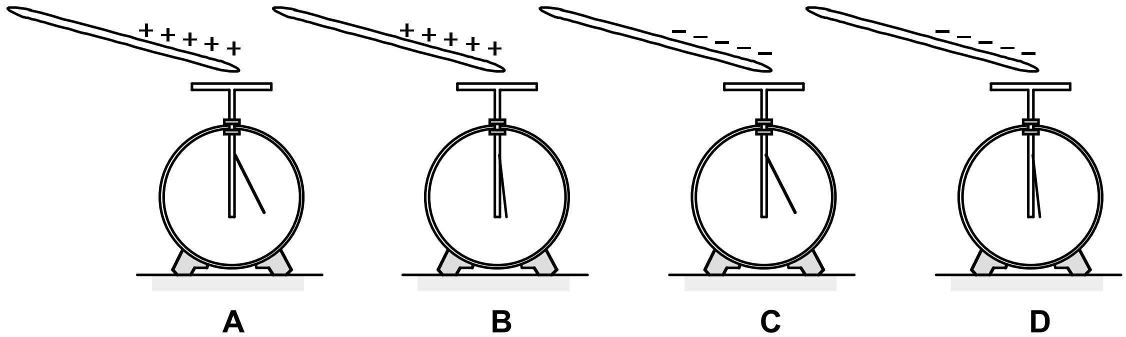
INSTRUCTORS MANUAL SECTION D

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

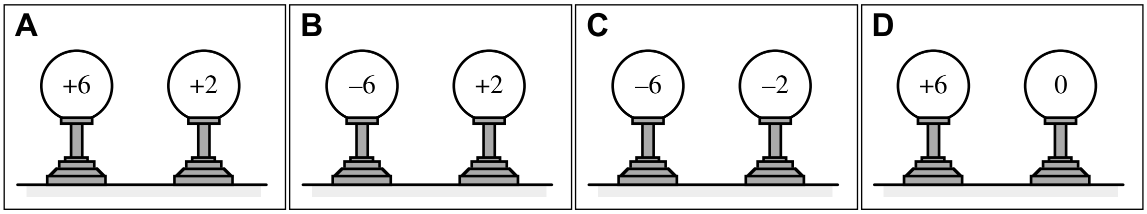
Explain your reasoning.

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

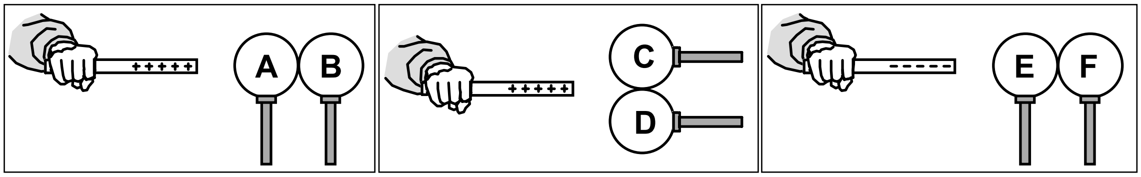
Explain your reasoning.

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

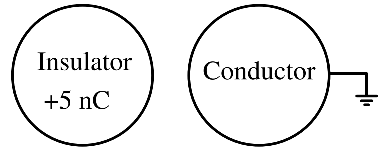
Explain your reasoning.

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:



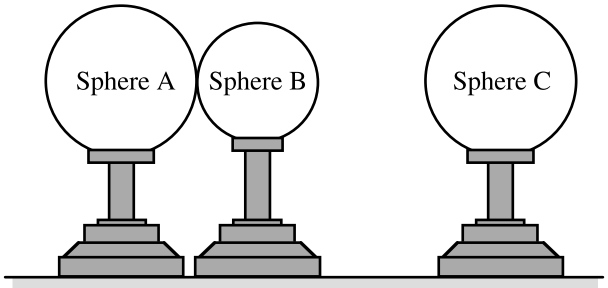
"When the charged insulator is brought close to the grounded conductor, it will cause the negative charges in the conductor to move to the side closest to the insulator. If the charged insulator is taken away, the conductor will be left with a negative charge evenly distributed over its surface."

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.

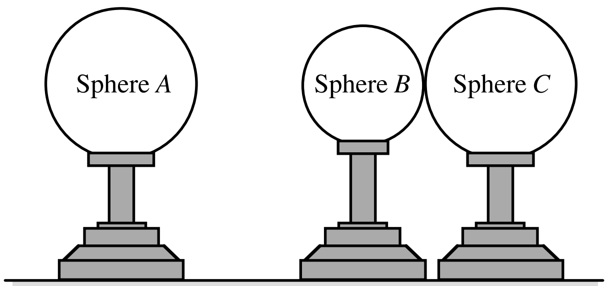
(c) Is the magnitude of the net charge on Sphere A (i) *greater than*, (ii) *less than*, or (iii) *equal to* the magnitude of the net charge on Sphere B? _____

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*? _____

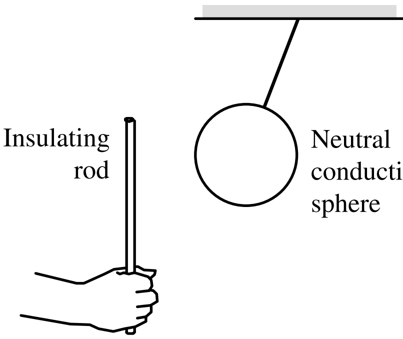
Explain your reasoning.

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:



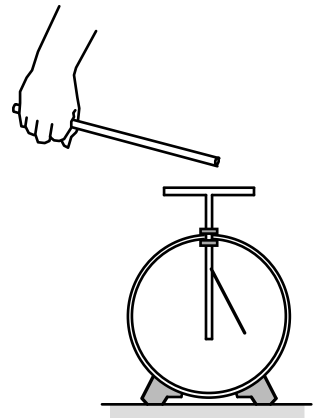
"As the negatively charged rod nears the sphere, it causes the electrons in the sphere to move away from the rod. The side of the sphere nearest to the rod becomes positively charged while the other side becomes negatively charged. So the sphere will be attracted toward the rod. If they touch, the sphere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

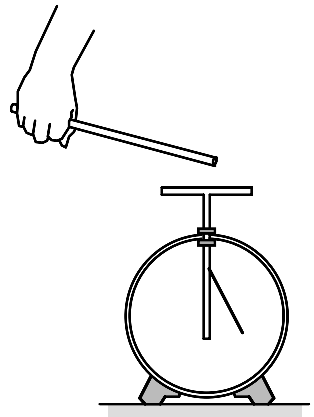
Explain your reasoning.

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.

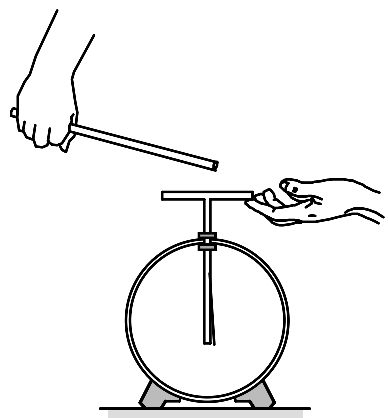


(a) Is the electroscope now (i) *positively charged*, (ii) *negatively charged*, or (iii) *neutral*. _____

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.

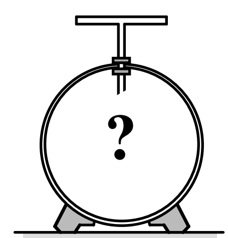


(b) Is the electroscope (i) *positively charged*, (ii) *negatively charged*, or (iii) *neutral*. _____

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*? _____

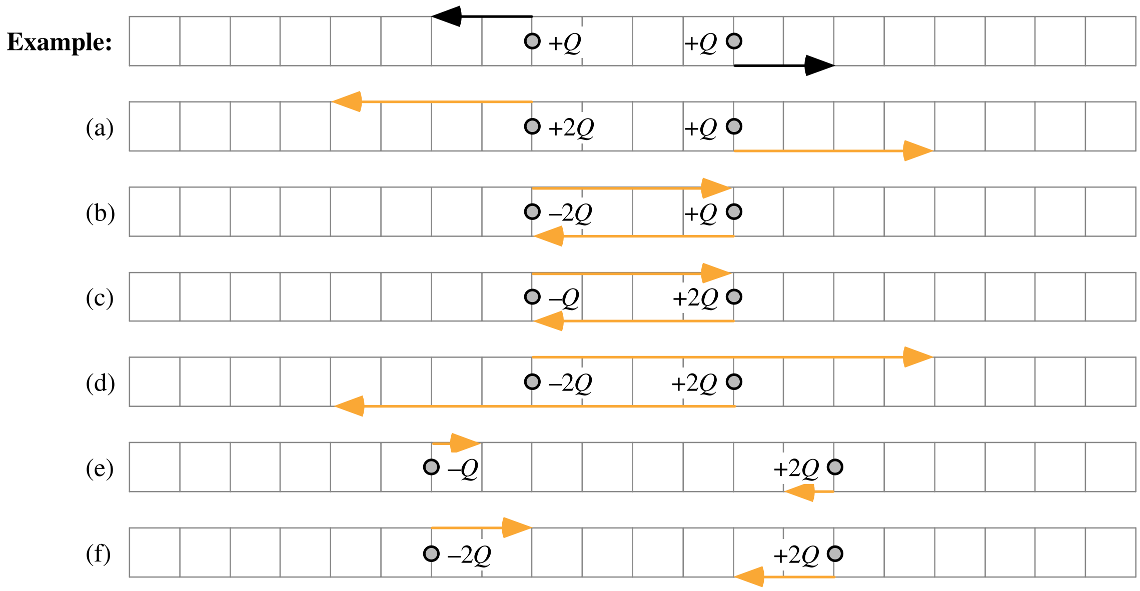
Explain your reasoning.

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.

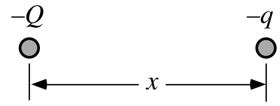


Explain your reasoning.

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."

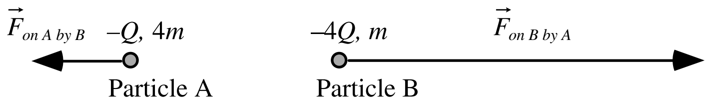
What, if anything, is wrong with this statement? If something is wrong, explain the error and how to correct it. If the statement is valid, explain why.

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.

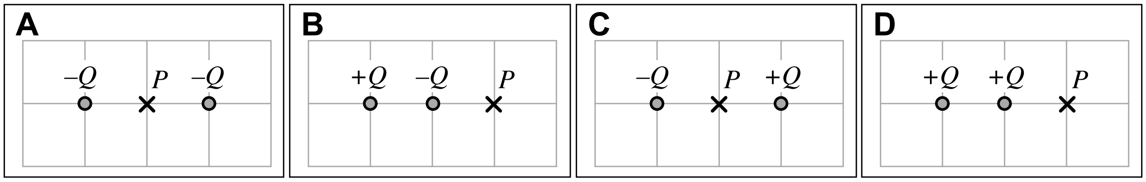


What, if anything, is wrong with this diagram? If something is wrong, explain the error and how to correct it. If the diagram is valid, explain why.

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

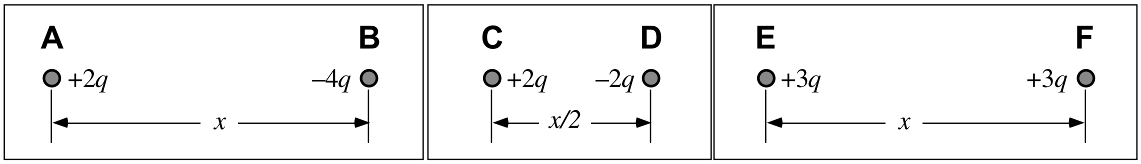
Explain your reasoning.

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

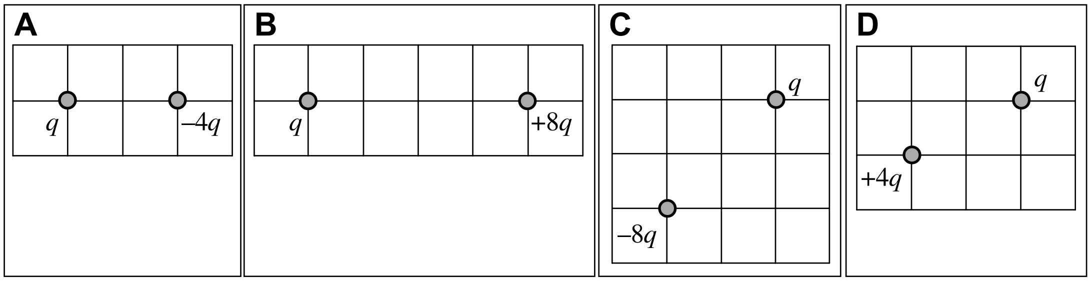
Explain your reasoning.

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.

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

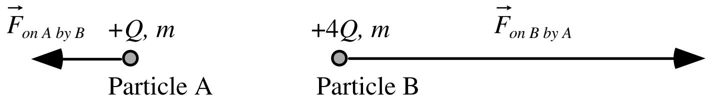
Explain your reasoning.

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 $+4Q$ and mass m).

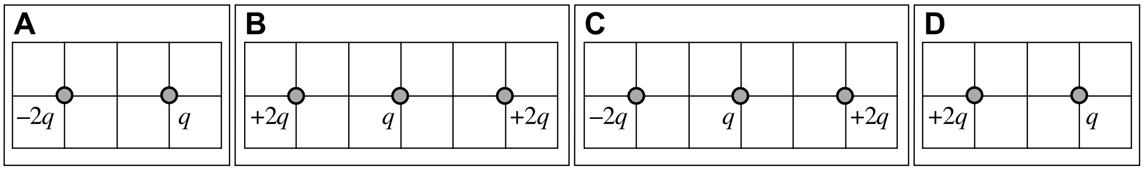


There is something wrong with this diagram. Explain what is wrong and how to correct it.

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

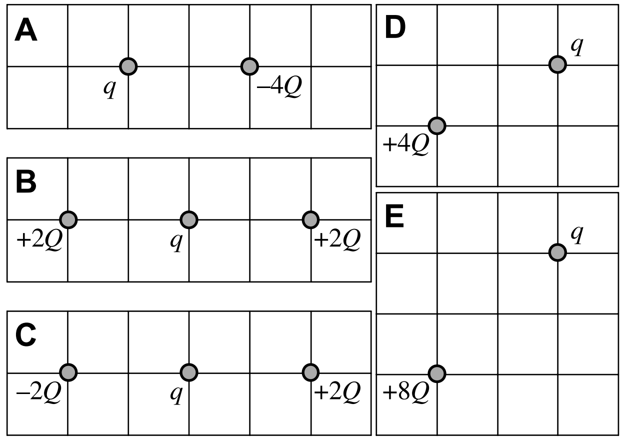
Explain your reasoning.

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

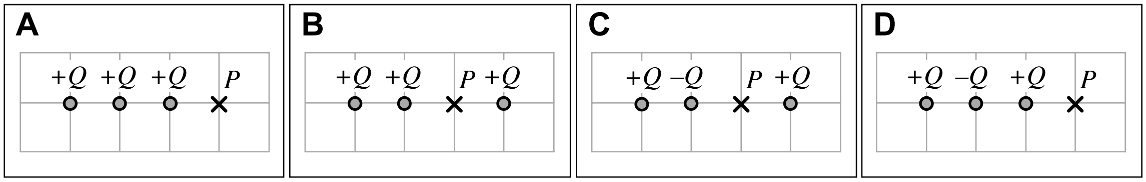
Explain your reasoning.

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.

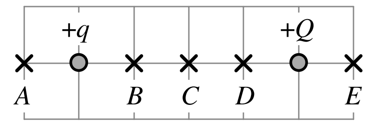
Answer: C > A > D > B.

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.

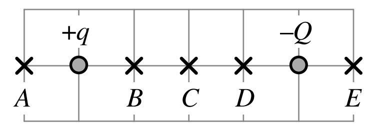


At which point *A–E* is it possible that the third charge was placed? _____
Explain your reasoning.

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.

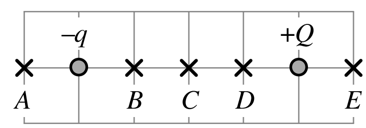


At which point *A–E* is it possible that the third charge was placed? _____
Explain your reasoning.

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.

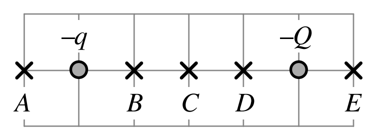


At which point *A–E* is it possible that the third charge was placed? _____
Explain your reasoning.

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
+	+	+	Direction: →
+	+	−	Direction: ←
+	−	+	Direction: ←
+	−	−	Direction: →
−	+	+	Direction: →
−	+	−	Direction: ←
−	−	+	Direction: ←
−	−	−	Direction: →

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

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

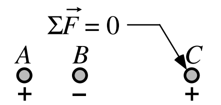
Charges (A, B, C)	$\Sigma\vec{F}$ on charge *A*	$\Sigma\vec{F}$ on charge *B*	$\Sigma\vec{F}$ on charge *C*
+ + +	Must be nonzero ☒ Possibly zero ☐	Must be nonzero ☐ Possibly zero ☒	Must be nonzero ☒ Possibly zero ☐
+ + −	Must be nonzero ☐ Possibly zero ☒	Must be nonzero ☒ Possibly zero ☐	Must be nonzero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



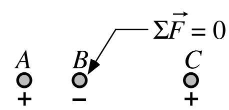
Indicate whether each of the following statements is *true*, *false*, or *cannot be determined*.

	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

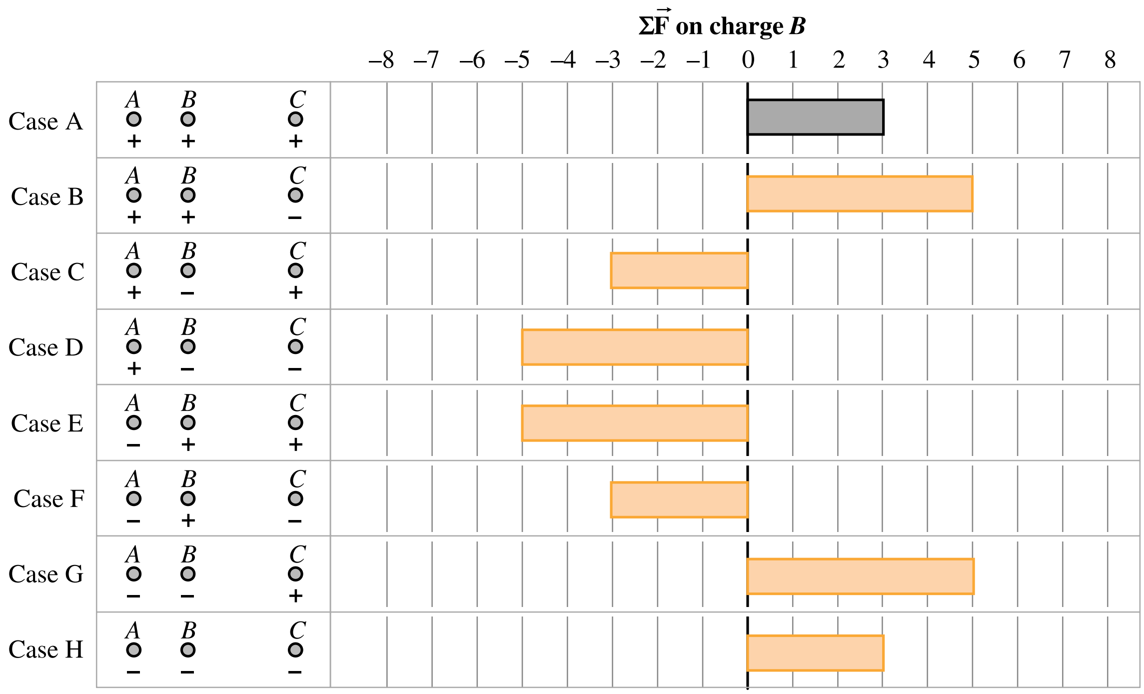
Explain your reasoning.

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.

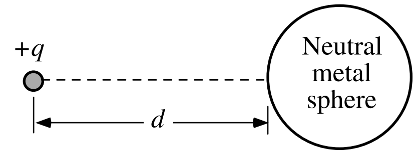


Explain your reasoning.

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.

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:

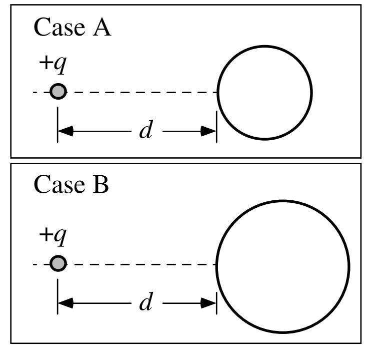
"There is an attraction between the point charge and the sphere. Since the sphere is a conductor, the external positive point charge pulls electrons in the sphere toward it. This leaves positive charges on the other side of the sphere, since the sphere is still neutral. The force between the point charge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

Answer: The induced positive charge on the sphere cannot be ignored since it repels the positive point charge, but has less effect than the negative charge because it is at a greater distance.

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 _____

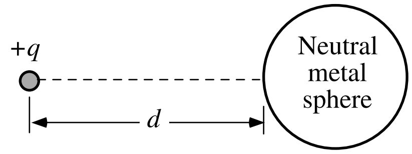
Explain your reasoning.

Answer: None of them are correct.

The positive point charges in both cases induce a charge distribution on the metal sphere that causes the conducting sphere to have a negative charge induced on the closest side of the sphere and a positive charge on the farthest side. Since in each case the charge is the same distance from the near side of the sphere, the effect of the farthest side will determine the net force. The larger sphere will have the largest net force because the repulsion force is smaller since the charges producing it are farther away from q.

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."

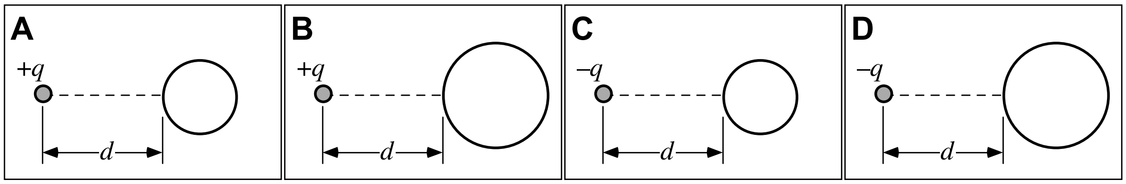
What, if anything, is wrong with this statement? If something is wrong, explain the error and how to correct it. If the statement is valid, explain why.

Answer: The statement is incorrect.

The charge induces a separation of charge on the sphere, with electrons attracted to the point charge moving to the left, leaving an equal positive charge on the right side of the sphere. Since the positive charge is farther from the point charge than the negative charge, there is a net attractive force.

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

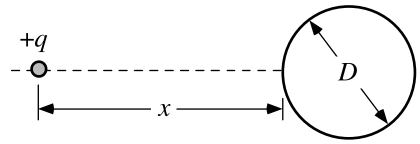
Explain your reasoning.

Answer: A = C > B = D.

The point charges in all these cases induce a charge distribution on the metal sphere that causes them to attract each other since the charge induced on the side of the sphere closer to the charge is opposite the sign of the point charge. The side of the sphere farther from the point charge will have the same sign as the point charge, which will cause a repelling force. Since in each case the charge is the same distance from the sphere, the effect of the farther side will determine the ranking. B and C have the larger net force because the spheres are larger and thus the repulsion force is smaller.

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.)

	Change	Effect on the force exerted on the particle.			
		No force	*Increases*	*Decreases*	*Remains the Same*
1.	Increase the distance x.			X	
2.	Increase D, keeping the charge a distance x away.		X		
3.	Increase the charge of the particle.		X		
4.	Make the charge of the particle $-q$.				X
5.	Add negative charge to the sphere.		X		

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.)

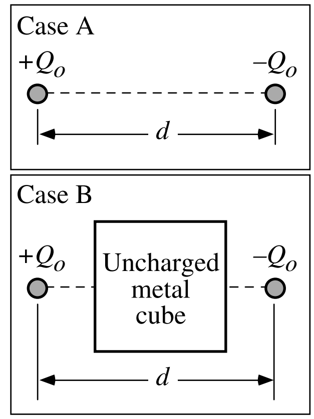
	Change	Effect on the force exerted on the sphere.			
		No force	*Increases*	*Decreases*	*Remains the Same*
6.	Increase the distance x.			X	
7.	Increase D, keeping the charge a distance x away.		X		
8.	Increase the charge of the particle.		X		
9.	Make the charge of the particle $-q$.				X
10.	Add negative charge to the sphere.		X		

Explain your reasoning.

Since the force is inversely proportional to the square of the separation distance, increasing the separation distance decreases the force. Increasing the diameter of the sphere moves the side of the sphere with the effective charge that is the same sign as the particle farther from the particle, thus reducing the repulsive force. Increasing the magnitude of the charge on the particle increases the force according to Coulomb's law. Adding negative charge to the sphere increases the force because there is now an attractive force even before the charge rearrangement on the sphere.

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? _____

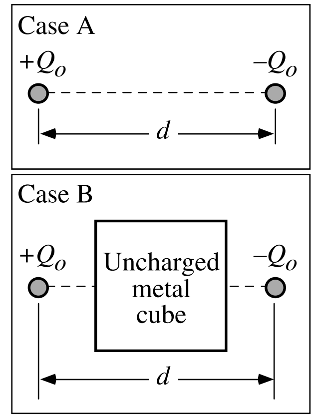
Explain your reasoning.

Answer: (ii) Greater in Case B.

The charged particles will create a separation of charges in the cube. Since the electrons in the cube will be attracted to the positive charge and some of them will move to the left, there will be an accumulation of negative charge on the left surface of the cube and an accumulation of positive charge on the right surface. The negative charge on the left surface creates a force on the positive charge to the right. The positive charge on the right surface will create a force on the positive charge to the left, but this force will be smaller than that due to the charge on the left surface since it is further away. The force on the positively charged particle by the negatively charged particle, which is unchanged by the placement of the cube, is to the right, and the net force due to the cube is also to the right, so the net electric force is larger in case B.

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?

