University of Texas at Austin 2024 Invitational
Optics B/C Exam

Directions:

- **This is a class set, DO NOT WRITE**
- Write all answers on the answer sheets; any marks elsewhere will not be scored. If additional space is needed on a question, **clearly mark the question number and your team number on the top left of the page** and attach to your test.
- There is no penalty for wrong answers. Answer as many questions as possible, even if you aren't sure if you're correct. For questions with parts that build on one another, points will be awarded for correct answers on parts regardless of previous part completion.
- Units are required whenever giving a numerical answer. Don't worry about significant figures.
- Good luck on the test!

Section 1

Circle True or False

1. True False In a converging lens, the image of an object located at twice the focal length is real, inverted, and the same size as the object.
2. True False The critical angle for total internal reflection depends solely on the refractive index of the denser medium.
3. True False Diffraction occurs prominently when the size of the aperture is comparable or smaller than the wavelength of light passing through it.
4. True False Polarization of light can only occur through reflection and cannot be achieved by scattering.
5. True False The resolving power of a microscope depends on the wavelength of the light used and the numerical aperture of the objective lens.
6. True False Brewster's angle occurs when light reflects at an angle such that the reflected and refracted rays are perpendicular to each other.
7. True False For a concave mirror, the image of an object placed beyond the center of curvature is virtual.
8. True False The thin lens equation is valid for lenses of any shape and thickness.
9. True False Light passing through a prism always undergoes chromatic dispersion.
10. True False Snell's law can be used to describe the behavior of light as it transitions between two media with the same refractive index.
11. True False The accuracy of a sextant decreases with increasing altitude of the observed celestial body.

Section 2

Circle the correct answer

1. (3 points) What is the magnification of an object placed 10 cm from a converging lens with a focal length of 5 cm?

   A. -2

   B. $+2$

   C. -0.5

   D. $+0.5$

   E. None of the above

2. (3 points) Which of the following phenomena demonstrates the wave nature of light?

   A. Diffraction

   B. Photoelectric effect

   C. Specular reflection

   D. Refraction

   E. None of the above

3. (3 points) A light ray enters a medium with a refractive index of 1.33 from insulating foam ($n = 1.02$) at an angle of 45°. What is the angle of refraction?

   A. 33.3°

   B. 32.8°

   C. 50.5°

   D. 75.1°

   E. None of the above

4. (3 points) What is the maximum number of bright fringes that can be observed in a double-slit interference experiment with slit separation of 0.1 mm and wavelength of 600 nm?

   A. 331

   B. 333

   C. 335

   D. 337

   E. None of the above

5. (3 points) The focal length of a convex mirror is -10 cm. Where is the image located if the object is placed 15 cm from the mirror?

   A. -4 cm

   B. $+4$ cm

   C. -6 cm

D. +6 cm

E. None of the above

6. (3 points) What happens to light in an optical fiber that results in total internal reflection?

   A. Light travels faster in the core than in the cladding

   B. The core has a higher refractive index than the cladding

   C. Light slows down when it enters the fiber

   D. The core and cladding have the same refractive index

   E. None of the above

7. (3 points) The critical angle for light traveling from glass ($n = 1.5$) to water ($n = 1.33$) is closest to:

   A. 42.1°

   B. 48.8°

   C. 62.5°

   D. 63.3°

   E. None of the above

8. (3 points) Which of the following optical instruments uses two convex lenses to form an image?

   A. Telescope

   B. Periscope

   C. Microscope

   D. Camera

   E. None of the above

9. (3 points) The dispersion of light through a prism causes which of the following phenomena?

   A. Polarization

   B. Chromatic aberration

   C. Total internal reflection

   D. Brewster's angle

   E. None of the above

10. (3 points) What is the correct relationship between the object distance d_o, the image distance d_i, and the focal length f for a convex lens?

    A. $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$

    B. $\frac{1}{f} = \frac{d_i}{d_o}$

    C. $\frac{1}{f} = d_o + d_i$

D. $\frac{1}{f} = d_o d_i$

E. None of the above

11. (3 points) A sextant is primarily used to measure the angle between two objects, such as the horizon and a celestial body. What is the primary principle that allows the sextant to function?

    A. Polarization of light waves

    B. Diffraction of light through a narrow slit

    C. Refraction of light through a prism

    D. Reflection of light using two mirrors

    E. None of the above

Section 3

Write out a short response to the following questions

1. (4 points) How does the vector form of the law of reflection apply to anisotropic materials where the surface properties change with direction?

2. (4 points) How does the Abbe number affect the dispersion of light in a prism? Calculate the chromatic aberration for a prism made of crown glass with an Abbe number of 60 when light enters at an angle of 45°.

