

Please write your CID here _____

No time limit. One 3x5 note card (handwritten, both sides). No books. Student calculators OK.

Constants which you may or may not need:

$g = 9.8 \text{ m/s}^2$	Linear exp. coeff. of copper: $17 \times 10^{-6} / ^\circ\text{C}$	Thermal conduct. of alum.: $238 \text{ J/s}\cdot\text{m}\cdot^\circ\text{C}$
$G = 6.67 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$	Linear exp. coeff. of steel: $11 \times 10^{-6} / ^\circ\text{C}$	Thermal conduct. of copper: $397 \text{ J/s}\cdot\text{m}\cdot^\circ\text{C}$
$k_B = 1.381 \times 10^{-23} \text{ J/K}$	Specific heat of water: $4186 \text{ J/kg}\cdot^\circ\text{C}$	Speed of sound in air: 343 m/s (unless otherwise specified)
$N_A = 6.022 \times 10^{23}$	Specific heat of ice: $2090 \text{ J/kg}\cdot^\circ\text{C}$	Index of refraction of water: $n_{\text{water}} = 1.33$
$R = k_B \cdot N_A = 8.314 \text{ J/mol}\cdot\text{K}$	Specific heat of steam: $2010 \text{ J/kg}\cdot^\circ\text{C}$	Index of refraction of glass: $n_{\text{glass}} = 1.5$ (unless otherwise specified)
$\sigma = 5.67 \times 10^{-8} \text{ W/m}^2\cdot\text{K}^4$	Specific heat of aluminum: $900 \text{ J/kg}\cdot^\circ\text{C}$	Index of refraction of air: $n_{\text{air}} = 1.0$ (unless otherwise specified)
$I_0 = 10^{-12} \text{ W/m}^2$	Specific heat of copper: $387 \text{ J/kg}\cdot^\circ\text{C}$	
Density of water: 1000 kg/m^3	Latent heat of melting (water): $3.33 \times 10^5 \text{ J/kg}$	
Density of air: 1.29 kg/m^3	Latent heat of boiling (water): $2.26 \times 10^6 \text{ J/kg}$	
Density of aluminum: 2700 kg/m^3	Latent heat of boiling (liquid nitrogen): $1.98 \times 10^5 \text{ J/kg}$	
Linear exp. coeff. of aluminum: $24 \times 10^{-6} / ^\circ\text{C}$		

Conversion factors which may or may not be helpful:

1 inch = 2.54 cm	1 atm = $1.013 \times 10^5 \text{ Pa} = 14.7 \text{ psi}$	$T_F = \frac{9}{5}T_C + 32$
1 m ³ = 1000 L	1 eV = $1.602 \times 10^{-19} \text{ J}$	$T_K = T_C + 273.15$

Other equations which you may or may not need to know:

$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$	Surface area of sphere = $4\pi r^2$	Volume of sphere = $(4/3)\pi r^3$
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Instructions:

- Record your answers to the multiple choice questions (“Problem 1” on the next page) on the bubble sheet.
- To receive full credit on the worked problems, please show all work and write neatly.
- In general, to maximize your partial credit on worked problems you get wrong it’s good to solve problems algebraically first, then plug in numbers (with units) to get the final answer. Draw pictures and/or diagrams to help you visualize what the problems is stating and asking, and so that your understanding of the problem will be clear to the grader.
- Unless otherwise instructed, give all numerical answers for the worked problems in SI units, to 3 or 4 significant digits. For answers that rely on intermediate results, remember to keep extra digits in the intermediate results, otherwise your final answer may be off. Be especially careful when subtracting two similar numbers.
- Unless otherwise specified, treat all systems as being frictionless (e.g. fluids have no viscosity).

