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1. [5 pts] A particle undergoes simple harmonic motion with an amplitude $A = 0.10$ m and period $T = 2.0$ s. What is the maximum speed of the particle?

   A) 0.050 m/s

   B) 0.080 m

   C) 0.10 m/s

   D) 0.16 m/s

   E) 0.31 m/s

   The maximum speed of a SHM oscillator is given as: $v_{max} = A\omega$.

   $$v_{max} = A\omega = A\frac{2\pi}{T} = (0.10\text{ m})\left(\frac{2\pi}{2.0\text{ s}}\right) = 0.31\text{ m/s}$$

2. [5 pts] A mass on a spring has an angular frequency of oscillation $\omega_0 = 5.0\text{ rad/s}$. The mass is then submerged in a viscous oil, and the new angular frequency of oscillations is now $\omega = 4.0\text{ rad/s}$. What is the time constant τ for this system?

   A) 0.17 s

   B) 0.33 s

   C) 0.66 s

   D) 1.0 s

   E) Not enough information

   $$\omega = \sqrt{\omega_0^2 - \frac{b^2}{4m^2}} \text{ and } \tau = \frac{m}{b}$$

   $$\omega = \sqrt{\omega_0^2 - \frac{b^2}{4(\tau b)^2}} = \sqrt{\omega_0^2 - \frac{1}{4\tau^2}}$$

   $$\omega^2 = \omega_0^2 - \frac{1}{4\tau^2}$$

   $$\tau = \sqrt{\frac{1}{4(\omega_0^2 - \omega^2)}} = \sqrt{\frac{1}{4((5\text{ rad/s})^2 - (4\text{ rad/s})^2)}} = 0.17\text{ s}$$

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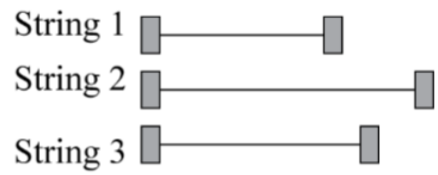
3. [5 pts] Three cylindrical strings are shown above with lengths L_1, L_2, and L_3, where $L_1 < L_3 < L_2$. The material in each string is different, such that the mass of each string is the same $(m_1 = m_2 = m_3)$. Is it possible to adjust the tension to make the wave speeds the same on each string?



A) Yes, set $T_1 = T_2 = T_3$

B) Yes, set $\frac{T_1}{L_1} = \frac{T_2}{L_2} = \frac{T_3}{L_3}$

C) Yes, set $T_1 L_1 = T_2 L_2 = T_3 L_3$

D) Yes, the wave speeds will be the same no matter what the tension is.

E) No, this is not possible.

The wave speed on a string is given as:

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{T}{\frac{m}{L}}} = \sqrt{\frac{TL}{m}}$$

When mass is constant, $v \propto \sqrt{TL}$

Since each string has the same mass, we can see that the wave speed will be same when the product of the tension and the length of the string is the same for all three strings.

4. [5 pts] At an indoor concert, the sound waves emitted from speakers are reflected off the front and back walls, interfering with the sound from the speakers and creating a standing wave [the side walls have absorbent material and do not reflect]. You are at a quiet spot (node) while your friend standing 1.00 m in front of you is at a loud spot (antinode). If there are no nodes or antinodes in between you and your friend, what is the frequency of the emitted sound from the speakers? The speed of sound in air is 343 m/s.

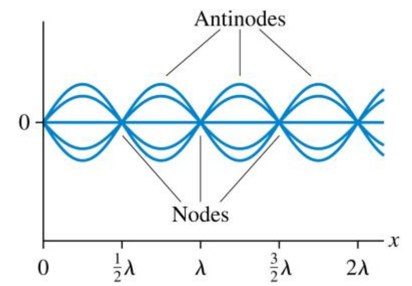
A) 86.0 Hz

B) 172 Hz

C) 257 Hz

D) 343 Hz

E) 686 Hz



The distance between a node and antinode is $\lambda/4$. *Since the distance between you (node) and your friend (antinode) is 1.00 m, the wavelength of the sound is 4.00 m. The frequency is:*

$$f = \frac{v}{\lambda} = \frac{343\ m/s}{4.00\ m} = 86\ Hz$$

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5. [5 pts] You are walking along a dock and see a thin film of oil ($n_{oil} = 1.50$) floating on water ($n_{water} = 1.33$). You notice constructive interference for monochromatic light with wavelength λ = 600 nm incident at 0 degrees to the film. What minimum thickness, t_{min}, of oil will lead to constructive interference?

