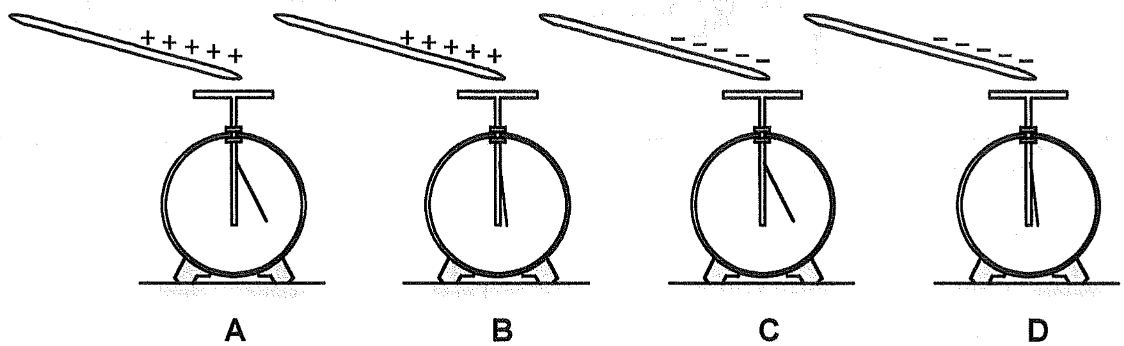
D1 ELECTROSTATICS

D1-RT01: ELECTROSCOPE NEAR A CHARGED ROD—ELECTROSCOPE NET CHARGE

A charged rod is brought close to an electroscope that is initially uncharged. In Cases A and B, the rod is positively charged; in Cases C and D, the rod is negatively charged. In Cases A and C, the leaf of the electroscope is deflected the same amount, which is more than it is deflected in Cases B and D.



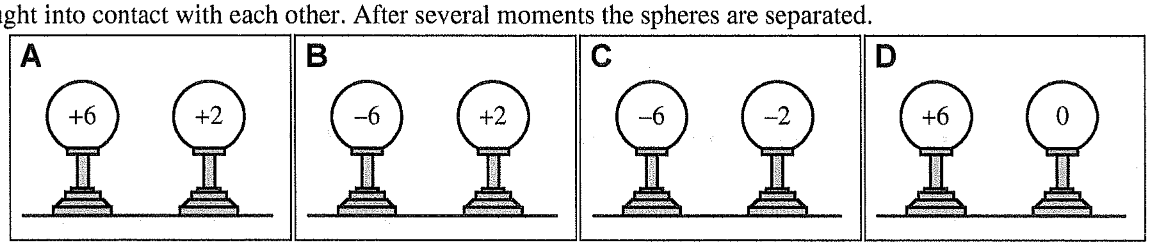
Rank the net charge on the electroscope while the charged rod is near. (The net charge will be a negative value if there is more negative than positive charge on the electroscope.)

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

Explain your reasoning.

D1-RT02: TRANSFER OF CHARGE IN CONDUCTORS—CHARGE ON LEFT CONDUCTOR

Two identical conducting spheres are shown with an initial given number of units of charge. The two spheres are brought into contact with each other. After several moments the spheres are separated.



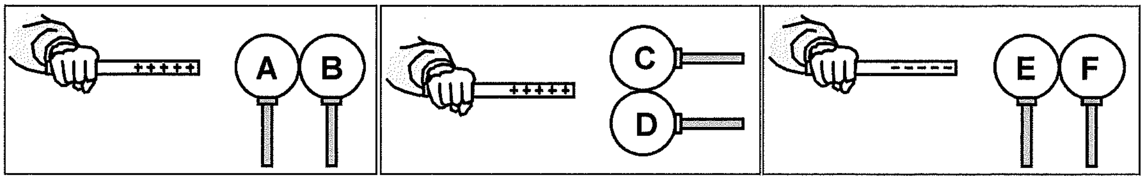
Rank the charge on the left sphere from the highest positive charge to the lowest negative charge after they have been separated. (Note that −6 is lower than −2).

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

Explain your reasoning.

D1-RT03: Induced Charges near a Charged Rod—Net Charge

A charged rod is moved to the same distance from a pair of uncharged metal spheres as shown. The spheres in each pair are initially in contact, but they are then separated while the rod is still in place. Then the rod is removed.



Rank the net charge on each sphere from most positive to most negative after the spheres have been separated and the charged rod removed.

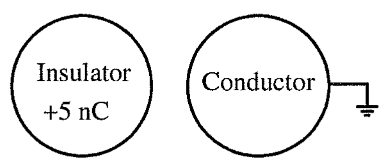
						OR	☐	☐	☐
1 Greatest	2	3	4	5	6 Least		All the same	All zero	Cannot determine

Explain your reasoning.

D1-WWT04: Charged Insulator and a Grounded Conductor—Induced Charge

A charged insulating sphere and a grounded conducting sphere are initially far apart. The charged insulator is then moved near the grounded conductor as shown. A student makes the following statement:

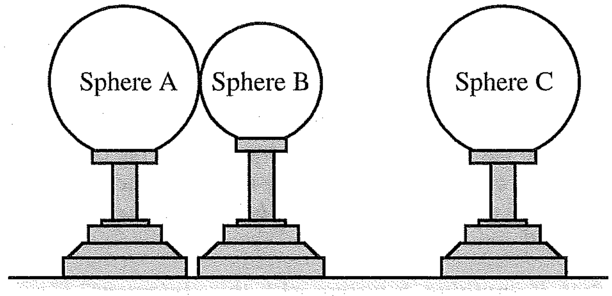
"When the charged insulator is brought close to the grounded conductor, it will cause the negative charges in the conductor to move to the side closest to the insulator. If the charged insulator is taken away, the conductor will be left with a negative charge evenly distributed over its surface."



What, if anything, is wrong with this statement? If something is wrong, explain the error and how to correct it. If the statement is valid, explain why.

D1-QRT05: THREE CONDUCTING SPHERES—CHARGE

Two conducting spheres rest on insulating stands. Sphere B is smaller than Sphere A. Both spheres are initially uncharged and they are touching. A third conducting sphere, C, has a positive charge. It is brought close to (but not touching) Sphere B as shown.



(a) Is the net charge on Sphere A at this time (i) *positive*, (ii) *negative*, or (iii) *zero*? _____

Explain your reasoning.

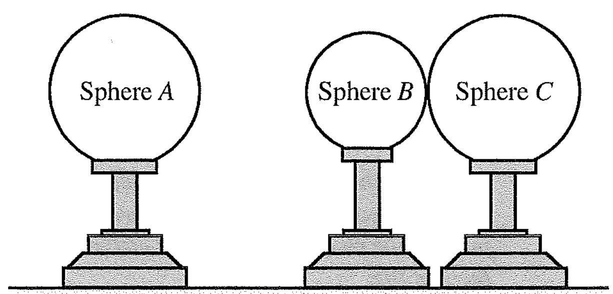
(b) Is the net charge on Sphere B at this time (i) *positive*, (ii) *negative*, or (iii) *zero*? _____

Explain your reasoning.

(c) Is the magnitude of the net charge on Sphere A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the net charge on Sphere B? _____

Explain your reasoning.

Sphere B is now moved to the right so that it touches Sphere C. As a result of this move:



(d) Does the magnitude of the net charge on Sphere A (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

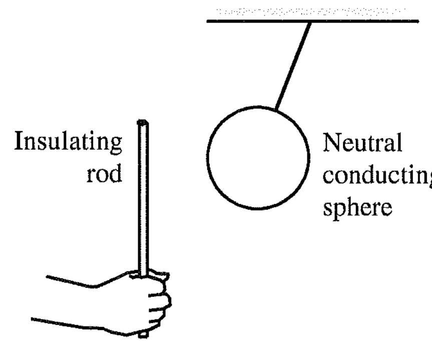
Explain your reasoning.

(e) Does the magnitude of the net charge on Sphere C (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

Explain your reasoning.

