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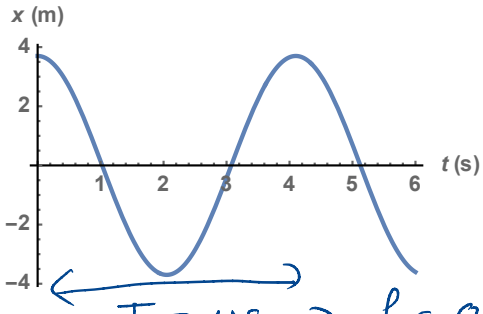
I. Lecture Multiple Choice [60 pts]. **Choose only one answer for each question, circle your answer in this booklet, and fill it out on your bubble sheet.**

Use the following situation to answer the next four questions:

A block of mass 6 kg is connected to an ideal spring of stiffness k and allowed to oscillate on a frictionless horizontal surface. The displacement of the block from equilibrium is shown at right.



$T = 4s \Rightarrow f = 0.25\ Hz$

1. [6 pts] Choose the correct function representing that displacement.

87%

A. $x(t) = (4.0\text{ m})\cos(1.6\text{ s}^{-1}\,t)$
B. $x(t) = (4.0\text{ m})\cos(5.0\text{ s}^{-1}\,t)$
C. $x(t) = (4.0\text{ m})\sin(1.6\text{ s}^{-1}\,t)$
D. $x(t) = (3.0\text{ m})\sin(0.5\text{ s}^{-1}\,t)$
E. $x(t) = (4.0\text{ m})\sin(5.0\text{ s}^{-1}\,t)$

$x(t) = (4.0\,m)\cos(2\pi f t)$

$= (4.0\,m)\cos(1.6t)$

2. [4 pts] What is the value of the spring stiffness k?

87%

A. 600 N/m
B. 120 N/m
C. 0.13 N/m
D. 15 N/m
E. 27 N/m

$2\pi f = \sqrt{\frac{k}{m}} \Rightarrow k = (2\pi f)^2 m$

$= (1.6\,s^{-1})^2 (6\,kg)$

$= 15\,N/m$

3. [4 pts] If the stiffness of the spring used is increased by a factor of 3 with the mass staying the same, which one of the following changes happens?

77%

A. The frequency decreases by a factor of 3.
B. The frequency increases by a factor of 3.
C. The period of oscillation decreases by a factor of $\sqrt{3}$
D. The period of oscillation increases by a factor of $\sqrt{3}$
E. More than one of the above happens.

$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

$k \to 3k$

$\Rightarrow f \to \sqrt{3} f$

$\Rightarrow T \to \frac{T}{\sqrt{3}}$

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4. [6 pts] Suppose now the mass-spring system is allowed to oscillate on a rough horizontal surface. The time-constant for that motion is found to be $\tau = 4.2$ s. How long would it take the amplitude of oscillation to drop to half its initial value?

87%

A. 1.4 s
B. 2.1 s
C. 2.9 s
D. 3.7 s
E. 4.2 s

$$A(t) = A_0 e^{-t/\tau}$$

$$\frac{A}{A_0} = 0.5 = e^{-t/\tau} \Rightarrow \ln 0.5 = -\frac{t}{\tau}$$

$$\Rightarrow t = -\tau \ln 0.5 = -4.2\,\text{s} \ln 0.5 = 2.9\,\text{s}$$

5. [5 pts] A uniform stick has a mass m_0 and length L_0. Another uniform stick has a mass $2m_0$ and length $L_0/3$. Each stick is hung from one end and allowed to oscillate as a pendulum. Find the ratio of period of oscillation of the second stick to that of the first.
The moment of inertia of a stick around one of its ends is $I = \frac{1}{3}mL^2$.