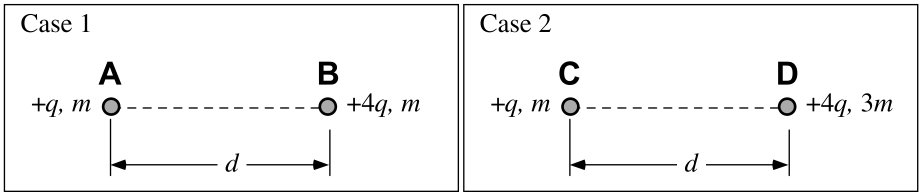
Explain your reasoning.

Answer: Yes.

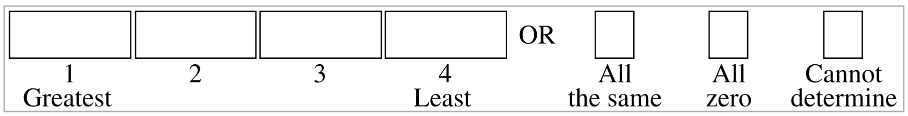
The polarized cube will exert an attractive force on the positive charge because the left side of the cube has a slightly negative charge compared to the right side of the cube.

D1-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.



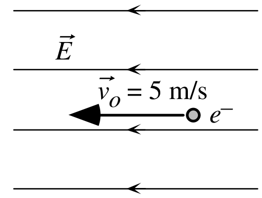
Explain your reasoning.

Answer: A = B = C > D.

Since all the forces acting on the particles are the same (based on Coulomb's Law), the acceleration is determined by the force divided by the mass. All the particles either have a mass of m or 3m. All the particles with mass m will have the same larger acceleration and the particle with mass 3m has the smaller acceleration.

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."

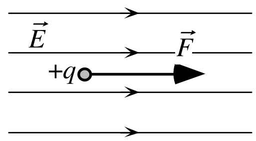
What, if anything, is wrong with this statement? If something is wrong, explain the error and how to correct it. If the statement is valid, explain why.

Answer: The statement is incorrect.

The electron will have a constant acceleration. The field is uniform, thus the force is constant. According to Newton's Second Law, the acceleration is proportional to the force. Therefore, the particle will have a constant acceleration and a decreasing velocity since the force will be opposite the velocity.

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.

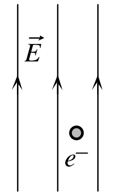
(c) The particle is given a push, causing a leftward initial velocity. _____
Explain your reasoning.
Answer:(vi) not affect the force.
The electric force does not depend on the velocity of the particle.

(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-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 _____

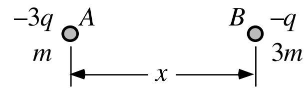
Explain your reasoning.

Answer: Chico is correct.

The electric field is uniform (electric field lines are evenly separated), producing a constant force and thus a constant acceleration. The electric field is the force per unit charge on a positive test charge; therefore the electron will accelerate opposite the electric field since it has a negative charge.

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 _____

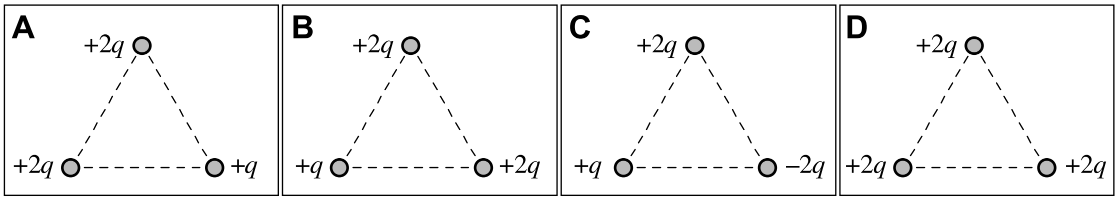
Explain your reasoning.

Answer: Antonio is correct.

We know the forces have the same magnitude either through Coulomb's Law or Newton's Third Law and then Newton's Second law tells us that the particles have different accelerations because of the different masses.

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.



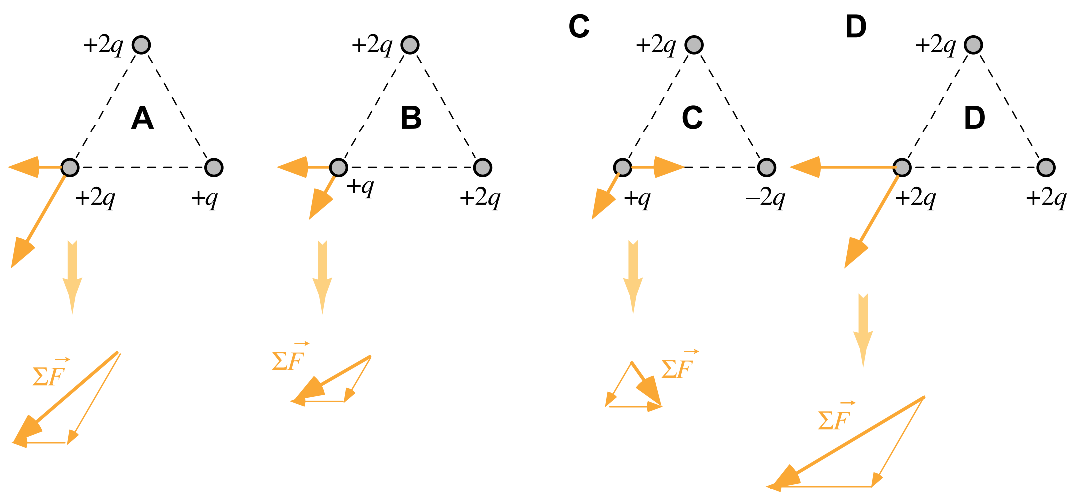
Rank the magnitude of the net electric force on the lower-left particle.

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

Explain your reasoning.

Answer: D > A > B > C.

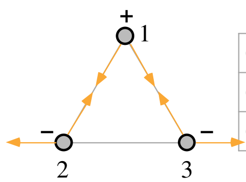
The individual forces are twice as large for an interaction between a +2q charge and a +2q charge as between a +2q charge and a +q charge, and point in the directions shown. A vector sum of the individual forces gives the net force.



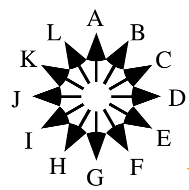
D1-QRT37: Force Direction on Three Charges in an Equilateral Triangle—Force

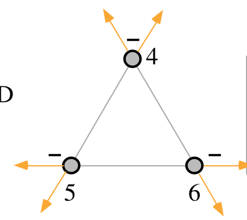
Three charges are fixed at the vertices of each of the equilateral triangles shown below. All charges have the same magnitude. Only charge 1 is positive.

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

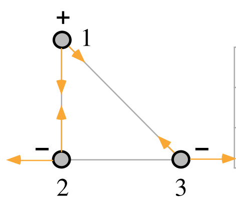
Explain your reasoning.

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.

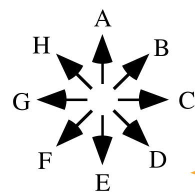
D1-QRT38: FORCE DIRECTION ON THREE CHARGES IN A RIGHT TRIANGLE—FORCE

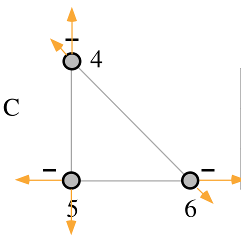
Three charges are fixed at the vertices of each of the right isosceles triangles shown below. All charges have the same magnitude. Only charge 1 is positive.

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	DE
Charge 2	H
Charge 3	BC





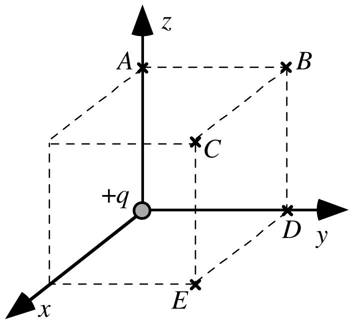
	Net Force Direction
Charge 4	AH
Charge 5	F
Charge 6	CD

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.

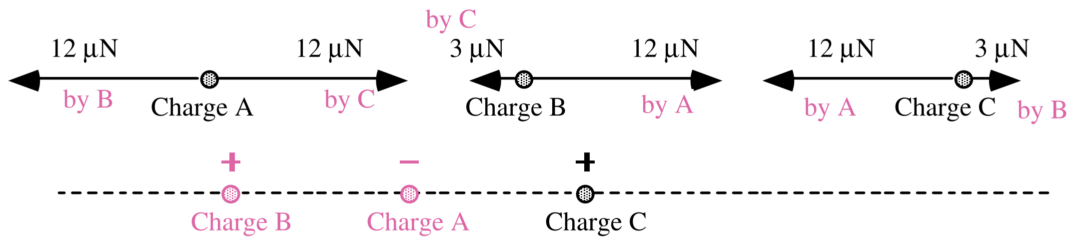
The force between two point charges decreases as the distance between those charges increases.

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

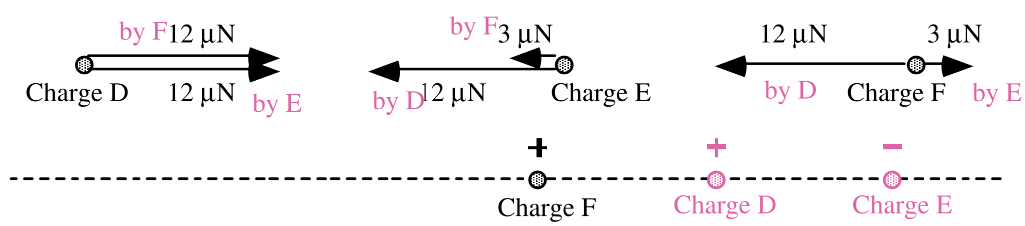
Three charges are fixed in place along a line. All three charges have the same magnitude, but they may have different signs. Shown below are diagrams showing the forces exerted on each charge by the other two charges.

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.**

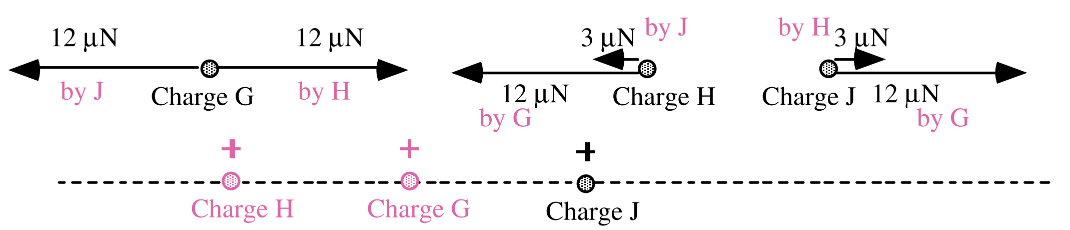
Case 1



Case 2



Case 3



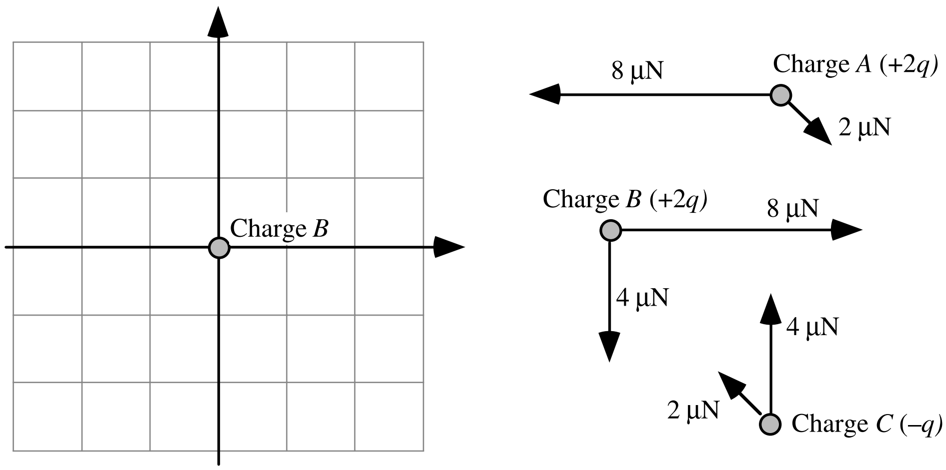
Explain your reasoning.

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

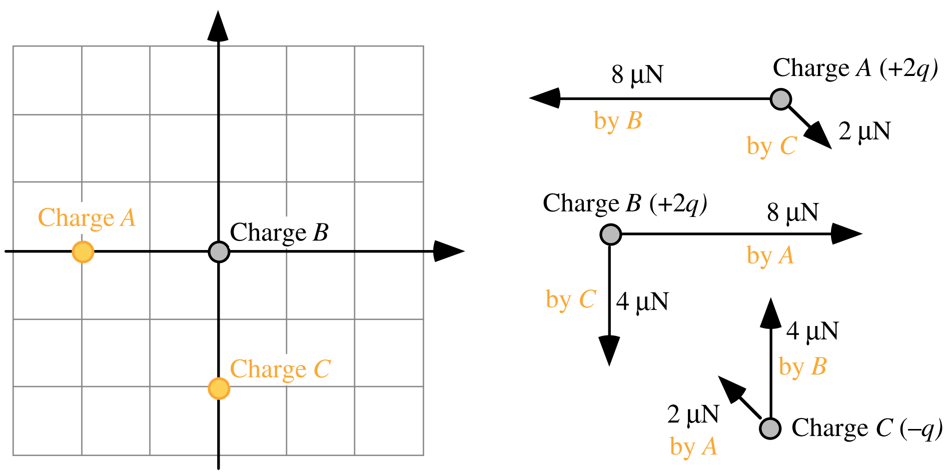
Three charged particles are fixed to a grid and are exerting electric forces on one another. Particles *A* and *B* have a charge +2*q*, and particle *C* has a charge –*q*. The diagrams at the right, below, show the electric forces exerted on each particle due to the other two particles.

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*.**



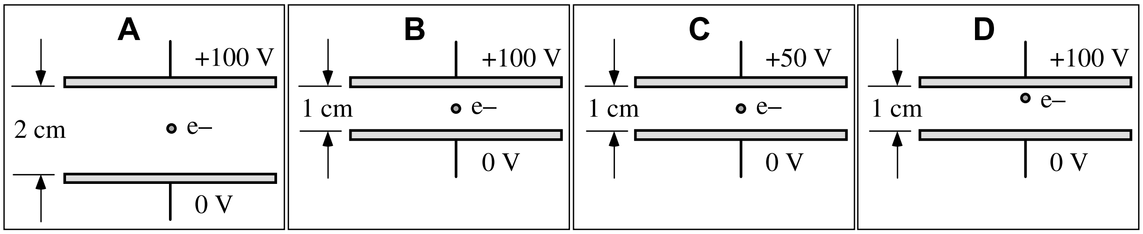
Explain your reasoning.

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-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

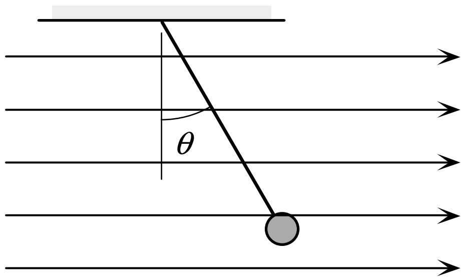
Explain your reasoning.

Answer: B = D > A = C.

The field between the plates, which is uniform, is proportional to the potential difference divided by the distance. The force is the product of the charge and the field.

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

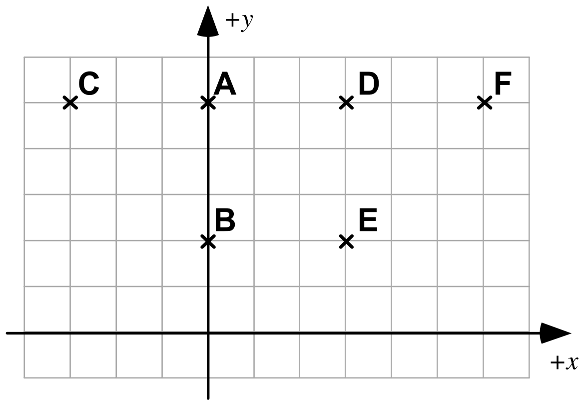
Explain your reasoning.

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-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.

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

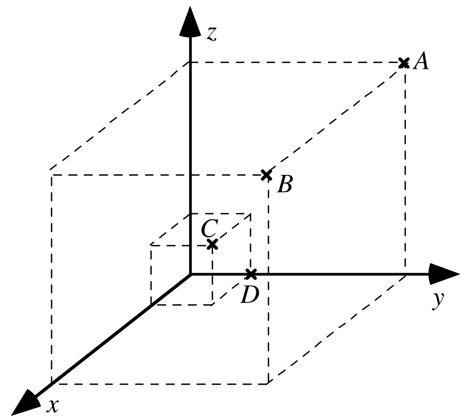
Explain your reasoning.

Answer: All the same.

Since the electric field is uniform throughout this region a charge is going to experience the same force anywhere in the field.

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.

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

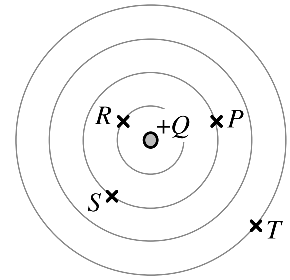
Explain your reasoning.

Answer: All the same.

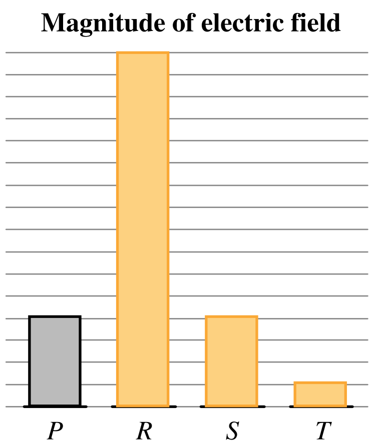
The field is uniform so the magnitude and direction of the force on the charge will be the same at all points in the field.

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*.

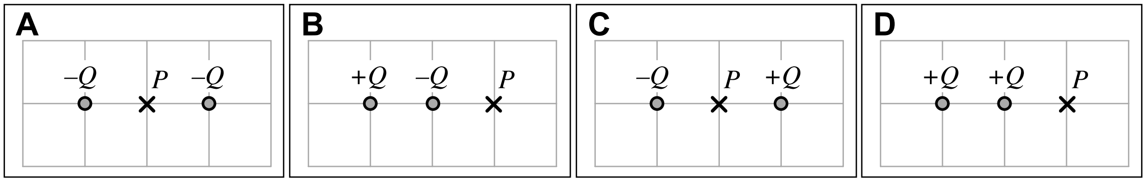


Explain your reasoning.

The magnitude of the electric field due to a point charge is inversely proportional to the square of the distance from the charge. P is two units from the charge so the magnitude of R, which is only one unit away, needs to be four times as large. S will have the same magnitude as P and T will be one-fourth the magnitude of P.

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*.

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

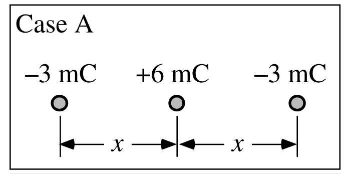
Explain your reasoning.

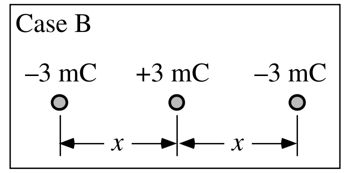
Answer: C > D > B > A.

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-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?

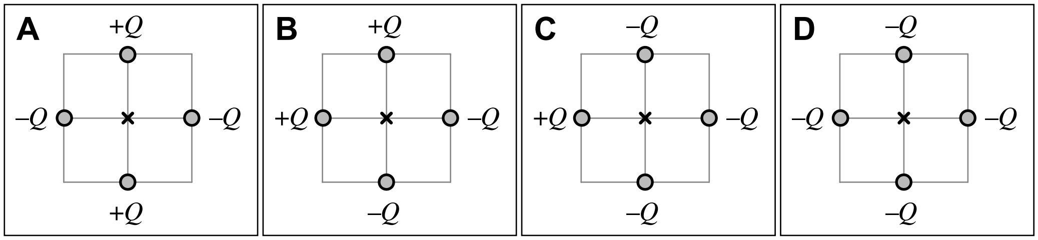
Adrianna ______ Brandon _____ Catalina _____ None of them _____

Explain your reasoning.

Answer: Catalina is correct that the middle charge is placed in the field produced by the other two charges and cannot experience its own field.

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

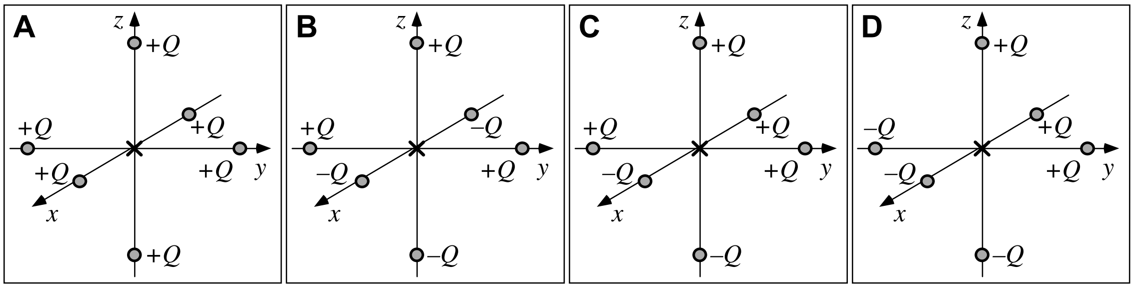
Explain your reasoning.

Answer: B > C > A = D.

In case B, the fields due to the charges above and below the 'x' both point down, and the fields due to the other two charges point right. The vector sum of the four field contributions, points down and to the right. In case C the field due to the charges above and below the 'x' cancel and the resulting field has a magnitude equal to the sum of the horizontal components of the other two charges. In cases A, and D, the field at 'x' is zero.

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.

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

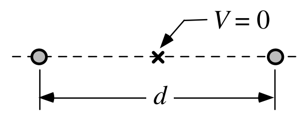
Explain your reasoning.

Answer: D > C > B > A.

Add the vector sums of the electric fields due to each point charge. First, consider the pairs of charges on each axis (take the x-axis for example): if the charges are of opposite sign, then the field component along that axis is non-zero at the origin. If the charges are of the same sign, then the field component along that axis is zero. The magnitude of the net field is greatest if all three components are non-zero, as in D. In case C, two components are non-zero, in B one component is non-zero and in A all the components are zero.

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*:*



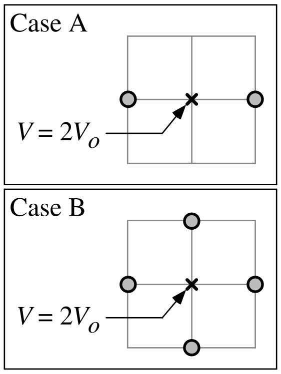
"The electric field at the midpoint between the two charges will be zero also, since the two charges are opposite in sign, so the fields will be equal but opposite, and add to zero."

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

Answer: The fact that the potential is zero means the two charges have opposite signs. Consequently, the field at the origin will not be zero since the vector electric fields due to the point charges add because those fields are in the same direction. We don't know whether the field points to the left or to the right.

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? _____

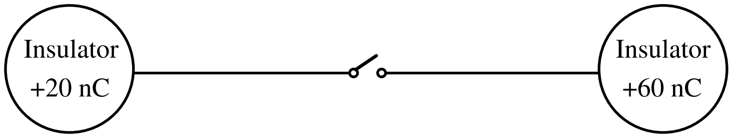
Explain your reasoning.

Answer: (ii) greater in Case B.

The potential is the same in both cases, but there are two charges in Case A and four in Case B. Since the two charges produce a potential of 2V, the charges have to have the same sign. Same sign charges will produce electric fields at the center that cancel each other. When the two additional charges are added the potential doesn't change, so the two new charges must produce potentials that sum to zero, which means they have opposite signs. Since they have opposite signs they will produce electric fields at the center that point in the same direction. So the field will be larger in Case B.

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 _____

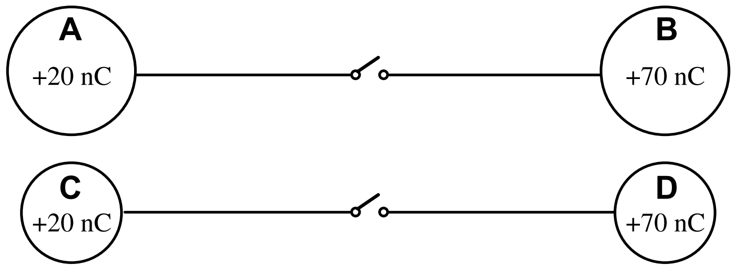
Explain your reasoning.

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

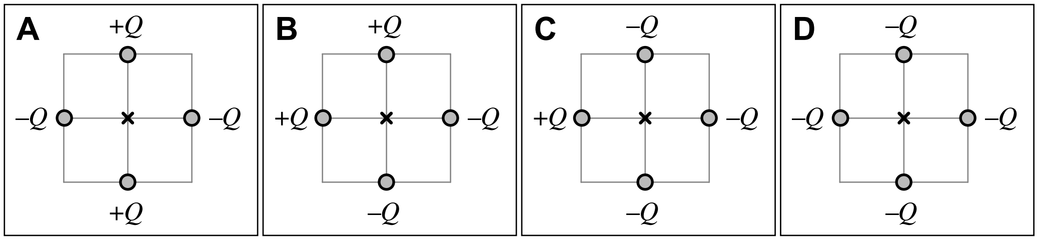
Explain your reasoning.

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-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."

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

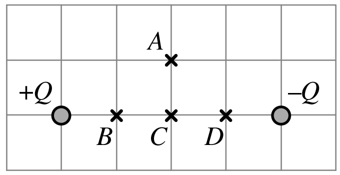
Explain your reasoning.

Answer: A = B > C > D.

Since all of the charges have the same magnitude we can simply sum them taking account of their signs and the sum will be proportional to the electric potential, A and B are zero, C is minus two and D is minus four.

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

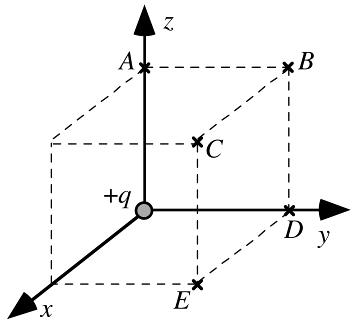
Explain your reasoning.

Answer: B > A = C > D.

