Physics 116 A
Autumn 2025

116A - K.TOLICH

Midterm 2
November 18th, 2025

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

Printed Name	

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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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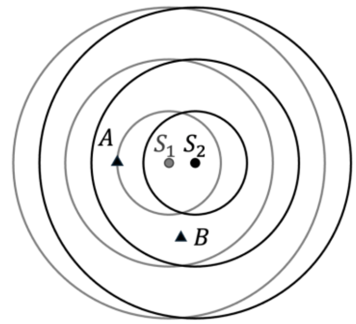
I. Lecture multiple choice (60 points – 12 questions)

1) (5 pts) Surface waves are generated from two coherent sources, S_1 and S_2, separated by a small distance. The figure shows the wave crests from S_1(gray) and S_2(black) at a particular instant. Point A is located at a position of perfect destructive interference, and Point B is located at a position of maximum constructive interference.
Now, the frequency of both sources is doubled. Which of the following statements are correct? **Select all that apply.**



   A. Point A remains a position of perfect destructive interference.
   B. Point A becomes a position of maximum constructive interference.
   C. Point B becomes a position of perfect destructive interference.
   D. Point B remains a position of maximum constructive interference.
   E. None of the above is correct.

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2) (5 pts) A light wave traveling in air, with frequency f_{air} and wavelength λ_{air}, enters a transparent gem. If the index of refraction of the gem is 2.0, which of these relationships for wavelength, λ_{gem}, and frequency, f_{gem}, in gem are correct? **Select all that apply.**

   A. $f_{\text{gem}} = 2f_{\text{air}}$
   B. $f_{\text{gem}} = 0.5f_{\text{air}}$
   C. $\lambda_{\text{gem}} = 2\lambda_{\text{air}}$
   D. $\lambda_{\text{gem}} = 0.5\lambda_{\text{air}}$
   E. None of the above is correct.

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3) (5 pts) Light with a wavelength of λ = 400 nm passes through a barrier containing two very narrow slits separated by a distance $d = 6.0 \times 10^{-6}$ m. A interference pattern is observed on a screen located 1.0 m away from the slits. Which of following best describes the nature of light observed at a point on the screen located 0.025 m from the center of the pattern?

   A. It is a minimum (completely dark).
   B. It is a maximum.
   C. It is neither a minimum nor a maximum.
   D. Not enough information is given.

4) (5 pts) A commercial diffraction grating has 800 lines per mm. When a student shines a 410 nm laser through this grating, how many bright spots could be seen on a screen behind the grating?

A. 3
B. 4
C. 5
D. 6
E. 7

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5) (5 pts) An antireflective coating is applied to eyeglass lenses to minimize the reflection of stray light. The coating has a minimum thickness of 90 nm and is most effective at reducing reflection for light with a wavelength of 480 nm in air. Assuming the index of refraction of the coating is less than that of the lens material, what is the index of refraction of the coating?

A. 1.3
B. 2.7
C. 4.0
D. 5.3
E. 8.0

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6) (5 pts) Green light with wavelength 532 nm passes through a single narrow slit and produces a diffraction pattern on a distant screen. Which of the following individual changes makes the central maximum on the screen *narrower*? **Select all that apply.**

A. Move the screen closer.
B. Use blue light with wavelength 473 nm instead.
C. Make the slit narrower.
D. None of the above.

7) (5 pts) A monochromatic light illuminates a hole with diameter 4.8×10^{-4} m. If the width of the central maximum on a screen located 5.0 m away is 1.6×10^{-2} m, what is the wavelength of the light?

A. 190 nm
B. 380 nm
C. 630 nm
D. 1300 nm
E. 1500 nm

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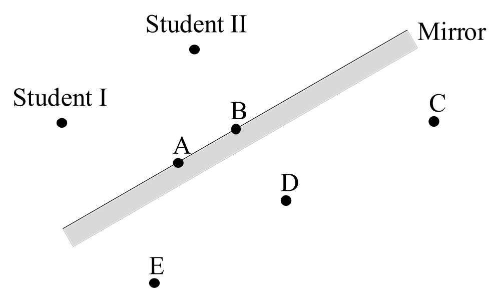
8) (5 pts) An object (not shown) is placed in front of a plane mirror, and Student I observes the image of the object to be located at position E indicated in the figure at right. Where does another student, Student II, observe the image to be located?