Scores: (for grader to fill in)	
Problem 1 _____	Problem 7 _____
Problem 2 _____	Problem 8 _____
Problem 3 _____	Problem 9 _____
Problem 4 _____	Extra Credit _____
Problem 5 _____	
Problem 6 _____	Total _____

(16 pts) **Problem 1:** Multiple choice conceptual questions. Choose the best answer. **Fill in your answers on the bubble sheet.**

- 1.1. The sound of a trumpet playing a note is qualitatively different than the sound of a flute playing a note at the same pitch. Why is that?
- The two notes have different amplitudes
 - The two notes have different durations
 - The two notes have different fundamental frequencies
 - The two notes have different phases
 - The two notes have different strengths of harmonics
- 1.2. Without using a multiple lens/mirror setup, a converging lens can produce a virtual image.
- True
 - False
- 1.3. Without using a multiple lens/mirror setup, a diverging lens can produce a real image.
- True
 - False
- 1.4. You compare the diffraction pattern between two single (“wide”) slits, one at a time. Slit A produces a pattern that has the maxima and minima more spaced out than the pattern produced by Slit B. Which is true?
- Slit A is narrower than Slit B
 - Slit A is wider than Slit B
- 1.5. Which is more likely to focus closer to a converging lens... a blue laser or a red laser?
- Blue laser
 - Red laser
- 1.6. What kind of lenses do far-sighted people need to correct their vision?
- Converging
 - Diverging
- 1.7. In slit problems, when can you make the approximation that the rays come out from the slits parallel to each other?
- When the slit size/spacing is much smaller than L
 - When the slit size/spacing is much larger than L
 - When the part of the diffraction pattern you are interested in is much smaller than L
 - When the part of the diffraction pattern you are interested in is much larger than L
- 1.8. In slit problems, when can you make the approximation that $\sin\theta = y/L$?
- When the slit size/spacing is much smaller than L
 - When the slit size/spacing is much larger than L
 - When the part of the diffraction pattern you are interested in is much smaller than L
 - When the part of the diffraction pattern you are interested in is much larger than L
- 1.9. How did Young do his famous “double-slit” experiment?
- He used a laser to ensure coherence between the two slits
 - He used a third slit to produce light that was coherent at the two slits
 - He used a gas lantern and did not worry about coherence between slits
- 1.10. A thin layer of oil (thickness t , index of refraction = 1.5) is covering a pool of water (infinitely thick, index of refraction = 1.33). For light shining directly on the pool from above and reflecting back, which of the following is true?
- The light will interfere constructively with itself when $2t = m\lambda_{\text{vacuum}}$
 - The light will interfere constructively with itself when $2t = (m + \frac{1}{2}) \lambda_{\text{vacuum}}$
 - The light will interfere constructively with itself when $2t = m\lambda_{\text{vacuum}}/n_{\text{oil}}$
 - The light will interfere constructively with itself when $2t = (m + \frac{1}{2}) \lambda_{\text{vacuum}}/n_{\text{oil}}$
 - The light will interfere constructively with itself when $2t = m\lambda_{\text{vacuum}}/n_{\text{water}}$
 - The light will interfere constructively with itself when $2t = (m + \frac{1}{2}) \lambda_{\text{vacuum}}/n_{\text{water}}$