A) 100 nm

B) 113 nm

C) 200 nm

D) 226 nm

E) 400 nm

The light wave that reflects off the air to oil interface will undergo a $\lambda/2$ phaseshift, since $n_{oil} > n_{air}$. However, the light wave that reflects off the oil to water interface will not undergo a $\lambda/2$ phaseshift. The condition for constructive interference in this context is:

$$2n_{oil}t = \left(m + \frac{1}{2}\right)\lambda$$

The minimum thickness occurs at the minimum value of m, which is 0 in this case.

$$2n_{oil}t_{min} = \frac{1}{2}\lambda$$

$$t_{min} = \frac{\lambda}{4n_{oil}} = \frac{600 \text{ nm}}{4(1.5)} = 100 \text{ nm}$$

6. [5 pts] If one could transport a simple pendulum of constant length from the Earth's surface to the Moon's, where the acceleration due to gravity is one-sixth (1/6) that of the Earth, by what factor would the pendulum frequency be changed?

A) 0.17

B) 0.41

C) 1.0 (No Change)

D) 2.5

E) 6.0

The frequency of a simple pendulum is given as: $f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$. *We can write the following ratio:*

$$\frac{f_{moon}}{f_{Earth}} = \frac{\frac{1}{2\pi}\sqrt{\frac{g_{moon}}{l}}}{\frac{1}{2\pi}\sqrt{\frac{g_{Earth}}{l}}} = \frac{\sqrt{g_{moon}}}{\sqrt{g_{Earth}}} = \frac{\sqrt{\frac{1}{6}g_{Earth}}}{\sqrt{g_{Earth}}} = \sqrt{\frac{1}{6}} = 0.41$$

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A loudspeaker at a rock concert generates an intensity of $1.0 \times 10^{-2}\ \mathrm{W/m^2}$ at 19.0 m at a frequency of 1.0 kHz. Assume the speaker spreads its energy uniformly in three dimensions. The next two questions refer to this setup.

7. [5 pts] What is the total acoustic power output of the speaker?

   A) 0.055 W

   B) 0.13 W

   C) 2.4 W

   D) 22 W

   E) 45 W

The relationship between intensity and power is given as:

$$I = \frac{P}{4\pi r^2}$$

Rearranging for power:

$$P = 4\pi I r^2 = 4\pi(1.0 \times 10^{-2}\ \mathrm{W/m^2})(19.0\ \mathrm{m})^2 = 45\ \mathrm{W}$$

8. [5 pts] At what distance will the intensity be at the pain threshold of $1.0\ \mathrm{W/m^2}$?

   A) 0.06 m

   B) 0.10 m

   C) 1.9 m

   D) 3.6 m

   E) 19 m

We can use the following relationship to solve this question:

$$\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$$

$$r_{1.0W} = \sqrt{\frac{1 \times 10^{-2}\ \mathrm{W/m^2}}{1\ \mathrm{W/m^2}}}(19\ \mathrm{m}) = 1.9\ \mathrm{m}$$

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9. [5 pts] Two waves, 1 and 2, are propagating along a string, where the vertical displacements are given by the following equations:

$$y_1(x,t) = A_1 \sin\,(kx - \omega t)$$
$$y_2(x,t) = A_2 \cos\,(kx - \omega t + \delta)$$

Which value of δ will make for total constructive interference?

