Please attempt ALL problems.

This is a “closed-book” examination.

You may NOT use your notes, nor any textbooks.

You must work independently. NO collaboration is allowed.

You may ask Dr. Curtright questions, however, especially if you think something is unclearly stated.

GOOD LUCK !!

“On my honor, I have neither received nor given aid on this exam.”

Name:  
Signature:  
ID #:  
Essay problem score (25 possible, 1 question):

Multiple choice total score (75 possible, 15 questions, 5 points each):

Exam total score (100 possible):
“Essay” Problem. Show all your work on this problem.

A light wave moving through air \((n = 1)\) is incident on a flat piece of glass material with index of refraction \(n > 1\) at an angle \(\theta\) as shown in the Figure. In terms of the thickness of the material \(d\), and the angle \(\theta\), determine the two distances, \(s_1\) and \(s_2\), traveled by the light reflected from the top surface and from the bottom surface, respectively, when the bottom wave finally emerges from the material. (These distances are shown in the Figure. Note that \(s_2\) is the total “down and back up” distance traveled by the lower wave.)
(extra page for essay problem)
**Multiple Choice Questions**  
Circle or underline the correct answer.

_Sometimes by accident or by design, none of the given answers may be correct. If you believe that to be the case, you should write-in what you believe to be the correct answer._

---

1. An LCR circuit, shown in the Figure, is subjected to an applied voltage \( V(t) = V_{\text{max}} \sin(\omega t) \). At one particular angular frequency, \( \omega_0 \), the power loss in the resistor has its biggest possible value for the given applied voltage. This frequency is called the “resonance” frequency. What is the correct relation between \( L \), \( C \), and this resonance frequency?

\[
\begin{array}{cccc}
(a) & C\omega_0^2 = 1/L & (b) & \omega_0^2 = 1/LC \\
(c) & L\omega_0^2 = 1/C & (d) & 1/\omega_0 = \sqrt{LC} \\
(e) & \omega_0 = \sqrt{1/LC} \\
\end{array}
\]

All are correct!!!

2. What is the equation which determines those values of \( \omega \) for which the power loss in the resistor is exactly one half of its value at the resonance?

\[
\begin{array}{ccc}
(a) & R^2 = \frac{1}{\omega C} & (b) & \omega L - \frac{1}{\omega C} = \pm \sqrt{3}R \\
(c) & R^2 = (\omega L - \frac{1}{\omega C})^2 & (d) & R^2 = \omega^2 L^2 \\
(e) & (\omega L - \frac{1}{\omega C})^2 = 0 \\
\end{array}
\]

A thin lens of focal length \( f_{\text{lens}} = 100 \text{ cm} \) is located at \( x = 0 \), on the \( x \) axis, in front of a convex spherical mirror located at \( x = 100 \text{ cm} \), also on the \( x \) axis. The radius of curvature of the mirror has magnitude \(|R| = 100 \text{ cm} \). A real object is placed on the \( x \) axis at position \( x = -200 \text{ cm} \). The following three questions are about this lens/mirror setup.

3. What is the focal length of just the mirror?

\[
\begin{array}{ccc}
(a) & f_{\text{mirror}} = 50 \text{ cm} & (b) & f_{\text{mirror}} = -50 \text{ cm} \\
(c) & f_{\text{mirror}} = 100 \text{ cm} & (d) & f_{\text{mirror}} = -100 \text{ cm} \\
(e) & f_{\text{mirror}} = -200 \text{ cm} \\
\end{array}
\]

4. What is the location, on the \( x \) axis, of the final image that results from light that leaves the real object, goes through the lens, strikes the mirror, and goes back through the lens?

\[
\begin{array}{ccc}
(a) & x = 50 \text{ cm} & (b) & x = -50 \text{ cm} \\
(c) & x = 100 \text{ cm} & (d) & x = -100 \text{ cm} & (e) & x = -200 \text{ cm} \\
\end{array}
\]

5. Which of the following describes the final image?

\[
\begin{array}{ccc}
(a) & \text{real and upright} & (b) & \text{real and inverted} \\
(c) & \text{virtual and upright} & (d) & \text{virtual and inverted} \\
(e) & \text{no image forms} \\
\end{array}
\]
Red light of wavelength 640 nm illuminates a planar screen in which there are two identical parallel slits of width 0.0640 mm and separation 0.256 mm = 0.256 \times 10^{-3} \text{ meter}. The incoming light waves are traveling in a direction perpendicular to the plane of the screen containing the slits. Light passes in equal amounts through each of the slits and produces an interference pattern on a “viewing” screen parallel to the first screen but at a distance 1.00 meter away. The sideways distance along the viewing screen is called z, and is measured from the center of the viewing screen in a direction perpendicular to the parallel slits. The next two problems are about this interference pattern.