The potential is zero at A and C because the two charges are the same distance from each of these points and one charge contributes a positive potential and the other a negative. B is the point with the largest potential since it is closest to the positive charge and D is the lowest potential since it is negative.

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

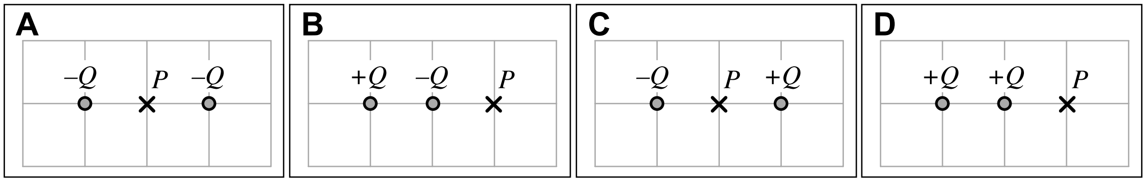
Explain your reasoning.

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

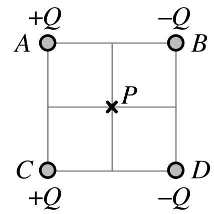
Explain your reasoning.

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.**

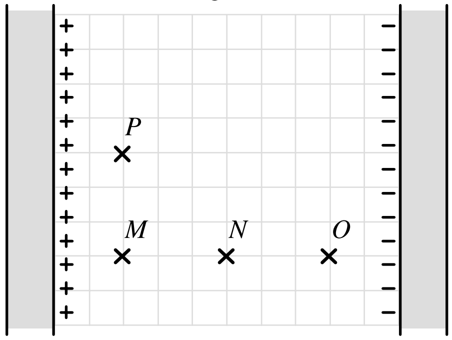
	Modification	Electric field	Electric potential	Electric field direction
1.	Change the sign of charge *A*.	*Decrease*	*Decrease*	↗
2.	Change the sign of charge *B*.	*Decrease*	*Increase*	↘
3.	Change the sign of charge *C*.	*Decrease*	*Decrease*	↘
4.	Change the sign of charge *D*.	*Decrease*	*Increase*	↗
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.

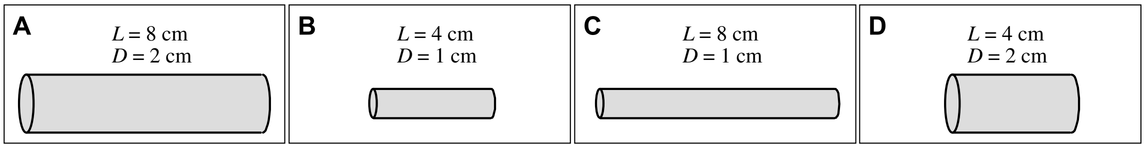
Answer: F > C > A = B = D > E.

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

DC CIRCUITS

D2-RT01: Carbon Resistors—Resistance

Four different resistors are created from the same piece of carbon. The length and the diameter of each resistor are shown.



Rank the resistance of the four resistors.

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

Explain your reasoning.

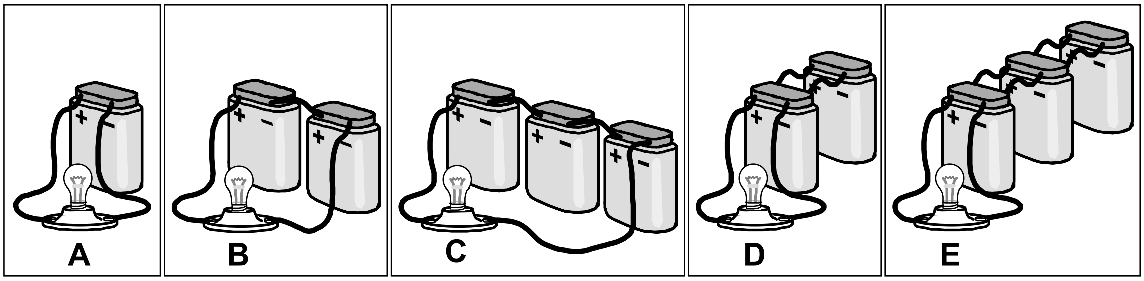
Answer: C > B > A > D.

The resistance is directly proportional to the length and inversely proportional to the cross-sectional area. Since the cross-sectional area is proportional to the square of the diameter, if two resistors have the same length but one has a diameter that is twice as large as the other, the resistance of the wider one will be one-fourth the resistance of the narrower one. In this case, the resistance of A is twice the resistance of D; the resistance of B is twice the resistance of A; and the resistance of C is twice the resistance of B.

D2-WWT02: Batteries and Light Bulbs—Bulb Brightness

All of the batteries in the circuits shown are identical, as are the light bulbs. A student comparing the brightness of the bulbs in these circuits states:

"Bulbs E and C are the brightest since they have three batteries, then bulbs B and D since they have two batteries, and the least bright one is A, since there is only one battery. The more batteries, the brighter the bulb, and it does not matter how they are connected."



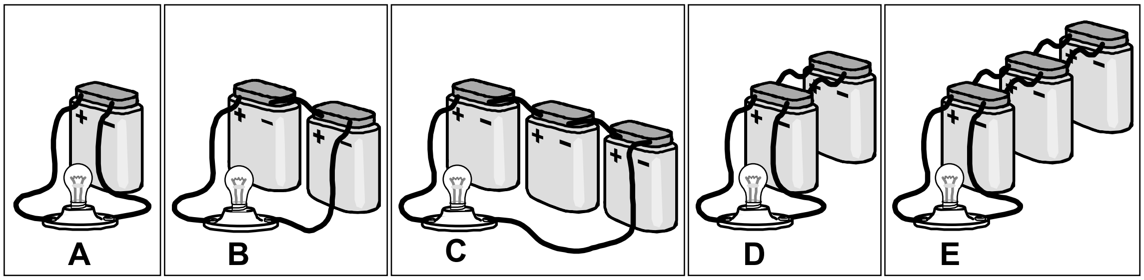
What, if anything, is wrong with this statement? If something is wrong, explain the error and how to correct it. If the statement is correct, explain why.

Answer: The statement is incorrect, because the arrangement of the batteries determines the brightness of the bulbs and not the number of bulbs.

The circuits in cases A, D, and E have the batteries connected in parallel with each other so the potential difference across the bulb in these cases is the voltage of a single battery. Thus the current in the bulb, and consequently the brightness, will be the same for all three. In case C the batteries are connected in series, and the voltage across the bulb is three times the voltage of a single battery, and similarly in case B, the voltage across the bulb is twice the voltage of a single battery. The ranking of the bulb brightnesses is therefore C > B > A = D = E.

D2-RT03: Batteries and Light Bulbs—Bulb Brightness

Identical ideal batteries are connected in different arrangements to identical light bulbs as shown.



Rank the brightness of the light bulbs.

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

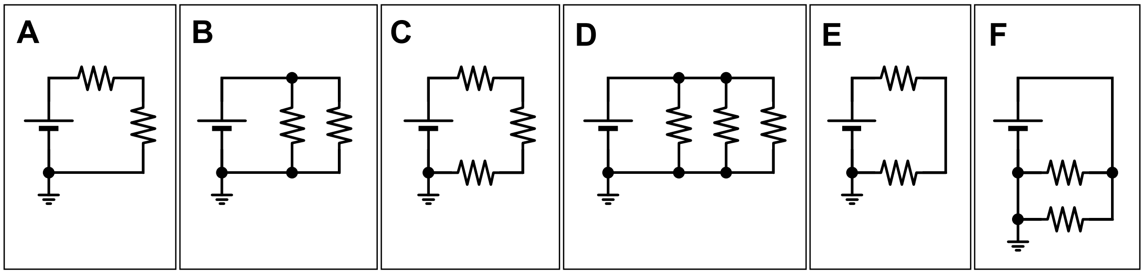
Explain your reasoning.

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

The circuits in cases A, D, and E have the batteries connected in parallel with each other so the potential difference across the bulb in these cases is the voltage of a single battery. In case C the batteries are connected in series, and the voltage across the bulb is three times the voltage of a single battery, and similarly in case B, the voltage across the bulb is twice the voltage of a single battery. The ranking of the brightness of the bulbs is the same as the ranking of the voltage differences across the bulbs, since the bulbs are identical.

D2-RT04: Simple Resistor Circuits I—Resistance

All of the resistors and batteries are identical in the circuits shown.



Rank the resistance that the circuits present to the battery.

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

Explain your reasoning.

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

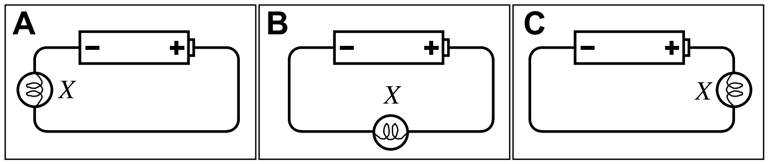
Since resistances add for resistors in series C will have the largest resistance. A and E are the same because they both have two resistors in series. B and F have two resistors in parallel so the resistance of those arrangements is R/2. And D has a resistance of R/3 since it has three resistors in parallel.

D2-RT05: Simple Light Bulb Circuits I—Bulb Brightness

All of the bulbs in the circuits below are identical, as are all of the batteries.

For the three items below, rank the brightness of the bulb labeled *X*.

(a)



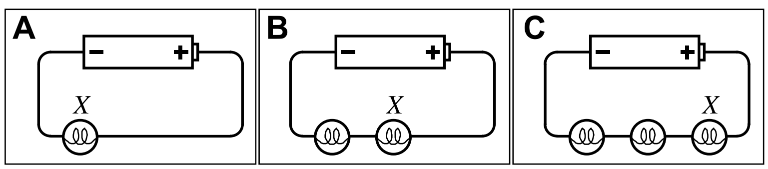
			OR			
1 Greatest	2	3 Least		All the same	All zero	Cannot determine

Explain your reasoning.

Answer: All the same.

The voltage drop across the bulb must be the same as the voltage of the battery, and the position of the bulb is irrelevant.

(b)



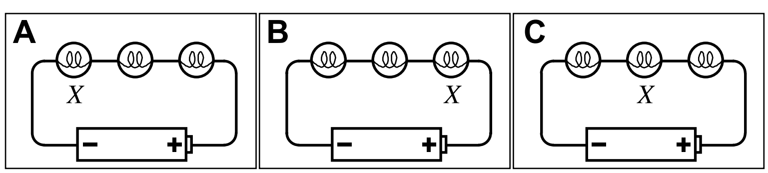
			OR			
1 Greatest	2	3 Least		All the same	All zero	Cannot determine

Explain your reasoning.

Answer: A > B > C.

The bulbs are in series for each circuit, and the resistance of the circuit increases for each bulb added in series. A large circuit resistance corresponds to a small current. Since all of the bulbs in each circuit will have the same current, the brightness will be determined by the potential differences across the bulbs.

(c)



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

Explain your reasoning.

Answer: All the same.

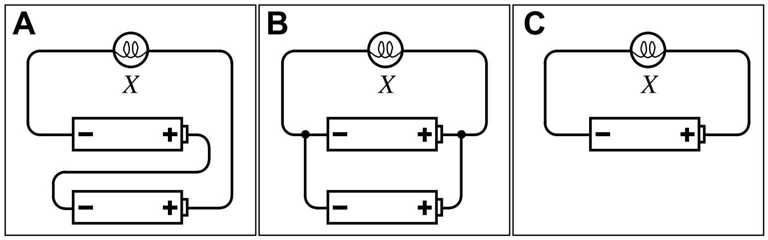
All of the bulbs have the same current and potential difference, so they have the same brightness.

D2-RT06: Simple Light Bulb Circuits II—Bulb Brightness

All of the bulbs in the circuits below are identical, as are all of the batteries.

In each of the items below rank the brightness of the bulb labeled *X*.

(a)



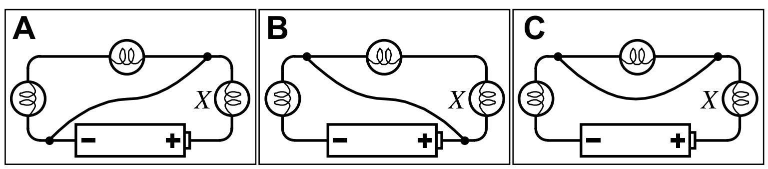
1 Greatest	2	3 Least	OR	All the same	All zero	Cannot determine

Explain your reasoning.

Answer: A > B = C.

Putting two batteries in series—case A—doubles the potential difference across the bulb compared to a single battery. In cases B and C, the voltage across the bulb is equal to one battery voltage. Putting batteries in parallel—case B—does not change the potential difference.

(b)



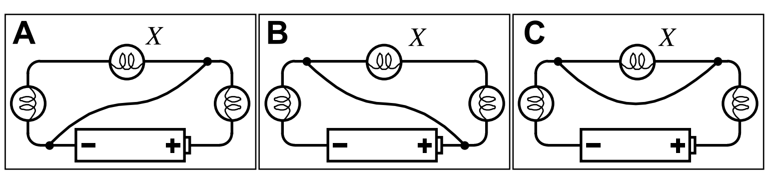
1 Greatest	2	3 Least	OR	All the same	All zero	Cannot determine

Explain your reasoning.

Answer: A > C > B.

In case A the voltage across bulb X is the battery voltage. In case B, the branch containing bulb X has no voltage difference from one end to the other, because the diagonal wire connects the ends, and so bulb X will not light. In case C, the wire provides a path with no resistance across the middle bulb, and the voltage across each of the other bulbs is half the battery voltage.

(c)



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

Explain your reasoning.

Answer: All zero.

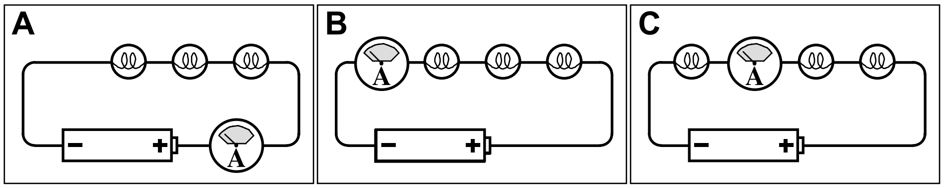
Bulb X will not have a current in any of these three cases because the wire provides a zero resistance path in parallel with bulb X.

D2-RT07: Simple Light Bulb Circuits I—Ammeter Reading

All of the bulbs in the circuits below are identical, as are all of the batteries.

For the two items below rank the current measured by the ammeter.

(a)



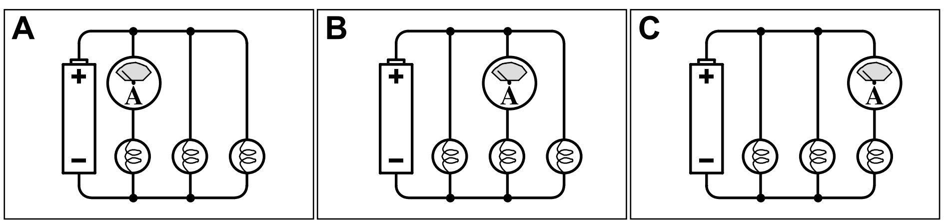
☐	☐	☐	OR	☐	☐	☐
1 Greatest	2	3 Least		All the same	All zero	Cannot determine

Explain your reasoning.

Answer: All the same.

There is only one path for the current and the resistance is the same in all cases. The current must be the same at all points in each circuit.

(b)



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

Explain your reasoning.

Answer: All the same.

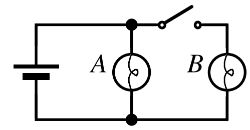
Since the three bulbs are identical the current from the battery will split into three equal parts in the three parallel branches.

D2-CT08: CIRCUIT WITH TWO LIGHT BULBS—CURRENT IN BULB

A battery is connected to a circuit with two bulbs and a switch as shown.

When the switch is closed, does the current in bulb *A* (i) *increase,* (ii) *decrease,* or (iii) *remain the same*? _____

Explain your reasoning.



Answer: (iii) The current in bulb A remains the same.

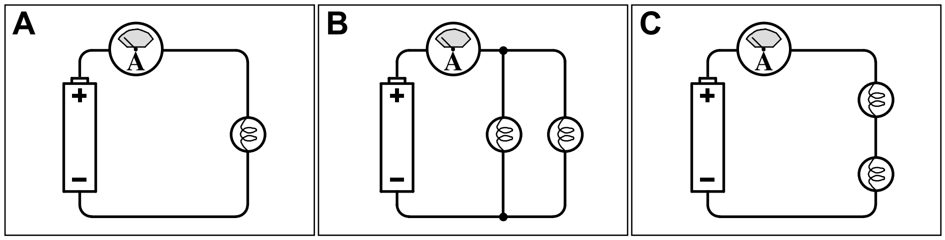
The voltage across bulb A does not change when the switch closes, because the voltage across the bulb must be the same as the battery voltage, and this voltage doesn't change. Since the voltage across the bulb doesn't change, the current in the bulb doesn't change.

D2-RT09: Simple Light Bulb Circuits II—Ammeter Reading

All of the bulbs in the circuits below are identical, as are all of the batteries.

For the two items below rank the current measured by the ammeter.

(a)



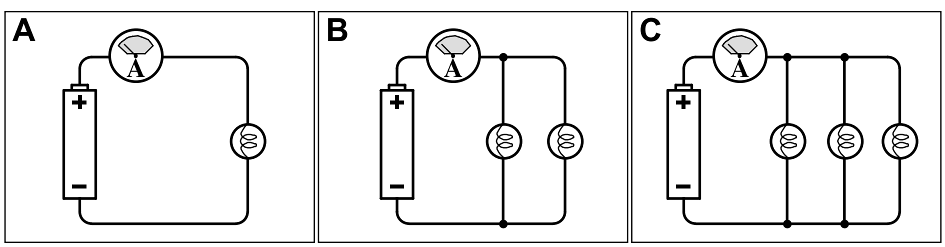
			OR			
1 Greatest	2	3 Least		All the same	All zero	Cannot determine

Explain your reasoning.

Answer: B > A > C.

The ammeter reads the current from the battery in each case, which depends on the total resistance of the circuit. Adding resistances in series increases the total resistance while adding them in parallel reduces the total resistance.

(b)



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

Explain your reasoning.

Answer: C > B > A.

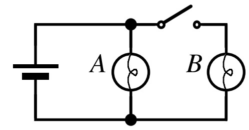
The ammeter is positioned to measure the current in the battery, which depends on the overall resistance of thecircuit. Adding resistances in parallel reduces the total resistance, so the larger the total resistance the smaller the current.

D2-CT10: CIRCUIT WITH TWO LIGHT BULBS—CURRENT IN BATTERY

A battery is connected to a circuit with two bulbs and a switch as shown.

When the switch is closed, does the current in the battery (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

Explain your reasoning.



Answer: (i) The current in the battery increases.

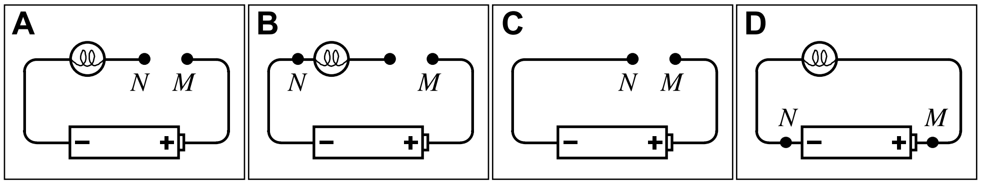
When the switch closes, the resistance of the circuit decreases because a path is added for charge to travel in. Since the resistance of the circuit decreases, the current in the battery increases. The current in bulb A remains the same when the switch closes (the voltage across bulb A doesn't change), and when the switch closes additional current from the battery is supplied for bulb B.

D2-RT11: Simple Light Bulb Circuits I—Potential Difference between Two Points

All of the bulbs in the circuits below are identical, as are all of the batteries.

In each item below, rank the magnitude of the potential difference between points *M* and *N*.

(a)



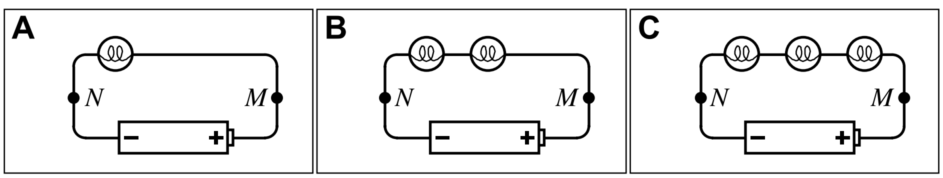
1 Greatest	2	3	4 Least	OR	All the same	All zero	Cannot determine

Explain your reasoning.

Answer: All the same.

In all four cases N is connected by a wire to the negative terminal of the battery and M is connected to the positive terminal. Since the batteries are all identical the potential differences are all the same.

(b)



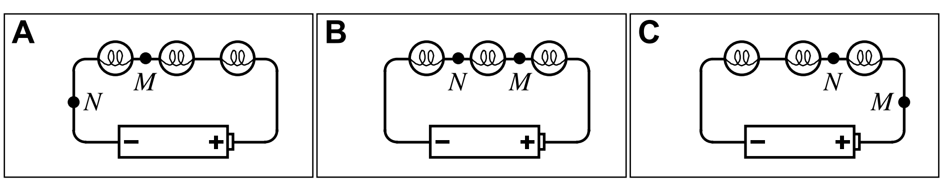
1 Greatest	2	3 Least	OR	All the same	All zero	Cannot determine

Explain your reasoning.

Answer: All the same.

In all four cases N is connected by a wire to the negative terminal of the battery and M is connected to the positive terminal. Since the batteries are all identical the potential differences are all the same.

(c)



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

Explain your reasoning.

Answer: All the same.

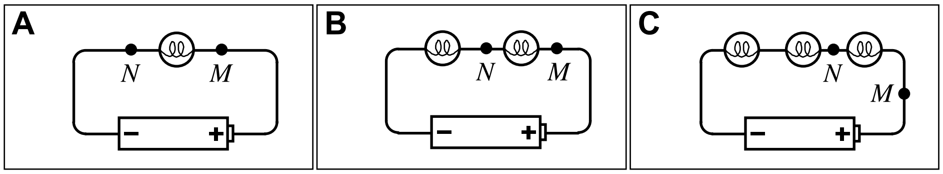
Here the potential difference for all three is the potential difference across one bulb when all the bulbs are identical and are in the same branch, so they have the same current.

D2-RT12: SIMPLE LIGHT BULB CIRCUITS II—POTENTIAL DIFFERENCE BETWEEN TWO POINTS

All of the bulbs in the circuits below are identical, as are all of the batteries.

For the two items below, rank the magnitude of the potential difference between points *M* and *N*.

(a)



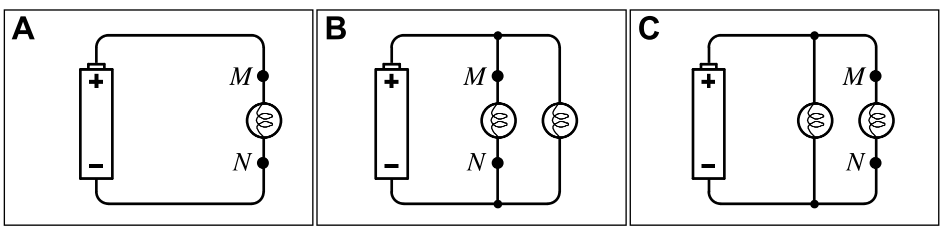
1 Greatest ____ 2 ____ 3 Least ____ OR All the same ____ All zero ____ Cannot determine ____

Explain your reasoning.

Answer: A > B > C.

The potential difference between points M and N is the potential across a single bulb in all cases. The potential across each bulb in case C is one-third the battery voltage, because the current in each bulb is the same and the bulbs are identical, and these potentials must add to the battery voltage. Similarly, the potential across each bulb in case B is half the battery voltage, and the potential across the bulb in case A is the full battery voltage.

(b)



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

Explain your reasoning.

Answer: All the same.

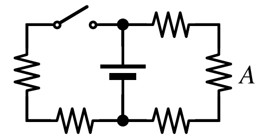
In each case, point M is connected by a wire to the top of the battery and point N is connected by a wire to the bottom of the battery, so the potential difference between points M and N is the battery voltage.

D2-CT13: Resistor Circuit with Switch—Current

Five identical resistors and a switch are connected to a battery as shown.

When the switch closes, will the current in resistor *A* (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

Explain your reasoning.



Answer: (iii) The current will remain the same.

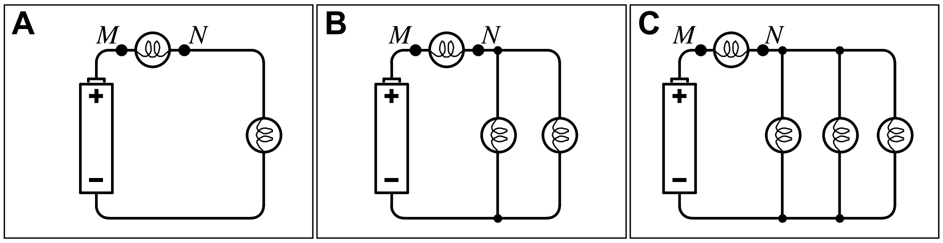
The resistance of the branch on the right containing three resistors is the sum of the resistances. The current in the branch (and therefore the current in bulb A) is the battery voltage divided by the resistance of the branch, and this is true whether the switch is open or closed.

D2-RT14: Simple Light Bulb Circuits III—Potential Difference between Two Points

All of the bulbs in the circuits below are identical, as are all of the batteries.

For the two items below, rank the magnitude of the potential difference between points *M* and *N*.

(a)



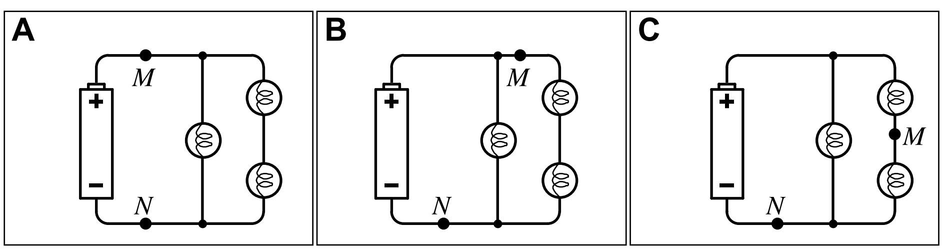
1 Greatest	2	3 Least	OR	All the same	All zero	Cannot determine

Explain your reasoning.