D1-WWT06: Uncharged Metal Sphere near a Charged Rod—Charge Distribution

A student observes a demonstration involving an interaction between a neutral metallic sphere suspended from a string and a negatively charged insulating rod. The student makes the following statement:

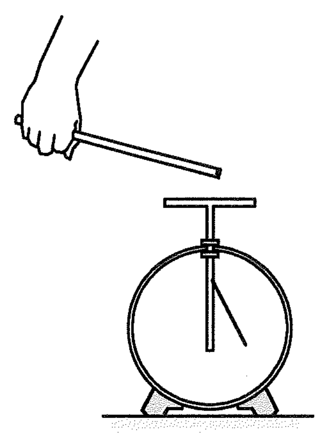


"As the negatively charged rod nears the sphere, it causes the electrons in the sphere to move away from the rod. The side of the sphere nearest to the rod becomes positively charged while the other side becomes negatively charged. So the sphere will be attracted toward the rod. If they touch, the sphere will swing back since they will both become neutral."

What, if anything, is wrong with this statement? If something is wrong, explain the error and how to correct it. If the statement is valid, explain why.

D1-SCT07: Charged Rod and Electroscope—Deflection

A positively charged rod is brought near an electroscope. Even though the rod does not touch the electroscope, the leaf of the electroscope deflects. Below, three students discuss this demonstration.



Amadeo: *"There are positive charges that jump from the rod to the plate of the electroscope. Since the electroscope is now charged, the leaf moves out."*

Barun: *"Charges don't have to move from the rod to the plate to deflect. When the rod comes close, electrons in the electroscope move toward the plate. This leaves the bottom of the electroscope positively charged, and the leaf lifts."*

Carmen: *"Positive charges are fixed in place. When the rod is brought close to the electroscope plate, the electrons in the plate are attracted and jump to the rod. This leaves the electroscope positively charged, and the leaf lifts."*

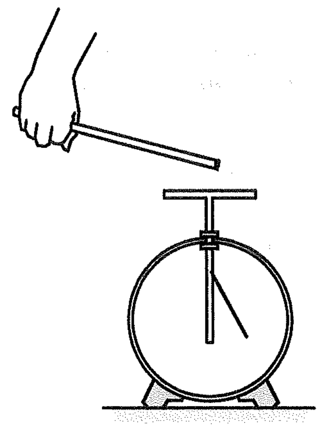
With which of these students do you agree?

Amadeo _____ Barun _____ Carmen _____ None of them _____

Explain your reasoning.

D1-QRT08: CHARGED ROD NEAR ELECTROSCOPE—CHARGE

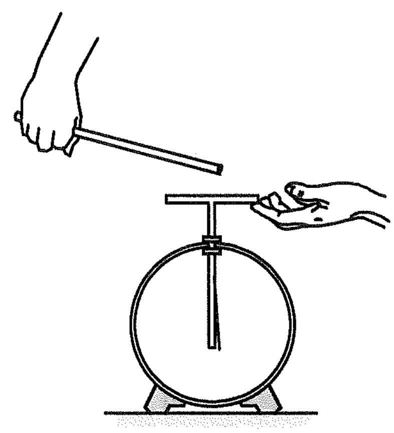
A student first holds a positively charged rod near the top plate of an electroscope without touching it. The electroscope foil deflects. The electroscope was initially uncharged.



(a) Is the electroscope now (i) *positively charged*, (ii) *negatively charged*, or (iii) *neutral*. _____

Explain your reasoning.

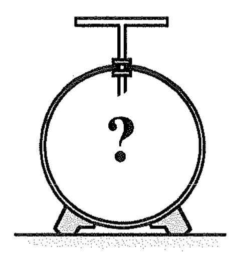
She then touches the electroscope plate while keeping the positively charged rod near the plate. The electroscope foil falls back to its undeflected position.



(b) Is the electroscope (i) *positively charged*, (ii) *negatively charged*, or (iii) *neutral*. _____

Explain your reasoning.

While holding the positively charged rod stationary, she removes her hand which is touching the electroscope. Finally, she removes the charged rod.



(c) Is the electroscope (i) *positively charged*, (ii) *negatively charged*, or (iii) *uncharged*. _____

Explain your reasoning.

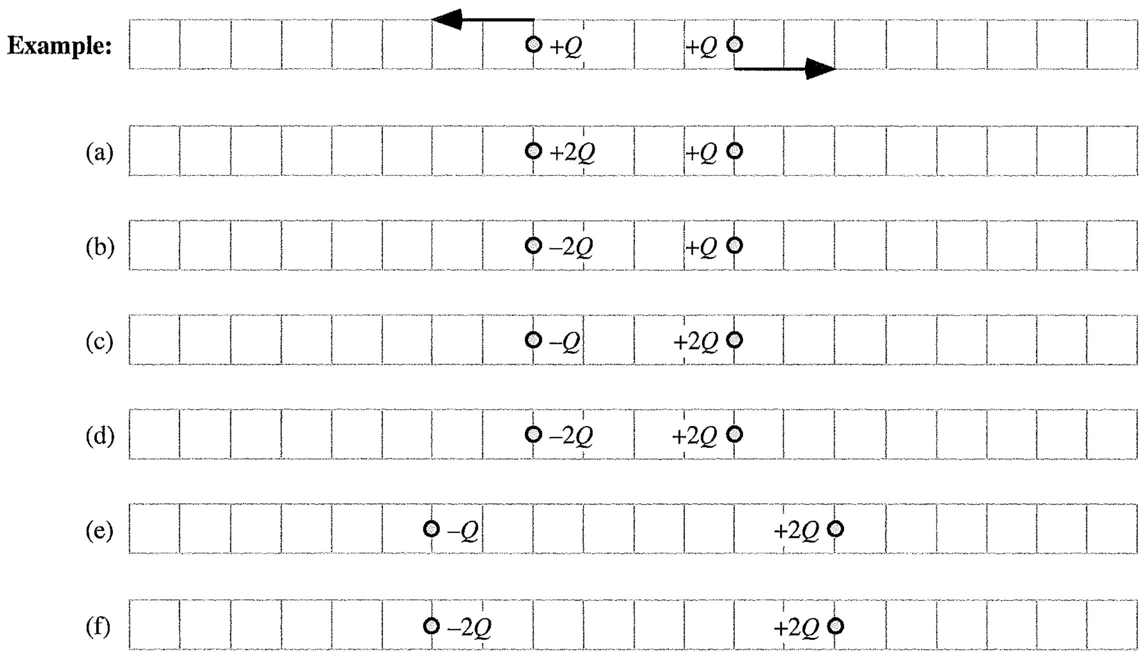
(d) Will the electroscope foil be (i) *deflected* or (ii) *undeflected*? _____

Explain your reasoning.

D1-QRT09: Two Charges—Force on Each

In each case shown below, two charges are fixed in place and are exerting forces on each other.

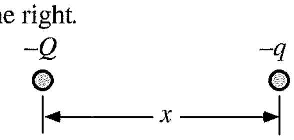
For each case, draw a vector of appropriate length and direction representing the electric force acting on each charge due to the other charge. Draw the vector representing the force *with the length proportional to the magnitude* on the left charge a*bove* that charge; and draw the vector representing the force *with the length proportional to the magnitude* on the right charge below that charge (see the example). For each diagram, use the same scale as the example.



Explain your reasoning.

D1-WWT10: Two Negative Charges—Force

Two negatively charged particles are separated by a distance x. The particle on the left has a charge $-Q$ which is three times the charge $-q$ of the particle on the right.



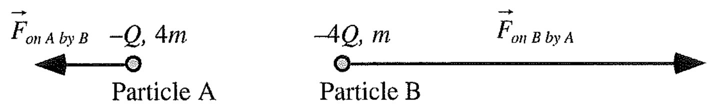
A student makes the following statement:

"Since $F = kQq/x^2$ and Q and q are both negative, the force on Q will be positive. Therefore, the force on Q points to the right."

What, if anything, is wrong with this statement? If something is wrong, explain the error and how to correct it. If the statement is valid, explain why.

D1-WWT11: TWO NEGATIVELY CHARGED PARTICLES—FORCE

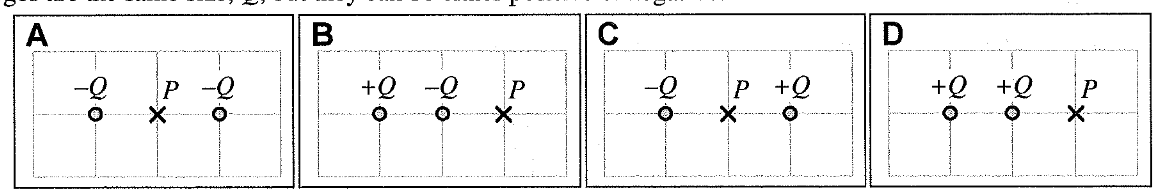
A student's diagram for the electric forces acting on two negatively charged ($-Q$ and $-4Q$) particles is shown. Particle A has four times the mass of particle B.



