Physics 116 A
Autumn 2025

116A - K.TOLICH

Midterm 1
October 21st, 2025

Please use the boxes below to clearly print your name and UW NetID.
Please write within the boxes.

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I certify that the work I shall submit is my own creation, not copied from any source.

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Clearly fill out this cover page and the top portion of the provided bubble sheet with the necessary information.

Do not open the exam until told to do so.
When prompted, clearly print the information required at the top of each page of this exam booklet.

For multi-select questions, you receive partial credit for each correct answer choice as long as you select none of the incorrect answer choices.

You can remove the equation sheet(s). Otherwise, keep the exam booklet intact. You will have 60 minutes to complete the examination.

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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] An object undergoes simple harmonic motion with period T. Consider two time instants: t_1 and t_2 where $t_2 = t_1 + T/2$. Which of the following statements is true? In the following choices, let $x(t)$ represent the position of the object, and $v(t)$ its velocity.

A. $x(t_2) = +x(t_1)$ and $v(t_2) = -v(t_1)$
B. $x(t_2) = -x(t_1)$ and $v(t_2) = +v(t_1)$
C. $x(t_2) = -x(t_1)$ and $v(t_2) = -v(t_1)$
D. $x(t_2) = +x(t_1)$ and $v(t_2) = +v(t_1)$
E. None of the above is correct.

2. [5 points] An object is attached to a horizontal spring on a frictionless table. It is initially held at rest at position $x = 1$ m, where the equilibrium position is $x = 0$ m. After being released, the object oscillates with a maximum velocity of 1 m/s. If the object were instead released from $x = 2$ m, what would be its maximum velocity during the oscillation?

A. 1 m/s
B. $\sqrt{2}$ m/s
C. 2 m/s
D. 4 m/s
E. Not enough information is given.

3. [5 points] A uniform ruler undergoes small oscillations about a pivot located at one of its ends. If the mass of the ruler is doubled without changing its length or shape, what happens to the oscillation period?
   A. halves
   B. remains the same
   C. doubles
   D. not enough information is given to answer
   E. None of the above

4. [5 points] An object begins undergoing damped oscillations on a spring at time $t = 0$ s. Its maximum displacement decays exponentially to 50% of its initial value at $t = 10.0$ s. At what time will the maximum displacement be 25% of its initial value?
   A. 6.9 s
   B. 14.4 s
   C. 15.0 s
   D. 20.0 s
   E. 40.0 s

5. [5 points] A small child with a mass of 17 kg sits on a swing that has a length of 2.1 m. You plan to give the child a small, brief push at regular intervals to increase the amplitude of her motion. Assuming that you can model the swing as a simple pendulum, how much time should you wait between pushes to increase the amplitude as quickly as possible?
   A. 0.34 s
   B. 0.83 s
   C. 2.9 s
   D. 5.8 s
   E. 49 s

6. [5 points] A wave travels along a string under tension with a speed of 150 m/s. If the tension is doubled, what will be the new wave speed?
   A. 17 m/s
   B. 75 m/s
   C. 110 m/s
   D. 210 m/s
   E. 300 m/s

7. [5 points] The wave function for a sinusoidal wave traveling along a string is given by $y(x,t) = (5.0\ \mathrm{cm})\cos(25.1\ \mathrm{m}^{-1}x - 628\ \mathrm{s}^{-1}t)$.
   What is the velocity of the wave?
   A. $+5.0\ \mathrm{m/s}$ in the *y*-direction
   B. $-5.0\ \mathrm{m/s}$ in the *y*-direction
   C. $+25\ \mathrm{m/s}$ in the *x*-direction
   D. $-25\ \mathrm{m/s}$ in the *x*-direction
   E. Not enough information is given

Use the following scenario for the next two questions.

A loudspeaker emits 36 W of sound power uniformly in all directions. A small microphone is placed some distance away from the speaker. The sound intensity at the position of the microphone is $8.0 \times 10^{-4}\ \mathrm{W/m^2}$.