Answer: C > B > A.

Adding extra paths in parallel in B and C reduces the total resistance of the circuit, so the battery will supply more current. Since in each case the current in the bulb between points M and N is the battery current, the voltage across this bulb is larger for larger battery currents.

(b)



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

Explain your reasoning.

Answer: A = B > C.

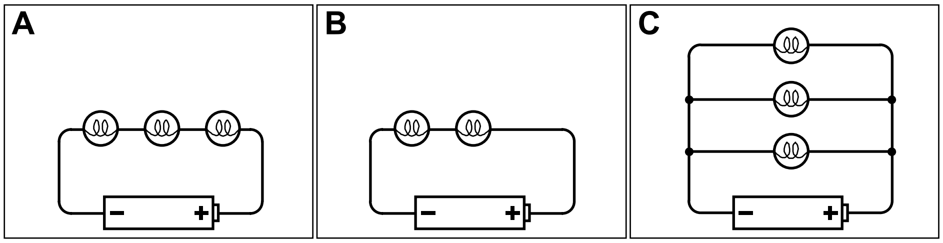
For A and B the potential difference will be the same as the battery potential because point M is connected by a wire to the top of the battery and point N is connected by a wire to the bottom of the battery. In case C the voltage across the bulb above point M must be the same as the voltage across the bulb below point M, because these bulbs are in the same branch and have the same current. Since these voltages add to the battery voltage, each of these bulbs has a potential difference of half the battery voltage across it, and so the potential difference between points M and N is half the battery voltage.

D2-RT15: SIMPLE LIGHT BULB CIRCUITS I—CURRENT IN BATTERY

All of the bulbs in the circuits below are identical, as are all of the batteries.

For the two items below, rank the current in the battery.

(a)



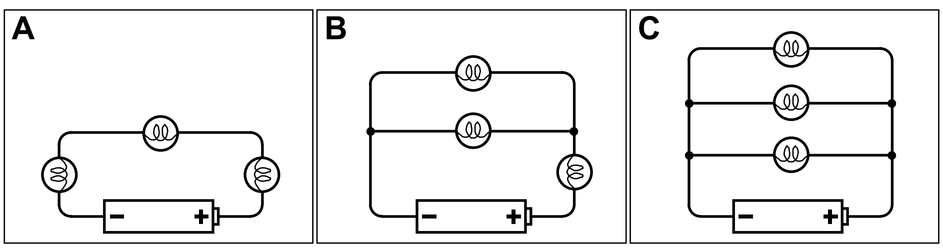
___	___	___	OR	☐	☐	☐
1 Greatest	2	3 Least		All the same	All zero	Cannot determine

Explain your reasoning.

Answer: C > B > A.

Bulbs placed in series add resistance to the circuit, which decreases the current from the batttery, while bulbs placed in parallel add paths to the circuit, which reduces the resistance and increases the current.

(b)



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

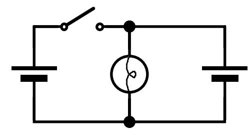
Explain your reasoning.

Answer: C > B > A.

There are three paths for the current in case C, each with the resistance of a single bulb. The multiple paths act to create a lower resistance. In case B, there is a single bulb in series with two bulbs in parallel, and the resistance of these three bulbs will be greater than the resistance of a single bulb but will be less than two bulbs in series. In case A, the three bulbs in series act to create a comparatively large resistance. The current in the battery gets larger as the equivalent resistance of the circuit gets smaller.

D2-CT16: CIRCUIT WITH TWO BATTERIES—BULB BRIGHTNESS

Two identical ideal batteries, a switch, and a bulb are connected as shown.



When the switch closes, will the brightness of the bulb (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

Explain your reasoning.

Answer: (iii) The bulb brightness will remain the same.

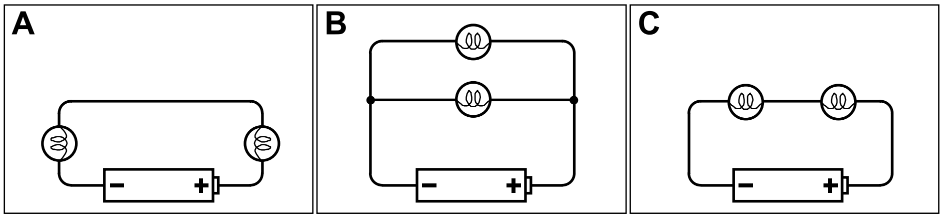
With the switch open, the electric potential difference across the bulb is equal to the voltage of the battery on the right, because the top (positive terminal) of the battery is connected by a wire to the top of the bulb, and the bottom (negative terminal) of the battery is connected by a wire to the bottom of the bulb. When the switch closes, the electric potential difference is still the same, since both batteries are identical. Since the voltage across the bulb does not change, the brightness of the bulb does not change either.

D2-RT17: Simple Light Bulb Circuits II—Current in Battery

All of the bulbs in the circuits below are identical, as are all of the batteries.

For the two items below, rank the current in the battery.

(a)



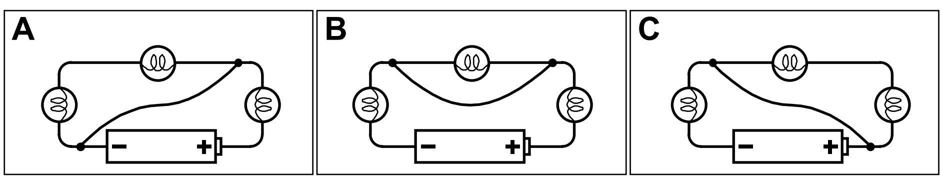
1 Greatest	2	3 Least	OR	All the same	All zero	Cannot determine

Explain your reasoning.

Answer: B > A = C.

In cases A and C there are two bulbs in series, creating a resistance that is greater than the resistance of a single bulb. Circuit B has two bulbs in parallel, and the multiple paths act to reduce the resistance, so the resistance in circuit B is smaller than the resistance of a single bulb. The battery current is largest where the circuit resistance is smallest.

(b)



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

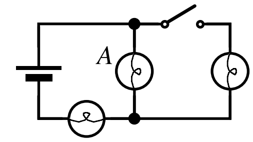
Explain your reasoning.

Answer: A = C > B.

There is no resistance in the wire, and when the wire is placed in parallel with the bulbs, all of the current is in the wire and there is no current in those bulbs – the bulbs are "shorted." In cases A and C two bulbs are shorted, leaving an equivalent resistance of only one bulb, while in case B only one bulb is shorted, leaving an equivalent resistance of two bulbs in series.

D2-CT18: LIGHT BULB CIRCUIT WITH SWITCH—CURRENT IN BULB

Three light bulbs and a switch are connected to a battery as shown.



When the switch is closed, will the current in bulb *A* (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

Explain your reasoning.

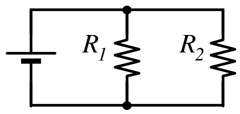
Answer: (ii) The current will decrease.

With the switch open, the current in bulb A is the same as the current in the lower bulb. Since the current is the same, the electric potential difference across the two lit bulbs must be the same, and they must add to the battery voltage. So the electric potential difference across bulb A is half the battery voltage. When the switch closes, the overall resistance of the circuit is reduced because a path is added, so the current in the battery increases, and the current in the lower bulb must increase because it is the same as the battery current. So the electric potential difference across the lower bulb is greater than half the battery voltage after the switch closes. This electric potential difference and the one across bulb A still add to the battery voltage (Kirchhoff's loop rule), and so the voltage across bulb A is less than half the battery voltage after the switch closes. Since the voltage across bulb A is reduced from half the battery voltage to less than half when the switch closes, the current in bulb A must go down when the switch closes.

D2-QRT19: TWO RESISTOR CIRCUITS—CURRENT, RESISTANCE, AND VOLTAGE DROP CHART

For items (a) and (b) below complete the table, showing the value of the currents in and voltages across all elements.

(a) The resistance values for this circuit are given in the table, as is the battery voltage.



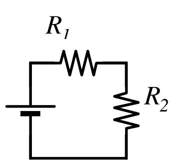
	ΔV	I	R
Battery	15.0 V		
R_1			5.0 Ω
R_2			3.0 Ω

Explain your reasoning.

Answer: The resistors have the same voltage drop as the battery voltage, because the tops of the resistors are connected by a wire to the positive terminal of the battery, and the bottoms of the resistors are connected to the negative terminal of the battery. The currents in the resistors can be found using Ohm's law •V=IR, and these currents add together to give the current in the battery.

	ΔV	I	R
Battery	15.0 V	8.0 A	
R_1	15.0 V	3.0 A	5.0 Ω
R_2	15.0 V	5.0 A	3.0 Ω

(b) The resistance values for this circuit are given in the table, as is the current in the battery.



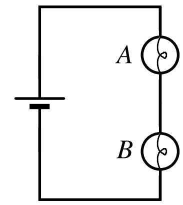
	ΔV	I	R
Battery		4.0 A	
R_1			2.0 Ω
R_2			1.0 Ω

Explain your reasoning.

Answer: The resistors have the same current as the battery since the battery and resistors are in series with each other. The voltage across the resistors can be found using Ohm's law, •V=IR. The potential drops across the resistors add together to equal the voltage drop across the battery.

	ΔV	I	R
Battery	12.0 V	4.0 A	
R_1	8.0 V	4.0 A	2.0 Ω
R_2	4.0 V	4.0 A	1.0 Ω

D2-CT20: Two Light Bulbs in a Circuit—Bulb Brightness



Two identical light bulbs are connected to a battery as shown.

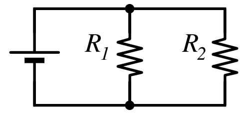
Is bulb *A* (i) *brighter than,* (ii) *dimmer than,* or (iii) *the same brightness as* bulb *B?* _____

Explain your reasoning.

Answr: (iii) The two bulbs will have the same brightness.

Since there are no branches in the circuit, all of the current in the battery will go through bulb A and through bulb B. Identical bulbs with equal current in them will have equal brightness.

D2-LMCT21: Two Resistors in Parallel—Battery Current



For the circuit shown, identify, from choices (i)–(iv), how each change described below will affect the current in the battery.

This change will:

(i) ***increase*** the current in the battery.
(ii) ***decrease*** the current in the battery.
(iii) ***have no effect*** on the current in the battery.
(iv) have an effect on the current in the battery that ***cannot be determined***.

All of these modifications are changes to the initial situation that is shown.

(a) The resistance in R_1 is reduced. _____
Explain your reasoning.

(i) The current in the battery will increase since the equivalent resistance of the circuit decreases.

(b) The resistance in R_2 is reduced. ______
Explain your reasoning.

(i) The current in the battery will increase since the equivalent resistance of the circuit decreases.

(c) The resistance in R_1 and R_2 are increased by the same amount. ______
Explain your reasoning.

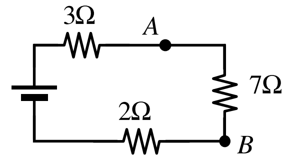
(ii) The current in the battery will decrease since the equivalent resistance of the circuit increases.

(d) The resistance in R_1 is reduced, and in R_2 it is increased. ______
Explain.

(iv) The effect cannot be determined, because the equivalent resistance might increase or decrease depending on specifics of what each resistor was initially and how much each resistance changes.

D2-CT22: CIRCUIT WITH THREE RESISTORS—CURRENT

Three resistors are connected to a battery as shown. Two points in the circuit are labeled *A* and *B*.



Is the current at point *A* (i) *greater than*, (ii) *less than*, or (iii) *equal to* the current at point *B*? _____

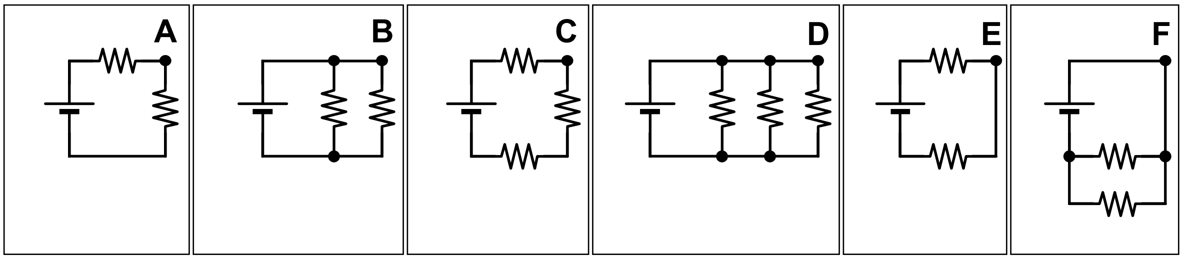
Explain your reasoning.

Answer: (iii) The current at point A is equal to the current at point B.

All of the charge that travels through one of these points must also travel through the other point, because there are no branches in the circuit. Since charge does not accumulate at any point in the circuit, the amount of charge passing any point in the circuit in a given amount of time – the current – is the same at all points in this circuit.

D2-RT23: Simple Resistor Circuits I—Current

All of the resistors in the circuits shown are identical, as are all of the batteries.



Rank the current at the upper right-hand corner of each circuit.

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

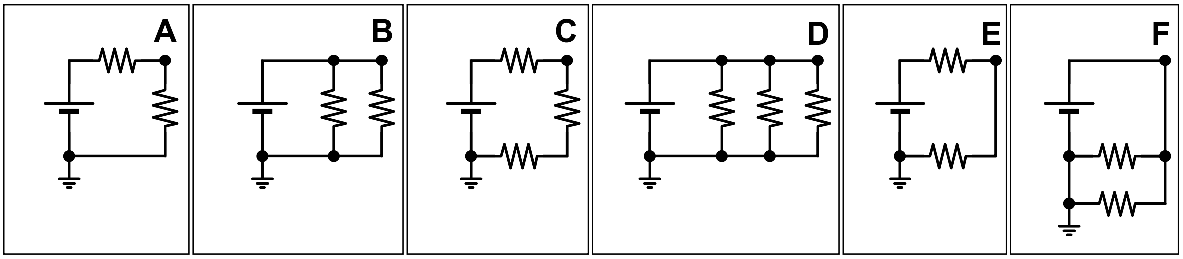
Explain your reasoning.

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

In cases B, D, and F, each resistor has one end connected by a wire to the top of the battery and the other end connected by a wire to the bottom of the battery. The voltage across each resistor in these circuits is therefore the battery voltage V, and the current in each resistor is V/R. In cases B and D the current in the upper right hand corner is the same, since in these cases it is equal to the current in the resistor below that point, or V/R. The current in case F is twice as big, since the current in the upper right hand corner is equal to the current in two resistors. In cases A, E, and C, the resistors are connected in series, and the current in the battery is equal to the battery voltage divided by the sum of the resistances, which is 2R in cases A and E, and 3R in case C. In these cases, the current in the upper right hand corner is the same as the battery current, since there are no junctions in the circuits. This current is V/2R in cases A and E, and V/3R in case C.

D2-RT24: SIMPLE RESISTOR CIRCUITS WITH A GROUND—VOLTAGE

All of the resistors in the circuits below are identical, as are all of the batteries.



Rank the voltage at the upper right-hand corner of the circuits relative to ground.

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

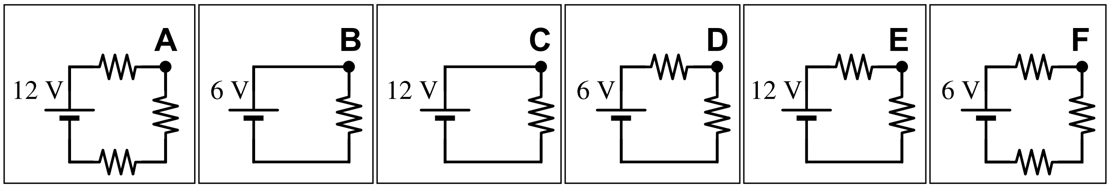
Explain your reasoning.

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

For cases B, D and F the upper right corner is connected by a wire to the positive terminal of the battery, which is higher in voltage than the negative terminal (connected to ground, or zero volts) by the voltage of the battery. In cases B, D, and F, then, the upper right hand corner has a voltage equal to the battery voltage V and is the same in theses cases. In cases A, C, and E, the resistors are connected in series, and the current in each one is the same, so the voltage drop across each resistor in the circuit is the same. In cases A and E each resistor must have a voltage across it of one-half the battery voltage, and in case C each resistor has one-third of the battery voltage across it. In case C, the voltage at the upper right hand corner must therefore be two-thirds of the battery voltage, and in cases A and E it must be one-half of the battery voltage.

D2-RT25: SIMPLE RESISTOR CIRCUITS II—CURRENT

All of the resistors in the circuits below are identical. Three of the circuits contain 6-volt batteries and three contain 12-volt batteries.



Rank the current at the upper right-hand corner of each circuit.

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

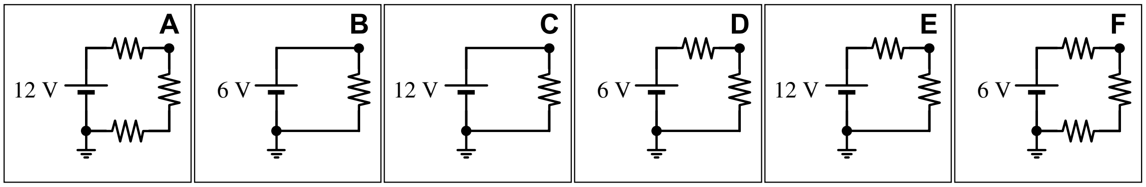
Explain your reasoning.

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

The resistors in each circuit are connected in series, and the current in each resistor is the same as the current in the battery. Because the resistors in each circuit are in series and the resistors are identical the voltage drop across each resistor is equal to the battery voltage divided by the number of resistors in the circuit. The voltage drop across each resistor is 12 volts in case C, 6 volts in cases B and E, 4 volts in case A, 3 volts in case D, and 2 volts in case F. The current in the upper right hand corner is the current in a single resistor of the circuit, which is proportional to the voltage drop across that resistor (since all of the resistors are identical).

D2-RT26: SIMPLE RESISTOR CIRCUITS WITH A GROUND—VOLTAGE DROP

The following circuits contain either a 6-volt or a 12-volt battery and one or more identical resistors.



Rank the reading on a voltmeter connected between the upper right-hand corner and ground.

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

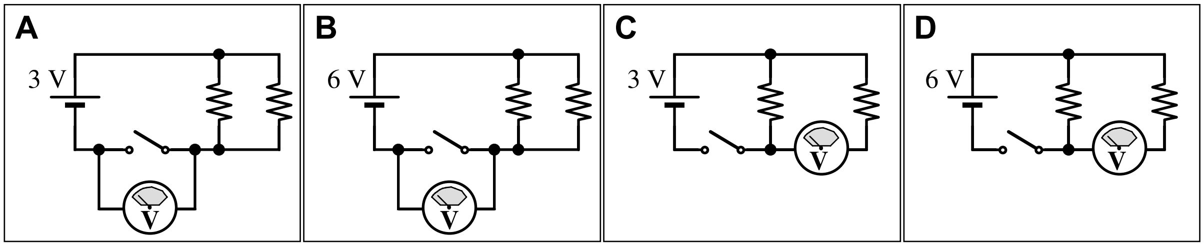
Explain your reasoning.

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

In cases B and C the voltmeter is connected across the battery, i.e., the upper right corner is connected by a wire to the positive terminal of the battery, which is higher in voltage than the negative terminal which is connected to ground. The voltmeter reads the battery voltage in these cases. In cases A, D, E, and F, the resistors are connected in series, and the current in each one is the same, so the voltage drop across each resistor in the circuit is the same. In cases D and E each resistor must have a voltage across it of one-half the battery voltage, and in cases A and F each resistor has one-third of the battery voltage across it. In cases A and F, the voltage at the upper right hand corner must therefore be two-thirds of the battery voltage, and in cases D and E it must be one-half of the battery voltage. The voltmeter reading is 8 volts in case A, 6 volts in case B, 12 volts in case C, 3 volts in case D, 6 volts in case E, and 4 volts in case F.

D2-RT27: PARALLEL CIRCUITS I—VOLTMETER READINGS ACROSS OPEN SWITCHES

All of the resistors in the circuits below are identical. The switch in each case is open.



Rank the voltmeter readings.

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

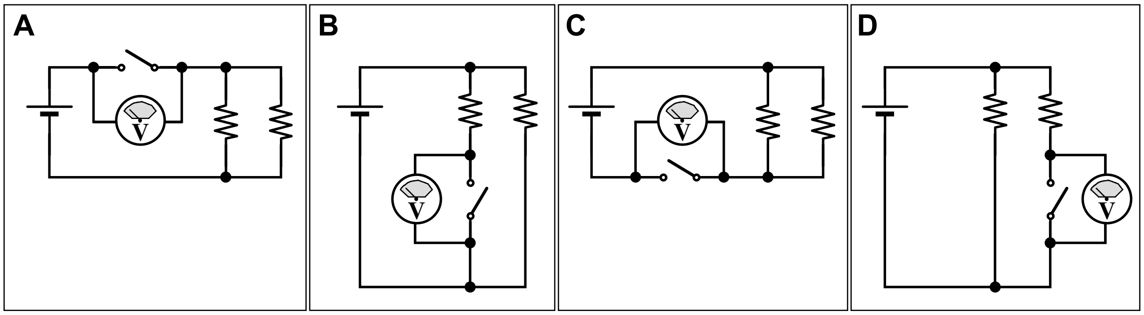
Explain your reasoning.

Answer: B > A > C = D.

In cases A and B, neither the open switch nor the voltmeter allow current to the battery, and so there is no current in the circuit. For this reason, there is no voltage across the resistors, and so the voltage at the right terminal of the voltmeter is the same as the voltage at the positive terminal of the battery. Since the left side of the voltmeter is connected to the negative terminal of the battery, the voltage drop across the meter is the battery voltage. In cases C and D there is also no current in the battery or in the resistors, and there is no voltage drop across the resistors. Both sides of the voltmeter are therefore at the same voltage, that of the positive terminal of the battery, and there is no voltage across the voltmeter.

D2-RT28: PARALLEL CIRCUITS II—VOLTMETER READINGS ACROSS OPEN SWITCHES

All of the resistors in the circuits below are identical, as are all of the batteries. The switch in each case is open.



Rank the voltmeter readings.

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

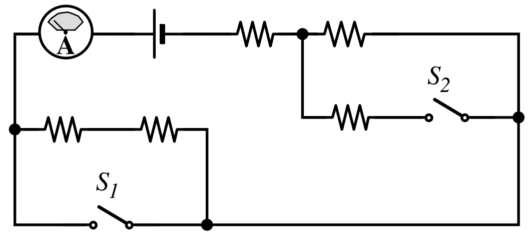
Explain your reasoning.

Answer: All the same.

In cases A and C, the open switch and the voltmeter won't provide paths for current to the battery, and so there is no current in the circuit. For this reason, the voltage on one terminal of the voltmeter is the same as the voltage of the positive terminal of the battery, and the voltage on the other terminal is the same as the negative terminal of the battery. In cases B and D, the open switch and the voltmeter don't allow current in the branch of the circuit that the voltmeter is connected to, so there is no current and no voltage drop across the resistor in that branch. Again, one terminal of the voltmeter will be at the same voltage as the positive terminal of the battery, and the other terminal will be at the same voltage as the negative terminal. The voltmeter readings in all cases will be the same as the battery potential.

D2-RT29: Circuit with Two Switches—Ammeter Readings

The circuit contains a battery, two switches, five identical resistors, and an ammeter. Four possible switch configurations (open or closed) for the circuit are shown in the table.



Configuration	Switch S_1	Switch S_2
A	Open	Open
B	Open	Closed
C	Closed	Open
D	Closed	Closed

Rank the ammeter reading for the four configurations.

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

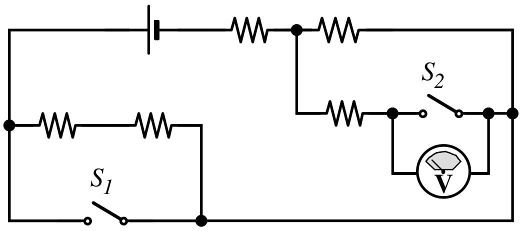
Explain your reasoning.

Answer: D > C > B > A.

Closing switch S_1 provides a path with no resistance around two resistors, effectively removing these resistors from the circuit. Closing switch S_2 adds a path to the circuit, reducing the effective resistance for that portion of the circuit from R to R/2. The equivalent resistance of the circuit is 4R in case A, 3.5R in case B, 2R in case C, and 1.5R in case D. The smaller the resistance the larger the current in the ammeter.

D2-RT30: CIRCUIT WITH TWO SWITCHES—VOLTMETER READINGS

The circuit contains a battery, two switches, five identical resistors, and a voltmeter. Four possible switch configurations (open or closed) for the circuit are shown in the table.



Configuration	Switch S_1	Switch S_2
A	Open	Open
B	Open	Closed
C	Closed	Open
D	Closed	Closed

Rank the voltmeter reading for the four configurations.

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

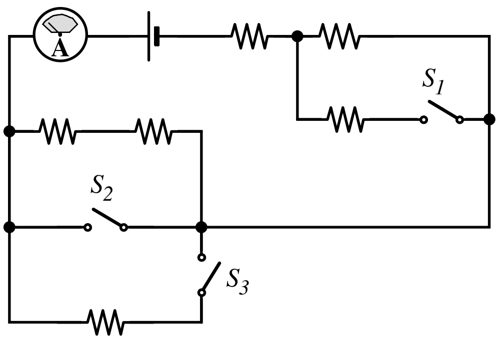
Explain your reasoning.

Answer: C > A > B = D.

When switch S_2 is closed the voltmeter will read zero, because the terminals of the voltmeter are connected by a conducting path. When switch S_2 is open there is no current in the branch containing the voltmeter, and the voltage it measures is the voltage across the resistor in the parallel branch, which is proportional to the current in the battery. The current in the battery is larger when S_1 is closed because closing switch S_1 provides a path with no resistance around two resistors, effectively removing these resistors from the circuit.

D2-RT31: Circuit with Three Switches—Ammeter Readings

The circuit contains a battery, three switches, six identical resistors, and an ammeter. Eight possible switch configurations (open or closed) for the circuit are shown in the table.