What, if anything, is wrong with this diagram? If something is wrong, explain the error and how to correct it. If the diagram is valid, explain why.

D1-RT12: TWO ELECTRIC CHARGES—ELECTRIC FORCE

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.



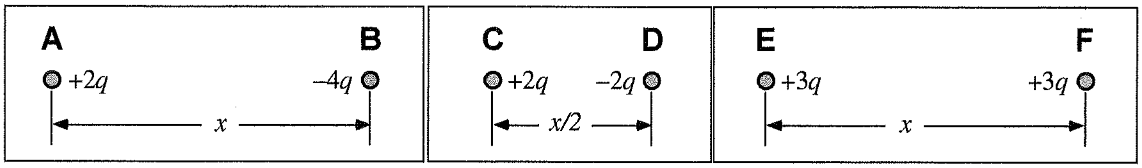
Rank the strength (magnitude) of the electric force on a charge $+q$ that is placed at point *P*.

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

Explain your reasoning.

D1-RT13: Pairs of Point Charges—Attractive and Repulsive Force

The following diagrams show three separate pairs of point charges.



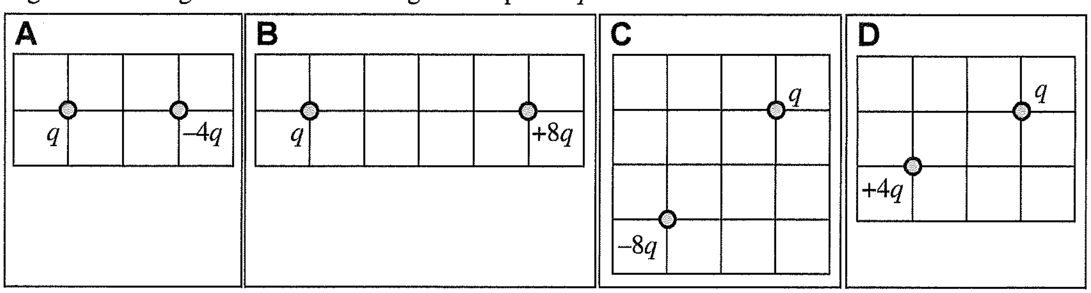
Rank the force on each point charge from most attractive to most repulsive.

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

Explain your reasoning.

D1-RT14: Two Charged Particles—Force

In each case, small charged particles are fixed on grids having the same spacing. Each charge q is identical, and all other charges have a magnitude that is an integer multiple of q.



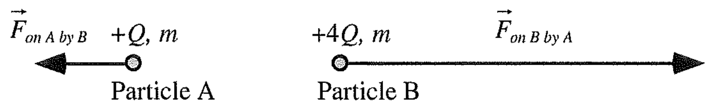
Rank the magnitude of the electric force on the charge labeled q due to the other charge.

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

Explain your reasoning.

D1-TT15: TWO CHARGED PARTICLES—FORCE

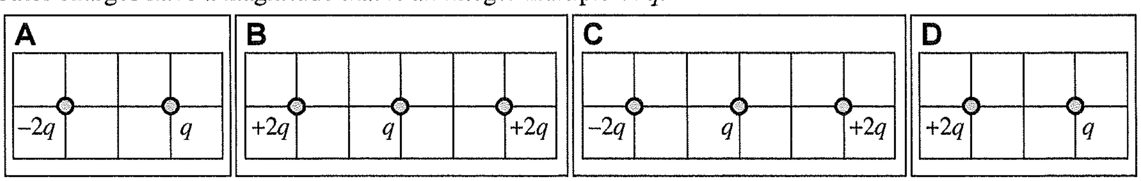
Shown below is a student's drawing of the electric forces acting on Particle A (with charge $+Q$ and mass m) and Particle B (with charge $+4Q$ and mass m).



There is something wrong with this diagram. Explain what is wrong and how to correct it.

D1-RT16: TWO AND THREE CHARGES IN A LINE—FORCE

In each case, small charged particles are fixed on grids having the same spacing. Each charge q is identical, and all other charges have a magnitude that is an integer multiple of q.



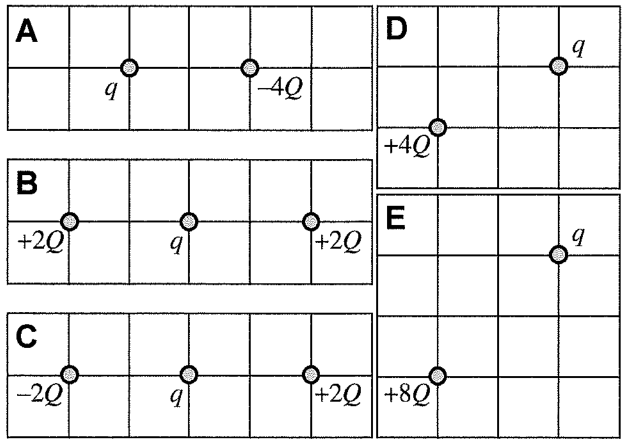
Rank the magnitude of the electric force on the charge labeled q due to the other charges.

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

Explain your reasoning.

D1-RT17: Charged Particles in a Plane—Force

In each case, small charged particles are fixed on grids having the same spacing. Each charge q is identical, and all other charges have a magnitude that is an integer multiple of Q.



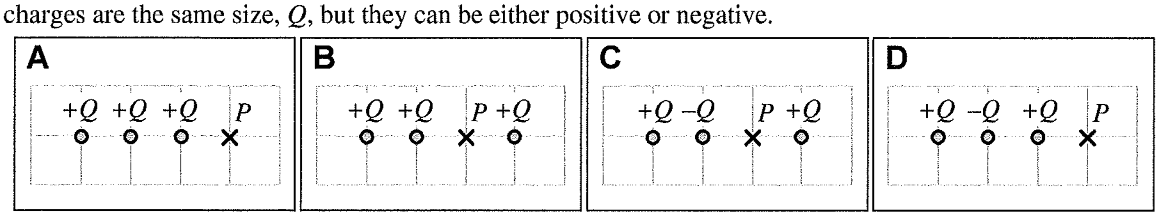
Rank the magnitude of the net electric force on the charge labeled *q* due to the other charges.

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

Explain your reasoning.

D1-RT18: Three Linear Electric Charges—Electric Force

In each figure, three 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 net electric force on a charge $+q$ that is placed at point P.

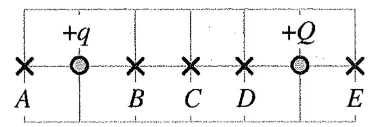
1 Greatest	2	3	4 Least	OR	All the same	All zero	Cannot determine

Explain your reasoning.

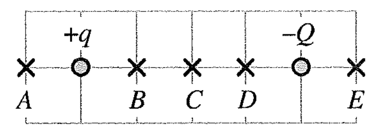
D1-QRT19: TWO UNEQUAL CHARGES—FORCE

Shown below are two charged particles that are fixed in place. The magnitude of the charge Q is greater than the magnitude of the charge q. A third charge is now placed at one of the points A–E. The net force on this charge due to q and Q is zero.

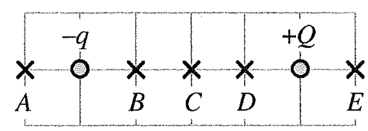
(a) Both q and Q are positive.
At which point A–E is it possible that the third charge was placed? _____
Explain your reasoning.



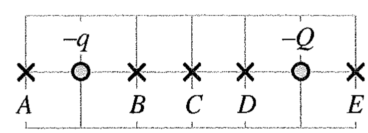
(b) Charge q is positive and charge Q is negative.
At which point A–E is it possible that the third charge was placed? _____
Explain your reasoning.



(c) Charge q is negative and charge Q is positive.
At which point A–E is it possible that the third charge was placed? _____
Explain your reasoning.



(d) Both q and Q are negative.
At which point A–E is it possible that the third charge was placed? _____
Explain your reasoning.