36%

A. $1/\sqrt{3}$
B. $\sqrt{3}$
C. 3
D. $\sqrt{2/3}$
E. $\sqrt{3/2}$

$$T = 2\pi\sqrt{\frac{I}{mgd}} = 2\pi\sqrt{\frac{\frac{1}{3}mL^2}{mg\frac{L}{2}}} = 2\pi\sqrt{\frac{2L}{3g}}$$

$$\Rightarrow \frac{T_2}{T_1} = \frac{2\pi\sqrt{\frac{2L_2}{3g}}}{2\pi\sqrt{\frac{2L_1}{3g}}} = \sqrt{\frac{L_2}{L_1}} = \sqrt{\frac{L_0/3}{L_0}} = \frac{1}{\sqrt{3}}$$

6. [6 pts] If $+x$ is to the right, which one of the following represents a wave traveling to the left?

35%

A. $y(x,t) = 4.0\text{ m}\cos(3\text{ m}^{-1}x - 4\text{ s}^{-1}t)$
B. $y(x,t) = 1.0\text{ m}\sin(-2\text{ m}^{-1}x + 4\text{ s}^{-1}t)$
C. $y(x,t) = -2.0\text{ m}\cos(3\text{ m}^{-1}x - 4\text{ s}^{-1}t)$
D. $y(x,t) = -5.0\text{ m}\sin(2\text{ m}^{-1}x - 4\text{ s}^{-1}t)$
E. None of these.

For a wave to travel to the left, signs of t and x must match.

7. [4 pts] Calculate the speed of the wave in choice (C) from the previous question.

72%

A. 0.75 m/s
B. 1.3 m/s
C. 12 m/s
D. 0.083 m/s
E. 8.0 m/s

$$y(x,t) = A\cos\left(\frac{2\pi x}{\lambda} - \frac{2\pi t}{T}\right)$$

$$\Rightarrow v = \frac{\lambda}{T} = \frac{\frac{2\pi}{T}}{\frac{2\pi}{\lambda}}; \quad \frac{2\pi}{\lambda} = 3\,\text{m}^{-1}$$

$$\frac{2\pi}{T} = 4\,\text{s}^{-1}$$

$$\Rightarrow v = \frac{4\,\text{s}^{-1}}{3\,\text{m}^{-1}} = 1.3\,\text{m/s}$$

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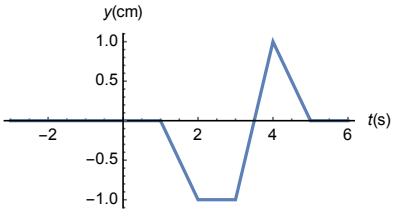
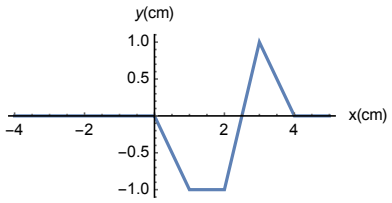
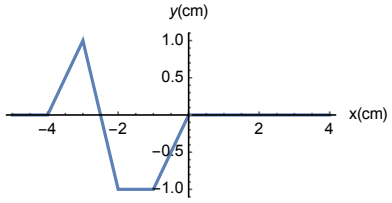
8. [4 pts] The figure at right shows a history graph at $x = 0$ cm for a pulse traveling at 1 cm/s ***to the left*** on a string. Which of the following represents the snapshot graph of the string at $t = 0$ s.



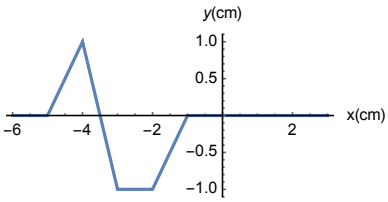
43%



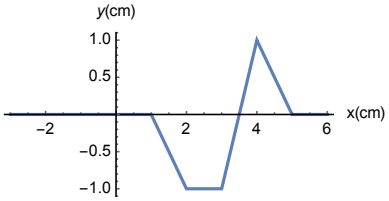
A.



B.



C.



D.

9. [5 pts] In 1972 a wind event pushed the temperature at the town of Loma, Montana from $-48°C$ ($-54°F$) one morning to $10°C$ ($49°F$) the next morning. Which is the greatest temperature change with 24 hours ever measured on earth! What is the ratio of the speed of sound in air during the second morning to that of the first?

