Optics C
Science Olympiad North Regional Tournament at the University of Florida

DO NOT WRITE ON THIS BOOKLET. IT IS A TEST SET.
Part I: General Body Knowledge Questions

1) (3 PTS) The surface of some arbitrary, reflective material has been highly polished such that the dimensions of the surface irregularities are significantly smaller than the wavelengths of visible light. Select the statement that is most accurate.

   a) The surface reflects diffusely with great efficiency
   b) The surface reflects specularly with great efficiency
   c) The surface reflects visible light
   d) Both (a) and (c) are true
   e) Both (b) and (c) are true
   f) None of the above are true

2) (3 PTS) Consider the diagram below where a ray of light enters a second medium ($n_2$) from a first medium ($n_1$). Select the statement that is most accurate.

   a) The ray of light travels slower through the first medium than the second
   b) There is no critical angle $\theta_c$ for a point source of light placed within the first medium $n_1$
   c) The image that will form from the ray is a real image
   d) The wavelength of the ray of light is longer in the second medium $n_2$ than in the first medium $n_1$
   e) Both (a) and (d) are true
   f) None of the above are true
3) **(3 PTS)** Depicted below is a picture of a 22° halo around the moon. Note that the colors of the rainbow can be seen in the halo. The current, standard hypothesis for the formation of the halo states that the interaction of light with ice crystals in the atmosphere produces the natural phenomenon. State the physical process responsible for the formation of the halo.

![image credit to Gladson Machado](image)

a) Refraction  
b) Diffraction  
c) Dispersion  
d) Reflection  
e) Both (a) and (c)  
f) Both (b) and (d)
4) **(3 PTS)** Anaglyph 3D images are images which contain two differently filtered color images. Traditionally, thin paper glasses with red and blue color filters were used to view these anaglyphs. The color filters thus cause each eye to view one of the two images in the anaglyph, tricking the brain into perceiving depth when the brain reassembles the two images into one. For the red color filter, which of the following is **most accurate** about color perception:

   a) Red through the filter appears white, blue light appears black
   b) Red through the filter appears black, blue light appears white
   c) Black and white through the filter remain unchanged
   d) Both (a) and (c) are accurate
   e) Both (b) and (c) are accurate
   f) None of the above are accurate

5) **(3 PTS)** Because of the loss of color accuracy, modern 3D glasses use polarizing filters instead of color filters to achieve stereoscopy (anaglyph 3D is a specific kind of stereoscopy). To allow each eye to see a different image, each polarizing filter is set orthogonal to the other. What is the intensity of the unpolarized light after passing through one of these filters (note: assume perfect polarizing efficiency)?

   a) There is no loss in intensity
   b) 75%
   c) 63%
   d) 50%
   e) 25%
   f) 0%
6) (3 PTS) Two circular observers are trying to see into an area obscured by two barriers (black). However, an ideal mirror offers vision into the area. Select the letter that both observers can see unobscured.

![Diagram of observers and barriers]

7) (3 PTS) In patients with retinitis pigmentosa, degeneration of structure(s) in the eye severely limits the patient’s sensitivity to light. As treatment, patients can opt to receive the Argus II retinal prosthesis. The prosthesis works by receiving information from a video camera and transmitting the information back through the eye to bypass the damaged structure(s). Based on this information, retinitis pigmentosa most likely affects which structure(s) in the eye?

a) Optic Nerve  
b) Rods  
c) Cones  
d) Lens  
e) Iris  
f) None of the above
8) **(3 PTS)** Given the following statement about optical instruments, select the statement that is least accurate:

a) For a simple compound microscope, the second focal point \( f_2 \) of the objective is separated from the first focal point \( f_1' \) of the eyepiece.

b) For a simple refractive telescope, the second focal point \( f_2 \) of the objective coincides in position with the first focal point \( f_1' \) of the eyepiece.

c) Refracting telescopes avoid the problem of chromatic and spherical aberration that plague reflecting telescopes.

d) For a simple compound microscope, the final virtual image \( I' \) forms almost at an infinite distance away from the microscope.

e) None of the above statements are incorrect.

f) All of the above statements are incorrect.

9) **(3 PTS)** Consider the lens of the human eye as a biconvex structure. Select the statement that is least accurate:

a) The lens changes shape to adjust its focal point.

b) The image formed on the retina is inverted.

c) The image formed on the retina is real.

d) Farsightedness results from a lens with the inability to assume a high curvature and short focal length.

e) None of above statements are incorrect.

f) Both (b) and (c) are incorrect.
10) **(3 PTS)** Depicted below is the absorption spectrum for xanthophyll, a photosynthetic pigment found in several plants. Based on the absorption spectrum, would color would you expect xanthophyll to be?

![Absorption Spectrum](image)

a) Red  
b) Orange  
c) Yellow  
d) Green  
e) Blue  
f) Violet
Part II: Application Questions

11) This question is about refractive phenomena in prisms. For parts (a), (b), and (c), refer to the diagram of the isosceles prism below.

![Diagram of isosceles prism with angles labeled: \( \phi = 30.0^\circ \), \( \Psi = 24.2^\circ \), and \( \theta \).]