D1-QRT20: Three Charges in a Line I—Force

Three charged particles, *A*, *B*, and *C*, are fixed in place in a line. Charge *C* is twice as far from charge *B* as charge *A* is. All charges are the same magnitude.

In the chart to the left below, use arrows (← or →) to indicate the direction of the net force on charge *C* due to charges *A* and *B*. If the force is zero, state that explicitly.

In the chart on the right below, use arrows (← or →) to indicate the direction of the net force on charge *B* due to charges *A* and *C*. If the force is zero, state that explicitly.

A	*B*	*C*	$\Sigma\vec{F}$ on charge *C*
O +	O +	O +	Direction:
O +	O +	O −	Direction:
O +	O −	O +	Direction:
O +	O −	O −	Direction:
O −	O +	O +	Direction:
O −	O +	O −	Direction:
O −	O −	O +	Direction:
O −	O −	O −	Direction:

A	*B*	*C*	$\Sigma\vec{F}$ on charge *B*
O +	O +	O +	Direction:
O +	O +	O −	Direction:
O +	O −	O +	Direction:
O +	O −	O −	Direction:
O −	O +	O +	Direction:
O −	O +	O −	Direction:
O −	O −	O +	Direction:
O −	O −	O −	Direction:

Explain your reasoning.

D1-QRT21: THREE CHARGES IN A LINE II—FORCE

Three charged particles, A, B, and C, are fixed in place in a line. Charge C is twice as far from charge B as charge A is. All charges have different magnitudes.

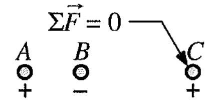
For each of the following combinations of charge signs, determine whether it is possible for the net electric force on each charge due to the other two charges to be zero.

A	B	C	$\Sigma\vec{F}$ on charge A	$\Sigma\vec{F}$ on charge B	$\Sigma\vec{F}$ on charge C
+	+	+	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐
+	+	−	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐
+	−	+	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐
+	−	−	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐
−	+	+	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐
−	+	−	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐
−	−	+	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐
−	−	−	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☐

Explain your reasoning.

D1-QRT22: Three Charges in a Line III—Force

Three charged particles are fixed in place in a line. Charge C is twice as far from charge B as charge A is. It is known that there is no net force on charge C due to charges A and B.

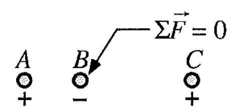


Indicate whether each of the following statements is *true*, *false*, or *cannot be determined.*

	Statement	True	False	Cannot be determined
(a)	Charge A has a greater magnitude than charge C.			
(b)	Charge A has a greater magnitude than charge B.			
(c)	Charge C has a greater magnitude than charge B.			
(d)	Charge A has the same magnitude as charge C.			
(e)	Charge A has the same magnitude as charge B.			
(f)	Charge C has the same magnitude as charge B.			

Explain your reasoning.

Three charged particles, A, B, and C, are fixed in place in a line. Charge C is twice as far from charge B as charge A is. It is known that there is no net force on charge B due to charges A and C.



Indicate whether each of the following statements is *true*, *false*, or *cannot be determined.*

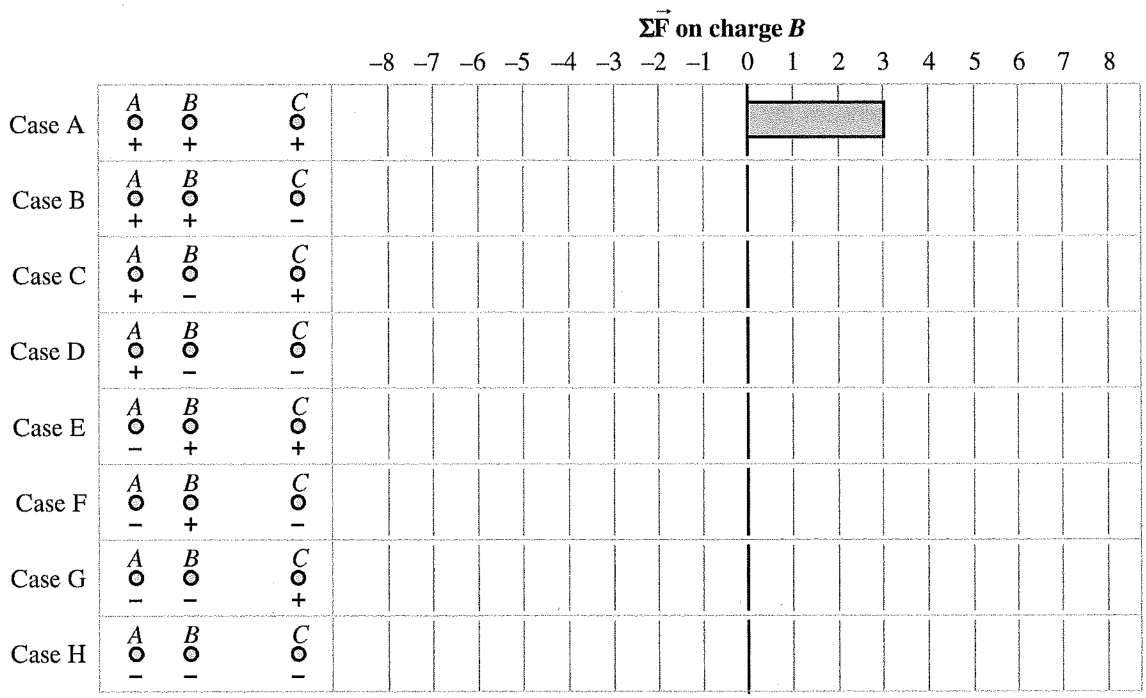
	Statement	True	False	Cannot be determined
(g)	Charge A has a greater magnitude than charge C.			
(h)	Charge A has a greater magnitude than charge B.			
(i)	Charge C has a greater magnitude than charge B.			
(j)	Charge A has the same magnitude as charge C.			
(k)	Charge A has the same magnitude as charge B.			
(l)	Charge C has the same magnitude as charge B.			

Explain your reasoning.

D1-BCT23: THREE CHARGES IN A LINE IV—FORCE

Three charged particles, *A*, *B*, and *C*, are fixed in place in a line. Charge *C* is twice as far from charge *B* as charge *A* is. All charges have the same magnitude.

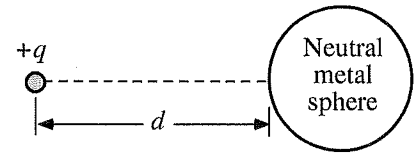
Construct a bar chart for the net force on charge *B* due to charges *A* and C. Use positive values for net forces directed to the right and negative values for net forces directed to the left. If the force is zero, state that explicitly.



Explain your reasoning.

D1-TT24: Neutral Metal Sphere near a Positive Point Charge—Force

A positive point charge is placed a distance d away from a neutral solid metal sphere.



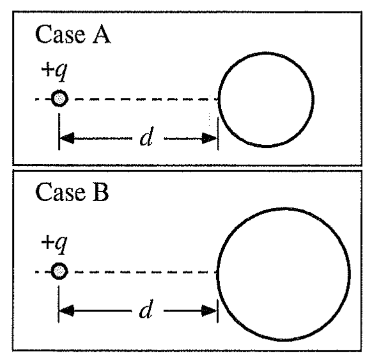
A student makes the following statement about the electric force between the neutral metal sphere and the point charge:

"There is an attraction between the point charge and the sphere. Since the sphere is a conductor, the external positive point charge pulls electrons in the sphere toward it. This leaves positive charges on the other side of the sphere, since the sphere is still neutral. The force between the point charge and the sphere is just the attraction between the negative charges on the left end of the sphere and the point charge."

There is at least one problem with this student's contention. Identify any problem(s) and explain how to correct it/them.

