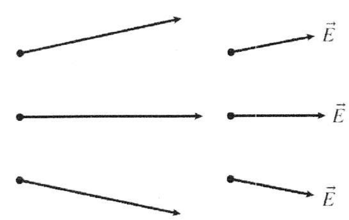
2. Is there an electric field at the position of the dot? If so, draw the electric field vector on the figure. If not, what would you need to do to create an electric field at this point?



Yes there is an electric field at this position.

3. This is the electric field in a region of space.

a. Explain the information that is portrayed in this diagram.



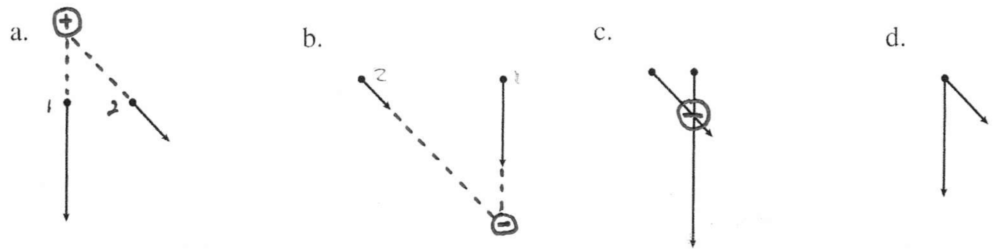
There is some source of positive charge on the left side. The longer vectors indicate a relatively larger electric field on the left, closest to the charge.

b. If field vectors were drawn at the same six points but each was only half as long, would the picture represent the same electric field or a different electric field? Explain.

It could represent the same electric field because the length of the field vector only represents <u>relative</u> magnitude of the electric field at that point.

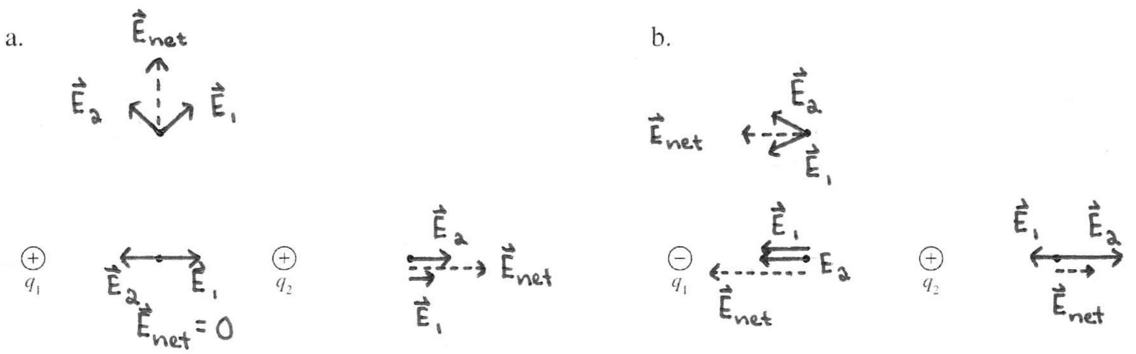
4. Each figure shows two vectors. Can a point charge create an electric field that looks like this at these two points? If so, add the charge to the figure. If not, why not?

   Note: The dots are the points to which the vectors are attached. There are no charges at these points.

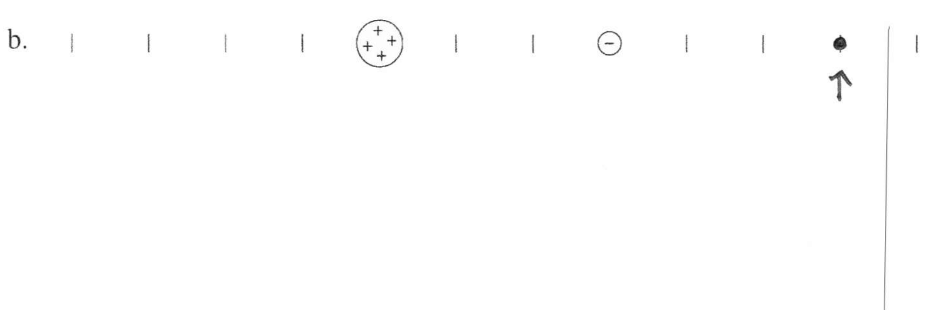


a.	b.	c.	d.
Yes Point 2 is farther away from charge.	Yes. Again, Point 2 is farther away.	Yes. The field vector shows the field only at the dot.	No. The field due to a point charge cannot go in two directions.

5. At each of the dots, use a **black** pen or pencil to draw and label the electric fields $\vec{E}_1$ and $\vec{E}_2$ due to the two point charges. Make sure that the *relative* lengths of your vectors indicate the strength of each electric field. Then use a **red** pen or pencil to draw and label the net electric field $\vec{E}_{net}$ at each dot.



6. For each of the figures, use dots to mark any point or points (other than infinity) where $\vec{E} = \vec{0}$.



7. Compare the electric field strengths E_1 and E_2 at the two points labeled 1 and 2. For each, is $E_1 > E_2$, is $E_1 = E_2$, or is $E_1 < E_2$?

a.

$E_1 < E_2$

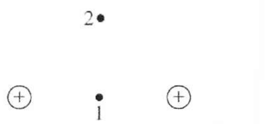
b.

$E_1 > E_2$

c.

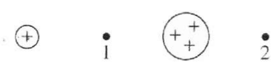
$E_1 = E_2$

d.



$E_1 < E_2$

e.



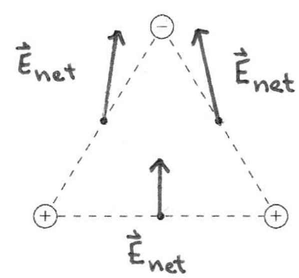
$E_1 < E_2$

f.

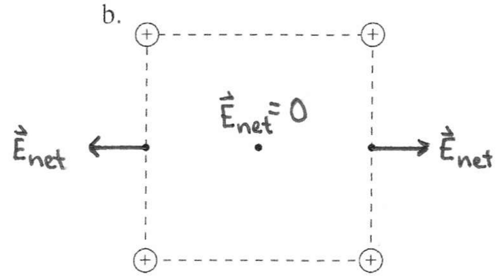
$E_1 > E_2$

8. For each figure, draw and label the net electric field vector $\vec{E}_{net}$ at each of the points marked with a dot or, if appropriate, label the dot $\vec{E}_{net} = \vec{0}$. The lengths of your vectors should indicate the magnitude of $\vec{E}$ at each point.