8. [5 points] What is the distance between the speaker and the microphone?
   A. 60 m
   B. 120 m
   C. 140 m
   D. 360 m
   E. 450 m

9. [5 points] If the microphone is moved such that the distance to the speaker is now doubled, what is the change in the sound intensity level at the microphone, i.e., what is $\beta_{\mathrm{new}} - \beta_{\mathrm{old}}$?
   A. +2.0 dB
   B. -2.0 dB
   C. +6.0 dB
   D. -6.0 dB
   E. Not enough information is given

10. [5 points] Consider the following two cases.
In case 1, a speaker emitting sound at frequency f_s is moving at a constant speed v toward a stationary student, where v is half of the speed of sound in air.
In case 2, the same speaker is stationary, and the student is moving toward the speaker at the same constant speed v.
How does the sound heard by the student compare in each case?
   A. They hear higher frequency in case 1 than in case 2.
   B. They hear higher frequency in case 2 than in case 1.
   C. They hear the same frequency in both cases.
   D. We need to know the value of the frequency emitted by the speaker to know.
   E. We need to know the value of the speed of sound in air to know.

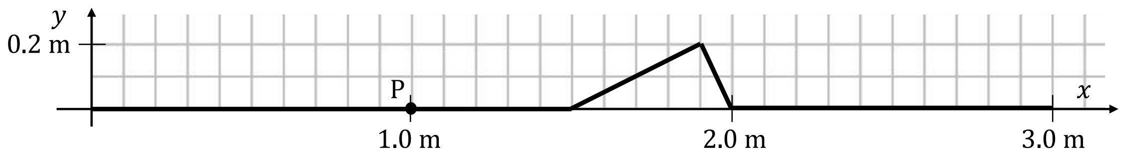
11. [5 points] Two pieces of strings, String 1 and String 2, have linear mass densities μ_1 and μ_2, respectively, where $\mu_1 < \mu_2$. The strings are tied together and placed under a tension. A transverse pulse is then sent down String 1 toward String 2. Which of the following statements is/are correct? **Select all that apply.**

   A. The reflected pulse is inverted.
   B. The reflected pulse is upright.
   C. The pulse travels faster in String 1.
   D. The pulse travels faster in String 2.
   E. The transmitted pulse is inverted.

12. [5 points] You blow into a pipe that is open at both ends and produce a note with a fundamental frequency of 440 Hz. Your friend uses an identical pipe, except one end is closed. What is the fundamental frequency of the note that your friend produces?
   A. 110 Hz
   B. 220 Hz
   C. 440 Hz
   D. 880 Hz
   E. 1800 Hz

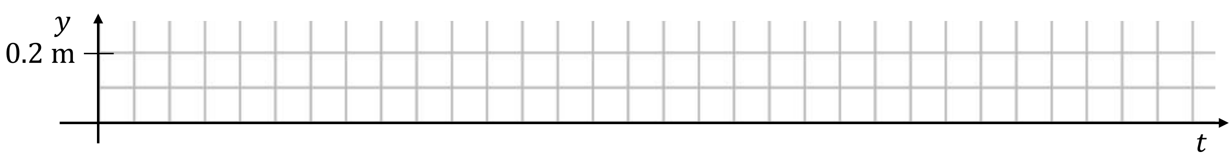
II. [20 points total] Lecture free response questions
<u>You must show your work to get the full credit.</u>

Consider the following scenario for the next two questions.
You attach the right end of a thin spring firmly to a pole at $x = 3.0\text{ m}$ and hold the left end at $x = 0.0\text{ m}$. 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 $x = 1.0\text{ m}$. The snapshot graph below shows the shape of the spring at t = 2.0 s, before the pulse has reached the fixed end.



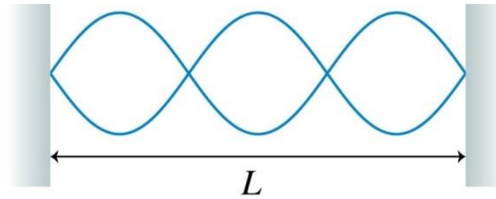
13. [4 points] What is the wave speed of the pulse? Show your work.

14. [7 points] Draw the history graph for Point P below. Make sure that the entire pulse is visible in the graph. Label the horizontal axis with appropriate tick marks so that the time scale is clear.



Use the following scenario for the next three questions.

A taut string of length L is fixed at both ends and driven to form a standing wave as shown at right.

