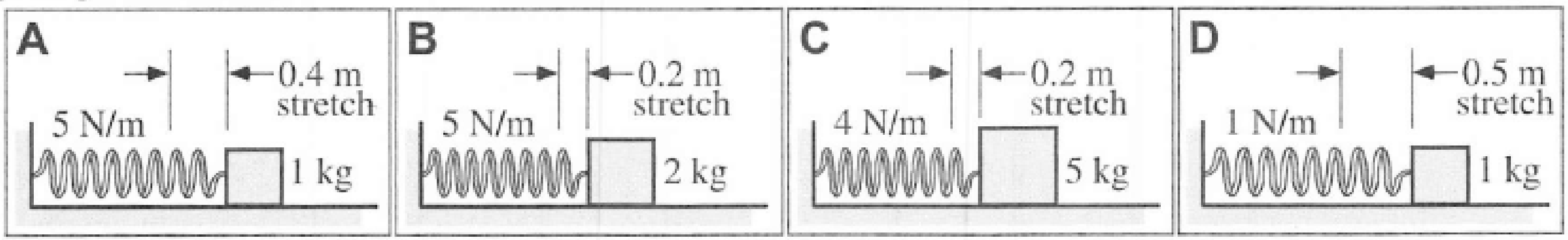
B7-RT01: MASS ON HORIZONTAL SPRING SYSTEMS I—OSCILLATION FREQUENCY

A block rests on a frictionless surface and is attached to the end of a spring. The other end of the spring is attached to a wall. Four block–spring systems are considered. The springs are stretched to the right by the distances shown in the figures and then released from rest. The blocks oscillate back and forth. The mass and force constant of the spring are given for each case.



Rank the frequency of the oscillatory motion of the block.

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

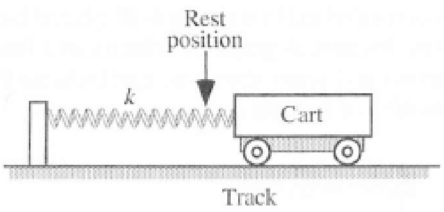
Explain your reasoning.

Answer: A > B > D > C.

Factors that affect the frequency for this system are the mass of the block and the stiffness of the spring, characterized by the spring constant. The frequency is independent of the amplitude, or maximum displacement. The frequency is proportional to the square root of the ratio of the spring constant k to the mass m, giving the specified ranking.

B7-QRT05: Position-Time Graph of a Cart Attached to a Spring—Mass and Period

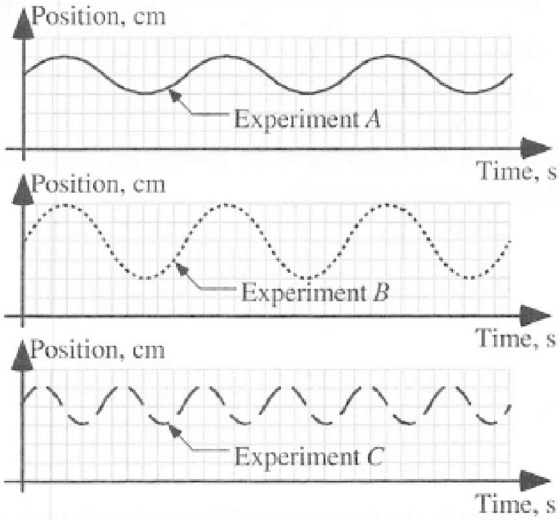
A frictionless cart of mass m is attached to a spring with spring constant k. When the cart is displaced from its rest position and released, it oscillates with a period τ that is given by



$$\tau = 2\pi\sqrt{m/k}$$

The graph of the position of this cart as a function of time is labeled Experiment A. Graphs for two other experiments that use different masses are shown below this. The same spring is used in all three experiments.

(a) Compared to Experiment A, in Experiment B the cart has



(i) *twice* as much mass.

(ii) *four times* as much mass.

(iii) *one-half* the mass.

(iv) *one-fourth* the mass.

(v) *the same* mass.

Explain your reasoning.

(b) Compared to Experiment A, in Experiment C the cart has

(i) *twice* as much mass.

(ii) *four times* as much mass.

(iii) *one-half* the mass.

(iv) *one-fourth* the mass.

(v) *the same* mass.