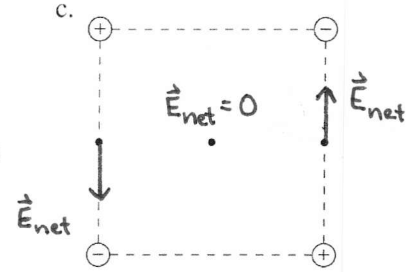
a.



b.

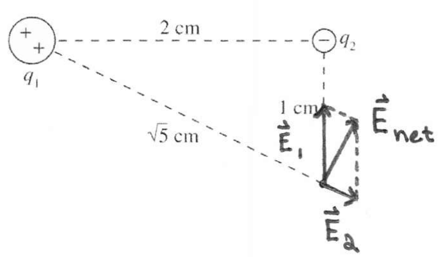


c.



9. At the position of the dot, draw field vectors $\vec{E}_1$ and $\vec{E}_2$ due to q_1 and q_2, and the net electric field $\vec{E}_{net}$. Then, in the blanks, state whether the x- and y-components of $\vec{E}_{net}$ are positive or negative.

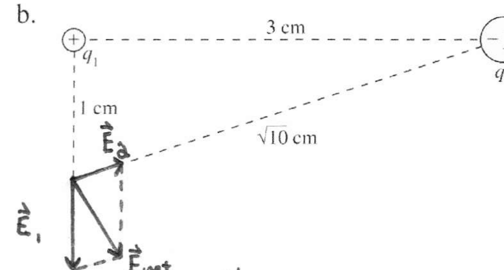
a.



$(E_{net})_x$ positive

$(E_{net})_y$ positive

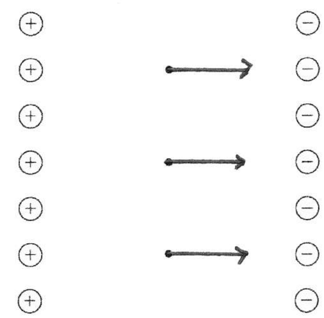
b.



$(E_{net})_x$ positive

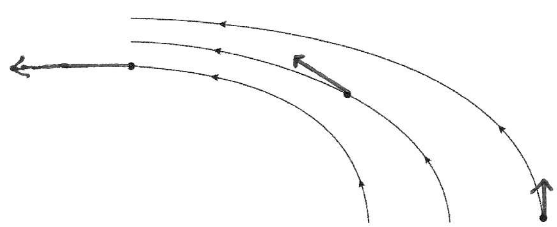
$(E_{net})_y$ negative

10. Draw the net electric field vector at the three points marked with a dot.
Hint: Think of the charges as horizontal positive/negative pairs, then use superposition.



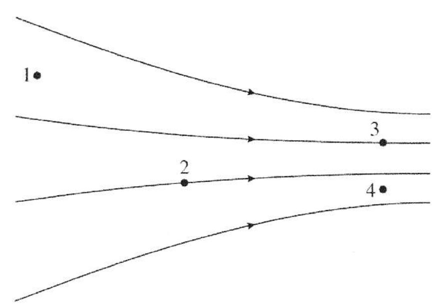
Any vertical component from a ⊕ charge is cancelled by the ⊖ charge opposite to it.

11. The figure shows the electric field lines in a region of space. Draw the electric field vectors at the three dots. The length of the vector should indicate the relative strength of the electric field at that point.



The field is greater where the field lines are closer together.

12. The figure shows the electric field lines in a region of space. Rank in order, from largest to smallest, the electric field strengths E_1 to E_4 at points 1 to 4.



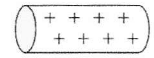
Order: $E_3 = E_4 > E_2 > E_1$

Explanation:

The electric field strength is larger in the region where the field lines are closer together (E_3 and E_4) and smaller where the field lines are farther apart.

26.3 The Electric Field of a Continuous Charge Distribution

13. A small segment of wire contains 10 nC of charge.



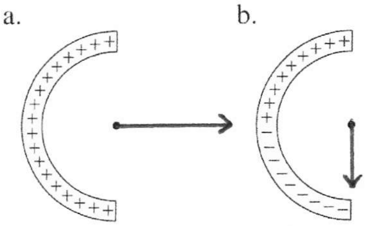
a. The segment is shrunk to one-third of its original length. What is the ratio λ_f/λ_i, where λ_i and λ_f are the initial and final linear charge densities?

$$\frac{\lambda_f}{\lambda_i} = \frac{(Q_f/L_f)}{(Q_i/L_i)} \quad \text{But } Q_i = Q_f \Rightarrow \frac{\lambda_f}{\lambda_i} = \frac{L_i}{L_f} = 3$$

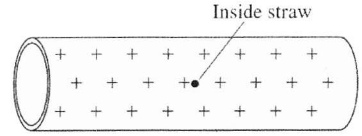
b. Suppose the original segment of wire is stretched to 10 times its original length. How much charge must be added to the wire to keep the linear charge density unchanged?

10 times the original amount of charge would give a constant linear charge density. So the amount of charge to add to the original is 9 times the original charge.

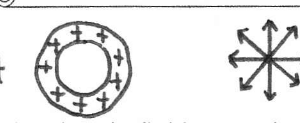
14. The figure shows two charged rods bent into a semicircle. For each, draw the electric field vector at the "center" of the semicircle.



15. A hollow soda straw is uniformly charged. What is the electric field at the center (inside) of the straw? Explain.



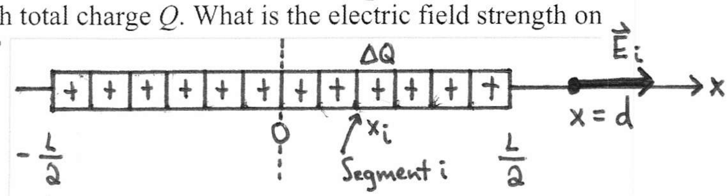
The electric field at the center is zero. We can think of the straw as being made up of as many rings of positive charge. At the center of the ring adding all field vectors gives a resultant electric field equal to zero.



16. A thin rod of length L is uniformly charged with total charge Q. What is the electric field strength on the axis of the rod at distance d from its center?

