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I. [60 points total] Lecture multiple choice questions
For questions with multiple correct answers, you need to identify all the correct answers without selecting any incorrect answers.

1. [5 points] In a loudspeaker, a paper cone moves sinusoidally at 1.6×10^3 Hz with an amplitude of 4.5×10^{-6} m. What is the cone's maximum acceleration?
   A. 7.2×10^{-3} m/s^2
   B. 4.5×10^{-2} m/s^2
   C. 12 m/s^2
   D. 4.5×10^{2} m/s^2
   E. Not enough information is given.

2. [5 points] An object with a mass $m = 0.50$ kg on a frictionless horizontal table is attached to a horizontal spring with spring constant $k = 2.0\ \mathrm{N/m}$. The object is initially held at rest at position $x = 1.0$ m, where the equilibrium position is $x = 0.0$ m. After the object is released, it undergoes an oscillation. What is its maximum speed during the oscillation?
   A. 0.25 m/s
   B. 0.50 m/s
   C. 1.0 m/s
   D. 2.0 m/s
   E. 4.0 m/s

3. [5 points] Consider two systems; a simple pendulum consisting of a point mass attached to a massless string of length L and a uniform rigid ruler of mass m and length L, pivoted about one end. The moment of inertia of the ruler about the pivot is $I = \frac{1}{3}mL^2$. Both systems are displaced by a small angle from their equilibrium positions and allowed to oscillate. Compare the natural frequencies of oscillations, f_{simple} for the simple pendulum and f_{ruler} for the ruler.
   A. $f_{\text{simple}} = f_{\text{ruler}}$
   B. $f_{\text{simple}} = \sqrt{\frac{3}{2}} f_{\text{ruler}}$
   C. $f_{\text{simple}} = \sqrt{\frac{2}{3}} f_{\text{ruler}}$
   D. $f_{\text{simple}} = \sqrt{3} f_{\text{ruler}}$
   E. $f_{\text{simple}} = \sqrt{\frac{1}{3}} f_{\text{ruler}}$

4. [5 points] A pendulum starts undergoing a damped oscillation with a frequency of 3.0 Hz and a time constant of 4.8 seconds. How many oscillations will this pendulum make before its maximum displacement has decreased to 30 % of its initial amplitude?
   A. 0.48
   B. 1.9
   C. 4.3
   D. 5.2
   E. 17

5. [5 points] Suppose that a system of a mass on an ideal spring is driven by a sinusoidal force. At a driving frequency f_1, the amplitude of oscillation is 1 cm. Then, as you gradually increase the driving frequency to f_2, the amplitude increases continuously to 2 cm, with no decrease observed in between. What can you conclude about the system's natural frequency f_{natural}?
   A. $f_{\text{natural}} \leq f_1$
   B. $f_1 < f_{\text{natural}} < f_2$
   C. $f_2 \leq f_{\text{natural}}$
   D. Not enough information is given.

6. [5 points] A string with length L and mass M is under tension. A wave of amplitude A is generated at one end and travels along the string. In each of the following cases, the setup is independent of each other, and **only the parameter mentioned is changed**, while all other aspects of the setup remain the same as the original setup. **Choose all the cases** where the wave speed on the string **doubles**.

A. Case A: Replace the string with another string of mass $\frac{1}{2}M$.

B. Case B: Replace the string with another string of length $2L$.

C. Case C: Replace the string with another string of mass $\frac{1}{4}M$.

D. Case D: Replace the string with another string of length $4L$.

E. Case E: Increase the wave amplitude to $2A$.

7. [5 points] A sinusoidal transverse wave with amplitude of 1.0 m and wavelength of 1.5 m is traveling in the $+x$ direction with wave speed of 3.0 m/s. Which of the following wave functions is consistent with this wave?

