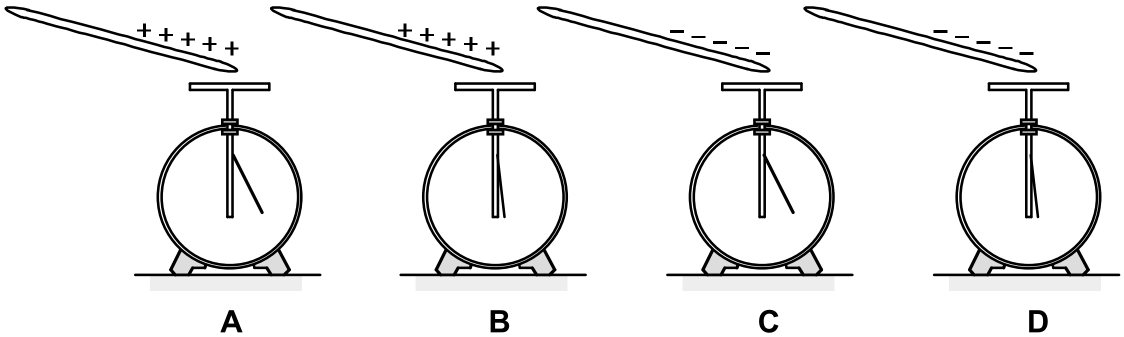
D1 ELECTROSTATICS

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

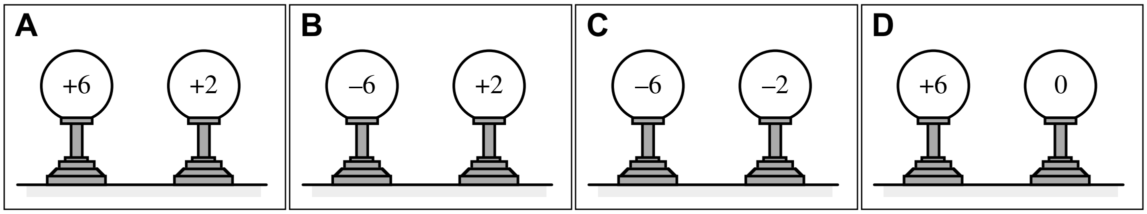
Explain your reasoning.

Answer: All zero.

The net charge on the electroscope, assuming the rod does not touch it, is zero in all four cases since no charge is transferred.

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

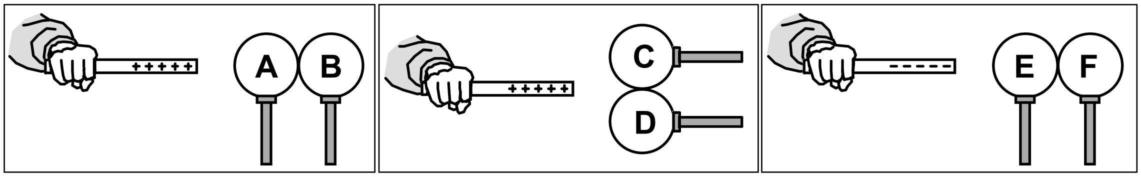
Explain your reasoning.

Answer: A > D > B > C.

When the two spheres are brought together the charges will redistribute equally between the two spheres since the spheres are conductors and they are the same size. When each pair of spheres is separated each of the two spheres will have half of the total charge, so the ranking goes from highest positive charge total to most negative charge total.

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

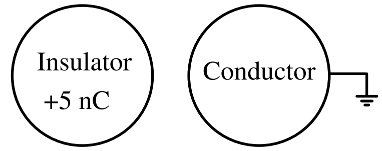
Explain your reasoning.

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

While the spheres are in contact the charges will move away from the charged rod. Since the spheres are going to be separated while the rod is in place, spheres A, B, E, and F will acquire net charges. The magnitudes of the charges on the four spheres will be the same with spheres B and E being positively charged while A and F will be negative. Spheres C and D do not have a net charge because of the symmetry of the situation.