76%

A. 1.1

B. 2.2

C. 1.3

D. 0.89

E. The speed of sound in air was not affected by that change.

$v = \sqrt{\frac{\gamma R T}{\mu}}$, γ, R, μ stay the same

$\Rightarrow \frac{v_2}{v_1} = \sqrt{\frac{\gamma R T_1}{\mu}}\sqrt{\frac{\mu}{\gamma R T_2}} = \sqrt{\frac{T_1}{T_2}} = \sqrt{\frac{10+273}{-48+273}} = 1.1$

10. [5 pts] A spider spins a web with silk threads with a linear mass density of 9.0×10^{-9}kg/m. A passing insect brushes an end of a strand of the web of a length 0.15 m, and the spider senses the vibration arriving at the other end of the strand 1.6×10^{-4} seconds later. What is the tension in the strand of the web?

82%

A. 8.4×10^{-6}N

B. 4.0×10^{-3}N

C. 7.9×10^{-3}N

D. 9.6×10^{-3}N

E. 1.0×10^{-2}N

Δx μ

Δt

$v = \frac{\Delta x}{\Delta t} = \sqrt{\frac{T}{\mu}} \Rightarrow T = \mu\left(\frac{\Delta x}{\Delta t}\right)^2$

$\Rightarrow T = \left(9.0\times10^{-9}\ \frac{kg}{m}\right)\left(\frac{0.15\ m}{1.6\times10^{-4}\ s}\right)^2$

$= 7.9 \times 10^{-3}$ s

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11. [6 pts] A student is running experiments to study the Doppler shift by using a sound source that emits a fixed frequency f. During one experiment the student measures the ***speed of the wave*** emitted by the source to be less than the speed of sound in the lab. Which of the following is consistent with this observation?

59%

A. The source is moving away from a stationary student.

B. The source is moving towards a stationary student.

C. The student is moving away from a stationary source.

D. The student is moving towards a stationary source.

E. More than one of the above is consistent with the observations.

Speed of sound changes only if observer is moving. It is reduced ⇒ observer is moving away from source

12. [5 pts] The frequency of an electromagnetic wave is 4.2×10^8Hz, what is its wavelength?

89%

A. 0.71 m

B. 1.6 m

C. 8.6 m

D. 0.34 m

E. 2.2 m

$c = \lambda f$

$\Rightarrow \lambda = \frac{c}{f} = \frac{3.0 \times 10^8 \text{ m/s}}{4.2 \times 10^8 \text{ Hz}} = 0.71 \text{ m}$

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II. Lecture Free Response [20 pts] **Show your work for full credit.**
A speaker produces a sound of frequency 3 kHz. While standing a distance of 2.0 m from it, you receive an intensity of $3.8 \times 10^{-8}\text{W/m}^2$. Your eardrum has a radius of about 1.0 cm.

13. [5 pts] Calculate the total power produced by the speaker.

$$P_{\text{tot}} = I_{\text{received}} a_{\text{sphere}} = (3.8 \times 10^{-8}\ \text{W/m}^2)(4\pi\ (2.0\ \text{m})^2) = \boxed{1.9 \times 10^{-6}\text{W}}$$

79%

14. [4 pts] How much power does your eardrum receive?

$$P_{\text{received}} = I_{\text{received}} a_{\text{eardrum}} = (3.8 \times 10^{-8}\ \text{W/m}^2)(\pi\ (0.01\ \text{m})^2) = \boxed{1.2 \times 10^{-11}\text{W}}$$

55%

15. [5 pts] What is the sound intensity level where you stand?

$$\beta = (10\ \text{dB}) \log_{10}\left(\frac{I}{I_0}\right) = (10\ \text{dB}) \log_{10}\left(\frac{3.8 \times 10^{-8}\text{W/m}^2}{1.0 \times 10^{-12}\text{W/m}^2}\right) = \boxed{46\ \text{dB}}$$

86%

16. [6 pts] If you move to a distance of 4.0 m from the speaker, by how much would the intensity level change, $\Delta\beta$, from where you originally stood?