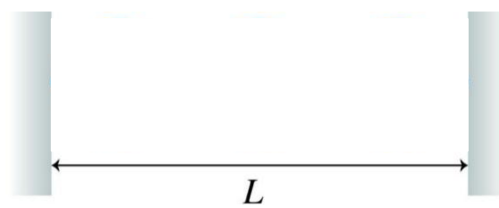


15. [3 points] What is the wavelength of the standing wave in terms of L? No explanation is necessary.

Now suppose that the tension of the string is increased by a factor of four ($T_{\text{new}} = 4T_{\text{old}}$), while the string continues to be driven at the same frequency. The length of the string remains unchanged.

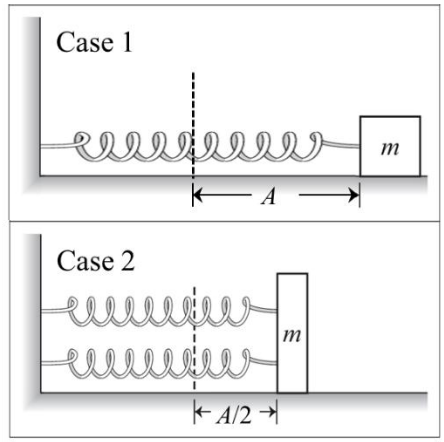
16. [3 points] What is the new wavelength of the wave on the string? Show your work.

17. [3 points] Is a standing wave still formed? If so, draw the new standing wave pattern at right. If not, explain why a standing wave is not formed.



III. [20 points total] Tutorial free response questions

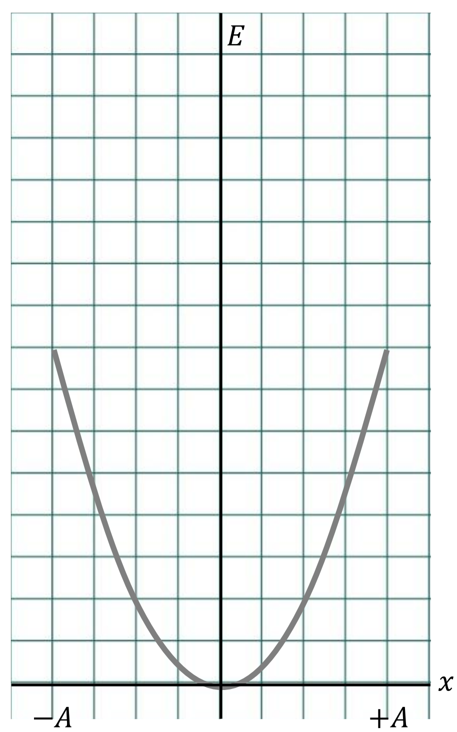
Use the following scenario for the next two questions.



Two block-and-spring(s) systems are shown on the right. Each block moves on a horizontal, frictionless table. The blocks have equal mass m, and the springs are identical and ideal. 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, 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).

18. [4 points] 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.

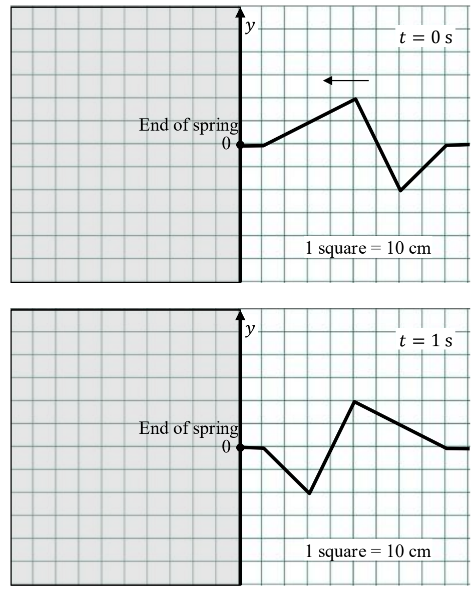
The graph on the right shows the potential energy of the system as a function of the position of the block in Case 1.



19. [6 points] On the same plot, draw and label the following curves for Case 2, 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

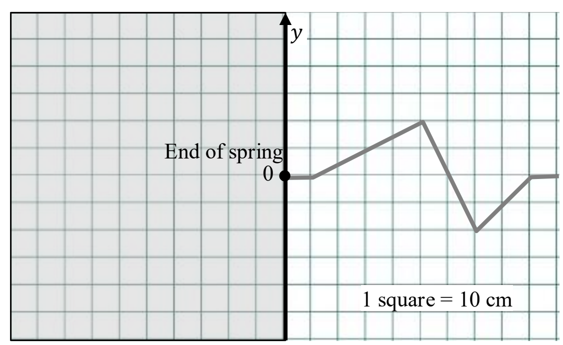
Use the following scenario for the next two questions.

