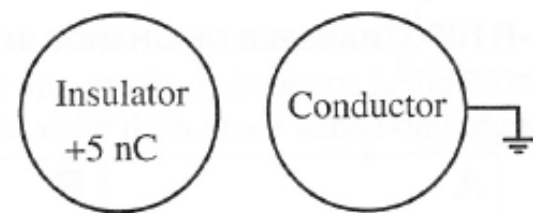


#### D1-WWT04: CHARGED INSULATOR AND A GROUNDED CONDUCTOR—INDUCED CHARGE

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-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."*

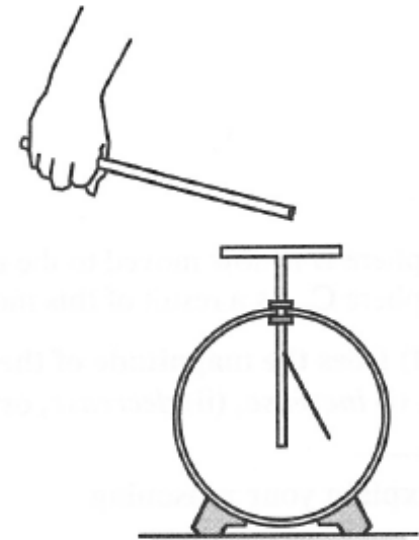
Barun: *"Charges don't have to move from the rod to the plate to deflect. When the rod comes close, electrons in the electroscope move toward the plate. This leaves the bottom of the electroscope positively charged, and the leaf lifts."*

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.**

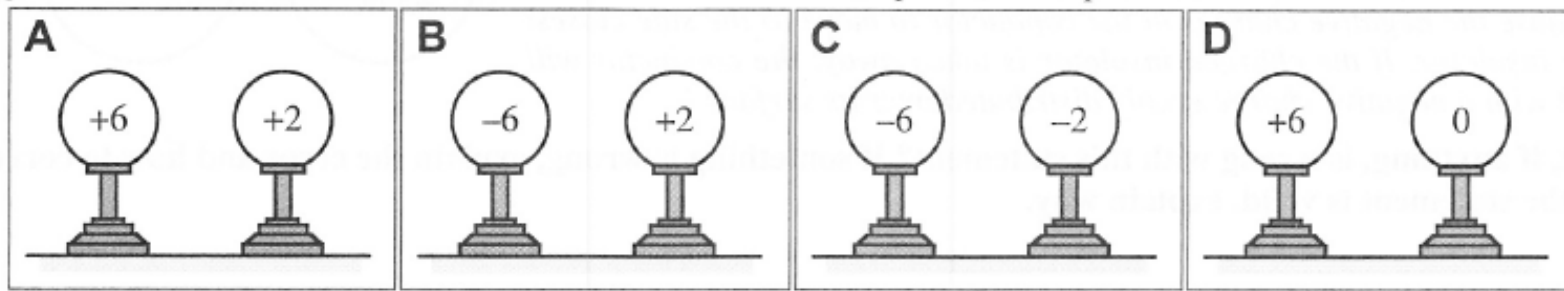


*Answer: Barun is correct.*

*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-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  $-2$ ).

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

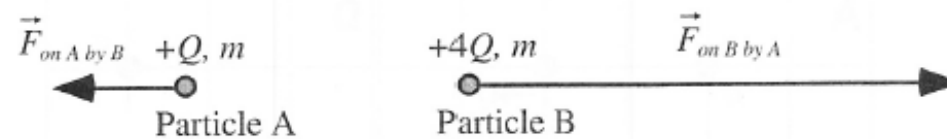
Explain your reasoning.

*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.*

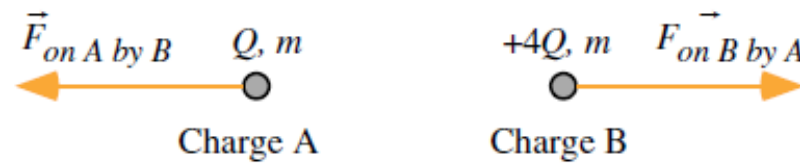
### D1-TT15: TWO CHARGED PARTICLES—FORCE

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.

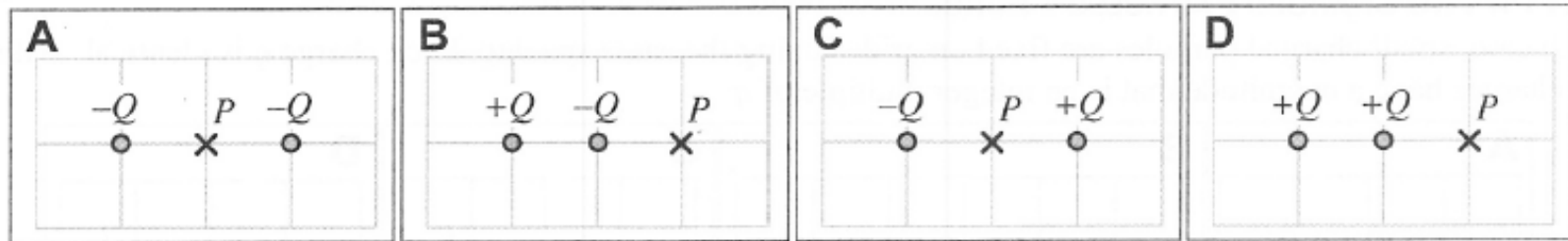
*Answer: The forces should be the same magnitude: to correct the diagram make the arrow on the  $+q$  charge the same length as the one on the  $+4q$  charge.*