A. $y(x,t) = (1.0\text{ m})\cos(4.2\text{ m}^{-1}x - 13\text{ s}^{-1}t)$

B. $y(x,t) = (1.5\text{ m})\cos(1.0\text{ m}^{-1}x - 0.33\text{ s}^{-1}t)$

C. $y(x,t) = (1.0\text{ m})\cos(1.5\text{ m}^{-1}x + 3.0\text{ s}^{-1}t)$

D. $y(x,t) = (1.0\text{ m})\cos(0.67\text{ m}^{-1}x + 19\text{ s}^{-1}t)$

E. None of the above is consistent.

Use the following scenario for the next two questions.

A loudspeaker emits 10 W of sound power uniformly in all directions. A small microphone is placed 100 m from the speaker.

8. [5 points] What is the sound intensity level measured at the location of the microphone?
   A. 69 dB
   B. 79 dB
   C. 85 dB
   D. 180 dB
   E. 200 dB

9. [5 points] If the sound power is now doubled to 20 W, what is the change in the sound intensity level at the microphone, i.e., what is $\beta_{\text{new}} - \beta_{\text{old}}$?
   A. +3.0 dB
   B. -3.0 dB
   C. +6.9 dB
   D. -6.9 dB
   E. Not enough information is given

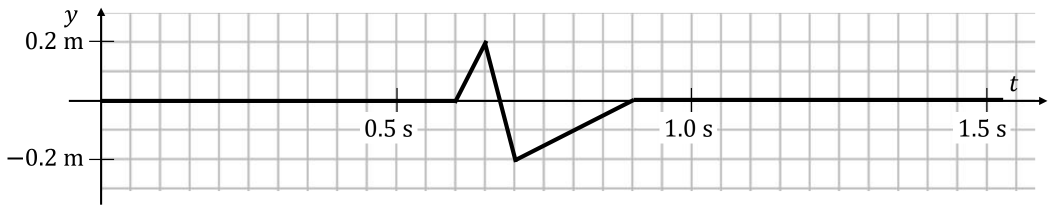
10. [5 points] An ambulance with its siren turned on moves at a constant speed toward a stationary observer, passes the observer, and then continues moving away. Which of the following statements best describes what the observer hears and provides the correct physical explanation?
    A. The observer perceives a sudden **decrease** in the pitch of the siren because the speed of sound in air decreases when the ambulance moves away.
    B. The observer perceives a sudden **increase** in the pitch of the siren because the speed of sound in air decreases when the ambulance moves away.
    C. The observer perceives a sudden **decrease** in the pitch of the siren because the wavelength of the sound wave from the observer's point of view is shorter in front of the ambulance and longer behind it.
    D. The observer perceives a sudden **increase** in the pitch of the siren because the wavelength of the sound wave from the observer's point of view is shorter in front of the ambulance and longer behind it.
    E. None of the above.

11. [5 points] A transverse wave pulse travels along a uniform, taut string and reaches an end that is rigidly attached to a wall. Assume the string is ideal so that energy losses are negligible. Which of the following statements about the wave pulse after it is completely reflected are correct? **Select all that apply.**
    A. The reflected wave pulse travels with the same speed as the incident pulse.
    B. The reflected wave pulse has the same width as the incident pulse.
    C. The reflected wave pulse has the same amplitude as the incident pulse.
    D. The reflected wave pulse is inverted relative to the incident pulse.
    E. None of the above is correct.

12. [5 points] Two air columns of equal length, columns A and B, each have a standing wave established at the **lowest frequency**. In column A, both ends are antinodes of pressure. In column B, one end is an antinode of pressure, and the other end is a node of pressure. If the frequency of the standing wave in column A is 220 Hz, what is the frequency of the standing wave in column B?
    A. 55 Hz
    B. 110 Hz
    C. 220 Hz
    D. 440 Hz
    E. 880 Hz

