Please utilize the space provided below each problem for your work. You may use extra paper if necessary. If you need additional clarification, be sure to ask. This quiz is open-book and open-notes. GOOD LUCK and DON’T STRESS!!! You may start as soon as you receive the quiz.

Please note that many of the problems on this practice quiz are NOT short-answer questions like you will see on the first Quiz. For problems similar in difficulty to ones you will see on the quiz, I have labelled them with an star (⋆). Each star represents the equivalent of one problem. Therefore, ⋆ is the equivalent of one quiz problem, ⋆⋆ is the equivalent of two quiz problems, etc...

So, this sample quiz should be roughly 3 times as long as the quiz you will take in class on Thursday. From start to finish, the sample quiz should take no longer than 2 1/2 hours to complete.

Please print your name here: ___________________________________

Please print your MIT ID number here: __________________________
Problem 1

A diver shines his unpolarized collimated head-light laser beam toward the surface of the water at an angle of incidence, $\theta$. Complete the ray-optics pictures below to show where the light goes. Also show the polarization effects, if any, of the water on the beams you draw.

\[
\theta_1 = \sin^{-1}\left(\frac{1}{1.33}\right)
\]

\[
\theta_2 = \tan^{-1}\left(\frac{1}{1.33}\right)
\]
Problem 2  

The six \( \mathbf{k} \)-vectors given in the diagrams on the next page all lie in the \((x-z)\) plane. They correspond to six uniform plane waves each of amplitude \( E_0 \) traveling in the directions shown. The polarization vectors are shown as \( \mathbf{\wedge}, \mathbf{\checkmark}, \mathbf{\bigcirc} \) or \( \mathbf{\otimes} \).

(a) Draw the magnetic-field vector onto diagrams \( a, b \) and \( c \).

(b) Write expressions for \( \mathbf{f}_1, \mathbf{f}_2 \) and \( \mathbf{f}_3 \), the spatial frequency vectors corresponding to the waves in diagrams \( a, b \) and \( c \) respectively.

(c) Write complete expressions for the plane waves corresponding to diagrams \( a, b \) and \( c \).

(d) Which pairs of waves, if any, are phase-conjugate pairs?
Problem 3**

(a) Determine the critical angle for the 2-layer medium shown below, given that \( n > n_0 \).

(b) For the \( m \)-layered medium shown below, given that \( n_0 < n_1 < n_2 < \ldots < n_m < n \) determine the critical angle for the entire layered structure.
Problem 4**

(a) For the three waveplates described below, $\phi_s$ and $\phi_f$ are the phase shifts associated with the slow and fast axes of the plate of thickness, $d$. Fill in the table below.

<table>
<thead>
<tr>
<th>Plate</th>
<th>Desired value of $\phi_s - \phi_f$</th>
<th>Formula for plate thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>quarter-wave plate</td>
<td></td>
<td>$d =$</td>
</tr>
<tr>
<td>half-wave plate</td>
<td></td>
<td>$d =$</td>
</tr>
<tr>
<td>full-wave plate</td>
<td></td>
<td>$d =$</td>
</tr>
</tbody>
</table>

(b) You found a wave plate in laboratory and measured its thickness, which turns out to be $32\frac{1}{2}\lambda$ microns, where $\lambda$ is the wavelength of laser light you happen to be using. The fast axis of the plate has a refractive index of 1.30 and a slow axis of refractive index 1.60. What kind of plate is this? (that is, quarter-, half-, or a full-wave plate?) No credit will be given for the correct answer without supporting calculation.
Complete the ray-optics picture for both diagrams shown below. Show all missing rays, their polarizations and angles.

(a) \( \theta_1 = 30^\circ \)

(b) \( \theta_2 = 30^\circ \)
Problem 2 ****

Consider an optical system consisting of two dielectric media with a planar interface. The medium on the left is free space and the medium on the right is isotropic with a refractive index, \( n \). In the questions below, ignore all reflected beams and assume the paraxial approximation holds.