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.

21. [8 points] On the diagram to the right, draw the shape of the spring at t = 0.6 s. <u>Make sure to include and label all pulses</u> you use to determine your answer. The shape of the pulse at t = 0 s is shown in gray for your reference.



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Constants

Gas constant	$R = 8.31\ \mathrm{J/(mol\cdot K)}$
Speed of light in vacuum	$c = 3.00 \times 10^{8}\ \mathrm{m/s}$
Permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/(N\cdot m^2)}$
Permeability of free space	$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T\cdot m/A}$
Planck's constant	$h = 6.63 \times 10^{-34}\ \mathrm{J\cdot s}$
	$h = 4.14 \times 10^{-15}\ \mathrm{eV\cdot s}$
Electron charge	$e = 1.602 \times 10^{-19}\ \mathrm{C}$

Equations from 114 and 115

Acceleration of gravity	$g = 9.8\ \mathrm{m/s^2}$
Kinematic equations	$(v_x)_\mathrm{f} = (v_x)_\mathrm{i} + a_x \Delta t$
	$x_\mathrm{f} = x_\mathrm{i} + (v_x)_\mathrm{i}\,\Delta t + \frac{1}{2} a_x (\Delta t)^2$
	$(v_x)_\mathrm{f}^2 = (v_x)_\mathrm{i}^2 + 2a_x \Delta x$
Newton's 2nd law	$\vec{F}_\mathrm{net} = m\vec{a}$
Linear momentum	$\vec{p} = m\vec{v}$
Translational kinetic energy	$K = \frac{1}{2} m v^2$
Elastic potential energy	$\Delta U_\mathrm{s} = \frac{1}{2} k \left(x_\mathrm{f}^2 - x_\mathrm{i}^2\right)$
Gravitational potential energy	$\Delta U_\mathrm{g} = mg\Delta y$
Power	$P = \dfrac{\Delta E}{\Delta t}$
Pressure	$p = \dfrac{F}{A}$
Temprature conversion	$T\,(\mathrm{K}) = T\,(^\circ\mathrm{C}) + 273$
Thermal radiation	$\dfrac{Q_\mathrm{net}}{\Delta t} = e\sigma A \left(T^4 - T_0^4\right)$

Oscillations

Position in SHM	$x(t) = A\cos(2\pi f t)$
Velocity in SHM	$v_x(t) = -2\pi f A \sin(2\pi f t)$
Acceleration in SHM	$a_x(t) = -(2\pi f)^2 A\cos(2\pi f t)$
Angular velocity	$\omega = 2\pi f = \dfrac{2\pi}{T}$
Mechanical energy in SHM	$E = K + U = \dfrac{1}{2} k A^2$

Frequency for:

Mass on a spring	$f = \dfrac{1}{2\pi}\sqrt{\dfrac{k}{m}}$
Simple pendulum	$f = \dfrac{1}{2\pi}\sqrt{\dfrac{g}{L}}$
Physical pendulum	$f = \dfrac{1}{2\pi}\sqrt{\dfrac{mgd}{I}}$
Damped oscillation	$x_\mathrm{max}(t) = Ae^{-t/\tau}$

Waves and sound

Sinusoidal wave function	$y(x,t) = A\cos\left(2\pi\left(\frac{x}{\lambda} \pm \frac{t}{T}\right)\right)$
Speed of sinusoidal waves	$v = \lambda f$
Speed of a wave on a string	$v_\mathrm{string} = \sqrt{\dfrac{T_\mathrm{s}}{\mu}}$
Speed of sound in gas	$v_\mathrm{sound} = \sqrt{\dfrac{\gamma R T}{M}}$
Intensity	$I = \dfrac{P}{a}$
Intensity of spherical wave	$I = \dfrac{P_\mathrm{source}}{4\pi r^2}$
Sound intensity level	$\beta = (10\,\mathrm{dB})\log_{10}\left(\dfrac{I}{I_0}\right)$
	$I_0 = 1.0 \times 10^{-12}\ \mathrm{W\cdot m^{-2}}$
Log function	$b = a^x \leftrightarrow \log_a(b) = x$
	$\log(ab) = \log(a) + \log(b)$
	$\log\left(\frac{a}{b}\right) = \log(a) - \log(b)$
	$\log\left(a^b\right) = b\log(a)$