II. [20 points total] Lecture free response questions
<u>You must show your work to get the full credit.</u>

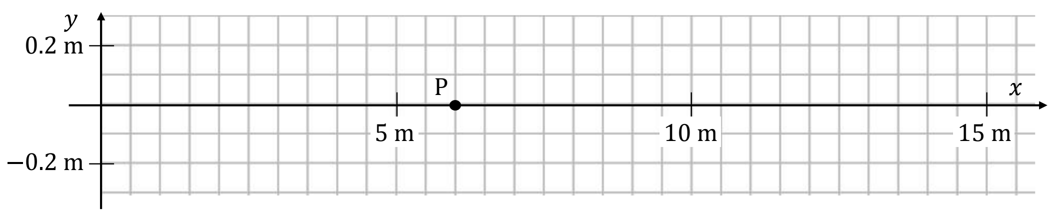
Consider the following scenario for the next two questions.
You hold the left end a thin spring at $x = 0.0$ m and firmly attach the right end of it to a pole. At $t = 0.0$ s, you begin moving the left end of the spring vertically to generate a pulse. Point P is located on the spring at $x = 6.0$ m. The figure below shows the history graph of the position of the spring element at point P, before the pulse has reached the fixed end.

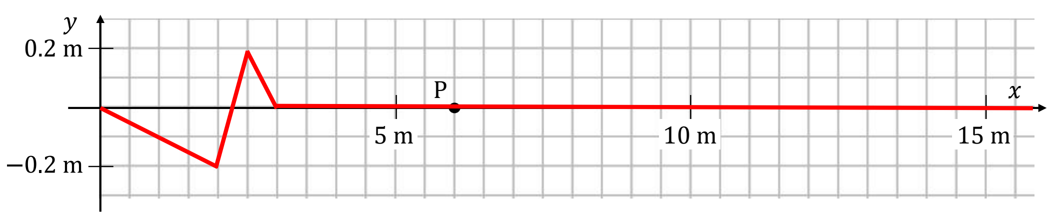


13. [4 points] What is the wave speed of the pulse? Show your work.

The leading edge of the pulse takes 0.6 seconds to reach point P at $x = 6.0$ m, so. So v = 6.0m/0.6 s = 10 m/s.
[4 points] correct answer
OR the following partial credit for wrong answer:
[1 point] choosing correct Delta t = 0.6 s
[1 point] the idea of speed = Delta x / Delta t

14. [7 points] Draw the snapshot graph for $t = 0.3$ s below.



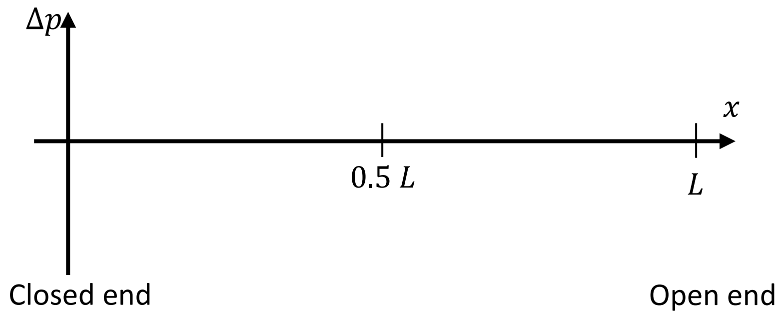


[2 points] The left end is at 0 m, or the right end at 3 m.
[2 points] pulse with correct width (3 m)
[1 point] max y = 0.2 m
[2 points] shape of the pulse is correct (the left-right orientation)

Use the following scenario for the next three questions.

A tuning fork of frequency f is held next to an open-closed pipe of length L, establishing a fundamental standing wave of air in the pipe. The closed end is located at $x = 0$, and the open end is at $x = L$.

