SSSS 2023 Optics Test

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Do not begin until instructed to do so.

Introduction

On behalf of **Optics** Air, the world's premier airline, we would like to welcome you aboard this flight. We know you have many choices when it comes to selecting carriers, and we sincerely appreciate you choosing to fly with us today. Your safety and comfort are our top priorities, and we are committed to providing you with the best possible travel experience. Today's flight will be a short **50 minutes**, with **100 points** in Optics Air Reward Miles available.

This flight was sponsored by **SSSS**. Please refrain from flying with any other sponsor (don't use this test or questions as part of any official tournament).

Remember to **show all work** for partial credit. Unless otherwise specified, use appropriate **SI units** and round to **three significant digits**.

Every question here involves a laser or the interaction with light and matter, so clearly, they are all on-topic.

Name(s): _____

_____

_____

Score _____/100 points

Off-topic Light Trivia

1. (3 points) You shoot a laser in a vacuum.

a. What is the speed of that light (give the exact value)?

b. How could that be calculated from the permittivity and permeability of free space?

c. The laser is not aimed at your eye. Can you still see the beam as it travels through space? Why or why not?

2. (4 points) Now, you shine a white laser.

a. Wait, what? Is a white laser even possible? Explain, via the internal workings of a laser, why this is or is not feasible.

b. What does the color white mean in terms of the distribution of photon frequencies?

c. What is the D65 definition of white light?

d. How is white light generated by a computer?

3. (3 points) You have a lamp that emits light uniformly in all directions for one second. A wall is one meter away.

a. If you were instead two meters away from the wall but kept the lamp for a period of three seconds, what percent of the original energy would reach the wall?

b. What is this relation called?

c. There are actually a few more walls, and they collectively form a cube. What fraction of the lamps energy does each cube receive?

4. (3 points) You shine a (harmless) laser into someone else's eyes.

a. For what range of frequencies would they see that light?

b. How do the cornea, pupil, lens, retina, rods, cones, aqueous humor, and vitreous humour interact with light entering the eye? Describe their functions as well.

5. (2 points) You spray paint a white wall so that, when illuminated by white light, it now appears red.

a. What is physically different about the wall that causes you to see the color red?

b. If you instead illuminated the white wall with red light, the wall would still appear red. How do the two ways of making the wall red differ?

6. (3 points) The sun illuminates a mist of suspended water droplets, and this forms a rainbow.

a. Does the rainbow form in front or behind the water droplets, and why?

b. Is it possible for two rainbows to be formed?

c. Over there is a snake. It can eat you even in complete darkness because of its pit organs, which can sense temperature. But it also likes rainbows. When a snake looks at a rainbow, which color appears at the top of the primary bow?

7. (3 points) For movies in 3D, the projector shines two beams of light intended to be viewed by different eyes. The two lenses in a pair of 3D glasses determine which beam goes to which eye. Why might the glasses prefer circular over linear polarization?

8. (0.5 points per part) Answer the following true or false questions.

a. Humans emit visible radiation differently from how lasers function. _____

b. Laser light can bend around objects only via gravitational lensing. _____

c. Shadows can occur when dark matter interacts with laser light. _____

d. A light year is the distance light (laser or otherwise) would travel, in standard temperature and pressure water, during one Julian year. _____

e. Laser light exhibits properties of both waves and massive particles. _____

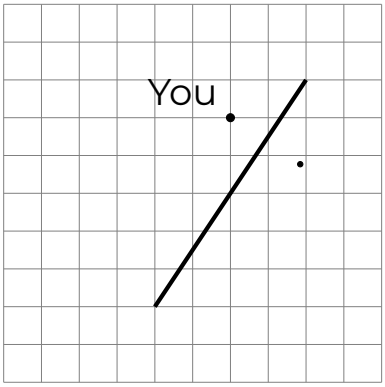
f. The wavelength of visible laser light is huge (a few hundred millimeters), which is why our eyes are able to see it, and why other animals are sensitive to different ranges of the electromagnetic spectrum. _____

Reflection

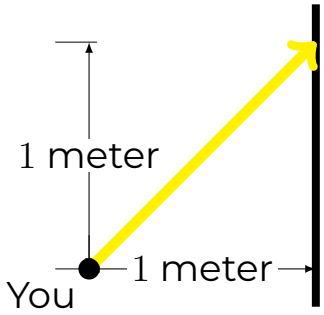
9. (3 points) Again, you are shining a laser at a wall one meter away from you.

a. In fact, the laser light happens to be green, with $\lambda = 5 \times 10^{-7}$ meters. What phase shift would be observed between the wave sent and the wave received? Express your answer in radians.

b. Now, assume the mirror is the black line in the diagram below (and you are at the point labeled You). Outline the area that you can see using the mirror. (It may be helpful to know that the second point is where you see your reflection in the mirror.)



