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I. Lecture multiple choice (45 points – 9 questions)

1) (5 pts) Two carts can move with negligible friction on a level surface. Cart 1 has mass m_1 and is attached by an ideal spring of spring constant k_1 to a rigid wall. Cart 2 has mass $m_2 = 2m_1$ and is attached by an ideal spring of spring constant $k_2 = 2k_1$ to a rigid wall. Each cart is displaced an amount A from equilibrium and released from rest. Which of the following relationships of their maximum speeds is correct?

   A. $v_{\max,2} = v_{\max,1}$
   B. $v_{\max,2} = 2\, v_{\max,1}$
   C. $v_{\max,2} = \sqrt{2}\, v_{\max,1}$
   D. $v_{\max,2} = 4\, v_{\max,1}$
   E. $v_{\max,2} = 0.5\, v_{\max,1}$

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2) (5 pts) A cart of mass $m = 0.50$ kg is attached to a rigid wall by an ideal spring of spring constant $k = 1.2$ N/m. The cart can move with negligible friction on a level surface. The cart is released from rest at $t = 0$ when it is 0.80 m away from equilibrium. At what time will it first be 0.60 m away from equilibrium?

   A. 0.72 s
   B. 0.47 s
   C. 3.04 s
   D. 1.12 s
   E. 0.55 s

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3) (5 pts) A system undergoes simple harmonic motion given by $D(t) = A\cos(\omega t + \phi_0)$ where $A = 0.50$ m. At $t = 0$ it is at $D = 0.18$ m and has speed $v = 1.86$ m/s. What is ω?

   A. 8.0 rad/s
   B. 4.0 rad/s
   C. 3.1 rad/s
   D. 1.6 rad/s
   E. 3.8 rad/s

4) (5 pts) A system consists of a cart attached to a rigid wall by an ideal spring. The cart can move with negligible friction on a level surface, but it experiences a drag force. At time $t_{1/2}$ it is oscillating with half its initial amplitude. The following are possible changes that can be made. Which could increase $t_{1/2}$ if they were the only change made?

   i. Increasing the mass
   ii. Decreasing the spring constant
   iii. Increasing the initial amplitude
   iv. Decreasing the drag force

   A. All of them
   B. None of them
   C. i and iv
   D. ii and iv
   E. Only i

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5) (5 pts) As a train approaches a stationary observer on a platform, they hear the train whistle with a frequency of 290 Hz. The train then halves its speed, and the observer now hears the whistle with a frequency of 280 Hz. What is the speed of the train before slowing down? Assume the speed of sound in air is 343 m/s.

   A. 8.0 m/s
   B. 17 m/s
   C. 23 m/s
   D. 45 m/s
   E. 130 m/s

---

6) (5 pts) One end of a pipe is open, and the other end is closed. If air in the pipe creates a standing wave, which of the following statements is correct?

   A. At the open end, the pressure is always the highest within the pipe.
   B. At the open end, the pressure alternates between being the lowest and highest within the pipe.
   C. At the closed end, the pressure is always the highest within the pipe.
   D. At the closed end, the pressure alternates between being the lowest and highest within the pipe.
   E. More than one of the above is correct.

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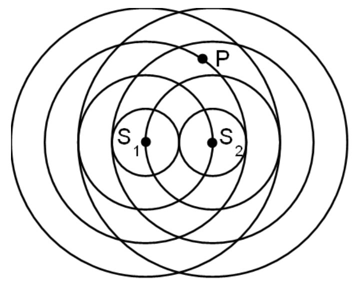
7) (5 pts) A flat sheet of glass with an index of refraction of 1.55 is coated with a film of material with a refractive index of 1.78. What is the minimum nonzero thickness of the film such that green light with a frequency of $f_{\text{green}} = 5.50 \times 10^{14}$ Hz is **not reflected** when white light is incident normally on the film?

A. 7.66×10^{-8} m
B. 1.36×10^{-7} m
C. 1.53×10^{-7} m
D. 1.76×10^{-7} m
E. 2.73×10^{-7} m

---

8) (5 pts) Two sources, S_1 and S_2 emit sound waves of equal wavelength and intensity. The wave fronts are indicated by the lines as shown on the right. At position P, which one of the following statements is correct?