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:



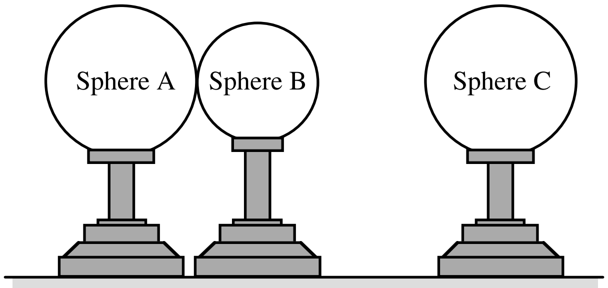
"When the charged insulator is brought close to the grounded conductor, it will cause the negative charges in the conductor to move to the side closest to the insulator. If the charged insulator is taken away, the conductor will be left with a negative charge evenly distributed over its surface."

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.

Answer: The net charge on the conductor will be zero when the insulator is taken away since any charge that is induced to move onto the conductor while the insulator is nearby will be free to leave the conductor as the insulator moves away.

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.

Answer: (i) positive.

C induces a negative charge on B, that is electrons will move from sphere A to sphere B to be closer to the positive charge on C, which induces a positive charge on A since it now has an electron deficiency.

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

Explain your reasoning.

Answer: (ii) negative.

The Sphere C induces negative charge on B because electrons will move to be closer to C.

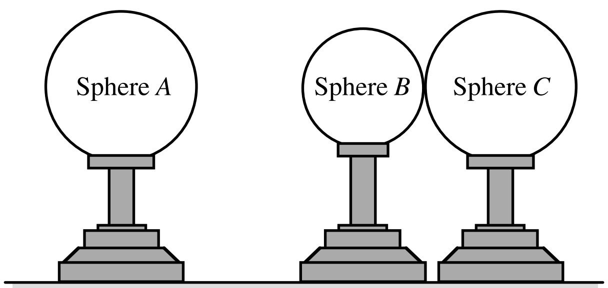
(c) Is the magnitude of the net charge on Sphere A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the net charge on Sphere B? _____

Explain your reasoning.

Answer: (iii)equal to.

The magnitudes of the net charges on A & B must be equal since both were neutral to start and for each electron that moved from A to B a positive was left behind on A.

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.

Answer: (iii) stays the same

There is no charge exchanged between spheres A and B when sphere B is moved.

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

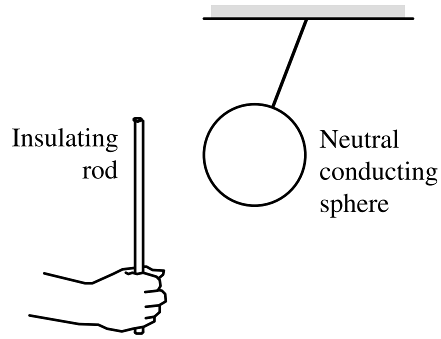
Explain your reasoning.

Answer: (ii) decrease.

Charge (electrons) moves from B to C resulting in a lower net positive charge on C.

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:



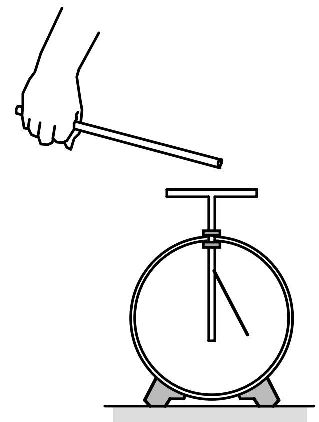
"As the negatively charged rod nears the sphere, it causes the electrons in the sphere to move away from the rod. The side of the sphere nearest to the rod becomes positively charged while the other side becomes negatively charged. So the sphere will be attracted toward the rod. If they touch, the sphere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

Answer: The first three sentences are correct. However, the rod will not become neutral because it is an insulator. Only a small amount of charge on the surface of the rod where contact is made will transfer to the metal sphere, which would then have a net negative charge.