**D1-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	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

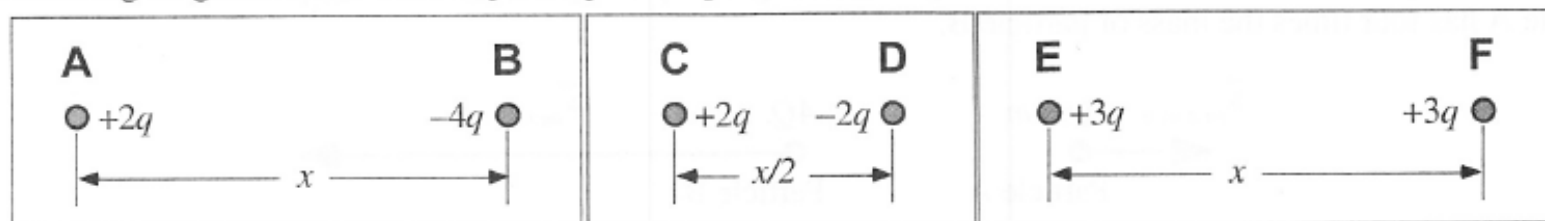
Explain your reasoning.

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

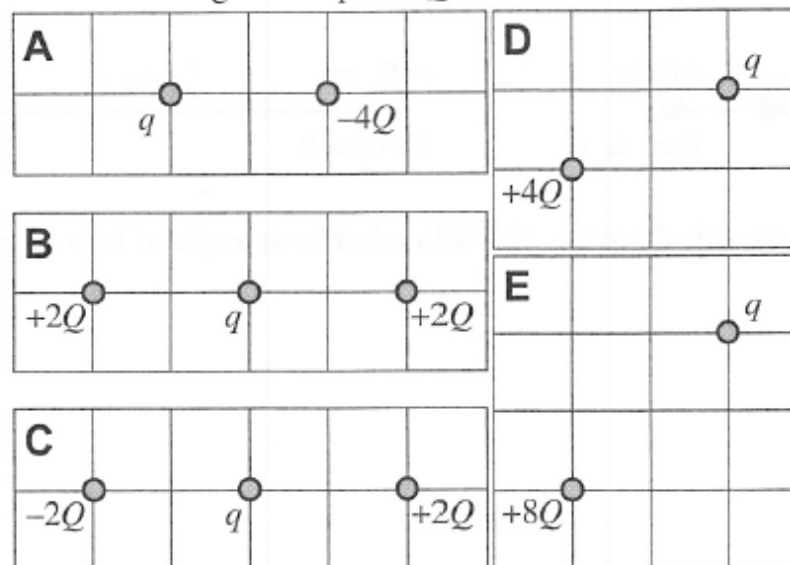
Explain your reasoning.

*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-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	2	3	4	5		All	All	Cannot
Greatest				Least		the same	zero	determine

Explain your reasoning.

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

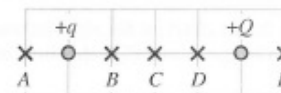
*From Coulomb's law, the force between two charges is proportional to the product of the charges and inversely proportional to the square of the distance between them. If we let  $F$  be the magnitude of the force between a  $2Q$  charge and a  $q$  charge that are two squares apart, then in case A there 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-QRT19: TWO UNEQUAL CHARGES—FORCE**

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

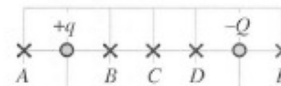
(a) Both  $q$  and  $Q$  are positive.

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



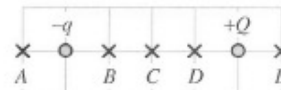
(b) Charge  $q$  is positive and charge  $Q$  is negative.

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



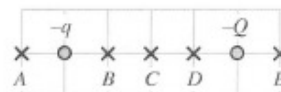
(c) Charge  $q$  is negative and charge  $Q$  is positive.

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



(d) Both  $q$  and  $Q$  are negative.

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



**D1-QRT09: TWO CHARGES—FORCE ON EACH**

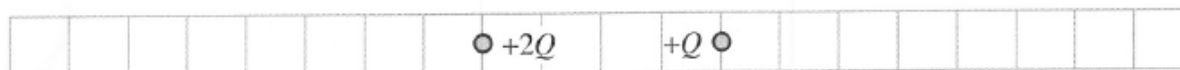
In each case shown below, two charges are fixed in place and are exerting forces on each other.

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 above 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.

Example:



(a)



(b)



(c)



(d)



(e)



(f)



Explain your reasoning.



Example:



(a)



(b)



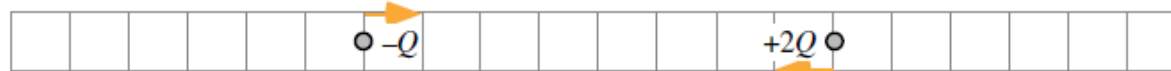
(c)



(d)



(e)



(f)



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.

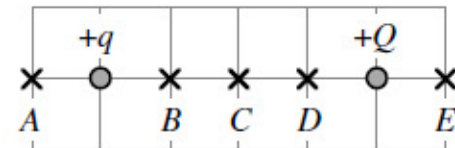
(a) Both  $q$  and  $Q$  are positive.

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 than  $+Q$  – so it is at least possible that the forces are equal at these points.*



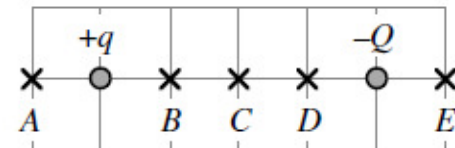
(b) Charge  $q$  is positive and charge  $Q$  is negative.

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.*



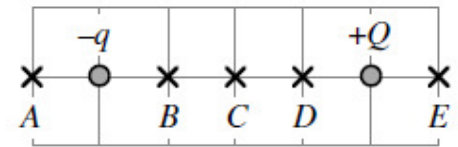
(c) Charge  $q$  is negative and charge  $Q$  is positive.