Explain your reasoning.

(a) Compared to Experiment *A*, in Experiment *B* the cart has

(i) *twice* as much mass.

(ii) *four times* as much mass.

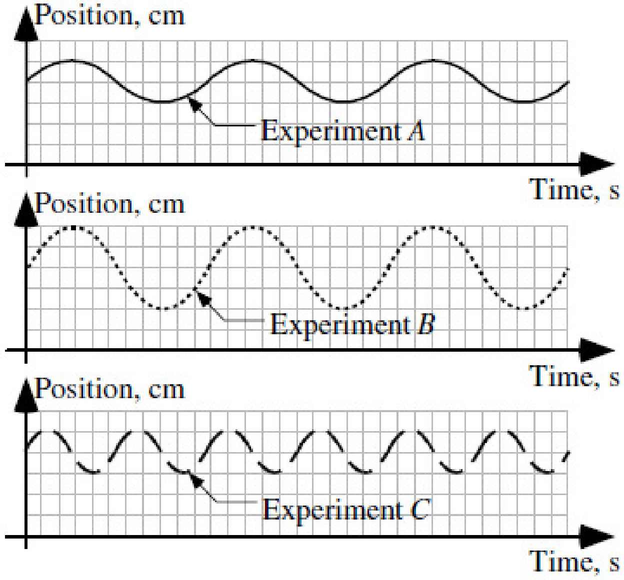
(iii) *one-half* the mass.

(iv) *one-fourth* the mass.

(v) *the same* mass.

Explain your reasoning.

Answer: (v) The cart has the same mass. The periods of the systems in the two experiments are the same, so the masses have to be the same also.



(b) Compared to Experiment *A*, in Experiment *C* the cart has

(i) *twice* as much mass.

(ii) *four times* as much mass.

(iii) *one-half* the mass.

(iv) *one-fourth* the mass.

(v) *the same* mass.

Explain your reasoning.

Answer: (iv) The cart has one-fourth the mass. The period of experiment C is half that of experiment A, so the mass is less for experiment C. Since the period is proportional to the square root of the mass, the mass in C has to be one-fourth that of A.

(c) Suppose that in a fourth experiment (Experiment *D*), the mass used in Experiment *A* was doubled and the spring was replaced with a spring with spring constant 2*k*. The period in Experiment *D* would be

(i) *the same* as the period in Experiment *A*.

(ii) *double* the period in Experiment *A*.

(iii) *four times* the period in Experiment *A*.

(iv) *one-half* the period in Experiment *A*.

(v) *one-fourth* the period in Experiment *A*.

Explain your reasoning.

(c) Suppose that in a fourth experiment (Experiment *D*), the mass used in Experiment *A* was doubled and the spring was replaced with a spring with spring constant 2*k*. The period in Experiment *D* would be

(i) *the same* as the period in Experiment *A*.

(ii) *double* the period in Experiment *A*.

(iii) *four times* the period in Experiment *A*.

(iv) *one-half* the period in Experiment *A*.

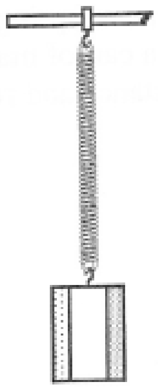
(v) *one-fourth* the period in Experiment *A*.

Explain your reasoning.

Answer: (i) The period would be the same in experiment D as it was in experiment A. Since the period is determined by the square root of the mass dievided by the spring constant, doubling both will not change the period.

B7-SCT07: Mass on a Vertical Spring—Acceleration

A mass is oscillating up and down at the end of a spring. Three students are discussing the acceleration of the mass:



Aileen: *"I think the acceleration of the mass will be largest when it is at the end of its oscillations turning around. That's where the spring is stretched the most."*

Brigitte: *"No, I don't see how that can be. Its velocity is zero at that point, so its acceleration has to be zero also."*

Chandra: *"I disagree. The acceleration is largest when the mass is halfway between the middle and the end because that is where its speed is changing the most."*