Configuration	S_1	S_2	S_3
A	Open	Open	Open
B	Open	Open	Closed
C	Open	Closed	Open
D	Open	Closed	Closed
E	Closed	Open	Open
F	Closed	Open	Closed
G	Closed	Closed	Open
H	Closed	Closed	Closed

Rank the current in the ammeter for these switch configurations.

								OR		
1 Greatest	2	3	4	5	6	7	8 Least		All the same	Cannot determine

Explain your reasoning.

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

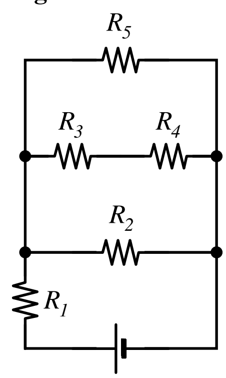
Closing switch S_2 provides a path of no resistance, effectively removing the three ressitors at the lower left from the circuit. If S_2 is open, closing switch S_3 adds a parallel branch to the circuit, lowering the resistance from 2R to 2R/3. Closing S_1 adds a parallel path, lowering the effective resistance of the two resistors in the upper right portion of the circuit from R to R/2. The ammeter reading is largest when the effective resistance of the circuit is smallest. The overall circuit resistance is 4R for case A, 2.67R for case B, 2R for cases C and D, 3.5R for case E, 2.17R for case F, and 1.5R for cases G and H.

D2-QRT32: FIVE RESISTOR CIRCUITS—CURRENT, RESISTANCE, AND VOLTAGE DROP

Four of the five resistance values for this circuit are given in the table, as is the battery voltage and the current in resistor R_3.

Complete the table, showing the value of R_1 and the currents in and voltages across all elements.

	ΔV	I	R
Battery	72.0 V		
R_1			
R_2			2.0 Ω
R_3		4.0 A	5.0 Ω
R_4			1.0 Ω
R_5			3.0 Ω



Explain your reasoning.

Answer: The current in R_3 is the same as the current in R_4 since they are in the same branch. The voltage drop across these resistors is found using Ohm's law, and the voltage across the branch is the sum of these voltage drops, 24V. The voltage across R_1 is the battery voltage minus the voltage across the parallel branches, 72V – 24V = 48V. The resistance of R_1 can now be found using Ohm's Law.

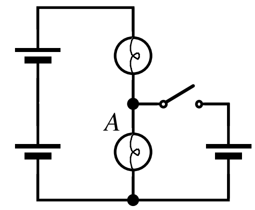
	ΔV	I	R
Battery	72.0 V	24.0 A	
R_1	48.0 V	24.0 A	2.0 Ω
R_2	24.0 V	12.0 A	2.0 Ω
R_3	20.0 V	4.0 A	5.0 Ω
R_4	4.0 V	4.0 A	1.0 Ω
R_5	24.0 V	8.0 A	3.0 Ω

D2-CT33: LIGHT BULBS CIRCUIT WITH THREE BATTERIES—BULB BRIGHTNESS

Three identical ideal batteries, a switch, and two bulbs are connected as shown.

When the switch closes, will the brightness of bulb *A* (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

Explain your reasoning.

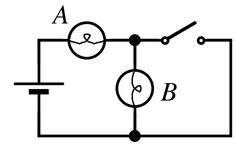


Answer: (iii) The bulb brightness will remain the same.

When the switch is open, the electric potential difference across the two bulbs is equal to twice the battery voltage, because there are two batteries connected in series across the two bulbs. The electric potential difference across bulb A is equal to one-half of this, or the voltage of one battery, because the two identical bulbs have the same current and therefore the same voltage across them, and the two voltages must add to two battery voltages. When the switch closes, the electric potential difference across bulb A must equal the electric potential difference of the battery on the right, which is equal to the potential difference of one of the other batteries since the batteries are identical. Since the voltage across bulb A does not change, the brightness of the bulb does not change either.

D2-CT34: LIGHT BULBS CIRCUIT WITH SWITCH—BRIGHTNESS OF BULBS

Two light bulbs and a switch are connected to a battery as shown.



(a) When the switch is closed, will the brightness of bulb *B* (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

Explain your reasoning.

Answer: (ii) The brightness will decrease.

With the switch open, there is current in bulb A, because there is a complete circuit consisting of the batttery and the two bulbs connected in series. The voltage across bulb B will be equal to half of the battery voltage. When the switch closes, the top of bulb B is connected by a conductor to the bottom of bulb B (through the switch), so there is no electric potential difference across bulb B. Bulb B goes out when the switch closes. An alternate way of seeing this is to recognize that there is no resistance in the branch containing the switch, and there is a resistance in the branch containing bulb B. So all of the current will travel through the branch with no resistance, or through the switch, instead of through bulb B.

(b) When the switch is closed, will the brightness of bulb *A* (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

Explain your reasoning.

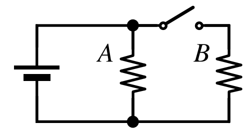
Answer: (i) The brightness will increase.

With the switch open, there is current in bulb B, because there is a complete circuit consisting of the batttery and the two bulbs connected in series. The voltage across bulb B will be equal to half of the battery voltage, and the voltage across bulb A will be equal to half the battery voltage. When the switch closes, the left side of bulb A is connected by a conductor to the positive terminal of the battery, and the right side of bulb A is connected by a conductor (through the switch) to the negative terminal of the battery. The potential difference across bulb A, then, is the voltage of the battery. Since the voltage across bulb A increases when the switch closes, the brightness of bulb A increases. An alternate way of seeing this is to recognize that there is no resistance in the branch containing the switch, and when the switch closes a path is added to the circuit that lowers the overall resistance of the circuit. As a result, the current in the battery increases, and the current in bulb A increases as well since it

D2-WWT35: CIRCUIT WITH TWO RESISTORS—CURRENT

A battery is connected to a circuit containing two resistors and a switch as shown. A student states:

"When the switch closes, the current in resistor A goes down, because resistor A now has to share the current from the battery with resistor B."



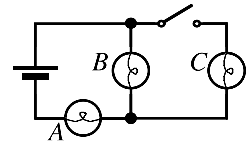
What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: The student's statement is incorrect.

The current in the battery is not fixed, it varies depending on the resistance of the circuit to which the battery is attached. When the switch closes, the resistance of the circuit goes down, because there is no another path for the current. The current in the battery increases in response to the reduced resistance of the circuit. The voltage across resistor A is equal to the voltage across the battery whether the switch is open or closed, because the top of the resistor is connected to the positive terminal of the battery by a wire and the bottom of the resistor is

D2-SCT36: LIGHT BULB CIRCUIT WITH SWITCH—BULB BRIGHTNESS

Three light bulbs and a switch are connected to a battery as shown. Four students are discussing what would happen to the brightness of bulb *A* when the switch closes:



Althea: *"The current in bulb A has to be the same as the current in the battery, since they are in the same branch. The battery is going to put out the same current whether the switch is open or closed, so the current in bulb A is going to remain the same, and its brightness won't change when the switch closes."*

Bertha: *"I agree. All that is going to happen when the switch closes is that bulb C is going to turn on, and it's going to get half of the current. Bulb B only gets half the current as well, so it gets dimmer. But bulb A still gets all the current, and its brightness doesn't change."*

Cassidy: *"I think bulb A gets brighter. The current in the circuit goes up, because when the switch closes the resistance of the circuit goes down. Since bulb A gets all the current in the circuit, it gets brighter."*

Dupree: *"When the switch closes, the resistance of the circuit goes up, because you've added one bulb, which has resistance. The current in the circuit goes down, and bulb A gets dimmer."*

With which, if any, of these students do you agree?

Althea _____ Bertha _____ Cassidy _____ Dupree _____ None of them_____

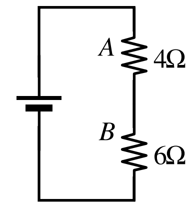
Explain your reasoning.

Answer: Cassidy is correct, the brightness of bulb A will increase.

With the switch open, the current in bulb B is the same as the current in the lower bulb. Since the current is the same, the electric potential difference across the two lit bulbs must be the same, and they must add to the battery voltage. So the electric potential difference across bulb A is half the battery voltage. When the switch closes, the overall resistance of the circuit is reduced because a path is added, so the current in the battery increases, and the current in the bulb A must increase because it is the same as the battery current. So the brightness of bulb A must go up when the switch closes.

D2-WWT37: CIRCUIT WITH TWO RESISTORS—CURRENT

A battery is connected to a circuit containing two resistors as shown. A student states:



"Using Ohm's law, the current is the voltage divided by the resistance, so when you have a bigger resister, you have a smaller current. In this case, resistor B is a larger resistance than A, so it will have a smaller current."

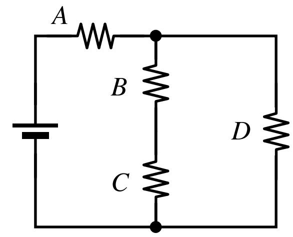
What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: The student's statement is incorrect.

Since there is only one path for charge, the current will be the same at all points in this circuit. The student is failing to take account of the third quantity in Ohm's Law the voltage, which does vary for the two resistors.

D2-WWT38: CIRCUIT WITH FOUR RESISTORS—CURRENT RANKING

A battery is connected to a circuit containing four identical resistors as shown. A student states:



"All of the current from the battery goes through resistor A. At the junction after A the current splits up. Half of the current goes through resistor D, and the other half is shared by resistors B and C. So resistor A has the most current, followed by resistor D, followed by resistors B and C, which have the same current."

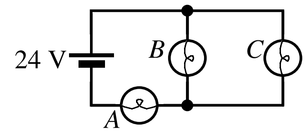
What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: The student's current ranking is correct, but the reasoning used to obtain this ranking is incorrect.

All of the current in the battery also goes through resistor A, and the current splits at the junction. But it does not split evenly as this student supposes. Since there is twice as much resistance in the branch containing resistors B and C as there is in the branch containing resistor D, there is only half as much current in the branch containing resistors B and C as in resistor D. (The voltage across the series combination of resistor B and resistor C must equal the voltage across resistor D, because B and C are connected to the same two junctions that D is connected to.) Since the current in resistor A must be the same as the current in resistor B plus the current in resistor D (applying Kirchhoff's junction rule), the current in resistor B must be one-third the current in resistor A, and the current in resistor D must be two-thirds the current in resistor A. The current in resistor B must equal the current in resistor C because the charge traveling along that branch must pass through both resistors.

D2-WWT39: CIRCUIT WITH THREE BULBS—VOLTAGES

A 24-volt battery is in a circuit containing three bulbs as shown. A voltmeter across bulb *A* measures 18 Volts. A student states:



"Since bulbs B and C are identical, then they will each have the same current and the same voltage across them. The sum of the voltages across the three bulbs must add to the battery voltage. So bulb B has a voltage of 3 volts across it, and bulb C also has a voltage of 3 volts."

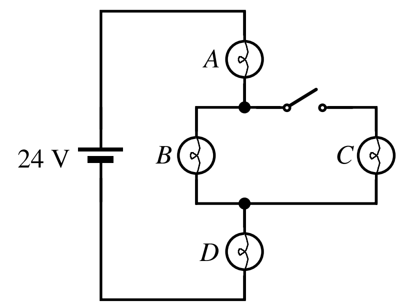
What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: The student's statement is incorrect.

The voltage around any loop must sum to zero, which means that the voltage increase across the battery must equal the voltage drop across the bulbs in a loop of the circuit containing the battery, not all of the bulbs. In this case, the sum of the voltages across bulbs A and B add to 24 volts, and the sum of the voltages across A and C add to 24 volts. Since there will be more current in bulb A, there will be more than half the battery voltage across it, or more than 12 volts, and there will be less than 12 volts across B and across C.

D2-CT40: FOUR LIGHT BULBS CIRCUIT WITH SWITCH—EFFECT OF CLOSING SWITCH

A battery is connected to four identical bulbs and a switch as shown.



(a) When the switch is closed, does the brightness of bulb *C* (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

Explain your reasoning.

Answer: (i) The brightness of bulb C increases.

With the switch open, bulb C has no current and is not lit, because there is not a complete circuit that includes bulb C. When the switch is closed, the current in bulb A will split at the junction below bulb A, with half of the current going to bulb B and half to bulb C. Bulb C will light up.

(b) When the switch is closed, does the current in the battery (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

Explain your reasoning.

Answer: (i) The current in the battery increases.

The resistance of two bulbs connected in parallel (as B and C are when the switch closes) is smaller than the resistance of a single bulb, so the resistance of the portion of the circuit containing bulbs B and C and the switch decreases when the switch closes. Since this portion of the circuit is connected in series with bulbs A and D, the overall resistance of the circuit goes down, and as a result the current in the battery increases.

(c) When the switch is closed, does the brightness of bulb *A* (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

Explain your reasoning.

Answer: (i) The brightness of bulb A increases.

Since the current in the battery increases, the current in bulb A increases as well, since these elements are in the same branch and their currents must be the same.

(d) When the switch is closed, is bulb *D* (i) *brighter* than bulb *A*, (ii) *dimmer* than bulb *A*, or (iii) *the same* brightness as bulb *A*? _____

Explain your reasoning.

Answer: (iii) The brightness of bulb D is the same as the brightness of bulb A whether the switch is open or closed.

Bulb A, bulb D, and the battery are connected in series, and the charge that goes through one of the elements per unit time (the current) must be the same as what goes through the other two as well. With the switch closed, the current in bulb A splits at the junction below A, but then recombines at the junction above D.

(e) When the switch is closed, does the brightness of bulb *D* (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

Explain your reasoning.

Answer: (i) The brightness of bulb D increases.

Since the current in the battery increases, the current in bulb D increases as well, since these currents must be equal.

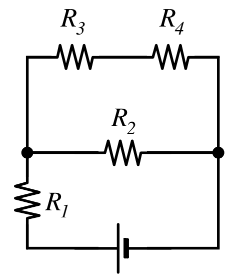
(f) When the switch is closed, does the brightness of bulb *B* (i) *increase*, (ii) *decrease*, or (iii) *remain the same*? _____

Explain your reasoning.

Answer: (ii) The brightness of bulb B decreases.

With the switch open, bulbs A, B, and D are connected in series, with each having the same current. Since these bulbs have the same current and are identical, they also have the same voltage across them, and the sum of these voltages must be equal to the battery voltage, or 24 Volts. Each of these bulbs therefore has 8 volts across it when the switch is open. When the switch closes, the current in the battery goes up (because the resistance of the circuit goes down), and so the current in bulbs A and D goes up as well. Since the current in these bulbs increases, the voltage across these bulbs also increases, and is therefore greater than 8 Volts. Whether the switch is open or closed, however, it remains true that the sum of the voltages across bulbs A, B, and D must add to the battery voltage, 24 Volts. With the switch closed, bulbs A and D have voltages across them greater than 8 Volts each, and so the voltage across bulb B must be smaller than 8 Volts. So the voltage across bulb B goes from 8 Volts when the switch is open to something less than 8 Volts, and bulb B must get dimmer.

D2-SCT41: Four Resistor Circuit I—Current



In the circuit shown, the sizes of the resistors vary as $R_3 > R_1 > R_2 > R_4$. Four students discussing the currents in this circuit make the following statements:

Ajay: *"I think the current in R_1 will be the largest because all of the current from the battery goes through it."*

Belen: *"Right, and after R_1 the current splits into two parts at the junction. The current through R_2, R_3, and R_4 will all be the same because there are two branches in the circuit and each branch will get half of the current."*

Ciara: *"From Ohm's law, current is biggest where resistance is smallest. I think the current through R_2 will be largest because that branch has the lowest resistance in the circuit."*

Damaris: *"Also using Ohm's law, I think the current in R_3 will be the smallest because R_3 has the largest resistance. The current in R_4 will be largest, because that resistor has the smallest resistance."*

Efren: *"The current in R_3 will be the same as the current in R_4 because they are in the same branch."*

With which, if any, of these students do you agree?

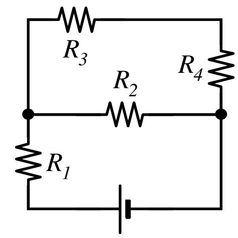
Ajay _____ Belen _____ Ciara _____ Damaris _____ Efren _____ None of them _____

Explain your reasoning.

Answer: Both Ajay and Efren's statements are correct.

As Ajay says, all of the current from the battery will go through R_1 because it is in series with the battery. Efren is also correct because R_3 and R_4 are connected in series. When the current splits at the junction above R_1, more current goes to R_2 than to R_3 and R_4, because that branch has a greater resistance. Efren is correct that the current in R_3 is the same as R_4.

D2-SCT42: Four Resistor Circuit II—Current



In the circuit shown, the sizes of the resistors vary as $R_3 > R_2 > R_4 > R_1$. Four students discussing the currents in this circuit make the following statements:

Ali: *"I think the current in R_1 will be the largest because all of the current from the battery goes through it."*

Ben: *"I think the current through R_2, R_3, and R_4 will all be the same because there are two branches in the circuit and each branch will get half of the current."*

Clyde: *"Well I disagree with Ben. I think the current in R_2 will be larger than the current in R_3 and R_4. The currents in the branches depend on the resistances of the branches."*

Dar: *"The only thing I am sure about is that the current in R_3 will be the same as that in R_4 because they are in the same branch."*

With which, if any, of these students do you agree?

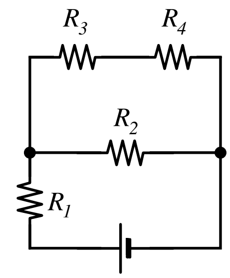
Ali _____ Ben _____ Clyde _____ Dar _____ None of them _____

Explain your reasoning.

Answer: All of the contentions except for Ben's are legitimate.

As Ali says all of the current will go through R_1 because it is in series with the battery. Clyde has correctly identified the fact that the current in parallel branches depends on the resistances in the branches. Dar is also correct because R_3 and R_4 are connected in series.

D2-SCT43: FOUR RESISTOR CIRCUIT III—POTENTIAL DIFFERENCE



In the circuit shown, the sizes of the resistors vary as $R_3 > R_1 > R_2 > R_4$. Four students discussing the potential differences in this circuit make the following statements:

Anselma: *"I think the potential difference across R_1 will be the largest because all of the current from the battery goes through it, and it is not the smallest resistance in the circuit."*

Brooke: *"I think the potential difference through R_2 will be largest because that branch will have the larger current of the two branches in the circuit."*

Chandra: *"I am not sure about the potential difference across R_1, but I think the potential differences across the two horizontal branches will be the same."*

Deangelo: *"I'm pretty sure the potential difference across R_3 will be larger than the potential difference across R_4 because R_3 has a larger resistance than R_4."*

Eloy: *"I think the two horizontal branches have the same potential difference as the battery since they are in parallel with the battery."*

With which, if any, of these students do you agree?

Anselma _____ Brooke _____ Chandra _____ Deangelo _____ Eloy _____ None of them _____

Explain your reasoning.

Answer: Both Chandra and Deangelo have made correct contentions.

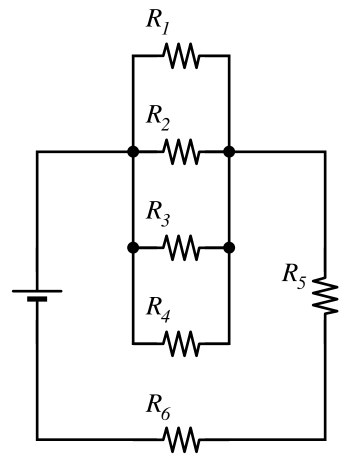
Chandra correctly points out that the potential differences across parallel branches are equal. Deangelo's contention is correct because R_3 and R_4 are connected in series so they will have the same current, which then means the potential difference across R_3 will be larger.

D2-SCT44: SIX RESISTOR CIRCUIT—CURRENT

In the circuit pictured below the sizes of the resistors vary as

$$R_3 > R_5 > R_1 > R_2 > R_4 > R_6$$

Four students discussing the currents in this circuit make the following statements:



Anne: *"I think the current in R_6 and R_5 will be the largest because all of the current from the battery goes through both of those resistors."*

Benicio: *"I think the current through R_6 will be the smallest because that resistor is the last one in the circuit to get the current, and it is the smallest resistor."*

Celestine: *"I am not sure about the largest current, but I think the current in R_3 will be the lowest because R_3 has the largest resistance."*

Dulce: *"The only thing I am sure about is that the current across R_6 will be the largest because it is the smallest resistor in the circuit."*

With which, if any, of these students do you agree?

Anne _____ Benicio _____ Celestine _____ Dulce _____ None of them _____

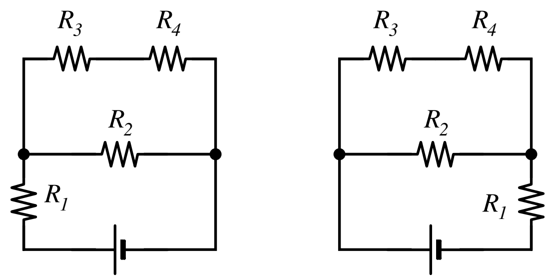
Explain your reasoning.

Answer: Anne and Celestine are both correct.

Since R_5 and R_6 are connected in series, the current in one must be the same as the current in the other. Celestine is correct because the current in the battery will split into four parts in the parallel section and the smallest current will be in the branch with the largest resistance.

D2-CT45: FOUR RESISTOR CIRCUITS III—CURRENT

For these two circuits, consider the current in the resistor R_1 closest to the battery.



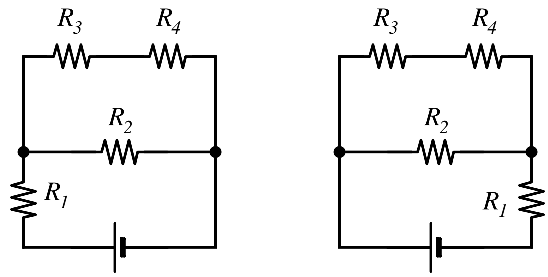
Will the current in R_1 be (i) *larger* in the circuit on the left, (ii) *smaller* in the circuit on the left, or (iii) *equal* in both circuits? _____
Explain your reasoning.

Answer: (iii) Equal in both circuits.

R_1 is in series with the battery in both cases and it doesn't matter which side of the battery it is connected to since there is only one path in each case.

D2-CT46: FOUR RESISTOR CIRCUITS III—POTENTIAL DIFFERENCE

For these two circuits, consider the potential difference across the resistor R_1 closest to the battery.



Will the potential difference across R_1 be (i) *larger* in the circuit on the left, (ii) *smaller* in the circuit on the left, or (iii) *equal* in both? _____
Explain your reasoning.

Answer: (iii) Equal in both circuits.

The current in R_1 is the same in both cases since it is connected directly to the battery in both, so the potential differences have to be the same also.

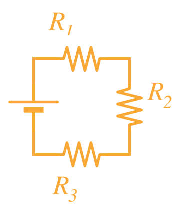
D2-WBT47: THREE RESISTORS CIRCUIT CHART I—CIRCUIT

A circuit contains three resistors and a battery. The chart gives the currents in each element, the potential difference across each element, and the resistance values of the resistors.

	ΔV	I	R
Battery	36.0 V	3.0 A	
R_1	9.0 V	3.0 A	3.0 Ω
R_2	15.0 V	3.0 A	5.0 Ω
R_3	12.0 V	3.0 A	4.0 Ω

Draw an electric circuit that is consistent with the values of this chart. Label the resistors.

The current in all elements is the same, which is consistent with all elements in series and the sum of the potential drops across the three resistors equals the battery potential.



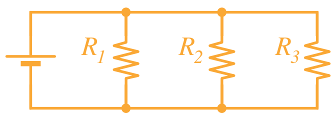
D2-WBT48: THREE RESISTORS CIRCUIT CHART II—CIRCUIT

A circuit contains three resistors and a battery. The chart gives the currents in each element, the potential difference across each element, and the resistance values of the resistors.

	ΔV	I	R
Battery	24.0 V	16.0 A	
R_1	24.0 V	8.0 A	3.0 Ω
R_2	24.0 V	6.0 A	4.0 Ω
R_3	24.0 V	2.0 A	12.0 Ω

Draw an electric circuit that is consistent with the values of this chart. Label the resistors.

The voltage across all of the resistors is that same as the battery voltage, which is consistent with all of the resistors in parallel branches. In addition the sum of the three currents equals the current in the battery.



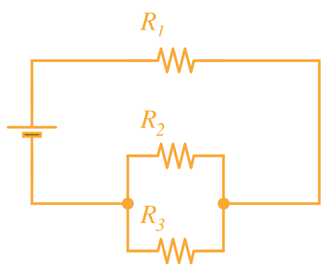
D2-WBT49: THREE RESISTORS CIRCUIT CHART III—CIRCUIT

A circuit contains three resistors and a battery. The chart gives the currents in each element, the potential difference across each element, and the resistance values of the resistors.

	ΔV	I	R
Battery	18.0 V	6.0 A	
R_1	6.0 V	6.0 A	1.0 Ω
R_2	12.0 V	2.0 A	6.0 Ω
R_3	12.0 V	4.0 A	3.0 Ω

Draw an electric circuit that is consistent with the values of this chart. Label the resistors.

The voltage across R_2 is the same as the voltage across R_3, which is consistent with connecting these resistors in parallel. The sum of the currents in these resistors is equal to the current in R_1, so we can place R_1 in series with the parallel combination. The battery voltage is the sum of the voltage across R_1 plus the voltage across the parallel combination.



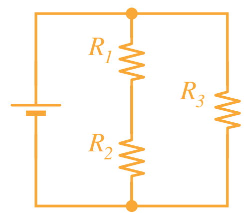
D2-WBT50: THREE RESISTORS CIRCUIT CHART IV—CIRCUIT

A circuit contains three resistors and a battery. The chart gives the currents in each element, the potential difference across each element, and the resistance values of the resistors.

	ΔV	I	R
Battery	12.0 V	4.0 A	
R_1	3.0 V	3.0 A	1.0 Ω
R_2	9.0 V	3.0 A	3.0 Ω
R_3	12.0 V	1.0 A	12.0 Ω

Draw an electric circuit that is consistent with the values of this chart. Label the resistors.

The current in R_1 is the same as the current in R_2, which is consistent with connecting these resistors in series. The sum of the voltages across these resistors is equal to the voltage across R_1, so we can place R_3 in parallel with the series combination. The battery current is the sum of the current in R_3 and the current in the series combination as required by applying the junction rule at either junction.