A. The waves always constructively interfere at P.
B. The waves always destructively interfere at P.
C. The interference of the waves at P oscillates between constructive and destructive.
D. The waves do not interfere at P.

---

9) (5 pts) Monochromatic light shines on a mask with two slits and produces the interference pattern on a faraway screen as shown in figure A, where bright spots are indicated by the dots. Which of the following changes could be made to the original experiment to form the interference pattern shown in figure B?

Figure A

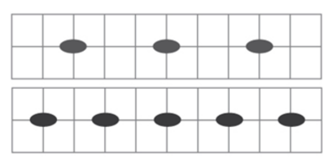


Figure B

A. Halve the wavelength of the light source.
B. Halve the distance between the mask and the screen.
C. Double the distance between the mask and the screen and halve the distance between the slits.
D. Halve the distance between the mask and the screen and triple the distance between the slits.
E. Double the wavelength of the light source and triple the distance between the slits.

II. Lab multiple choice (15 points)

10) (5 pts) In Lab A1, a lab team measured the driving frequency that resulted in a standing wave with two antinodes on a string. The display of the function generator used to vibrate the string showed the frequency with a precision of 0.01 Hz. The team repeated the measurement and obtained the following frequencies: 37.18 Hz, 36.87 Hz, 37.21 Hz, and 36.98 Hz. Which of the following is consistent with the rules for reporting measurements that we use in this class?

    A. 37.1 ± 0.16 Hz
    B. 37.06 ± 0.01 Hz
    C. 37.060 ± 0.165 Hz
    D. 37.06 ± 0.16 Hz
    E. 37.06 ± 0.165 Hz

---

11) (5 pts) In Lab A1, a lab team used four strings with equal lengths but different linear mass densities, and for each string they measured the driving frequency that caused a standing wave with two antinodes. For this lab team to validate the simulation used in Lab A2 (where a string is modeled as balls connected by springs), which value should the team vary as their **independent variable**?

    A. The mass of the balls
    B. The number of balls
    C. The driving frequency
    D. The number of antinodes
    E. The spring constant of the springs

---

12) (5 pts) Suppose you conducted an experiment to validate a simulation. In the physical setup you measured variable y_1 at different values of variable x_1. To conduct the equivalent experiment, you measured variable y_2 at different values of x_2 in the simulation. You make the following two graphs that each include a linear best-fit line:
    - Graph A of y_1 versus x_1
    - Graph B of y_2 versus x_2

    To validate the simulation using these graphs, which one of the following statements is correct?

    A. Only the best-fit line graph A needs to be a good fit.
    B. Only the best-fit line graph B needs to be a good fit.
    C. Both best-fit lines need to be good fits.
    D. None of the above statements is correct.

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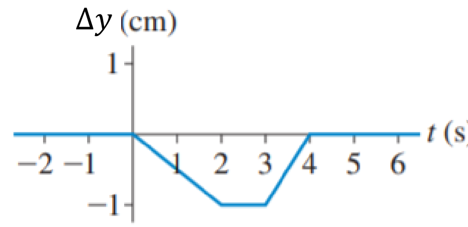
III. Lecture free response (25 points)

Use the following scenario for the next two questions.

A long string is held tightly at both ends, and a transverse wave is moving in the positive x direction with a speed of 1 m/s. The graph on the right shows the history graph for a particle at $x = 2$ m on the string.