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

Aileen _____ Brigitte _____ Chandra _____ None of them_____

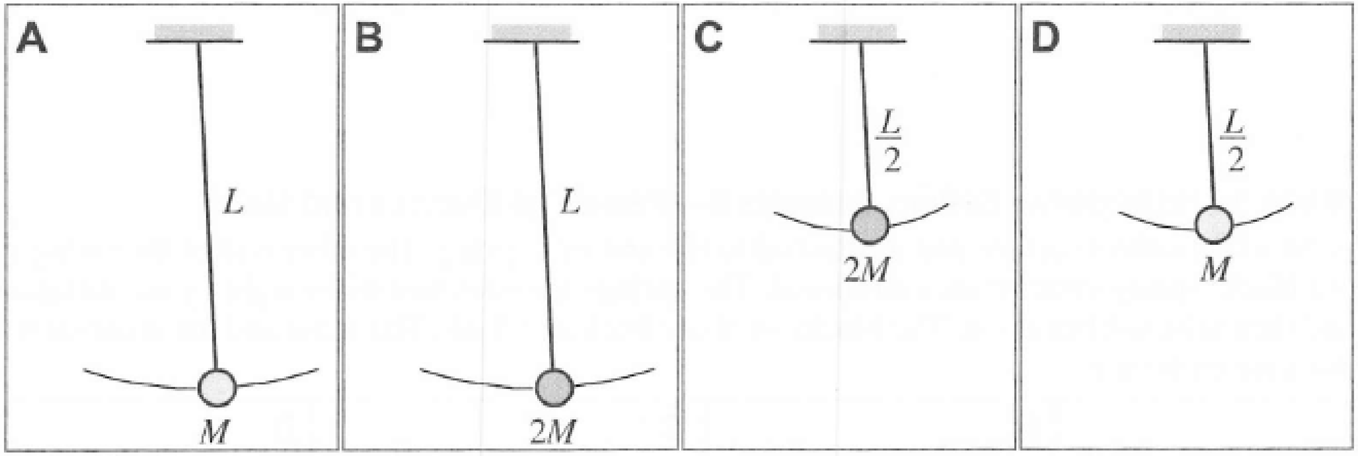
Explain your reasoning.

Answer: Aileen is correct.

Since maximum displacement is the point where the spring is stretched, or compressed, the most the force exerted by the spring has to be largest there.

B7-RT02: Swinging Simple Pendula—Oscillation Frequency

The simple pendulum shown in Case A consists of a mass M attached to a massless string of length L. If the mass is pulled to one side a small distance and released, it will swing back and forth. Cases B, C, and D are variations of this system.



Rank the oscillation frequency of the masses.

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

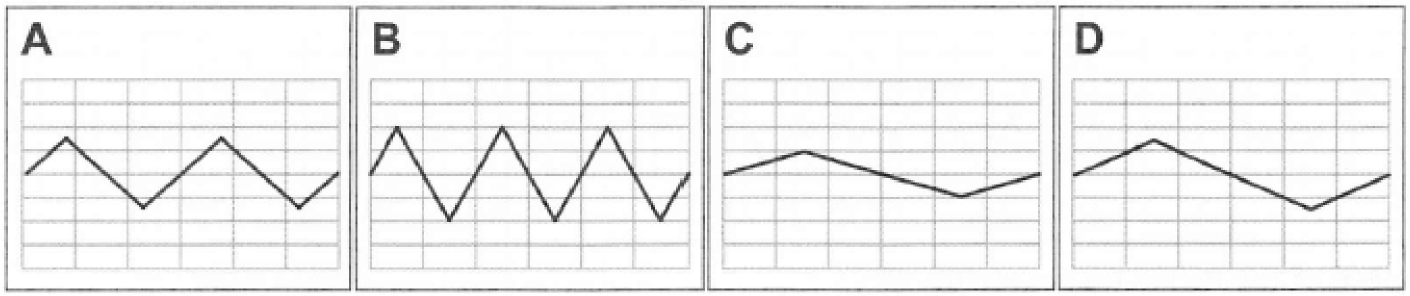
Explain your reasoning.

Answer: C = D > A = B.

The frequency is the inverse of the period or time for one complete swing. So the higher the frequency the smaller the time. The period is independent of the mass of the bob and depends only on the length.

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.