3. (4 points) Explore how additive color theory is applied in modern display technology (e.g., OLED) and compare it with subtractive color theory in high-quality printing.

4. (4 points) Calculate the reflectance for light at normal incidence on a metal surface, given its complex refractive index. Discuss how this affects the perception of color for different metals (e.g., gold, silver).

5. (4 points) Explain how spherical aberration affects vision and how the eye naturally compensates for this. Discuss the limitations of this compensation in aging populations.

6. (4 points) Model how the arrangement of photoreceptors in the retina can create blind spots and why our brains typically don't notice these spots in normal vision.

7. (4 points) Explain how the lensmaker's equation can be modified to account for spherical aberration in high-precision optical systems.

8. (4 points) Explain the Rayleigh scattering polarization effect in the context of the Earth's atmosphere. How does the degree of polarization vary with the angle of observation?

9. (4 points) Derive the threshold condition for laser action in terms of population inversion and discuss the impact of cavity design on laser coherence length.

10. (4 points) Explore how femtosecond lasers can be used in LASIK surgery to correct aberrations in the human eye. Include a discussion of wavefront-guided techniques.

11. (4 points) Explain the role of laser diffraction in reading information stored in CD/DVD media, and discuss how error correction algorithms help in compensating for optical imperfections.

Section 4

Write out your work and answer to the following questions

1. (4 points) A beam of light enters a prism with a refractive index of 1.6 at an angle of 30°. Calculate the angle of refraction, to the nearest hundredth of a degree, inside the prism.

2. (4 points) A plano-convex lens has a radius of curvature of 20 cm. Calculate the focal length, to the nearest tenth of a centimeter, of the lens if it is made of glass with a refractive index of 1.5.

3. (4 points) Calculate the total internal reflection angle, to the nearest hundredth of a degree, for light moving from water ($n = 1.33$) to air.

4. (4 points) A converging lens has a focal length of 20 cm. An object is placed 30 cm from the lens. Calculate the position relative to the lens, to the nearest tenth of a centimeter, and the nature (real or virtual, magnified or diminished) of the image.

5. (4 points) A beam of light passes through a double slit, with slit separation of 0.5 mm, and produces an interference pattern on a screen placed 1.5 meters away. If the wavelength of light is 600 nm, calculate the distance, to the nearest tenth of a millimeter, between the central bright fringe and the first-order bright fringe.

6. (4 points) Light of wavelength 500 nm passes through a diffraction grating with 10^4 lines per centimeter. Calculate the angle, to the nearest hundredth of a degree, where the second-order maximum occurs.

7. (4 points) A telescope's objective lens has a focal length of 2 meters, and its eyepiece has a focal length of 10 cm. Calculate the magnification produced by this telescope, assuming normal adjustment.

8. (4 points) A monochromatic light source has a wavelength of 400 nm in air. If the light enters water, which has a refractive index of 1.33, calculate the new wavelength of the light in water, to the nearest nanometer.

9. (4 points) A concave lens has a focal length of -20 cm. If an object is placed 15 cm from the lens, calculate the image distance, to the nearest hundredth of a centimeter, and describe the nature (real or virtual, magnified or diminished) of the image.

10. (4 points) A light ray traveling through glass (refractive index 1.5) strikes a glass-to-air boundary at an angle of incidence of 40°. Calculate the angle of refraction, to the nearest hundredth of a degree, of the light as it passes into the air.

11. (4 points) In a double-slit experiment, the distance between the slits is 0.13 mm, and the distance to the screen is 1 meter. If the second-order bright fringe is observed at a position 12 mm away from the central maximum, calculate the wavelength of the light, to the nearest nanometer.

12. (4 points) A certain telescope has an angular resolution of $1.22 \times \frac{\lambda}{D}$, where λ is the wavelength of light and D is the diameter of the objective lens. If the telescope's objective lens has a diameter of 1 meter and the wavelength of light is 500 nm, calculate the angular resolution to the nearest thousandth of an arcsecond.

13. (4 points) A laser emits light with a power of 2 mW and a wavelength of 650 nm. Calculate the energy, in joules, of a single photon emitted by the laser.

14. (4 points) A concave mirror has a focal length of 12 cm. Calculate the magnification of the image if the object is placed 8 cm from the mirror.

15. (8 points) Prove that when light is incident at Brewster's angle, the reflected light is completely polarized perpendicular to the plane of incidence. *Hint: Start by using Fresnel's equations and prove that the reflection coefficient for light polarized parallel to the plane of incidence goes to zero at Brewster's angle.*