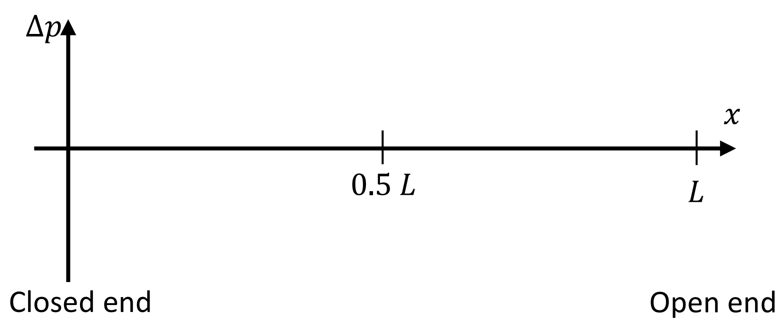
15. [3 points] In the graph below, qualitatively draw the pressure variation, Δp, as a function of position in the pipe.



At $x = 0$ (closed end) = antinode (the average displacement of the molecules at the closed end is zero, and the pressure maximally changes as the average displacement of the neighboring molecules comes closer and farther away).
At $x = L$ (open end) = node (the pressure should be constant at the atmospheric pressure).
[1 point] antinode at $x = 0$
[1 point] node at $x = L$
[1 point] fundamental mode

16. [2 points] What is the wavelength of the standing wave in terms of L? No explanation is necessary.
[2 points] $\lambda = 4L$

17. [4 points] Now suppose that the tuning fork is replaced with a tuning fork of frequency $3f$. Would the new tuning fork establish a standing wave in the pipe? If so, draw the pressure variation, Δp, as a function of position in the pipe below. If not, explain.

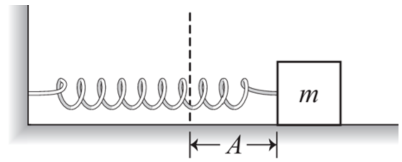


When frequency is increased to $3f$, the wavelength would be 1/3 of the original

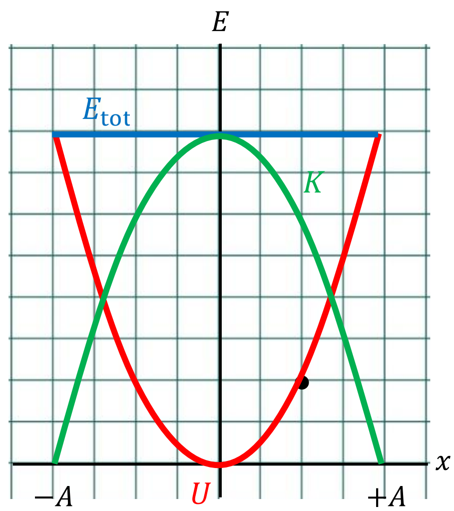
wavelength, $\lambda = \frac{v}{f}$, since wave speed v does not change (since the medium, air, did not change).
[4 points] for correct answer (yes) and drawing (or drawing indicating the 1/3 of wavelength compared to Q15)
OR the following partial credit for wrong answer
[0.5 points] yes
[1 point] quoting $\lambda = \frac{v}{f}$
[1 point] for getting 1/3 wavelength compared to Q15 or [0.5 point] shorter (but not 1/3) wavelength compared to Q15
[1 point] the boundary condition did not change from the drawing of Q15

III. [20 points total] Tutorial free response questions

Use the following scenario for the next two questions.



A block-and-spring system is shown on the right. The block with mass m moves on a horizontal, frictionless table. The spring force, F, obeys Hooke's law $F = -kx$, where k is the spring constant, and x is the displacement of the block from its equilibrium position. At the instant shown, the block is released from rest a distance A to the right of its equilibrium position (indicated by the dashed line).