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.*



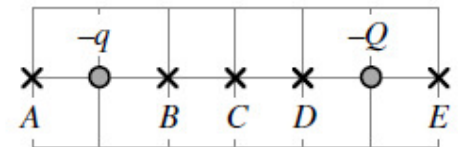
(d) Both  $q$  and  $Q$  are negative.

At which point A–E is it possible that the third charge was placed? \_\_\_\_\_

Explain your reasoning.

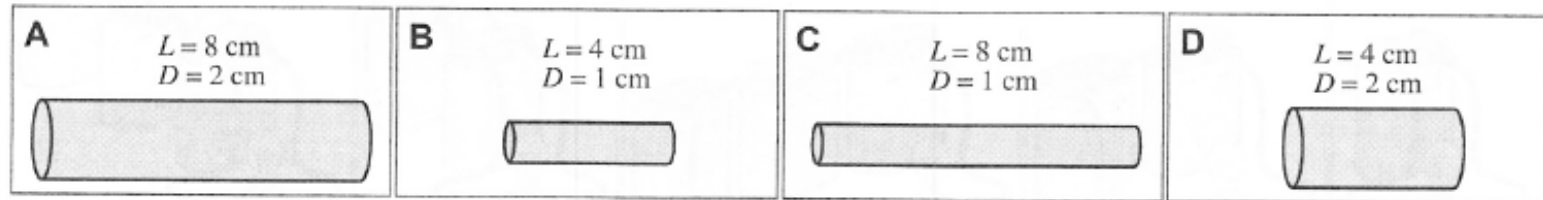
*Answer: Point B.*

*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.*



**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.

<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	determine

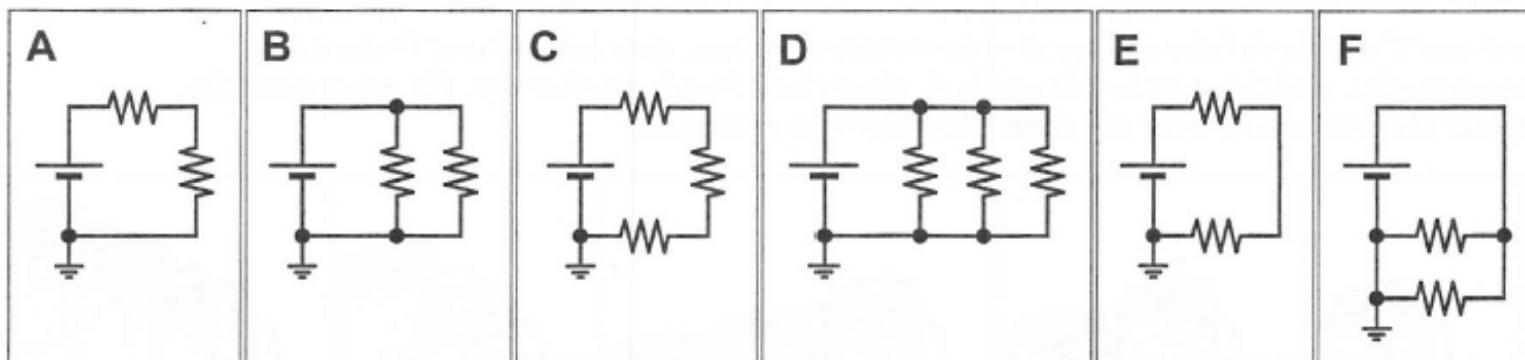
Explain your reasoning.

*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-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	2	3	4	5	6		All	All	Cannot
Greatest					Least		the same	zero	determine

Explain your reasoning.

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

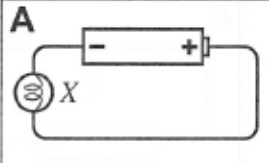
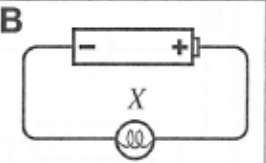
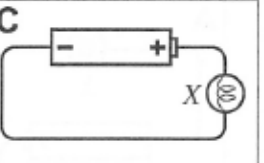
*Since resistances add for resistors in series  $C$  will have the largest resistance.  $A$  and  $E$  are the same because they both have two resistors in series.  $B$  and  $F$  have two resistors in parallel so the resistance of those arrangements is  $R/2$ . And  $D$  has a resistance of  $R/3$ 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

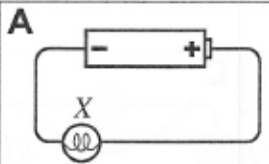
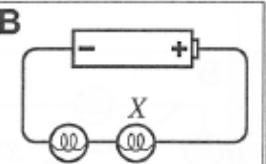
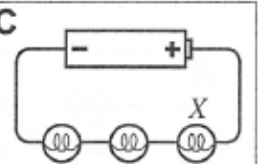
For the three items below, rank the brightness of the bulb labeled *X*.

(a)

<b>A</b> 	<b>B</b> 	<b>C</b> 
<div style="border: 1px solid black; width: 50px; height: 25px; margin: 0 auto;"></div> <div style="text-align: center;">1 Greatest</div>	<div style="border: 1px solid black; width: 50px; height: 25px; margin: 0 auto;"></div> <div style="text-align: center;">2</div>	<div style="border: 1px solid black; width: 50px; height: 25px; margin: 0 auto;"></div> <div style="text-align: center;">3 Least</div>
OR		
<div style="border: 1px solid black; width: 50px; height: 25px; margin: 0 auto;"></div> <div style="text-align: center;">All the same</div>	<div style="border: 1px solid black; width: 50px; height: 25px; margin: 0 auto;"></div> <div style="text-align: center;">All zero</div>	<div style="border: 1px solid black; width: 50px; height: 25px; margin: 0 auto;"></div> <div style="text-align: center;">Cannot determine</div>

Explain your reasoning.