A. Location A
B. Location B
C. Location C
D. Location D
E. Location E

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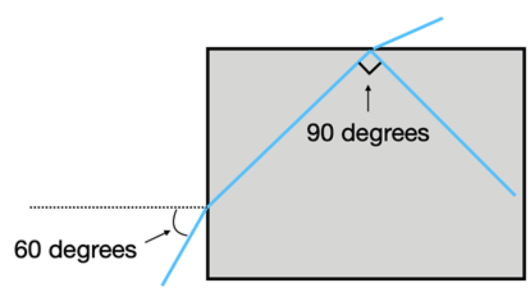
9) (5 pts) A light ray enters a slab of transparent material at an angle of 60 degrees to the normal. At the subsequent internal reflection, the ray bends by 90 degrees as shown. What is the index of refraction of the material?



A. 0.0
B. 0.50
C. 0.82
D. 1.2
E. 1.6

10) (5 pts) A thin glass rod is submerged in water. What is the critical angle for light traveling inside the rod? The index of refraction of water is 1.33, and the index of refraction of the glass rod is 1.50.

A. 27.5°
B. 41.8°
C. 45.0°
D. 48.8°
E. 62.5°

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11) (5 pts) Consider a **converging** mirror with a focal length of 1.0 m. If an object is placed 0.5 m in front of the mirror, which of the following statements about the image formed are correct? **Select all that apply.**

A. It is real.
B. It is enlarged.
C. It is inverted.
D. None of the above is correct.

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12) (5 pts) Two telescopes have identical objectives, but the focal length of the eyepiece of telescope A is twice as long as that of telescope B. Which telescope has a greater absolute value of angular magnification?

A. Telescope A
B. Telescope B
C. Both telescopes have the same angular magnification.
D. Not enough information is given to determine.

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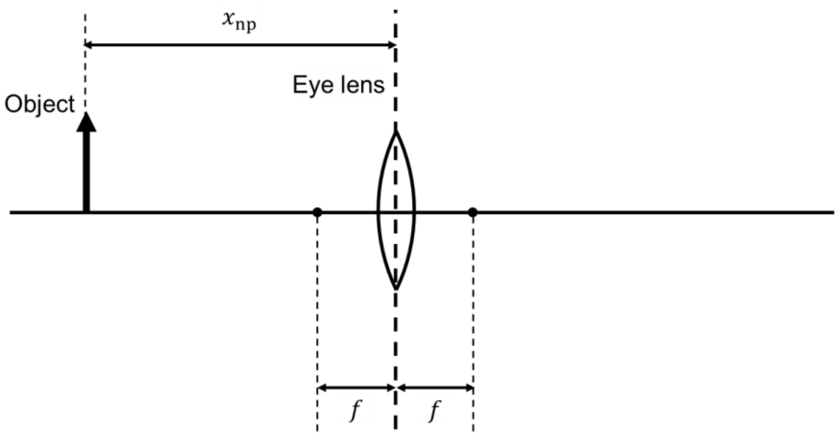
II. Lecture free response (20 points)

Use the following scenario for the next four questions.
Approximate an eye as a single thin converging lens placed in front of the retina. An object is placed at your near point, x_{np}, in front of your eye lens, and the eye adjusts the lens's focal length to f so that the image of the object is focused on the retina.



14) (7 pts) On the diagram above, draw the three "special" rays in ray tracing to determine the location of the imaged formed by the lens. Clearly indicate where the image is formed.

15) (5 pts) What is the distance between the eye lens and the retina in terms of x_{np} and f?

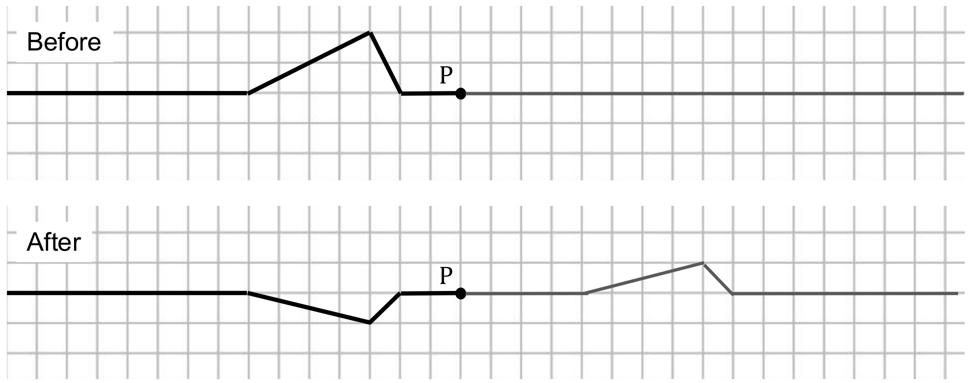
Suppose that your near point, x_{np}, is greater than the distance of the normal near point, $x_{\mathrm{np,normal}}$, and you wish to use a corrective lens so that your vision for seeing nearby objects is normal. Assume that the distance between the corrective lens and the eye lens is negligible.

