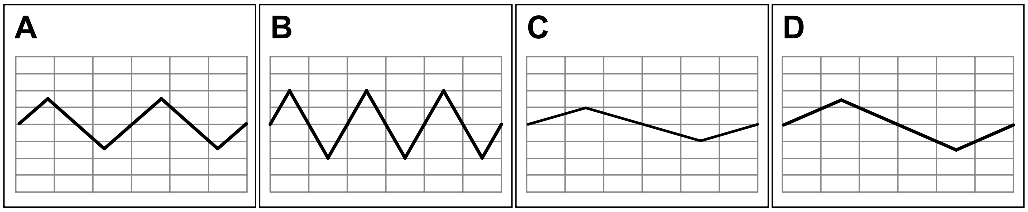
Instructors Manual Sections E & F

E1 WAVES

E1-RT01: WAVES—WAVELENGTH

The drawings represent snapshots taken of waves traveling to the right along strings. The grids shown in the background are identical. The waves all have the same speed, but their amplitudes vary.



Rank the wavelength of the waves.

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

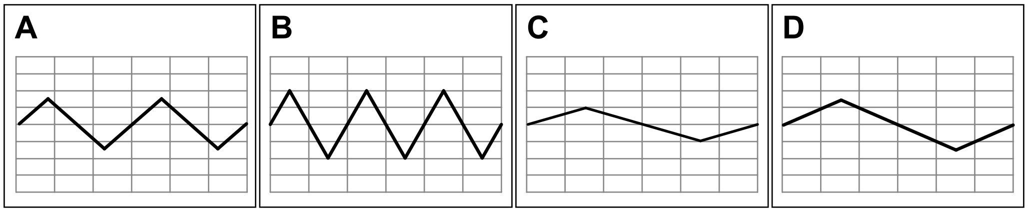
Explain your reasoning.

Answer: C = D > A > B

The wavelength is the horizontal distance between the same point of the wave. C and D are 6 horizontal units while A is 4 horizontal units and B is 2 horizontal units.

E1-RT02: WAVES—FREQUENCY

The drawings represent snapshots taken of waves traveling to the right along strings. The grids shown in the background are identical. The waves all have the same speed, but their amplitudes and wavelengths vary.



Rank the frequency of the waves.

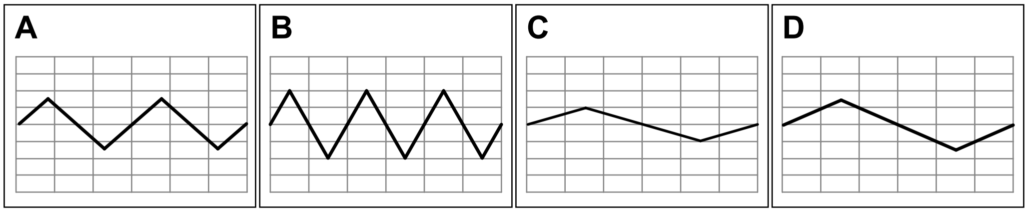
1 Greatest	2	3	4 Least	OR	All the same	All zero	Cannot determine

Explain your reasoning.

Answer: B > A > C = D
The number of waves per second (the frequency) times the length of the waves (the wavelength) equals the speed of the waves along the string. All of these waves have the same wave speed, so the frequency must be inversely proportional to the wavelength. The frequency is independent of amplitude. The wavelength can be measured – it is the horizontal distance taken by one complete cycle of the wave, or the horizontal distance between the same point on two successive cycles of the wave, so from the drawings the ranking sequence for the wavelengths is C = D > A > B . Thus the frequency ranking will be the inverse or B > A > C = D.

E1-RT03: WAVES WITH SAME FREQUENCY—WAVE SPEED

The drawings represent snapshots taken of waves traveling to the right along strings. The grids shown in the background are identical. The waves all have the same frequency, but their amplitudes and wavelengths vary.



Rank the speed of the waves on the string.

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

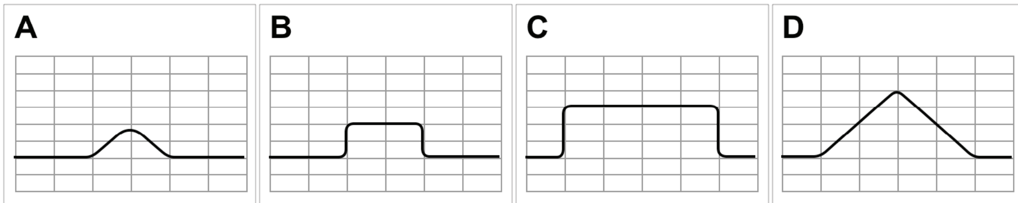
Explain your reasoning.

Answer: C = D > A > B

The number of waves per second (the frequency) times the length of the waves (the wavelength) equals the speed of the waves along the string. All of these waves have the same frequency, so the wave speed is proportional to the wavelength. The wave speed is independent of amplitude. The wavelength can be measured – it is the horizontal distance taken by one complete cycle of the wave.

E1-RT04: Wave Pulses—Leading Edge Time to Travel

The drawings represent snapshots taken of waves traveling along a rope. The grids shown in the background are identical. These pulses, which vary in amplitude, are all sent down identical ropes under equal tension. The ropes are all the same length, and there is no distortion of the pulses as they travel down the ropes.



Rank the time it takes the leading edge of the pulse to travel 3 m.

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

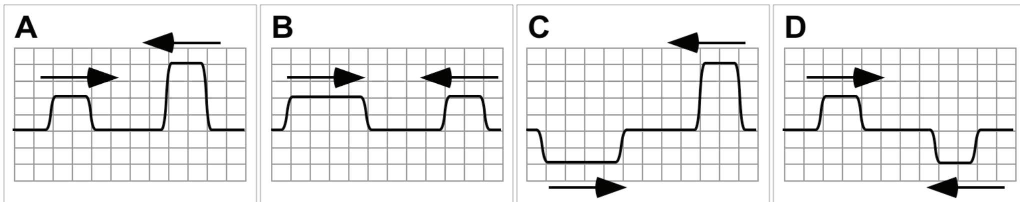
Explain your reasoning.

Answer: All the same.

The time to move 3 m will be determined by the wave speed, which since they are all traveling in the same medium (equal length, identical ropes under the same tension), is the same for all cases.

E1-RT05: PAIRS OF TRANSVERSE WAVES—SUPERPOSITION

Rectangular transverse wave pulses are traveling toward each other along a string. The grids shown in the background are identical, and the pulses vary in height and length. The pulses will meet and interact soon after they are in the positions shown.



Rank the maximum amplitude of the string at the instant that the positions of the centers of the two pulses coincide.

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

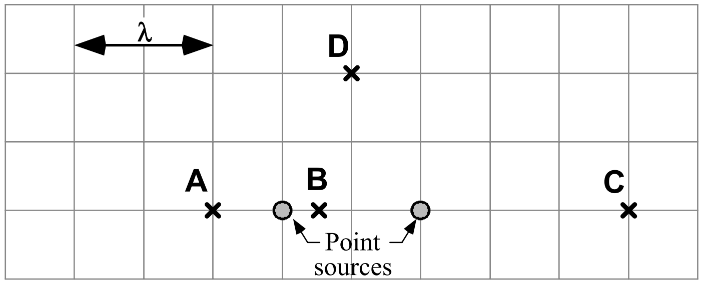
Explain your reasoning.

Answer: A > B > C > D.

The peak height is the sum of the two amplitudes taking account of their signs. For cases A and B, the pulses are on the same side of the string, and they will interfere constructively. For cases C and D, the pulses are on opposite sides of the string, and they will interfere destructively. For C there will be a non-zero amplitude, but for D the amplitude will be zero.

E1-RT06: Wave Sources Separated by One Wavelength—Intensity

Two identical point sources are generating waves with the same frequency and amplitude. The two sources are in phase with each other, so the two sources generate wave crests at the same instant. The wavelength of the waves is equal to the distance between the two sources.



Rank the maximum amplitude of the wave at the labeled points.

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

Explain your reasoning.

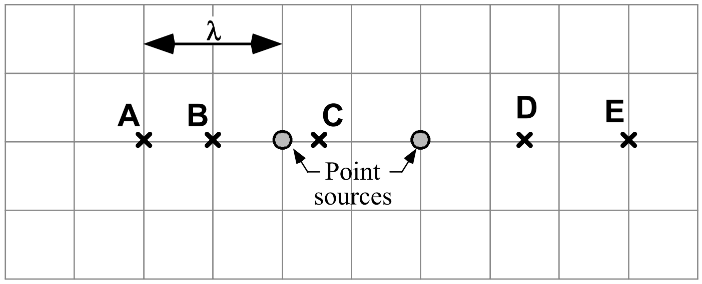
Answer: A = C = D > B, or A > D > C > B, depending on the level of detail included in the explanation.

The intensity at each point depends on the relative phases of the two waves when they reach the point. The sources are in phase, so if they travel the same distance from each source to some point, they will still be in phase when they reach that point (as at point D), and the maximum amplitude will be twice the amplitude of a single wave at that point. The distance from the left source to point A is one-half wavelength, and the distance from the right source to point A is 1.5 wavelengths, so the difference in path length from the sources to point A is one wavelength. The crests and troughs coincide, and the maximum amplitude will be twice the amplitude of a single wave at that point. At point C the difference in distance for the waves from the two sources is again one wavelength (2.5 wavelengths from the left source an 1.5 wavelengths from the right source). As at points A and D, the crests and troughs coincide, and the maximum amplitude will be twice the amplitude of a single wave at that point. For point B the path distance from the left source is one-quarter wavelength and the distance from the right source is three-quarters of a wavelength, so the path difference is one-half wavelength. At point B, then, a crest from one source arrives at the same time as a trough from the other source, and there is destructive interference. The wave amplitude at point B is close to zero.

If we only take into account whether the waves constructively or destructively interfere, then, our ranking for the maximum wave amplitudes is A = C = D > B. However, as waves get farther from their sources the maximum amplitude of the waves diminishes. For this reason, the maximum amplitude at point A will in reality be greater than the maximum amplitude at point D, which will in turn be greater than the maximum amplitude at point C. Taking the distance into account, then, the ranking will be A > D > C > B.

E1-QRT07: Wave Sources Separated by One Wavelength I—Interference

Two identical point sources are generating waves with the same frequency and amplitude. The two sources are in phase with each other, so the two sources generate wave crests at the same instant. The wavelength of the waves is equal to the distance between the two sources.



List all the labeled points where the waves from the two sources constructively interfere. If there are no such points, indicate that by stating "none of them." _____

Explain your reasoning.

Answer: A, B, D, and E

Constructive interference occurs at points where the crests from the two sources arrive at the same time, as do the troughs from the two sources. At these points the maximum amplitude of the wave is the sum of the amplitudes of the waves from the two sources, and is bigger than the individual waves at that point. If the path length to a point from the farthest source is an integer multiple of a wavelength larger than the path length to that point from the closest source, then the waves constructively interfere. This occurs at point A (where the distance from the left source is one wavelength, the distance from the right source is two wavelengths, and the difference in distances is one wavelength) and at point B (where the distance from the left source is one-half wavelength, the distance from the right source is one and one-half wavelengths, and the difference in distances is one wavelength) and at point D (where the distance from the right source is 0.75 wavelengths, the distance from the left source is 1.75 wavelengths, and the difference in distances is one wavelength) and at point E (where the distance from the right source is 1.5 wavelengths, the distance from the left source is 2.5 wavelengths, and the difference in distances is one wavelength).

List all the labeled points where the waves from the two sources destructively interfere. If there are no such points, indicate that by stating "none of them." _____

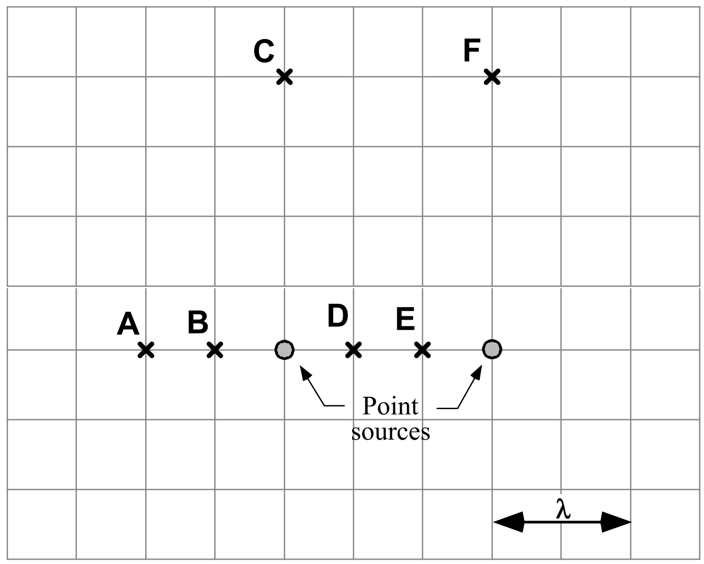
Explain your reasoning.

Answer: C

Destructive interference occurs at points where the crest from one source arrives at the same time as the trough from the other source. At these points the maximum amplitude of the wave is the difference the amplitudes of the waves from the two sources, and is smaller than the individual waves at that point. (The amplitude is close to zero at all times if the distances from the sources is about the same.) If the path length to a point from the farthest source is one-half wavelength larger than the path length to that point from the closest source, (or 1.5 wavelengths, or 2.5 wavelengths, etc) then the waves destructively interfere. This occurs at point C (where the distance from the left source is 0.25 wavelengths, the distance from the right source is 0.75 wavelengths, and the difference in distances is one-half wavelength).

E1-QRT08: WAVE SOURCES SEPARATED BY ONE AND ONE-HALF WAVELENGTHS—INTERFERENCE

Two identical point sources are generating waves with the same frequency and amplitude. The two sources are in phase with each other, so the two sources generate wave crests at the same instant. The distance between the two sources is equal to one and one-half times the wavelength, or 1.5 .



List all the labeled points where the waves from the two sources constructively interfere. If there are no such points, indicate that by stating "none of them." _____
Explain your reasoning.

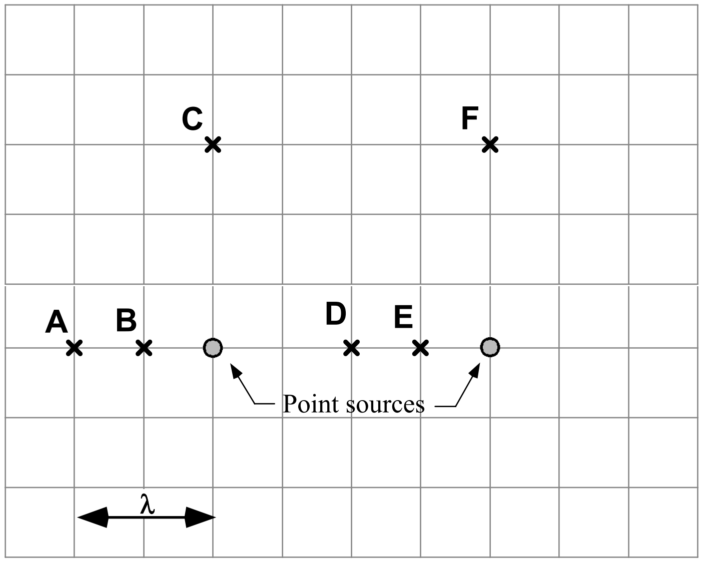
Answer: None of them.
Constructive interference occurs at points where the crests from the two sources arrive at the same time, as do the troughs from the two sources. At these points the maximum amplitude of the wave is the sum of the amplitudes of the waves from the two sources, and is bigger than the individual waves at that point. If the path length to a point from the farthest source is an integer multiple of a wavelength larger than the path length to that point from the closest source, then the waves constructively interfere. For points A and B, the left source is one and one-half wavelengths closer than the right source, not an integer multiple. For points D and E, the nearer source is one-half wavelengths away and the farther source is a full wavelength away, leaving a difference of one-half wavelength, also not an integer multiple. For point C, the nearer source is four half-wavelengths away, and since the distance between sources is three half-wavelengths, the distance from C to the more distant source is five half-wavelengths (point C and the sources form a 3-4-5 right triangle), and the difference in path lengths is one-half wavelength. Point F also has a path difference of one-half wavelength for the same reason as point C. There are no points where the difference in path length is an integer multiple of one wavelength, and no points where constructive interference occurs.

List all the labeled points where the waves from the two sources destructively interfere. If there are no such points, indicate that by stating "none of them." _____
Explain your reasoning.

Answer: All of them.
Destructive interference occurs at points where the crest from one source arrives at the same time as the trough from the other source. At these points the maximum amplitude of the wave is the difference the amplitudes of the waves from the two sources, and is smaller than the individual waves at that point. (The amplitude is close to zero at all times if the distances from the sources is about the same.) If the path length to a point from the farthest source is one-half wavelength larger than the path length to that point from the closest source, (or 1.5 wavelengths, or 2.5 wavelengths, etc) then the waves destructively interfere. This occurs at points A and B (where the difference in path lengths is one and one-half wavelengths), at points D and E (where the difference in path lengths is one-half wavelengths), and at points C and F (where the difference in path lengths is also one-half wavelengths).

E1-QRT09: WAVE SOURCES SEPARATED BY TWO WAVELENGTHS—INTERFERENCE

Two identical point sources are generating waves with the same frequency and amplitude. The two sources are in phase with each other, so the two sources generate wave crests at the same instant. The distance between the two sources is equal to two wavelengths, or 2 .



List all the labeled points where the waves from the two sources constructively interfere. If there are no such points, indicate that by stating "none of them." _____

Explain your reasoning.

Answer: All of them

Constructive interference occurs at points where the crests from the two sources arrive at the same time, as do the troughs from the two sources. At these points the maximum amplitude of the wave is the sum of the amplitudes of the waves from the two sources, and is bigger than the individual waves at that point. If the path length to a point from the farthest source is an integer multiple of a wavelength larger than the path length to that point from the closest source, then the waves constructively interfere. For points A and B, the left source is two wavelengths closer than the right source, an integer multiple. For point D, both sources are one wavelength away and there is no difference in path distance from the sources, so the crests arrive at the same time. For point E, the right source is one-half wavelengths away and the left source is one and one-half wavelengths away, leaving a path difference of one wavelength. For point C, the nearer source is three half-wavelengths away, and since the distance between sources is four half-wavelengths, the distance from C to the more distant source is five half-wavelengths (point C and the sources form a 3-4-5 right triangle), and the difference in path lengths is one wavelength. Point F also has a path difference of one wavelength for the same reason as point C. Thus all points have a difference in path length of an integer multiple of one wavelength, and there is constructive interference at all points.

List all the labeled points where the waves from the two sources destructively interfere. If there are no such points, indicate that by stating "none of them." _____

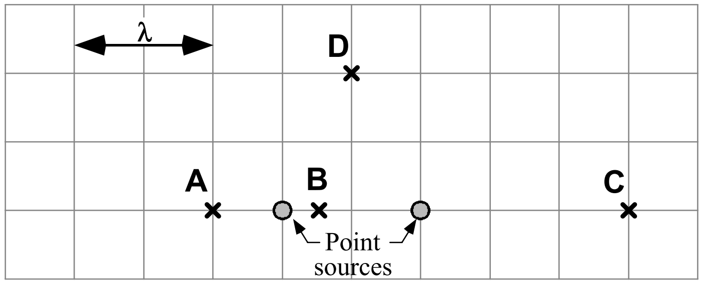
Explain your reasoning.

Answer: None of them.

Destructive interference occurs at points where the crest from one source arrives at the same time as the trough from the other source. At these points the maximum amplitude of the wave is the difference the amplitudes of the waves from the two sources, and is smaller than the individual waves at that point. (The amplitude is close to zero at all times if the distances from the sources is about the same.) If the path length to a point from the farthest source is one-half wavelength larger than the path length to that point from the closest source, (or 1.5 wavelengths, or 2.5 wavelengths, etc) then the waves destructively interfere. As described above, all points listed here have integer-wavelength differences in path lengths, and so there are no points where there is destructive interference.

E1-QRT10: WAVE SOURCES SEPARATED BY ONE WAVELENGTH II—INTERFERENCE

Two identical point sources are generating waves with the same frequency and amplitude. The two sources are *out of phase* with each other, so at the instant that one source is creating a crest, the other source is creating a trough. The wavelength of the waves is equal to the distance between the two sources.



List all the labeled points where the waves from the two sources constructively interfere. If there are no such points, indicate that by stating "none of them." _____

Explain your reasoning.

Answer: B

Constructive interference occurs at points where the crests from the two sources arrive at the same time, as do the troughs from the two sources. At these points the maximum amplitude of the wave is the sum of the amplitudes of the waves from the two sources, and is bigger than the individual waves at that point. Since in this case the waves are out of phase, and one wave is creating a crest when the other is creating a trough, if the path lengths from the sources to a point are the same (as they are at point D) then a crest will arrive from one source at the same instant that a trough arrives from the other source, and the waves will cancel. Only if the path length to a point from the farthest source is one-half wavelength larger than the path length to that point from the closest source, (or 1.5 wavelengths, or 2.5 wavelengths, etc) will the waves constructively interfere, because then the path distance from the further source will mean that crest meets crest and trough meets trough at that point. For point B the path distance from the left source is one-quarter wavelength and the distance from the right source is three-quarters of a wavelength, so the path difference is one-half wavelength. For this reason a crest from the left source arrives at B at the same time as a crest from the right source, and there is constructive interference.

List all the labeled points where the waves from the two sources destructively interfere. If there are no such points, indicate that by stating "none of them." _____

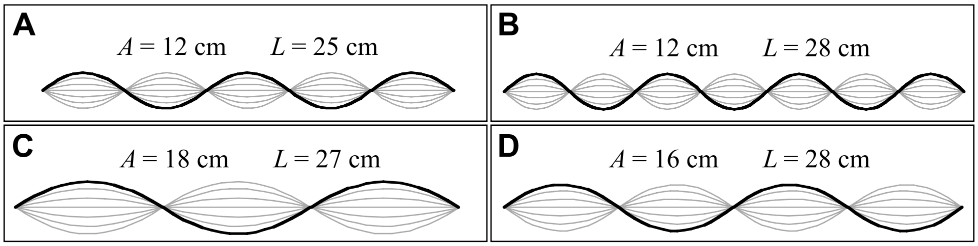
Explain your reasoning.

Answer: A, C and D.

Destructive interference occurs at points where the crests from the two sources arrive at the same time, as do the troughs from the two sources. At these points the maximum amplitude of the wave is the difference of the amplitudes of the waves from the two sources, and is smller than the individual waves at that point. Since in this case the waves are out of phase, and one wave is creating a crest when the other is creating a trough, if the path lengths from the sources to a point are the same (as they are at point D) then a crest will arrive from one source at the same instant that a trough arrives from the other source, and the waves will cancel. The waves will also cancel if the difference in distance is an integer multiple of one wavelength. The distance from the left source to point A is one-half wavelength, and the distance from the right source to point A is 1.5 wavelengths, so the difference in path length from the sources to point A is one wavelength, and destructive interference occurs. For point C, right source is 1.5 wavelengths away and the left source is 2.5 wavelengths away, giving a path difference of one wavelengths and again destructive interference occurs.