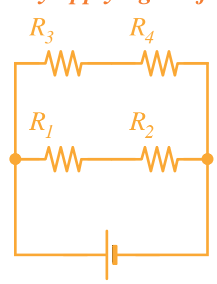
D2-WBT51: FOUR RESISTORS CIRCUIT CHART I—CIRCUIT

A circuit contains four resistors and a battery. The chart gives the currents in each element, the potential difference across each element, and the resistance values of the resistors.

	ΔV	I	R
Battery	60.0 V	5.0 A	
R_1	20.0 V	2.0 A	10.0 Ω
R_2	40.0 V	2.0 A	20.0 Ω
R_3	45.0 V	3.0 A	15.0 Ω
R_4	15.0 V	3.0 A	5.0 Ω

Draw an electric circuit that is consistent with the values of this chart. Label the resistors.

The current in R_1 is the same as the current in R_2, which is consistent with connecting these resistors in series. Similarly, the current in R_3 is the same as the current in R_4, which is consistent with connecting these resistors in series. The sum of the voltages across these pairs of series resistors is equal to the voltage across the battery, so we can place these series combinations in parallel across the battery. The battery current is the sum of the currents in the two resistor branches as required by applying the junction rule at either junction.



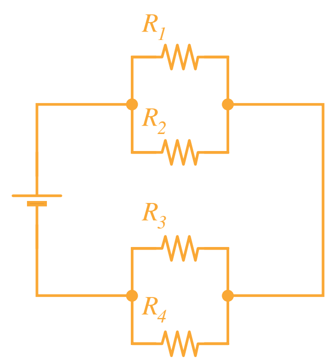
D2-WBT52: Four Resistors Circuit Chart II—Circuit

A circuit contains four resistors and a battery. The chart gives the currents in each element, the potential difference across each element, and the resistance values of the resistors.

	ΔV	I	R
Battery	36.0 V	9.0 A	
R_1	12.0 V	6.0 A	2.0 Ω
R_2	12.0 V	3.0 A	4.0 Ω
R_3	24.0 V	6.0 A	4.0 Ω
R_4	24.0 V	3.0 A	8.0 Ω

Draw an electric circuit that is consistent with the values of this chart. Label the resistors.

The voltage across R_1 is the same as the voltage across R_2, which is consistent with connecting these resistors in parallel. Similarly, the voltage across R_3 is the same as the voltage across R_4, which is consistent with connecting these two resistors in parallel. The sum of the currents in each parallel combination is 9 Amperes, the same as the current in the battery, so we can place the parallel combinations in series. The battery voltage is the sum of the voltage across the parallel combinations.



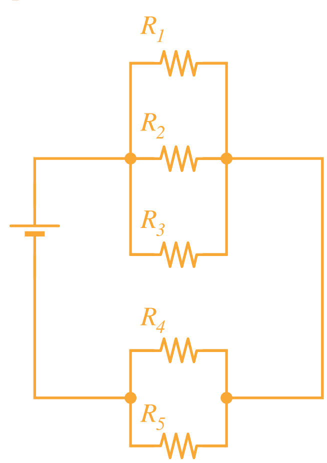
D2-WBT53: FIVE RESISTORS CIRCUIT CHART—CIRCUIT

A circuit contains five resistors and a battery. The chart gives the currents in each element, the potential difference across each element, and the resistance values of the resistors.

	ΔV	I	R
Battery	30.0 V	9.0 A	
R_1	12.0 V	2.0 A	6.0 Ω
R_2	12.0 V	3.0 A	4.0 Ω
R_3	12.0 V	4.0 A	3.0 Ω
R_4	18.0 V	3.0 A	6.0 Ω
R_5	18.0 V	6.0 A	3.0 Ω

Draw an electric circuit that is consistent with the values of this chart. Label the resistors.

The voltage across R1 is the same as the voltage across R2 and across R3, which is consistent with connecting these resistors in parallel. Similarly, the voltage across R4 is the same as the voltage across R5, which is consistent with connecting these resistors in parallel. The sum of the currents in each parallel combination is 9 Amperes, the same as the current in the battery, so we can place the parallel combinations in series. The battery voltage is the sum of the voltage across the parallel combinations.



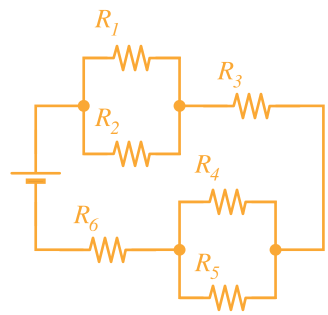
D2-WBT54: SIX RESISTORS CIRCUIT CHART I—CIRCUIT

A circuit contains six resistors and a battery. The chart gives the currents in each element, the potential difference across each element, and the resistance values of the resistors.

	ΔV	I	R
Battery	39.0 V	5.0 A	
R_1	6.0 V	3.0 A	2.0 Ω
R_2	6.0 V	2.0 A	3.0 Ω
R_3	10.0 V	5.0 A	2.0 Ω
R_4	8.0 V	4.0 A	2.0 Ω
R_5	8.0 V	1.0 A	8.0 Ω
R_6	15.0 V	5.0 A	3.0 Ω

Draw an electric circuit that is consistent with the values of this chart. Label the resistors.

The voltage across R_1 is the same as the voltage across R_2, which is consistent with connecting these resistors in parallel. Similarly, the voltage across R_4 is the same as the voltage across R_5, so we can place these resistors in parallel. The sum of the currents in these parallel resistor combinations is 5 Amperes, equal to the current in R_3 and to the current in R_6, so we can place these resistors in series with the parallel combinations. The battery voltage is the sum of the voltage across R_3 and R_6 plus the voltages across the parallel combinations.



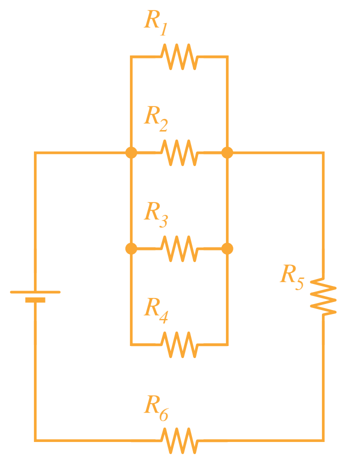
D2-WBT55: Six Resistors Circuit Chart II—Circuit

A circuit contains six resistors and a battery. The chart gives the currents in each element, the potential difference across each element, and the resistance values of the resistors.

	ΔV	I	R
Battery	62.0 V	10.0 A	
R_1	12.0 V	3.0 A	4.0 Ω
R_2	12.0 V	1.0 A	12.0 Ω
R_3	12.0 V	4.0 A	3.0 Ω
R_4	12.0 V	2.0 A	6.0 Ω
R_5	20.0 V	10.0 A	2.0 Ω
R_6	30.0 V	10.0 A	3.0 Ω

Draw an electric circuit that is consistent with the values of this chart. Label the resistors.

The voltage across R_1 is the same as the voltage across R_2, R_3 and R_4, which is consistent with connecting these four resistors in parallel. The sum of the currents in these parallel resistors is 10 Amperes, equal to the current in R_5 and to the current in R_6, so we can place these resistors in series with the parallel combination. The battery voltage is the sum of the voltage across R_6 and R_6 plus the voltage across the parallel combination.



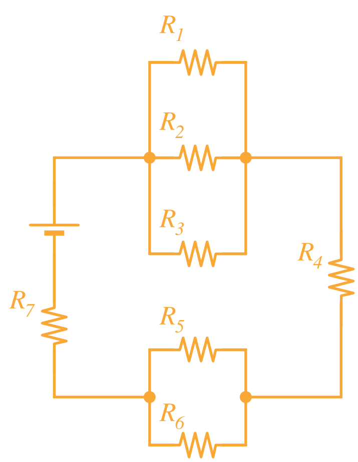
D2-WBT56: Seven Resistors Circuit Chart—Circuit

A circuit contains seven resistors and a battery. The chart gives the currents in each element, the potential difference across each element, and the resistance values of the resistors.

	ΔV	I	R
Battery	64.0 V	12.0 A	
R_1	20.0 V	5.0 A	4.0 Ω
R_2	20.0 V	2.0 A	10.0 Ω
R_3	20.0 V	5.0 A	4.0 Ω
R_4	24.0 V	12.0 A	2.0 Ω
R_5	8.0 V	4.0 A	2.0 Ω
R_6	8.0 V	8.0 A	1.0 Ω
R_7	12.0 V	12.0 A	1.0 Ω

Draw an electric circuit that is consistent with the values of this chart. Label the resistors.

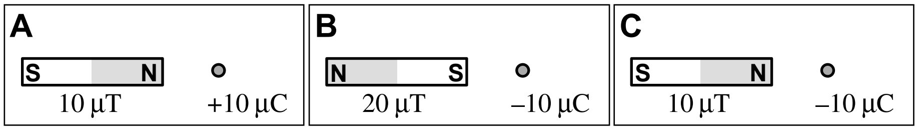
The voltage across R_1 is the same as the voltage across R_2 and R_3, which is consistent with connecting these resistors in parallel. The voltage across R_5 is the same as the voltage across R_6, which is consistent with connecting these resistors in parallel. The sum of the currents in these parallel resistor combinations is 12 Amperes, equal to the current in R_4 and to the current in R_7, so we can place these resistors in series with the parallel combinations. The battery voltage is the sum of the voltage across R_4 and R_7 plus the voltages across the parallel combinations.



D3 MAGNETISM

D3-QRT01: ELECTRIC CHARGE NEAR A BAR MAGNET—FORCE DIRECTION

A charged particle is placed so that it is at rest near one pole of a bar magnet. All of the charges are the same distance from the magnet. The strength of the magnetic field due to the bar magnet at the location of the particle is given.



For each case, draw the direction of the force on the magnet and on the charged particle.

	Direction of force on the magnet	Direction of force on the particle
Case A		
Case B		
Case C		

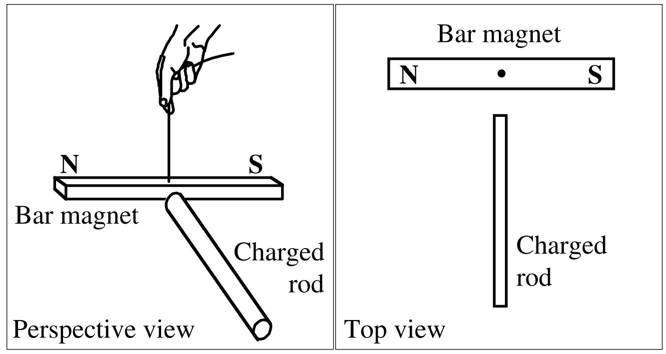
Explain your reasoning.

There is an electrostatic attraction between the positive charged particle and the magnet, because the charged particle polarizes the magnet. This attraction acts on both objects and is equal in magnitude, but opposite in direction. There is no magnetic force between the magnet and charged particle since the particle is not moving.

	Direction of force on the magnet	Direction of force on the particle
Case A	→	←
Case B	→	←
Case C	→	←

D3-SCT02: CHARGED ROD NEAR A SUSPENDED BAR MAGNET—ROTATION

A bar magnet is suspended by a string. With the magnet held in place, a charged rod is brought close to the point of suspension of the magnet as shown. The suspended bar magnet is then released so that it is free to rotate. Students are discussing what will happen when the magnet is free to rotate.



Aaron: *"I think the magnet will rotate clockwise when viewed from above. The north pole will be repelled by the positive charge, and the south pole will be attracted."*

Ben: *"I think the magnet will just sit there. A north pole is not like a positive charge."*

Carl: *"It's more complicated than that. The magnet will induce a north pole on the charged rod because the magnetic field will cause the electron spins to align. Since there are then two north poles close to each other, the magnet will rotate clockwise."*

With which of these students do you agree?

Aaron _____ Ben _____ Carl_____ None of them _____

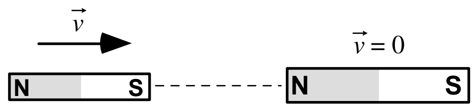
Explain your reasoning.

Answer: Ben is correct.

Assuming the rod is slowly and carefully brought up exactly along the centerline, the electrostatic polarization can be ignored and there will be no torque in this situation. This is very difficult to do in practice. Only moving charges experience a force in a magnetic field.

D3-SCT03: TWO MAGNETS—FORCE

Three students are discussing the strengths (or magnitudes) of the forces between two permanent magnets. The smaller magnet is moving to the right. The larger magnet is stronger than the smaller magnet.



Alejandro: *"The velocities and magnet strengths don't matter. The magnets will attract each other with equal strength."*

Bernardo: *"No, the stronger magnet will push more than the weaker one because it has a stronger field."*

Cecilia: *"I don't think we can compare the strength of the forces unless we know the velocity of the smaller magnet."*

With which of these students do you agree?

Alejandro_____ Bernardo_____ Cecilia_____ None of them _____

Explain your reasoning.

Answer: Alejandro is correct.

Newton's third law applies so Alejandro is correct. Magnetic forces (like all forces) are interactions between two objects and are always found to be the same, as described by Newton's third law.

D3-SCT04: ELECTRIC CHARGE NEAR A BAR MAGNET—FORCE DIRECTION

Consider the following students' statements about the magnetic force on a positively charged particle placed at rest near a permanent magnet.

Aurelia: *"A positively charged particle placed near the north pole of a permanent magnet will experience a repulsive force because the north pole acts like a positive charge."*

Ben: *"I think it will experience an attractive force, but not because it is a magnet."*

Chila: *"Since it's not moving, I think it won't experience any electromagnetic force."*

With which of these students do you agree?

Aurelia _____ Ben _____ Chila _____ None of them _____

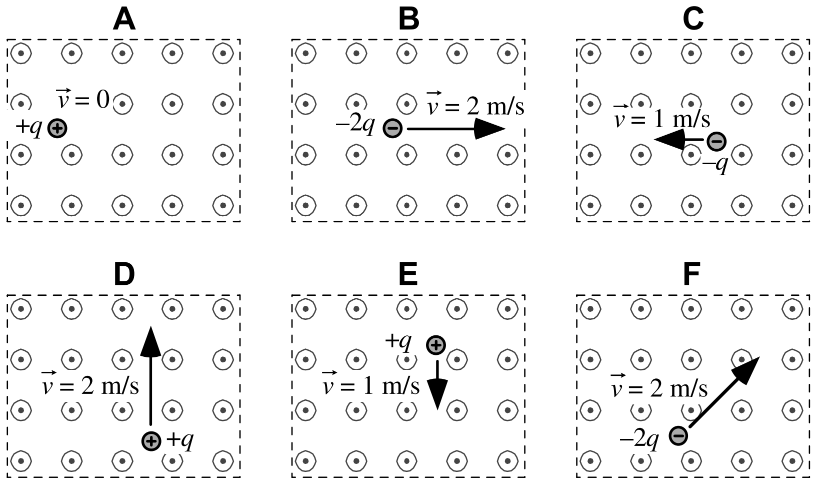
Explain your reasoning.

Answer: Ben is correct.

Charged particles have to be moving in a magnetic field to feel a magnetic force. However, the charged particles will polarize the magnet when they are brought close, and will experience an electrostatic attraction to electrically neutral magnets.

D3-RT05: CHARGE WITHIN A UNIFORM MAGNETIC FIELD—MAGNETIC FORCE

In each case, charged particles are in a magnetic uniform magnetic field. All magnetic fields have the same strength.



Rank the strength (magnitude) of the magnetic force on each charge.

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

Explain your reasoning.

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

The magnetic force is proportional to the product of the charge, the velocity, and the magnetic field strength perpendicular to the direction of the charge velocity: $F_B = qvB\sin\theta$. Since B is the same in all cases, and $\sin\theta = \sin 90° = 1$ in all 6 cases, then the magnetic force F_B is proportional to q times v .

D3-WWT06: Charged Particles and a Uniform Magnetic Field—Direction of Motion

Two particles that have the same mass and electric charge enter the same uniform magnetic field traveling at the same speed. The distance between the two particles is so great that they do not affect each other.

A student makes the following statement:

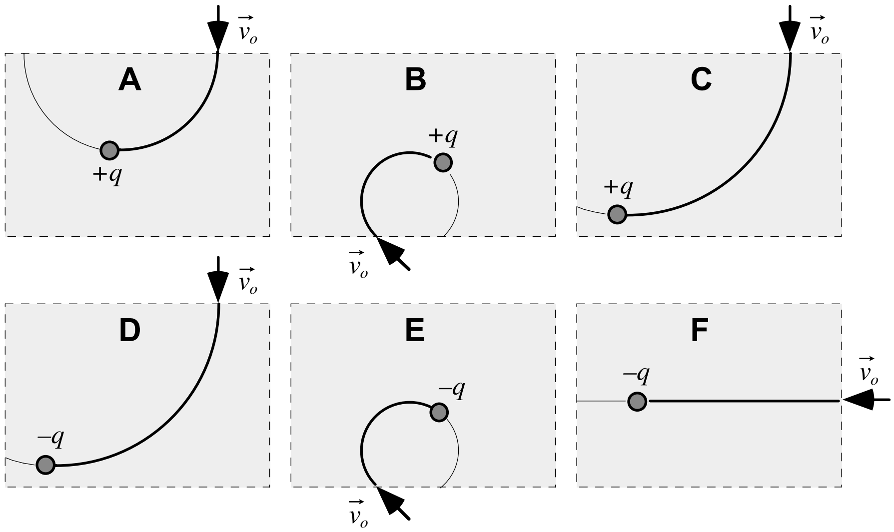
"*These particles will travel in circular paths of equal radius.*"

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: This statement is correct only if they both enter the uniform magnetic field at the same angle relative to the direction of the magnetic field. If they do not enter at the same angle, then the statement is not true since the magnetic force depends on the relative directions of the velocity and magnetic field. The speed gives no information about the direction of the motion of the particle compared to the direction of the magnetic field.

D3-RT07: Moving Charge Path—Direction and Strength of the Magnetic Field

In each case, the shaded region contains a uniform magnetic field that may point either into the page or out of the page. A charged particle moves through the region along the path indicated. All of the charged particles have the same mass and enter the region with the same initial speed.



Rank the magnetic field in the region. Fields directed out of the page (considered positive) are ranked higher than fields directed into the page (considered negative).

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

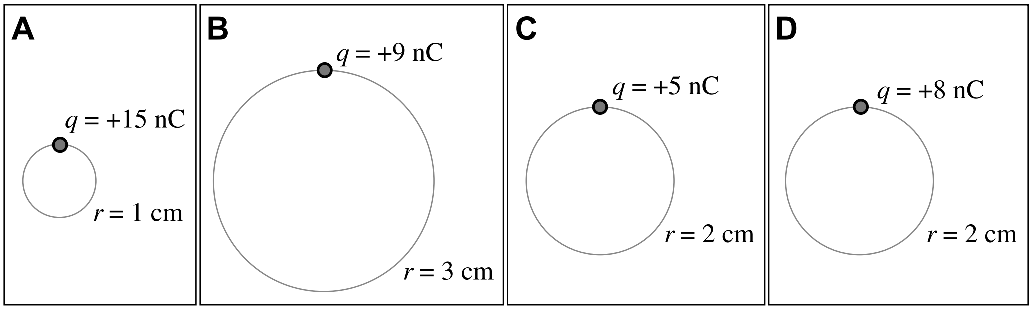
Explain your reasoning.

Answer: B > A > C > F > D > E, ranked from greatest out of the page to greatest into the page.

Since all particles are moving in a direction perpendicular to the magnetic field, the force on each particle is equal to qvB. All of the particles have the same mass, so the accleration of the particles is proportional to the magnetic force. Larger accelerations will create smaller curvatures, since the speeds are all the same, and the magnitude of the acceleration of an object moving in a circle at constant velocity is a=v2/r. The direction of the magnetic field is determined by the right-hand rule. We know the field in case F is zero because the charge moves in a straight line.

D3-RT08: CHARGED PARTICLE AND A UNIFORM MAGNETIC FIELD—FORCE

In each case, a charged particle is moving in a uniform magnetic field. The particle charge and the strength of the field vary among the four cases. The particles all have the same mass, and they were all given the same initial speed.



Rank the magnitude of the force on each charge.

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

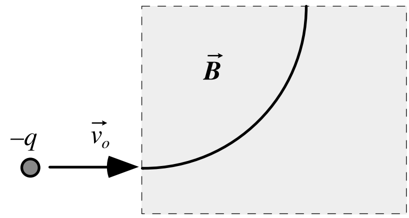
Explain your reasoning.

Answer: A > C = D > B.

The particles are moving in a circle, so the net force on them (the magnetic force) must point toward the center of the circle. The masses of the charges are all the same, so the ranking of the force will be the same as the ranking of the acceleration. The centripetal acceleration is the square of the speed divided by the radius of the circle. The particles all have the same speed, so their accelerations are inversely proportional to the radius of the circle they are moving in.

D3-QRT09: Charged Particle and a Uniform Magnetic Field—Path

The dark quarter-circle indicates the path of a negatively charged particle as it passes through a region containing a uniform magnetic field.



(a) What is the direction of the magnetic field in the shaded region?
Explain your reasoning.

Answer: Out of the paper.
Using the right hand rule, we can see that with the velocity to the right just as the particle enters the magnetic field (and taking into account that the charge is negative!) the field must point out of the paper for the force to

(b) If we double the speed of the particle, how will the path change?
Explain your reasoning.

Answer: It will curve towards the top of the page as above, but along a circular path of larger radius.

(c) If we double the magnitude of the uniform magnetic field, how will the path change?
Explain your reasoning.

Answer: It will curve towards the top of the page as above, but along a circular path of smaller radius.

(d) If we replace the original particle with a negative particle of twice the charge and the same mass, how will the path change?
Explain your reasoning.

Answer: It will curve towards the top of the page as above, but along a circular path of smaller radius.

(e) If we replace the original particle with a positive particle of the same mass and same magnitude charge as the original negative charge, how will the path change?
Explain your reasoning.

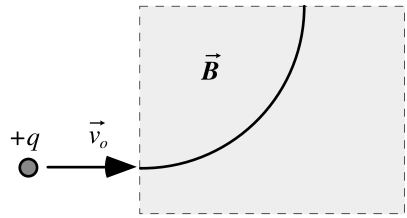
Answer: Positive and negative charges experience opposite magnetic forces. It will curve downward toward the bottom of the page.

(f) If we replace the original particle with a negative particle of twice the mass and the same charge, how will the path change?
Explain your reasoning.

Answer: It will curve towards the top of the page as above, but along a circular path of larger radius.

D3-LMCT10: MOVING CHARGE WITHIN A UNIFORM MAGNETIC FIELD—FORCE

A positively charged particle moving at a constant speed is entering a region in which there is a uniform magnetic field. The particle follows the curved path shown.



A number of changes to this initial situation are described in (a)–(f) below. Select from choices (i)–(vi) how each change will affect the magnetic force on the particle shortly after it enters the magnetic field.

This change will:

(i) alter only the **direction** of the force on the particle.
(ii) only **increase** the magnitude of the magnetic force on the particle.
(iii) only **decrease** the magnitude of the magnetic force on the particle.
(iv) alter **both the magnitude and direction** of the magnetic force on the particle.
(v) **not affect** the magnetic force on the particle.
(vi) cause the magnetic force on the particle to be **zero**.

Each change below refers to the initial situation described above:

(a) The +*q* particle is replaced by a +2*q* particle. _____
Explain your reasoning.
Answer: (ii) The magnitude of the force is proportional to the charge, so a doubling of the particle charge will double the force.

(b) The +*q* particle is replaced by a • *q* particle. _____
Explain your reasoning.
Answer: (i) The force direction reverses when the charge sign reverses.

(c) The +*q* particle is replaced by a neutral particle. _____
Explain your reasoning.
Answer: (vi) The magnetic force acts only on charged particles.

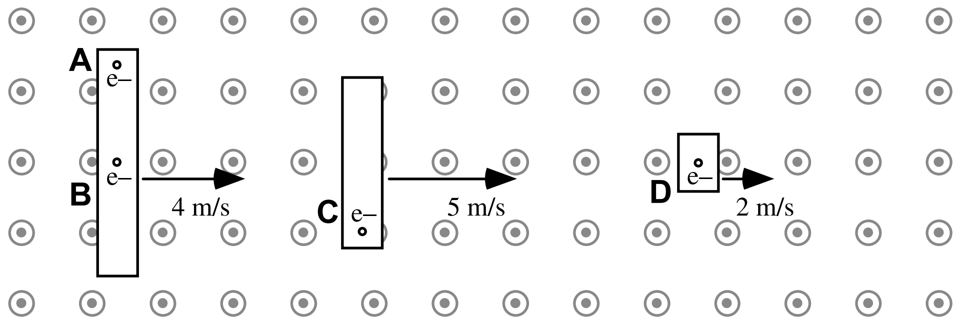
(d) The particle enters the region moving at a slower initial velocity. _____
Explain your reasoning.
Answer: (iii) The magnitude of the force is proportional to the velocity, so when the velocity is reduced the force is reduced as well.

(e) The magnetic field is one-third its original strength. _____
Explain your reasoning.
Answer: (iii) The magnitude of the force is proportional to the magnetic field strength, so when the velocity is reduced by a factor of 3 the force is reduced by a factor of 3 as well.

(f) The direction of the magnetic field is parallel to the particle's initial velocity. _____
Explain your reasoning.
Answer: (vi) The magnetic force depends on the component of the velocity that is perpendicular to the direction of the magnetic field: When the field and the velocity are parallel or antiparallel the force is zero.

D3-RT11: Bars Moving in Magnetic Fields—Force on Electrons

Three straight bars are moving at different speeds through a region in which there is a uniform magnetic field. The bars are made of the same conducting material and are moving in a plane perpendicular to the magnetic field. The bars have different lengths and are moving at constant but different speeds, as shown. Within the bars, four electrons are located and labeled.



Rank these electrons on the strength (magnitude) of the magnetic forces acting on them.

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

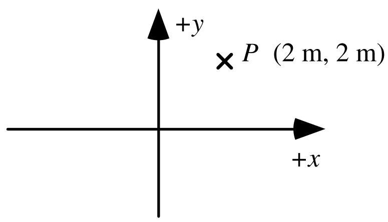
Explain your reasoning.

Answer: C > A = B > D.