(b)

<b>A</b> 	<b>B</b> 	<b>C</b> 
<div style="border: 1px solid black; width: 50px; height: 25px; margin: 0 auto;"></div> <div style="text-align: center;">1 Greatest</div>	<div style="border: 1px solid black; width: 50px; height: 25px; margin: 0 auto;"></div> <div style="text-align: center;">2</div>	<div style="border: 1px solid black; width: 50px; height: 25px; margin: 0 auto;"></div> <div style="text-align: center;">3 Least</div>
OR		
<div style="border: 1px solid black; width: 50px; height: 25px; margin: 0 auto;"></div> <div style="text-align: center;">All the same</div>	<div style="border: 1px solid black; width: 50px; height: 25px; margin: 0 auto;"></div> <div style="text-align: center;">All zero</div>	<div style="border: 1px solid black; width: 50px; height: 25px; margin: 0 auto;"></div> <div style="text-align: center;">Cannot determine</div>

Explain your reasoning.

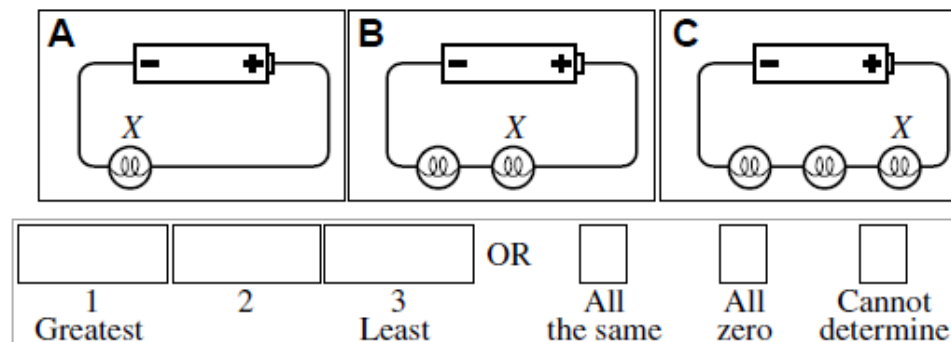


**Explain your reasoning.**

*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)

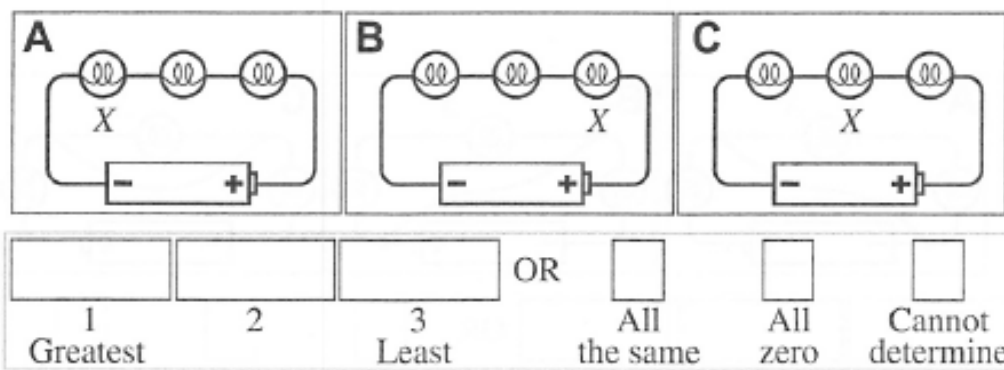


**Explain your reasoning.**

*Answer:  $A > B > C$ .*

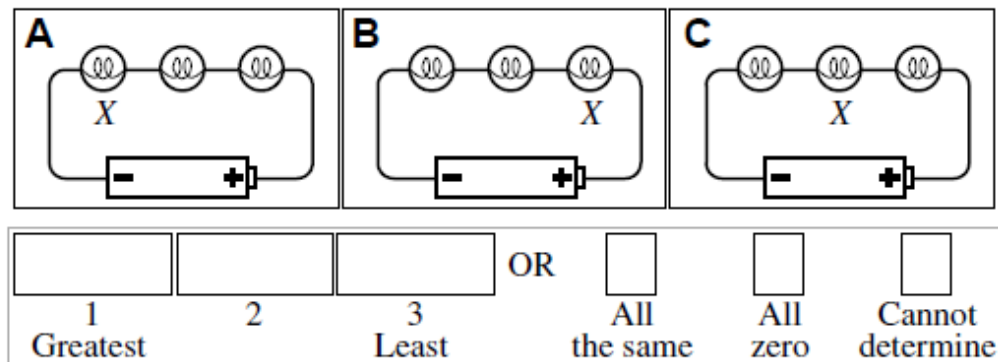
*The bulbs are in series for each circuit, and the resistance of the circuit increases for each bulb added in series. A large circuit resistance corresponds to a small current. Since all of the bulbs in each circuit will have the same current, the brightness will be determined by the potential differences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

(c)



Explain your reasoning.