A) -π

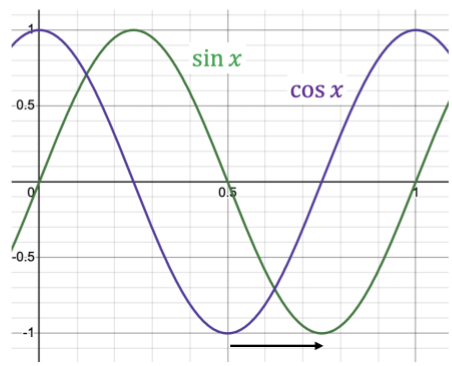
B) $-\pi/2$

A) $\pi/2$

B) π

C) Since they are traveling in the same direction, there will never be constructive interference with these waves.

We can consider graphs of $\sin x$ *and* $\cos x$*, as shown at right. For the cosine function to line up with the sine function, the cosine function needs to be shifted to the right by one-quarter of a cycle. This is equivalent to a phase shift of* $-\pi/2$.



$\frac{1}{4}$ cycle to the right $= -\frac{2\pi}{4} = -\frac{\pi}{2}$

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Lab Multiple Choice Questions

10. [5 pts] A group of students, group A, is running the same experiment as that in Lab A1. Their goal is to find a relationship between the standing wave frequency and the length of the string. The table at right shows possible variables for this experiment. Identify which variables the students should choose as independent, dependent and control for their experiment.

No.	Variable
1	Standing Wave Frequency
2	String length
3	Mass attached to the hanger
4	Number of antinodes
5	Linear mass density of the string

A) Variable (1) is independent, (2) is dependent and all others are control.

B) Variable (3) is independent, (4) is dependent and all others are control.

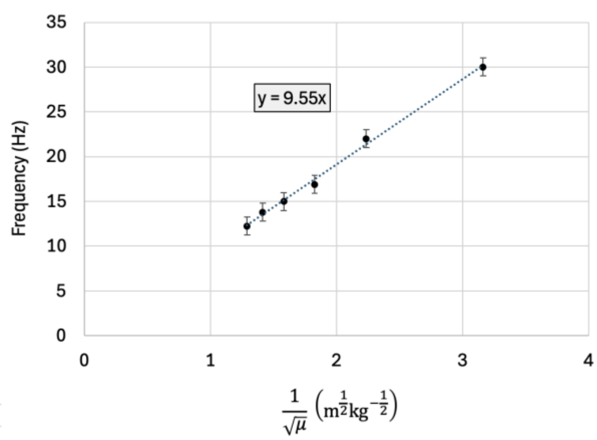
C) Variable (4) is independent, (3) is dependent and all others are control.

D) Variable (2) is independent, (1) is dependent and all others are control.

E) Variable (2) is independent, (5) is dependent and all others are control.

In Lab A1, the standing wave frequency was the dependent variable (1). Since students are examining the relationship between frequency and the length of the string, they will make changes to the length of the string, making the length of the string the independent variable (2). All other variables (3, 4, and 5) should be controlled.

11. [5 pts] A different group of students, group B, is examining the relationship between standing wave frequency (f) and the linear mass density of the string (μ) using the same equipment as that in Lab A1. They collect data and form the linearized plot at right. Which of the statements below are consistent with the student's data?