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 _____

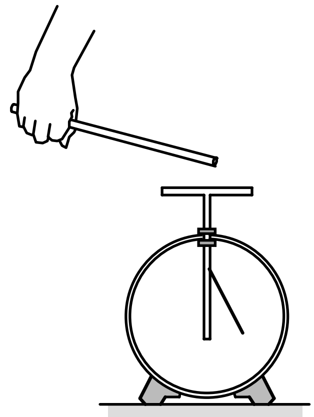
Explain your reasoning.

Answer: Barun is correct.

Since the electroscope leaf falls again when the rod is removed, we can assume that no charges were transferred to the plate. The plate, rod, and leaf are electrically isolated, and unless they are touched or a spark jumps the overall charge (zero) remains the same. When the rod is brought near, electrons in the rod and plate move toward it and onto the plate, leaving the rod and leaf with the same negative charge. They repel, and the leaf lifts. When the rod is removed, the electrons in the plate move back to the rod and leaf, and the leaf falls.

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.

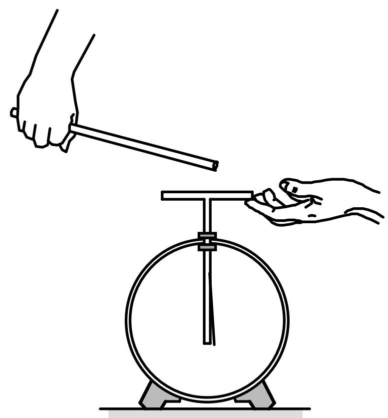


(a) Is the electroscope now (i) *positively charged*, (ii) *negatively charged*, or (iii) *neutral*. _____

Explain your reasoning.

Answer: (iii) neutral.
No charge has been transferred to the electroscope. The electroscope leaf deflects because the bottom part of the electroscope is all positively charged (the top plate has an equivalent negative charge since the electrons from the rod and leaf have been attracted to the top plate) and so the vertical rod and the leaf repel each other.

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

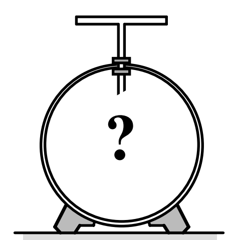


(b) Is the electroscope (i) *positively charged*, (ii) *negatively charged*, or (iii) *neutral*. _____

Explain your reasoning.

Answer: (ii) negatively charged.
By touching the electroscope, the student has provided a large area for charges to redistribute themselves over. The foil of the electroscope has fallen, indicating that the bottom of the electroscope is uncharged. The top of the electroscope will still be negatively charged, since there are still positive charges in the rod that are pulling the electrons in the electroscope (and the student) toward the rod and onto the plate. The overall charge of the electroscope is therefore negative.

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.

Answer: (ii) The electroscope is negatively charged.
When the student removes her hand, there are negative charges on the plate, and the rod and leaf are uncharged, so the overall charge of the electroscope is negative.

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

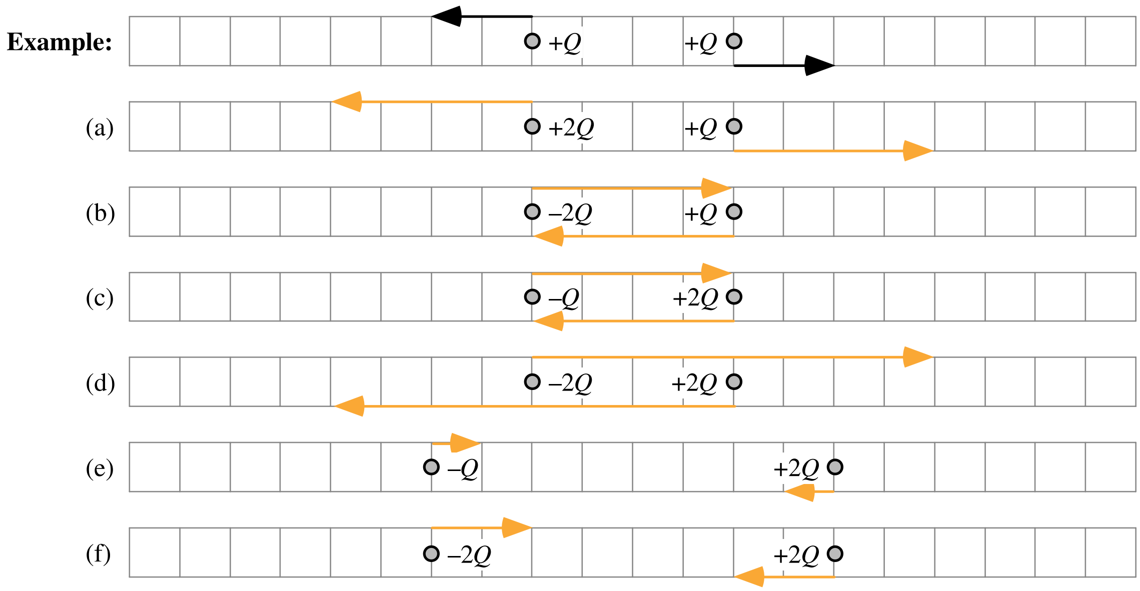
Explain your reasoning.