E1-RT11: Standing Waves—Frequency

A string is stretched so that it is under tension and is tied at both ends so that the endpoints don't move. A mechanical oscillator then vibrates the string so that a standing wave is created. The dark line in each diagram represents a snapshot of a string at an instant in time when the amplitude of the standing wave is a maximum. The lighter lines represent the string at other times during a complete cycle. All of the strings are identical except for their lengths, and all strings have the same tension. The number of nodes and antinodes in each standing wave is different. The lengths of the strings (L) and the amplitudes at the antinodes (A) are given in each figure.



Rank the frequencies of the waves.

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

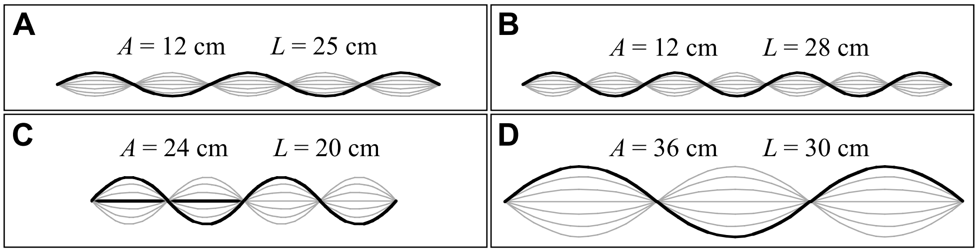
Explain your reasoning.

Answer: B > A > D > C.

Since all of these waves are on the strings under the same tension, and the mass per unit length of the strings are identical, they all have the same wave speed. The wave speed is equal to the product of the frequency and wavelength, so the shorter the wavelength the higher the frequency. The wave frequency is independent of the amplitude of the standing wave.

E1-RT12: STANDING WAVES—WAVELENGTH

A string is stretched so that it is under tension and is tied at both ends so that the endpoints don't move. A mechanical oscillator then vibrates the string so that a standing wave is created. The dark line in each diagram represents a snapshot of a string at an instant in time when the amplitude of the standing wave is a maximum. The lighter lines represent the string at other times during a complete cycle. All of the strings are identical except for their lengths, and all strings have the same tension. The number of nodes and antinodes in each standing wave is different. The lengths of the strings (L) and the amplitudes at the antinodes (A) are given in each figure.



Rank the wavelengths of the waves.

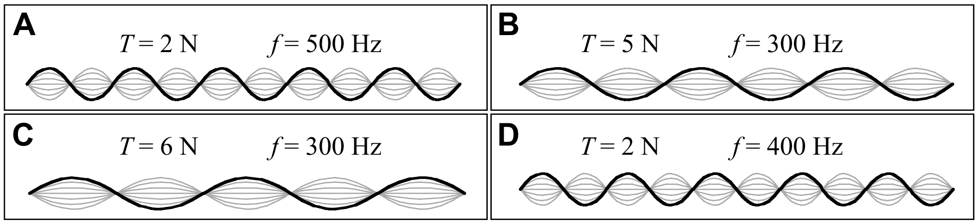
				OR			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

Answer: D > A = C > B.
The wavelength is the distance of one complete cycle, which in the figures is the length of a complete cycle of the black line. In case A this is two-fifths of the length of the string, or 10 cm; in case B two-sevenths of the length of the string, or 8 cm; in case C two-fourths of the length of the string, or 10 cm; and in case D two-thirds of the length of the string, or 20 cm. The wavelength is independent of the amplitude of the standing wave.

E1-RT13: STANDING WAVES SYSTEMS—WAVE SPEED

A string is stretched so that it is under tension and is tied at both ends so that the endpoints don't move. A mechanical oscillator then vibrates the string so that a standing wave is created. The dark line in each diagram represents a snapshot of a string at an instant in time when the amplitude of the standing wave is a maximum. The lighter lines represent the string at other times during a complete cycle. All of the strings have the same length but may not have the same mass. The number of nodes and antinodes in the standing wave is the same in Cases A and D. The tensions in the strings (T) and the standing wave frequencies (f) are given in each figure.



Rank the speeds of the waves in the strings.

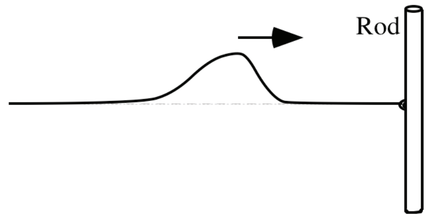
____	____	____	____	OR	☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain your reasoning.

Answer: C > A = B > D.
The wave speed is equal to the product of the frequency and wavelength. The frequencies are given and the wavelength is the distance of one complete cycle, which in the figures is the length of a complete cycle of the black line. In cases A and D this is two-tenths of the length of the string; in case B two-sixths of the length of the string; and in case C this is two-fifths of the length of the string. The amplitudes of the waves is not given, but the speed of the waves is independent of the amplitude of the standing wave. If we label the length of the string L, then for case A, the wave speed will be (500Hz)(0.2L); for case B (300Hz)(0.33L); for case C (300Hz)(0.4L); and for case D (400Hz)(0.2L).

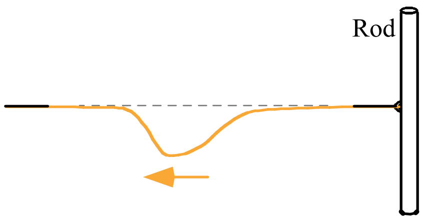
E1-QRT14: WAVE PULSE ON HORIZONTAL SPRING WITH FIXED END—REFLECTION SHAPE

A long spring is firmly connected to a stationary metal rod at one end. A student holding the other end moves her hand rapidly up and down to create a pulse with the shape shown in the figure. The pulse moves along the taut spring toward the rod.



In the space below, draw what the pulse on the spring looks like after it has completely reflected from the wall and is moving to the left.

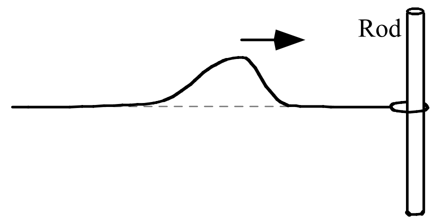
Explain your reasoning.



Answer: When the pulse reaches the fixed end of the spring, the rod exerts downward forces on the spring. These forces serve to invert the pulse, which reflects to the left with the deflection beneath the spring rather than above it. The steeper leading edge of the pulse remains the leading edge as the pulse moves to the left.

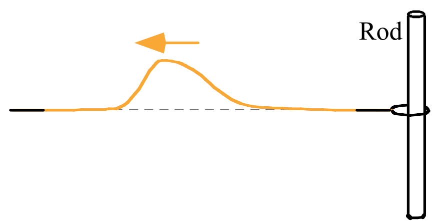
E1-QRT15: Wave Pulse on Horizontal Spring with Free End—Reflection Shape

A long spring is connected to a loop that passes around a stationary metal rod at one end. The loop is free to move vertically without friction along the rod. A student holding the other end moves her hand rapidly up and down to create a pulse with the shape shown in the figure. The pulse moves along the taut spring toward the rod.



In the space below, draw what the pulse on the spring looks like after it has completely reflected from the wall and is moving to the left.

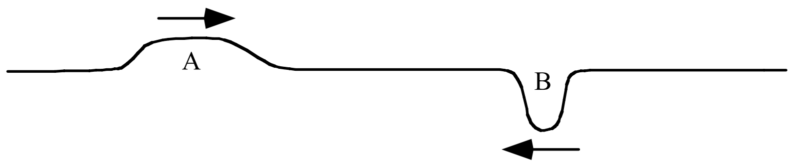
Explain your reasoning.



Answer: When the pulse reaches the free end of the spring, the rod exerts no vertical forces on the spring. The pulse reverses direction without changing shape, and stays on the same side of the spring. The steeper leading edge of the pulse remains the leading edge as the pulse moves to the left.

E1-CT16: WAVE PULSES TRAVELING TOWARD EACH OTHER—SPEED

Two pulses travel toward each other along a long stretched spring as shown. Pulse A is wider than pulse B, but not as high.



Is the speed of pulse A (i) *larger than,* (ii) *smaller than,* or (iii) *equal to* the speed of pulse B? If there is not enough information to tell, state that explicitly. _____
Explain your reasoning.

Answer: The speed of pulse A is the same as the speed of pulse B.

The pulse speed depends only on the tension in the spring and the mass per unit length of the spring, which is the same for both pulses.

E1-WWT17: TWO WAVE PULSES INTERACTING—IMPACT

A student states:

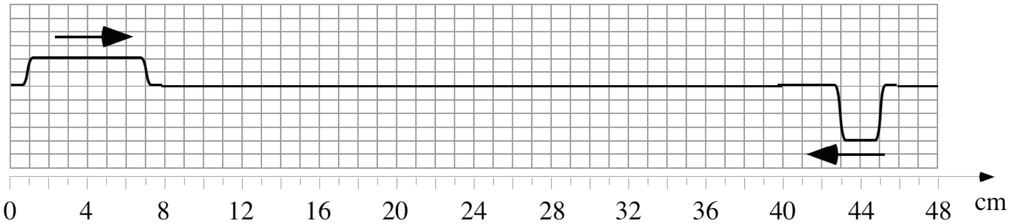
"If two wave pulses traveling in opposite directions along the same string meet, they reflect from one another and go back the way they came from."

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.

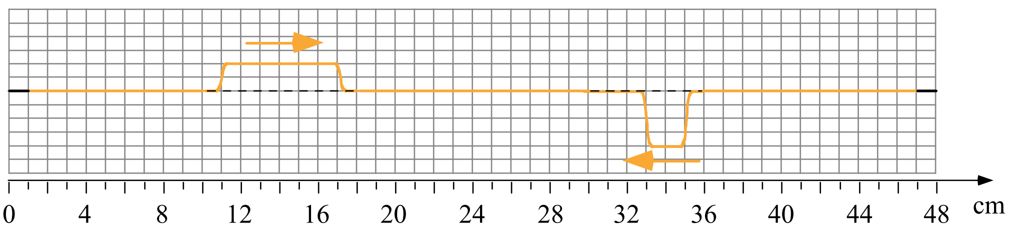
Answer: The student is incorrect.
The string obeys the principal of superposition at all times: The shape of the string is the sum of the individual pulse shapes as they move along the string. When the pulses are in the same location on the string, the shape of the string is determined by the sum of the pulse shapes as each shape continues along the string at the same speed and in the same direction. After the trailing edge of each pulse has passed the other pulse, the shape of the pulses is the same as the shape before there was any interaction, and the two pulses appear to have passed through one another.

E1-QRT18: WAVE PULSES TRAVELING TOWARD EACH OTHER—SHAPE AND DIRECTION

Two pulses travel toward each other along a long, stretched spring. The speed of each pulse is 100 cm/s. Each square on the grid is 1 cm long, as can be seen on the ruler markings below the grid. The left pulse is about 6 cm wide, and the right pulse is about 2 cm wide and twice as tall as the left pulse. The figure below represents a snapshot of the spring taken at time $t = 0$.



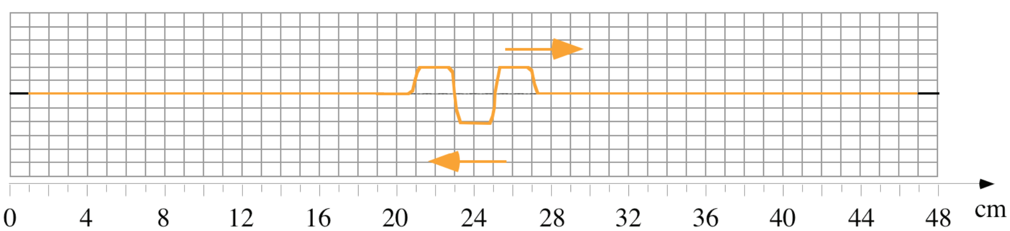
(a) In the space below, sketch the shape of the spring at time $t = 0.1$ seconds.



Explain your reasoning.

Answer: After 0.1 seconds, each pulse will have moved 10 cm (0.1s)(100cm/s). Their wave shapes do not change.

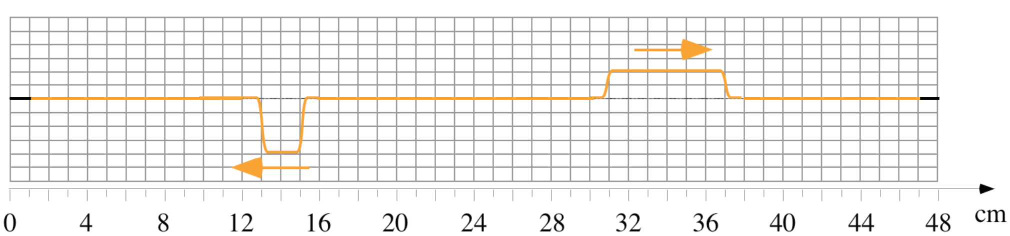
(b) In the space below, sketch the shape of the spring at time $t = 0.2$ seconds.



Explain your reasoning.

Answer: After 0.2 seconds, each pulse will have moved 20 cm (0.2s)(100cm/s). The centers of the two pulses are now both at 24 cm on the scale. The amplitude at each location is the sum of the amplitudes of the two pulses.

(c) In the space below, sketch the shape of the spring at time $t = 0.3$ seconds.

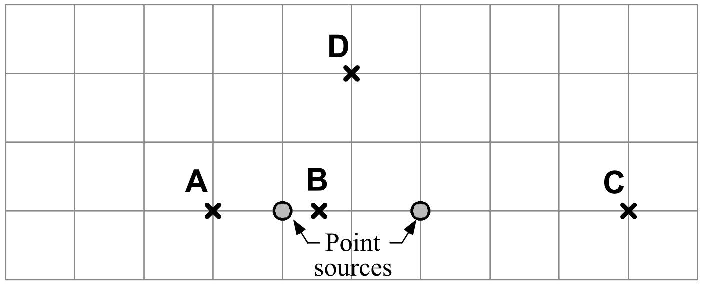


Explain your reasoning.

Answer: After 0.3 seconds, each pulse will have moved 30 cm (0.3s)(100cm/s). Their wave shapes do not change.

E1-RT19: Wave Source—Intensity at Various Locations

Two point sources can generate waves with the same frequency and amplitude. The sources can be turned on and off individually.



(a) Rank the intensity of the wave at the labeled points if the left point source is turned on and the right point source is turned off.

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

Explain.

Answer: B > A > D > C.
The intensity at each point depends on the distance from the point source, diminishing as the distance increases.

(b) Rank the intensity of the wave at the labeled points if the right point source is turned on and the left point source is turned off.

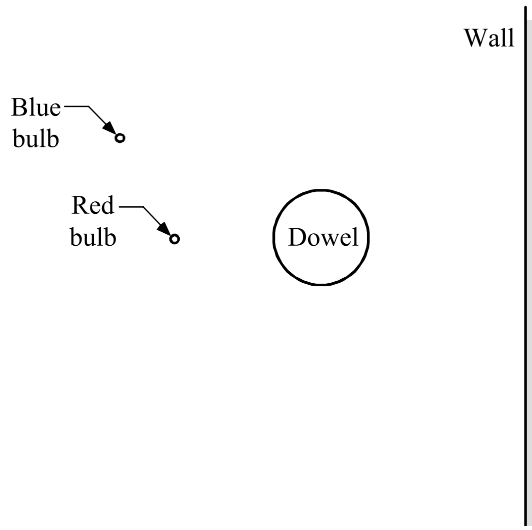
				OR			
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

Explain.

Answer: B > D > A = C.
The intensity at each point depends on the distance from the point source, diminishing as the distance increases.

E2-QRT01: COLORED BULBS NEAR A DOWEL—SHADOWS

A red light bulb and a blue light bulb are placed near a wall as shown in the top-view diagram. A cylindrical dowel is placed between the bulbs and the wall, creating shadows. Where light from both bulbs hits the wall, the wall will appear magenta in color. Where no light from either bulb hits the wall, the wall will appear black.

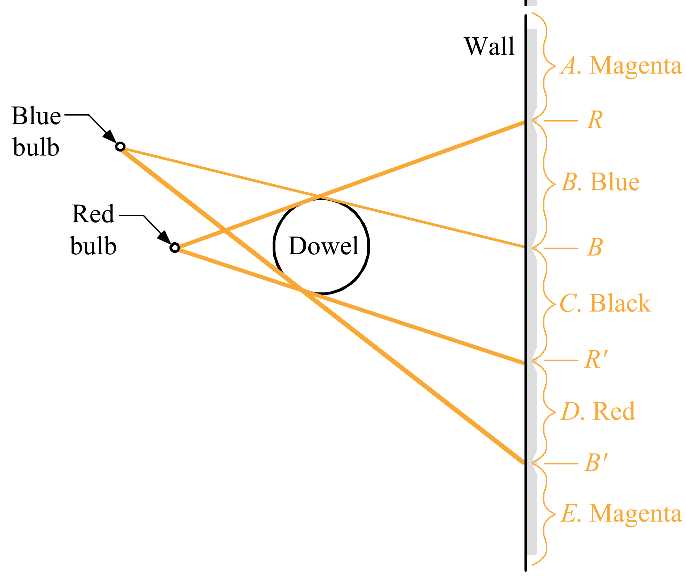


(a) Draw rays to determine where light from each bulb hits the wall.

(b) Indicate where the wall appears magenta, where it appears black, where it appears red, and where it appears blue.

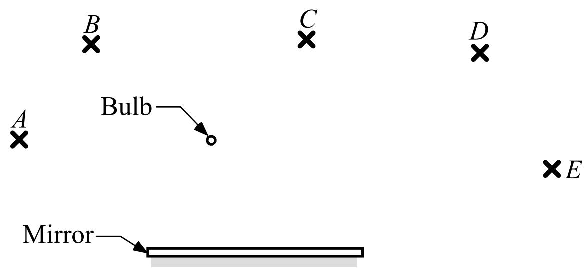
Explain your reasoning.

Answer: Light travels in straight lines in all directions from each bulb. If a light ray from a bulb hits the dowel, it is blocked. Light from the red bulb is blocked by the dowel between the rays marked R and R', and light from the blue bulb is blocked by the dowel between the rays marked B and B'. In regions A and E, light from both bulbs hit the wall, and so these regions appear magenta. In region C, no light from either bulb hits the wall, and the wall appears black. In region B, light from the blue bulb hits the wall but light from the red bulb is blocked, so the wall appears blue. In region D, light from the red bulb hits the wall, but light from the blue bulb is blocked by the dowel, so the wall appears red.



E2-SCT02: PLANE MIRROR I—OBSERVER LOCATION

A small light bulb is placed near a plane mirror. The locations of five observers are marked, labeled *A*–*E* as shown. Three students are discussing which observers will see an image of the bulb:



Agustin: *"The image of the bulb will be formed the same distance behind the mirror as the bulb is in front. All of the observers can see the mirror, so they will be able to see the image."*

Bruno: *"The images formed by a plane mirror are virtual images—none of the observers will be able to see them because they aren't real."*

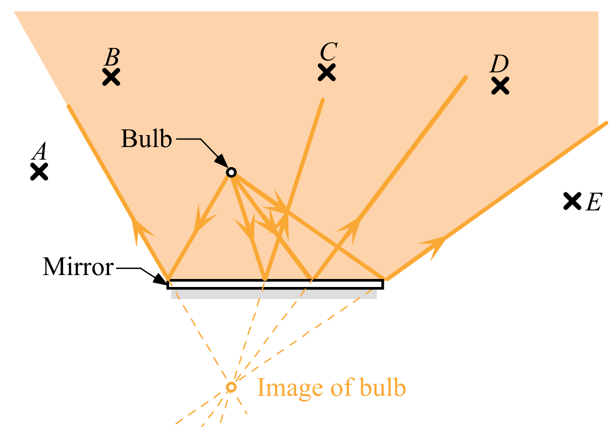
Carol: *"There will be an image of the bulb, because rays from the bulb hit the mirror and bounce off. But only observer C will see the image, because only C is in front of the mirror."*

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

Agustin _____ Bruno _____ Carol _____ None of them _____

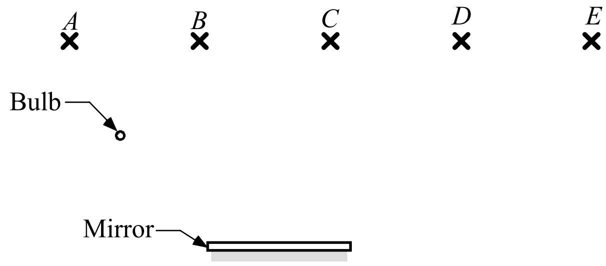
Explain your reasoning.

Answer: None of these students is correct, and observers at locations B, C, and D will see the image. Light from the bulb reflects off of the mirror, and the reflected rays diverge from the image location. The image for the bulb will be behind the plane of the mirror, the same distance from the plane as the bulb. The image is virtual, because the reflected rays don't actually pass through the image location. However, if the reflected rays travel to an observer, that observer will see the image of the bulb because the reflected rays appear to be diverging from the location of the image. The region where the image of the bulb can be seen is determined by the reflected rays from the edges of the mirror, and is shaded in the solution diagram.



E2-SCT03: Plane Mirror II—Observer Location

A small light bulb is placed near a plane mirror. The locations of five observers are marked, labeled *A*–*E* as shown. Three students are discussing which observers will see an image of the bulb:



Ashley: *"None of them will see an image. The bulb isn't in front of the mirror, so no image is formed."*

Briar: *"Even though the bulb isn't in front of the mirror, rays from the bulb still hit the mirror and bounce off. They bounce off in the direction of observers D and E, so these two will see the image."*

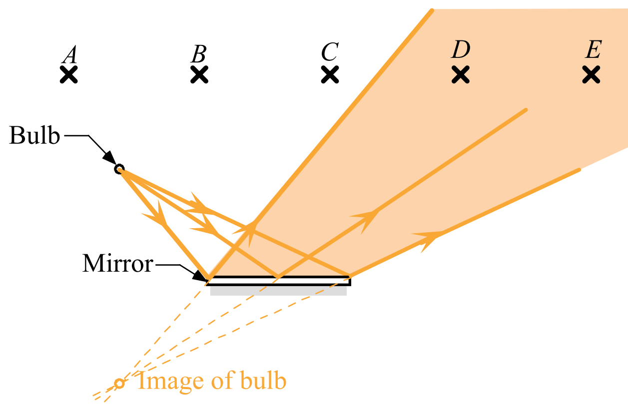
Capria: *"The image is in the mirror. As long as you are in front of the mirror you will see it. Observer C will see the image, but the rest of the observers aren't in front of the mirror."*

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

Ashley _____ Briar _____ Capria _____ None of them _____

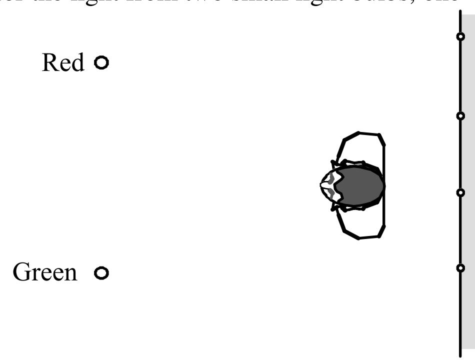
Explain your reasoning.

Answer: Briar is correct.
Light from the bulb reflects off of the mirror, and the reflected rays diverge from the image location. The image for the bulb will be behind the plane of the mirror, the same distance from the plane of the mirror as the bulb. The image is virtual, because the reflected rays don't actually pass through the image location. However, if the reflected rays travel to an observer, that observer will see the image of the bulb because the reflected rays appear to be diverging from the location of the image. The region where the image of the bulb can be seen is determined by the reflected rays from the edges of the mirror, and is shaded in the solution diagram.