D1-SCT25: Uncharged Metal Sphere near a Positive Point Charge—Force

In each case shown, a point charge $+q$ is a distance d from the closest point of an uncharged metal sphere. The sphere in Case B has a larger diameter than the sphere in case A. Three students are comparing the two cases:



Aaron: *"I don't think there would be any electric forces in either case. Since the sphere has no net charge, there is no attraction or repulsion."*

Bae: *"The forces on the point charges are equal in the two cases. There is an attraction because the point charge will pull the electrons in the sphere toward it. But the distance between the point charge and the electrons is the same in both cases, so the force of attraction is the same."*

Carlota: *"When the electrons are pulled toward the point charge, they leave a pool of positive charges on the other side of the sphere. These positive charges repel the point charge, and this balances the attraction of the electron. The sphere overall is still uncharged, so there is as much positive charge as negative charge, and there is no net force between the objects."*

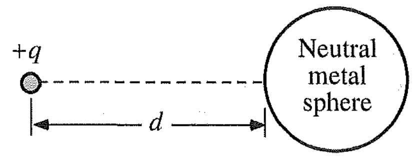
With which of these students do you agree?

Aaron _____ Bae _____ Carlota _____ None of them _____

Explain your reasoning.

D1-WWT26: NEUTRAL METAL SPHERE NEAR A POSITIVE POINT CHARGE—FORCE

A positive point charge is placed a distance *d* away from a neutral metal sphere.



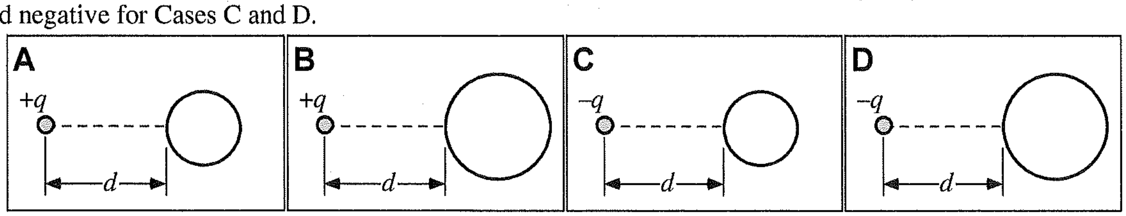
A student makes the following statement:

"The electric force is zero. Coulomb's law states that the electric force between two objects is proportional to the product of the charges. Since the charge of the sphere is zero, and zero times anything gives zero, the force between the point charge and the sphere is zero."

What, if anything, is wrong with this statement? If something is wrong, explain the error and how to correct it. If the statement is valid, explain why.

D1-RT27: NEUTRAL METAL SPHERE NEAR A POINT CHARGE—FORCE

A point charge is placed a distance *d* away from a neutral metal sphere. The diameters of the spheres in Cases A and C are the same and smaller than the equal diameters in Cases B and D. The point charge is positive for Cases A and B, and negative for Cases C and D.



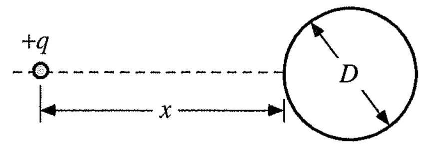
Rank the magnitude of the force exerted on the point charge by the sphere.

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

Explain your reasoning.

D1-LMCT28: NEUTRAL METAL SPHERE NEAR A POSITIVE POINT CHARGE—FORCE

A positive point charge is placed a distance x away from the closest surface of a neutral metal sphere that has a diameter D.



(a) For each change listed, state whether the magnitude of the force exerted on the point charge by the sphere *increases*, *decreases*, or *remains the same*. (Assume that all of the other given variables remain the same for each change given.)

		Effect on the force exerted on the particle			
	Change	*No force*	*Increases*	*Decreases*	*Remains the Same*
(a)	Increase the distance x.				
(b)	Increase D, keeping the charge a distance x away.				
(c)	Increase the charge of the particle.				
(d)	Make the charge of the particle $-q$.				
(e)	Add negative charge to the sphere.				

Explain your reasoning.

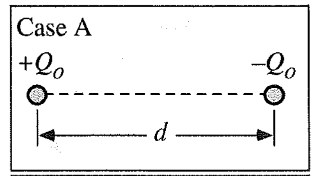
(b) For each change listed, state whether the magnitude of the force exerted on the sphere by the point charge *increases*, *decreases*, or *remains the same*. (Assume that all of the other given variables remain the same for each change given.)

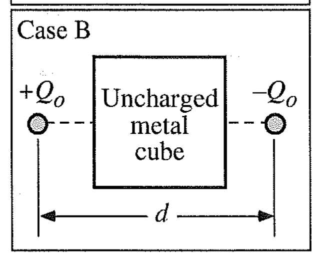
		Effect on the force exerted on the sphere			
	Change	*No force*	*Increases*	*Decreases*	*Remains the Same*
(f)	Increase the distance x.				
(g)	Increase D, keeping the charge a distance x away.				
(h)	Increase the charge of the particle.				
(i)	Make the charge of the particle $-q$.				
(j)	Add negative charge to the sphere.				

Explain your reasoning.

D1-CT29: CONDUCTING CUBE BETWEEN POINT CHARGES—NET FORCE

In both cases, two particles with 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 particles.



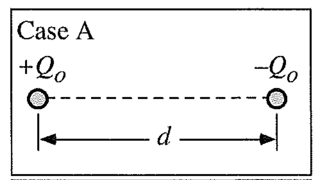


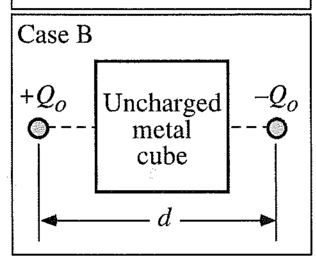
Is the net electric force on the positively charged particle (i) *greater in* Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

Explain your reasoning.

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.

(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.

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? _____

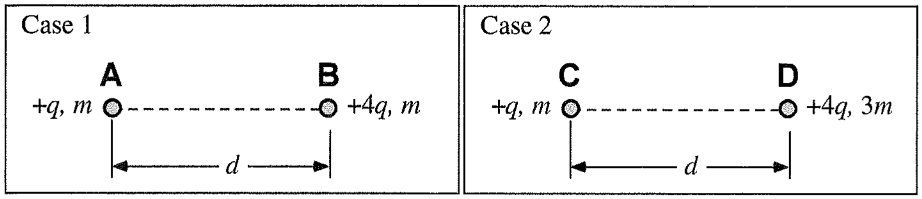
Explain your reasoning.

(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.

D1-RT31: Two Charged Particles—Acceleration

In each case shown, a particle of charge $+q$ is placed a distance d from a particle of charge $+4q$. The particles are then released simultaneously. The masses of the particles are indicated in the diagram.



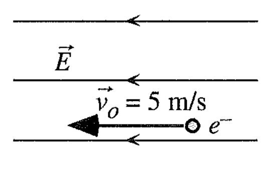
Rank the magnitude of the acceleration of each particle just after it is released.

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

Explain your reasoning.

D1-WWT32: Electron in a Uniform Electric Field—Velocity

An electron is placed in a uniform electric field with an initial velocity of 5 m/s as shown. A student makes the following statement:

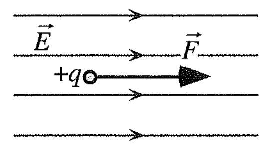


"The electron will continue to move in the same direction at a constant velocity because it is moving in the same direction as the electric force on it; since the electric field is constant, the force on the electron is constant."

What, if anything, is wrong with this statement? If something is wrong, explain the error and how to correct it. If the statement is valid, explain why.

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.

(b) The sign of the charge q on the particle is changed to the opposite sign. _____
Explain your reasoning.

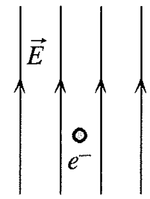
(c) The particle is given a push, causing a leftward initial velocity. _____
Explain your reasoning.

(d) The magnitude of the uniform electric field is halved. _____
Explain your reasoning.

(e) The direction of the uniform electric field is rotated 90° clockwise. _____
Explain your reasoning.

D1-SCT34: ELECTRON IN A UNIFORM ELECTRIC FIELD—ELECTRIC FORCE

Consider the following statements about the motion of an electron placed at rest in a uniform electric field as shown and then released:



Anna: *"Since the electron is negative, it will move downward. Since the field is uniform, it will move at a constant velocity proportional to the strength of the electric field."*

Brooke: *"The electron will accelerate upward because particles move in the direction of the electric field, which points upward."*

Chico: *"The electron will move downward because it is a negative particle. The force acting on it will be opposite the direction of the electric field. It will move with a constant acceleration."*

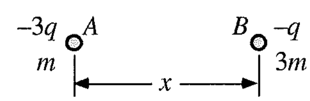
With which of these students do you agree?