I. f is *proportional* to $\sqrt{\mu}$.

II. As the value of μ increases, the value of f also increases.

III. As the value of μ increases, the value of f decreases.

IV. μ was the independent variable for this experiment.

A) Statements I, III, and IV

B) Statements I and II

C) Statements II and IV

D) Statements III and IV

E) Statement III only

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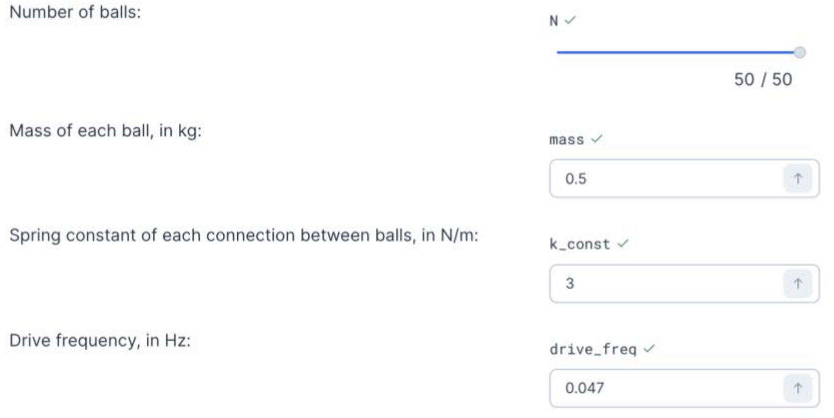
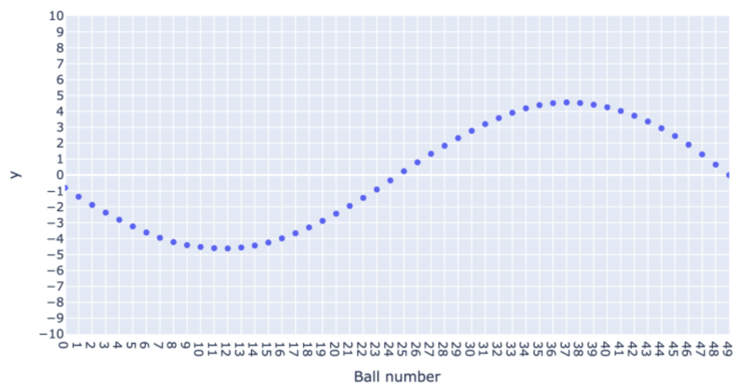
From the graph in Q11, we can see that $f \propto 1/\sqrt{\mu}$, which means that statement I is incorrect. Since $f \propto 1/\sqrt{\mu}$, an increase in μ would result in a decrease in f. This means ***statement III is correct*** *and statement II is incorrect. For this experiment, the students would have changed the linear mass density of the string making it the independent variable, making* ***statement IV correct****.*

12. [5 pts] Group B (from *Q*11) is now trying to replicate their experiment using the simulation in Labs A1 and A2. Using the settings at right, the students form a standing wave with two antinodes.



The students then change the mass of each ball to 1.0 kg. Based on their data in *Q*11, if they want to replicate the standing wave as shown, what approximate drive frequency should they use?



A) 0.024 Hz

B) 0.033 Hz

C) 0.058 Hz

D) 0.066 Hz

E) 0.094 Hz

Changing the mass of the balls in the simulation and not changing the length is equivalent to altering the linear mass density. From Q11, we know that $f \propto 1/\sqrt{\mu}$ and $\mu = m/L$. Since the mass is doubled, the linear mass density will also double. This means that the frequency should change by a factor of $1\sqrt{u}$. So, $f' = \frac{1}{\sqrt{2}} f = \frac{1}{\sqrt{2}}(0.047\ Hz) = 0.033\ Hz$.

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Lecture Free Response

13. [5 pts] An ambulance is driving down the street at a speed of 25 m/s emitting a sound at 800 Hz with power 100W. The speed of sound in air is 343 m/s. What is the ratio of the frequency you hear as the ambulance drives towards you, to the frequency of the sound you hear as it is driving away from you? Show your work.

The perceived frequency for an approaching source moving at speed v_s is given as:

$$f_+ = \frac{f_0}{1 - \frac{v_s}{v}}$$

And a receding source is given as:

$$f_- = \frac{f_0}{1 + \frac{v_s}{v}}$$

The ratio of these frequencies is therefore:

$$\frac{f_+}{f_-} = \frac{\frac{f_0}{1 - \frac{v_s}{v}}}{\frac{f_0}{1 + \frac{v_s}{v}}} = \frac{1 + \frac{v_s}{v}}{1 - \frac{v_s}{v}} = \frac{v + v_s}{v - v_s} = \frac{368 \text{ m/s}}{318 \text{ m/s}} = 1.16$$

14. [5 pts] An ambulance is driving down the street a speed of 25 m/s emitting a sound at 800 Hz with power 100W. How much louder (in decibels) is the sound you hear when the ambulance is 2 m away from you, in comparison with when the ambulance is 100 m away from you? Show your work.