E2-SCT04: Shadows on a Wall—Color

A student stands in front of a white wall in a room that is dark except for the light from two small light bulbs, one red and one green. In the top-view at right, four locations on the wall are labeled *A*–*D*. Three students are discussing the color of the wall at the labeled points:



Anuradha: *"No light from either bulb will reach point C, so I think that point is going to be black or very dark. The wall there will have no color."*

Brandon: *"The wall at point A will get light from both bulbs. The color of the wall there will be a mix of red and green light—sort of yellow."*

Carlos: *"Point B will get light from the red bulb but not from the green one, so it will be red. The opposite happens at point D: Light reaches it from the green bulb but not the red one, so it will appear green."*

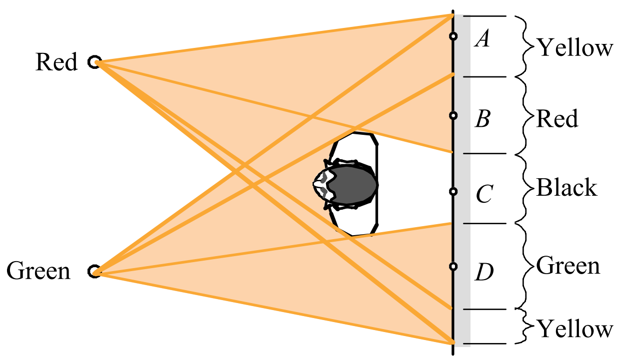
With which, if any, of these students do you agree?

Anuradha _____ Brandon _____ Carlos _____ None of them _____

Explain your reasoning.

Answer: All of the students are correct.

Light will travel outwards from each bulb in straight lines in every direction, and will hit the wall except for regions where the person is blocking it. Since there is an unobstructed path from either bulb to point A, both red and green light will hit the wall there, and the color will formed by the addition of red and green light, which makes yellow. The student blocks light from either bulb from reaching point C, so the wall will be black or very dark there. The student will block light from the green bulb from reaching point B but not light from the red bulb, so at that point the wall will appear red. The student will block light from the red bulb from reaching point D but not light from the green bulb, so at that point the wall will appear green.

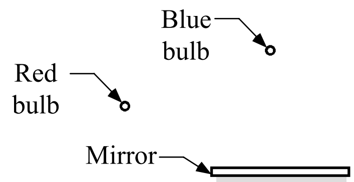


E2-QRT05: Colored Bulbs near a Plane Mirror—Observer Locations

A red light bulb and a blue light bulb are placed near a plane mirror as shown.

(a) A person in front of the mirror can see the image of both bulbs.

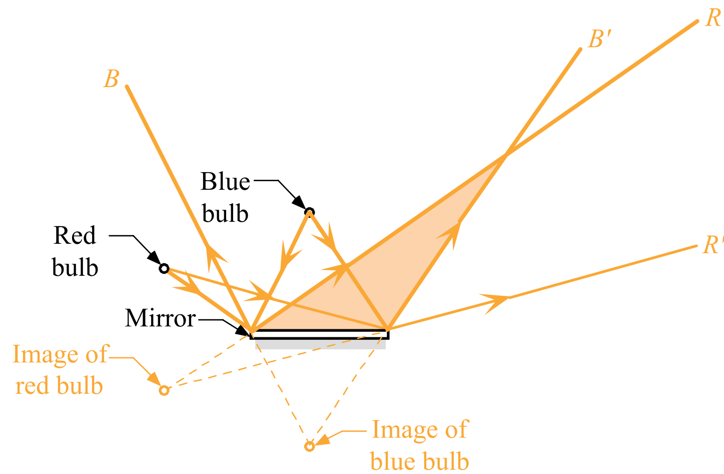
Where is this person located? In the diagram, shade the region.



Explain your reasoning.

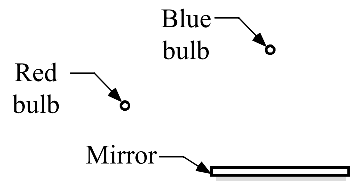
Answer: The person could be anywhere in the shaded triangle.

Light from each bulb reflects off of the mirror, and the reflected rays diverge from the image location. The image for the bulb will be behind the plane of the mirror, the same distance from the plane of the mirror as the bulb. If the reflected rays travel to an observer, that observer will see the image of the bulb because the reflected rays appear to be diverging from the location of the image. The region where the image of a bulb can be seen is determined by the reflected rays from the edges of the mirror. An observer anywhere between rays B and B' can see the image of the blue bulb. An observer anywhere between rays R and R' can see the image of the red bulb. An observer in the region of the shaded triangle can therefore see both bulbs.



(b) A person in front of the mirror can see the image of the red bulb but cannot see the image of the blue bulb.

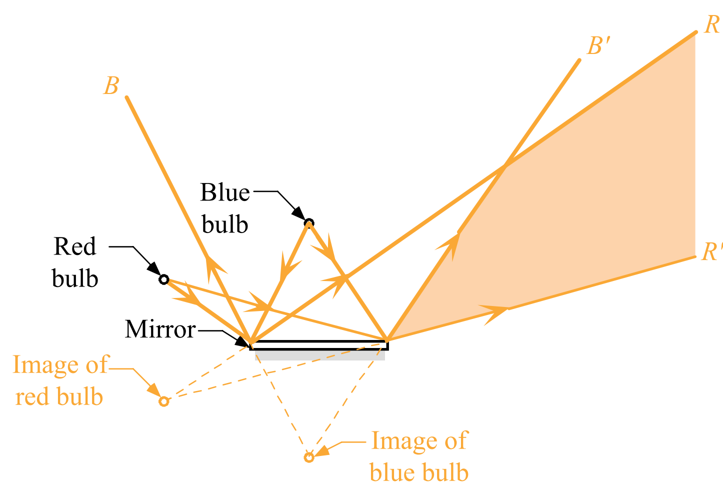
Where is this person located? In the diagram, shade the region.



Explain your reasoning.

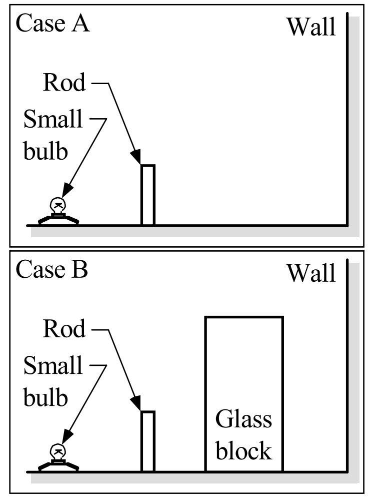
Answer: The image for the bulb will be behind the plane of the mirror, the same distance from the plane of the mirror as the bulb.

If the reflected rays travel to an observer, that observer will see the image of the bulb because the reflected rays appear to be diverging from the location of the image. The region where the image of a bulb can be seen is determined by the reflected rays from the edges of the mirror. An observer anywhere between rays B and B' can see the image of the blue bulb. An observer anywhere between rays R and R' can see the image of the red bulb. An observer in the shaded region of the shaded triangle can therefore see the red bulb, but not the blue bulb.



E2-CT06: LIGHT FROM A SMALL BULB—HEIGHT OF SHADOW

In both cases shown, a small light bulb illuminates a wall. A shadow is created on the wall of a rod placed between the wall and the bulb. The two cases are identical except that in Case B there is a glass block between the rod and the wall.

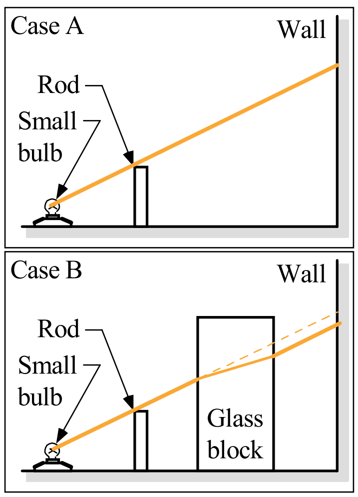


(a) Is the height of the shadow of the rod on the wall (i) *greater in Case A*, (ii) *greater in Case B*, or (iii) *the same in both cases*? _____

Explain your reasoning.

Answer: (i) Greater in case A.

With the glass block in place, the ray at the boundary between shadow and light is bent toward the normal to the glass block surface on the left hand side, and away from the glass block surface on the right hand side. As a result, it emerges from the glass parallel to but below the ray at the boundary without the glass block. The shadow height will be lower with the glass block in place.



(b) If the entire arrangement from Case B—bulb, rod, glass block, and wall—were submerged in water, would the height of the shadow on the wall (i) *increase,* (ii) *decrease,* or (iii) *remain the same?* _____

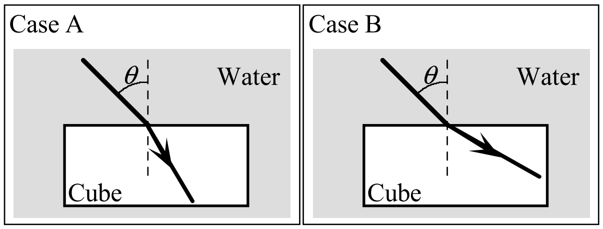
Explain your reasoning.

Answer: (i)The height of the shadow would increase.

The amount that the light is bent when it hits the glass block depends on the index of refraction of the medium that it is traveling through as well as the index of refraction of the glass. The index of refraction of water is greater than the index of refraction of air, and is closer to the index of refraction of glass. So there will be less bending at the water-glass interface than there was at the air-glass interface, and the amount that the light ray is deflected will be smaller, making the shadow taller.

E2-CT07: LIGHT RAYS BENT AT A SURFACE—INDEX OF REFRACTION

In both cases shown, a light ray traveling in water bends at the surface of a cube. The cases are identical except that the cube in Case A is made of a different material than the cube in Case B.



Is the index of refraction of the cube (i) *greater in Case A,* (ii) *greater in Case B,* or (iii) *the same in both cases?*

_____

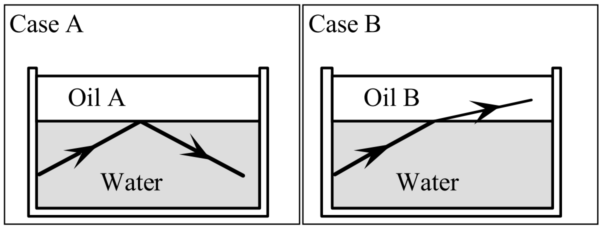
Explain your reasoning.

Answer: (i)The index of refraction is greater in case A.

When a light ray travels from a medium into a second medium with a larger index of refraction, the light bends toward the normal at the interface. In case A, therefore, the index of refraction of the cube must be greater than the index of refraction of water. When a light ray travels from a medium into a second medium with a smaller index of refraction, the light ray bends away from the normal (if it refracts instead of reflecting). In case B the index of refraction of the cube must be smaller than the index of refraction of water. So the index of refraction in case A must be greater than the index of refraction in case B.

E2-CT08: WATER AND OIL IN AN AQUARIUM—INDEX OF REFRACTION OF OIL

In both cases, an aquarium is partially filled with water, and a layer of oil is floating on top of the water. The two cases are identical except for the type of oil used. In Case A, a laser beam in the water totally reflects off of the oil/water boundary as shown. In Case B, the same laser beam refracts at the oil/water boundary as shown.



(a) Is the index of refraction of the oil (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 index of refraction of the oil is smaller than the index of refraction of the water, since the light ray internally reflects in case A and refracts away from the normal in case B. The smaller the index of refraction of the oil, the greater the angle of refraction will be. If we imagine reducing the index of refraction of the oil from what it is in case B, we would observe the refracted ray bending further and further from the normal. Once this angle reaches 90°, the light no longer refracts, and instead reflects off the surface as it does in case A. So the index of refraction is smaller in case A.

(b) Is the speed of light in the oil (i) *greater in Case A*, (ii) *greater in Case B*, or (iii) *the same in both cases*? _____

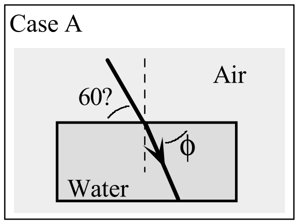
Explain your reasoning.

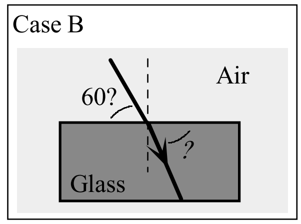
Answer: (i) Greater in case A.

The index of refraction is smaller in case A, and the speed of light in a medium is inversely proportional to the index of refraction.

E2-CT09: BENDING OF LASER BEAM IN AIR—ANGLE BENT

A laser beam traveling in air enters water at an angle of 60° with respect to the surface and is bent in water to an angle of • from the surface as shown in Case A. (Note that the drawings may or may not be accurately portraying the situation.)





If the water is replaced by glass, is the angle with respect to the surface that the laser beam is bent (i) *greater than*, (ii) *smaller than*, or (iii) *equal to* •? _____

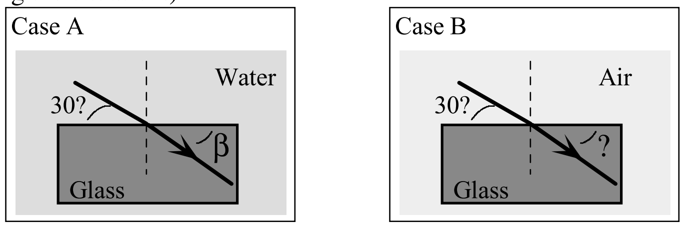
Explain your reasoning.

Answer: (i) greater

Since the index of refraction is larger in glass than in water the beam will be bent more in the glass. .

E2-CT10: Bending of Laser Beam in Glass—Angle Bent

A laser beam is traveling in water. This beam strikes a water-glass surface at an angle of 30.0° from the glass surface and is at an angle of with respect to the surface, as shown in Case A. (Note that the drawings may or may not be accurately portraying the situation.)



If the water is replaced by air, the angle that the laser beam is bent in the glass from the surface is (i) *greater than*, (ii) *smaller than*, or (iii) *equal to* ? _____

Explain your reasoning.

Answer: (i) greater than

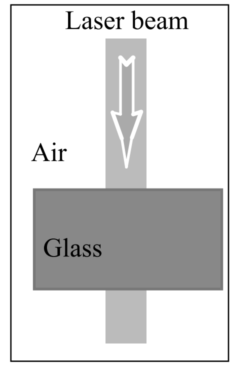
Since the index of refraction is larger for the glass than for either the water or the air, in both cases the beam will be bent toward the normal. The change in effective speed is larger going from air to glass than from water to glass, so the beam will be bent more toward the normal in case B.

E2-CT11: LASER LIGHT PULSE TRAVELING THROUGH SLAB—TIME

It has been noted that red light bends less than blue light in glass when it enters the glass at an angle.

Is the time that it takes for a pulse of red light to pass perpendicularly through a slab of glass surrounded by air (i) *greater than*, (ii) *less than*, or (iii) *equal to* the time for a blue light pulse? _____

Explain your reasoning.



Answer: (ii) less than

The index of refraction for red light is slightly smaller than for blue light. This means that red light travels faster than blue light.

E2-WWT12: Moving Candle Away from a Lens—Focal Length

A student thinking about a candle in front of a converging lens states:

"I noticed that if I move a candle back away from a converging lens that this results in a larger image being produced. This is due to the change in the focal length of the lens. I think it got shorter."

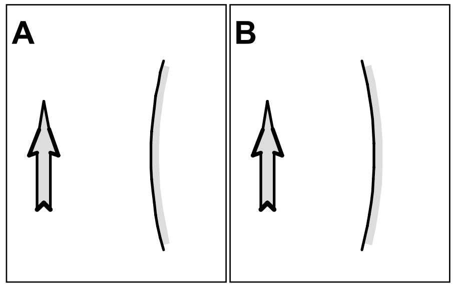
What, if anything, is wrong with this statement? If something is wrong, identify and explain how to correct all errors. If this statement is correct, explain why.

Answer: The student is wrong.

The focal length of a lens is a property of the lens and is not affected by where the object is located.

E2-CT13: OBJECTS INSIDE FOCAL LENGTH OF CURVED MIRRORS—IMAGE DISTANCE

In the two situations shown, the mirrors have the same focal lengths, and the object distance from the mirror to the arrow is the same. In both cases, the object distance is less than the focal distance.



Will the image distance for Case A be (i) *greater than,* (ii) *less than,* or (iii) *equal to* the image distance for Case B? _____

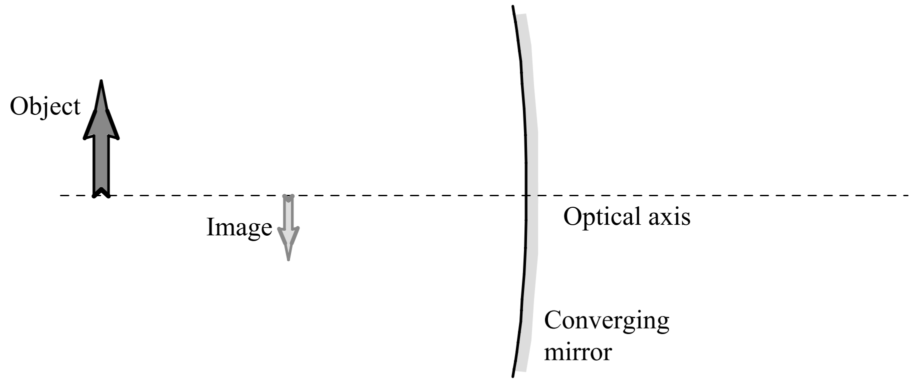
Explain your reasoning.

Answer: (i) greater than.

Since the mirror in case A is a diverging mirror and the object is placed inside the focal point a magnified virtual image will be produced on the opposite side of the mirror. For case B the image, which will also be virtual for this arrangement, will also be on the other side of the mirror, but it will be reduced in size, so the image distance has to be smaller than for case A.

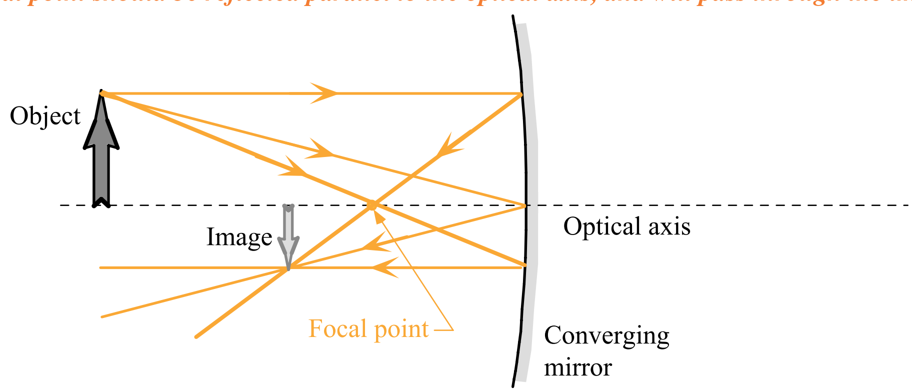
E2-WBT14: OBJECT AND INVERTED IMAGE FOR A CONVERGING MIRROR—FOCAL POINT

An object is placed in front of a converging mirror. An inverted image of the object is formed at the location shown.



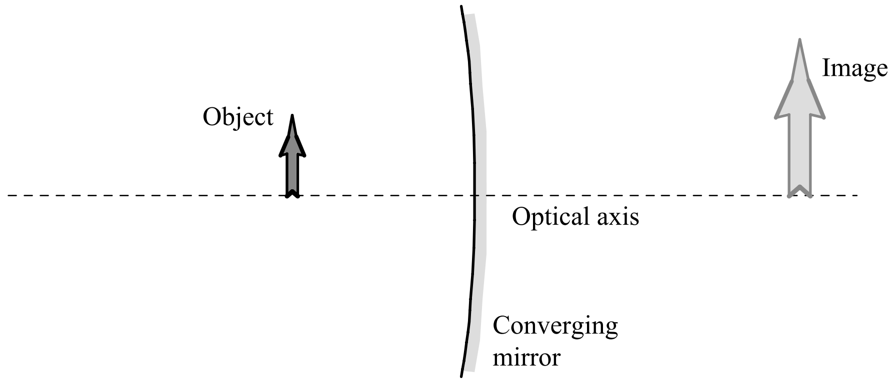
Based on the image and object locations above, find the focal point for this mirror. Explain your reasoning.

Answer: All of the light rays from a point on the object that are reflected by the mirror will converge at the image location for that point. A parallel ray from the object to the mirror will reflect from the mirror and will pass through the focal point at the optical axis, and continue from there to pass through the image location for the arrow tip. The focal point is therefore at the optical axis along this reflected ray. We can confirm this focal point location by drawing the other principal rays: A ray from the tip of the arrow to the optical axis of the mirror will be reflected at the same angle, and should pass through the image point, and a ray from the tip of the arrow through the focal point should be reflected parallel to the optical axis, and will pass through the image point.



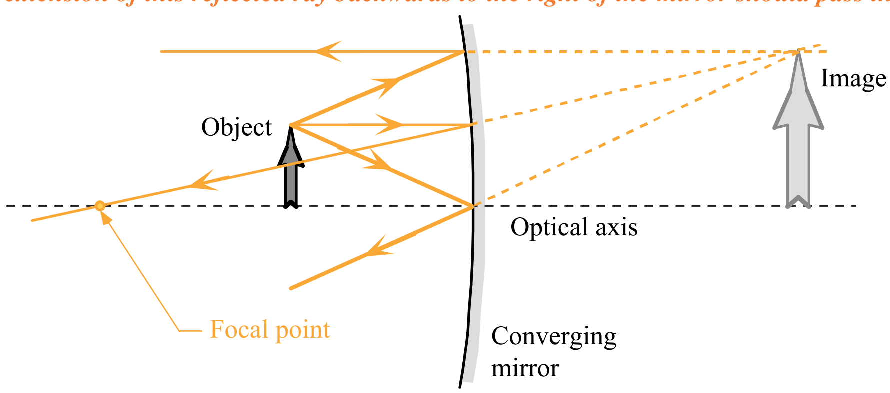
E2-WBT15: OBJECT AND UPRIGHT IMAGE FOR A CONVERGING MIRROR—FOCAL POINT

An object is placed in front of a converging mirror. An upright image of the object is formed behind the mirror at the location shown.



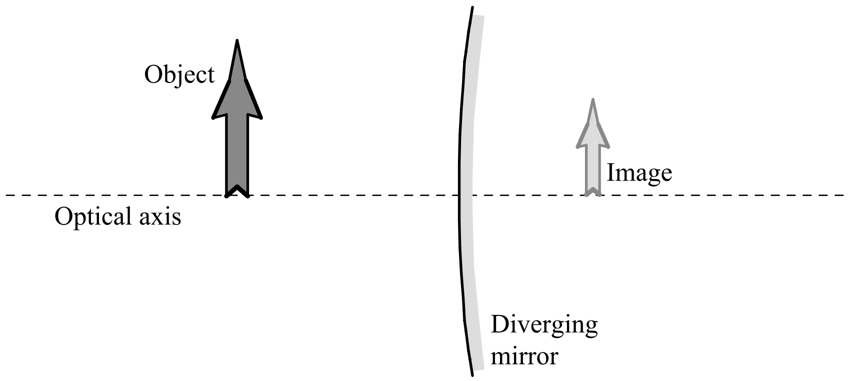
Based on the image and object locations above, find the focal point for this mirror. Explain your reasoning.

