**Question 1** Draw an accurate ray-tracing diagram for a concave mirror with radius of curvature equal to 12.0 cm, and an object 18.0 cm from the mirror. Use the mirror equation (same as the lens equation) to find the “theoretical” position of the image, and compare this to your ray-tracing diagram.

![Ray-tracing diagram](image)

We note that the focal length is half the radius of curvature: \( f = 6.0 \text{ cm} \). Using the mirror (or lens) equation:

\[
\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}
\]

\[
\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o} = \frac{1}{6.0 \text{ cm}} - \frac{1}{18.0 \text{ cm}} = 0.1111 \text{ cm}^{-1}
\]

\[
d_i = \frac{9.0 \text{ cm}}{0.1111 \text{ cm}^{-1}} = 9.0 \text{ cm}
\]

This looks just like the distance in the diagram.

---

**Question 2** Suppose a light beam hit a surface of some transparent material, as you saw in the “2-D optics” lab. The angle of incidence is 70°, and the angle of refraction is 36°. (A) Draw an accurate diagram showing this situation. Your diagram will have a line representing the surface, a dotted line showing the normal, and two lines showing the incident and refracted rays. Use a protractor to get the angles right. (B) Find the index of refraction, \( n \), for the material.

(A)
Question 3  Suppose you look at a mylar “birthday” balloon. Its convex surface has a radius of curvature equal to 80 cm. If your face is 60 cm from the surface of the balloon, how far below the balloon’s surface does the image of your face appear?

The focal length of any spherical mirror is 1/2 the radius of curvature, which in this case makes the focal length 40 cm. However, we know that the rays diverge when they hit the mirror, so the focal length is negative: \( f = -40 \text{ cm} \). We can then use the lens or mirror equation:

\[
\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}
\]

\[
\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}
\]

\[
\frac{1}{d_i} = \frac{1}{-40 \text{ cm}} - \frac{1}{60 \text{ cm}}
\]

\[
\frac{1}{d_i} = -0.4167 \text{ cm}^{-1}
\]

\[
d_i = -24 \text{ cm}
\]

So your face is 40 cm below the front surface of the balloon.

Question 4  Diamond has an index of refraction equal to 2.42. What is the critical angle for light hitting the diamond-air interface, coming from inside the diamond?

**Background for this question:** In the lab you saw that when light is traveling inside a “slow” medium and hits the interface (such as between plastic and air) at a large enough angle, it cannot get out: 100% of the light is reflected. The smallest angle at which this happens is called the critical angle. At that angle, the light coming out would “graze” the surface of the interface: the angle of refraction is 90°. That means that in the equation

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

if we let \( n_2 \) and \( \theta_2 \) correspond to the air, then \( n_2 = 1 \) and \( \theta_2 = 90^\circ \). Then \( \theta_1 \) would be the critical angle.

Using Snell’s Law,

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

\[ (1) \sin 90^\circ = (2.42) \sin \theta_2 \]

\[ \sin \theta_2 = \frac{1}{2.42} = 0.413 \]

\[ \theta_2 = 24.4^\circ \]
Question 5  Suppose you hold a diverging lens, with a focal length of -8.0 cm, a distance 5.0 cm above a piece of paper on a table. Where would the (virtual) image of the writing on the paper appear? (Use the lens equation, \(1/f = 1/d_o + 1/d_i\).)

We use the lens equation:

\[
\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}
\]

\[
\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}
\]

\[
= \frac{1}{-8.0 \text{ cm}} - \frac{1}{5.0 \text{ cm}}
\]

\[
\frac{1}{d_i} = -0.325 \text{ cm}^{-1}
\]

\[
d_i = -3.1 \text{ cm}
\]

The virtual image is 3.1 cm in back of the lens, which is 1.9 cm above the table.

---

Question 6  Suppose you hold a converging lens, with a focal length of 8.0 cm, a distance 12.0 cm above a piece of paper on a table. Where would the real image appear? (Use the lens equation, \(1/f = 1/d_o + 1/d_i\).)

We use the lens equation:

\[
\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}
\]

\[
\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}
\]

\[
= \frac{1}{8.0 \text{ cm}} - \frac{1}{12.0 \text{ cm}}
\]

\[
\frac{1}{d_i} = 0.04167 \text{ cm}^{-1}
\]

\[
d_i = 24 \text{ cm}
\]

The real image would appear 24 cm from the lens, which is 36 cm above the table.

---

Question 7  How did Galileo’s theory of the origin of tides differ from that of Johannes Kepler? Why did Galileo discount the effect of the moon?

Kepler believed that the tides were linked to effects of the moon, while Galileo dismissed any such connection as mystical as akin to astrology. He thought the moon was too far away to have any effect on the earth. He believed that the tides were somehow caused by the motion of the Earth, making the water in the Mediterranean, for example, “slosh” back and forth like water in a basin.