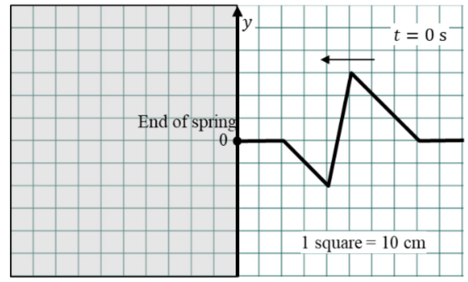
18. [5 points] The dot on the figure at right shows the potential energy of the system when the block is at $x = +\frac{A}{2}$. On the same plot, draw and label the following curves as a function of the position of the block.
    A. The total energy of the system
    B. The kinetic energy of the system
    C. The potential energy of the system

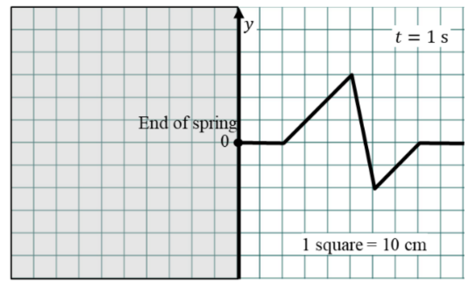
    [0.5 points] graph is between -A and +A.
    [0.5 points] labeling
    [0.5 points] total energy is constant
    [1 point] total energy, max. kinetic energy, or max. potential energy is 8 square high
    [0.5 point] E_total = K + U
    [0.5 points] potential energy is parabolic shape
    [0.5 points] min. potential energy is 0.
    [0.5 points] kinetic energy is upside down parabolic shape
    [0.5 points] min. kinetic energy is 0.
19. [5 points] If the mass of the block is increased to $2m$ while everything else in the set-up remains the same, does any of the graphs you drew above change? If so, explain the change. If not, explain why not.

    None of the graphs change. The potential energy as a function of position is given by $U = \frac{1}{2}kx^2$, so it does not depend on mass. The total energy remains the same because energy does not dissipate (since there is no friction) and is equal to the maximum potential energy. Kinetic energy is total energy minus potential energy, and since neither changes, kinetic energy does not change either.
    [2 points] nothing changes.
    [1 point each] correct explanation for each type of energy

Use the following scenario for the next two questions.

At t = 0 s, a pulse is traveling along a spring to the left as shown in the top right figure. It is unknown whether the left end of the spring is free or fixed. The shape of the spring at t = 1 s, after the pulse is fully reflected, is shown in the bottom right figure. Each square in the diagram represents 10 cm.

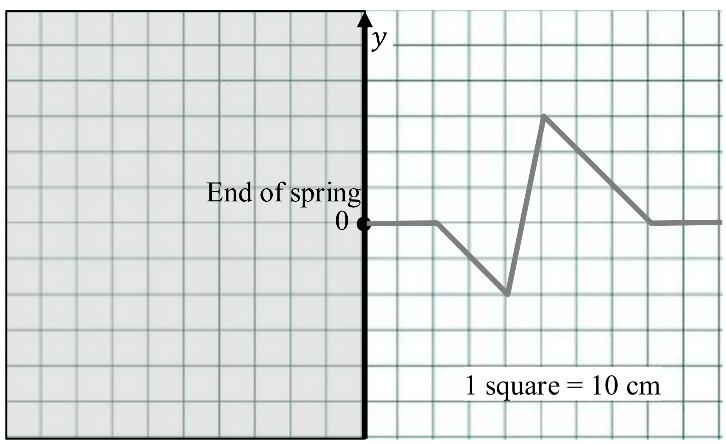




20. [2 points] Is the end of the spring free or fixed? No explanation is necessary.

[2 points] correct answer, free

21. [8 points] On the diagram below, draw the shape of the spring at t = 0.6 s. Make sure to use incident and virtual pulses to construct the resulting pulse and label all of them. The shape of the pulse at t = 0 s is shown in gray for your reference.



[1 point] correct incident pulse shape

[1 point] correct incident pulse horizontal position
[1 point] correct virtual pulse up-down orientation
[1 point] correct virtual pulse right-left orientation
[1 point] correct virtual pulse horizontal position
[1 point] attempting to apply superposition
[2 points] correct final pulse shape

Incident virtual resulting