Answer: All of the light rays from a point on the object that are reflected by the mirror will diverge. The image is formed at the point behind the mirror that these reflected rays seem to be coming from. A parallel ray from the object to the mirror will reflect from the mirror and pass through the focal point. If we extend this reflected ray backward it will pass through the image location behind the mirror. So if we draw a line from the image point of the tip of the arrow that hits the mirror where a parallel ray from the object hits the mirror, this line will cross the optical axis at the location of the focal point. We can verify this focal point location by drawing the other principal rays: A ray from the tip of the arrow to the optical axis of the mirror will be reflected at the same angle, and the extension of this reflected ray backwards to the right of the mirror should pass through the image point.



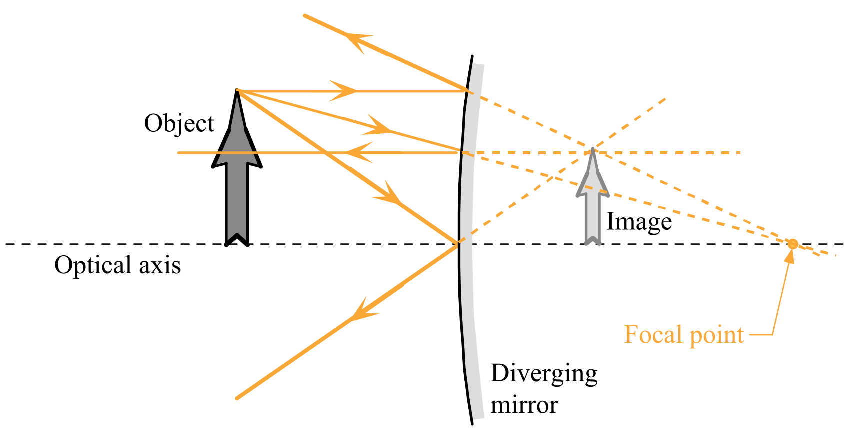
E2-WBT16: OBJECT AND UPRIGHT IMAGE FOR A DIVERGING MIRROR—FOCAL POINT

An object is placed in front of a diverging mirror. An upright image of the object is formed behind the mirror at the location shown.



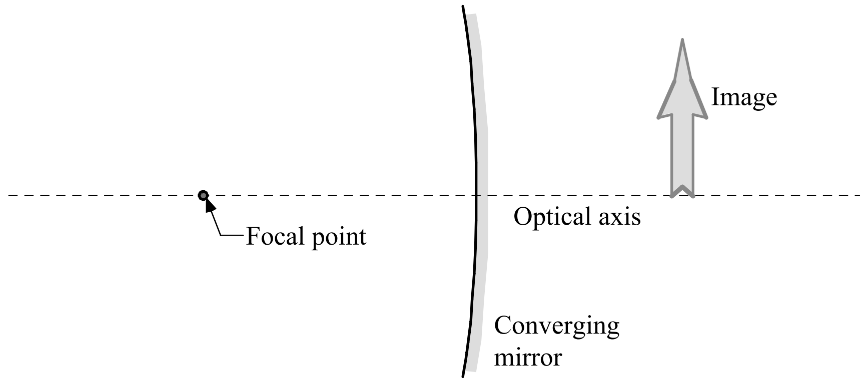
Based on the image and object locations, find the focal point for this mirror. Explain your reasoning.

Answer: All of the light rays from a point on the object that are reflected by the mirror will diverge. The image is formed at the point behind the mirror that these reflected rays seem to be coming from. A parallel ray from the object to the mirror will reflect from the mirror away from the focal point. If we extend this reflected ray backward it will pass through the image location behind the mirror. So if we draw a line from the image point of the tip of the arrow that hits the mirror where a parallel ray from the object hits the mirror, this line extended to the right will cross the optical axis at the location of the focal point. We can verify this focal point location by drawing the other principal rays: A ray from the tip of the arrow to the optical axis of the mirror will be reflected at the same angle, and the extension of this reflected ray backwards to the right of the mirror should pass through the image point. A ray from the tip of the arrow that heads toward the focal point will bounce off of the mirror parallel to the optical axis, and the extension of this parallel ray to the right of the mirror will pass through the image point.



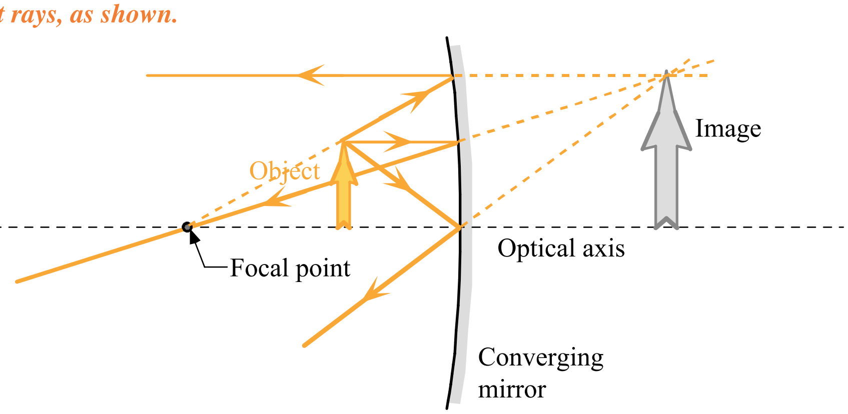
E2-WBT17: Image for a Converging Mirror—Object

An arrow is placed in front of a converging mirror. An upright image of the arrow is formed to the right of the mirror at the location shown.



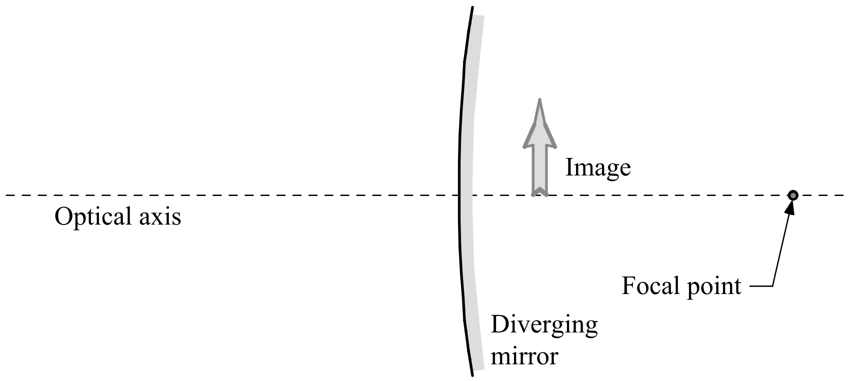
Based on the location of its image, find the location of the arrow.
Explain your reasoning.

Answer: All of the light rays from the tip of the arrow that are reflected by the mirror will diverge as if they came from the image location. The principal rays for a converging mirror are: (1) A ray from the object parallel to the optical axis reflects through the focal point. (2) A ray coming from the object away from the focal point is reflected parallel. (3) A ray from the object to the mirror at the optical axis reflects at the same angle. In this case, these reflected rays must be diverging, since they all seem to be coming from the image point which is behind the mirror. We can reconstruct the principal rays based on the reflected rays: (1) A reflected ray along a line from the tip of the image arrow toward the focal point must have an incident ray from the object parallel to the optical axis. (2) A ray coming from the focal point hitting the mirror at the height of the image bounces back parallel to the optical axis. (3) A reflected ray pointing away from the mirror along a line connecting the image arrow tip and the center of the mirror has an incident ray at the same angle. The object is at the intersection of the three incident rays, as shown.



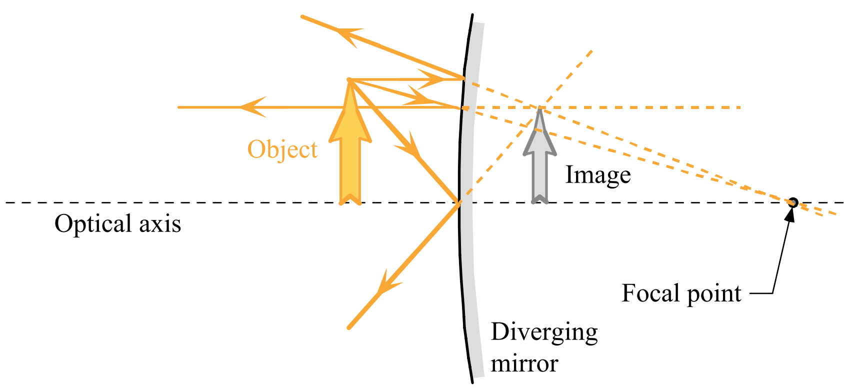
E2-WBT18: IMAGE FOR A DIVERGING MIRROR—OBJECT

An arrow is placed in front of a diverging mirror. An upright image of the arrow is formed to the right of the mirror at the location shown.



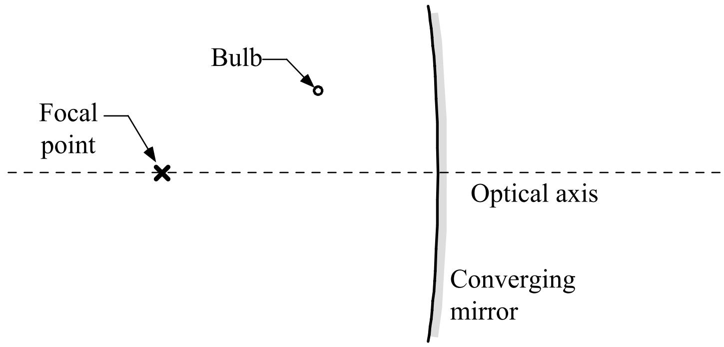
Based on the location of its image, find the location of the arrow.
Explain your reasoning.

Answer: All of the light rays from the tip of the arrow that are reflected by the mirror will diverge as if they came from the image location. The principal rays for a diverging mirror are: (1) A ray from the object parallel to the optical axis reflects away from the focal point. (2) A ray coming from the object toward the focal point is reflected parallel. (3) A ray from the object to the mirror at the optical axis reflects at the same angle. In this case, these reflected rays are diverging, since they all seem to be coming from the image point which is behind the mirror. We can reconstruct the principal rays based on the reflected rays: (1) A reflected ray along a line from the tip of the image arrow away from the focal point must have an incident ray from the object parallel to the optical axis. (2) A reflected ray away from the mirror at the height of the image must have an incident ray from the object toward the focal point. (3) A reflected ray pointing away from the mirror along a line connecting the image arrow tip and the center of the mirror has an incident ray at the same angle. The object is at the intersection of the three incident rays, as shown.



E2-QRT19: BULBS NEAR A CONVERGING MIRROR—OBSERVER LOCATION

A small bulb is placed in front of a converging mirror as shown.

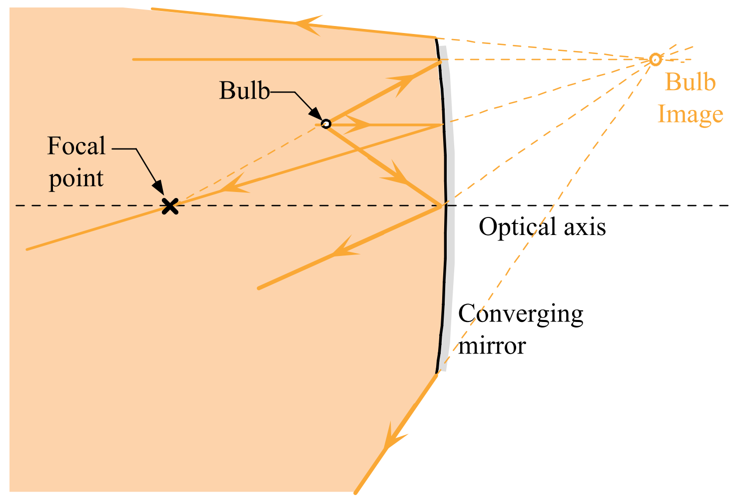


In the diagram, (a) draw rays to determine the location of the image of the light bulb.

(b) Then determine where an observer must be located to see the image of the bulb.

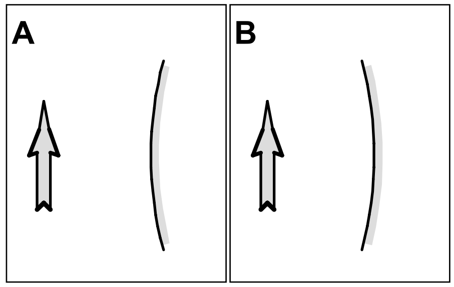
Explain your reasoning.

Answer: We draw principal rays to determine the location of the image of the bulb. A ray from the bulb parallel to the optical axis reflects through the focal point. A ray from the bulb toward the optical axis reflects from the mirror at the same angle. A ray from the bulb directed away from the focal point is reflected parallel to the optical axis. The image of the bulb is located at the intersection of these reflected rays, behind the mirror. The region where an observer can see the image is determined by the reflected rays from the edges of the mirror: these reflected rays (like all rays from the bulb reflected from the mirror) reflect away from the image location. An observer anywhere in the shaded region shown will see the image of the bulb.



E2-CT20: OBJECTS OUTSIDE THE FOCAL LENGTH OF MIRRORS—IMAGE DISTANCE

In the two situations shown, the mirrors have the same focal lengths, and the object distance from the mirror to the arrow is the same. In both cases, the object distance is greater than the focal distance.



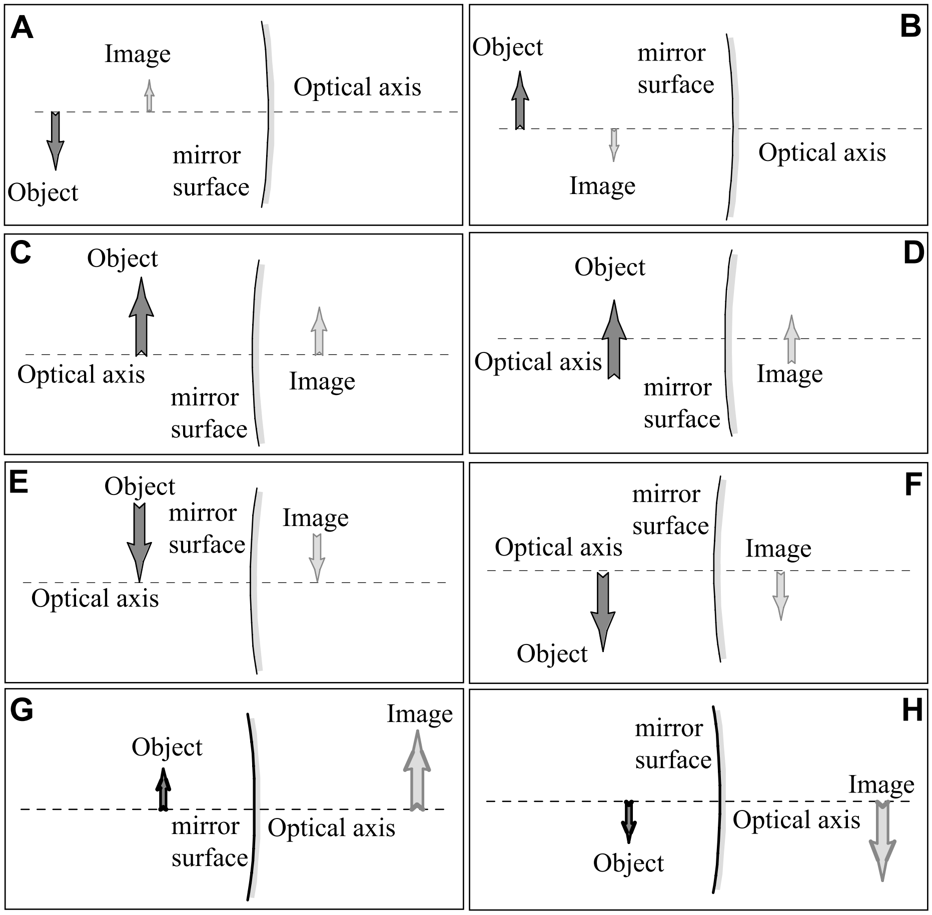
Will the image distance for A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the image distance for B? _____ Explain your reasoning.

Answer: (i) greater than.

Since the mirror in case A is a diverging mirror and the object is placed outside the focal point a virtual image will be produced on the opposite side of the mirror. In contrast for case B the image, which will be real, will be between the object and the mirror, so the image distance has to be smaller than for case A.

E2-QRT21: IMAGE AND OBJECT LOCATIONS RELATIVE TO MIRRORS—IMAGE TYPES

Consider the following image positions for the mirrors arranged as shown with the objects placed on the left side.



(a) List all the cases that produced a virtual image of the object: __*C, D, E, F, G, and H*___

Explain your reasoning.

With the object on the left the incoming rays will all be reflected back to the left, so for these images the rays do not actually go through the location of the images.

(b) List all the cases that produced an inverted image of the object: __*A and B*___

Explain your reasoning.

These two images are the only ones that are oriented opposite to the objects.

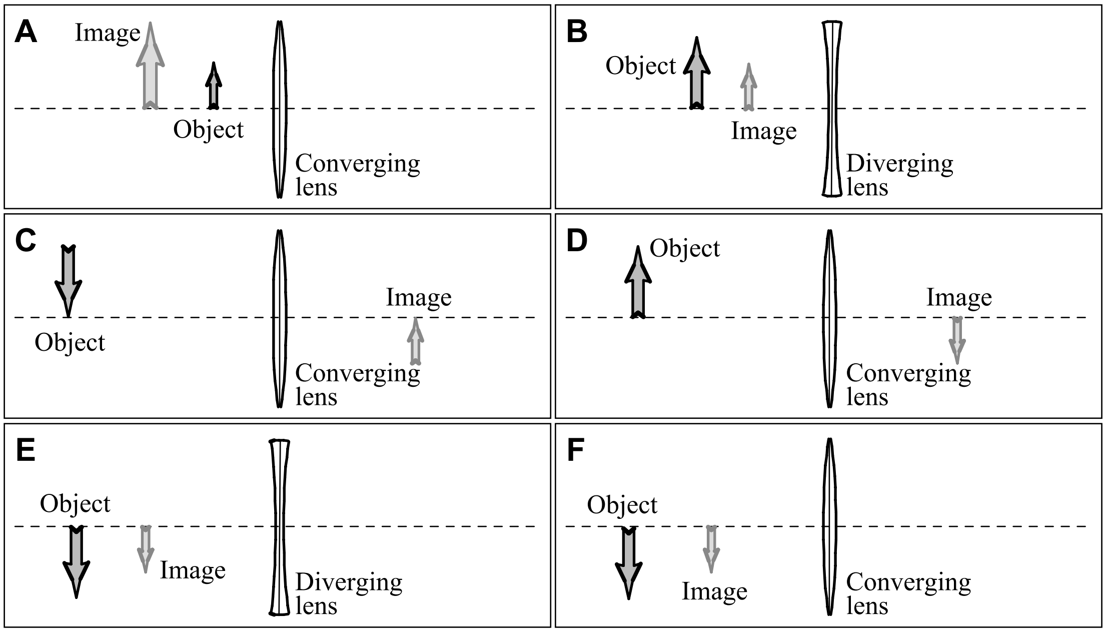
(c) List all the cases that produced a reduced size image of the object: __*A, B, C, D, E, and F*___

Explain your reasoning.

Since the real images in A and B are closer to the mirror than the object they have to be reduced in size. The other four are virtual images produced by diverging mirrors which are always smaller than the object.

E2-QRT22: Image and Object Locations Relative to Lens—Image Types

Consider the following image positions for the lenses arranged as shown with the objects placed on the left side.



(a) List all the cases that produced a virtual image of the object: __*A, B,and E*___
Explain your reasoning.

A is virtual since the object is inside the focal point of a converging lens. Images B and E are produced by diverging lenses which can only produce virtual images.

(b) List all the cases that produced an inverted image of the object: __*C and D*___
Explain your reasoning.

Real images are always inverted, i.e., have the opposite orientation of the object.

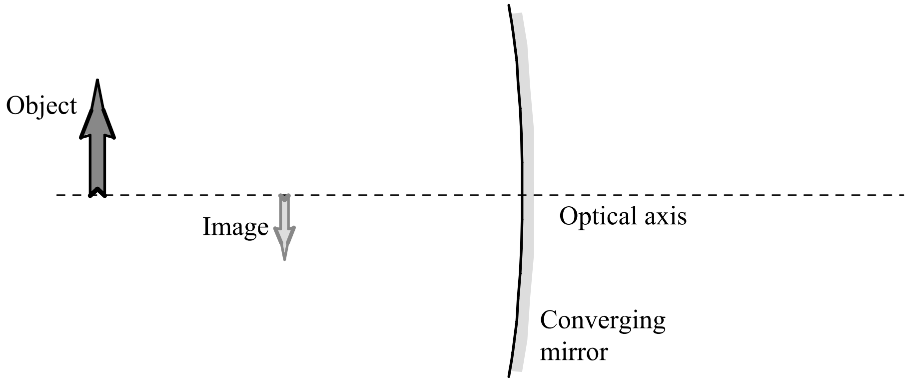
(c) List all the cases that produced a reduced size image of the object: _*B, C, D, and E*____
Explain your reasoning.

All of these images are closer to the lens than the object, so they have to be smaller.

Case F is not possible.

E2-QRT23: IMAGE AND OBJECT LOCATIONS RELATIVE TO MIRROR—IMAGE TYPE

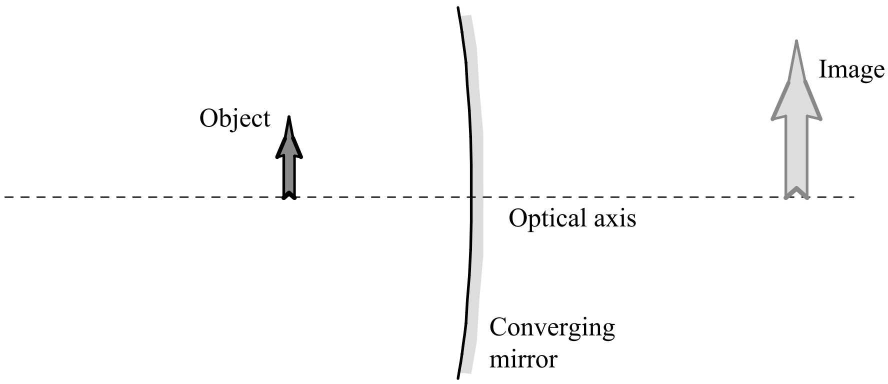
A student determines the image positions shown for the three arrangements shown below, with the objects placed on the left side of the mirror.



(a) Is this image (i) *real,* (ii) *virtual,* or (iii) *cannot be determined*? _____

Explain your reasoning.

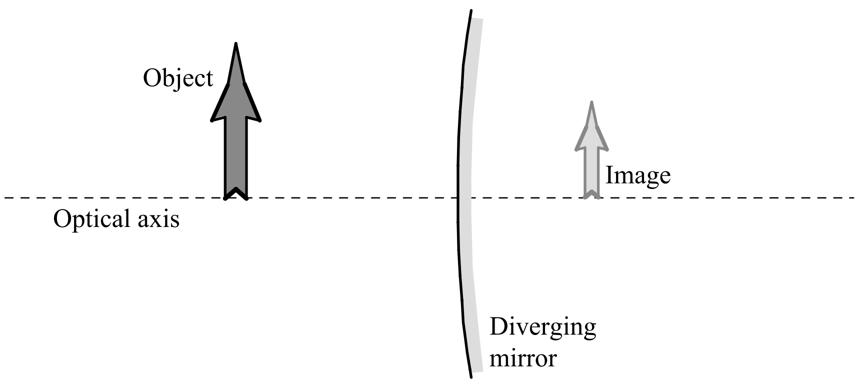
Answer: (i) real since the rays reflect and pass back thru the image.