The sound intensity level (SIL) is related to the sound intensity by the following equation:

$$\beta = 10 \text{ dB} \log\left(\frac{I}{I_0}\right)$$

The SIL difference can be written as:

$$\beta_{2\text{m}} - \beta_{100\text{m}} = 10 \text{ dB} \log\left(\frac{I_{2\text{m}}}{I_0}\right) - 10 \text{ dB} \log\left(\frac{I_{100\text{m}}}{I_0}\right) = 10 \text{ dB} \log\left(\frac{I_{2\text{m}}}{I_{100\text{m}}}\right)$$

$$\beta_{2\text{m}} - \beta_{100\text{m}} = 10 \text{ dB} \log\left(\frac{(100 \text{ m})^2}{(2 \text{ m})^2}\right) = 34 \text{ dB}$$

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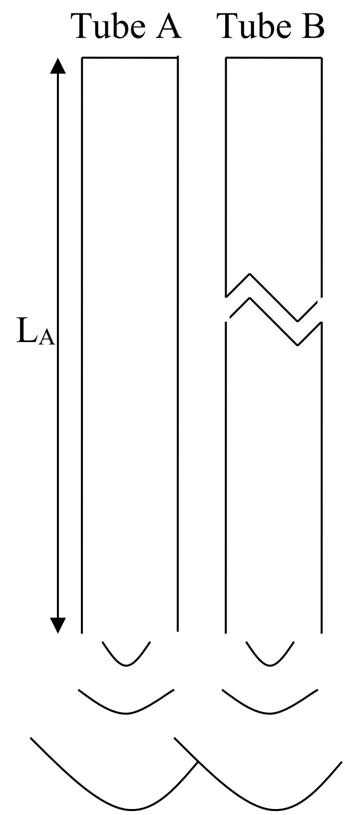
Two open-at-one-end tubes play slightly different notes when they resonate in their fundamental mode (lowest tone). Tube A, with length L_A, has a higher pitch (frequency) than tube B. The tubes are identical other than their length. The speed of sound is v_s. When both tubes resonate simultaneously a beat frequency, f_T, is heard.



15. [5 pts] If the frequency of tube A is f_A, write down the frequency of tube B, f_B, in terms of the given quantities. Show your work.

The beat frequency is given as:

$$f_{beat} = f_T = |f_A - f_B|$$

Since $f_A > f_B$, we can state:

$$f_T = f_A - f_B$$

$$f_B = f_A - f_T$$

16. [5 pts] Write down the frequency of tube A, f_A, in terms of the given quantities. Show your work.

Tube A is an open-closed tube, so the fundamental wavelength is $4L_A$. The fundamental frequency can be written as follows:

$$f_A = \frac{v_s}{\lambda_A} = \frac{v_s}{4L_A}$$

17. [5 pts] Is $L_A > L_B, L_A < L_B$, or $L_A = L_B$? Make sure to explain your reasoning.

The fundamental frequency of an open-closed tube is inversely proportional to its length, $f \propto \frac{1}{L}$. Since we are given that $f_A > f_B$, then $L_A < L_B$.

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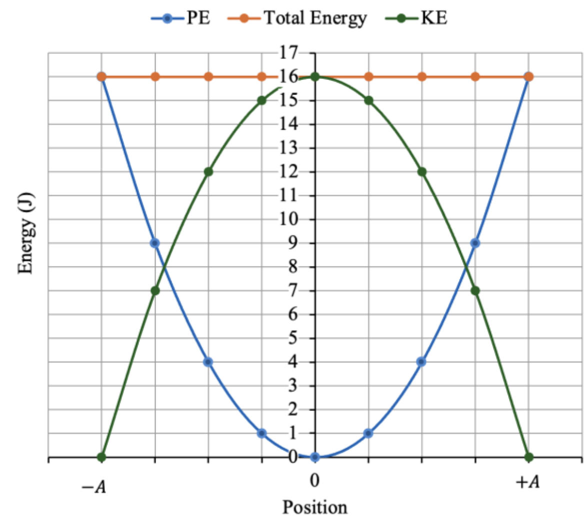
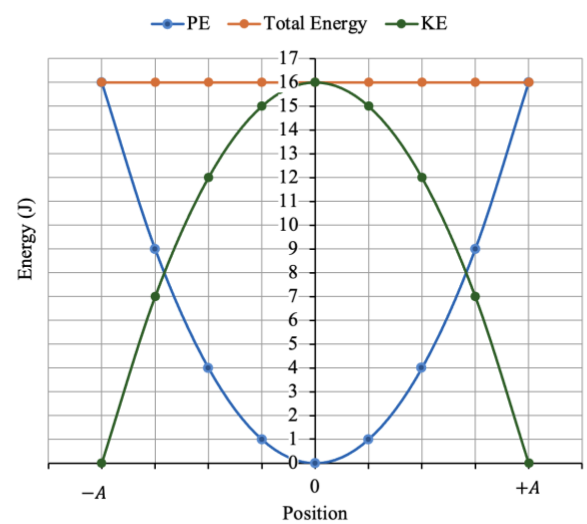
Tutorial Free Response Questions