10. (4 points) The laser is now oriented to match the diagram below.



a. What is the angle of reflection?

b. It is also possible that the mirror is not quite smooth.

a. What phenomenon would that be called, and where does the light go?

b. How do we define smoothness in the first place?
(Bonus **5 points** if you can derive the criterion.)

Color

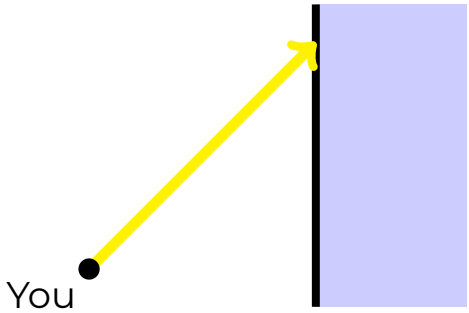
11. (3 points) The wall is now a transparent green color.

a. If you shine a cyan light through the green glass, what color would be seen on the other side, assuming no other illumination, pure light, and a thick enough glass?

b. Why are those assumptions necessary?

c. What about shining red light through the glass?

12. (3 points) If you instead shone white light through colorless glass (see the diagram below), what would happen to the colors? What order would the colors be in, and why?



13. (3 points) Purple, violet, and indigo all look the same, but two of them are spectral colors, and one of them is not.

a. Identify the imposter.

b. How do spectral colors relate to lasers?

14. (2 points) When you shine orange or green light at a band-pass filter, they

go through, but if you shine indigo light, it does not go through. Next to each of the following colors, put **T** if the color is necessarily transmitted, an **A** if the color is necessarily attenuated, and an **IDK** if there is not enough information.

a. Red _____

b. Orange _____

c. Yellow _____

d. Green _____

e. Blue _____

f. Indigo _____

g. Violet _____

15. (2 points) When you shine light through a tube of hot hydrogen gas, the wavelength 486 nanometers shows up in its emission spectra.

a. Identify that color and its energy in electronvolts.

b. What does this tell you about the composition of Hydrogen?

Refraction

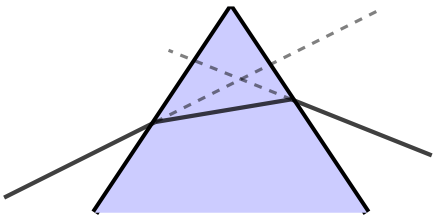
16. (3 points) You now shine at a block of glass. If you shine with some angle θ above the horizontal, the light goes through the glass and refracts. After the light comes out, what angle does it make to the normal?

17. (3 points) The glass is shaped into an isosceles triangular prism.

a. Define the angle of the prism and the angle of deviation in this context.

b. Why does the light bend upon entering the prism, and how would you quantify the bending?

c. Given the angle of the prism and the angles of incidence and refraction at the first point of incidence, how would you determine the second pair of angles, the angle of deviation, and the ratio of the refractive indices?



18. (3 points) The prism morphs into a biconcave lens with a focal length of 30 centimeters. An object is half a meter away from the pole of the lens and 10 centimeters above the axis.

a. What is the power of the lens in diopters? Answer to 20 significant figures.

b. Where is the image formed? What is its magnification? Is it real or virtual? Is it upright or inverted?

c. How would you derive the thin lens and magnification equations through ray diagrams?

d. Is that biconcave lens used in glasses for myopic or hyperopic people, and why?

19. (3 points) You shine a laser into an optical system. This optical system can be described by one of the terms catoptric, catadioptric, or dioptric. Give an example and a brief etymology for each.