(c)



**Explain your reasoning.**

*Answer: All the same.*

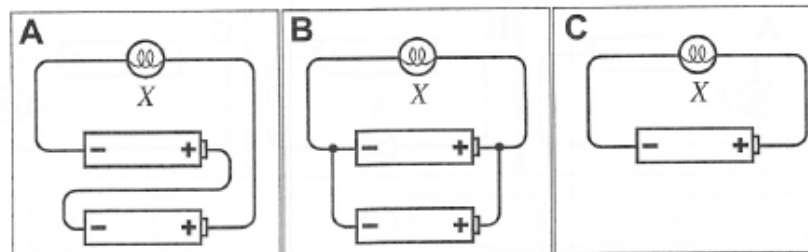
*All of the bulbs have the same current and potential difference, so they have the same brightness.*

**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*.

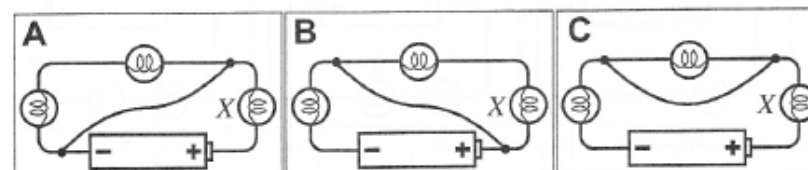
(a)



<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3		All	All	Cannot
Greatest		Least		the same	zero	determine

Explain your reasoning.

(b)



<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3		All	All	Cannot
Greatest		Least		the same	zero	determine

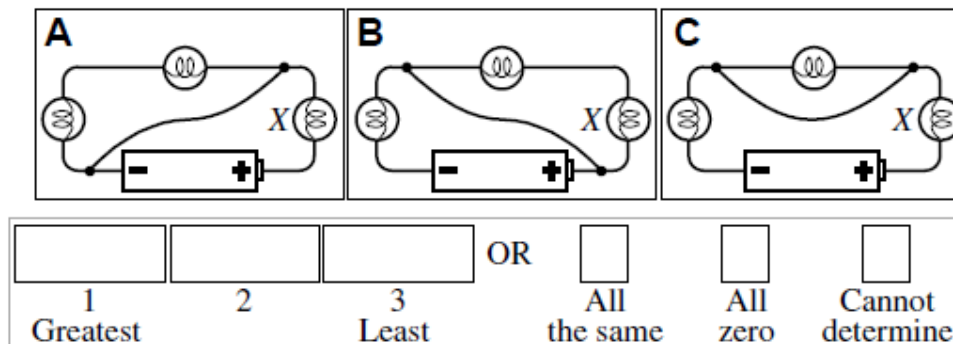
Explain your reasoning.

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)

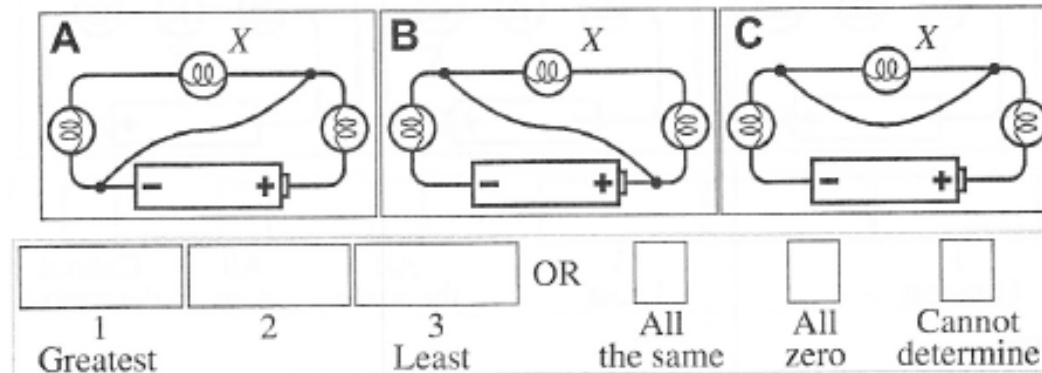


Explain your reasoning.

Answer:  $A > C > B$ .

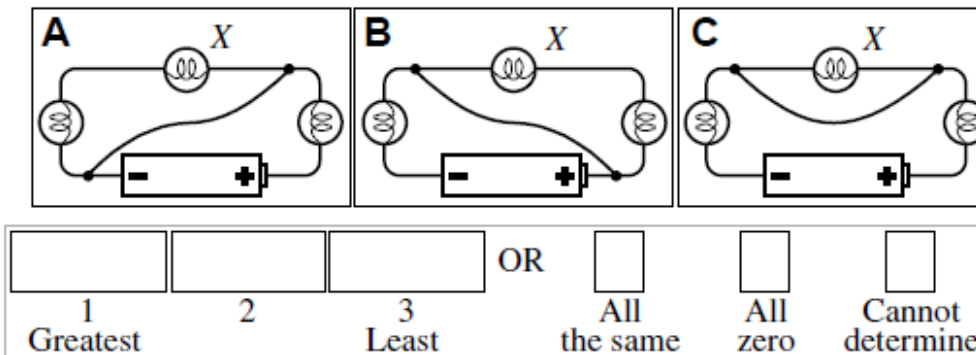
In case A the voltage across bulb X is the battery voltage. In case B, the branch containing bulb X has no voltage difference from one end to the other, because the diagonal wire connects the ends, and so bulb X will not light. In case C, the wire provides a path with no resistance across the middle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

(c)



Explain your reasoning.

