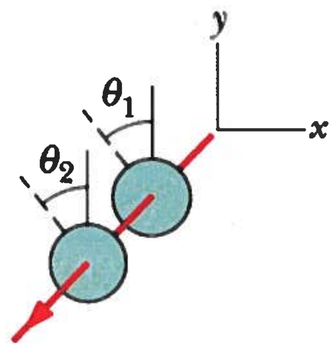
Question #1 (no points) Bubble in the answer choice corresponding to your class section number.

A. Sec. 1; MWF 11:30 am (S. Marley)
B. Sec. 2; MWF 1:30 pm (M. Gaarde)
C. Sec. 3; TuTh 9:00 am (P. Sprunger)

Question #2 (no points)
Your version of the test is **A**. Bubble in answer **A** on your ScanTron.

Question #3 (5 points)

A beam of initially unpolarized light travels through two polarizing sheets, with polarizing directions given by the angles $\theta_1=52°$ and $\theta_2=90°$, measured from the y-axis as shown in the figure (note: angles not drawn to scale). Given the initial light intensity of 26.2 W/m² what is the intensity of the transmitted light?



(A) 6.2 W/m²
(B) 19.6 W/m²
(C) 16.3 W/m²
(D) ~~2.2 W/m²~~
(E) 8.1 W/m²

$I_1 = \frac{1}{2} I_0$

$I_2 = I_1 \cos^2(90-52)°$

$= \frac{1}{2} I_0 \cos^2 38° = 8.13\ \mathrm{W/m^2}$

Question #4 (5 points)

Assume (unrealistically) that a TV station acts as a point source broadcasting isotropically at 55 MW. What is the intensity of the transmitted signal reaching Alpha Centari, the closest star to our Sun, that is 4.3 ly away. A light-year (ly) is the distance light travels in one year (1 year ≅ $\pi \times 10^7$ sec)

A) 6.7×10^{-28} W/m²
B) 2.7×10^{-27} W/m²
C) 6.7×10^{-37} W/m²
D) 2.7×10^{-36} W/m²
E) 6.7×10^{-31} W/m²

$I = \frac{P}{A} = \frac{P}{4\pi r^2}$

$1\ ly = c \cdot \Delta t_{year}$

$I = \frac{55 \cdot 10^6\ W}{4\pi (4.3 \cdot 3\cdot 10^8\ m/s \cdot \pi \cdot 10^7 s)^2}$

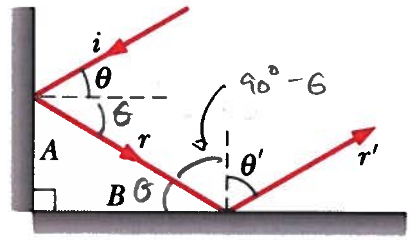
$= 2.7 \cdot 10^{-27}\ W/m^2$

Question #5 (5 points)

Mirror A and mirror B are arranged at right angles as shown in the drawing. Light ray i is incident on mirror A at an angle of $\theta = 40.0°$. At what angle θ' does the exiting ray r' leave mirror B?

(A) 20.0°
(B) 45.0°
(C) 40.0°
(D) 10.0°
(E) 50.0°

$\theta' = 90° - \theta = \underline{\underline{50°}}$



Question #6 (5 points)

In the figure (not to scale), light is incident at angle $\theta_1 = 40°$ on a boundary between two transparent materials. The light travels down through the next three layers of transparent materials. If $n_1 = 1.20$, $n_2 = 1.80$, $n_3 = 1.40$, and $n_4 = 1.60$, what is the value of angle θ_4?

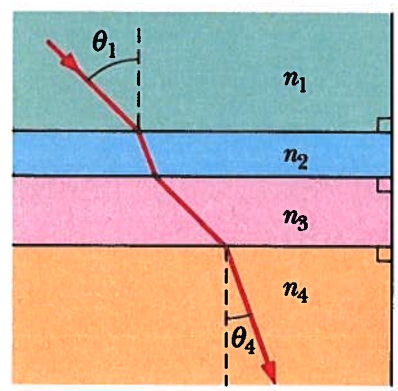
(A) 25.37°
(B) 33.43°
(C) 28.82°
(D) 31.70°
(E) None of these.