20. (3 points) A laser in one medium is shone at a second, transparent medium. Normally, light can refract, but when the angle of incidence is greater than the critical angle, the light is too oblique for refraction to occur. This phenomenon is known as total internal reflection.

a. Explain why there could ever be a case where refraction is impossible, and using this, derive the value of the critical angle.

b. Explain why certain cases of frustrated total internal reflection show comparisons to quantum tunneling.

21. (2 points) The sun illuminates a sign saying *Objects in Mirror Are Closer Than They Appear*. What does it mean, and aside from in the rear-view mirrors of vehicles, where else might this label make sense?

22. (4 points) You shine a light toward a concave mirror, and it happens to have a focal length.

a. Is this focal length positive or negative?

b. How do you define the focal length of a parabola?

c. Can any other shapes have a focal length?

23. (1 point) If the radius of curvature of a mirror in a specific orientation is -0.2 meters, find the focal length of that mirror after it is rotated π radians in a direction perpendicular to the axis of the mirror.

24. (1 point per part) For each of the following, write the definition or associated equation.

a. Thin lens

b. Thin lens equation

c. Aberration

d. Positive meniscus

e. Diverging mirror

f. Magnification equation

g. Cartesian Sign Convention

h. Lensmaker's Formula

i. Nodal point

j. Surface vertex

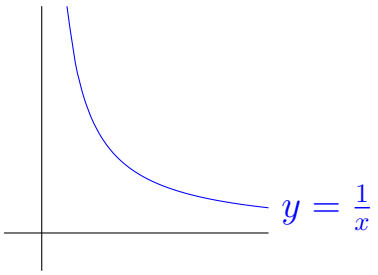
Optical Devices

25. (3 points) To illuminate a specimen, a microscope shines a light from below the specimen. Describe the path of the light after, and name the parts of the microscope it interacts with.

26. (3 points) A rangefinder or telemeter is an optical device that measures the distance from an observer to a certain target. One type of rangefinder is known as a laser rangefinder, which shoots a laser and hopes it comes back.

a. Describe why a laser rangefinder might fail (both practically and physically).

b. A stadiametric rangefinder is an alternative, and a hint at its operation is shown below. Fully explain how it works.



c. Based on its name, describe how a stereoscopic rangefinder works. Remember that a stereoscope is a device that creates an apparently three-dimensional image by showing different images to the two eyes.

27. (2 points) MRI, CT, and PET scans all use electromagnetic waves to image the body.

a. What ranges of the electromagnetic spectrum are used, and why?

b. Specific to CT and PET scans, what is being measured and why does that give information about the position of bones and other body parts?

28. (1 point) Is a true one-way mirror, which reflects light in one direction, but transmits light in the other direction, impossible, without an external energy source controlling the mirror? Why or why not?

Math

29. (1 point) A 50-watt monochromatic light source emits 10^{20} photons every second. What is the frequency of those photons?

30. (2 points) You have a cool infinity mirror setup. The mirror in front of you is currently 5 meters away, and the mirror behind you is currently 15 meters away. If you are walking at a speed of one meter per second forward, at what speed (possibly negative) are you and the 25th closest reflection of you approaching each other?

31. (6 points) You shine a light at a wall with two small holes, and behind the wall is a screen. But instead of seeing two bright spots on the screen, you see a whole bunch of bright spots, all aligned along a line.

a. What is causing these bright spots?

b. What is the distance between any two consecutive bright spots in terms of any necessary variables?

c. What approximations did you use in creating your formula (list as many as you can)?

32. (6 points) A common "paradox" in polarization is known as the three-polarizer paradox. You shine unpolarized light of intensity I_0 through three linear polarizers, with axes of angles $0, 45,$ and 90° to the horizontal (in that order).

a. What is the resulting intensity in terms of I_0?

b. What is the resulting intensity if the middle polarizer (45°) is removed?

c. Why is this considered a paradox?

d. We can generalize this result to the n-polarizer paradox. There, n polarizers have angles equally spaced from 0 to 90° inclusive. What is the least integer value of n such that the resulting intensity is greater than $\frac{I_0}{3}$?

e. As n approaches infinity, what does the resulting intensity approach? Justification via calculus is not necessary, but its inclusion would be helpful. (Hint: for calculus approaches, use the double angle formula $\cos 2\theta = 2\cos^2\theta - 1$ and later the Taylor expansion $\cos\theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - \frac{\theta^6}{6!} + \cdots$.)