(a) Write the ABCD matrix for the dielectric boundary.

(b) Now consider a plane \( P_1 \) in the free-space medium that is a distance \( d_1 \) from the boundary, and a plane \( P_2 \) in the dielectric medium at a distance \( d_2 \) from the boundary. Find the ABCD matrix for the system bounded by the \( P_1 \) and \( P_2 \) planes, where \( P_1 \) is considered the input plane and \( P_2 \) the output plane.
(c) If an object is placed in the $P_1$ plane, what condition would have to hold such that $P_2$ is an image plane?

(d) Now, set $n = -1$, and determine the image distance, $d_2$, with respect to the object distance, $d_1$ (again, assume the boundary is matched, and that there is no reflection – all rays incident from the first medium enter the second medium).

(e) With $n = -1$, what will be the magnification of the image? Is it Real or Virtual at $d_2$? Assume the boundary is matched, and that there is no reflection – all rays incident from the first medium enter the second medium according to the paraxial approximation and Snell’s law.
(f) Draw the ray-optics picture on the diagram below for $n = -1$.

Note: Having a negative index of refraction does NOT violate Maxwell’s equations. Researchers have several names for such media, such as ‘negative media’ or ‘left-handed media.’ Such media, made of metamaterials (mixtures of normal materials that exhibit peculiar electromagnetic properties) exhibit a bulk negative index of refraction for a small range of electromagnetic frequencies.
The light beams from two He-Ne lasers that you found in lab are first expanded and collimated, and then combined on a screen as shown in the figure below. The wavelength of both lasers is 633nm. Calculate the fringe separation and give the orientation of the fringes in the resulting interference pattern.
Problem 2*
A semiconductor laser diode with a wavelength of 500nm and a coherence length of 10cm is used as the light source in a Michelson interferometer. The fixed mirror is 10cm from the beam splitter. A glass block (n=1.5) of thickness 5cm is placed in the fixed arm as shown. The moveable mirror is permitted to move only through a range that causes the detector current to go through appreciable maxima and minima. What is this range? That is, what are the numerical values of $l_{\text{max}}$ and $l_{\text{min}}$, where $l$ is the distance of the movable mirror from the beam splitter?
Problem 3 **
A thin soap film is stretched on a wire hoop as was demonstrated in the classroom and shown in the figure below. The index of refraction of the soap film is 1.33 (mostly water). A student views a particular spot $S$ on the soap film at a $30^\circ$ angle of reflection under the diffuse white light illumination present in the classroom. The film appears red at the spot $S$ with $\lambda = 600$nm.

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{soap_film_diagram.png}
\caption{Diagram of soap film and light reflection.}
\end{figure}

(a) If $h$ is the thickness of the film and $n$ is its refractive index, what is the interference condition for a bright maximum in reflection for wavelength $\lambda$ incident at an angle $\theta$?

(b) Using the values given in the problem statement, what is one possible thickness of the soap film?
DIFFRACTION

Problem 1**

Draw the far-field (Fraunhofer) diffracted intensity pattern for the objects pictured below; use your pencil or ink lines to indicate intensity maxima. These do not require any calculation; just draw a qualitative sketch, noting any special features (e.g., intensity peaks and troughs near the origin, as well as the overall diffraction patterns). (a) consists of randomly oriented, transmissive rectangular apertures (all of the same dimensions), (b) consists of an opaque square on a transparent substrate, (c) consists of a transmissive inner circle, and a transmissive outer annulus that imparts a phase change of \( \pi \) radians relative to the inner circle. The inner circle and the outer annulus have the same area. The surrounding background is opaque.
Problem 2 ***
Below we have a set of nine transmissive apertures: A, B, S, L, Z, E, X, 2 and P. Match the appropriate aperture with its magnitude-squared Fourier transform (far-field intensity diffraction pattern) by inserting the letter or character in the box below its corresponding diffraction pattern. If you are not sure about an answer, explain your reasoning for partial credit. No credit will be given for illegible characters.
Problem 3 **