$n_4 \sin\theta_4 = n_1 \sin\theta_1$

$\therefore \theta_4 = \sin^{-1}\left(\frac{n_1}{n_4}\sin\theta_1\right)$

$= \sin^{-1}\left(\frac{1.2}{1.6}\sin 40°\right)$

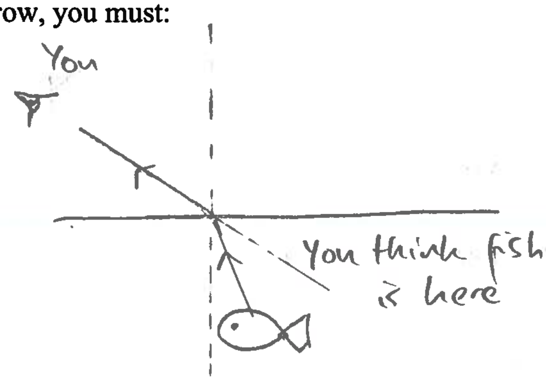
$= \underline{\underline{28.8°}}$



Question #7 (5 points)

At a quiet pond with crystal clear water, you decide to fish with a bow and arrow. You see a fish swimming below the surface of the water. In order to hit the fish with the arrow, you must:
(Note: a sketch may help you here)

(A) aim above the image of the fish.
(B) aim directly at the image of the fish.
(C) aim below the image of the fish.
(D) It depends on how large the fish is.
(E) It depends on how deep the pond is.



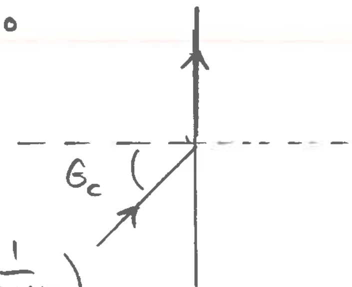
Question #8 (5 points)

A light ray is traveling in a diamond ($n = 2.419$). If the ray approaches the diamond-air interface, what is the minimum angle of incidence that will result in all of the light being reflected back into the diamond? The index of refraction for air is 1.000.

(A) 24.42°
(B) 32.46°
(C) 54.25°
(D) 65.58°
(E) 77.54°

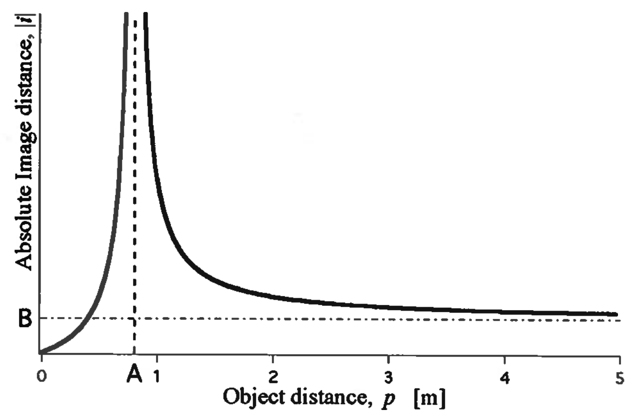
Critical angle when $\theta_{out} = 90^\circ$

$$n_D \sin\theta_c = n_{air} \sin 90^\circ$$
$$= n_{air}$$
$$\theta_c = \sin^{-1}\left(\frac{1}{n_D}\right) = \sin^{-1}\left(\frac{1}{2.419}\right)$$
$$\approx 24.4^\circ$$



Question #9 (5 points)

An object is placed against the center of a converging lens and then moved along the central axis until it is 5.0 m from the lens. During the motion, the distance $|i|$ between the lens and the image it produces is measured.



On the graph, what value of p is indicated by the dotted line A?

(A) $p = f$
(B) $p = 2f$
(C) $p = f/2$
(D) $p = |i|$
(E) None of these.

$$i = \frac{1}{\frac{1}{f} - \frac{1}{p}}$$

So when $\frac{1}{p} = \frac{1}{f}$ (or $p = f$)

we get $i \to \frac{1}{0} = \infty$

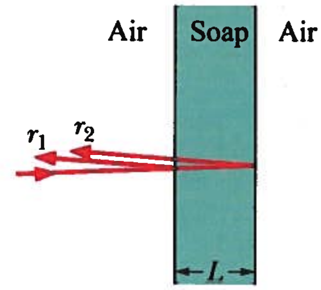
Question #10 (5 points)

Light of wavelength 610 nm is incident perpendicularly on a thin soap film ($n = 1.38$) that makes the wall of a soap bubble. (In the figure, the rays are tilted only for clarity.) What <u>*minimum*</u> thickness L of the soap film will result in <u>constructive interference</u> of the reflected rays r_1 and r_2?

