Read these instructions carefully. Work rapidly. Write your name in the upper right hand corner of this page. Do all your work on the test pages. Explain all work completely. **Answers without units are incomplete.**

Constants: \( c = 3 \times 10^8 \text{ m/s} \)

1. A ray of light strikes a plane mirror at a 45° angle of incidence. The mirror is then rotated by 15° into a new position, while the incident ray is kept fixed.
   a) Through what angle \( \phi \) does the reflected ray rotate?
   
   \[ \psi = 30° \]

2) A dentist’s mirror is placed 1.8 cm from a tooth. The enlarged image is located 6 cm behind the mirror.
   a) What is the focal length of the mirror?
   b) Is the mirror convex, concave, or planar?
   c) What is the magnification of the image?
   d) Draw the arrangement to scale.
3. Horizontal rays of red light (660 nm) and violet light (410 nm) are incident on the flint-glass prism as shown. The indices of refraction for red and violet light are 1.662 and 1.698 respectively.

a) What is the angle between the two rays as they exit the prism?

b) Draw and label the rays as they exit prism.

\[
\frac{n_R}{n_V} \sin \theta_R = \sin \theta_V
\]

\[
\theta_R = 44.6^\circ \quad \theta_V = 45.9^\circ
\]

4. A diverging lens is used to produce a virtual image 2 cm from the lens that is 1/3 as tall as the object that formed it.

a) Draw the arrangement.

b) What is the focal length of this lens?

\[
m = \frac{1}{3} = \frac{1}{f}
\]

\[
f = -3
\]

5. A 1 cm high object is placed 4 cm to the left of a converging lens with a focal length of 8 cm. A diverging lens of focal length -16 cm is 6 cm to the right of the converging lens.

a) On the back of this sheet, draw the ray diagram to scale:

b) Calculate the final image distance for the combination.

c) What is the height of the final image?

d) Is it real or virtual?

\[
\frac{1}{s_1} + \frac{1}{s_2} = \frac{1}{f_1} + \frac{1}{f_2}
\]

\[
\frac{1}{s_1} + \frac{1}{s_2} = \frac{1}{f_1} + \frac{1}{f_2}
\]

\[
s_1 = 8 \text{ cm} \quad s_2 = -16 \text{ cm} \quad O_1 = 4 \text{ cm} \quad O_2 = 14 \text{ cm}
\]

\[
m_1 = \frac{-s_1}{s_1} = 2
\]

\[
m_2 = \frac{-s_2}{f_2} = 0.533
\]

\[
m_3 = \frac{m_1 m_2}{m_1 + m_2} = 1.07 \times 1 \text{ cm}
\]

\[
h_i = 107 \text{ cm}
\]
Let's analyze the diagram step by step:

1. The diagram shows a ray of light passing through a lens, with points labeled for initial and final positions.
2. The distances are marked with a scale: 6 cm from the lens.
3. The final object distance is marked as 414 cm from the lens.

From the diagram, we can see:
- The initial object distance is labeled as \( o_1 \).
- The image distance is labeled as \( i_2 \).
- The focal length of the lens is labeled as \( f_2 \).

To find the distances, we need to use the lens formula:

\[ \frac{1}{f} = \frac{1}{o_1} + \frac{1}{i_2} \]

where \( f \) is the focal length, \( o_1 \) is the initial object distance, and \( i_2 \) is the image distance.

Given that the final object distance is 414 cm, we can set up an equation to solve for \( i_2 \).

However, without the actual focal length and initial object distance from the diagram, we can't solve for the exact values. The key points are understanding the labeling and the use of the lens formula to analyze the image formation.
6. A single slit of width 0.5 mm is illuminated with light of wavelength 500 nm, and a screen is placed 120 cm in front of the slit. Find the width of the first maximum on either side of the central bright maximum.

7. A coating is applied to a lens to minimize reflections. The index of refraction of the coating is $n=1.55$ and the index of the lens is $n_{\text{len}}=1.48$. If the coating is 177.4 nm thick, what is the wavelength of visible light that is minimally reflected?

\[ \lambda = \frac{2t}{m \cdot \frac{n_{\text{len}}}{n}} \]

8. Vertically polarized light is incident upon three polarizing plates whose transmission axes are oriented $20^\circ$, $40^\circ$, and $60^\circ$ from the vertical as shown. If 10 W/m² of light is incident on the first plate, what intensity of light makes it through the third?

\[ I_1 = 10 \cos^2 20 = 8.83 \text{ W/m}^2 \]
\[ I_2 = 8.83 \cos^2 20 = 7.79 \text{ W/m}^2 \]
\[ I_3 = 7.79 \cos^2 20 = 6.89 \text{ W/m}^2 \]