Answer: (i) It will be deflected.
Once the rod is removed, these negative charges will distribute themselves around the electroscope plate, rod, and leaf, and both the rod and the leaf will be negatively charged. The leaf and the rod repel each other, and the leaf deflects.

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.

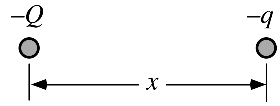


Explain your reasoning.

Using the example as our template when the charge magnitudes doubled with no change in distance the force doubled. Changing from two positive charges to a positive and a negative makes the forces attractive rather than repulsive. In (d) both charges are doubled so the force is four times as large as the example. In (e) the distance is doubled reducing the force by four and for (f) that force is doubled when the second charge magnitude was doubled.

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."

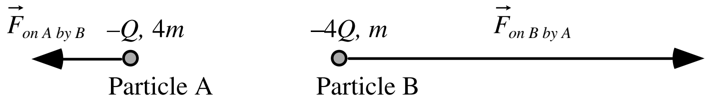
What, if anything, is wrong with this statement? If something is wrong, explain the error and how to correct it. If the statement is valid, explain why.

Answer: The student's statement is wrong.

The force on Q will point to the left, since two negative charges will repel each other, just as two positive charges will repel each other. Whether the force on Q is in the positive or negative direction depends on the coordinate system that has been set up, since none has been established here we cannot say whether the force on Q is positive or negative.

D1-WWT11: TWO NEGATIVELY CHARGED PARTICLES—FORCE

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

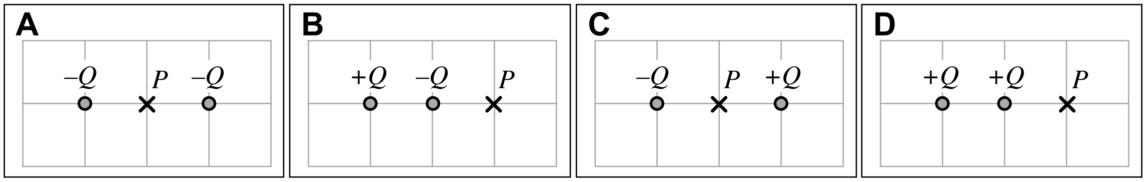


What, if anything, is wrong with this diagram? If something is wrong, explain the error and how to correct it. If the diagram is valid, explain why.

Answer: The two forces should have the same magnitude according to Newton's Third Law or Coulomb's Law: to correct the diagram the arrow on the +4Q charge could be shortened so that it is the same length as the one on the +Q charge.

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

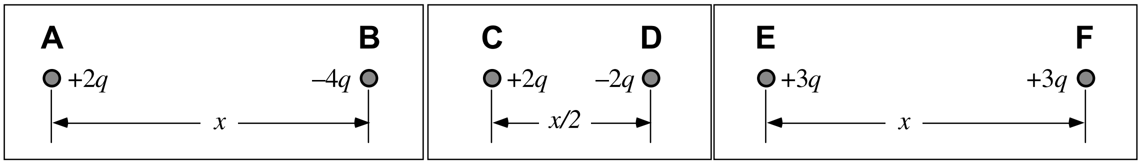
Explain your reasoning.