PSS 26.1

a. Begin with a visual representation. Draw a horizontal rod, then divide it into 10 or 12 boxes with a + in each box. Add an x-axis with the rod centered at the origin. Label the ends of the rod $x = -L/2$ and $x = L/2$. Put a dot on the x-axis at some point to the right of the rod; label it $x = d$.



b. Pick one of your + boxes to the right of the origin; label it "segment i," label its position as x_i, and write ΔQ beside it to show the charge in segment i. At the dot, draw the electric field vector due to segment i; label it $\vec{E}_i$.

c. Does $\vec{E}_i$ have an x-component? yes A y-component? no A z-component? no

d. Imagine the electric field $\vec{E}_j$ due to some other segment j.
Is $\vec{E}_j$ the same length as $\vec{E}_i$? no Does $\vec{E}_j$ point the same direction as $\vec{E}_i$? yes

e. The rod's electric field $\vec{E}$ is the sum of all the $\vec{E}_i$. Based on what you've said so far:
Does $\vec{E}$ have an x-component? yes A y-component? no A z-component? no
You should have found that $\vec{E}$ has only one component, requiring only one summation.

f. Using what you know about the electric field of a point charge, write an expression for the electric field component of $\vec{E}_i$—the component you identified in part e—in terms of ΔQ, x_i, d, and various constants.

$$E_{i_x} = \frac{1}{4\pi\epsilon_0} \frac{\Delta Q}{(d-x_i)^2}$$

g. Now write an expression of this component of the rod's field $\vec{E}$ as a sum over all i of your answer to part f.

$$E_x = \frac{1}{4\pi\epsilon_0} \sum_i \frac{\Delta Q}{(d-x_i)^2}$$

h. The rod has charge Q in length L. What is the linear charge density? $\lambda =$ Q/L

i. Segment i has width Δx. Based on λ and Δx, the segment has charge $\Delta Q =$ $\lambda \Delta x$

j. Rewrite your answer to part g with this substitution for ΔQ.

$$E_x = \frac{1}{4\pi\epsilon_0} \sum \frac{\lambda \Delta x}{(d-x_i)^2}$$

k. Now you're ready to convert the sum to an integral. What are the integration limits?
Lower limit $-L/2$ Upper limit $L/2$

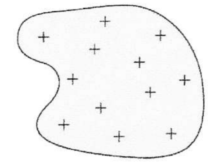
l. Write your expression for the electric field as a definite integral. That means (a) Change Δx to dx, (b) drop the subscript from x_i because x is now a continuous variable, (c) show the integration limits, and (d) take all multiplicative constants outside the integration.

$$E_x = \frac{\lambda}{4\pi\epsilon_0} \int_{-L/2}^{L/2} \frac{dx}{(d-x)^2}$$

We're going to stop here. You've done the physics by figuring out what to integrate. Now it's "just" a calculus problem of carrying out the integration to get a final answer.

26.4 The Electric Fields of Rings, Disks, Planes, and Spheres

17. An irregularly-shaped area of charge has surface charge density η_i. Each dimension (x and y) of the area is reduced by a factor of 3.163.



a. What is the ratio η_f/η_i, where η_f is the final surface charge density?

$A_f = \dfrac{A_i}{3.163^2}$ $\dfrac{\eta_f}{\eta_i} = \dfrac{(Q/A_f)}{(Q/A_i)} = \dfrac{A_i}{A_f} = 3.163^2 = 10.00$

b. Compare the final force on a electron very far away to the initial force on the same electron.

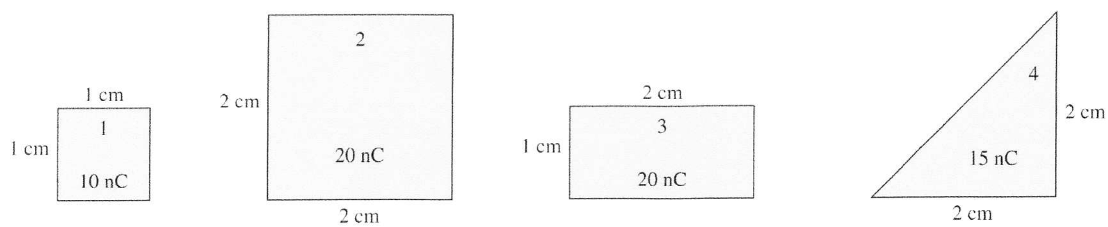
The force would be the same for an electron very far away because the irregular shape is seen as a point charge.

18. A circular disk has surface charge density 8 nC/cm^2. What will be the surface charge density if the radius of the disk is doubled?

$\eta_1 = \dfrac{Q}{A_1} = \dfrac{Q}{\pi r_1^2} = 8\,\dfrac{nC}{cm^2}$

$\eta_2 = \dfrac{Q}{A_2} = \dfrac{Q}{\pi r_2^2} = \dfrac{Q}{\pi(2r_1)^2} = \dfrac{Q}{4\pi r_1^2} = \dfrac{1}{4}\eta_1 = 2\,\dfrac{nC}{cm^2}$

19. Rank in order, from largest to smallest, the surface charge densities η_1 to η_4 of surfaces 1 to 4.



Order: $\eta_1 = \eta_3 > \eta_4 > \eta_2$

Explanation:

$\eta_1 = \dfrac{Q_1}{A_1} = \dfrac{10\,nC}{(1\,cm \times 1\,cm)} = 10\,\dfrac{nC}{cm^2}$ $\eta_2 = \dfrac{20\,nC}{(2\,cm \times 2\,cm)} = 5\,\dfrac{nC}{cm^2}$

$\eta_3 = \dfrac{20\,nC}{(1\,cm \times 2\,cm)} = 10\,\dfrac{nC}{cm^2}$ $\eta_4 = \dfrac{15\,nC}{\frac{1}{2}(2\,cm \times 2\,cm)} = 7.5\,\dfrac{nC}{cm^2}$

20. A sphere of radius R has charge Q. What happens to the electric field strength at $r = 2R$ if:

a. The quantity of charge is halved?

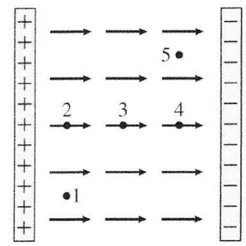
$E = \dfrac{Q}{4\pi\epsilon_0 r^2}$ If Q is halved, then E is also halved.

b. The radius of the sphere is halved?

The field outside a sphere is the same as that of a point charge Q located at the center of the sphere. So if the radius of the sphere changes, the field remains the same outside the sphere at the distance $r = 2R_i$.

26.5 The Parallel-Plate Capacitor

21. Rank in order, from largest to smallest, the electric field strengths E_1 to E_5 at each of these points.



Order: $E_1 = E_2 = E_3 = E_4 = E_5$

Explanation:

The electric field is constant everywhere between the plates. This is indicated by the electric field vectors which are all the same length and in the same direction.