62%

$$\Delta\beta = (10\ \text{dB})\left(\log_{10}\frac{I_f}{I_0}\right) - (10\ \text{dB})\left(\log_{10}\frac{I_i}{I_0}\right)$$
$$= (10\ \text{dB})\left[\left(\log_{10}\frac{I_f}{I_0}\right) - \left(\log_{10}\frac{I_i}{I_0}\right)\right]$$
$$= (10\ \text{dB})\left(\log_{10}\frac{I_f}{I_0}\frac{I_0}{I_i}\right) = (10\ \text{dB})\left(\log_{10}\frac{I_f}{I_i}\right)$$

Now,

$$I = P_{\text{tot}}/4\pi d^2$$
$$\Rightarrow \Delta\beta = (10\ \text{dB})\left[\log_{10}\left(\frac{P_{\text{tot}}}{4\pi d_f^2}\frac{4\pi d_i^2}{P_{\text{tot}}}\right)\right] = (10\ \text{dB})\left[\log_{10}\left(\frac{d_i^2}{d_f^2}\right)\right]$$
$$\Rightarrow \Delta\beta = (10\ \text{dB})\left[\log_{10}\left(\frac{(2.0\ \text{m})^2}{(4.0\ \text{m})^2}\right)\right] = \boxed{-6.0\ \text{dB}}$$

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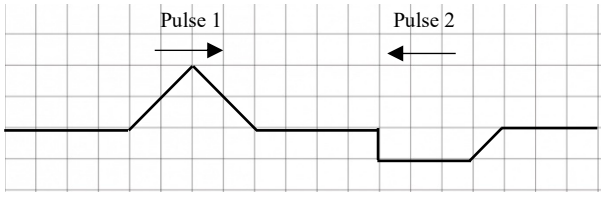
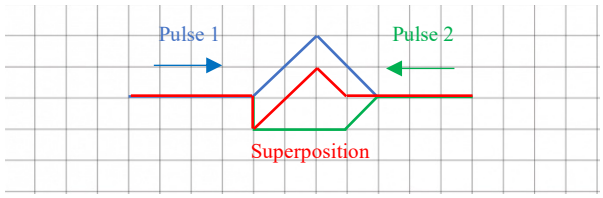
III. Tutorial Free-Response [20 pts]. **Explain your reasoning where stated to get full credit.**

17. [6 pts] Two pulses moving towards each other are formed on a spring, as shown at right. In the space provided below the figure draw the shape of the spring after 4 seconds, assuming that the two pulses are moving at 1 square per second.



45%

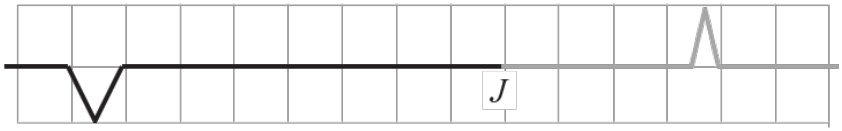
18. [4 pts] A student makes the following statement: "I think if we make the second pulse shorter in the horizontal direction, it would move faster than pulse 1, since it would not need to cover as much distance in the same amount of time." Do you agree or disagree? Explain briefly.



76%

I disagree, since the factors that control wave speed are tension and linear mass density; the student's statement is wrong because they didn't take into account that each point on the wave will move with the same speed regardless of what the other points look like at the same time.

19. Two springs are connected joining at point J, as shown. A pulse is generated in one of the two springs.



75%

A. [3 pts] Is the speed of the pulse on the left spring *greater than*, *less than* or *equal to* the speed of the pulse on the right spring? No explanation needed.
The speed of the pulse on the left spring is ***greater than*** the speed of the pulse on the right spring, since the pulse on the left is wider than the one on the right and has covered a larger distance.

70%

B. [3 pts] Is the linear mass density of the spring on the left *greater than*, *less than* or *equal to* the linear mass density of the spring on the right? No explanation needed.
The tension has to be the same throughout the two springs, and the speed of the wave is greater on the left, therefore, the linear mass on the left is ***less than*** that on the right.

20. [4 pts] Was the pulse originally generated on the left end of the left spring or the right end of the right spring? Explain briefly.

64%

Since one of the two pulses is inverted relative to the other, this could only happen if the pulse is incident from the lighter to the heavier spring, with the junction acting as a fixed end, therefore the pulse must have been incident from ***left***.