- 1.11. For diffraction from a single “wide” slit, which is true of the central point ($y=0$)?
- The intensity at $y=0$ is infinite
 - The intensity is finite, but typically much larger than the surrounding maxima
 - The intensity is finite, and about the same magnitude as the surrounding maxima
 - The intensity is finite, and substantially smaller than the surrounding maxima
 - The intensity is zero
- 1.12. For diffraction from two infinitely narrow slits, which is true of the central point ($y=0$)?
- The intensity at $y=0$ is infinite
 - The intensity is finite, but typically much larger than the surrounding maxima
 - The intensity is finite, and about the same magnitude as the surrounding maxima
 - The intensity is finite, and substantially smaller than the surrounding maxima
 - The intensity is zero
- 1.13. For diffraction from a circular aperture, which is true of the central point ($r=0$)?
- The intensity at $y=0$ is infinite
 - The intensity is finite, but typically much larger than the surrounding maxima
 - The intensity is finite, and about the same magnitude as the surrounding maxima
 - The intensity is finite, and substantially smaller than the surrounding maxima
 - The intensity is zero
- 1.14. Suppose you shine a laser through a piece of foil which has two identical holes shaped like tiny llamas, spaced apart by a distance d (you may assume d is twice as big as the size of each llama). What will the diffraction pattern look like?
- The same as a pattern from a single llama
 - Two single-llama patterns, superimposed on one another
 - A single-llama pattern, modulated by a double slit pattern
- 1.15. The electric field in a light wave is described by the following equation: $\vec{E} = A\hat{x} \cos \left[k \left(\frac{y+z}{\sqrt{2}} \right) - \omega t \right]$. In what direction is it traveling? (The vectors given as answer choices are all unit vectors.)
- \hat{x}
 - $-\hat{x}$
 - $\frac{\hat{y} + \hat{z}}{\sqrt{2}}$
 - $\frac{-\hat{y} - \hat{z}}{\sqrt{2}}$
 - $\frac{\hat{y} - \hat{z}}{\sqrt{2}}$
 - $\frac{-\hat{y} + \hat{z}}{\sqrt{2}}$
- 1.16. Same equation. In what direction is the electric field oscillating?
- From \hat{x} to $-\hat{x}$
 - From $\frac{\hat{y} + \hat{z}}{\sqrt{2}}$ to $\frac{-\hat{y} - \hat{z}}{\sqrt{2}}$
 - From $\frac{\hat{y} - \hat{z}}{\sqrt{2}}$ to $\frac{-\hat{y} + \hat{z}}{\sqrt{2}}$

(16 pts) **Problem 2.**

(a) If you are underwater, and shine a laser at the surface, at what angles from the perpendicular will none of the laser light emerge from the surface? ($n_{\text{water}} = 1.33$; $n_{\text{air}} = 1.00$)

(b) At what angle above the horizon will sunlight reflecting off of a lake be completely polarized to you?

(c) If you shine vertically polarized laser light that at a (perfect) polarizer whose transmission axis is angled at 30° clockwise away from the vertical, (i.e., it would completely allow light through that is polarized at a 30° angle clockwise away from vertical), what fraction of the laser intensity will pass through?

(d) You want a laser beam going from air ($n_{\text{air}} = 1.00$) into glass ($n_{\text{glass}} = 1.50$) to have a 30° angle measured from the perpendicular, inside the glass. At what angle (from the perpendicular) should you have the laser beam in the air?

(12 pts) **Problem 3.** Explain the following, in 1-2 sentences each. Do NOT use equations, but you can use pictures if you like.

(a) Why is angular resolution (in radians) of a telescope limited to $1.22\lambda/D$?

(b) Why do rainbows form when white light passes through a prism?

(c) Why do cameras need lenses? (I.e., what would happen if you tried to make a camera without a lens?)

(d) Why is the *angular* magnification used to describe the magnification produced by magnifying glasses and telescopes?

(12 pts) **Problem 4.** (a) Joanna is near-sighted, and her eyes have a far point of about 100 cm. That is, she cannot focus on anything farther away than 100 cm. Assuming she does not have anything else wrong with her eyes (like astigmatism, which we didn't talk about), what should the focal length of her corrective lenses be? Be sure to specify whether f is plus or minus.

(b) TVs and computer monitors are made up of pixels, which are colored dots very closely spaced together. For someone with a near point of 25 cm, how close does the Rayleigh criterion predict that the dots need to be, in order to make viewing individual pixels completely impossible without the aid of a magnifying device? Assume a maximum pupil diameter of 9 mm and a minimum visible wavelength of 390 nm. (The actual pixel spacing needed will not be as tight as your answer predicts, due to smaller average pupil diameters, larger wavelengths for the light emitted by pixels, and the fact that the optically-sensitive molecules in your retina are not infinitely small.)