(b) Is this image (i) *real*, (ii) *virtual*, or (iii) *cannot be determined*? _____

Explain your reasoning.

Answer: (ii) virtual since the rays reflect back from the mirror and only appear to be coming from the image



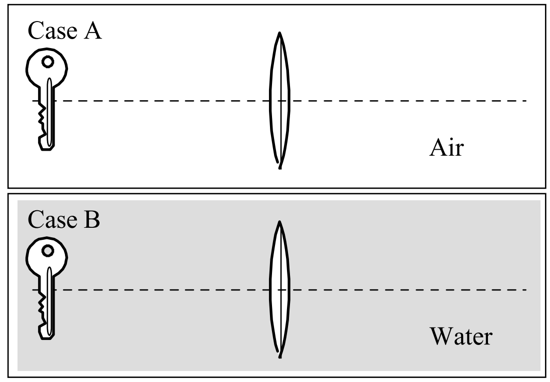
(c) Is this image (i) *real*, (ii) *virtual*, or (iii) *cannot be determined*? _____

Explain your reasoning.

Answer: (b) virtual since the rays reflect back and only appear to be coming from the image.

E2-CT24: Image Formed in Air and in Water—Distance from Lens or Mirror

(a) In each case, a key is placed in front of a converging lens so that an inverted image of the key is formed on the other side of the lens. (The object distance is greater than the focal distance.) The two cases are identical except that the key and lens are in air in Case A and in water in Case B.



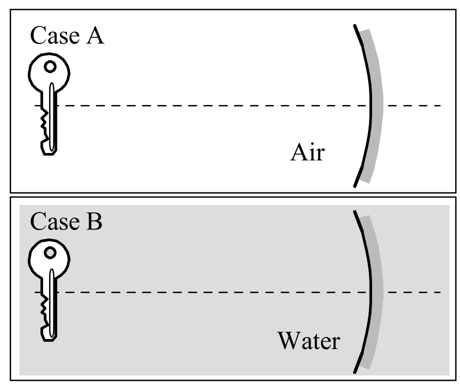
Is the distance from the lens to the image of the key (the image distance) (i) *greater in Case A*, (ii) *greater in Case B*, or (iii) *the same in both cases*? _____

Explain your reasoning.

Answer: (ii) Greater in case B.

The lens bends the light rays traveling into it because the index of refraction of the lens is greater than the index of refraction of the medium that the light is traveling through before it hits the lens. The amount of bending at each surface of the lens depends on the ratio of the refractive indices. Since water has an index of refraction that is closer to the index of refraction of the lens than air, the lens won't bend the light as much when it is immersed in water, and so the image will be formed further away. The effective focal length of the lens is greater when it is immersed in water.

(b) In each case, a key is placed in front of a converging mirror so that an inverted image of the key is formed on the same side of the mirror. (The object distance is greater than the focal distance.) The two cases are identical except that the key and mirror are in air in Case A, and in water in Case B.



Is the distance from the mirror to the image of the key (the image distance) (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.

A mirror forms an image by reflecting the light rays that are incident on it. The direction that a ray takes when it reflects off of the mirror depends on the angle that the incident ray makes with the mirror surface, but the reflected direction does not depend on the medium in which the mirror is immersed. The light rays that hit the mirror from the key will behav
e identically in both cases, and the image location will be the same.

E2-TT25: POSITIVE FOCAL LENGTH LENS—IMAGE TYPE

A student makes the following contention:

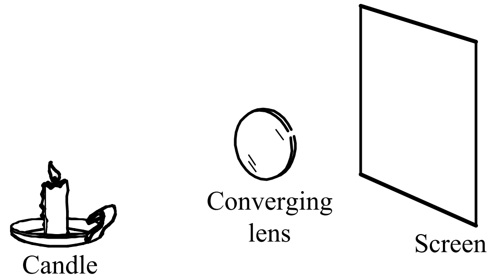
"If a positive focal length lens produces an image that is larger than the object, then the image will be virtual."

There is a problem with this contention; identify the problem and explain how to correct it.

Answer: Positive focal length lenses (converging lenses) can produce both real and virtual images that are magnified. Any virtual image produced by a positive focal length lens will be magnified because it will form "behind" the object on the same side of the lens. But positive focal length lenses can also produce real images that are magnified if the object distance is greater than the focal distance but less than twice the focal distance.

E2-SCT26: Removing a Converging Lens—Image

In a darkened room, a candle is placed in front of a white screen, and a converging lens with focal distance 16 cm is placed between the candle and the screen. The position of the lens is adjusted until an inverted image of the candle appears on the screen. The lens is then removed. Three students are discussing the appearance of the screen after the lens is removed:



Adan: *"The lens was bending the light to form the image, and when you remove it, all that's left is the light from the candle lighting up the screen. But there won't be an image of the candle anymore."*

Belmiro: *"The lens was turning the image of the candle upside down, and when you remove it, the image of the candle will be right side up. The light from the tip of the flame now travels in a straight line to the top part of the screen, and the light from the bottom of the candle travels a straight line to the bottom of the screen."*

Chanthana: *"I agree that you can still get an image, and it will be right side up because the lens isn't turning it upside down any more. But I think without the lens to bend the rays, the image will be a lot farther away. Without moving the screen you'll get a fuzzy image of the candle, and you have to move the screen away from the candle to see an upright image of the candle."*

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

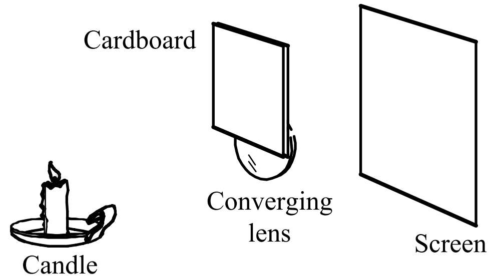
Adan _____ Belmiro _____ Chanthana _____ None of them _____

Explain your reasoning.

Answer: Adan is correct.

The image appears because the rays from each point on the candle are bent by the lens so that they converge on a single point on the screen. Without the lens, the light rays from each point on the candle diverge or spread out and don't meet again, so no image forms.

E2-SCT27: BLOCKED LENS—IMAGE



In a darkened room, a candle is placed in front of a white screen, and a converging lens is placed between the candle and the screen. The position of the lens is adjusted until an inverted image of the candle appears on the screen. A piece of cardboard is then placed in front of the lens so that it covers the top half of the lens. Four students are discussing what will happen to the image of the candle when the cardboard is placed in front of the lens:

Ajit: *"No image of the candle will form. The image location is determined by the principal rays, and in this case the ray from the candle parallel to the optical axis has been blocked."*

Binh: *"I think the image doesn't change at all. The bottom half of the lens still works like it did before, and it focuses the light from the candle onto the screen. The image might be dimmer, though, because there is less total light converging to form the image."*

Colette: *"Only the image from the top half of the candle has been blocked. The light from the bottom half still forms an image. What you'll see on the screen is an image of the candle holder and the bottom half of the candle, but not of the flame."*

Diamontina: *"I think you'll only see an image of the top half of the candle. The lens inverts the image, so when you block the top half of the lens, you block the image of the bottom half of the candle."*

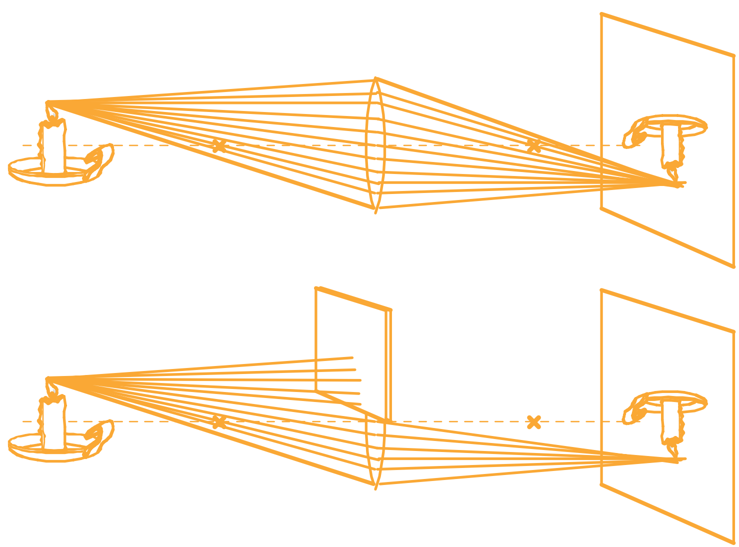
With which, if any, of these students do you agree?

Ajit _____ Binh _____ Colette _____ Diamontina _____ None of them _____

Explain your reasoning.

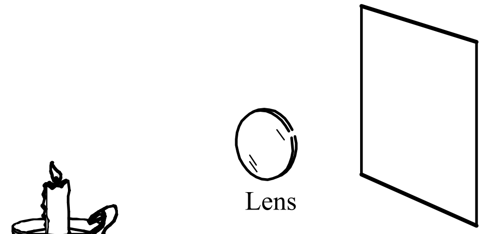
Answer: Binh is correct.

While the principal rays are useful in determining the location of the image, all of the light rays from each point on the candle that hit the lens are bent by the lens to a single point on the screen to form the image of that point on the candle. If half of these rays are blocked, the other half still form the image. The image will be dimmer because there is less total light forming it.



E2-SCT28: REPLACING A CONVERGING LENS WITH A DIVERGING LENS—IMAGE

In a darkened room, a candle is placed in front of a white screen, and a converging lens with focal length 16 cm is placed between the candle and the screen. The position of the lens is adjusted until an inverted image of the candle appears on the screen. Students are discussing the appearance of the screen when the converging lens is replaced with a diverging lens with focal distance –16 cm:



Alonzo: *"The same image is going to form, except this time it will be right side up. Converging lenses invert images, and diverging lenses don't."*

Bonifacio: *"The image will still form, at the same place because the focal distances are the same, but it will be smaller. The image from a diverging lens is always smaller than the object, whereas the image from a converging lens could be smaller or larger."*

Carlita: *"The image is going to be formed on the same side of the screen as the candle, because the focal distance is negative. Also, the negative sign makes the image noninverted instead of inverted. If we move the screen to the front of the lens we'll see the image."*

Dominic: *"I think Carlita is right that the image is on the same side of the lens as the candle, but I don't think you'll see it if you put the screen there."*

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

Alonzo _____ Bonifacio _____ Carlita _____ Dominic _____ None of them _____

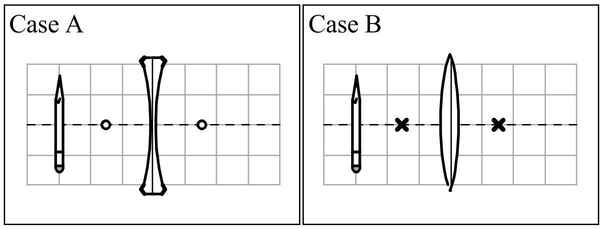
Explain your reasoning.

Answer: Dominic is correct.

The image for the diverging lens will be upright and smaller than the candle, and will be on the same side as the candle. However, this image won't appear on a screen because (1) the image location is before the lens, and the light rays from the candle have not been bent by the diverging lens before they hit the screen, and (2) the image formed by a diverging lens is a virtual image, and the rays that are bent by the lens don't actually converge at a point.

E2-CT29: Diverging and Converging Lenses—Distance from Object to Image

In both cases, a lens is shown with its focal points marked over a grid. A pencil is placed to the left of the lens. The situations are identical, except that the lens in Case A is a diverging lens and the lens in Case B is a converging lens.

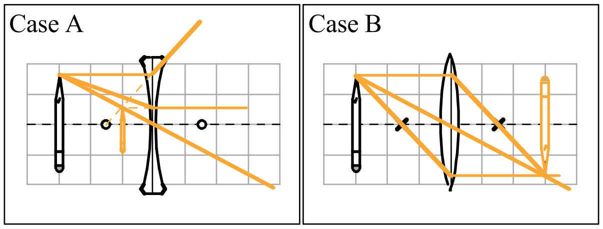


Is the distance from the pencil to the image of the pencil (i) *greater in Case A*, (ii) *greater in Case B*, or (iii) *the same in both cases*? _____

Explain your reasoning.

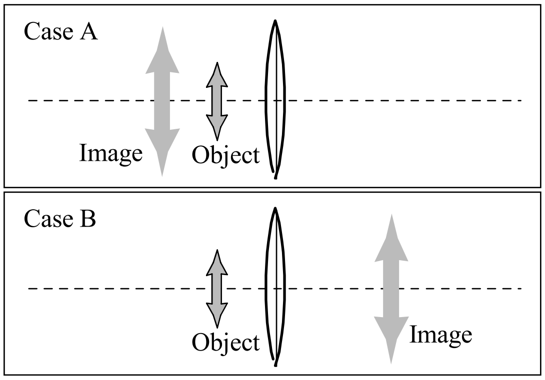
Answer: (ii) Greater in case B.

The image in case A will be on the left side of the lens and will be a virtual image, located as shown in the ray diagram. The image in case B will be located on the right side of the lens and will be real, as shown in the ray diagram.



E2-CT30: Converging Lenses—Focal Distance

In both cases, an object is placed 20 cm from a converging lens. The image position in Case A is to the left of the lens (and also to the left of the object), while in Case B the image position is to the right of the lens.

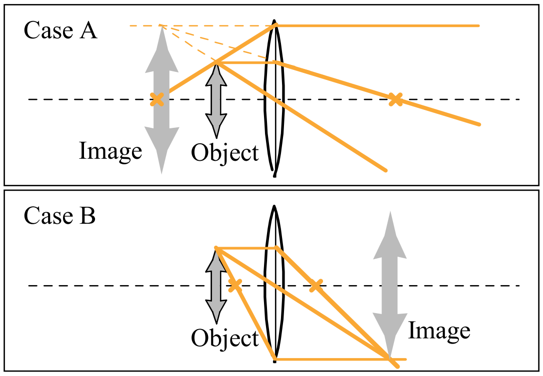


Is the focal distance of the lens (i) *greater in Case A*, (ii) *greater in Case B*, or (iii) *the same in both cases*? _____

Explain your reasoning.

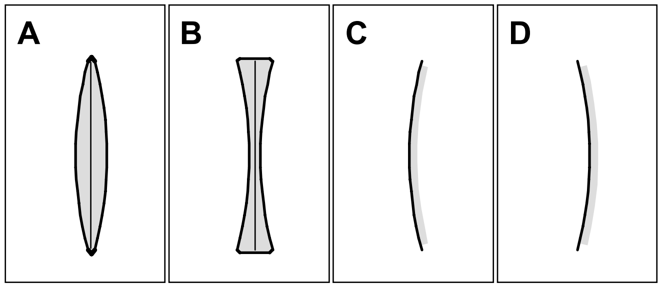
Answer: (i) Greater in case A.

In case B, a real image is being formed, so the object must be outside of the focal distance. In case A, the image is virtual, so the object must be inside the focal distance. Since the object is the same distance away in both cases, the focal distance must be smaller in case B than in case A. This is consistent with the rays being bent more by the lens in case B than in case A.



E2-RT31: LENSES AND MIRRORS—FOCAL LENGTH IN WATER

The figures below show converging (A) and diverging (B) thin lenses as well as diverging (C) and converging (D) mirrors. The lenses are made of glass with an index of refraction of 1.6. All lenses and mirrors have the same magnitude focal length when placed in air (n = 1).



Rank the focal lengths of the mirrors and lenses when they are placed in water (n = 1.33).

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

Explain your reasoning.

Answer: A = B > C = D.

The focal length of the mirrors does not change since the reflection angle does not depend on the index of refraction of the medium. The focal length of the lenses will increase because there will be less bending of light entering or leaving the glass lens.

E2-WWT32: SINGLE LENS—FOCAL LENGTH

A student makes the following contention:

"If a single lens can only produce images that are smaller than the objects involved, then the lens is a negative focal length lens."

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

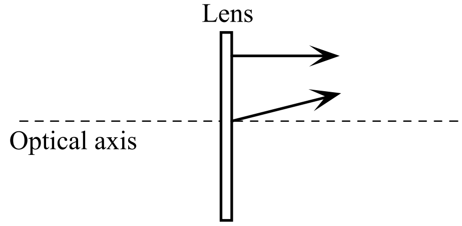
Answer: This statement is correct.

The images produced by diverging lenses (lenses with negative focal distances) always form between the object and the lens, and they are always smaller than the object.

E2-QRT33: RAYS EMERGING FROM A LENS I—LENS AND IMAGE TYPE

The vertical rectangle in the figure represents a thin lens. The dashed line is the optical axis of that lens. Two of the three principal light rays are shown emerging from the lens. These light rays originated at a single point on an object placed to the left of the lens.

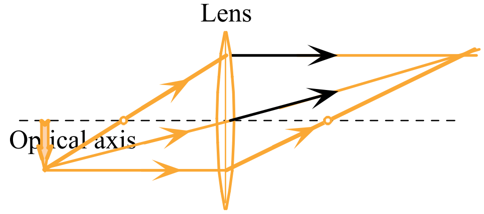
(a) What type of lens is this, and how do you know?



Answer: This is a converging lens. The rays that pass through the lens are converging and will meet at the image point, forming a real image. This will not happen with a diverging lens, which always produces virtual images. A real image will be created by a converging lens when an object is placed further from the lens than the focal distance.

(b) Draw the third ray that is commonly used to find the image.

Answer: The three principal rays most commonly used to locate an image are the ray that passes through the optical axis (the diagonal ray shown), the ray that passes through the focal point on the object side of the lens, emerging parallel (also shown) and the parallel incident ray that passes through the focal point on the other side of the lens.

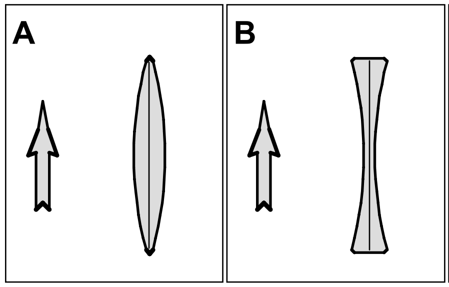


(c) What type of image will form here, and how do you know?

Answer: A real image will form. The refracted rays will meet at the image location, which means we could put a screen where they meet and see an image on the screen.

E2-CT34: OBJECTS INSIDE FOCAL LENGTH OF LENSES—IMAGE DISTANCE I

In the two situations shown, the lenses have the same focal lengths, and the object distance from the lens to the arrow is the same. In both cases the object distance is less than the focal distance.



Will the image distance for Case A be (i) *greater than*, (ii) *less than*, or (iii) *equal* to the image distance for Case B? _____

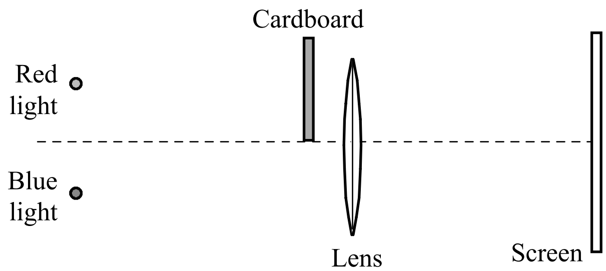
Explain your reasoning.

Answer: (i) greater than.

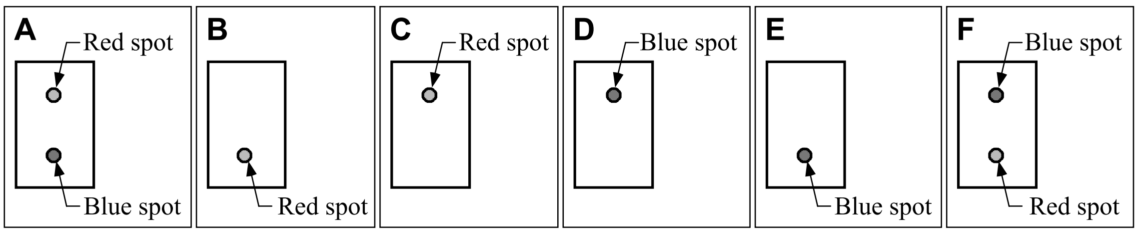
The image for A will be farther from the lens than the object, but for B the image will be between the object and the lens.

E2-QRT35: Red and Blue Lights in Front of Lens—Image on Screen

Light from two small bulbs, one red and one blue, passes through a lens to form an image of the bulbs on a screen. Without changing the location of the bulbs, the lens, or the screen, a piece of cardboard is placed so that it covers half of the lens, as shown in the side view diagram.



Which choice below best represents what will appear on the screen?



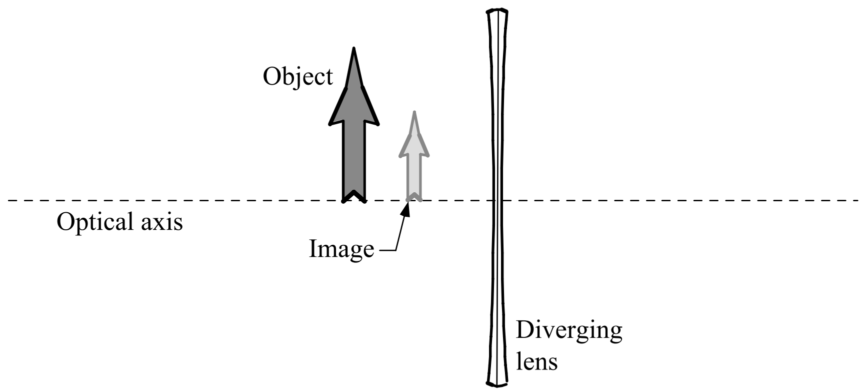
Explain your reasoning.

Answer: F.

The cardboard will only reduce the brightness of the image. An image is formed by all of the light rays passing through the bottom of the lens, and the location of the image of each bulb will not change.

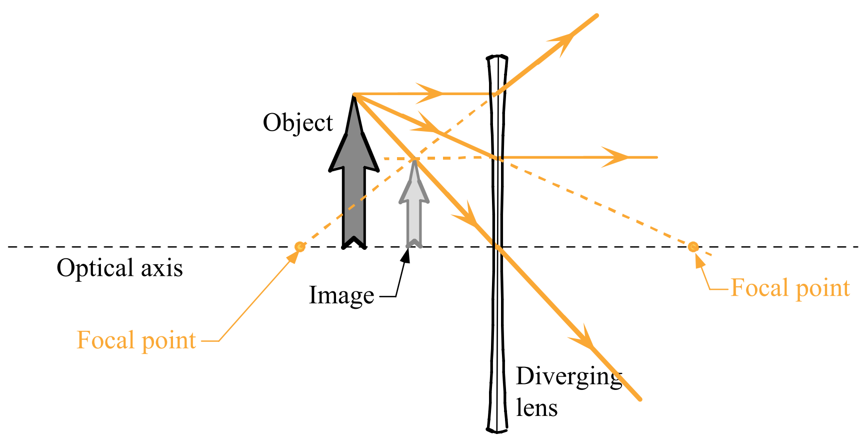
E2-WBT36: OBJECT AND UPRIGHT IMAGE FOR A DIVERGING LENS—FOCAL POINT

An object is placed in front of a diverging lens. An upright image of the object is formed to the left of the lens at the location shown.