Sound Doppler effect for:

Moving source	$f_\pm = \dfrac{f_\mathrm{s}}{1 \mp v_\mathrm{s}/v}$
Moving observer	$f_\pm = \left(1 \pm \dfrac{v_\mathrm{o}}{v}\right) f_\mathrm{s}$
Moving object reflection	$\Delta f = \pm 2 f_\mathrm{s} \dfrac{v_\mathrm{o}}{v}$ for $v_\mathrm{o} \ll v$

Standing waves:

On a string	$f_m = m\left(\dfrac{v}{2L}\right) = m f_1,$
	$\lambda_m = \dfrac{\lambda_1}{m} = \dfrac{2L}{m},\ m = 1, 2, 3, \ldots$

Open-open or	$f_m = m\left(\frac{v}{2L}\right) = mf_1,$
closed-closed pipe	$\lambda_m = \frac{\lambda_1}{m} = \frac{2L}{m},\ m = 1, 2, 3, ...$
Open-closed pipe	$f_m = m\left(\frac{v}{4L}\right) = mf_1,$
	$\lambda_m = \frac{\lambda_1}{m} = \frac{4L}{m},\ m = 1, 3, 5, ...$

Circular aperture:

Central maximum diameter	$w = \frac{2.44\lambda L}{D}$
First dark fringe	$\theta_1 = \frac{1.22\lambda}{D}$
	$y_1 = \frac{1.22\lambda L}{D}$

Wave optics

Index of refraction	$v = \frac{c}{n}$
Wavelength in material	$\lambda_{\text{mat}} = \frac{\lambda_{\text{vac}}}{n}$

Double-slit interference:

Small angle approx.	$\sin(\theta) \approx \theta$
Bright (sources in phase)	$\sin(\theta_m) = m\frac{\lambda}{d}$
	$y_m = \frac{m\lambda L}{d}$
	$m = 0, 1, 2, ...$
Dark (sources in phase)	$y'_m = \left(m + \frac{1}{2}\right)\frac{\lambda L}{d}$
	$m = 0, 1, 2, ...$
Diffraction grating (bright)	$d\sin\theta_m = m\lambda$
	$y_m = L\tan\theta_m$
	$m = 0, 1, 2, ...$

Thin film:

Bright (0 or 2 phase changes)	$2t = m\frac{\lambda}{n}$
or dark (1 phase change)	$m = 0, 1, 2, ...$
Dark (0 or 2 phase changes)	$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n}$
or bright (1 phase change)	$m = 0, 1, 2, ...$

Single slit diffraction:

Dark fringes	$a\sin\theta_p = p\lambda$
	$p = 1, 2, 3, ...$
Central maximum width	$w = \frac{2\lambda L}{a}$ for $\frac{\lambda}{a} \ll 1$

Ray optics

Law of reflection	$\theta_{\text{r}} = \theta_{\text{i}}$
Image by plane mirror	$s' = s$
Snell's law	$n_1\sin\theta_1 = n_2\sin\theta_2$
Critical angle	$\theta_{\text{c}} = \sin^{-1}\left(\frac{n_2}{n_1}\right),\ n_1 > n_2$
Image by refraction	$s' = \frac{n_2}{n_1}s$
Magnification of lens or mirror	$m = -\frac{s'}{s}$

Thin lens & curved mirrors:

Thin-lens equation	$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$

Sign conventions:

Object	$s > 0$, always
Image	$s' > 0$, for real image
Focal length	$f > 0$, for converging lens
	or converging mirror
Magnification	$m > 0$ for upright image

Optical instruments

Refractive power	$P = \frac{1}{f}$
Normal near point	$\text{NP}_{\text{normal}} = 25$ cm

Angular magnifications:

Magnifying glass	$M = \frac{\text{NP}}{f}$
Microscope	$M = -\frac{L \times \text{NP}}{f_{\text{o}}f_{\text{e}}}$
Telescope	$M = -\frac{f_{\text{o}}}{f_{\text{e}}}$