(A) 222 nm
(B) 111 nm
(C) 0 nm
(D) 153 nm
(E) 305 nm

r_1 : $\frac{\lambda}{2}$ phase shift

r_2 : no phase shif

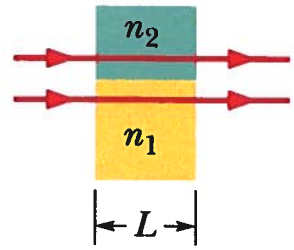


So constructive means

$$2L + \frac{\lambda_f}{2} = m\lambda_f \quad \text{or} \quad 2L = \left(m + \frac{1}{2}\right)\lambda_f$$

$m = 0$ gives $L = \frac{\lambda_f}{4} = \frac{\lambda}{4n} = \frac{610 \text{ nm}}{4 \cdot 1.38} = 110 \text{ nm}$

Question #11 (5 points)



In the figure, assume the two light waves, of wavelength 650 nm in air, are initially in phase. The indices of refraction of the two media are $n_1 = 1.31$ and $n_2 = 1.73$, and the media are both $L = 1.00$ μm thick.

What is the phase difference $\Delta\phi$ between the rays when they exit the two media?

(A) 0 rad
(B) 0.10 rad
(C) 0.65 rad
(D) 2.03 rad
(E) 4.06 rad

$$N_1 = \frac{L}{\lambda_1} = \frac{n_1 L}{\lambda}$$

$$N_2 = \frac{n_2 L}{\lambda}$$

$$\Delta N = (n_2 - n_1)\frac{L}{\lambda}$$

$$\Delta\varphi = 2\pi \cdot \Delta N = 2\pi(1.73 - 1.31)\frac{1\cdot 10^{-6}\,m}{650\cdot 10^{-9}\,m}$$

$$= 4.06 \text{ rad}$$

Question #12 (5 points)

If the distance between the slits in Young's two-slit experiment is decreased, which one of the following statements is true of the interference pattern?

(A) The distance between the maxima stays the same.
(B) The distance between the maxima decreases.
(C) The distance between the minima stays the same.
(D) The distance between the minima increases.
(E) Impossible to tell without knowing the wavelength of light in use.

$$\sin\theta = \frac{m\lambda}{d}$$

So d smaller

$\rightarrow$ θ larger

Question #13 (5 points)

The Hubble space telescope is in orbit around the earth. The aperture diameter of the telescope is 2.4 m. You are using the telescope to look at the cover of your physics textbook sitting on the surface of the earth. In red light (650 nm) Hubble can resolve the letters "P" and "s" in the word "Physics" on the cover. These two letters are separated by a distance of 16.5 cm. What is the height of Hubble's orbit? (Neglect the effects of earth's atmosphere.)

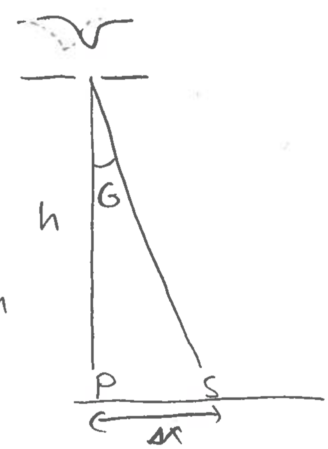
(A) 545 km
(B) 499 × 10⁴ km
(C) 499 km
(D) 303 × 10⁴ km
(E) 303 km

$$\Delta x_R = h\tan\theta_R \simeq h\theta_R$$

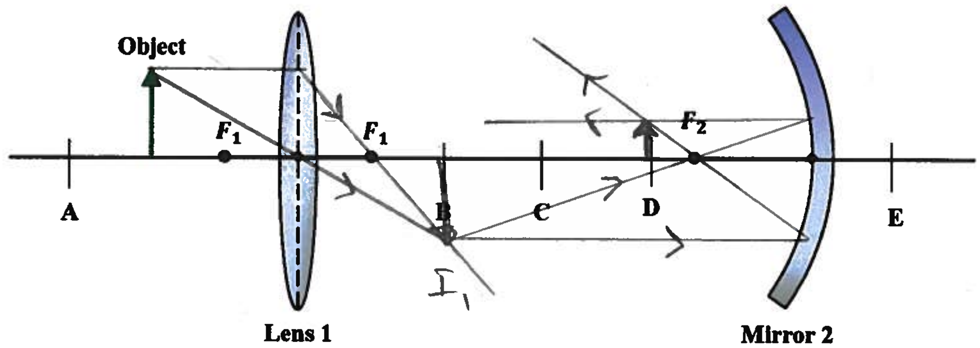
$$h = \frac{\Delta x}{\theta_R}$$

$$\theta_R = 1.22\frac{\lambda}{D}$$

So $h = \frac{\Delta x}{1.22\lambda/D} = \underline{\underline{499 \text{ km}}}$



Problem #1 (24 points) – Show your work: An object is located to the left of a compound system consisting of a <u>converging</u> lens (lens 1) followed by a <u>concave</u> mirror (mirror 2). The focal lengths of the lens ($F_1 = 2.1$ cm) and mirror ($F_2 = 3.4$ cm) are labelled as shown. The distance from the object to the lens is 4.2 cm, and the distance from the lens to the mirror is 14.7 cm.