22. A parallel-plate capacitor is constructed of two square plates, size $L \times L$, separated by distance d. The plates are given charge $\pm Q$. What is the ratio E_f/E_i of the final electric field strength E_f to the initial electric field strength E_i if:

a. Q is doubled?

$$\frac{E_f}{E_i} = \frac{\eta_f/\epsilon_0}{\eta_i/\epsilon_0} = \frac{\eta_f}{\eta_i} = \frac{Q_f/A_f}{Q_i/A_i}$$

If Q is doubled (A = constant)

$$\frac{E_f}{E_i} = \frac{Q_f}{Q_i} = 2$$

b. L is doubled?

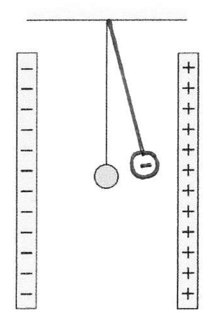
If L is doubled then $A_f = 4A_i$ (Q = constant)

$$\frac{E_f}{E_i} = \frac{A_i}{A_f} = \frac{A_i}{4A_i} = \frac{1}{4}$$

c. d is doubled?

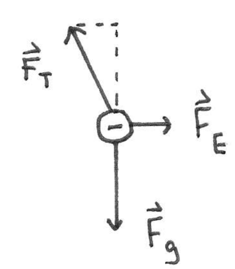
E does not depend on d. $\frac{E_f}{E_i} = 1$

23. A ball hangs from a thread between two vertical capacitor plates. Initially, the ball hangs straight down. The capacitor plates are charged as shown, then the ball is given a small negative charge. The ball moves to one side, but not enough to touch a capacitor plate.



a. Draw the ball and thread in the ball's new equilibrium position.

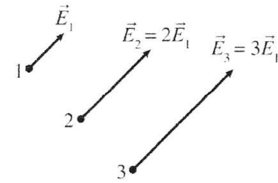
b. In the space below, draw a free-body diagram of the ball when in its new position.



26.6 Motion of a Charged Particle in an Electric Field

26.7 Motion of a Dipole in an Electric Field

24. A small positive charge q experiences a force of magnitude F_1 when placed at point 1. In terms of F_1:



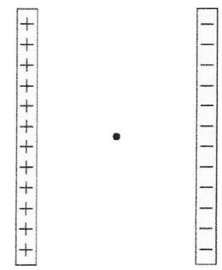
a. What is the force on charge q at point 3? $3F_1$

b. What is the force on a charge $3q$ at point 1? $3F_1$

c. What is the force on a charge $2q$ at point 2? $4F_1$

d. What is the force on a charge $-2q$ at point 2? $-4F_1$

25. A small object is released from rest in the center of the capacitor. For each situation, does the object move to the right, to the left, or remain in place? If it moves, does it accelerate or move at constant speed?



a. Positive object.

Accelerates to the right.

b. Negative object.

Accelerates to the left.

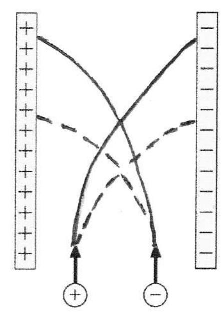
c. Neutral object.

Remains in place.

26. Positively and negatively charged objects, with equal masses and equal quantities of charge, enter the capacitor in the directions shown.

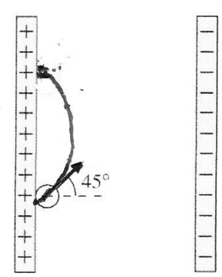
a. Use solid lines to draw their trajectories on the figure if their initial velocities are fast.

b. Use dashed lines to draw their trajectories on the figure if their initial velocities are slow.



27. An electron is launched from the positive plate at a 45° angle. It does not have sufficient speed to make it to the negative plate. Draw its trajectory on the figure.

Parabolic, landing at 45°.



28. First a proton, later an electron are released from rest in the center of a capacitor.

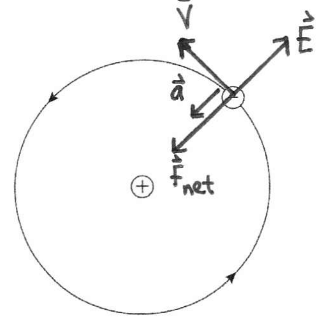
a. Compare the forces on the two charges. Are they equal, or is one larger? Explain.

The forces on the two charges are equal. $F = qE$ They each have the same amount of charge and are placed in the same field.

b. Compare the accelerations of the two charges. Are they equal, or is one larger? Explain.

The acceleration of the electron is larger because the electron has a smaller mass. $a = \frac{F}{m}$

29. The figure shows an electron orbiting a proton in a hydrogen atom.



a. What force or forces act on the electron?

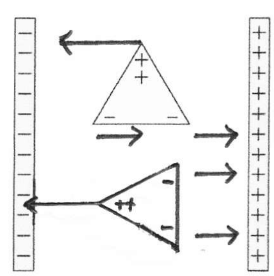
The electric force.

b. Draw and label the following vectors on the figure: the electron's velocity $\vec{v}$ and acceleration $\vec{a}$, the net force $\vec{F}_{net}$ on the electron, and the electric field $\vec{E}$ at the position of the electron.

30. Does a charged particle always move in the direction of the electric field? If so, explain why. If not, give an example that is otherwise.

No. If the charged particle has an initial velocity component in a perpendicular direction then it would travel in a different direction than the field. For example, a charge could move in circular motion as in problem #29 above.

31. Three charges are placed at the corners of a triangle. The ++ charge has twice the quantity of charge of the two – charges; the net charge is zero.



a. Draw the force vectors on each of the charges.

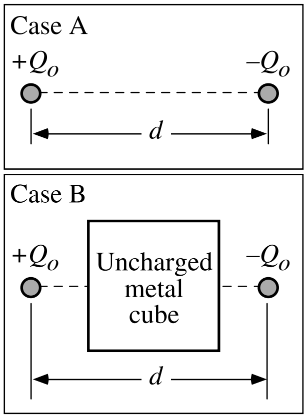
b. Is the triangle in equilibrium? No If not, draw the equilibrium orientation directly beneath the triangle that is shown.

c. Once in the equilibrium orientation, will the triangle move to the right, move to the left, rotate steadily, or be at rest? Explain.

In equilibrium the triangle will remain in place because the net force is zero and the net torque is zero.

D1-QRT30: CUBES BETWEEN POINT CHARGES—FORCE EXERTED BY ONE CHARGE ON THE OTHER

In both cases, two equal and opposite charges are fixed in place a distance *d* apart. The cases are identical, except that in Case B an uncharged metal cube is placed between the two charges.



(a) Will the force exerted on the positive charge by the negative charge be (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

Explain your reasoning.