[6] Which of the following figures best illustrates the interference pattern produced on the viewing screen as a function of z?

(a) ![Image](a)  (b) ![Image](b)  (c) ![Image](c)  (d) ![Image](d)  (e) ![Image](e)

[7] Referring to the previous problem, what is the width of the central intensity peak on the viewing screen?

(a) 0.250 cm  (b) 0.375 cm  (c) 0.750 cm  (d) 0.500 cm  (e) 1.00 cm

A proton is a particle with rest mass energy \( mc^2 = 938.272 \text{ MeV} \). At the Fermi National Accelerator Laboratory near Chicago, individual protons are accelerated until they reach a final total energy of 2.00 TeV = 2.00 \times 10^6 \text{ MeV}. (The following three questions are about these protons.)

[8] What is the relativistic \( \gamma \) factor for one of these final protons?

(a) 1.00  (b) 32.7  (c) 1070  (d) 2130  (e) 1.15 \times 10^6

[9] What is the speed of such a proton?

(a) \( v = c \)  (b) \( v = 0.9999996 \) \( c \)  (c) \( v = 0.9999996 \) \( c \)  (d) \( v = 1.0000004 \) \( c \)  (e) \( v = 1.0000009 \) \( c \)
[10] Linearily polarized light is incident normally on a sheet of ideal polaroid, with a 45° angle between the incident light’s electric field and the transmission axis of the polaroid. What fraction of the incident light’s intensity is transmitted through the polaroid?

(a) 1/4  (b) 1/2  (c) 3/4  (d) 1  (e) 0

[11] An FM station broadcasts at a frequency \( f = 100 \) \( MHz \), and at a power level of 100 kilowatts. How many photons does the station radiate, and hence “waste”, during a political ad that lasts for 60 s?

(a) \( 2.3 \times 10^{31} \)  (b) \( 4.5 \times 10^{31} \)  (c) \( 7.5 \times 10^{31} \)  (d) \( 9.1 \times 10^{31} \)

(e) None. (Politics has nothing to do with photons!)

[12] In an electrical discharge tube like the one we showed in class, electrons in hydrogen atoms are excited from \( n = 1 \) energy levels to \( n = 3 \) energy levels. How much energy has each individual electron absorbed?

(a) 2.86 eV  (b) 13.6 eV  (c) 12.09 eV  (d) −12.09 eV  (e) −12.75 eV

[13] If these excited electrons now emit photons and go to lower energy levels, which of the following wavelengths will be detected for the emitted light?

(a) 97 nm  (b) 103 nm  (c) 122 nm  (d) 434 nm  (e) 656 nm

[14] Red light (\( \lambda_{red} = 650 \) nm) strikes a metal plate and liberates electrons from the metal. These electrons are observed to have a maximum kinetic energy of 1.00 eV. What would be the maximum kinetic energy of the liberated electrons if blue light (\( \lambda_{blue} = 480 \) nm) were to strike the same metal?

(a) 0 eV (no electrons would be liberated)  (b) 1.00 eV  (c) 1.68 eV  (d) 2.58 eV  (e) 1.91 eV

[15] A particle of mass \( m \) is confined to an infinitely long pipe of square cross section. Each side of the square is of length \( L \). What is the smallest possible kinetic energy for the particle in the box?

(a) 0  (b) \( \frac{\hbar^2}{2mL^2} \)  (c) \( \frac{\hbar^2}{2mL^2} \)  (d) \( \frac{3\hbar^2}{2mL^2} \)  (e) \( \frac{3\hbar^2}{mL^2} \)

BONUS QUESTION! Red light (\( \lambda = 650 \) nm), green light (\( \lambda = 550 \) nm), and blue light (\( \lambda = 450 \) nm) are all projected simultaneously onto a screen. A pair of miraculous devices (called the “eye” and the “brain”) somehow manage to collect the light reflected from the screen and jointly come up with a perceived color. What is the perceived color?

(1) yellow  
(2) blue  
(3) red  
(4) green  
(5) white