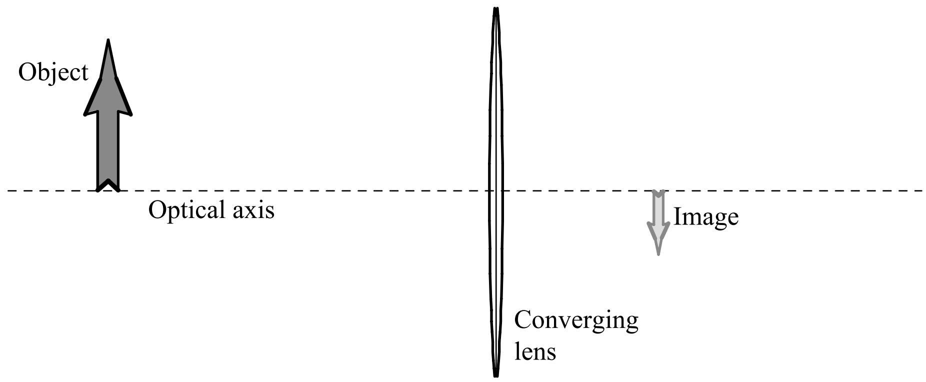
Based on the image and object locations, find the two focal points for this lens. Explain your reasoning.

Answer: All of the light rays from a point on the object will diverge after they are refracted by the lens. The image is formed at the point to the left of the lens that these refracted rays seem to be coming from. A parallel ray from the object to the lens will bend away from the focal point that is to the left of the lens. If we extend this refracted ray backward it will pass through the image location to the left of the lens. So if we draw a line from the image point of the tip of the arrow that hits the lens where a parallel ray from the object hits the lens, this line extended to the left will cross the optical axis at the location of one focal point. The other focal point will be the same distance to the right of the lens. A ray drawn from the tip of the arrow toward this second focal point will bend at the lens and will be parallel to the optical axis to the right of the lens. If we extend this parallel ray to the left of the lens it should pass through the image point of the tip of the arrow. The final principal ray is a ray from the tip of the arrow through the optical axis. This ray also passes through the image point.



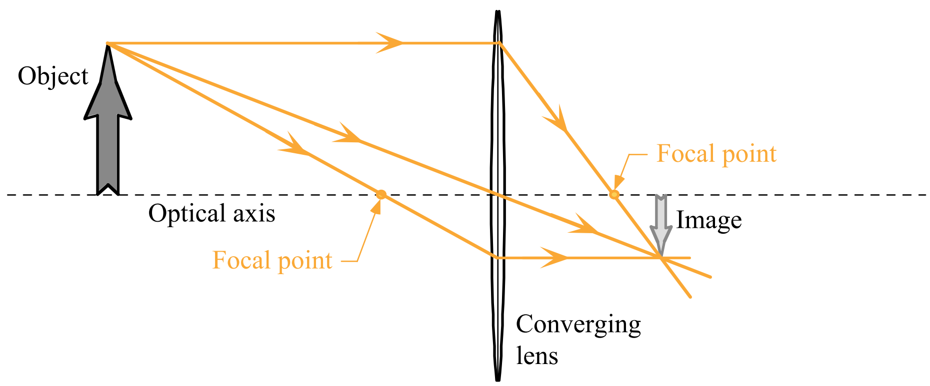
E2-WBT37: OBJECT AND INVERTED IMAGE FOR A CONVERGING LENS—FOCAL POINT

An object is placed in front of a converging lens. An inverted image of the object is formed to the right of the lens at the location shown.



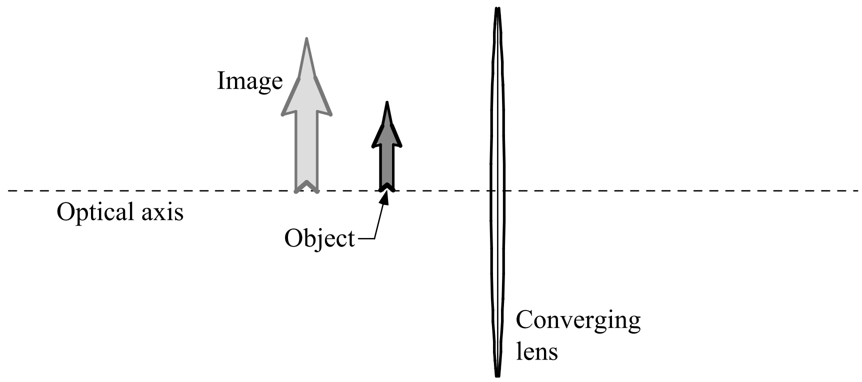
Based on the image and object locations, find the two focal points for this lens. Explain your reasoning.

Answer: All of the light rays from a point on the object will converge after they are refracted by the lens. The image is formed at the point to the right of the lens that these refracted rays pass through. A parallel ray from the object to the lens will bend toward the focal point to the right of the lens. This refracted ray will then pass through the image location to the right of the lens. So if we draw a line from the point where a parallel ray from the object hits the lens to the image point, the focal point to the right of the lens is where this line intersects the optical axis. The other focal point will be the same distance to the left of the lens. A ray drawn from the tip of the arrow through this second focal point will bend at the lens and will emerge parallel to the optical axis to the right of the lens, and will pass through the image point. (We could find the focal point to the left of the lens by drawing a line parallel to the optical axis from the lens to the image of the tip of the arrow. A line from the tip of the object to the point where this parallel line hits the mirror will intersect the optical axis at the focal point.) The final principal ray is a ray from the tip of the arrow through the optical axis. This ray also passes through the image point.



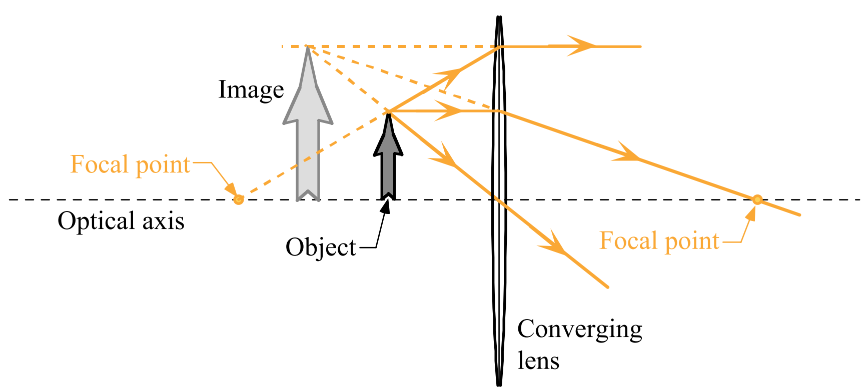
E2-WBT38: Object and Upright Image for a Converging Lens—Focal Point

An object is placed in front of a converging lens. An upright image of the object is formed to the left of the lens at the location shown.



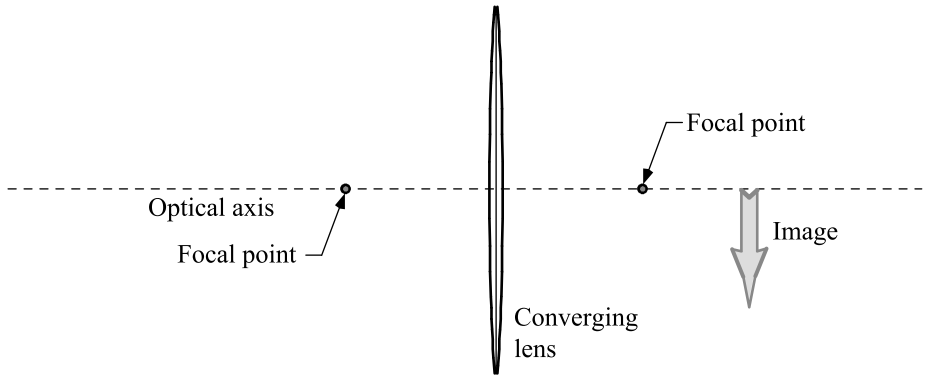
Based on the image and object locations, find the two focal points for this lens.
Explain your reasoning.

Answer: All of the light rays from a point on the object will diverge from each other after they are refracted by the lens. The image is formed at the point to the left of the lens that these refracted rays seem to be coming from. A parallel ray from the tip of the arrow (the object) to the lens will bend toward the focal point to the right of the lens. If we extend this refracted ray to the right of the lens, it will pass through the image point. So if we draw a line from the point that a parallel ray from the object hits the lens to the image point, the focal point to the right of the lens is where this line intersects the optical axis. The other focal point will be the same distance to the left of the lens. A ray drawn from this second focal point toward the tip of the arrow will continue toward the lens, and will bend at the lens so that it is parallel to the optical axis to the right of the lens. An extension of this parallel line to the left of the lens will pass through the image point. (We could find the focal point to the left of the lens by drawing a line parallel to the optical axis from the lens to the image of the tip of the arrow. A line from the tip of the object to the point where this parallel line hits the lens will extend to the left and intersect the optical axis at the focal point.) The final principal ray is a ray from the tip of the arrow through the optical axis. If this ray is extended to the left it also passes through the image point.



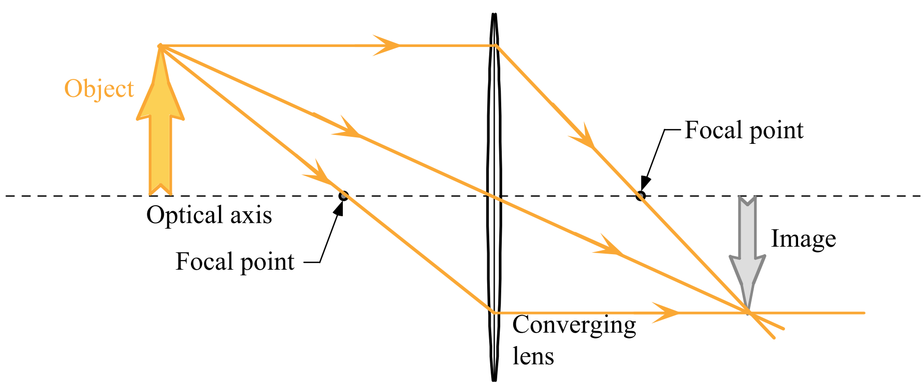
E2-WBT39: IMAGE FOR A CONVERGING LENS—OBJECT

An arrow is placed to the left of a converging lens. An inverted image of the arrow is formed to the right of the mirror at the location shown.



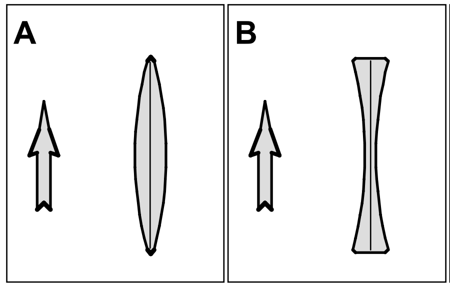
Based on the location of its image, find the location of the arrow.
Explain your reasoning.

Answer: All of the light rays from the tip of the arrow that are refracted by the lens will pass through the image location. The principal rays for a converging lens are: (1) A ray from the object parallel to the optical axis bends at the lens toward the focal point on the other side of the lens. (2) A ray coming from the object through the focal point on the same side is refracted so that it is parallel to the optical axis. (3) A ray from the object to the lens at the optical axis passes straight through. In this case, these refracted rays converge to form the image at the location shown. We can reconstruct the principal rays based on the refracted rays: (1) A reflected ray along a line from the tip of the image arrow through the focal point on the right must have an incident ray from the objecparallel to the optical axis. (2) A refracted ray on the right side of the lens parallel to the optical axis at the height of the image must have an incident ray from the object coming from the object and passing through the focal point on the left side of the lens. (3) A refracted ray pointing away from the lens along a line connecting the image arrow tip and the center of the lens has an incident ray along the same line. The object is at the intersection of the three incident rays, as shown.



E2-CT40: Objects Outside Focal Length of Lenses—Image Distance

In the two situations shown, the lenses both have the same focal lengths but opposite signs, and the object distance from the lens to the arrow is the same. In both cases the object distance is greater than the focal distance.



Will the image distance for Case A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the image distance for Case B? _____

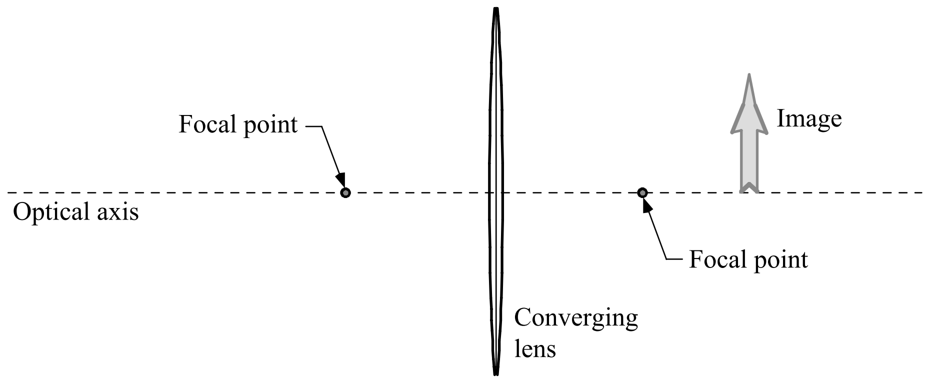
Explain your reasoning.

Answer: (i) greater than.

Since the lens in A is a converging lens and the object is placed outside the focal point a real image will be produced on the opposite side of the lens. In contrast for B the image, which will be virtual, will be between the object and the lens, so the image distance has to be smaller than for A.

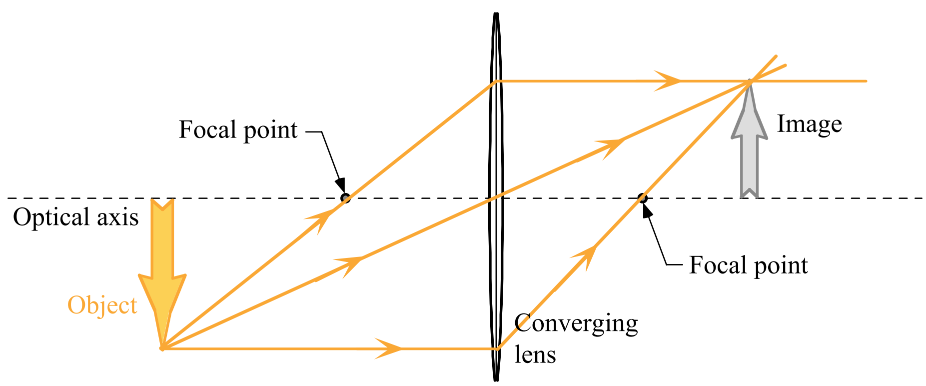
E2-WBT41: IMAGE FOR A CONVERGING LENS—OBJECT

An arrow is placed to the left of a converging lens. An inverted image of the arrow is formed to the right of the mirror at the location shown.



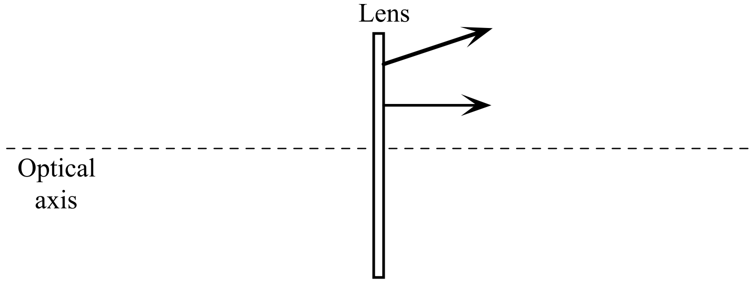
Based on the location of its image, find the location of the arrow.
Explain your reasoning.

Answer: All of the light rays from the tip of the arrow that are refracted by the lens will pass through the image location. The principal rays for a converging lens are: (1) A ray from the object parallel to the optical axis bends at the lens toward the focal point on the other side of the lens. (2) A ray coming from the object through the focal point on the same side is refracted so that it is parallel to the optical axis. (3) A ray from the object to the lens at the optical axis passes straight through. In this case, these refracted rays converge to form the image at the location shown. We can reconstruct the principal rays based on the refracted rays: (1) A reflected ray along a line from the tip of the image arrow through the focal point on the right must have an incident ray from the object parallel to the optical axis. (2) A refracted ray on the right side of the lens parallel to the optical axis at the height of the image must have an incident ray from the object coming from the object and passing through the focal point on the left side of the lens. (3) A refracted ray pointing away from the lens along a line connecting the image arrow tip and the center of the lens has an incident ray along the same line. The object is at the intersection of the three incident rays, as shown.



E2-SCT42: Emerging Rays—Type of Lens

The vertical rectangle in the figure represents a thin lens. The dashed line is the optical axis of that lens. Two light rays are shown emerging from the lens. These light rays originated at a single point on an object placed to the left of the lens. Three students discussing this figure make the following contentions.



Anna: *"I think this has to be a diverging (negative) lens since the two rays are spreading out after passing through the lens."*

Brandon: *"I don't think we can say this since an object inside the focal point of a converging (positive) lens would also have rays that spread apart after passing through the lens."*

Carlos: *"Well, if these are two of the three principal rays, then this has to be a negative lens, but if they are other rays I'm not sure we can say."*

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

Anna _____ Brandon _____ Carlos _____ None of them _____

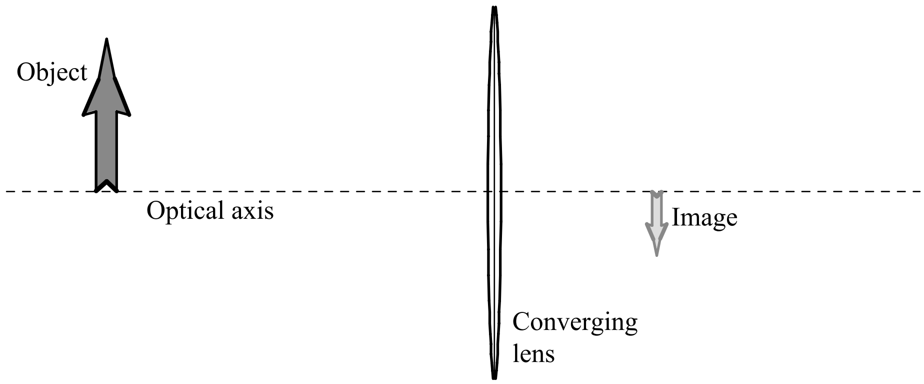
Explain your reasoning.

Answer: Brandon and Carlos are correct.

If these are two of the three principal rays then they have to be the two that pass, or would pass, through the focal points. We know this since one is emerging parallel to the principal axis so that ray has to be associated with one of the two focal points. The other rays shown is associated with the other focal point, so it had to have entered the lens parallel to the principal axis. That means it was bent away from the principal axis, so we have a diverging lens. If these are not principal rays then we cannot determine for sure.

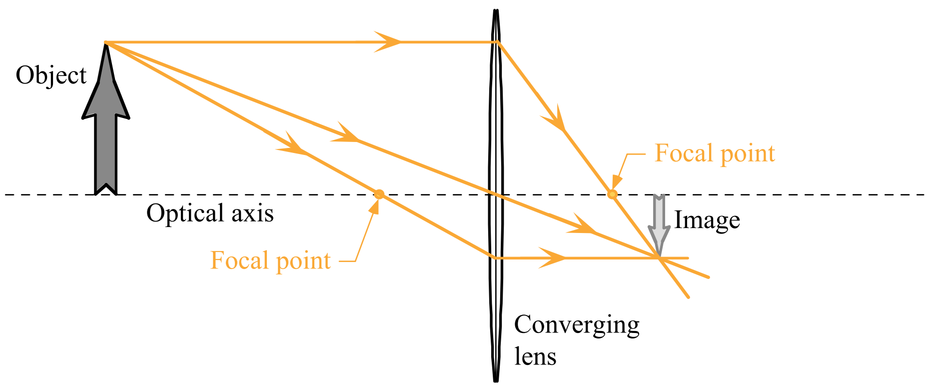
E2-QRT43: IMAGE AND OBJECT LOCATIONS RELATIVE TO LENSES—IMAGE TYPE

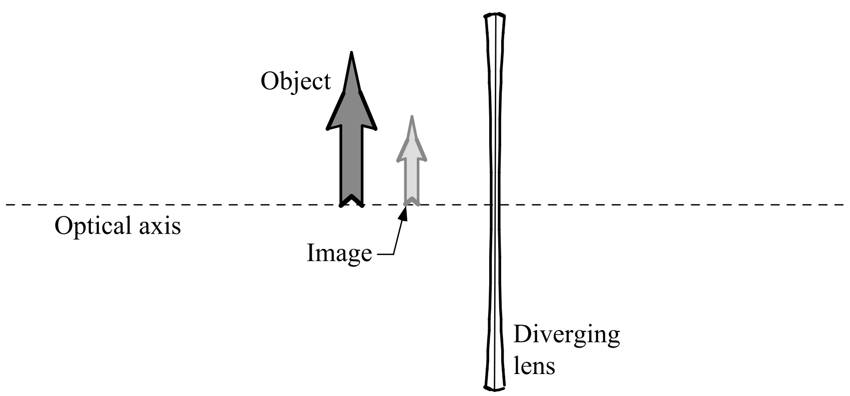
A student determines the image positions shown for the three setups below with the objects placed on the left side of the lens.



(a) Is this image (i) *real*, (ii) *virtual*, or (iii) *cannot be determined*? _____
Explain your reasoning.

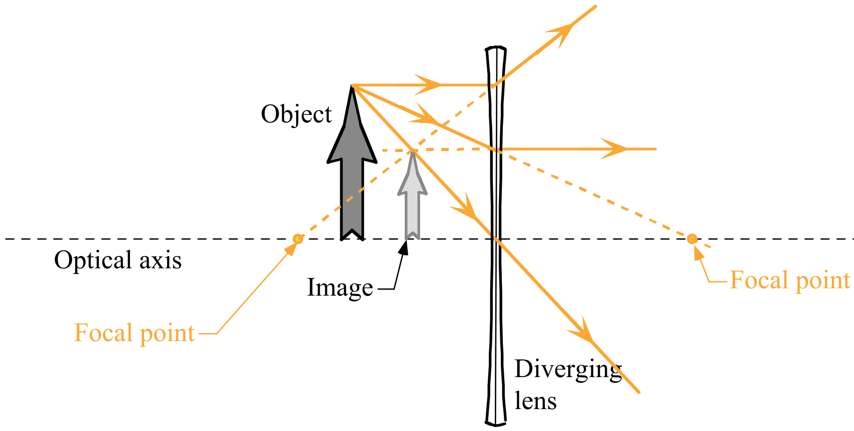
Answer: (i) real since the rays that have been refracted by the lens actually pass thru the image location as shown below.

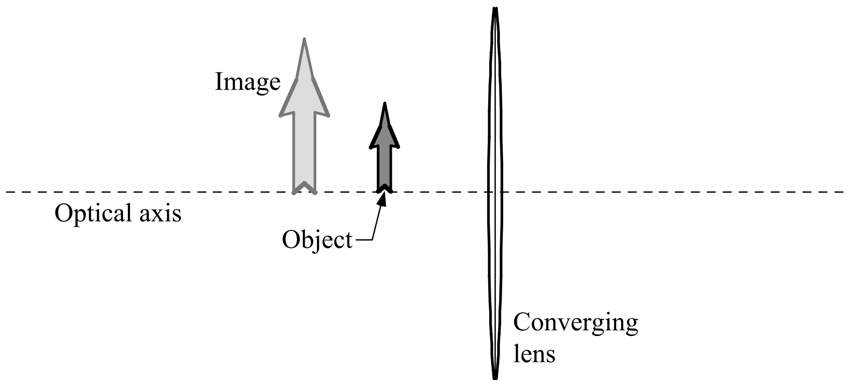




(b) Is this image (i) *real*, (ii) *virtual*, or (iii) *cannot be determined*? _____
Explain your reasoning.