Answer: (iii) The same in both cases.
The forces the charged particles exert on each other are independent of whether any other objects are present.

(b) Since the cube in Case B is metal, there will be electrons in it that are free to move around. What, if anything, will happen to those electrons?

Explain your reasoning.

Answer: Some of the free electrons will move to the half of the cube near the positive charge because of the attraction from the positive charge and the repulsion from the negative charge.

Now the uncharged metal cube in Case B is replaced with an uncharged plastic cube, keeping everything else exactly the same.

(c) Will the force exerted on the positively charged particle by the negatively charged particle be (i) *greater* in Case A, (ii) *greater* in case B, or (iii) *the same* in both cases? _____

Explain your reasoning.

Answer: (c) The same in both cases.

The forces the charged particles exert on each other are independent of whether any other objects are present.

(d) Since the cube is plastic, there will be no electrons in it that are free to move around, but the molecules can become polarized (i.e., the electrons move closer on average to one end of the molecule and the protons move closer to the other). Will the plastic cube exert a force on the positive charge?

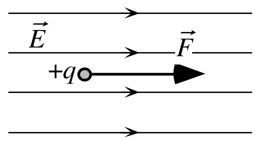
Explain your reasoning.

Answer: Yes.

The polarized cube will exert an attractive force on the positive charge because the left side of the cube has a slightly negative charge compared to the right side of the cube.

D1-LMCT33: Positive Charge in a Uniform Electric Field—Electric Force

A particle with a charge $+q$ is placed in a uniform electric field.



Identify from choices (i)–(vi) how each change described in (a) to (e) will affect the electric force on the particle.

This change will:

(i) change only the **direction** of the electric force.
(ii) **increase** the magnitude of the electric force.
(iii) **decrease** the magnitude of the electric force.
(iv) **increase** the magnitude and change the **direction** of the electric force.
(v) **decrease** the magnitude and change the **direction** of the electric force.
(vi) **not affect** the electric force.

All of these modifications are changes to the initial situation shown in the diagram.

(a) The charge q on the particle is doubled. _____
Explain your reasoning.
Answer: (ii) increase.
The force is proportional to the product of the charge and the field, this will increase the force.

(b) The sign of the charge q on the particle is changed to the opposite sign. _____
Explain your reasoning.
Answer: (i) change only the direction.
Changing the sign will reverse the direction of the force.

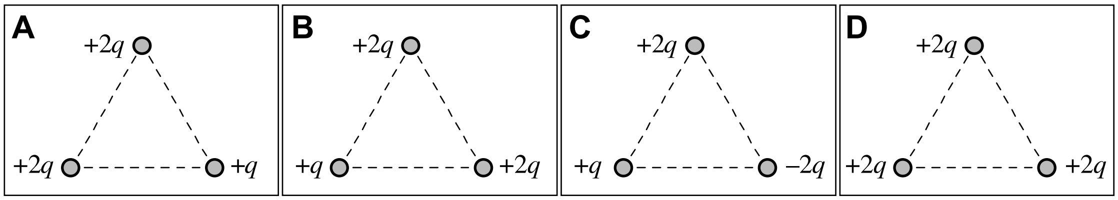
(c) The particle is given a push, causing a leftward initial velocity. _____
Explain your reasoning.
Answer:(vi) not affect the force.
The electric force does not depend on the velocity of the particle.

(d) The magnitude of the uniform electric field is halved. _____
Explain your reasoning.
Answer: (iii) decrease.
Since the force is proportional to the product of the charge and the field, this will decrease it.

(e) The direction of the uniform electric field is rotated 90º clockwise. _____
Explain your reasoning.
Answer: (i) change only the direction.
The force will still point in the direction of the field, which is now down toward the bottom of the page.

D1-RT36: THREE CHARGED PARTICLES ARRANGED IN A TRIANGLE—FORCE

In each case, three charged particles are fixed in place at the vertices of an equilateral triangle. The triangles are all the same size.



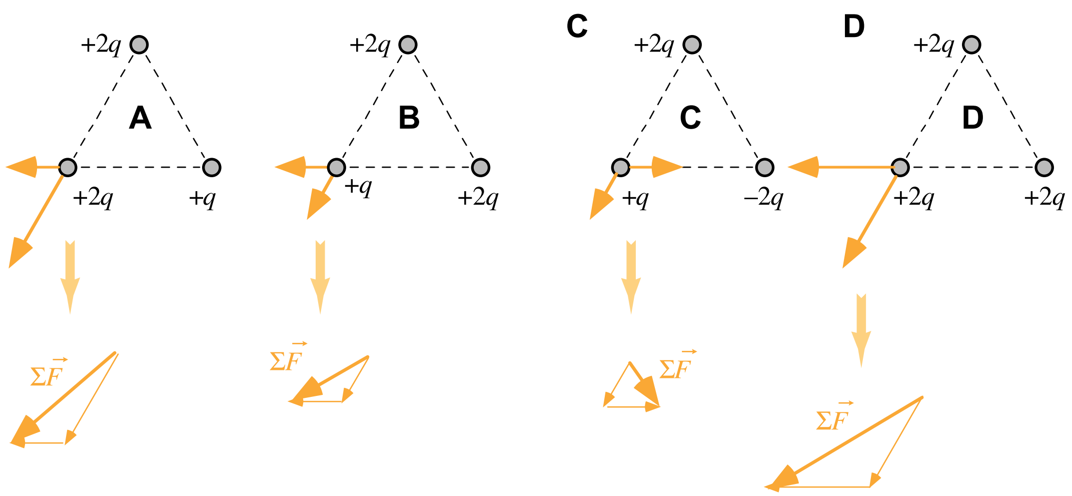
Rank the magnitude of the net electric force on the lower-left particle.

1 Greatest	2	3	4 Least	OR	All the same	All zero	Cannot determine

Explain your reasoning.

Answer: D > A > B > C.

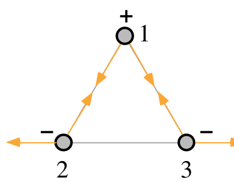
The individual forces are twice as large for an interaction between a +2q charge and a +2q charge as between a +2q charge and a +q charge, and point in the directions shown. A vector sum of the individual forces gives the net force.



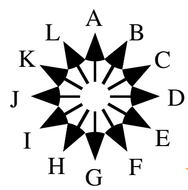
D1-QRT37: FORCE DIRECTION ON THREE CHARGES IN AN EQUILATERAL TRIANGLE—FORCE

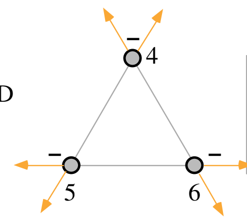
Three charges are fixed at the vertices of each of the equilateral triangles shown below. All charges have the same magnitude. Only charge 1 is positive.