Some of the following patterns were obtained in the laboratory by plotting the intensity as a function of space across a screen placed in the far-field of various diffracting apertures. In the spaces provided at the bottom of the next page, match the patterns to the apertures that produced them:

(1) multiple slit grating ________
(2) double slit grating ________
(3) single slit grating ________
(4) sinusoidal amplitude grating ________
(5) two partially-coherent point sources ________
(6) phase-only grating ________
(7) rectangular profile amplitude grating ________
An ideal thick hologram is recorded, using the setup shown in Figure 1 below, with light of wavelength $\lambda$.

For the four read-out cases shown below, (a), (b), (c) and (d): (i) show the location of the output beams and (ii) label the beams (e.g., virtual image, real image, etc.). For (c) and (d) first draw in the readout beams before finishing these parts.
Show (i) readout angle $\alpha$, (ii) location of output beams and (iii) label output beams

Show (i) readout wave, (ii) location of output beams and (iii) label output beams

(b) Reference wave readout

c) Conjugate-of-object-wave readout

d) Optimal reference-beam readout configuration with a plane wave of wavelength $1.5\lambda$
Problem 2

In this question, you will need to perform troubleshooting as one might do in lab. In the laboratory you made a long-exposure transmission hologram of an old civil-war relic that consists of a rigid, upside-down L-shaped bracket that supports a ball by means of a chain (see diagram).

\[ \text{thick metal bracket} \]
\[ \text{loosely-linked chain} \]
\[ \text{welded joint} \]
\[ \text{supporting base} \]
\[ \text{ball} \]

Draw what you would expect to see as the virtual image when the hologram is read out.
What should you do if water begins to flood the lab (Only you and a lab partner are in the lab.)?

What should you do if a lens shatters on the floor? (Only you and a lab partner are in the lab.)

What should you do if you spill photographic chemicals? (Only you and a lab partner are in the lab.)

What are three flammable or poisonous chemicals stored in the laboratory?

Shorter wavelength optical radiation, such as UV, contains __________ energy per photon than IR radiation, and is therefore __________ likely to cause damage to ocular tissues.

Infrared laser light will most likely cause damage to what part of the eye? __________

Ultraviolet laser light will most likely cause damage to what part of the eye? __________

What band of radiation includes the wavelength range 200-400nm?

ANSI ocular laser exposure limits are based on an assumed pupil size of _____ mm.

If you feel a sharp pain in your eye, hear a pop emanating from your eye or suddenly experience cataract-like occluded vision you should... (Only you and a lab partner are in the lab.)
All laser beams should be confined within what volume? (Answer in relation to the optics table as well as your colleagues.)

What type of damage is blue laser light (488nm) most likely to cause? (Hint: It’s the official term for optical cooking of tissue.)

What defines a class IV laser (list two things)? Give an example from the Modern Optics Lab.

What defines a class IIIb laser (list two things)? Give an example from the Modern Optics Lab.

What is the human blink reflex time in seconds?

What is the ANSI standard (reference number) on the Safe Use of Lasers?

What is OD and how does it relate to protective eye wear?

What are the preferred ODs for protective laser goggles while working with lasers in the Modern Optics Lab?

What is the maximum amount of time you may work alone with a class IV laser or a high-voltage power supply?
What should you do if your laboratory partner is being electrocuted? (Only you and a lab partner are in the lab.)

Give one unsafe behavior that will lead to laboratory dismissal.

What are three things you must do before turning on a laser?

What type of clothes must be worn while working in the lab? What other precautions should be taken? Why? (shoes, sleeves, and hair)

What should you do if you accidentally go through the alarmed doors? (Assume that the TA is in the lab.)

What should you do in the case of a fire inside or outside the Modern Optics Lab? (Only you and a lab partner are there.)

What is the building and room number for the Modern Optics Lab? What is the telephone number?

What is the most important rule of safety? (Hint: It was #9 in the safety section of the course syllabus.)