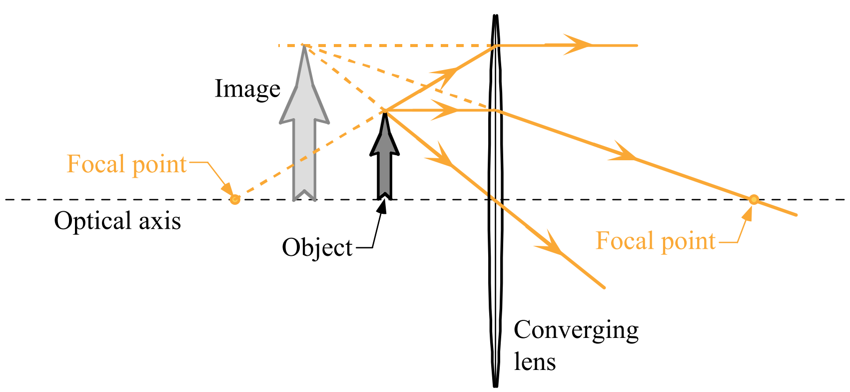
Answer: (ii) virtual since the rays that have been refracted by the lens do not actually pass thru the image location as shown below. The rays only appear to have come from the image if they are observed from the opposite side of the lens.





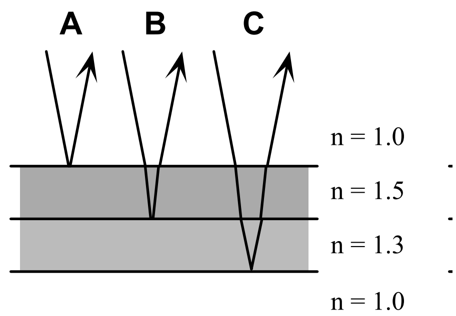
(c) Is this image (i) *real*, (ii) *virtual*, or (iii) *cannot be determined*? _____
Explain your reasoning.

Answer: (ii) virtual since the rays that have been refracted by the lens do not actually pass thru the image location as shown below. The rays only appear to have come from the image if they are observed from the opposite side of the lens.



E2-QRT44: THIN FILMS IN AIR—PHASE CHANGES

A beam of light is reflected from a thin film made of two layers of different materials. The figure shows what happens to three of the incident rays. The light is initially traveling in air.



When ray A is reflected from the top layer, will there be a phase change?
Explain your reasoning.

Answer: Yes

There is a phase change when a light ray reflects from a material that has a higher index of refraction than the index for the initial medium.

When ray B is reflected from the top of the second layer, will there be a phase change?
Explain your reasoning.

Answer: No

There is no phase change when a light ray reflects from a material that has a lower index of refraction than the index for the medium in which it is currently traveling.

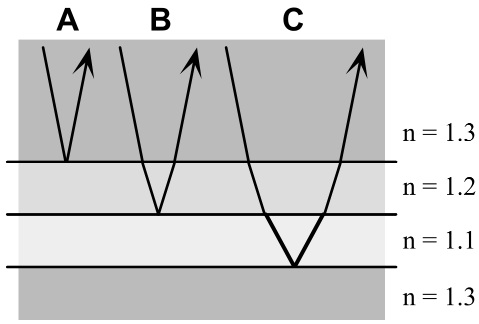
When ray C is reflected from the bottom of the second layer, will there be a phase change?
Explain your reasoning.

Answer: No

There is no phase change when a light ray reflects from a material that has a lower index of refraction than the index for the medium in which it is currently traveling.

E2-QRT45: THIN FILMS IMMERSED IN WATER—PHASE CHANGES

In each case, a light ray is reflected from a thin film made of two layers of different materials immersed in water with a refraction index of 1.3. In all three cases, the incident ray is in water.



When ray A is reflected from the top layer, will there be a phase change? Explain your reasoning.

Answer: No

There is no phase change when a light ray reflects from a material that has a lower index of refraction than the index for the medium in which it is currently traveling.

When ray B is reflected from the top of the second layer, will there be a phase change? Explain your reasoning.

Answer: No

There is no phase change when a light ray reflects from a material that has a lower index of refraction than the index for the medium in which it is currently traveling.

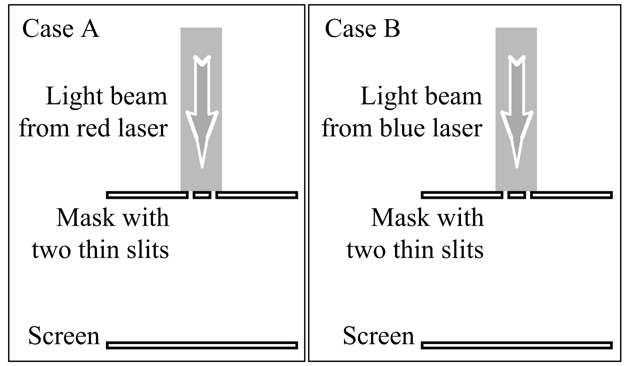
When ray C is reflected from the bottom of the second layer, will there be a phase change? Explain your reasoning.

Answer: Yes

There is a phase change when a light ray reflects from a material that has a higher index of refraction than the index for the medium in which it is currently traveling.

E2-CT46: Two Lasers and Two Slits—Bright Fringe Separation

In each case, a beam of light from a laser passes through very narrow slits cut in a mask. The light then hits a distant screen, creating an interference pattern. The two cases are identical except that in Case A the light beam is red, and in Case B it is blue.



Will the distance between bright fringes on the screen in Case A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the distance between bright fringes on the screen in Case B? _____

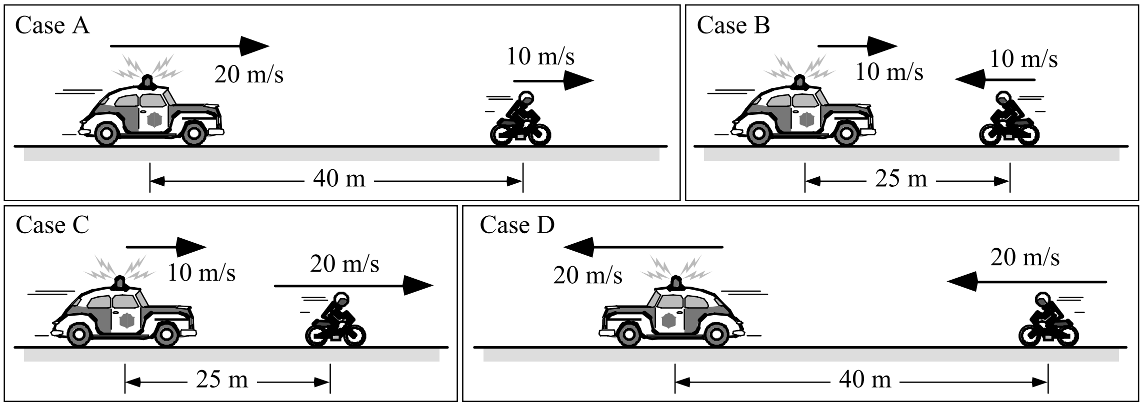
Explain your reasoning.

Answer: (i) Greater than.

A bright fringe on the screen is created when the light from the two slits is in phase when it reaches the screen. This occurs at points on the screen where the distance to the further slit is an integer number of wavelengths greater than the distance to the nearer slit. Because the wavelength of red light is greater than the wavelength for blue light, it takes a greater change in angle to add one more wavelength to the difference in path distances, and the bright fringes are further apart.

E3-RT01: POLICE CAR AND MOTORCYCLE—SIREN FREQUENCY

A police car with a 600 Hz siren is traveling along the same street as a motorcycle. The velocities of the two vehicles and the distance between them are given in each figure.



Rank the frequency of the siren as measured by the motorcycle rider.

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

Explain your reasoning.

Answer: B > A > D > C.

The frequency of the siren as measured by the motorcycle rider depends on the velocity of the police car in the reference frame of the motorcycle rider, and does not depend at all on the distance between the two. In the reference frame of the motorcycle rider, the police car is coming toward it at 10 m/s in case A, coming toward it at 20 m/s in case B, moving away from it at 10 m/s in case C, and at rest in case D. When the police car (in the reference frame of the motorcyclist) is coming toward it, the measured frequency is higher than 600 Hz, and when it is moving away from it the measured frequency is lower than 600 Hz. In case C, the measured frequency will be equal to 600 Hz.

E3-SCT02: TRAIN APPROACHING OBSERVER AT STATION—FREQUENCY HEARD

A train approaches a station at a constant speed, sounding its whistle continuously. Three students are discussing what an observer standing at a station would hear as the train is approaching:

Anish**:** *"The train is not accelerating or decelerating. I think the observer will hear a constant pitch that matches the pitch of the whistle."*

Brooke**:** *"Even if it isn't accelerating, the observer will hear a higher pitch than the whistle actually emits since the train is moving toward the observer. I agree that the observer will hear a constant pitch."*

Cruz**:** *"I agree with Brooke that the observer will hear a higher pitch, but I think the observer will also hear the frequency increase constantly as the train gets closer and closer."*

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

Anish _____ Brooke _____ Cruz _____ None of them ______

Explain your reasoning.

Answer: Brooke is correct.

Between the time that a crest of a sound wave is emitted from the train whistle and the time that the next crest is emitted the train will have moved toward the station, reducing the distance between crests of waves traveling toward the observer standing at the station. The sound waves traveling toward the station have a smaller wavelength and a higher frequency than the frequency of the whistle in the reference frame of the train. This frequency will be constant since the speed of the train is constant.

E3-CT03 MOVING TRAIN WHISTLE AND STATIONARY SPEAKER—PERCEIVED FREQUENCY

A train with a 1,000 Hz whistle passes by a train station at a constant speed of 30 m/s. A speaker on the station platform emits a 700 Hz warning siren as the train approaches.

(a) As the train approaches the station, is the frequency of the train whistle as perceived by an observer on the train platform (i) *greater than* 1,000 Hz, (ii) *less than* 1,000 Hz, or (iii) *equal* to 1,000 Hz? _____

Explain your reasoning.

Answer: (i) Greater than 1,000 Hz.

Between the time that a crest of a sound wave is emitted from the train whistle and the time that the next crest is emitted the train will have moved toward the station, reducing the distance between crests of waves traveling toward the station. The sound waves traveling toward the station have a smaller wavelength and a higher frequency than 1,000Hz. This frequency change is called a Doppler shift.

(b) As the train approaches the station, is the frequency of the station warning siren as perceived by a passenger on the train (i) *greater than* 700 Hz, (ii) *less than* 700 Hz, or (iii) *equal to* 700 Hz? _____

Explain your reasoning.

Answer: (i) Greater than 700 Hz.

Between the time that a crest of a sound wave is emitted from the warning siren and the time that the next crest is emitted the train will have moved toward the station, and the crests will arrive at the passenger's ears in less time than the time between crests had the passenger been at rest with respect to the siren. The frequency is Doppler shifted upward, and the passenger will hear a sound with a frequency greater than 700 Hz.

(c) As the train moves away from the station, is the frequency of the train whistle as perceived by an observer on the train platform (i) *greater than* 1,000 Hz, (ii) *less than* 1,000 Hz, or (iii) *equal to* 1,000 Hz? _____

Explain your reasoning.

Answer: (ii) Less than 1,000 Hz.

Between the time that a crest of a sound wave is emitted from the train whistle and the time that the next crest is emitted the train will have moved away from the station, increasing the distance between crests of waves traveling toward the station. The sound waves traveling toward the station have a longer wavelength and a lower frequency than 1,000Hz. This frequency change is called a Doppler shift.

(d) As the train moves away from the station, is the frequency of the train whistle as perceived by a passenger on the train (i) *greater than* 1,000 Hz, (ii) *less than* 1,000 Hz, or (iii) *equal to* 1,000 Hz? _____

Explain your reasoning.

Answer: (iii) equal to 1,000 Hz.

The distance between the train whistle and the passenger is constant, and the number of wave crests per unit time emitted by the whistle will be the same as the number of crests per unit time arriving at the passenger's ears. The frequency perceived by the passenger is equal to 1,000 Hz.

E3-QRT04: VIBRATING GUITAR STRING AND TUNING FORK—FREQUENCY

A guitar string is strummed near a tuning fork that has a frequency of 512 Hz. Initially, the guitar and tuning fork together create a sound wave with a beat frequency of 5 Hz. The tension in the guitar string is then increased, after which the guitar and tuning fork together create a sound wave with a beat frequency of 4 Hz.

(a) Before the tension in the guitar string is increased, is the frequency of the guitar string (i) *greater than* 512 Hz, (ii) *less than* 512 Hz, or (iii) *equal to* 512 Hz? If it is not possible to determine how the guitar frequency compared to 512 Hz, state that explicitly.

Explain your reasoning.

Answer: (ii) Less than 512 Hz.
Since the beat frequency was initially 5 Hz, the absolute value of the difference in the frequency between guitar and tuning fork was initially 5 Hz. The guitar could have had a frequency of 507 Hz or of 517 Hz. When the tension in the guitar string is increased, the beat frequency decreased to 4 Hz, so the new frequency of the guitar string is either 508 Hz or 516 Hz. But the tightening of the guitar string would have produced an increase in frequency, i.e., the new frequency would be higher than the original, either 508 Hz or 518 Hz. Only the 508 Hz would give a new beat frequency of 4 Hz, so we know that the original frequency of the guitar string was 507 Hz,

(b) After the tension in the guitar string is increased, is the frequency of the guitar string (i) *greater than* 512 Hz, (ii) *less than* 512 Hz, or (iii) *equal to* 512 Hz? If it is not possible to determine how the guitar frequency compares to 512 Hz, state that explicitly.

Explain your reasoning.

Answer: (ii) less than 512 Hz.
The frequency of the guitar string after the tension is increased is 508 Hz.

E3-WWT05: SOUND LEVELS AND DISTANCE—COMPARISON

A student learns that the intensity of sound diminishes as the square of the distance from the source. He states:

"If a sound from a horn is 40 dB at a distance of 3 meters from the source, then it will be only 20 dB at a distance of 6 meters."

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 has made two mistakes. First, since the distance from the source is doubled and the intensity diminishes as the square of the distance, the sound intensity will be only one-fourth as great, not one-half. Second, the decibel scale is a logarithmic scale, not a linear scale. If sound intensity halves, the intensity level measured in decibels is reduced by about 3 dB. In this case, the intensity level at a distance of 6 meters will be about 6 dB less, or 34 dB.

E3-WWT06: SOUND WAVE VELOCITY AND FREQUENCY—DISTANCE

A student states:

"The distance between a compression and the next compression for a sound wave with a velocity of 800 ft/s and a frequency of 400 Hz is 2 feet. If the wave had a higher frequency, it would travel faster."

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: This statement is incorrect.
The speed of sound remains constant in a given medium. For a higher frequency wave, the wavelength would be shorter, but the product of wavelength and wave frequency would remain constant.

E3-SCT07: CLARINET AND SAXOPHONE PLAYING SAME NOTE—DIFFERENCE

Three students are discussing why a clarinet and saxophone playing the same note can be distinguished from one another. They state:

Anisha**:** *"I think this is due to the difference in pitch between the two."*

Blanca**:** *"If they are playing the same note that means they have the same pitch. I think the difference in the way the sound is created results in differences in the velocity of the sound waves, and our ear detects these differences."*

Cristobal**:** *"I think the real difference is that even though the frequencies are the same, the shapes of the waves are different, and our ear detects this."*

Dawn**:** *"Neither instrument is really playing a single pure tone—for example, they each are also emitting sound an octave above the note they are playing. It's the differences in these overtones that allow us to tell the difference."*

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

Anisha _____ Blanca _____ Cristobal _____ Dawn _____ None of them _____

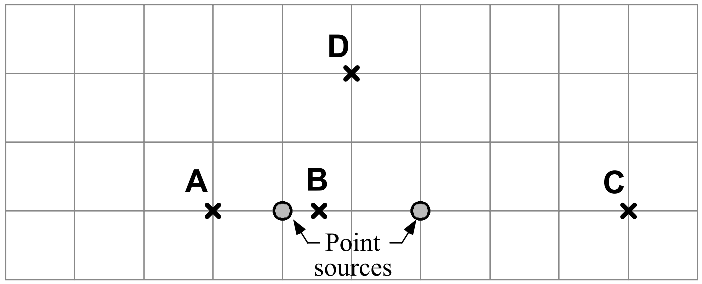
Explain your reasoning.

Both Cristobal and Dawn are correct.

The sound from musical instruments (and voices) are a mix of the lowest frequency (the note played, called the fundamental) and overtones – sounds at higher frequencies than the note played. The amplitudes and phases of the overtones are different for each instrument, and the mixture of all of the sounds emitted are what gives an instrument its characteristic sound. The mixture of sounds creates a complicated wave shape that is unique for each instrument. The velocity of each sound wave depends on the air it is traveling through, and is the same for each instrument.

E3-RT08: TWO DIFFERENT WAVE SOURCES—BEAT FREQUENCY AT VARIOUS LOCATIONS

The point source on the left is generating a 600 Hz sound wave. The point source on the right is creating a 608 Hz sound wave.



Rank the beat frequency 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 beat frequency will be the same for all four locations since the frequency of the waves does not change as they propagate away from the sources.

E3-WWT09: TWO TUNING FORKS PRODUCING BEATS—FREQUENCY

A student states:

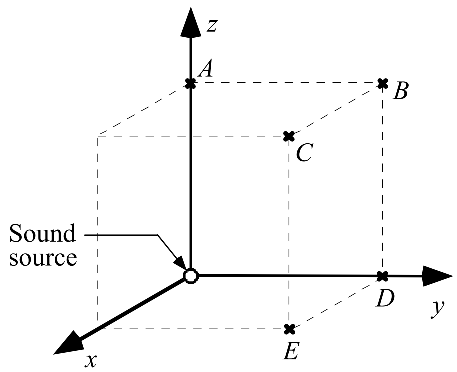
"Two tuning forks are sounded simultaneously and a beat frequency of 9 Hz is detected. If one of the tuning forks has a frequency of 480 Hz, then the other fork should have a frequency of 489 Hz."

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 may or may not be correct about the frequency.
A 9 Hz beat frequency will be heard whenever the difference in frequency between the two tuning forks is 9 Hz.
So there are two possibilities for the frequency of the second tuning fork, 471 Hz or 489 Hz.

E3-CT10: THREE-DIMENSIONAL LOCATIONS NEAR A SOUND SOURCE—LOUDNESS

A point sound source emits sound waves in every direction. The point source is located at the origin, and points *A*–*E* are located on the corners of an imaginary cube, as shown.

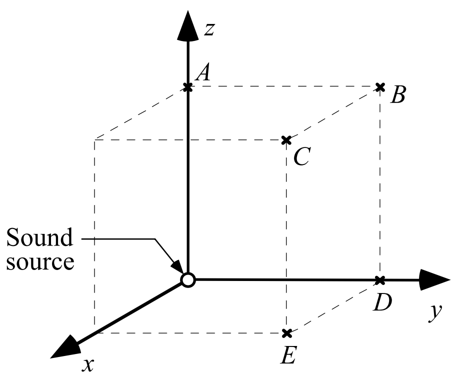


$I_B =$	I_A
$I_C =$	I_A
$I_D =$	I_A
$I_E =$	I_A

If the intensity (loudness) at the point labeled *A* is I_A, in the table to the right of the figure express the intensity at the other labeled points in terms of I_A.

Explain your reasoning.

Answer:



$I_B =$	$\frac{1}{2} I_A$
$I_C =$	$\frac{1}{3} I_A$
$I_D =$	$1\ I_A$
$I_E =$	$\frac{1}{2} I_A$

The intensity of sound is inversely proportional to the square of the distance to the sound source. Point D is the same distance away from the point source as point A, so they will have the same sound intensity. Points B and E are the square root of 2 times further from the source as point A, so the sound intensity will be twice as small as at point A. Point C is the square root of 3 times further from the source as point A, so the sound intensity will be three times as small as at point A.

E3-WWT11: TROMBONE WITH SOAP BUBBLE SOLUTION—TIME TO BURST BUBBLE

A student dips the bell of her trombone into a soap bubble, and makes a prediction about the soap film covering the bell:

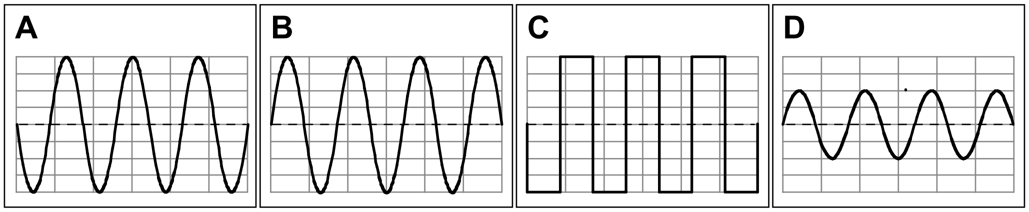
"The speed of sound is about 340 meters per second. The air from the trombone will push the film outward pretty quickly. It will only take a fraction of a second for the film to burst after I start playing."

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 is incorrect.
The speed of sound is the speed at which the longitudinal vibration of the air spreads outward, not the speed of the air molecules moving through the air. The soap bubble will slowly inflate as the student plays, and there won't be much effect on the sound of the trombone.

E3-RT12: SOUND WAVES WITH SAME WAVELENGTH—WAVE SPEED

Sound waves, all with the same wavelength, are traveling in the same direction through a pool of water. The graphs show the amplitude of the waves as a function of their position. All graphs have the same scale.



Rank these waves on their speed in the water.

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

Explain your reasoning.

Answer: All the same.
The speed of a wave through a medium is determined by the properties of the medium (in this case, the water in the pool), so these all have the same speed since they are all traveling through the same water.

E3-CT13: DROPPED SPEAKER—TONE IN WATER

A waterproof siren is emitting sound at a single frequency. The siren is dropped from air into water.

Is the frequency of the waves produced by the siren in the water (i) *greater than*, (ii) *less than*, or (iii) *equal to* the frequency of the waves produced by the siren in the air? _____

Explain your reasoning.

Answer (iii) equal to.

The frequency of the sound depends on the siren, and will stay constant in air or in water. The sound waves in water will have the same frequency as in air, but the wave speed of the sound and the wavelength of the sound will change.

E3-CT14: DROPPED SIREN—WAVELENGTH IN WATER

A waterproof siren is emitting sound at a single frequency. The siren is dropped from air into water.

Is the wavelength of the waves produced by the siren in the water (i) *greater than*, (ii) *less than*, or (iii) *equal to* the wavelength of the waves produced by the siren in the air? _____

Explain your reasoning.

Answer (i) greater than.

When a wave goes from one medium into another the frequency of the waves remains the same, but the wavelength changes. The speed of the sound waves in water is much larger than in air, and the frequency is the same. Since the wavelength times the frequency is equal to the wave speed, an increase in wave speed at a constant frequency corresponds to an increase in wavelength.