Determine the direction of the net electric force acting on each charge due to the other two charges in the same triangle. Answer by using letters A through L representing directions from the choices below.



	Net Force Direction
Charge 1	G
Charge 2	L
Charge 3	B





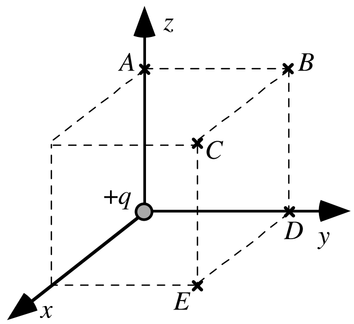
	Net Force Direction
Charge 4	A
Charge 5	I
Charge 6	E

Explain your reasoning.

Using the signs of the charges we can determine whether the forces between two charges are attractive or repulsive. Then we Draw those forces along the lines connecting the two charges and determine what direction the vector sum of the two forces acting on each charge will have.

D1-RT39: NEAR A POINT CHARGE—ELECTRIC FORCE AT THREE-DIMENSIONAL LOCATIONS

There is a positive point charge $+q$ located at (0, 0, 0) in the three-dimensional region below. Within that region are points located on the corners of a cube as shown.



Rank the strength (magnitude) of the electric force on a $+3q$ point charge if it is placed at the labeled points.

					OR			
1 Greatest	2	3	4	5 Least		All the same	All zero	Cannot determine

Explain your reasoning.

Answer: A = D > B = E > C.

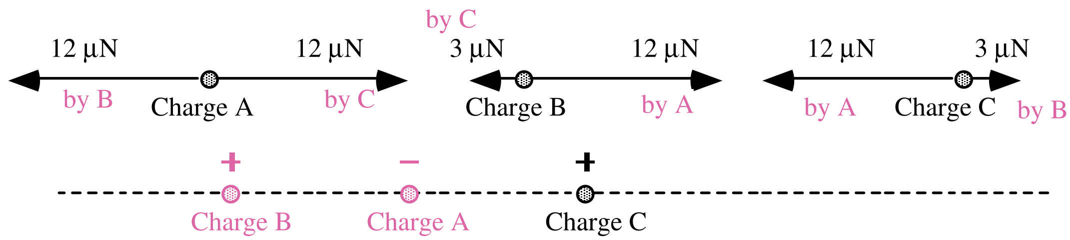
The force between two point charges decreases as the distance between those charges increases.

D1-WBT40: Forces on Three Charges Along a Line—Charge Location*

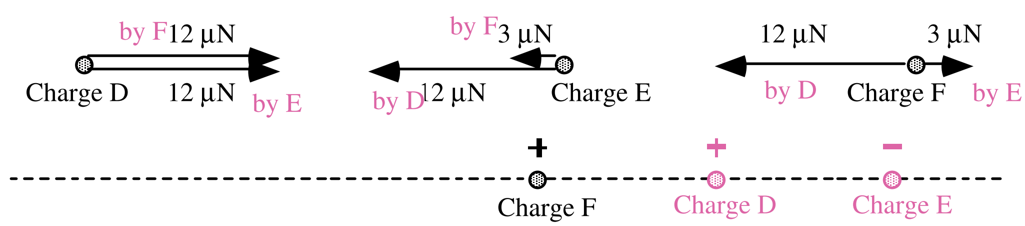
Three charges are fixed in place along a line. All three charges have the same magnitude, but they may have different signs. Shown below are diagrams showing the forces exerted on each charge by the other two charges.

In each case, the sign of one of the charges is shown, as well as its position along a dashed line. **Indicate the signs of the other two charges and their approximate positions on the dashed line.**

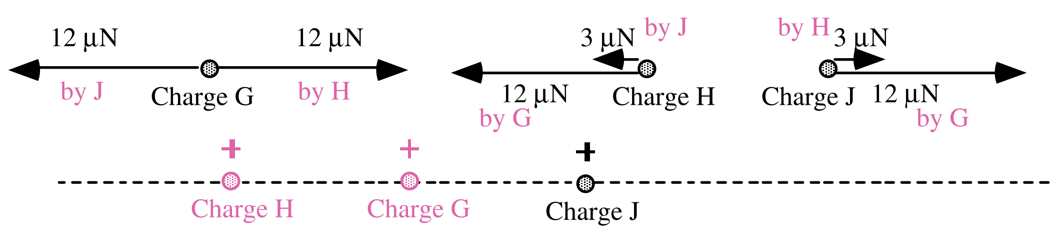
Case 1



Case 2



Case 3



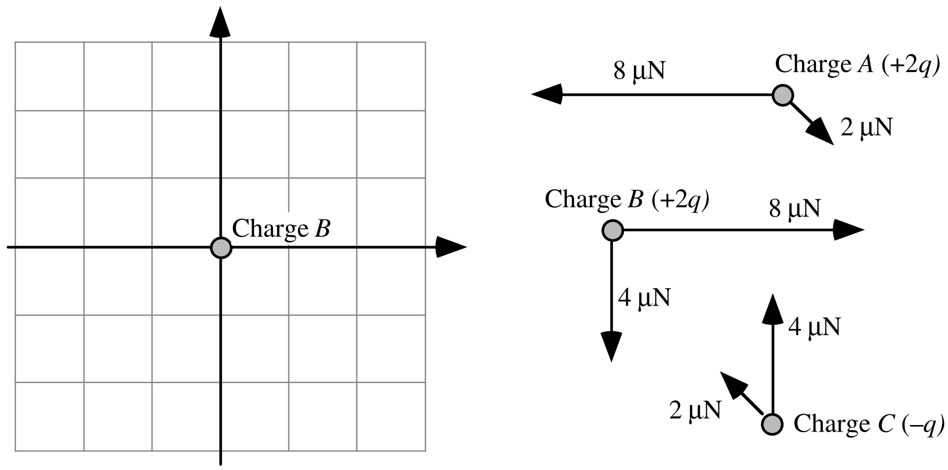
Explain your reasoning.

In working these we can first figure out which charge is in the middle in each case since it will be the one with two equal magnitude forces acting on it. For cases 1 and 3 the other two charges on the ends then have to have the same sign and either be attracting or repelling the central charge. For case 2 the two outside charges have opposite signs. For case 1 then we have charges B and C are on the outside and we were given that C is positive so B has to be also. Since the forces on B and C due to A point toward A—they have to be the 12 µN forces on B and C—we know A is negative. For case 2 we now know that E, which is on the right end is negative since both forces acing on it point to the left. Since both forces on D point toward E that means F, which is positive, is exerting a repelling force on D, so D is positive. Case 3 is similar to case 1, but both forces on charges H and J point outward, so all three charges have to be positive.