16) (3 pts) Should the corrective lens be converging or diverging? Explain.

17) (5 pts) What is the expression for the refractive power of the corrective lens in terms of x_{np} and $x_{\mathrm{np,normal}}$?

III. Tutorial free response (20 points)

18) (7 pts) Two horizontal springs are connected at point P. The pulse speed in the right spring is **twice** that in the left spring. A pulse is sent from the left end of the left spring toward point P. The upper figure below shows the incident pulse before it reaches point P. The lower figure below shows the transmitted and reflected pulses after the incident pulse reaches point P. However, this figure contains several flaws. Identify the flaws and describe how you can correct them.



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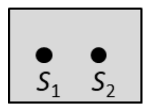
19) (6 pts) Two point sources, S_1 and S_2, are oscillating in phase in water, each producing periodic circular waves with wavelength λ. The sources are separated by a distance of 1.5λ. A top-view diagram of the sources is shown below. In the space provided below, draw qualitatively accurate nodal lines (use dashed lines) and antinodal lines (use solid lines) resulting from the interference of the waves. You do not need to draw any lines inside the gray box near the sources. Label each line with path length difference, δs, expressed in terms of λ.



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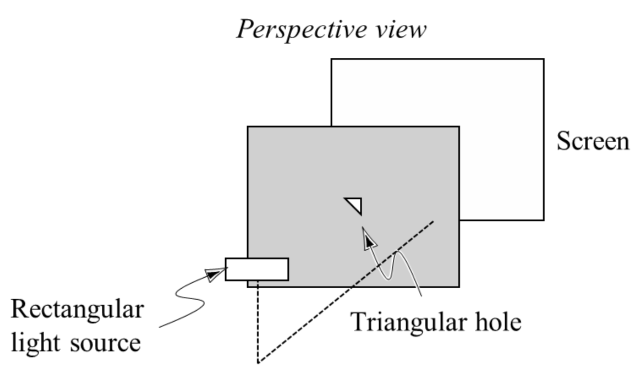
20) (7 pts) A mask with a triangular hole is placed between a rectangular light source and a screen as shown in the diagram. In the space below, draw and/or describe the features of the image pattern observed on the screen.



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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	$K = \frac{1}{2}mv^2$
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	$E = K + U = \dfrac{1}{2}kA^2$

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	$v_\mathrm{sound} = \sqrt{\dfrac{\gamma RT}{M}}$
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	$\Delta f = \pm 2f_\mathrm{s}\dfrac{v_\mathrm{o}}{v}$ for $v_\mathrm{o} \ll v$

Standing waves:

On a string	$f_m = m\left(\dfrac{v}{2L}\right) = mf_1,$
	$\lambda_m = \dfrac{\lambda_1}{m} = \dfrac{2L}{m},\ m = 1,2,3,\ldots$

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

Wave optics

Index of refraction	$v = \frac{c}{n}$
Wavelength in material	$\lambda_{\mathrm{mat}} = \frac{\lambda_{\mathrm{vac}}}{n}$
Double-slit interference:	
Small angle approx.	$\sin(\theta) \approx \theta$
Bright (sources in phase)	$\sin(\theta_m) = m\frac{\lambda}{d}$
	$y_m = \frac{m\lambda L}{d}$
	$m = 0, 1, 2, \ldots$
Dark (sources in phase)	$y'_m = \left(m + \frac{1}{2}\right)\frac{\lambda L}{d}$
	$m = 0, 1, 2, \ldots$
Diffraction grating (bright)	$d\sin\theta_m = m\lambda$
	$y_m = L\tan\theta_m$
	$m = 0, 1, 2, \ldots$
Thin film:	
Bright (0 or 2 phase changes)	$2t = m\frac{\lambda}{n}$
or dark (1 phase change)	$m = 0, 1, 2, \ldots$
Dark (0 or 2 phase changes)	$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n}$
or bright (1 phase change)	$m = 0, 1, 2, \ldots$
Single slit diffraction:	
Dark fringes	$a\sin\theta_p = p\lambda$
	$p = 1, 2, 3, \ldots$
Central maximum width	$w = \frac{2\lambda L}{a}$ for $\frac{\lambda}{a} \ll 1$