Answer: C > D > B > A.

In case C the two charges produce electric fields at P that both point to the left. In case D both charges produce fields pointing to the right, but one is one-quarter of the other. In case B the two charges produce oppositely directed fields at P. And in case A the two fields at P point in opposite directions and are equal in magnitude, so the net field is zero.

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

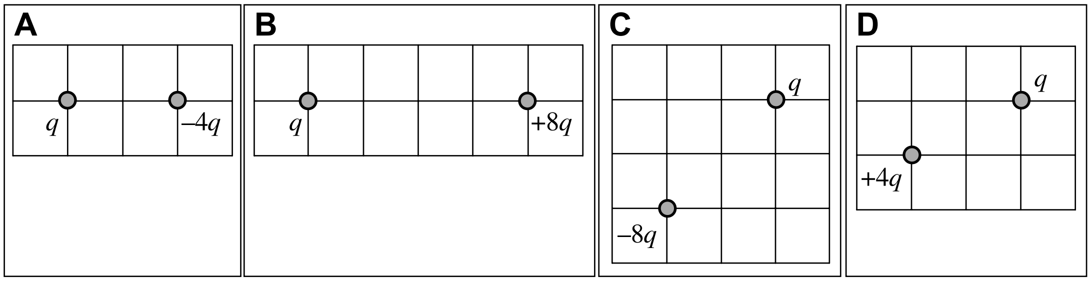
Explain your reasoning.

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

Since opposite charges attract and the magnitude of the force is inversely proportional to the square of the separation distance C and D are first, A and B are next, and E and F will be last since they repel each other.

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

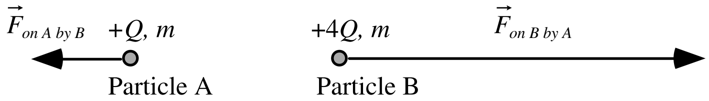
Explain your reasoning.

Answer: A = C > D > B.

From Coulomb's law, the force between two charges is proportional to the product of the charges and inversely proportional to the square of the distance between them. If we let F be the magnitude of the force between two q charges placed one square apart, then in case A there is a net force on q of F, since the distance is two squares but one of the charges is four times as large. In case B, the two charges are twice as far apart, and if the charges had the same size as in case A, then the force would be one quarter as large as in case A, since the force varies as the inverse square of the distance. However one of the two charges is twice as large, so the force in case B is 0.5F. In case C, the distance between the two charges is the square root of 2 times as large as it is in case A, and since the force varies as the inverse square of the distance, the force would be half as big if the charges were the same as they are in case A, However the size of one of the charges has doubled as well; these two effects cancel and the net force in case C is F as well. In case D, the distance between the charges is the square root of 5, and

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 +4*Q* and mass *m*).

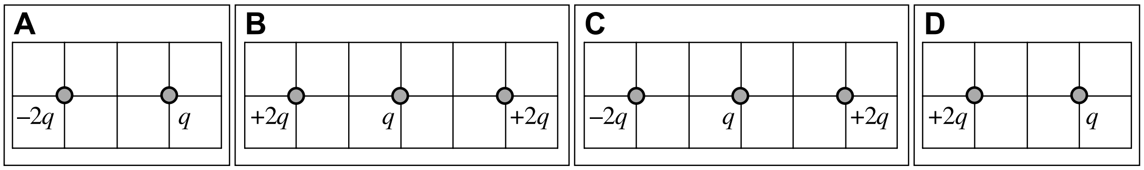


There is something wrong with this diagram. Explain what is wrong and how to correct it.

Answer: The forces should be the same magnitude: to correct the diagram make the arrow on the +q charge the same length as the one on the +4q charge.

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.