(12 pts) **Problem 5.** Draw accurate ray diagrams for the following situations to indicate where each image will be formed, how large it will be, and whether it will be real or virtual. Use at least three rays for each diagram. Use dashed lines for virtual rays, if present. No equations are necessary, but you are of course free to use equations to double check your final image position if you wish.

(a) An object 20 cm to the left of a converging mirror, $f = +15$ cm.

Real or virtual? _____

(b) An object 20 cm to the left of a diverging mirror, $f = -10$ cm.

Real or virtual? _____

(c) An object 20 cm to the left of a converging lens, $f = +40$ cm.

Real or virtual? _____

(d) An object 20 cm to the left of a diverging lens, $f = -50$ cm.

Real or virtual? _____

(12 pts) **Problem 6.** An object is placed 30 cm to the left of lens 1 (converging, $f = +20$ cm). Lens 1 is placed 40 cm to the left of lens 2 (diverging, $f = -50$ cm). Where will the final image be formed? Will it be real or virtual? What will the magnification be? You do not have to provide ray diagrams for this problem, although you are certainly welcome to draw them if that will help you visualize the situation.

$q =$ _____ cm (relative to lens 2)

real vs. virtual: _____

$M_{\text{tot}} =$ _____

(12 pts) **Problem 7.** You set up a diffraction apparatus like the one I used in class, where a 633 nm laser shines on various slits, and forms a diffraction pattern on a screen 10 m away.

(a) If two infinitely narrow slits are used, separated by 100×10^{-6} m, how far apart will the maxima be?

(b) If a single (wide) slit is used, and the width of the central maxima (as measured by the distance between the first minima on either side) is measured to be 10 cm, what was the width of the slit?

(c) If a diffraction grating is used, with 600 lines per millimeter, how far away will the first maximum be from the center? (I'm counting the maximum at the center as the "zeroeth" maximum.)

(4 pts, no partial credit) **Problem 8.** This equation:

$$\frac{d^2x}{dt^2} = -\frac{\gamma}{m} \frac{dx}{dt} - \frac{k}{m}x$$

has a solution (meaning a function for which the equation is true) of the form $x(t) = Ae^{-t/\tau} \cos(\omega t)$. That solution represents, for example, a spring with an oscillating mass hanging from it, where the amplitude of oscillation continually decreases due to air resistance. For homework, and for a problem on a previous exam, you represented $x(t)$ as a complex exponential,

$$x(t) = Ae^{t(-\frac{1}{\tau} + i\omega)}$$

took derivatives, and plugged them into the equation. Doing so allowed you to get an equation with both real and imaginary parts to it. Setting the real parts of the left hand side equal to the real parts of the right hand side, and similarly with the imaginary parts, allowed you to find two equations. Those two equations then allowed you to solve for the values of τ and ω (the oscillation frequency and decay time) in terms of the given quantities k , m , and γ . (That's all assuming you did the problem correctly, of course.)

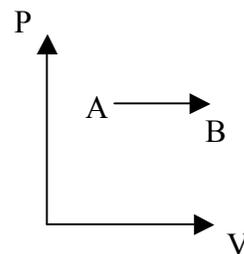
For this problem, go through the same procedure, but stop after you get to the two equations you could use to solve for τ and ω .

Two equations you get from the real and imaginary parts: (you must get both correct to get any credit for this problem)

(simplified as much as possible) Eqn from real parts: _____

(simplified as much as possible) Eqn from imaginary parts: _____

(4 pts, no partial credit) **Problem 9.** Heat is added to 2 moles of a diatomic ideal gas at 600K, while keeping its pressure constant as shown in the diagram. Heat comes in from a reservoir kept at 601 K, which causes the temperature of the gas to increase to 601K as shown (in exaggerated form) in the P-V diagram. What was the change in entropy of the universe during this process? (You can assume that the heat lost by the reservoir is equal to the heat added to the gas.)



(4 pts, no partial credit) **Extra Credit.** Deduce the diffraction pattern (intensity vs angle θ) of four infinitely narrow slits, where the slit separation distances are given in the figure.