Since the electrons all have the same charge and are all moving through the same magnetic field with a velocity perpendicular to the field, the strength of the force will depend on the their velocities. The location of the electron within the bar is irrelevant.

D3-RT12: MOVING CHARGES IN UNIFORM MAGNETIC FIELD—ACCELERATION

Moving charged particles are released at point *P* (2 m, 2 m) in a region of space with a uniform magnetic field in the +*x* direction. All these particles have the same mass, and they are released one at a time into the field with the given velocities.



Case	Charge	Speed	Direction
A	+5 mC	3 m/s	+*x*
B	+5 mC	3 m/s	–*x*
C	–10 mC	5 m/s	+*y*
D	–10 mC	5 m/s	–*y*

Rank the magnitude of the initial acceleration of the charged particles as they are released from *P*.

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

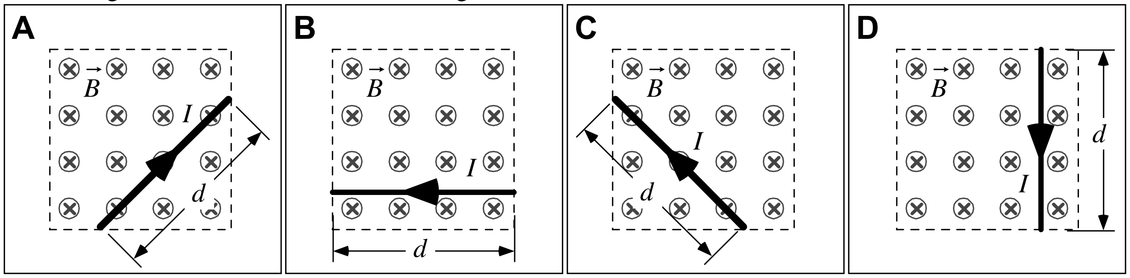
Explain your reasoning.

Answer: C = D > A = B.

For A and B there will not be any magnetic force on the particles since they are moving parallel (Case A) or anti-parallel (Case B) to the magnetic field. The magnitude of the magnetic force on particles Cand D will be the same, since they have the same charge and velocity and they are both moving perpendicular to the magnetic field.

D3-RT13: Current–Carrying Wire in a Uniform Magnetic Field—Magnetic Force

The figures below show identical current-carrying wire segments in identical uniform magnetic field regions. All the magnetic field regions are the same width and height.



Rank the strength (magnitude) of the magnetic force on the wire segments.

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

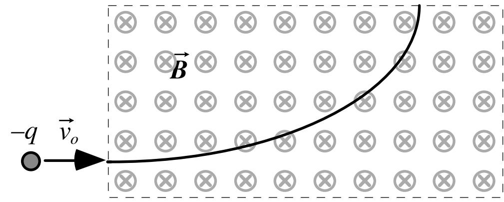
Explain your reasoning.

Answer: A = B = C = D.

In all cases the wire is perpendicular to the field, so the force on the wire due to the magnetic field is proportional to the strength of the field, the length of wire in the field, and the current in the wire (F = ILB). The current I, the length of wire in the magnetic field region L, and the magnetic field strength B are the same in all cases.

D3-TT14: PATH OF A MOVING ELECTRON IN A UNIFORM MAGNETIC FIELD

An electron is moving to the right at a velocity *v* when it enters a region containing a uniform magnetic field pointing into the paper. The path of the electron in the magnetic field is shown.

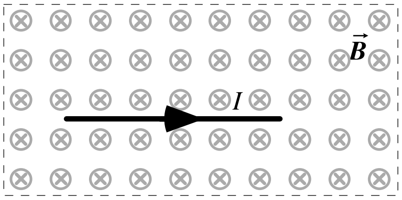


There is at least one error in the diagram. **Identify all errors and explain how to correct them.**

Answer: Once it is inside the magnetic field, the path of the electron should be curved downwards since the particle is negatively charged. In addition, the path of the particle should be a segment of a circle, because the only force acts perpendicular to the motion, and is thus a centripetal force.

D3-QRT15: STRAIGHT CURRENT–CARRYING WIRE IN A UNIFORM MAGNETIC FIELD—MAGNETIC FORCE

A current-carrying straight wire segment is in a uniform magnetic field directed into the paper. There are connecting wires running parallel to the magnetic field that are not shown.



(a) What is the direction of the magnetic force acting on the wire segment due to the uniform magnetic field?

Explain your reasoning.

Answer: The magnetic force direction is towards the top of the page, found using the right hand rule.

(b) What would the direction of the magnetic force acting on the wire segment be if the direction of the uniform magnetic field were out of the paper?

Explain your reasoning.

Answer: The magnetic force direction would be towards the bottom of the page, again using the right hand rule.

(c) What would happen to the magnitude of the magnetic force acting on the wire segment if the wire segment were longer but still completely within the uniform magnetic field?

Explain your reasoning.

Answer: The force would be larger since the force is proportional to the length of the wire.

(d) What would happen to the direction of the magnetic force acting on the wire segment if the direction of current in the wire segment were reversed?

Explain your reasoning.

Answer: The direction of the magnetic force would be reversed, applying the right hand rule.

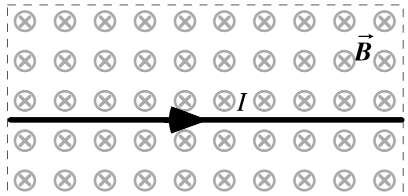
(e) What would happen to the magnitude of the magnetic force acting on the wire segment if the wire segment were moved (without changing its orientation) so that its length was half-in and half-out of the uniform magnetic field region?

Explain your reasoning.

Answer: The magnitude of the magnetic force would be half of the initial value since the force is proportional to the length of the wire within the magnetic field.

D3-LMCT16: Current in a Uniform Magnetic Field—Magnetic Force

A section of straight wire within a magnetic field is conducting a current to the right. The external magnetic field is uniform and directed into the paper.



A number of changes to the initial force are described in (a)-(e) below. Select from choices (i)-(vii) the possible causes of the change in the force.

This change could be caused by:

(i) **increasing** the current.
(ii) **decreasing** (but not to zero) the current.
(iii) **reversing the direction** of current.
(iv) **increasing** the strength of the magnetic field.
(v) **decreasing** (but not to zero) the strength of the magnetic field.
(vi) **reversing the direction** of the magnetic field.
(vii) none of these.

If more than one choice is correct, please indicate *all* correct choices for the answer.

Each change below refers to the initial situation described above:

(a) The magnetic force on the wire is larger and in the same direction. _____
Explain your reasoning.
Answer: (i) and (iv). The magnetic force is proportional to the current and also proportional to the magnetic field strength.

(b) The magnetic force on the wire is larger and in the opposite direction. _____
Explain your reasoning.
Answer: (vii). No single change from (a) through (f) above would both increase the magnetic force and reverse the direction of the force.

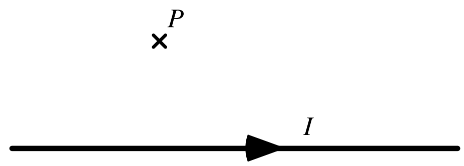
(c) The magnetic force on the wire is smaller and in the same direction. _____
Explain your reasoning.
Answer: (ii) and (v). The magnetic force is proportional to the current and also proportional to the magnetic field strength.

(d) The magnetic force magnitude remains the same, but the direction changes. _____
Explain your reasoning.
Answer: (iii) and (vi). The direction of the magnetic force could be reversed either by changing the direction of current in the wire, or by reversing the direction of the magnetic field.

(e) The magnetic force on the wire is zero. _____
Explain your reasoning.
Answer: (vii). Since the wire is perpendicular to the field, there will be a force as long as the current in the wire is nonzero and the magnetic field is nonzero.

D3-QRT17: STRAIGHT CURRENT–CARRYING WIRE—MAGNETIC FIELD NEARBY

The figure below shows a point *P* near a long current-carrying wire.



(a) What is the direction of the magnetic field at point *P* due to the current in the wire?

Explain your reasoning.

Answer: The direction of the magnetic field is out of the page, found by applying the right hand rule.

(b) What would the direction of the magnetic field at point *P* be if the current in the wire were reversed?

Explain your reasoning.

Answer: The direction of the magnetic field would reverse (it would be into the page).

(c) What would happen to the magnetic field at point *P* if the current in the wire were increased?

Explain your reasoning.

Answer: The magnitude of the magnetic field would increase.

(d) What would happen to the magnetic field at *P* if point *P* were farther away from the wire?

Explain your reasoning.

Answer: The magnitude of the magnetic field would decrease.

D3-WWT18: CURRENT–CARRYING WIRE—MAGNETIC FIELD DIRECTION

A long, straight wire is conducting a current whose direction is pointed out of the paper toward you. A student makes the following statement:

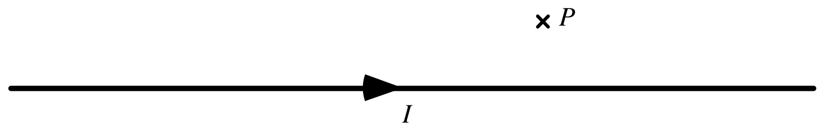
“The magnetic field generated by this wire points straight out from the wire.”

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 direction of the magnetic field (as detected by the direction of the north seeking end of a compass needle) around the long, straight wire pointed out of the page towards you is always tangent to concentric circles of varying radii with the current-carrying wire as the center of the circle.

D3-LMCT19: LONG WIRE WITH A CURRENT—MAGNETIC FIELD NEARBY

Point *P* is located above a long straight wire that has a current to the right.



A number of changes to the initial magnetic field at point *P* are described in (a)–(e) below. Select from choices (i)–(vii) what might have caused this change in the magnetic field at point *P*.

This change could be caused by:

(i) an **increase** in the current.
(ii) a **decrease** in the current.
(iii) **reversing** the direction of the current.
(iv) moving *P* **farther away** from the wire toward the top of the page.
(v) moving *P* **closer** to the wire but still on the same side of the wire.
(vi) moving *P* **below the wire** and the **same distance** from the wire.
(vii) **none of these**.

If more than one choice is correct, please indicate *all* correct choices for the answer.

Each change below refers to the initial situation described above:

(a) The magnetic field at *P* decreases, but the direction remains the same. _____
Explain your reasoning.
Answer: (ii) and (iv). The magnetic field strength depends on the magnitude of the current and the distance between the wire and the point of interest.

(b) The direction of the magnetic field at *P* is reversed. _____
Explain your reasoning.
Answer: (iii) and (vi). The direction of the magnetic field depends on the direction of the current in the wire, and since it is tangent to a circle centered on the wire it will point in the other direction on the other side of the wire.

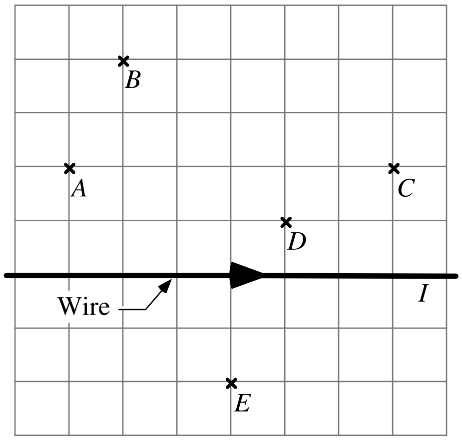
(c) The magnetic field at *P* is decreased and the direction is reversed. _____
Explain your reasoning.
Answer: (vii). No single change from (a) through (f) above would both decrease the magnetic field and reverse the direction of the field.

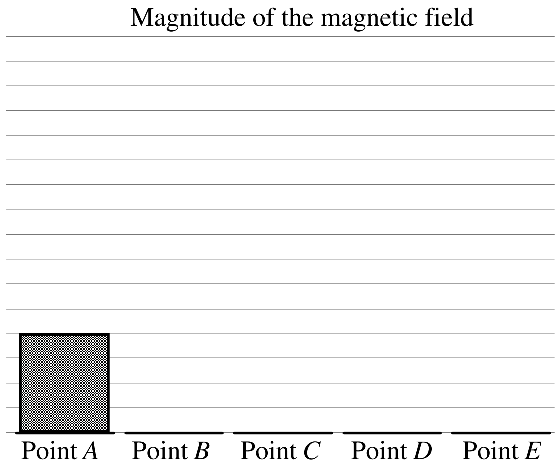
(d) The magnetic field at *P* points toward the right. _____
Explain your reasoning.
Answer: (vii). The magnetic field near a wire always points tangent to a circle centered on the wire.

(e) The magnetic field at *P* increases and points toward the top of the page. _____
Explain your reasoning.
Answer: (vii). The magnetic field near a wire always points tangent to a circle centered on the wire.

D3-BCT20: Straight Current–Carrying Wire—Magnetic Field Nearby

A long, straight conducting wire has a current in the +x-direction.

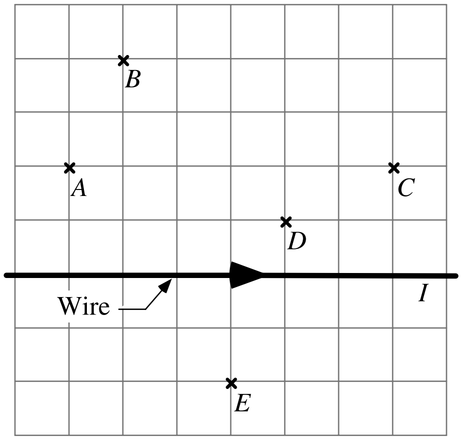


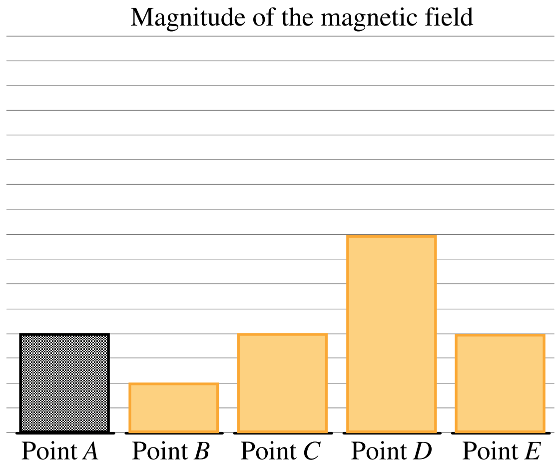


Show the magnitude of the magnetic field at the various points shown in the diagram on the bar chart to the right, above. The magnitude at point *A* is given in the chart.

Explain your reasoning.

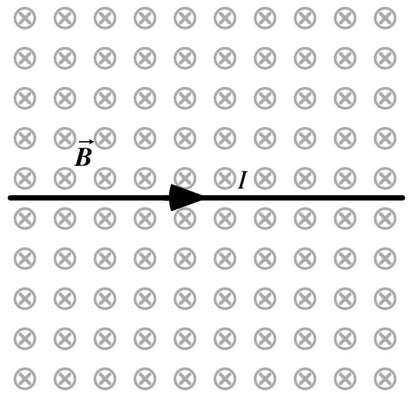
Answer: ***The strength of a magnetic field near a wire is inversely proportional to the distance of that point from the wire. For a long wire, the position along the wire doesn't't' matter – only the distance from the wire does. Since points C and E are the same distance as A from the wire, the field will be the same at C and E as at A. Point B is twice as far as A from the wire, so the field will be half as large there. Point D is half as far as A from the wire, so the field will be twice as large there.***





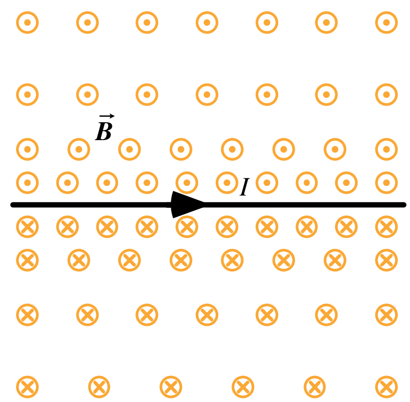
D3-TT21: STRAIGHT CURRENT–CARRYING WIRE—MAGNETIC FIELD NEARBY

A student draws the following diagram representing the magnetic field generated by a straight current-carrying wire.



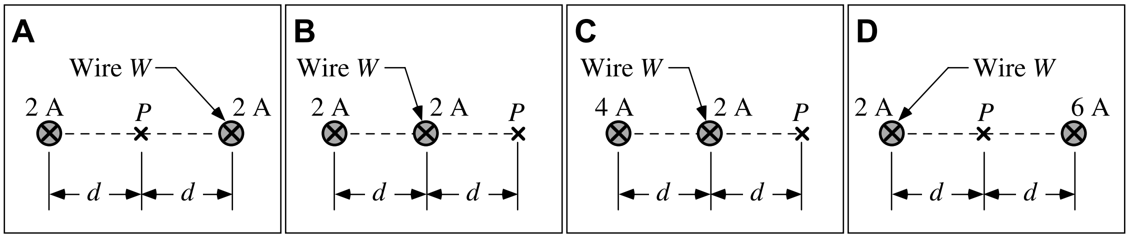
There is at least one problem with the diagram. **Identify any problems and explain how to correct them.**

***Answer:** The magnetic field direction below the wire is correct, but the field above the wire should be coming out of the page. The field strength both above and below the wire should be decreasing with increasing distance from the wire. This decrease in field strength is represented by a smaller number of field vectors per unit area at greater distances from the wire.*



D3-RT22: Current–Carrying Straight Wires—Magnetic Field Nearby

In these cases, long, straight wires that are perpendicular to the page are carrying electric currents into the page.



Rank the strength (magnitude) of the magnetic field at *P* due to wire *W*.

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

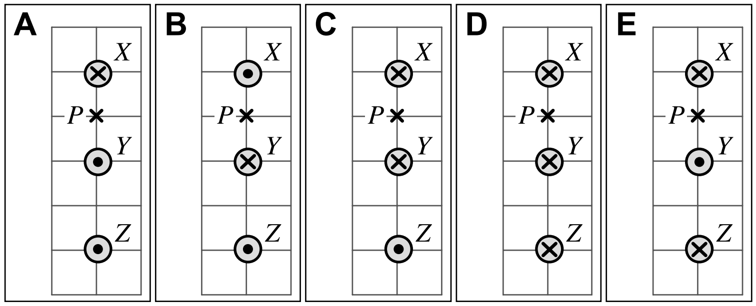
Explain your reasoning.

Answer: A = B = C = D.

Reasoning from the principle of superposition, the magnetic field at point P due to wire W won't depend on the other wire. Since wire W has the same current in all four cases and point P is the same distance from wire W in all four cases, the strength of the magnetic field at point P due to wire W is the same in all cases.

D3-RT23: Three Parallel Current–Carrying Wires I—Magnetic Field Nearby

In these cases, three long, straight parallel wires carry currents either into or out of the page. Point *P* is midway between the top two wires. The current has the same magnitude in all wires.



Rank the strength (magnitude) of the total magnetic field at point *P*.

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

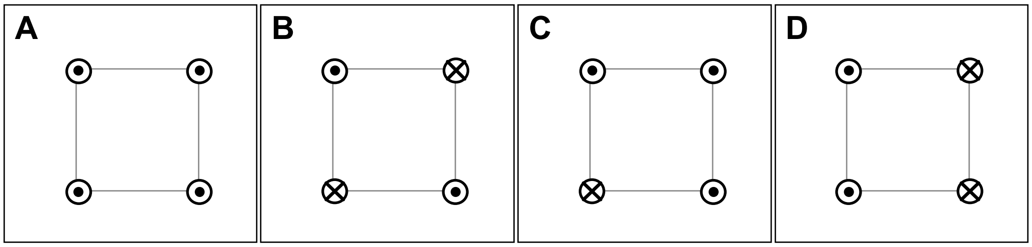
Explain your reasoning.

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

The top two wires are the same distance from P so they produce the same magnitude field at P. The field contribution from the bottom wire is one-third the field from the other wires, since it is three times farther from P. In cases A, B and E the fields due to the top two wires add together, but for case C and D they cancel each other. In case A the field from the bottom wire adds to the other two where it subtracts from that sum in cases B and E. For cases C and D the only contribution to the field at P is due to the bottom wire.

D3-RT24: CURRENTS AT CORNERS OF SQUARES—MAGNETIC FIELD AT CENTER

Current-carrying wires are positioned at the corners of a square. All of the currents have the same magnitude, but some are into the page and some are out of the page.



Rank the magnitude of the net magnetic field at the center of the square.

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

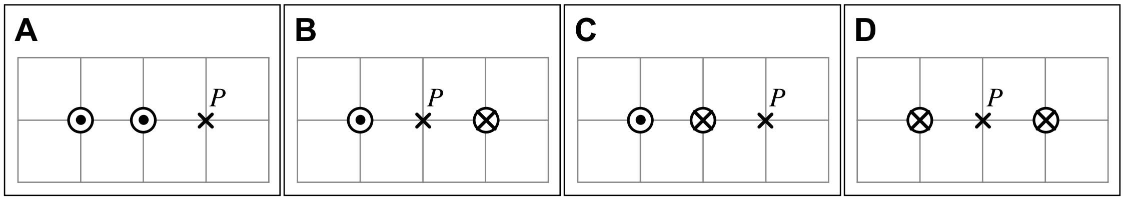
Explain your reasoning.

Answer: D > C > A = B.

The net magnetic fields at the centers of squares A and B are both zero since the fields from opposite corners cancel. In C the upper left and lower right wires create fields that cancel, and the upper right and lower left wires both create fields down and to the right. In case D, the fields from the upper left and lower right wires add to create a field up and to the right, and the fields from the upper right and lower left wires add to create a field up and to the left. Each of these two fields have the same magnitude as the net field in case C, and the vector sum of these fields creates a field pointing straight up that is larger by 1.4 than the field in case C.

D3-RT25: Pairs of Long Current-Carrying Wires—Magnetic Field Nearby

In these cases, the two parallel wires have the same magnitude current perpendicular to the plane of the page. The direction of the current in each wire is shown.



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

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

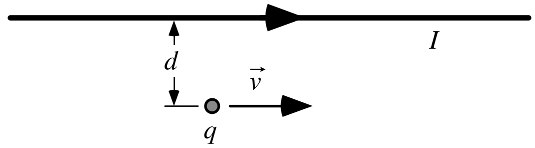
Explain your reasoning.

Answer: B > A > C > D.

For case B the two fields add and have equal magnitudes. In case A the two fields add, but one is only half as large as the other because one wire is twice as far away. In case C the two fields subtract. In case D the field is zero since the two fields subtract and they have the same magnitude.

D3-LMCT26: Charge Moving along Straight Wire—Magnetic Force

At the instant shown, a particle with a charge of $+q$ is a distance d from a long, straight wire and is moving parallel to the wire.



A number of changes to this initial situation are described in (a)–(f) below. Select from choices (i)–(v) how each change will affect the magnetic force on the particle at this instant.

This change will:

(i) have **no effect** on the force.
(ii) **increase** the strength (magnitude), but not affect the direction of the force.
(iii) **decrease** the strength, but not affect the direction of the force.
(iv) **alter the direction**, but not affect the strength of the force.
(v) **alter both** the strength and direction of the force on the particle.

Each change below refers to the initial situation described above:

(a) The current in the wire is doubled. _____
Explain your reasoning.
Answer: (ii) The force will be doubled in magnitude, because the magnetic field due to the wire will be doubled and the force will be doubled.

(b) The direction of the current in the wire is reversed. _____
Explain your reasoning.
Answer: (iv) The force on the charge will reverse directions, because the magnetic field reverses direction.

(c) The +q particle is replaced with a +2*q* particle with the same mass. _____
Explain your reasoning.
Answer: (ii) The force will double since the force is proportional to the charge.

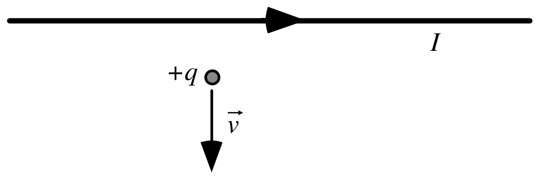
(d) The +q particle is replaced with a –*q* particle with the same mass. _____
Explain your reasoning.
Answer: (iv) The direction of the force will be opposite, radially outward.

(e) The +*q* particle is replaced with a particle having triple the mass and the same charge. _____
Explain your reasoning.
Answer: (i) The magnitude of the force is independent of the mass. (However, the acceleration of the particle will be one-third as great, from Newton's second law.)

(f) The charged particle's initial velocity is toward the bottom of the page. _____
Explain your reasoning.
Answer: (iv) The charge velocity is still perpendicular to the direction of the magnetic field, which points into the page at the location of the charge, so the angle between the magnetic field and the velocity does not change and the magnitude of the force does not change. However, the direction of the force changes from radially inward toward the wire to parallel to the wire.

D3-TT27: MOVING AWAY POSITIVE CHARGE NEAR STRAIGHT CURRENT–CARRYING WIRE—FORCE

At the instant shown, a positively charged particle has a velocity that is perpendicular to a current-carrying wire.



A student makes the following statement:

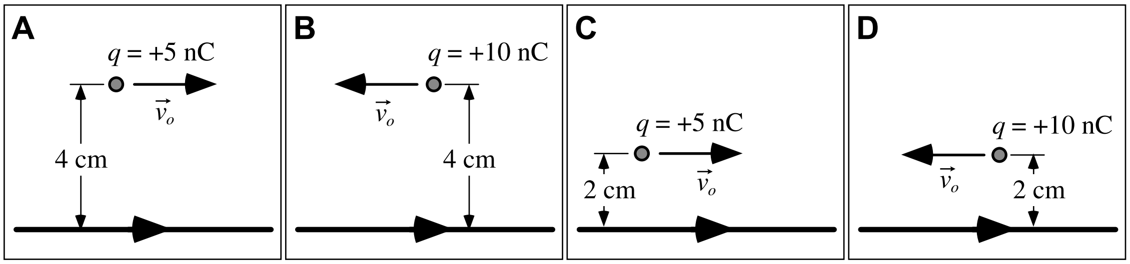
"The force exerted on the charged particle by the magnetic field is zero because the velocity is parallel to the magnetic field produced by the wire."

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

Answer: The force on the charged particle is non-zero, because the magnetic field from the wire is directed into the page at the location of the particle, which is perpendicular to the direction of charge motion.

D3-RT28: MOVING CHARGE ALONG A STRAIGHT CURRENT–CARRYING WIRE—ACCELERATION

Four charged particles have been projected parallel to identical current-carrying wires. The particles have the same mass and are projected with the same initial speed.