D1-WBT41: Forces on Three Charges in Two Dimensions—Charge Locations

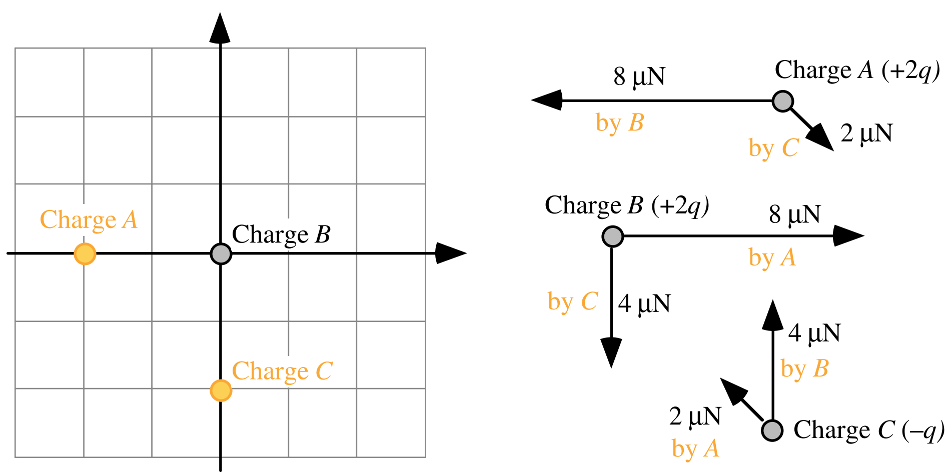
Three charged particles are fixed to a grid and are exerting electric forces on one another. Particles *A* and *B* have a charge +2*q*, and particle *C* has a charge –*q*. The diagrams at the right, below, show the electric forces exerted on each particle due to the other two particles.

Particle *B* is shown fixed at the origin of a grid. **On the grid, indicate the positions of particles *A* and *C* relative to particle *B*.**



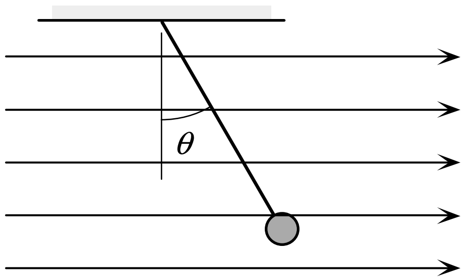
Explain your reasoning.

Since A and B are both +2q they will repel. The fact that there are two large horizontal forces tells us that A is on the x-axis to the left of B. Then since charge C, which is negative, experiences a force directed along the positive Y axis and a force up to the left, charge C must be directly below B. Actual locations can be found from the magnitudes of the forces.



D1-RT43: Suspended Charges in an Electric Field—Angle

A charged sphere is suspended from a string in a uniform electric field directed horizontally. There is an electric force on the sphere to the right and a gravitational force pointing downward. As a result, the sphere hangs at an angle θ from the vertical. Combinations of sphere mass and electric charge are listed in the chart for four cases, all in the same uniform electric field.



	Mass	Charge
A	3 g	8 nC
B	6 g	4 nC
C	9 g	2 nC
D	6 g	8 nC

Rank the angle θ that the string forms with the vertical for these different spheres.

1 Greatest	2	3	4 Least	OR	All the same	All zero	Cannot determine

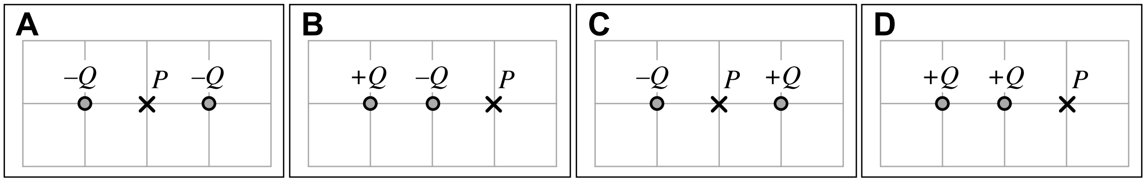
Explain your reasoning.

Answer: A > D > B > C.

The larger the charge the larger the electric force so more horizontal shift, but a larger mass means a larger weight and reduces the angle.

D1-RT47: Two Electric Charges—Electric Field along a Line

In each figure, two charges are fixed in place on a grid, and a point near those particles is labeled *P*. All of the charges are the same size, *Q*, but they can be either positive or negative.



Rank the magnitude of the electric field at point *P*.

				OR			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

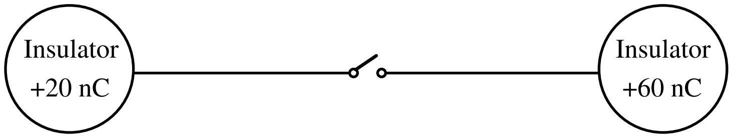
Explain your reasoning.

Answer: C > D > B > A.

C is largest because both charges are the same distance from P and both produce fields at P pointing to the left. Next is D because both charges produce fields in the same direction, but the two fields do not have the same magnitude. B follows third because the two fields are in opposite directions, so they subtract. A is last since the field at P in A is zero.

D1-SCT53: CHARGED INSULATORS CONNECTED WITH A SWITCH—CHARGE

Two solid, insulating spheres are connected by a wire and a switch. The spheres are the same size, but they have different initial charges.



Three students are discussing what would happen if the switch was closed.

Arturo: *"Since the spheres are the same size, charge will move until there is an equal charge of 40 nC on each."*

Beth: *"I agree, but since they are insulators, the charge will move very slowly. Eventually there will be the same charge of 40 nC on each, but it will take a long time, perhaps 5 to 10 minutes.*

Caitlin: *"No, since they are insulators the charge cannot move. It doesn't matter whether the switch is open or closed."*

With which of these students do you agree?

Arturo _____ Beth _____ Caitlin _____ None of them _____

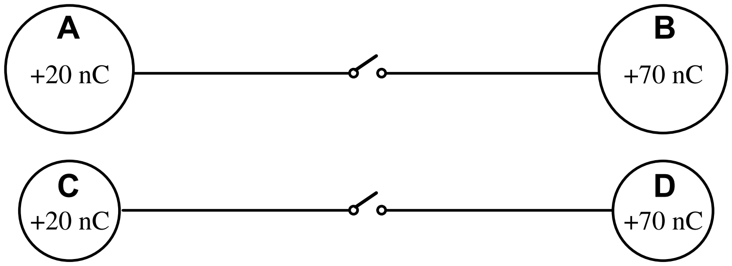
Explain your reasoning.