Anna _____ Brooke _____ Chico _____ None of them _____

Explain your reasoning.

D1-SCT35: TWO NEGATIVELY CHARGED PARTICLES—ACCELERATION

Two negatively charged particles labeled A and B are separated by a distance x. The particles have different charges and masses as shown.



Three students are discussing what will happen just after the particles are released.

Antonio: *"The magnitude of the force that A exerts on B will be the same as the magnitude of the force that B exerts on A. Since A has less mass, it will have a larger acceleration."*

Brenda: *"The magnitude of the force on A by B is greater than the magnitude of the force on B by A since B has more mass. So A will have the largest acceleration."*

Cho: *"A has more charge but it has less mass. The larger mass of B is exactly compensated for by the larger charge of A. The acceleration of both will be the same."*

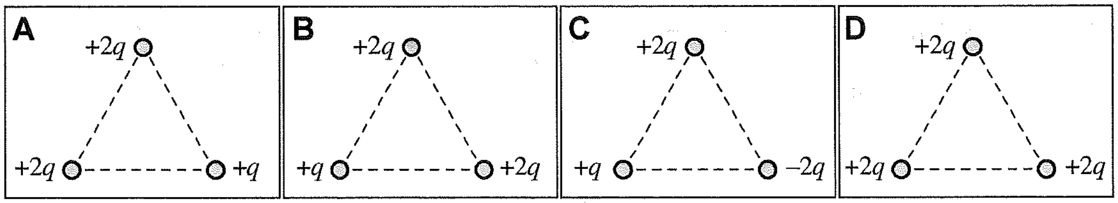
With which of these students do you agree?

Antonio _____ Brenda _____ Cho _____ None of them _____

Explain your reasoning.

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.

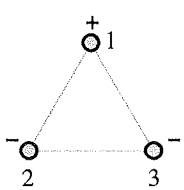
1 Greatest	2	3	4 Least	OR	All the same	All zero	Cannot determine

Explain your reasoning.

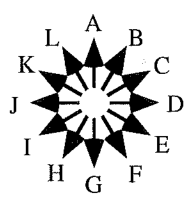
D1-QRT37: FORCE DIRECTION ON THREE CHARGES IN AN EQUILATERAL TRIANGLE—FORCE

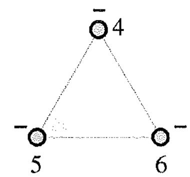
Three charges are fixed at the vertices of each of the equilateral triangles shown below. All charges have the same magnitude. Only charge 1 is positive.

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	
Charge 2	
Charge 3	





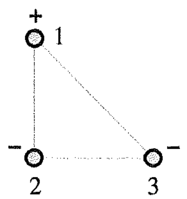
	Net Force Direction
Charge 4	
Charge 5	
Charge 6	

Explain your reasoning.

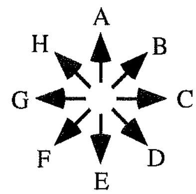
D1-QRT38: Force Direction on Three Charges in a Right Triangle—Force

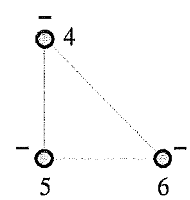
Three charges are fixed at the vertices of each of the right isosceles triangles shown below. All charges have the same magnitude. Only charge 1 is positive.

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 H representing directions from the choices below. If the angle is between two directions, indicate both directions such as AB for a direction between A and B.



	Net Force Direction
Charge 1	
Charge 2	
Charge 3	



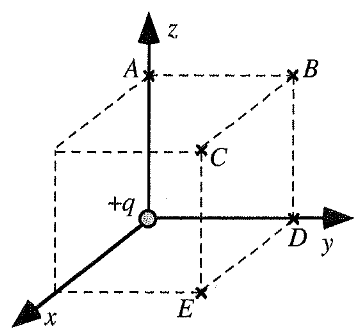


	Net Force Direction
Charge 4	
Charge 5	
Charge 6	

Explain your reasoning.

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

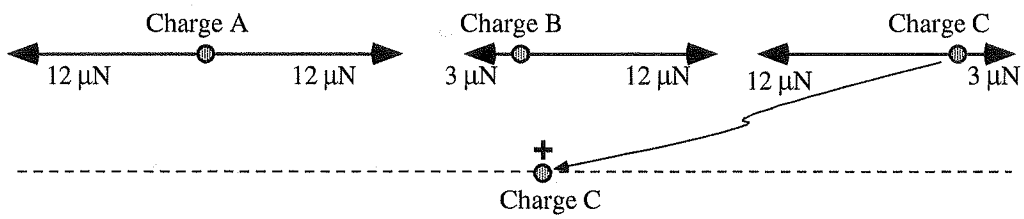
Explain your reasoning.

D1-WBT40: FORCES ON THREE CHARGES ALONG A LINE—CHARGE LOCATION

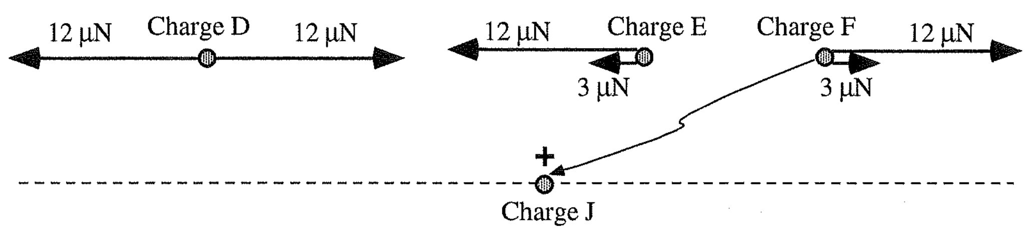
Three charges are fixed in place along a line. All three charges have the same magnitude, but they may have different signs. Shown below are diagrams showing the forces exerted on each charge by the other two charges.

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.**

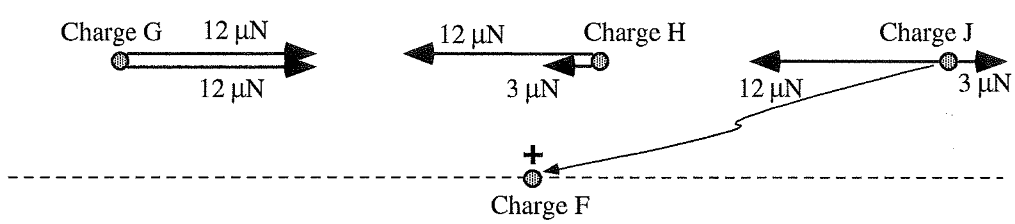
Case 1



Case 2



Case 3

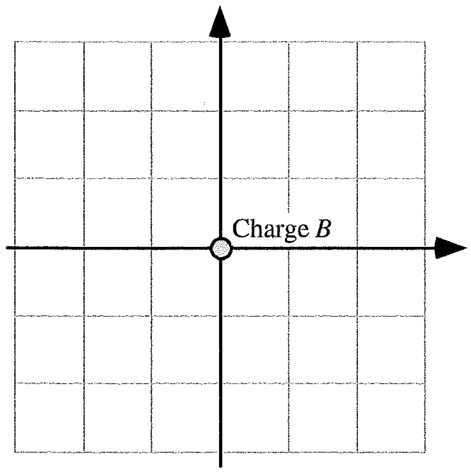


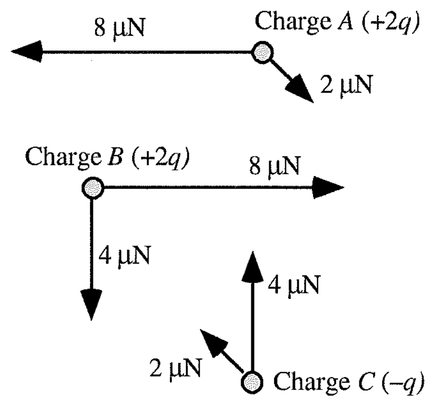
Explain your reasoning.