Not To Scale

a) (1 PT) In this case, what is the name given to angle \( \Psi' \)?

b) (2 PTS) Following the information given, what material is the prism most likely made from?

c) (2 PTS) What is angle \( \theta \) (in degrees)?
12) This question is about image formation in the lens of the human eye. For parts (a), (b), and (c), refer to the simplified diagram of the human lens below:

a) (1 PT) Complete a ray tracing on the diagram to locate the image

b) (3 PTS) To focus the image of an object 1.25 m away, the lens must stretch to maintain what focal length? Note that the focal length for an object at the near point is 1.68 cm (take the near point to be 25 cm).

c) (1 PT) What is the magnification for this image when it is focused by the eye (include the sign)
13) This question is about the operating principles of fiber optics. Fiber optics work by trapping light within a thin fiber. In such a way, light can be used to transfer information in a network. A cross-sectional view of a simplified optical fiber is shown below for information. Refer to this diagram for information.

Take the refractive index of the silica glass core $n_{\text{core}} = 1.557$, the refractive index of the cladding $n_{\text{cladding}} = 1.343$, and the refractive index of the air $n_{\text{air}} = 1.000$

a) (1 PT) State the optical phenomenon demonstrated by the path of the ray of light

b) (1 PT) A fiber optic cable runs from New York City to Sydney, Australia, a distance of 16,000 km. What is the delay in the signal from the optical cable?

c) (3 PTS) In order to ensure that light is trapped within the fiber, the fiber can only accept a range of angles from the outside air. This range is called the Numeric Aperture ($NA$) of the optical fiber, and is depicted in the diagram. Find the numeric aperture for this optical fiber (note that this is a unitless quantity).
14) This question is about the Rayleigh Sky Model. As we all know, the sky is blue because of Rayleigh Scattering. When light from the sun hits the air molecules in the atmosphere, the light is absorbed and then diffusely scattered. As a result, the reemitted light is polarized by scattering, resulting in a defined polarization pattern in the sky which some animals use for navigation. The Rayleigh sky model depicts this polarization pattern. Shown below are polarization patterns for when the sun has set in the horizon.

- **a)** (2 PTS) Describe what is meant by the term “polarization by scattering”
- **b)** (1 PT) For the sky, what is the color of light that is least polarized
- **c)** (2 PTS) Draw a 2D polarization pattern (similar to the one shown above) for when the sun is at its zenith (i.e. the center of the sky).

15) This question is about microscopes. Antonie van Leeuwenhoek (1632 - 1723) is often regarded as the father of microscopy and is renowned historically for his then-revolutionary telescopes. His telescopes were simple magnifiers which used small glass spheres as lenses to reach magnifications of 200 times for his more precise microscopes. Taking $n_{\text{glass}} = 1.50$, find:

- **a)** (2 PTS) The focal length of these microscopes
- **b)** (3 PTS) The maximum diameter of these spherical lenses
16) This question is about human color perception with specific reference to imaginary colors. A real color is any color that can be produced by a physical light source. Any additive mixture of two real colors is also real. In contrast, an imaginary color can be defined as a color that violates the rules of color addition. Answer the following:
   a) **(1 PT)** State the two kinds of photoreceptors in the eye.
   b) **(1 PT)** Describe color addition.
   c) **(3 PTS)** Because they cannot be replicated visually, imaginary colors are often defined in some mathematical color space. One such example is ‘supergreen’, which we can describe in the sRGB system (where each value reflects the intensity of the respective component color) as the point \((R = 0, G = 255, B = 0)\). It is impossible for the photoreceptors in the human eye to send information to the brain about such a color. With specific reference to the human photoreceptors, explain why not.

17) This question is about plane mirrors. A light bulb is held 2.50 m above an empty pit which is 1.86 m deep. At the bottom of the pit is an ideal plane mirror. Answer the following questions:
   a) **(2 PTS)** What is the distance of the image relative to the plane mirror?
   b) **(3 PTS)** The pit is now filled with water. What is the distance of the image relative to the plane mirror? (Take the refractive index of water \(n_{\text{water}} = 1.33\)). Refer to the illustration below.

![Diagram of a light bulb above a pit with a plane mirror]
18) This question is about concave mirrors with specific reference to caustics. A caustic is an envelope of light rays caused either by reflection or refraction. Shown below is an example of a caustic forming from a concave mirror. Answer the following questions:

a) **(3 PTS)** A caustic has formed from the concave mirror in the above illustration. What does this say about the optical or geometric properties of the mirror?

b) **(2 PTS)** Caustics may also form from refraction. The bright lines of light often at the bottom of swimming pools are examples of refracted caustics. Taking this example, what does this suggest about the surface of the water in a swimming pool?
19) This question is about structures of the human eye analogous to components of a DSLR camera. Refer to the diagram below to answer the following questions:

a) (1 PT) The aperture is analogous to what structure(s) in the human eye?

b) (1 PT) The CMOS sensor (labelled in the diagram as “sensor”) is analogous to what structure(s) in the human eye?

c) (3 PTS) There is a pentaprism (labelled in the diagram as “prism”) that reflects the light twice to redirect it 90 degrees. There is no analogous structure to the pentaprism in the human eye. What is the function of the pentaprism (hint: consider why a pentaprism is used instead of a plane mirror)?
20) This question is about optical absorption spectra of fluorescent dyes. Fluorescence is the emission of light by some substance after absorbing electromagnetic radiation, and is a type of luminescence. Shown below is the absorption and emission spectra for a specific Lumogen pigment, a commercial fluorescent dye. Answer the following questions:

![Absorption and Emission Spectra](image)

a) (1 PT) What portion of the electromagnetic spectrum does the dye most readily absorb (state the color, if applicable)?

b) (1 PT) What portion of the electromagnetic spectrum does the dye emit (state the color, if applicable)?

c) (3 PTS) Suggest a reason for the difference in wavelengths between the absorption and emission spectrums

**PART III: TIEBREAKER**

List all the optical devices you can think of.