18. [6 pts] Case 1: A block of mass m is attached to an ideal spring and oscillates between $x = +A$ and $x = -A$ on a frictionless horizontal surface. The graph shows a single data point of the block-spring system's potential energy when the block is located at $x = +A/2$. On the graph sketch curves or lines that represent the system's total energy, potential energy and kinetic energy. Label clearly and explain.



The potential energy of a spring is given as: $U = \frac{1}{2}kx^2$*. This means that* $U(x)$ *is a quadratic and since* $U \propto x^2$*, when the stretched length of the spring is doubled from* $+A/2$ *to* A*, the potential increases by a factor of 4, or 16 J in this case. It is also given that* $U_{max} = E_{total}$*. Since there are no dissipative forces, the total energy is constant at 16 J. We can form the graph of the kinetic energy by applying* $K(x) = E_{total} - U(x)$*.*

19. [4 pts] Case 2: The mass of the block is halved and released from rest at $x = +A$. The scale of the graph at right is identical to that in *Q*18. Sketch the total energy, kinetic energy and potential energy of the block-spring system for this case. Explain. If not enough information is given, state so explicitly.



The total energy of the system is given as: $E_{total} = U_{max} = \frac{1}{2}kA^2$*. Since the spring constant and the amplitude are not changed, the total energy and potential energy stored in the spring do not change. Since* E_{total} *and* $U(x)$ *do not change, the graph of* $K(x)$ *also does not change.*

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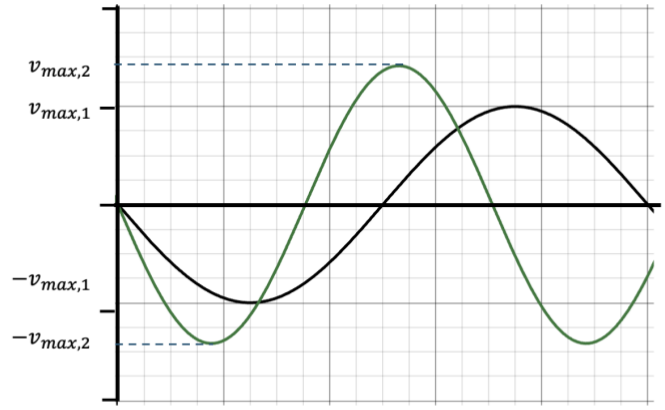
20. [5 pts] The graph at right shows the velocity-time curve of the block in Case 1. On the graph, sketch a velocity-time curve for the block in Case 2. Your graph only needs to be qualitatively correct. Explain.



The period of a block on a spring is given as: $T = 2\pi\sqrt{m/k}$. *Since* $T \propto \sqrt{m}$ *and the mass is halved, the period must decrease. (Quantitatively,* $T_1 = \frac{1}{\sqrt{2}}T_2$*).*

The maximum speed of the block is given as: $v_{max} = A\omega = A\frac{2\pi}{T}$. *Since* $v_{max} \propto \frac{1}{T}$ *and the period decreases, the maximum speed must increase. (Quantitatively,* $v_{max,1} = \sqrt{2}v_{max,2}$*).*