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 $+2q$, 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*.**

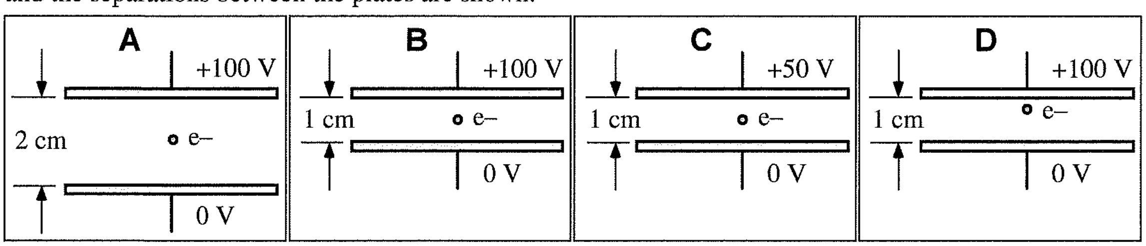




Explain your reasoning.

D1-RT42: Electron Between Two Parallel Charged Plates—Force on the Electron

In each case, an electron is momentarily at rest between two parallel charged plates. The electric potential of each plate and the separations between the plates are shown.



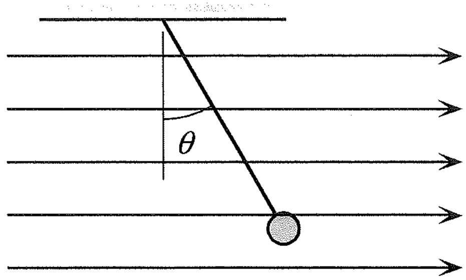
Rank the magnitude of the force exerted on the electron.

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

Explain your reasoning.

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

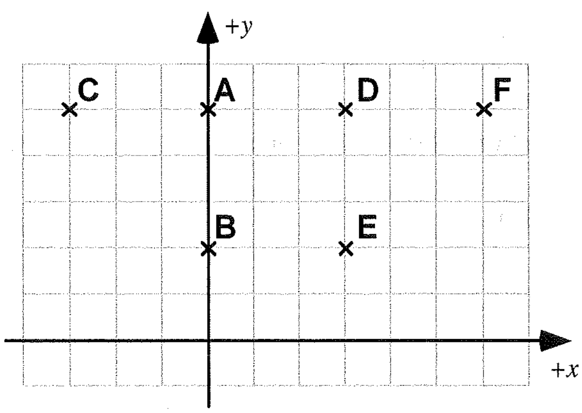
Rank the angle θ that the string forms with the vertical for these different spheres.

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

Explain your reasoning.

D1-RT44: UNIFORM ELECTRIC FIELD—ELECTRIC FORCE ON CHARGE

A large region of space has a uniform electric field in the +*x* direction (⇒). At the point (0,0) m, the electric field magnitude is 30 N/C.



	x	*y*
A	0 m	5 m
B	0 m	2 m
C	-3 m	5 m
D	3 m	5 m
E	3 m	2 m
F	6 m	5 m

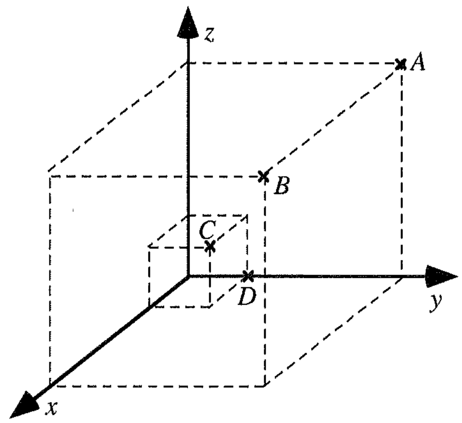
Rank the strength (magnitude) of the electric force on a +5 μC charge when it is placed at rest at each of the labeled points.

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

Explain your reasoning.

D1-RT45: Uniform Electric Field—Electric Force at Three-Dimensional Locations

All the labeled points are within a region of space with a uniform electric field. The electric field points toward the top of the page (that is, in the positive z-direction).



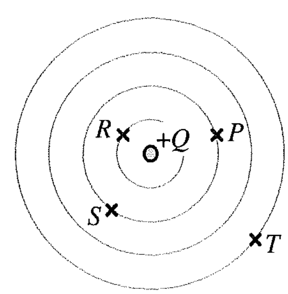
Rank the magnitude of the electric force on a charge of +2 μC at the labeled points.

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

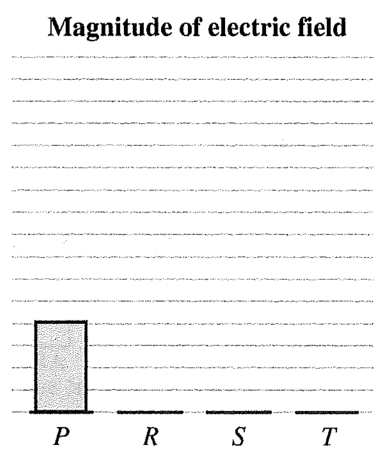
Explain your reasoning.

D1-BCT46: Point Charge—Electric Field

Points P, R, S, and T lie close to a positive point charge. The concentric circles shown are equally spaced with radii of r, $2r$, $3r$, and $4r$. The magnitude of the electric field at point P due to the point charge is shown in the bar chart below.



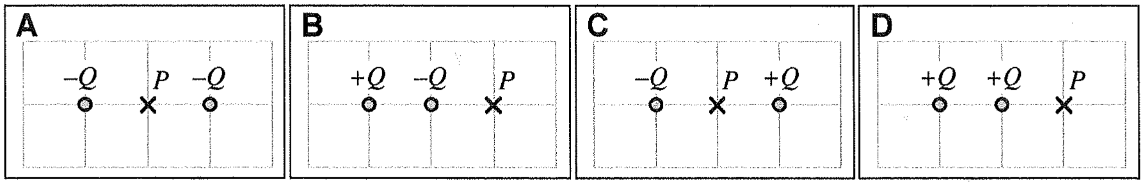
Complete the bar chart to indicate the relative magnitude of the electric field at points *R*, *S*, and *T*.



Explain your reasoning.

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.



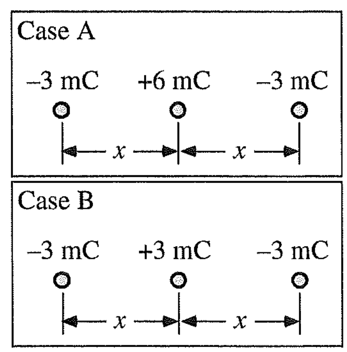
Rank the magnitude of the electric field at point *P*.

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

Explain your reasoning.

D1-SCT48: THREE CHARGES IN A LINE—ELECTRIC FIELD

Shown are two cases where three charges are placed in a row. Three students are comparing the electric field that exerts a force on the middle charge in the diagrams.



Adrianna: *"All three charges contribute by the principle of superposition. So the field is going to be greatest in case A since the contributions due to the three charges will be greatest."*

Brandon: *"I think it's a bogus question. The field at that point is undefined because there is a charge there."*

Catalina: *"I don't think that's right. The field that exerts a force on the middle charge is the field due to the other two charges because a charge cannot feel it own field. Since those other two charges don't change, the field acting on the middle charge is the same in both cases."*

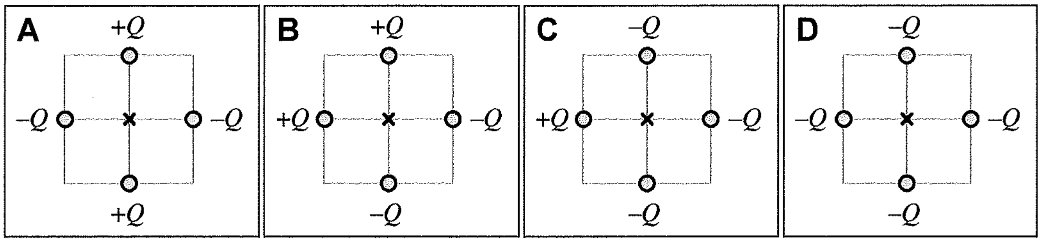
With which of these students do you agree?

Adrianna ______ Brandon _____ Catalina _____ None of them _____

Explain your reasoning.

D1-RT49: Four Point Charges in Two Dimensions—Electric Field

In each case, four charged particles, each with a charge magnitude Q, are fixed on grids. The cases are identical except for the signs of the charges.