(a) (5 pts) Find the image distance i_1 for the intermediate image produced by only the lens.

$$i_1 = \frac{1}{\frac{1}{f_1} - \frac{1}{p_1}} = \frac{1}{\frac{1}{2.1\text{cm}} - \frac{1}{4.2\text{cm}}} = \underline{\underline{4.2\text{ cm}}}$$

So $m_1 = -\frac{i_1}{p_1} = -1$ (real, inverted, same height)

(b) (7 pts) Calculate the image distance i_2 for the final image produced by Lens 1 and Mirror 2.

$$p_2 = d - i_1 = 14.7\text{cm} - 4.2\text{ cm} = 10.5\text{ cm}$$

$$i_2 = \frac{1}{\frac{1}{f_2} - \frac{1}{p_2}} = \frac{1}{\frac{1}{3.4\text{cm}} - \frac{1}{10.5\text{cm}}} = +5.03\text{ cm}$$

$$m_2 = -\frac{i_2}{p_2} = -\frac{5.03}{10.5} = -0.5$$

Real, inverted (relative to $O_2 = I_1$), smaller

(c) (3 pts) Calculate the magnification of the final image:

$$M = m_1 m_2 = -1 \cdot (-0.5) = \underline{\underline{+0.5}}$$

("Real", upright, smaller)

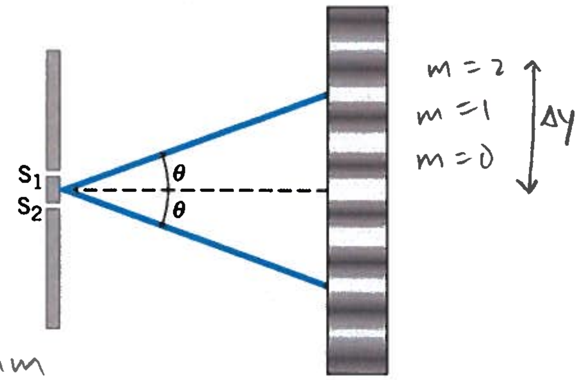
(c) (3 pts) Which of the positions A through E marked on the sketch is closest to i_2? (Circle the answer below)

A B C D E

(d) (6 pts) Use ray tracing to determine where the final image of the object will be located for the compound system. Your answer should be consistent with your answer in (b) and (c).

Problem #2 (20 Points) – Show your work!!!

In a double-slit experiment, the angle for the first <u>interference</u> side maximum is measured to be 0.0011 rad when light with wavelength 550 nm is used. The observation screen is placed 2.0 m from the slits.



(a) (4 pts) Calculate the separation between the two slits

$$d \sin\theta_1 = 1\lambda$$

$$\therefore \quad d = \frac{\lambda}{\sin\theta_1} = \frac{550 \cdot 10^{-9}\ \text{m}}{\sin 0.0011} = \underline{0.5\ \text{mm}}$$

(b) (6 pts) Calculate the location of the third <u>interference</u> side minimum on the screen, relative to the central axis:

Third side minimum, $m = 2$

$$\theta_{3m} \cong \sin\theta_{3m} = \frac{(2 + \frac{1}{2})\lambda}{d}$$

$$\Delta y = D \tan\theta_{3m} \cong D\theta_{3m} = D\,\frac{2.5\lambda}{d}$$

$$= \frac{2\text{m} \cdot 2.5 \cdot 550 \cdot 10^{-9}\ \text{m}}{0.5 \cdot 10^{-3}\ \text{m}} = 5.5\ \text{mm}$$

(c) (6 pts) Calculate the width that each slit must have so that the first <u>diffraction</u> minimum exactly corresponds to the third <u>interference</u> side minimum discussed above.

Need a so that $a \sin\theta_{3m} = \lambda$ (diffraction minimum overlaps θ_{3m})

$$\therefore \quad a = \frac{\lambda}{\sin\theta_{3m}} \cong \frac{\lambda}{\theta_{3m}} = \frac{\lambda}{2.5\lambda/d}$$

$$= \frac{d}{2.5} = \underline{0.2\ \text{mm}}$$

(d) (4 pts) Describe in a few sentences and/or equations how the pattern on the screen would change if the whole apparatus were submerged in water (n = 1.33). Would both the diffraction and the double-slit patterns change?

λ changes to $\lambda_n = \frac{\lambda}{1.33}$, smaller.

Both patterns will be <u>narrower</u>, since

Interference max $\quad \sin\theta = \frac{m\lambda_n}{d} \rightarrow \theta$ smaller

Diffraction min $\quad \sin\theta = \frac{k\lambda_n}{a} \rightarrow \theta$ smaller

(Diffraction min still falls on top of third interference minimum)