(c)



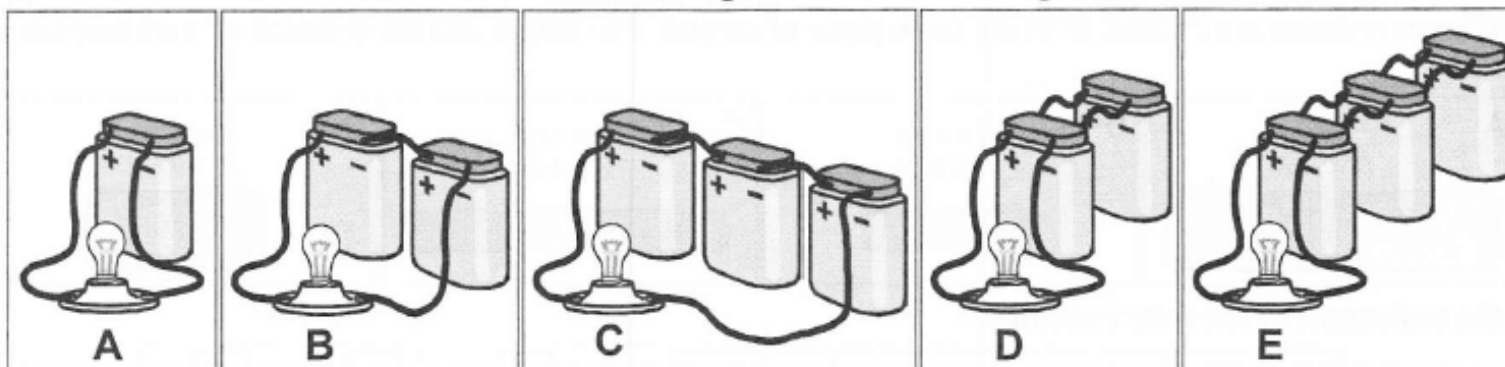
**Explain your reasoning.**

**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-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	2	3	4	5		All	All	Cannot
Greatest				Least		the same	zero	determine

Explain your reasoning.



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

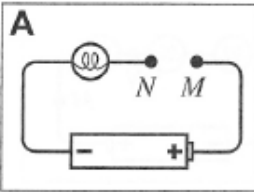
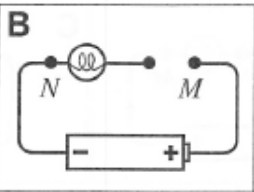
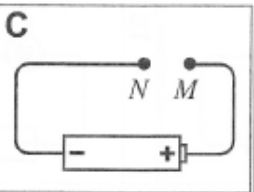
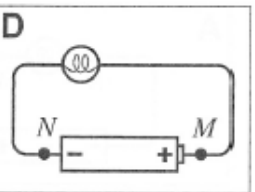
*The circuits in cases A, D, and E have the batteries connected in parallel with each other so the potential difference across the bulb in these cases is the voltage of a single battery. In case C the batteries are connected in series, and the voltage across the bulb is three times the voltage of a single 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-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.

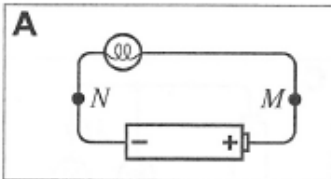
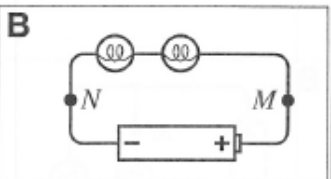
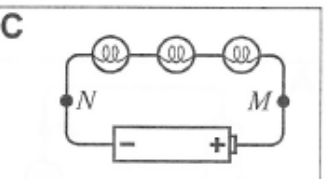
In each item below, rank the magnitude of the potential difference between points  $M$  and  $N$ .

(a)

<b>A</b> 	<b>B</b> 	<b>C</b> 	<b>D</b> 				
<div style="border: 1px solid black; width: 40px; height: 20px; margin: 0 auto;"></div> <div style="text-align: center;">1 Greatest</div>	<div style="border: 1px solid black; width: 40px; height: 20px; margin: 0 auto;"></div> <div style="text-align: center;">2</div>	<div style="border: 1px solid black; width: 40px; height: 20px; margin: 0 auto;"></div> <div style="text-align: center;">3</div>	<div style="border: 1px solid black; width: 40px; height: 20px; margin: 0 auto;"></div> <div style="text-align: center;">4 Least</div>	OR	<div style="border: 1px solid black; width: 40px; height: 20px; margin: 0 auto;"></div> <div style="text-align: center;">All the same</div>	<div style="border: 1px solid black; width: 40px; height: 20px; margin: 0 auto;"></div> <div style="text-align: center;">All zero</div>	<div style="border: 1px solid black; width: 40px; height: 20px; margin: 0 auto;"></div> <div style="text-align: center;">Cannot determine</div>

Explain your reasoning.

(b)

<b>A</b> 	<b>B</b> 	<b>C</b> 				
<div style="border: 1px solid black; width: 40px; height: 20px; margin: 0 auto;"></div> <div style="text-align: center;">1 Greatest</div>	<div style="border: 1px solid black; width: 40px; height: 20px; margin: 0 auto;"></div> <div style="text-align: center;">2</div>	<div style="border: 1px solid black; width: 40px; height: 20px; margin: 0 auto;"></div> <div style="text-align: center;">3 Least</div>	OR	<div style="border: 1px solid black; width: 40px; height: 20px; margin: 0 auto;"></div> <div style="text-align: center;">All the same</div>	<div style="border: 1px solid black; width: 40px; height: 20px; margin: 0 auto;"></div> <div style="text-align: center;">All zero</div>	<div style="border: 1px solid black; width: 40px; height: 20px; margin: 0 auto;"></div> <div style="text-align: center;">Cannot determine</div>

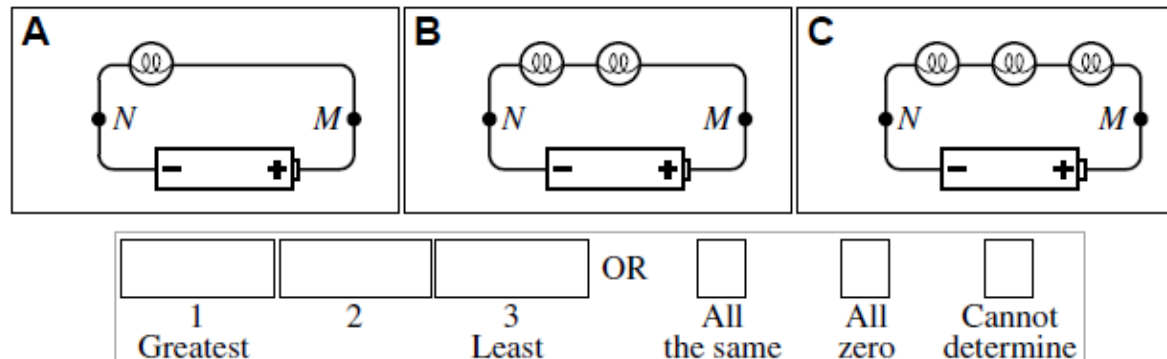
Explain your reasoning.