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

Ray optics

Law of reflection	$\theta_{\mathrm{r}} = \theta_{\mathrm{i}}$
Image by plane mirror	$s' = s$
Snell's law	$n_1\sin\theta_1 = n_2\sin\theta_2$
Critical angle	$\theta_{\mathrm{c}} = \sin^{-1}\left(\frac{n_2}{n_1}\right),\ n_1 > n_2$
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	$\mathrm{NP}_{\mathrm{normal}} = 25\ \mathrm{cm}$
Angular magnifications:	
Magnifying glass	$M = \frac{\mathrm{NP}}{f}$
Microscope	$M = -\frac{L \times \mathrm{NP}}{f_{\mathrm{o}}f_{\mathrm{e}}}$
Telescope	$M = -\frac{f_{\mathrm{o}}}{f_{\mathrm{e}}}$

Resolution:

Telescope	$\theta_1 = \dfrac{1.22\lambda}{D}$
Microscope	$d_{\min} = \dfrac{0.61\lambda}{\mathrm{NA}} = \dfrac{0.61\lambda}{n\sin\phi_0}$

Electromagnetic waves

Speed	$c = \lambda f = \dfrac{E_0}{B_0}$
Intensity	$I = \frac{P}{A} = \frac{1}{2}c\epsilon_0 E_0^2 = \frac{1}{2}\frac{c}{\mu_0}B_0^2$
Malus's law	$I_{\text{transmitted}} = I_{\text{incident}}\left(\cos\theta\right)^2$

Quantum physics

Thermal radiation	$\lambda_{\text{peak}} = \dfrac{2.9 \times 10^6\ \text{nm}\cdot\text{K}}{T}$
Bragg condition	$\Delta r = 2d\cos\theta_m = m\lambda$
	$m = 1, 2, 3, \ldots$
Photon energy	$E = hf$

Photo-electric effect:

Cutoff frequency	$f_0 = \dfrac{E_0}{h}$
Stopping potential	$V_{\text{stop}} = \dfrac{K_{\max}}{e} = \dfrac{hf - E_0}{e}$
de Broglie wavelength	$\lambda = \dfrac{h}{p} = \dfrac{h}{mv}$
Uncertainty principle	$\Delta x \Delta p_x \geq \dfrac{h}{4\pi}$

Atoms and molecules

Balmer formula	$\lambda = \dfrac{91.1\ \text{nm}}{\left(\frac{1}{m^2} - \frac{1}{n^2}\right)}$,
	m & n integers, $n > m$

Bohr hydrogen atom:

Radius	$r_n = n^2 a_{\text{B}}$
	$= \left(5.29 \times 10^{-11}\ \text{m}\right) n^2$
Energy	$E_n = -\dfrac{E_1}{n^2} = -\left(13.6\,\text{eV}\right)\dfrac{1}{n^2}$
	$n = 1, 2, 3, \ldots$

Nuclear physics

Mass number	$A = Z + N$
Designation	${}^{A}_{Z}X$
Binding energy	$B = \left(Zm_{\text{H}} + Nm_{\text{n}} - m_{\text{atom}}\right)$
	$\times\left(931.49\ \frac{\text{MeV}}{\text{u}}\right)$
Alpha decay	${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + \alpha + \text{energy}$
Beta-minus decay	${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + e^- + \text{energy}$
Beta-plus decay	${}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + e^+ + \text{energy}$
Time constant	$\tau = \dfrac{t_{1/2}}{\ln 2} = (1.44)\, t_{1/2}$
Half-life	$t_{1/2} = \tau \ln 2 = 0.693\tau$
Number of nuclei	$N = N_0\left(\frac{1}{2}\right)^{t/t_{1/2}} = N_0 e^{-t/\tau}$
Activity	$R = \frac{N}{\tau} = R_0\left(\frac{1}{2}\right)^{t/t_{1/2}} = R_0 e^{-t/\tau}$
Radiation dose	$1\text{Gy} = 1.00\ \text{J/kg}$
(absorbed energy)	
Dose equivalent	dose equivalent in Sv
	= dose in Gy × RBE