Rank the magnitude of the acceleration of each charge at the instant shown.

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

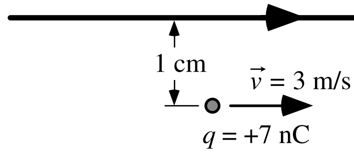
Explain your reasoning.

Answer: D > B = C > A.

The magnetic field due to the wire points out of the page at the location of the charge in all cases, and the magnitude of the field is inversely proportional to the distance from the wire. For all particles, then, the field is perpendicular to the velocity, and the force on the charge is then equal to qvB. Since all particles have the same speed, the force on the charged particle is proportional to qB, which is proportional to q divided by the distance d from the wire. Since all particles have the same mass the ranking of the accelerations is the same as the ranking of the forces, which is proportional to q / d.

D3-QRT29: MOVING CHARGE NEAR A STRAIGHT CURRENT–CARRYING WIRE—ACCELERATION

At the instant shown, a particle with charge of +7 nC is moving at 3 m/s parallel to a long, straight wire that has a current of 8 A.



(a) What is the direction of acceleration of the charged particle?

Explain your reasoning.
Since the magnetic field due to the wire is into the page at the location of the charge and the velocity of the positive charge is to the right, applying the right hand rule to the directions of the velocity and the magnetic field will give us the direction of the force. The force is toward the wire so the acceleration is also toward the wire.

(b) If we double the charge on the particle, what will happen to the acceleration?

Explain your reasoning.
The acceleration will also double, since the force is proportional to the charge.

(c) If we replace the charge with a negative charge of the same mass and same magnitude charge as the original charge, what will happen to the acceleration?

Explain your reasoning.
The acceleration will be the same in magnitude, but opposite in direction.

(d) If we double the distance from the wire to the particle, what will happen to the acceleration?

Explain your reasoning.
The acceleration will be halved, because the magnetic field due to the wire will be halved and the force will be halved.

(e) If we double the mass of the particle, what will happen to the acceleration?

Explain your reasoning.
The acceleration will be halved, because the force won't change and the acceleration is inversely proportional to the mass.

(f) If we double the velocity of the particle, what will happen to the acceleration?

Explain your reasoning.
The acceleration will be doubled, because the magnetic force is proportional to the velocity.

(g) If we reduce the magnitude of the current, what will happen to the acceleration?

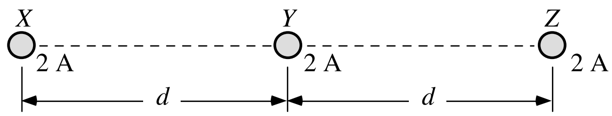
Explain your reasoning.
The acceleration will be reduced in magnitude, because the magnetic field due to the wire will be reduced and the force will be reduced.

(h) If we reverse the direction of the current, what will happen to the acceleration?

Explain your reasoning.
The acceleration will be reversed in direction, because the force will reverse direction.

D3-SCT30: THREE PARALLEL CURRENT–CARRYING WIRES—FORCE

There is a 2 A current in wires *X, Y,* and *Z*. There is no magnetic force on wire *Y*. The distance between adjacent wires is the same. Three students are discussing this situation.



Arcadio: *"For the force on wire Y to cancel, the currents in X and Z must be in opposite directions."*

Bruce: *"No, for the forces on wire Y to cancel, the current in X and Z must be in the same direction, but opposite the current direction in Y."*

Carolina: *"All we care about is the current in X and Z being in the same direction. They don't have to be opposite Y."*

With which of these students do you agree?

Arcadio _____ Bruce _____ Carolina _____ None of them _____

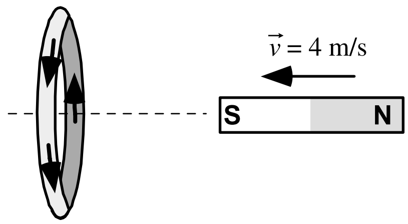
Explain your reasoning.

Answer: Carolina is correct.

Using the right hand rule, the currents in X and Z have to be in the same direction if we want their magnetic fields to cancel at

D3-SCT31: Moving Magnet and Circular Loop—Force

Three students are comparing the forces on a permanent magnet and a current-carrying circular loop of wire. The mass of the magnet is much larger than the mass of the loop.



Amador: *"The coil will push or pull on the magnet just as hard as the magnet pushes or pulls on the coil."*

Barbara: *"I think the magnet has to push harder on the coil than the coil pushes on the magnet because the magnet is more massive than the wire."*

Charlene: *"I think the magnet will push or pull on the coil but the coil will not push or pull on the magnet at all because the coil is not a magnet."*

With which of these students do you agree?

Amador _____ Barbara _____ Charlene _____ None of them _____

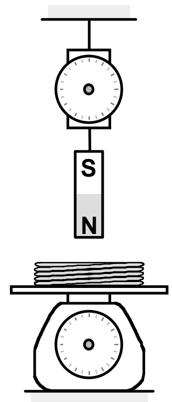
Explain your reasoning.

Answer: Amador is correct.

Newton's third law applies, and magnetic forces (like all forces) are always equal in magnitude (and opposite in direction).

D3-QRT32: SUSPENDED PERMANENT MAGNET AND CIRCULAR COIL—SCALE READING

A small, permanent magnet is suspended by a spring balance above the center of a circular coil of wire that is sitting on a balance. A large current is now introduced into the coil, causing the magnet to be attracted to the coil.



(a) Will the reading on the upper spring balance *increase*, *decrease*, or *stay the same*? Explain your reasoning.

It will increase since the magnet is being attracted to the coil. The magnetic force is added to the gravitational force (the weight) since it is in the same direction as the gravitational force.

(b) Will the reading on the balance supporting the coil *increase*, *decrease*, or *stay the same*? Explain your reasoning.

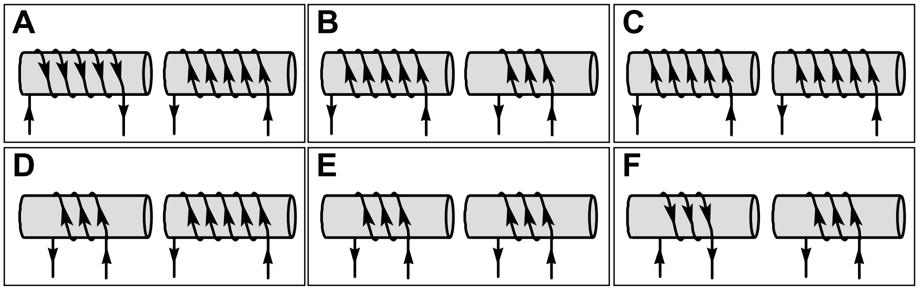
It will decrease since the coil is being attracted to the magnet. This force is subtracted from the gravitational force (the weight) since it is in the opposite direction to the gravitational force.

(c) Compare the sizes of the changes that will be observed in parts (a) and (b). Explain your reasoning.

The changes will be the same size. With the current turned off, the spring balance is measuring the tension in the string attached to the permanent magnet, which is equal to the weight of the magnet, and the balance supporting the coil is measuring the normal force upward on the coil, which is equal to the weight of the coil. When the current is turned on, the spring balance is reading the weight of the permanent magnet plus the magnetic force, and the balance supporting the coil is reading the weight of the coil minus the magnetic force upward on the coil. Each net force has changed by the contribution of the magnetic force, which is equal and opposite on the two objects according to Newton's third law.

D3-RT33: PAIRS OF EQUAL CURRENT ELECTROMAGNETS—FORCE

In each case, a pair of electromagnets is shown placed close together. The electromagnets are made with identical wires wrapped around identical iron cores, but the number of turns of wire varies. Each wire has the same current, and the pairs of electromagnets are separated by the same distance. Carefully observe the orientation of the coil and direction of current flow.



Rank the forces between the magnets from the most attractive (greatest) to the most repulsive (least).

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

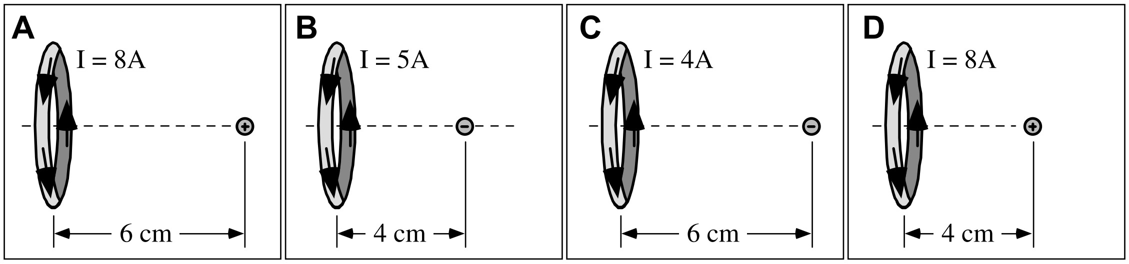
Explain your reasoning.

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

Currents in the same direction attract while currents in the opposite directions repel. The strength of the magnetic force depends on number of turns of wire.

D3-QRT34: CHARGE NEAR A CIRCULAR CURRENT LOOP—MAGNETIC FORCE DIRECTION

An electrically charged particle is placed at rest near a circular current-carrying loop of wire, along the centerline of the loop. All of the charges have the same magnitude. In Cases A and D, the particle is positively charged, while in Cases B and C they are negative. The currents in all the loops are in the same direction.



For these situations, draw the direction of the magnetic force exerted on the charged particle and on the current loop in the chart below.

	Direction of force on the current loop	Direction of force on the particle
Case A		
Case B		
Case C		
Case D		

Explain your reasoning.

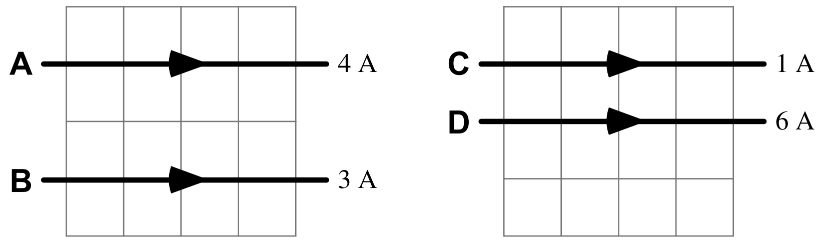
	Direction of force on the current loop	Direction of force on the particle
Case A	*None*	*None*
Case B	*None*	*None*
Case C	*None*	*None*
Case D	*None*	*None*

There is no magnetic force between the current loop and the charged particle since the particle is not moving.

Although this question asks only about the direction of the magnetic force, there is an electrostatic attraction between the positive/negative charged particle and the loop of wire, because the charged particle will polarize the wire loop, pulling charges of opposite sign closer to the charged particle and pushing like sign charges to the side of the loop away from the charged particle. Because the charges of opposite sign to the particle are closer than the charges of like sign, the attractive force is larger than the repulsive force, and there is a net attraction. This attraction acts on both objects and is equal in magnitude, but opposite in direction.

D3-RT35: Parallel Current–Carrying Wires—Magnetic Force on Wire

In each case below, two very long, straight wires are parallel to each other.



Rank the magnitude of the magnetic force on each of the labeled wires.

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

Explain your reasoning.

Answer: All the same.

The magnetic field due to a single wire is proportional to the current in the wire and inversely proportional to the distance from the wire, and the force on a current carrying wire is proportional to the field at the location of the wire and the current in the wire. As a result, the force of one wire on another is proportional to the product of the two currents divided by the distance of the wires from each other. The wires in each pair (A and B, C and D) exert the same force on each other, as required by Newton's third law, so the forces are all the same magnitude.

D3-SCT36: CHARGED PARTICLE AND STRAIGHT CURRENT–CARRYING WIRE—FORCE

Three students discuss the force on a charged particle moving parallel to a long, straight wire that is carrying a current.

Amalia: *"If the velocity and current are parallel, then the force is zero."*

Brenda: *"There is a force if the particle is moving parallel to the wire because the velocity is perpendicular to the magnetic field."*

Carlos: *"As long as the particle is moving near the wire, the particle will experience a force."*

With which of these students is do you agree?

Amalia _____ Brenda _____ Carlos _____ None of them _____

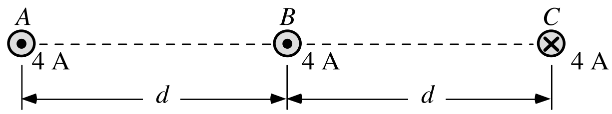
Explain your reasoning.

Answer: Brenda is correct.

The field of the current is concentric around the wire, so the velocity and field will be perpendicular to each other.

D3-LMCT37: THREE PARALLEL CURRENT–CARRYING WIRES—MAGNETIC FORCE ON WIRE

Wires *A* and *B* have 4 A currents coming out of the page, and wire *C* has a 4 A current going into the page. All the wires are parallel and equally spaced.



A number of changes to this initial situation are described in (a)–(f) below. Select from choices (i)–(v) how each change will affect the magnetic force on the center wire *B*.

This change will:

(i) **increase** the magnitude of the force without changing its direction.
(ii) **decrease** the magnitude of the force without changing its direction.
(iii) **reverse** the direction of the force without changing its magnitude.
(iv) **change** both the magnitude and direction of the force.
(v) have **no effect** on the magnetic force.

Each change below refers to the initial situation described above:

(a) The current in wire *B* is reversed. _____
Explain your reasoning.
Answer:(iii). The force on wire B depends on the direction of the current in wire B.

(b) The currents in all three wires are doubled. _____
Explain your reasoning.
Answer: (i). The force is proportional to the current in both the wire that the force is acting on, and on the strength of the field at the location of that wire, which in turn depends on the current in the wires creating the field. Doubling the current in wires A and C will double the strength of the magnetic field at the location of wire.

(c) The currents in the wires *A* and *C* are both reversed. _____
Explain your reasoning.
Answer: (iii). Reversing the currents in wires A and C will reverse the field at B, which in turn will reverse the direction of the force.

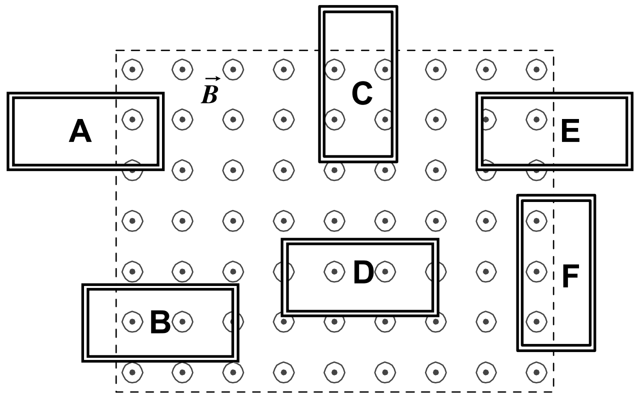
(d) The current in wire *B* is reduced. _____
Explain your reasoning.
Answer: (ii). The magnitude of the force on wire B depends on the current in B.

(e) The currents in the wires *A* and *C* are reversed and cut in half._____
Explain your reasoning.
Answer: (iv). Cutting the current in both A and C in half will halve the magnetic field strength at the location of wire B, which in turn will halve the force on B. Reversing the directions of the currents in A and C will reverse the direction of the force on B.

(f) Both wires *A* and *C* are moved the same distance so that they are both closer to wire *B*. _____
Explain your reasoning.
Answer: (i). Since the field due to a current-carrying wire is inversely proportional to the distance, bringing wires A and C closer to B will increase the magnetic field strength at the location of wire B, which in turn will increase the force on wire B.

D3-RT38: Moving Rectangular Loops in Uniform Magnetic Fields—Current

Six identical rectangular wire loops are moving to the right at the same constant speed. There is a uniform magnetic field coming out of the page in the region enclosed by the dashed line. The rectangular loops are all 5 cm by 10 cm.



Rank the magnitude of the induced current in the rectangular loops at the instant shown. Assume there is no effect or interaction between the loops.

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

Explain your reasoning.

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

The wire loops are identical, so they all have the same resistance, and the current is directly proportional to the induced emf. The induced emf is proportional to the rate of change of flux. Loops C and D have no change in flux since the portion of the loop within the magnetic field is constant (until they reach the limit of the field). For the others, the rate of change of flux is due to the rate of change of area, which is proportional to the length of the rectangle perpendicular to the direction of motion and the velocity (i.e., the height). (Or, emf = BvH where H is the height of the rectangle.)

D3-SCT39: Moving Rectangular Loops in Uniform Magnetic Fields—Current

Three students are discussing a rectangular wire loop moving at a constant speed as it enters a region in which there is a uniform magnetic field perpendicular to the plane of the loop. The sides of the rectangular wire loop are perpendicular or parallel to the leading edge of the magnetic field.

Allison: *"The current will increase as more of the loop gets into the field since there will be more magnetic flux inside the loop."*

Blanca: *"I think the current in the wire loop will start out big and then decrease as the loop moves into the field region since less of the loop will be outside of the field."*

Chithra: *"No, the current in the wire loop will be constant from the time the loop starts into the field region until it is fully into the field region. Then the current will go to zero."*

With which of these students do you agree?

Allison _____ Blanca _____ Chithra _____ None of these students _____

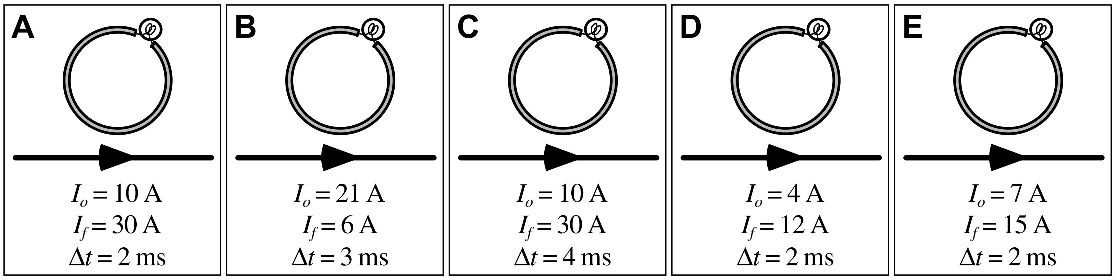
Explain your reasoning.

Answer: Chithra is correct.

The change in flux per unit time is constant from the time the leading edge of the loop enters the field region to the time the trailing edge enters. Allison is relating the current to the magnetic flux, but the emf (and therefore the induced current) depends on the time rate of change of magnetic flux rather than on the flux itself. Blanca is also relating the flux to the induced current rather than the change in flux.

D3-RT40: Changing Current in Long Wire—Bulb Brightness in Nearby Loop

In each case, a long, straight wire is placed next to a circular wire loop that has a small light bulb in it. The currents in the long wires are changing at uniform rates. The initial current, the final current, and the time interval during which the change occurs are given. The bulbs and wire loops are all identical, and the straight wires are all the same distance from the wire loops.



Rank the bulb brightness during the time that the current changes.

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

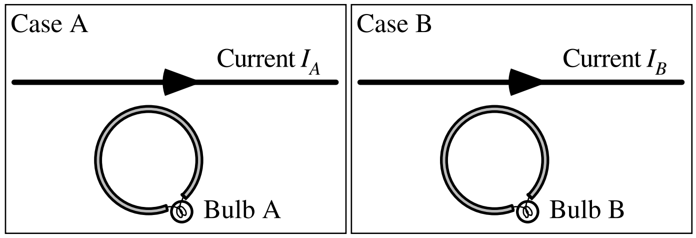
Explain your reasoning.

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

A current in the wire creates a magnetic field. A changing current in the wire creates a changing magnetic field and thus a changing magnetic flux that induces an emf in the loop. This emf produces a current in the wire loop and causes the bulb to light. Bulb brightness thus depends on the amount of induced emf, which in turn depends on the rate of change of magnetic flux through the loop caused by the rate of change in current in the wire. We can calculate the rate of change of current by finding the change in the current current and dividing this by the time interval over which this change occurs.

D3-SCT41: CHANGING CURRENT IN LONG WIRE—BULB BRIGHTNESS IN NEARBY LOOP

A circular loop of wire with a small bulb in it is placed beside a long straight current-carrying wire. In both cases below, these loops are the same distance away from the current-carrying wire. Bulb A is brighter than Bulb B. The wire loops, bulbs, and long straight wires are identical for the two situations.



Three students discussing this arrangement contend:

Adela: *"Bulb A is brighter than Bulb B because the long wire next to the brighter bulb has a larger current in it."*

Bryce: *"No, Bulb A is brighter than Bulb B because the current in the long wire next to it is increasing at a faster rate than the current in the other wire."*

Consuelo: *"We don't know that. The current in the long wire must be changing at a faster rate, but it could also be decreasing."*

With which of these students do you agree?

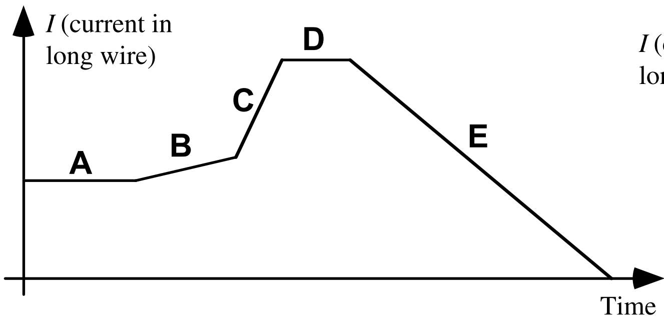
Adela _____ Bryce _____ Consuelo _____ None of these students _____

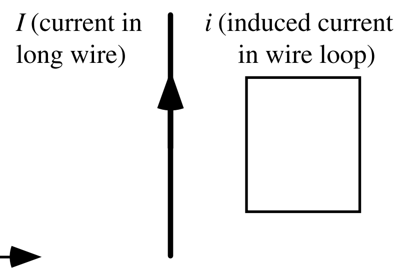
Explain your reasoning.

Answer: Consuelo is correct because the emf induced in the wire loop depends on the rate of change of magnetic flux through the loop. The flux in the loop changes because the magnetic field changes, since the current producing the magnetic field in the straight wire changes. The bulb will be brighter where the current changes at the greater rate, whether it is increasing or decreasing, or whether the current is large or small.

D3-RT42: Current in Wire Time Graph—Induced Current in Nearby Loop

The current in a long wire changes with time as indicated in the graph below. A square wire loop is placed near the wire as shown in the diagram.





Rank the magnitude of the induced current *i* in the square loop for the labeled time intervals.

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

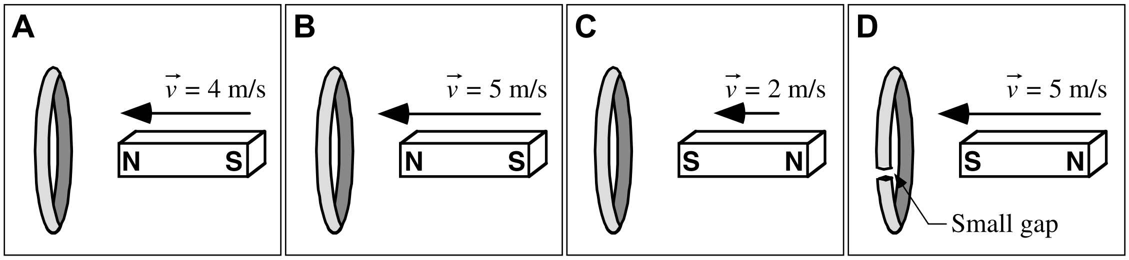
Explain your reasoning.

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

Current will be induced in the loop when the field through the loop is changing, which will be when the current in the long wire is changing. A faster rate of change for the current in the long wire produces a larger field change, and consequently, a large induced current. In time intervals A and D there is no change in the current in the long wire, and therefore no induced current in the wire loop.

D3-RT43: WIRE LOOPS AND MOVING MAGNETS—LOOP MOTION

In each case, a permanent magnet is moving toward a circular wire loop that is fixed in place. All of the wire loops are identical, but the wire in Case D has a small gap. The magnets are all identical, but they are approaching the loops at different speeds and with different poles facing the loops. At the instant shown, all of the magnets are the same distance from the wire loops.



Rank the magnitude of the repulsive force on the loop by the approaching magnet at the instant shown.

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

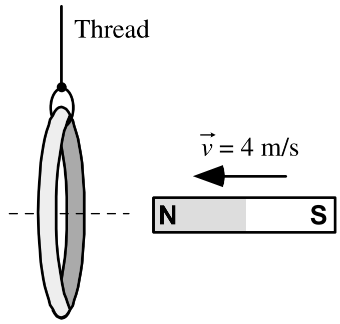
Explain your reasoning.

Answer: B > A > C > D.

All the coils, except for D, experience repulsion due to the induced current since the flux is changing as the magnet gets closer. This repulsion is a consequence of Lenz's law: as the magnet approaches, the flux increases, and a current is induced that acts to oppose the increase in flux. The largest rate of change of magnetic flux is associated with the largest velocity of the approaching magnet. For case D, there is no induced current (although there is an induced emf) and therefore no induced field.

D3-QRT44: WIRE LOOPS AND MOVING MAGNETS—MOTION OF THE SYSTEM

A circular loop of wire is suspended from a thread so that it hangs freely. A permanent bar magnet is moved toward the center of the wire loop as shown.



Describe how each of the following changes affects this system.

(a) The magnet is moved toward the loop at twice the speed.
Explain your reasoning.
Answer: The time rate of change of the flux will double, and the loop will experience a larger repulsive force and thus move more.

(b) A small gap is cut in the wire loop.
Explain your reasoning.
Answer: There will still be an emf induced in the wire loop, but there will be no corresponding current in the loop, and therefore no motion of the loop because there is no repulsive force.

(c) The south pole of the magnet is on the side of the magnet closer to the loop.
Explain your reasoning.
Answer: The current direction in the loop will be reversed, but there will be no observable difference in the motion of the loop. The repulsive force on the loop will be the same.

(d) The north pole is moving toward the loop from the left at the same speed.
Explain your reasoning.
Answer: The loop will experience the same repulsive force and thus move away at the same rate, only in the opposite direction.

(d) The strength of the magnet is increased.
Explain your reasoning.
Answer: The flux in the loop will increase, and the time rate of change of the flux will also increase, so the loop will experi
ence a larger repulsive force and thus move more strongly or rapidly away.

(e) The magnet is moving away from the loop at the same speed.
Explain your reasoning.
Answer: The magnitude of the flux in the loop will decrease instead of increase, and the induced current will be