E3-WWT15: PIPE ORGAN—FUNDAMENTAL FREQUENCY

After reading that the speed of sound increases as the temperature increases, a student states:

"That's why an instrument needs to be retuned when it gets warm. From the wave equation, when the velocity increases, the frequency also has to increase, since the frequency is proportional to the velocity. Without retuning, the instrument is going to sound sharp."

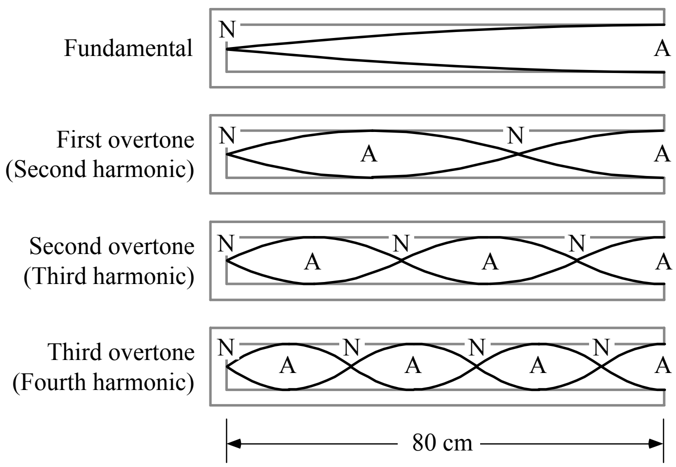
What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

Answer: The student's contention is incorrect.

The wave equation states that the velocity of a wave is proportional to the product of the frequency and the wavelength, so the frequency is proportional to the wave speed only if the wavelength is held constant. For a musical instrument, the frequency is determined by the mechanical properties of the vibrating parts of the instrument. If these stay the same (which is not a good assumption, since these depend on temperature as well), then the frequency of the sound emitted stays the same.

E3-CRT16: Pipe Closed at One End—Sound Frequency, Wavelength, and Velocity

A pipe of length 80 cm is closed at one end and open at the other. Sound is created in the pipe at four different frequencies. The diagram shows the location of nodes (N) and antinodes (A) in the pipe for the four different modes. The table to the right has an entry for wave speed of the second overtone.



Frequency	Wavelength	Wave speed
106 Hz	320 cm	340 m/s
318 Hz	107 cm	340 m/s
531 Hz	64 cm	340 m/s
744 Hz	45.7 cm	340 m/s

Complete the table of frequencies, wavelengths, and wave speeds for the four modes.

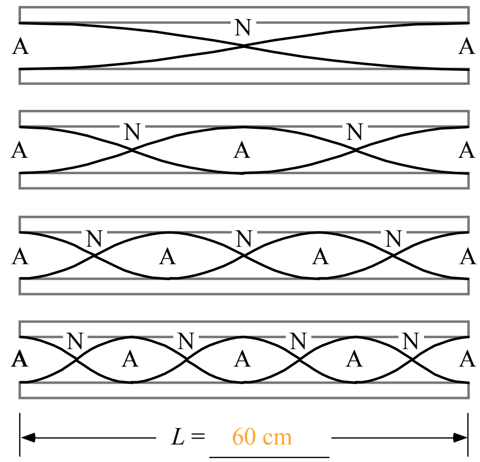
Explain your reasoning.

Answer: The speed of sound in air will be the same for all modes (340 m/s), as it depends only on the temperature of the air and the humidity. The wavelength of a wave is the distance that it takes for the wave to repeat itself. From a node to an adjacent antinode is one-quarter of a wavelength, so a full wavelength is the four times the distance from a node to an adjacent antinode. For the fundamental, this is four times the length of the pipe, or 320 cm. For the first overtone, three quarters of a complete wave fit along the pipe, so the wavelength is four thirds the length of the pipe, or 107 cm. For the second overtone, a complete wave fits in four-fifths of the pipe, so the wavelength is four-fifths of the length of the pipe, or 64 cm. For the third overtone, a complete wave fits in four-sevenths of the pipe, so the wavelength is four-sevenths of the length of the pipe, or 45.7 cm. The wave equation will determine the frequency of the wave, $f = v/\lambda$. (340 m/s = 34,000 cm/s)

E3-CRT17: PIPE OPEN AT BOTH ENDS—SOUND FREQUENCY, WAVELENGTH, AND VELOCITY

A pipe of length L is open at both ends. Sound is created in the pipe at four different frequencies. The diagram shows the location of nodes (N) and antinodes (A) in the pipe for the four different modes. The table to the right has an entry for wave speed of the first overtone, and an entry for the wavelength of the second overtone.

Use the given information to find the length L of the pipe. Then complete the table of frequencies, wavelengths, and wave speeds for the four modes.



	Frequency	Wavelength	Wave speed
Fundamental	283 Hz	120 cm	340 m/s
First overtone (Second harmonic)	567 Hz	60 cm	340 m/s
Second overtone (Third harmonic)	850 Hz	40 cm	340 m/s
Third overtone (Fourth harmonic)	1130 Hz	30 cm	340 m/s

Explain your reasoning.

Answer: The speed of sound in air will be the same for all modes (340 m/s), as it depends only on the temperature of the air and the humidity. The wavelength of a wave is the distance that it takes for the wave to repeat itself. From a node to an adjacent antinode is one-quarter of a wavelength, so a full wavelength is the four times the distance from a node to an adjacent antinode. For the second overtone, this distance is 40 cm and is also two-thirds the length of the pipe. The length of the pipe is therefore three-halves of 40cm, or 60 cm. For the fundamental this is one-half of a wavelength, so the fundamental wavelength is twice the pipe length or 120 cm. For the first overtone the wavelength equals the pipe length, 60 cm. For the third overtone, a complete wave fits into one-half the length of the pipe, so the wavelength is 30 cm. The wave equation will determine the frequency of the wave, $f = v/\lambda$. (340 m/s = 34,000 cm/s)

F MODERN PHYSICS

F1-SCT01: RADIATION FROM HEATED OBJECTS—COLOR EMITTED

A 1-kg ceramic cube and a 1-kg iron cube both have holes drilled into their sides. When the cubes are heated to the same high temperature, light is emitted through the holes from the interior of the cubes. Three students make the following contentions about the color of the emitted light:

Arkady: *"The color of the light depends on what color the cubes were before they were heated. Most ceramic is white to start with, and iron is dull gray. After they are heated, the ceramic will glow with white light, and the iron will be a dull red like an electric stove element."*

Brigid: *"It takes less energy to heat a metal to a high temperature than it does to heat an equal amount of ceramic to the same temperature. Since less energy was put into the metal, it will glow less brightly and will be a duller red than the ceramic, which will be whiter in color."*

Chen: *"If the cubes are at the same temperature, the molecules in the interior have the same average kinetic energies, and they will emit the same color of light."*

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

Arkady _____ Brigid _____ Chen _____ None of them _____

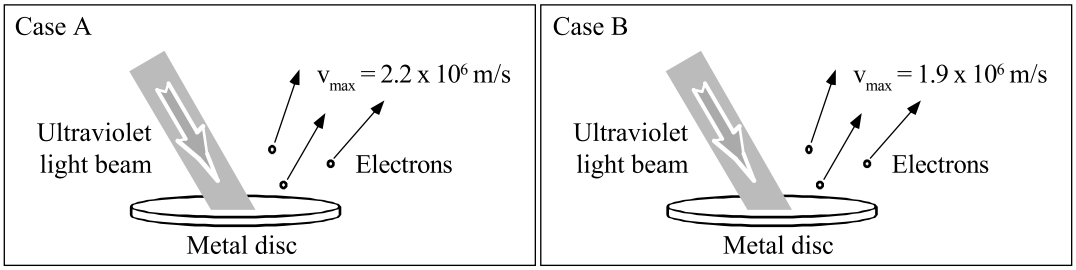
Explain your reasoning.

Answer: Chen is correct.

The color of light from the interior of the cube depends on the kinetic energy of the vibrating molecules of the walls of the hole. If the temperatures of the cubes are the same, then the energy distribution of the molecules is the same for the two materials, and the light emitted by these molecules as they vibrate has the same energy spectrum and the same color. The color of this 'blackbody radiation' or cavity radiation does not depend on the material.

F1-CT02: ULTRAVIOLET LIGHT ON METAL DISCS—WORK FUNCTION

A beam of ultraviolet light shines on a metal disc, causing electrons to be emitted from the disc. The two cases are identical, except that the metals are different and the emitted electrons have a higher maximum speed in Case A than in Case B.



Is the work function of the metal (i) *greater in Case A*, (ii) *greater in Case B*, or (iii) *the same in both cases*? _____

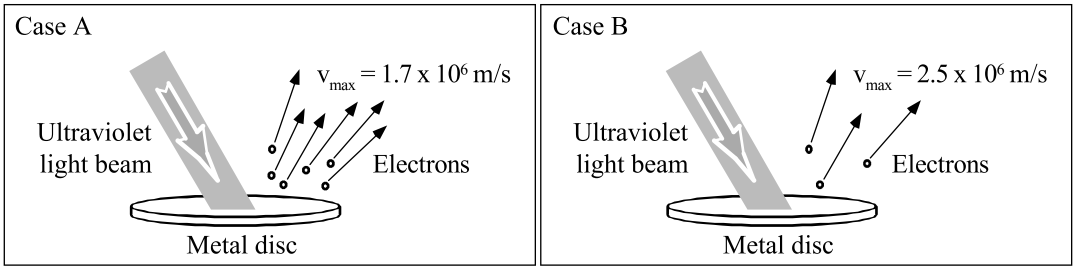
Explain your reasoning.

Answer: (ii) Greater in case B.

The energy of the photons in the ultraviolet beam is the same in both cases. When a single photon interacts with the metal, some of the photon energy can be used to free an electron from the metal. The work function of the metal is the amount of energy required to do this. The energy of the photon beyond the energy required to free the electron is converted into kinetic energy. If more energy is required to free the electron (a larger work function), then less energy will be available to be transformed into kinetic energy. Since the maximum speed of the electrons is greater in case A, then the kinetic energy of the electrons is greater in case A, since the kinetic energy is proportional to the square of the speed. The work function must be smaller for the metal in case A.

F1-CT03: TWO ILLUMINATED METALS—WORK FUNCTION

A beam of ultraviolet light shines on a metal disc, causing electrons to be emitted from the disc. The wavelength of the beam is the same in both cases, but the intensities are different. More electrons are ejected from metal A than from metal B, but the electrons ejected from metal B have a higher maximum speed.



Is the work function of the metal (i) *greater in Case A*, (ii) *greater in Case B*, or (iii) *the same in both cases*? _____

Explain your reasoning.

Answer: (i) Greater in case A.
A has the larger work function since the electrons ejected from A have a lower maximum kinetic energy. A larger work function means more energy is required to "kick" the electron out of the metal, so the electrons that are emitted have less kinetic energy. The difference in the number of the electrons is caused by a difference in the intensity of the beams.

F1-SCT04: PHOTOELECTRIC EFFECT INVESTIGATIONS—MORE ELECTRONS

In two experiments, electromagnetic waves are used to eject electrons from a metal. The electromagnetic waves have a longer wavelength in experiment A than in experiment B. More electrons were ejected from metal B than from metal A. Three students are discussing the experiments:

Arturo: *"Since more electrons were ejected from metal B, that means the intensity of the light used in that investigation was higher."*

Bonifacio: *"I don't think we can say that for sure. Since the wavelength used in B was shorter, those waves would have more energy, and they could eject more electrons even though the intensity of the wave was lower."*

Carla: *"I think that all we can conclude is that the work function for metal B is smaller than the work function of metal A, and that is why more electrons were ejected from B."*

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

Arturo _____ Bonifacio _____ Carla _____ None of them _____

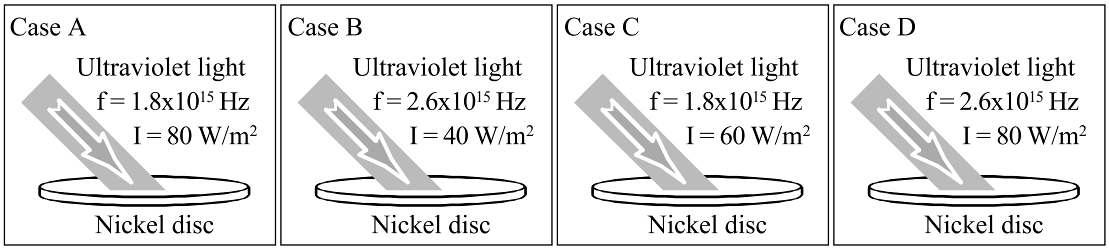
Explain your reasoning.

Answer: Arturo is correct.

The intensity is a measure of the number of photons in the beam per unit time, and each photon ejects a maximum of one electron, so the number of electrons emitted depends on the intensity of the beam (as long as the wavelength is short enough to eject electrons). The beam must have been more intense in experiment B.

F1-RT05: ULTRAVIOLET LIGHT INCIDENT ON NICKEL—NUMBER OF EJECTED ELECTRONS

A nickel disc emits electrons when it is illuminated with a beam of ultraviolet light. The frequency of the light and the intensity of the light beam are given for each case.



Rank the number of electrons ejected from the nickel per unit time.

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

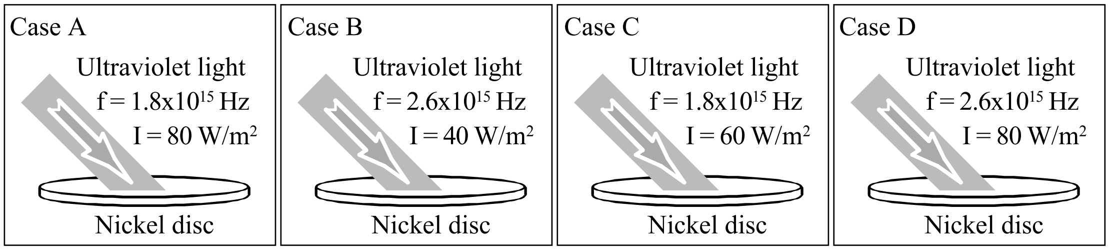
Explain your reasoning.

Answer: A = D > C > B.

The number of electrons ejected depends on the intensity of the ultraviolet beam. All of the waves have sufficient energy to kick electrons out of nickel, so a variation in frequency will only change the maximum kinetic energy of the ejected electrons.

F1-RT06: Ultraviolet Light Incident on Nickel—Ejected Electron Speed

A nickel disc emits electrons when it is illuminated with a beam of ultraviolet light. The frequency of the light and the intensity of the light beam are given for each case.



Rank the maximum speed of the electrons ejected from nickel.

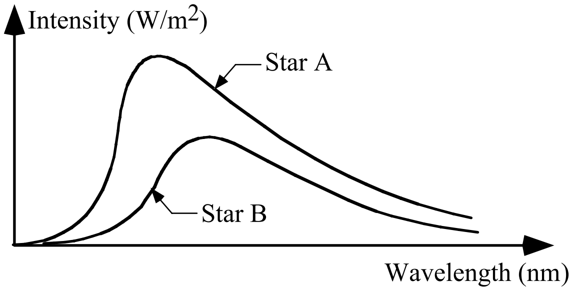
1 Greatest ____ 2 ____ 3 ____ 4 Least ____ OR All the same ☐ All zero ☐ Cannot determine ☐

Explain your reasoning.

Answer: B = D > A = C.
All of the metal discs are nickel, so they all have the same work function. The maximum speed of the ejected electrons depends on the energy of the photons in the beam in excess of the work function. The energy of the photons in the beam is proportional to the frequency of the ultraviolet light.

F1-CT07: BLACKBODY CURVES OF STARS—SURFACE TEMPERATURE

A graph of intensity of emitted radiation as a function of wavelength (a blackbody curve) is shown for two stars.



Is the surface temperature of the star (ai) *greater for star A*, (ii) *greater for star B*, or (iii) *the same for both stars*? _____

Explain your reasoning.

Answer: (i) Greater for A.

Higher temperatures on the star surface correspond to higher energies of the atoms on the star surface and to higher frequencies of emitted light. The peak frequency of emitted light is higher for a higher temperature, and (since wavelength is inversely proportional to frequency) the wavelength of peak emission intensity is lower for higher temperature stars.

F1-WWT08: HIGH-FREQUENCY X-RAYS—ENERGETIC PHOTONS

A student contends:

"Higher frequency X-rays contain more energetic photons than lower frequency electromagnetic waves because higher frequency waves have more energy."

What, if anything, is wrong with this student's contention? If something is wrong, identify the problem and explain how to correct it. If the student is correct, explain the physics supporting his/her statement.

Answer: The student is correct.
For electromagnetic waves the photon energy is proportional to the frequency of the waves, so higher frequency waves have more energetic photons.

F1-CT09: TWO MOVING PROTONS—DEBROGLIE WAVELENGTH

Two protons are moving through a vacuum. Proton A has a speed of 4×10^4 m/s, and proton B has a speed of 9×10^5 m/s.

Will the deBroglie wavelength for proton A be (a) *greater than*, (b) *less than*, or (c) *equal to* the deBroglie wavelength of proton B? _____

Explain your reasoning.

Answer: A has the longer deBroglie wavelength.

The protons have the same mass but proton B has a higher speed, so the momentum of proton B is greater than the momentum of proton A. The deBroglie wavelength of a particle is inversely proportional to the momentum, so the wavelength is greater for proton A.

F1-SCT10: HEISENBERG UNCERTAINTY PRINCIPLE—POSITION AND SPEED

Three students talking about the Heisenberg Uncertainty Principle make the following contentions:

Arno: *"The Heisenberg Uncertainty Principle says that you can't measure both the position and speed of an electron at the same time."*

Bobbie: *"I don't think it means you can't measure them at the same time. It just means that if you gain precision in measuring one quantity, you lose precision in measuring the other quantity for the same point in time."*

Carissa: *"I think it is possible to become more precise in measuring both quantities, but only up to a point. Once the product of position and momentum are equal to h over four pi, one quantity has to go up when the other goes down."*

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

Arno _____ Bobbie _____ Carissa _____ None of them _____

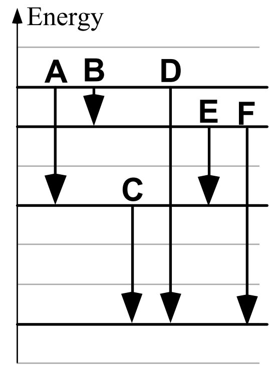
Explain your reasoning.

Answer: None of the students is completely correct.

Bobbie is correct if the precision of the two simultaneous measurements are already small enough that their product equals h / 4π. Carissa is correct in that if the product is not already equal to h / 4π, then it is possible to improve the precision of both. However, it is the product of the uncertainties of these measurements that must be greater than h / 4π, not the product of the measurements themselves.

F2-RT11: ENERGY LEVEL TRANSITIONS—EMISSION FREQUENCY

Shown are four energy levels for an atom along with six possible transitions between pairs of energy levels. Adjacent horizontal lines (light gray or dark) are separated by the same energy difference.



Rank the frequency of the emitted photons for the labeled transitions.

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

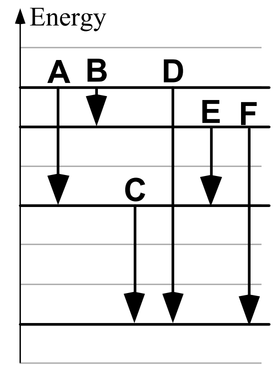
Explain your reasoning.

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

The frequency is proportional to energy difference between levels, or the length of the arrow representing the transition.

F2-RT12: ENERGY LEVEL TRANSITIONS—EMISSION WAVELENGTH

Shown are four energy levels for an atom along with six possible transitions between pairs of energy levels. Adjacent horizontal lines (light gray or dark) are separated by the same energy difference.



Rank the wavelength of the emitted photons for the labeled transitions.

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

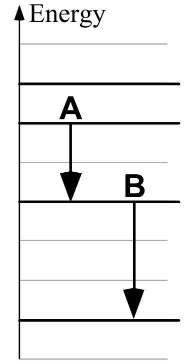
Explain your reasoning.

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

The frequency is proportional to energy difference between levels, or the length of the arrow representing the transition. Since the wavelength is inversely proportional to the frequency, smaller energy transitions correspond to longer wavelengths.

F2-WWT13: ENERGY LEVEL DIAGRAM—WAVELENGTH

A student comparing two transitions on an energy level diagram contends:



"The wavelength of light emitted in transition A will be shorter than the wavelength of light emitted in transition B, because transition A starts from a higher energy level."

What, if anything, is wrong with this student's contention? If something is wrong, identify the problem and explain how to correct it. If the student is correct, explain the physics supporting his/her statement.

Answer: The student's contention is incorrect.

Transition B will produce a shorter wavelength than transition A. Since the atom loses more energy in transition B than in transition A (the loss in energy from the initial level to the final level is greater), the energy of the photon emitted is greater for transition B than for transition A. Higher energy photons have shorter wavelengths, so the wavelength of the emitted photon is greater for transition A than for transition B. The energy of the initial or final state of the electron doesn't determine the photon wavelength, only the difference between the energies of the two levels.

F3-CT14: CARBON ISOTOPES— PROTONS, NEUTRONS, AND ELECTRONS

A carbon-14 atom has 6 electrons, 6 protons, and 8 neutrons.

(a) Will an atom of carbon-11 have (i) *more electrons*, (ii) *fewer electrons*, (iii) or *the same number of electrons* as an atom of carbon-14? _____

Explain your reasoning.

Answer: (iii) The same number of electrons.

Isotopes are atoms of the same element, so they must have the same number of protons since they have to have the same atomic number. They must have the same number of electrons as protons since they are electrically neutral.

(b) Will an atom of carbon-11 have (i) *more protons*, (ii) *fewer protons*, or (iii) *the same number of protons* as an atom of carbon-14? _____

Explain your reasoning.

Answer: (iii) The same number of protons.

Isotopes are atoms of the same element, so they must have the same number of protons since they have to have the same atomic number.

(c) Will an atom of carbon-11 have (i) *more neutrons*, (ii) *fewer neutrons*, or (iii) *the same number of neutrons* as an atom of carbon-14? _____

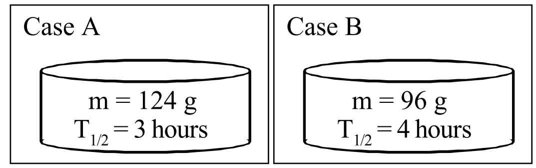
Explain your reasoning.

Answer: (ii) Fewer neutrons.

The mass number (14 for carbon-14, 11 for carbon-11) is the number of nucleons (neutrons + protons) in the nucleus. Since both carbon-14 and carbon-11 have 6 protons (since they are both carbon!), carbon-14 must have 8 neutrons, and carbon 11 must have 5 neutrons.

F3-CT15: TWO RADIOACTIVE SAMPLES—MASS REMAINING

The masses of samples of radioactive elements are measured and then measured again 12 hours later. The initial mass for two samples of different elements are given, along with the half-life of each element.



After 12 hours, will the mass of the sample in Case A be (i) *greater than*, (ii) *less than*, or (iii) *equal to* the mass of the sample in Case B? _____

Explain your reasoning.

Answer: (ii) Less than.

Each sample loses half of its mass for every half-life. After 3 hours there will be 62 grams of sample A; after 6 hours 31 grams; after 9 hours 15.5 grams, and after 12 hours 7.75 grams. After 4 hours there will be 48 grams of sample B; after 8 hours 24 grams; and after 12 hours 12 grams.