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

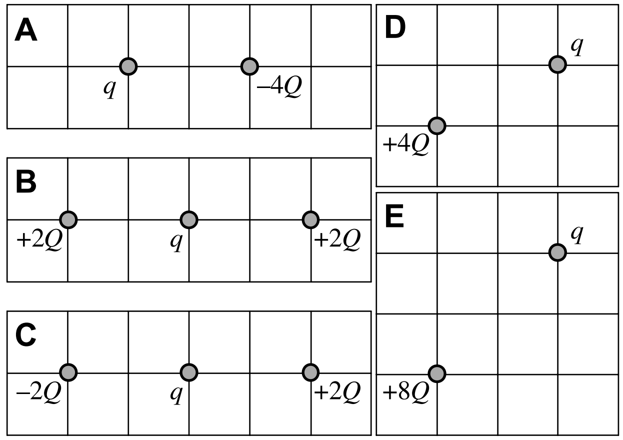
Explain your reasoning.

Answer: C > A = D > B.

From Coulomb's law, the force between two charges is proportional to the product of the charges and inversely proportional to the square of the distance between them. If we let F be the magnitude of the force between two q charges placed one square apart, then in cases A and D there is a net force on q of 0.5 F, since the distance is two squares but one of the charges is two times as large. In case B, the two forces on q act in opposite directions and have the same magnitude, so there is no net force. In case C, they act in the same direction, and each has a magnitude 0.5 F, so the net force on q is F.

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.

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

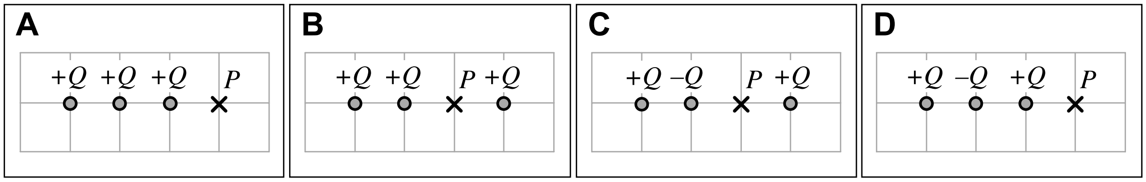
Explain your reasoning.

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

From Coulomb's law, the force between two charges is proportional to the product of the charges and inversely proportional to the square of the distance between them. If we let F be the magnitude of the force between a 2Q charge and a q charge that are two squares apart, then in case A there is a net force on q of 2F. In case B, the two forces on q act in opposite directions and have the same magnitude, so there is no net force. In case C, they act in the same direction, and each has a magnitude F, so the net force on q is 2F. In case D, the distance between the charges is greater than it is in case A, so the net force will be smaller (but it is not zero). In case E, the distance between the two charges is the square root of 2 times as large as it is in case A, and since the force varies as the inverse square of the distance, the force would be half as big if the charges were the same as they are in case A, However the size of one of the charges has doubled as well; these two effects cancel and the net force in case E is 2F as well.

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.

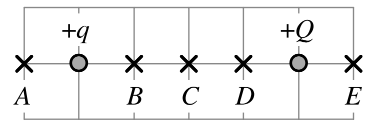
Answer: C > A > D > B.

In case C the two charges closest to P exert forces in the same direction, but the other positive charge exerts a force in the opposite direction. In case A all three of the forces act in the same direction so they add. In case D the two positive forces exert forces in the same direction but the negative charge exerts a force in the opposite exerted by the third positive charge.

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.

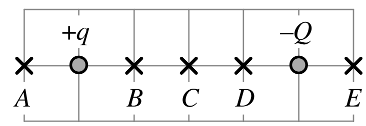


At which point *A–E* is it possible that the third charge was placed? _____
Explain your reasoning.

Answer: Point B.

To get zero net force, the force due to +q on a third charge must be the same size as the force due to +Q on that charge, but these two forces must point in opposite directions. If the charge is placed at points A or E, the force from +q and +Q will be in the same direction. (For example, if we place a positive charge at A, both other charges will push it to the left, and if we place a negative charge there, both other charges will pull it to the right.) So it is not possible for the net force to be zero at these points. Between +q and +Q, the two forces on a third charge will point in opposite directions, so we need to find a position where these opposing forces are the same size. Point C is the same Q is a larger charge and it is closer. At point B, the +q charge is closer, so if +q and +Q were the same size, the force due to +q would be greatest. But we know that +q is smaller that +Q – so it is at least possible that the forces are equal at these points.