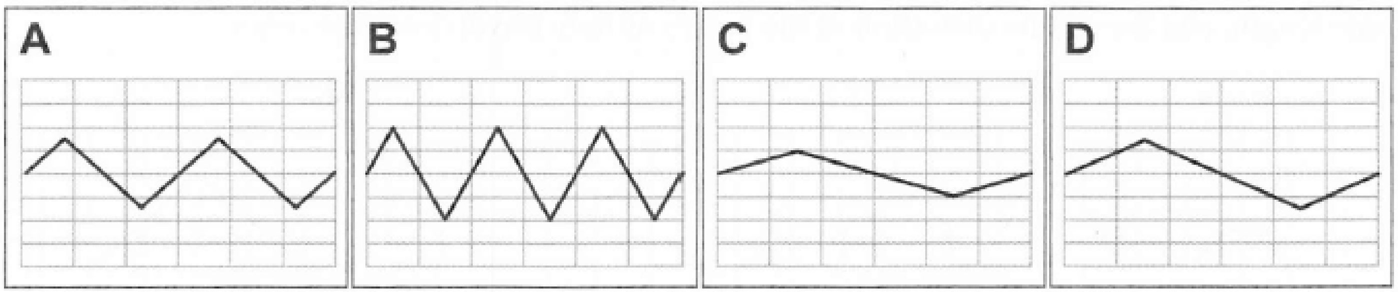
Explain your reasoning.

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.

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

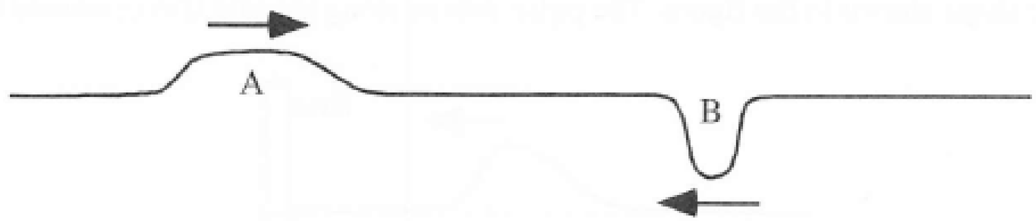
Explain your reasoning.

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-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.

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.

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."

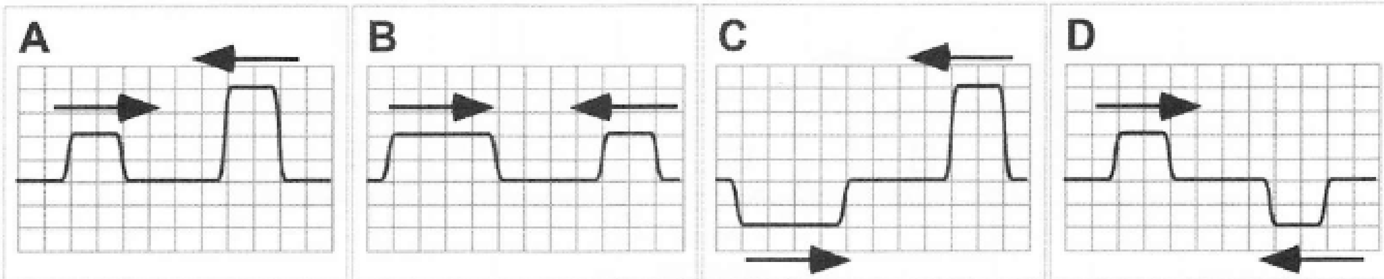
What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

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-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.

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

Explain your reasoning.

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.

E3-WWT09: TWO TUNING FORKS PRODUCING BEATS—FREQUENCY

A student states:

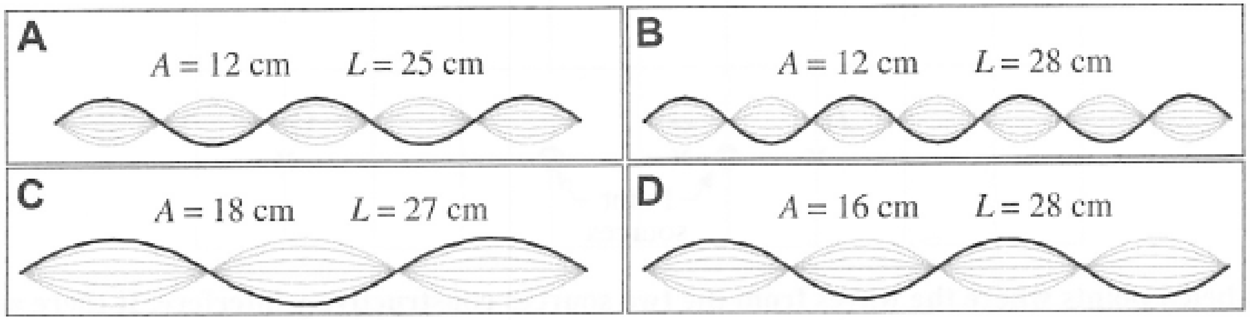
"Two tuning forks are sounded simultaneously and a beat frequency of 9 Hz is detected. If one of the tuning forks has a frequency of 480 Hz, then the other fork should have a frequency of 489 Hz."