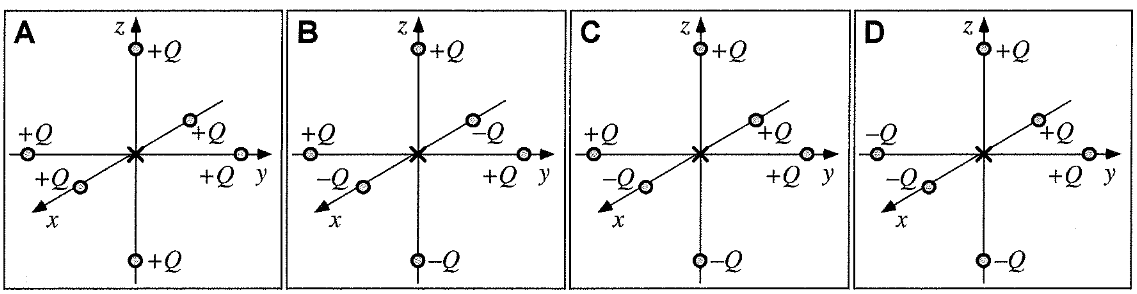
Rank the magnitude of the electric field at the location marked with an "x."

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

Explain your reasoning.

D1-RT50: Six Charges in Three Dimensions—Electric Field

In each case, six point charges are all the same distance from the origin as shown. All charges are either $+Q$ or $-Q$.



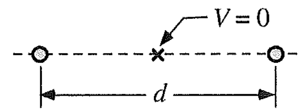
Rank the magnitude of the electric field at the origin.

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

Explain your reasoning.

D1-TT51: POTENTIAL NEAR TWO CHARGES—ELECTRIC FIELD

Two equal magnitude electric charges are separated by a distance d. The electric potential at the midpoint between these two charges is zero. A student considering this situation says:

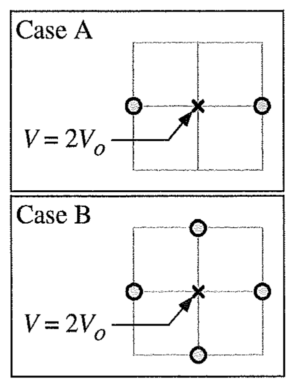


"The electric field at the midpoint between the two charges will be zero also, since the two charges are opposite in sign, so the fields will be equal but opposite, and add to zero."

There is something wrong with the student's statement. **Identify any problem(s) and explain how to correct it/them.**

D1-CT52: POTENTIAL NEAR CHARGES—ELECTRIC FIELD

In each case, a point midway between equal magnitude electric charges is identified. The signs of these charges are not given. The electric potential at this midpoint is $2V_0$ in both cases, where V_0 is the potential due to a single positive charge.

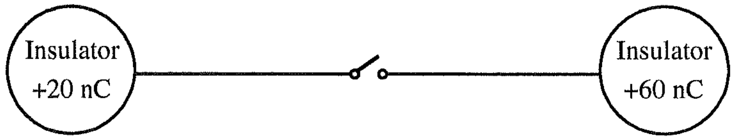


Is the magnitude of the electric field at the midpoint (i) *greater* in Case A, (ii) *greater* in Case B, or (iii) *the same* in both cases? _____

Explain your reasoning.

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."*

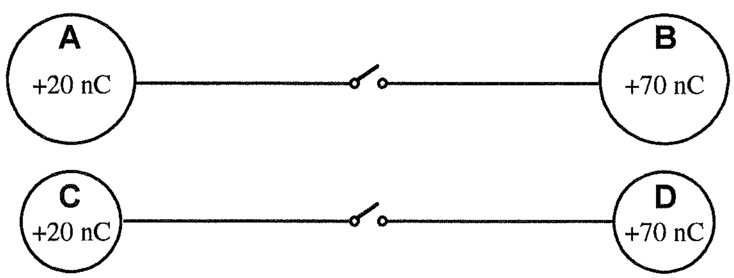
With which of these students do you agree?

Arturo _____ Beth _____ Caitlin _____ None of them _____

Explain your reasoning.

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.



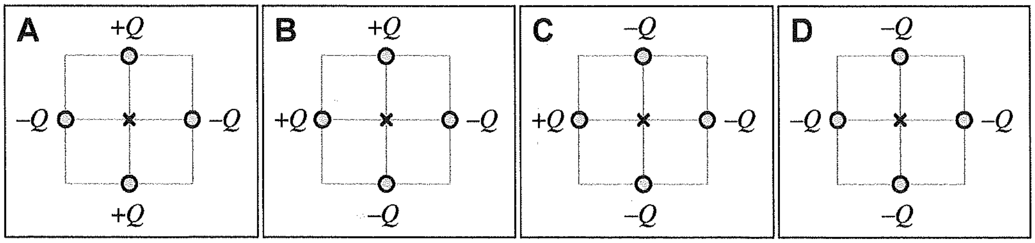
Rank the electric charge on the spheres after the switches are closed.

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

Explain your reasoning.

D1-RT55: FOUR CHARGES IN TWO DIMENSIONS—ELECTRIC POTENTIAL

In each situation shown below, small charged particles are fixed on grids having the same spacing. Each charge Q on this page has the same magnitude with the signs indicated in the diagrams.



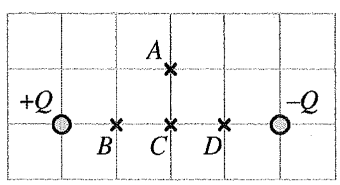
Rank the electric potential at the location marked with an "x."

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

Explain your reasoning.

D1-RT56: POINTS NEAR A PAIR OF EQUAL OPPOSITE CHARGES—ELECTRIC POTENTIAL

Two equal and opposite charges are fixed to a grid at the locations shown. Four points in the vicinity of these charges are labeled *A–D*.



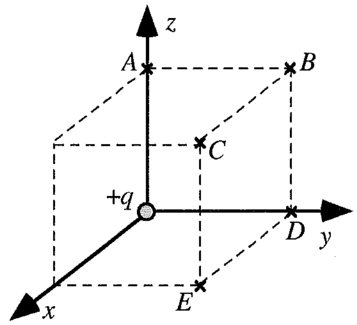
Rank the electric potential at the labeled points.

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

Explain your reasoning.

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.



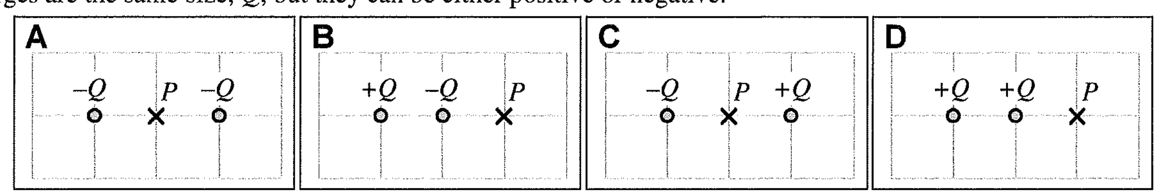
Rank the electric potential at the labeled points.

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

Explain your reasoning.

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.



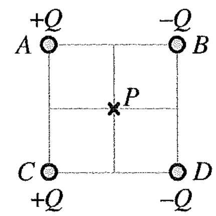
Rank the strength (magnitude) of the electric potential at point P.

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

Explain your reasoning.

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:

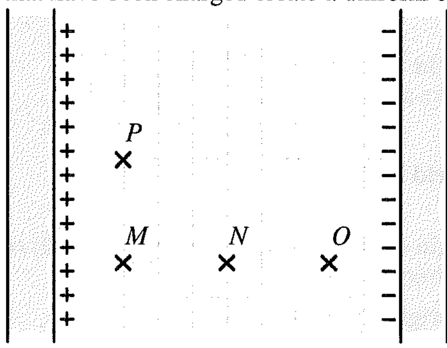
- **Indicate whether the magnitude of the electric field at the origin (i) *increases*, (ii) *decreases*, or (iii) *remains the same.***
- **Indicate whether the electric potential at the origin (i) *increases*, (ii) *decreases*, or (iii) *remains the same.*** (Use the convention that the electric potential 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
(a)	Change the sign of charge A.			
(b)	Change the sign of charge B.			
(c)	Change the sign of charge C.			
(d)	Change the sign of charge D.			
(e)	Change the signs of charges B and D.			
(f)	Exchange charges A and B.			
(g)	Exchange charges A and D.			

Explain your reasoning.

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.)

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

Explain your reasoning.