**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)

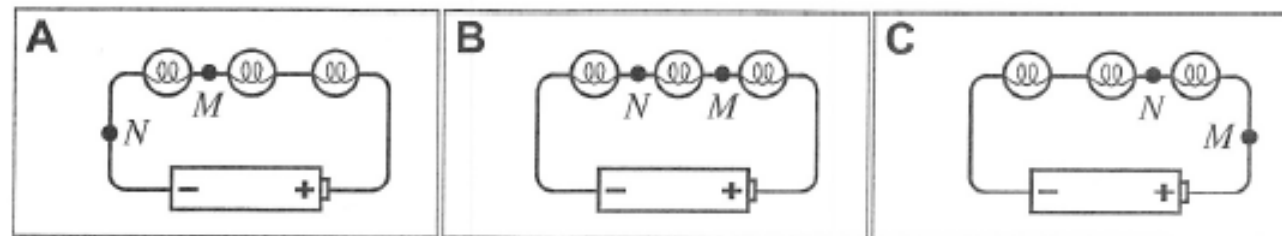


**Explain your reasoning.**

*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.*

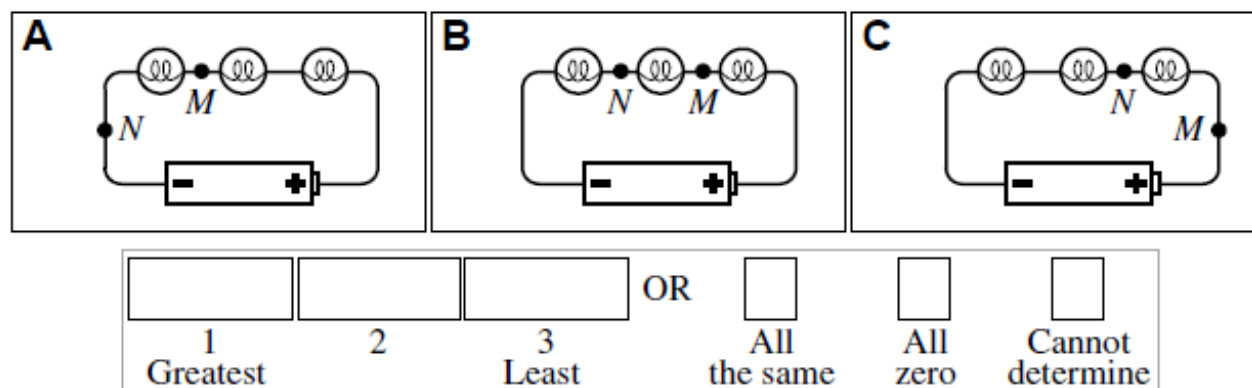
(c)



<input type="text"/>	<input type="text"/>	<input type="text"/>	OR	<input type="text"/>	<input type="text"/>	<input type="text"/>
1	2	3		All	All	Cannot
Greatest		Least		the same	zero	determine

Explain your reasoning.

(c)



**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-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)

**A**

**B**

**C**

1

2

3

OR

All  
the same

All  
zero

Cannot  
determine

Greatest

Least

Explain your reasoning.

(b)

**A**

**B**

**C**

1

2

3

OR

All  
the same

All  
zero

Cannot  
determine

Greatest

Least

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)

**A**

**B**

**C**

1

2

3

OR

All  
the same

All  
zero

Cannot  
determine

1  
Greatest

2

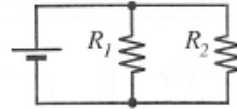
3  
Least

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-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.

(b) The resistance in  $R_2$  is reduced. \_\_\_\_\_  
Explain your reasoning.

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

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



(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.*

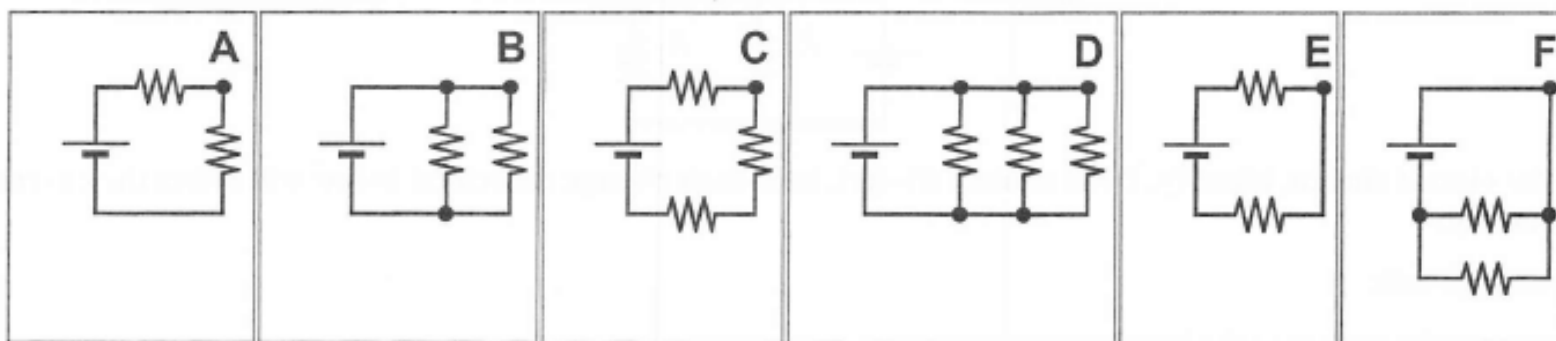
(d) The resistance in  $R_1$  is reduced, and in  $R_2$  it is increased. \_\_\_\_\_