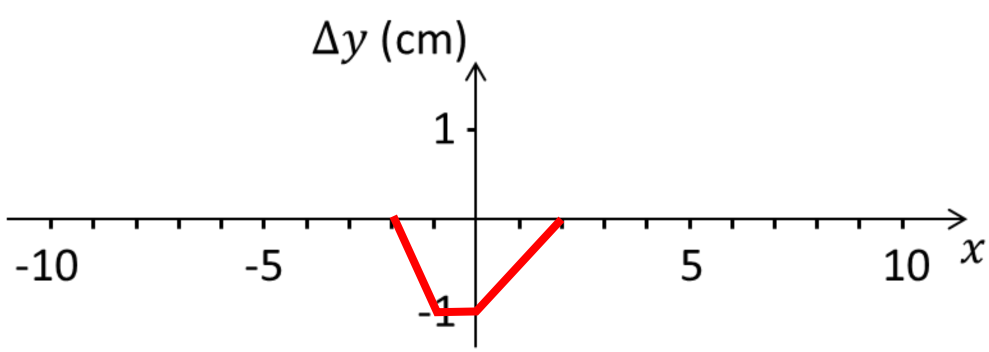
13) (6 pts) Consider a particle at $x = 2$ m on the string. At $t = 1$ s what is the velocity of this particle? Be sure to include the direction of the velocity. Show your work and explain how you determined any numbers used.

Velocity is given by change in Δy over Δt. If we consider Δt between $t = 0$ s and $t = 2$ s where the slope in the graph is constant, Δy changes from $\Delta y = 0\text{cm}$ to $\Delta y = -1\text{cm}$. So, the velocity is $v = \frac{-1\text{ cm}}{2\text{ s}} = -0.5\text{ cm/s}$.

[2 points] Uses a Δy and t at a point or describes rise in region where $0 < t < 2$, or describes slope's rise in that region
[2 points] Uses a Δy and t at a second point in region where $0 < t < 2$, or describes slope's run in that region

[1 point] Correct speed, 0.5 m/s
[1 point] Correct direction (negative)

14) (7 pts) On the graph below draw the snapshot graph at $t = 0$ s.

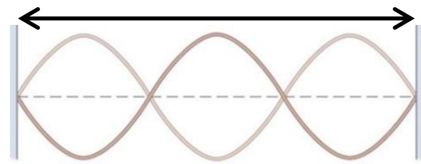


[2 points] Correct left-right orientation in shape
[2 points] Correct scale in horizontal direction (4 m wide)
[2 points] Correct location of either the start (-2 m) or the end (+2 m) of the pulse
[1 point] The "valley" of the pulse is deepest at $\Delta y = -1$ cm.

Use the following scenario for the next two questions.

L

A string with a length L and a mass M is fixed at both ends and under a tension of T_S. A standing wave on the string vibrates as shown at right.



15) (6 pts) What is the frequency of the vibration in terms of the variables given? Show your work.

$f = \frac{v}{\lambda} = m\frac{v}{2L} = 3\frac{v}{2L} = \frac{3}{2L}\sqrt{\frac{LT_S}{M}} = \frac{3}{2}\sqrt{\frac{T_S}{ML}}$

[1 point] Uses $\lambda = \frac{v}{f}$ or $f_m = \frac{mv}{2L}$

[1 point] Uses $v = \sqrt{\frac{T_S}{\mu}}$

[1 point] Uses $\mu = \frac{M}{L}$

[1 point] Determines that $\lambda = \frac{2L}{3}$

[2 points] Correct answer: $\frac{3}{2}\sqrt{\frac{T_S}{ML}}$ (No need to simplify L's)

16) (6 pts) If the string tension is increased to four times its original value while the vibration frequency remains the same, is a standing wave produced on the string? If so, sketch the standing waveform below. If not, explain why.

The wave speed increases by a factor of two if the tension is increased by a factor of four while the linear mass density remains the same since $v = \sqrt{\frac{T_S}{\mu}}$. Then, λ increases by a factor of two since $\lambda = \frac{v}{f}$, and frequency remains the same. L is then equal to 0.75λ. Both ends of the string need to be at nodes for a standing wave to be established, but the new wave with $L = 0.75\lambda$ cannot meet this boundary condition, so it's not possible.

[1 point] Using $v = \sqrt{\frac{T_S}{\mu}}$

[1 point] Using $\lambda = \frac{v}{f}$

[1 point] Concluding that v doubles

[1 point] Concluding that λ doubles

[1 point] Discussing boundary conditions for the standing wave and if the wave with double the wavelength is consistent with this.