(b) Charge q is positive and charge Q is negative.

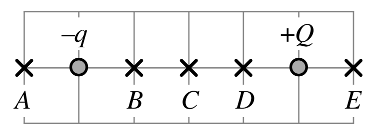


At which point *A–E* is it possible that the third charge was placed? _____
Explain your reasoning.

Answer: Point A.

At points B, C, and D, the force on the third charge due to +q points in the same direction as the force due to –Q – one force pushes and the other one pulls. At point E, the forces will be in opposite directions, but the force due to –Q will be larger, since this is a larger charge and it is closer. At point A, the proximity of +q might compensate for the smaller charge in just the right way so that the forces due to –Q and +Q are equal in magnitude.

(c) Charge q is negative and charge Q is positive.

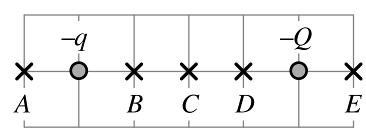


At which point *A–E* is it possible that the third charge was placed? _____
Explain your reasoning.

Answer: Point A.

As with question b, between –q and +Q the forces on the third charge will point in the same direction, so it is not possible for the two forces to add to zero. At point E, the larger charge is also closer, so the force due to the larger charge must be larger. At point A, the smaller charge is also closer, and so it is possible for the two forces to be equal and opposite.

(d) Both q and Q are negative.



At which point *A–E* is it possible that the third charge was placed? _____
Explain your reasoning.

Answer: Point B.

As with question a, the forces act in the same direction for charges placed at A or E. At points C and D, the two forces cannot be the same magnitude. At point B, the forces point in opposite directions, and the smaller charge is also closer, so it is possible that the net force is zero on a third charge placed at this point.

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.

$\Sigma\vec{F}$ on charge *C*

A	*B*	*C*	Direction:
+	+	+	→
+	+	−	←
+	−	+	←
+	−	−	→
−	+	+	→
−	+	−	←
−	−	+	←
−	−	−	→

$\Sigma\vec{F}$ on charge *B*

A	*B*	*C*	Direction:
+	+	+	→
+	+	−	→
+	−	+	←
+	−	−	←
−	+	+	←
−	+	−	←
−	−	+	→
−	−	−	→

Explain your reasoning.

The closer charge will exert a greater force because of the inverse square law. Therefore, whether the forces due to the other two charges are in the same or opposite directions, the closer one will determine the direction of the net force.

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.

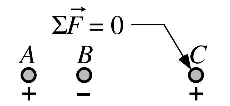
Charges (*A* *B* *C*)	$\Sigma\vec{F}$ on charge *A*	$\Sigma\vec{F}$ on charge *B*	$\Sigma\vec{F}$ on charge *C*
+ + +	Must be nonzero ☒ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☒	Must be nonzero ☒ Possibly zero ☐
+ + −	Must be nonzero ☐ Possibly zero ☒	Must be nonzero ☒ Possibly zero ☐	Must be 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.

For these we need to use the fact that opposite signed charges attract and same signed charges repel. If the two forces on a charge point in the same direction then the net force has to be nonzero. Similarly, if the two forces are in opposite directions then they could sum to zero since the magnitudes of the charges are different.

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*.



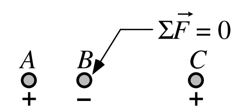
Indicate whether each of the following statements is *true*, *false*, or *cannot be determined*.

	Statement	True	False	Cannot be determined
1.	Charge *A* has a greater magnitude than charge *C*.			X
2.	Charge *A* has a greater magnitude than charge *B*.	X		
3.	Charge *C* has a greater magnitude than charge *B*.			X
4.	Charge *A* has the same magnitude as charge *C*.			X
5.	Charge *A* has the same magnitude as charge *B*.		X	
6.	Charge *C* has the same magnitude as charge *B*.			X

Explain your reasoning.

Charges A and B exert oppositely directed forces on charge C since they have different signs. Since A is farther from C than B we know that A has to have a larger magnitude in order for the two forces to cancel. We cannot make any comparisons between the magnitudes of A and C or B and C since charge C is the common element in the calculations of the magnitudes of the two forces.