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.

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

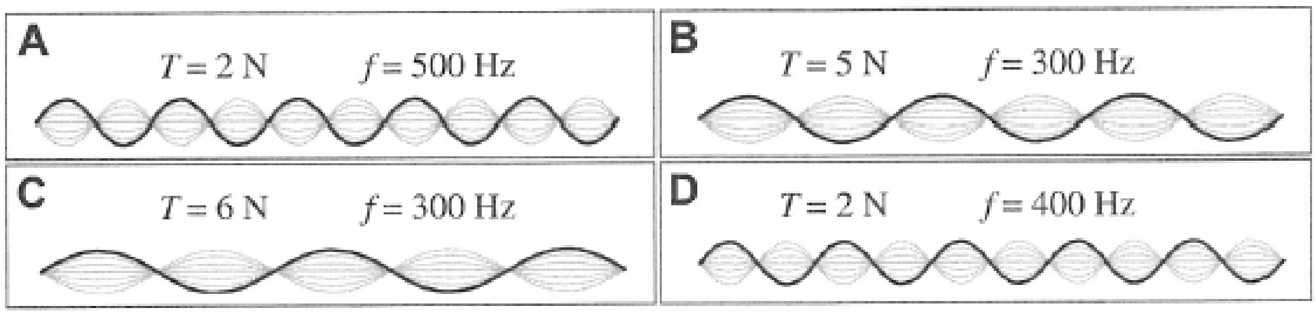
Explain your reasoning.

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-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.

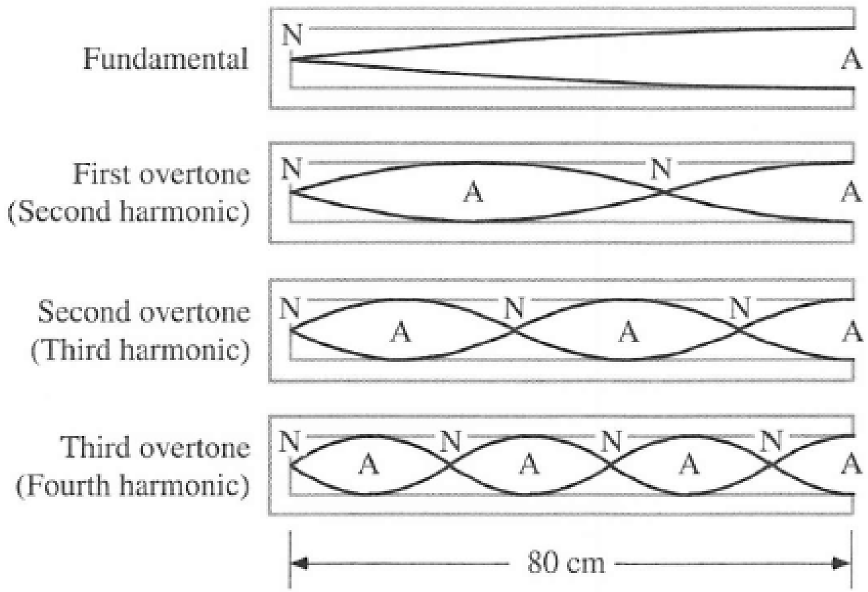
1 Greatest	2	3	4 Least	OR	All the same	All zero	Cannot determine

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).