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

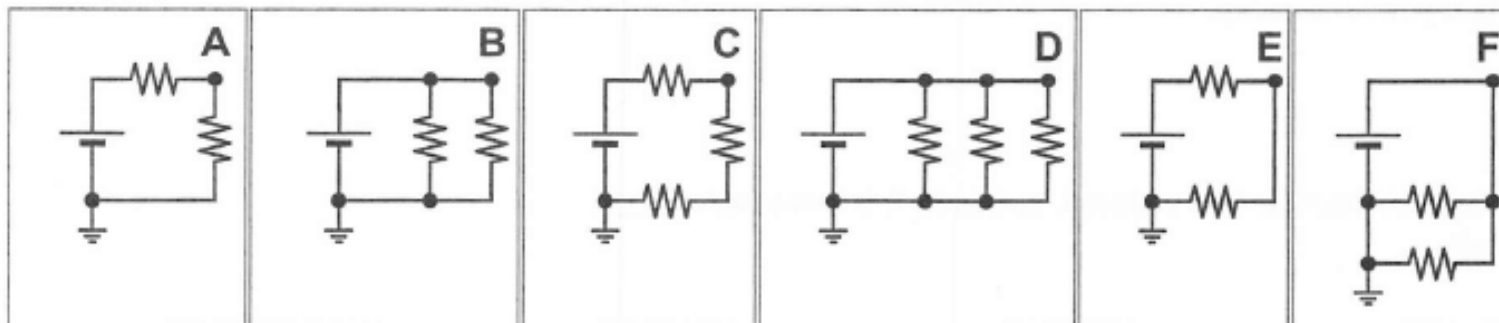
Explain your reasoning.

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

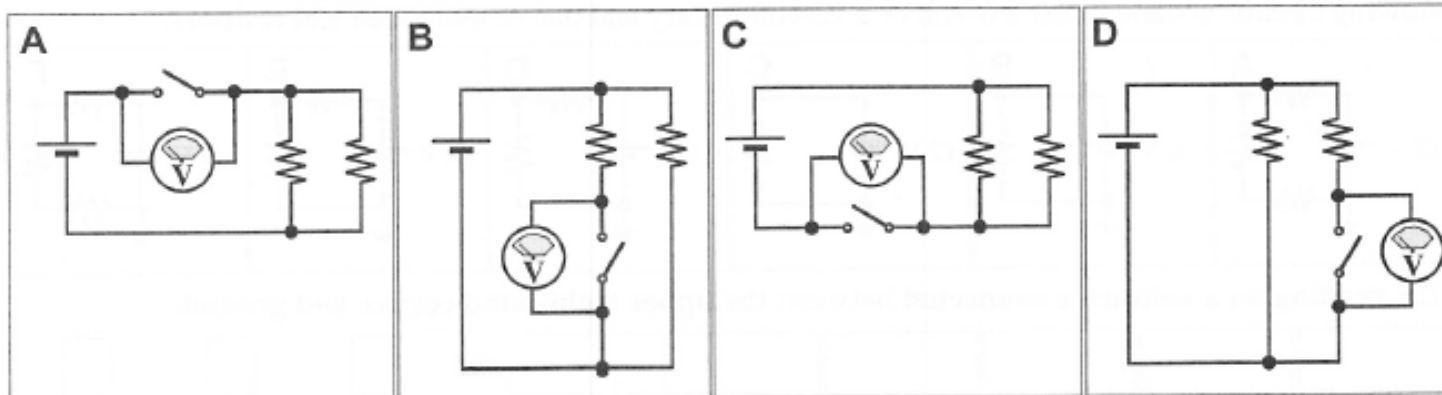
Explain your reasoning.

*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 these 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-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	2	3	4		All	All	Cannot
Greatest			Least		the same	zero	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-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.

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

Explain your reasoning.

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

Explain your reasoning.

(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*? \_\_\_\_\_

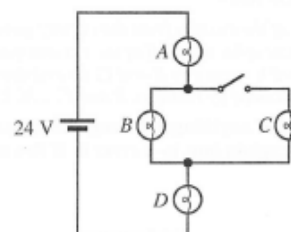
Explain your reasoning.

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

Explain your reasoning.

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

Explain your reasoning.





(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.*

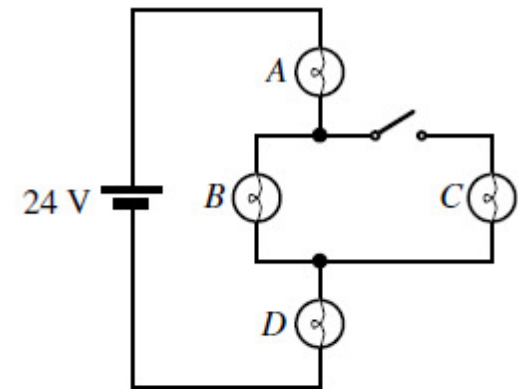
*The resistance of two bulbs connected in parallel (as B and C are when the switch closes) is smaller than the resistance of a single bulb, so the resistance of the portion of the circuit containing bulbs B and C and the switch decreases when the switch closes. Since this portion of the circuit is connected 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.*