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
7.	Charge *A* has a greater magnitude than charge *C*.		X	
8.	Charge *A* has a greater magnitude than charge *B*.			X
9.	Charge *C* has a greater magnitude than charge *B*.			X
10.	Charge *A* has the same magnitude as charge *C*.		X	
11.	Charge *A* has the same magnitude as charge *B*.			X
12.	Charge *C* has the same magnitude as charge *B*.			X

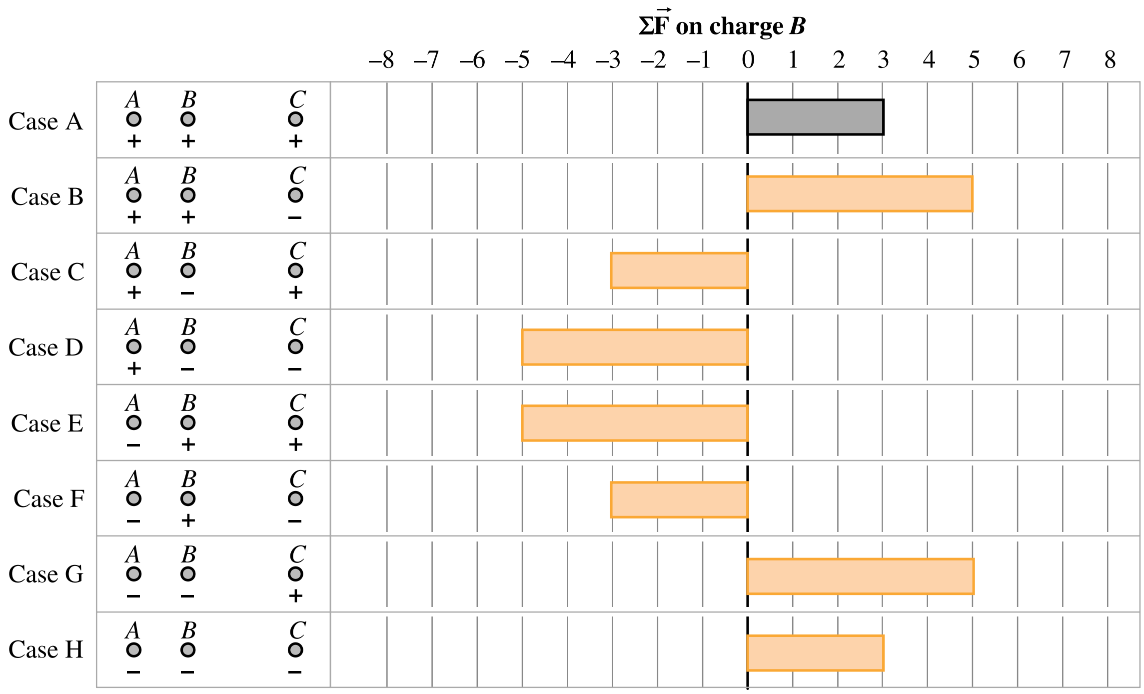
Explain your reasoning.

Charges A and C exert oppositely directed forces on charge B since they have the same sign but on opposite sides of B. Since C is farther from B than A we know that C has to have a larger magnitude in order for the two forces to cancel. We cannot make any comparisons between the magnitudes of A and B or C and B since charge B is the common element in the calculations of the magnitudes of the two forces.

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.

Since charge C is twice as far away from B as charge A is, a charge q placed at A will exert a force on B that is 4 times as large as the same charge placed at C. In case A, These forces act in opposite directions, and the resultant is a force of magnitude 3 to the right, so we can conclude that a charge placed at A produces a force on B that is 4 to the right, and a charge placed at C produces a force on B that is 1 to the left, giving a net force of magnitude 3 to the right. In cases B and G, the two forces both act to the right, and in cases D and E the forces both act to the left, and the net force is 4+1=5. In cases A and H the force from A acts to the right and the force from B acts to the left, giving a net force 4-1=3 to the right, and in cases C and F the force from A acts to the left and the force from C acts to the right giving a force of 4-1=3 to the left.