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
		340 m/s

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

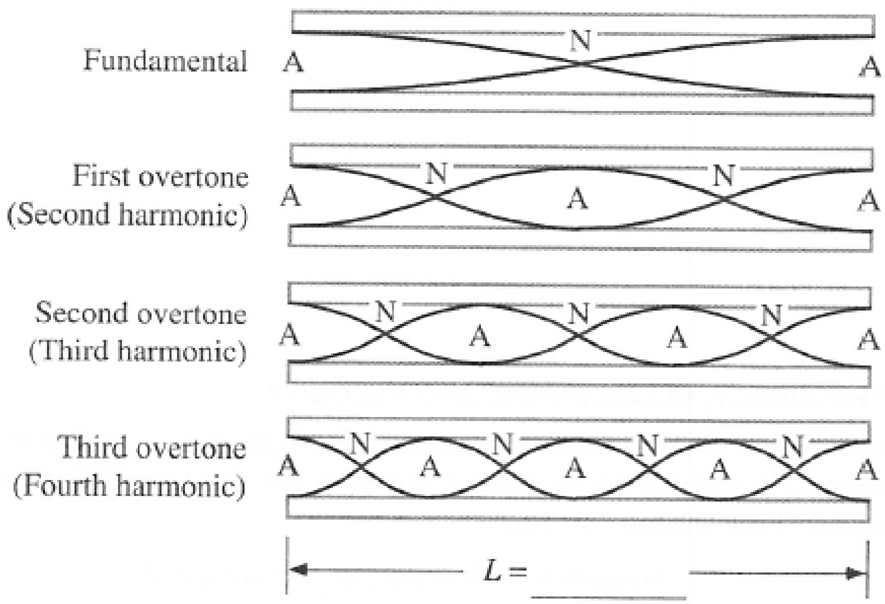
Explain your reasoning.

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
		340 m/s
	40 cm	

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)

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?

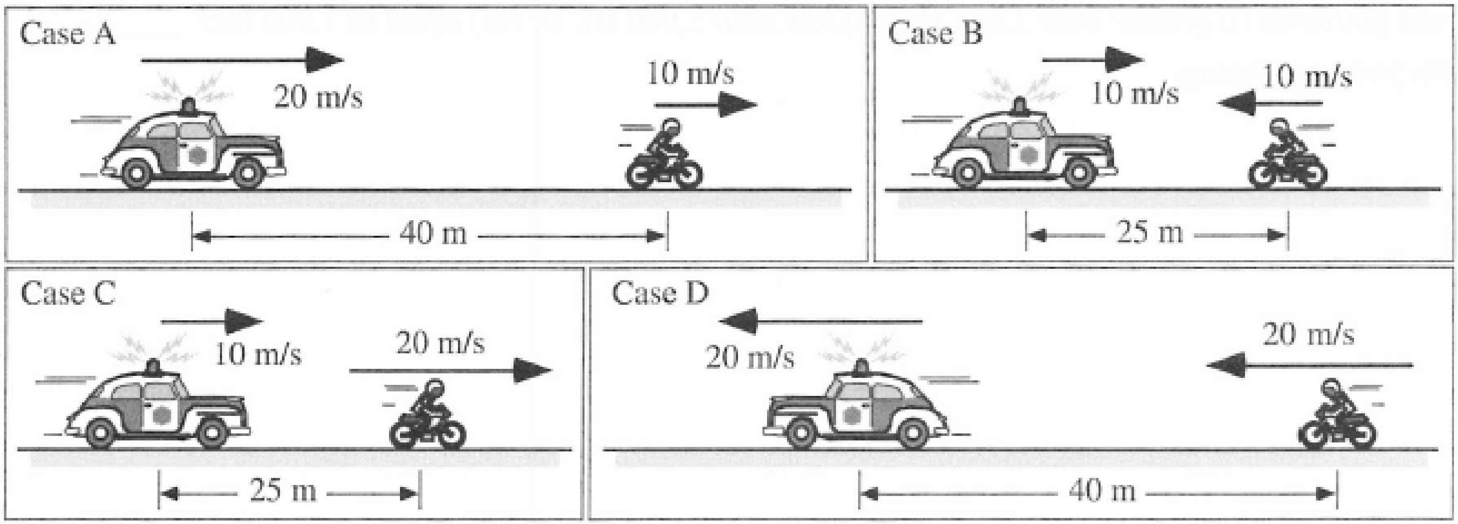
Anisha _____ Blanca _____ Cristobal _____ Dawn _____ None of them _____

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-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.