[1 point] Correct answer: not possible

[-1 point] Failing to mention that f or μ remains constant in conclusion about v or λ

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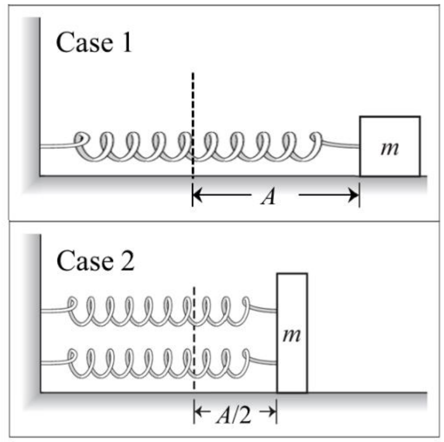
IV. Tutorial free response (15 points)

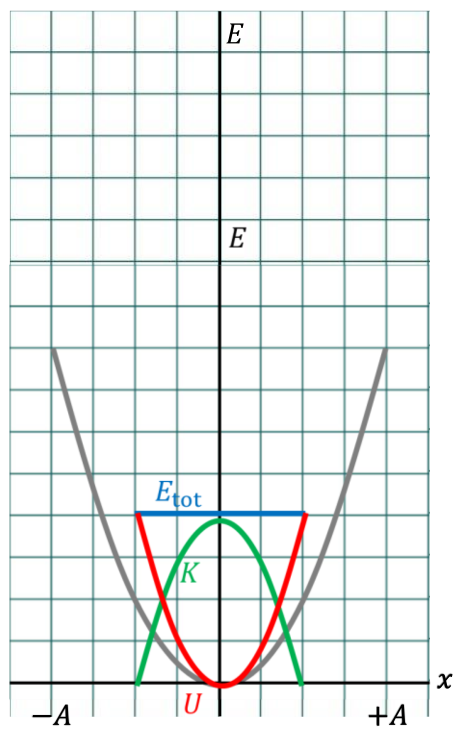
Use the following scenario for the next three questions.

Two block-and-spring(s) systems are shown on the right. Each block moves on a horizontal, frictionless table. The blocks have the same mass m, and the springs are identical and ideal, with spring constant k. At the instant shown, each block is released from rest at a position, a distance A in Case 1 and a distance $A/2$ in Case 2 to the right of its equilibrium position (indicated by the dashed line).



17) (5 pts) At the moment the blocks are released, as shown, is the magnitude of the acceleration of the block in Case 1 *greater than*, *less than*, or *equal to* the magnitude of the acceleration of the block on Case 2? Explain your reasoning.
[1 point] Correct answer (same)
[2 points] Uses argument based on Hooke's law to show that the net forces are the same.
[1 point] Mentions that mass is the same
[1 point] Uses Newton's 2^{nd} law to relate net force to acceleration.

The graph on the right shows the potential energy of the system as a function of the position of the block in Case 1.



18) (6 pts) On the same plot, draw the following plots as a function of the position of the block for Case 2 and label them.

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/2 and +A/2.
[0.5 points] total energy is constant
[0.5 points] potential energy is parabolic shape
[0.5 points] kinetic energy is upside down parabolic shape
[2 points] E_tot = U + K
[2 points] total energy, max potential energy, or max kinetic energy is 4 square high

19) (4 pts) Is the speed of the block at the equilibrium position for Case 1 *greater than*, *less than*, or *equal to* the speed of the block at the equilibrium position for Case 2? Explain your reasoning.

Greater than: The maximum kinetic energy is equal to the total energy. The total energy is 8 units for Case 1 and 4 units for Case 2. So, the maximum kinetic energy for Case 1 is greater. The maximum kinetic energy is achieved when the block is at the equilibrium position. The greater the maximum kinetic energy the system has, the greater the maximum speed at the equilibrium position.

[1 point] correct answer: greater than (or consistent with Q18)

[1 point] Correctly determining the max. kinetic energy for Case 1

[1 point] Correct comparison of kinetic energy between cases

[1 point] Relating max kinetic energy to speed at equilibrium position