Answer: Caitlin is correct.

Over long time periods, the insulators may become discharged, but this would typically happen through interaction with the air, and the charge would not transfer from one insulator to the other.

D1-RT54: PAIRS OF CONNECTED CHARGED CONDUCTORS—CHARGE

Two pairs of charged, isolated, conducting spheres are connected with wires and switches. The spheres are very far apart. The larger spheres (A and B) are identical, and the smaller spheres (C and D) are identical. Before the switches are closed, both spheres on the left have a charge of +20 nC, and both spheres on the right have a charge of +70 nC.



Rank the electric charge on the spheres after the switches are closed.

				OR			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

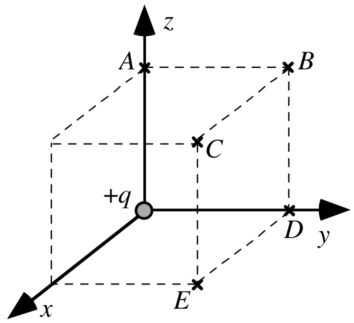
Explain your reasoning.

Answer: A = B = C = D.

The charges will move until the potential of each sphere is the same. Since the spheres that are connected have the same size, they share the charge equally. Each sphere will have a final charge of +45 nC.

D1-RT57: NEAR A POINT CHARGE—ELECTRIC POTENTIAL AT THREE-DIMENSIONAL LOCATIONS

There is a positive point charge $+q$ located at (0, 0, 0) as shown in the three-dimensional region below. Within that region are points located on the corners of a cube as shown.



Rank the electric potential at the labeled points.

					OR			
1 Greatest	2	3	4	5 Least		All the same	All zero	Cannot determine

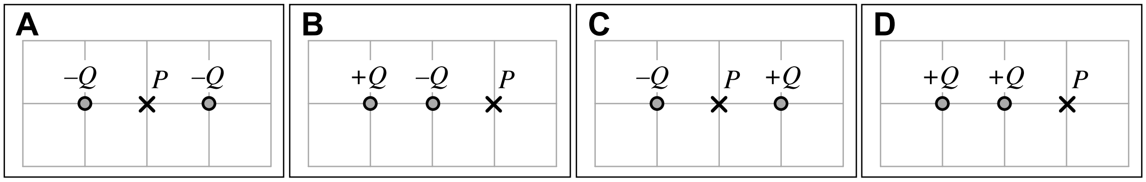
Explain your reasoning.

Answer: A = D > B = E > C.

The farther the point is from the charge the lower the potential.

D1-RT58: Two Electric Charges—Electric Potential

In each figure, two charges are fixed in place on a grid, and a point near those particles is labeled *P*. All of the charges are the same size, *Q*, but they can be either positive or negative.



Rank the strength (magnitude) of the electric potential at point *P*.

				OR			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

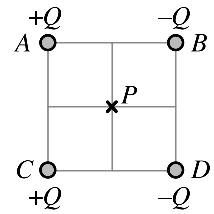
Explain your reasoning.

Answer: D > C > B > A.

The potential in case D is positive since it is due to two positive charges. In case C it is zero because the two charges have opposite signs, but the same magnitude and are the same distance from P. In case B it is negative because the negative charge is closer to P than the positive charge is, and in case A the potential is a larger negative number because it is due to two negative charges.

D1-LMCT59: Four Charges in Two Dimensions—Field and Potential

Four identical point charges are fixed at the same distance from point *P*. The charges are either +*Q* or –*Q*.



Each action described is made to the situation shown in the diagram (*i.e.*, "Change sign of charge *D*" means that charges *A, C,* and *D* will be positive and charge *B* will be negative).

For each modification:

- **Indicate whether the magnitude of the electric field at the origin (i) *increases*, (ii) *decreases*, or (iii) *remains the same*.**
- **Indicate whether the electric potential at the origin (i) *increases*, (ii) *decreases*, or (iii) *remains the same.*** (Use the convention that the electric potential is zero far from the charges.)
- **Indicate the direction of the electric field at the origin after the modification.**

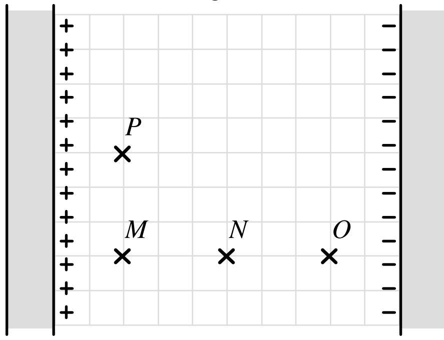
	Modification	Electric field	Electric potential	Electric field direction
1.	Change the sign of charge *A*.	***Decrease***	***Decrease***	↗
2.	Change the sign of charge *B*.	***Decrease***	***Increase***	↘
3.	Change the sign of charge *C*.	***Decrease***	***Decrease***	↘
4.	Change the sign of charge *D*.	***Decrease***	***Increase***	↗
5.	Change the signs of charges *B* and *D*.	***Decrease***	***Increase***	***None:*** $\vec{E} = 0$
6.	Exchange charges *A* and *B*.	***Decrease***	***Same***	***None:*** $\vec{E} = 0$
7.	Exchange charges *A* and *D*.	***Same***	***Same***	↑

Explain your reasoning.

In the original situation the field is the maximum unless we change the magnitudes of the charges, so changing the signs of one charge, or A and B both will result in a decrease in the Field. In the initial situation the potential is zero, so making negative charges positive will increase the potential and making positive charges negative will decrease it. The field direction is found from the vector sum of the four field components.

D1-RT60: UNIFORM ELECTRIC FIELD—POTENTIAL DIFFERENCE

Two parallel plates that have been charged create a uniform electric field of 30 N/C between the plates.



	From	To
A	M	N
B	N	O
C	P	M
D	P	N
E	P	O
F	N	M

Rank the electrical potential differences of all the different combinations listed between the four points *M* at (2, 0) m; *N* at (5, 0) m; *O* at (8, 0) m; and *P* at (2, 3) m within this region. (Positive values are larger than negative values.)

						OR			
1 Greatest	2	3	4	5	6 Least		All the same	All zero	Cannot determine

Explain your reasoning.

Answer: F > C > A = B = D > E.

The potential difference depends on the horizontal distances only and is positive when the final position is closer to the positive plate.