Physics 123 Optics Review

I. Definitions & Facts

concave	converging	convex
diverging	real image	virtual image
real object	virtual object	upright
inverted	dispersion	nearsighted, farsighted
near point, far point	total internal reflection	interference
Newton's rings	diffraction	diffraction gratings
polarization	Brewster's Angle	chromatic aberration
spherical aberration		

II. Mathematics & Tools

All of ray optics can be reduced to the laws of reflection and refraction combined with geometry.
Know how to do ray tracings with the principle rays (see the text for examples).
Waves of the same wavelength but different phases can conveniently be added by using "phasors"
Know how to use phasors to qualitatively predict the intensity patterns of multiple slits
Know how to use the intensity formulas. You need not memorize them.

$$\text{Double slit:} \quad \frac{I(\theta)}{I(0^\circ)} = \cos^2\left(\frac{\pi d \sin\theta}{\lambda}\right),$$

$$\text{Single slit:} \quad \frac{I(\theta)}{I(0^\circ)} = \frac{\sin^2(\beta/2)}{(\beta/2)^2}, \qquad \beta = \frac{2\pi a \sin\theta}{\lambda}$$

III. Basic Concepts

Huygens's Principle relates wavefronts to ray optics.
Refraction is the result of light changing speed as it passes between two media.
The index of refraction is the ratio of the velocity of light in vacuum to the velocity of light in a medium.
The index of refraction is usually a function of wavelength. Thus different colors of light refract differently. This is the principle of the prism.
In multiple lens (mirror) systems, the image of the first lens becomes the object of the second lens.
There is a phase shift of 180° whenever light reflects off a surface of greater index of refraction
Intensity is proportional to the square of the amplitude
Real slits produce a multiple slit pattern within the single slit envelope
Diffraction gratings have intense maxima separated by regions of near-zero intensity because adding many waves of slightly different phase produces destructive interference
Single slits can be taken to be a series of many small slits

IV. Equations to Memorize

Law of reflection: $\theta_i = \theta_r$

Snell's Law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

For mirrors: $R = 2f$.

The lens/mirror equation:

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

Magnification:

$$M = -\frac{q}{p}$$

Double slit: $m\lambda = d\sin\theta$, $(m + ½)\lambda = d\sin\theta$

Single slit: $m\lambda = a\sin\theta$

Multiple slits: $m\lambda = d\sin\theta$

Thin film, normal incidence: $m\frac{\lambda_0}{n} = 2t$, $(m + ½)\frac{\lambda_0}{n} = 2t$

Path difference: $\Delta r = d\sin\theta$

Phase difference: $\Delta\varphi = k\Delta r$

Review Problems

Conceptual Questions

1. Lens A alone can produce only virtual images. Lens B alone can produce both real and virtual images.

A. Lens A is convex and lens B is convex.

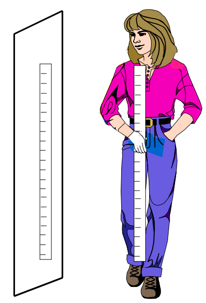
B Lens A is convex and lens B is concave.

C. Lens A is concave and lens B is convex.

D. Lens A is concave and lens B is concave.

E. None of the above.

2. A girl stands in front of a mirror. She vertically holds a meter stick directly in front of her. Attached to the mirror is a second meter stick (as shown). As she looks into the mirror, the image of the meter stick she holds (not shown) is measured with the meter stick on the mirror. (She reads on the mirror's meter stick the numbers that correspond to the top and bottom of the image.) In this fashion she measures the apparent height of the image to be:



A. 0.50 m

B. 0.67 m

C. 1.00 m

D. 2.00 m

E. None of the above.

(Hint: Draw a sketch of the rays from the top and bottom of the meter stick that reflect to the girl's eyes.)

3. In an eight slit diffraction pattern, there are minima when the difference in phase angle between beams from adjacent slits is:

A. 90.0°

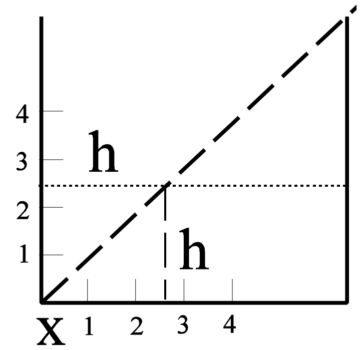
B. 67.5°

C. 45.0°

D. 22.5°

Problems

4. A cubical tank has a length *H* on each side (and bottom). A person views the empty tank from such an angle that he can see the bottom of the opposite side of the tank directly in line with the top of the near side of the tank, as illustrated. A ruler is placed along the far wall of the tank and another along the bottom of the tank as shown in the figure. The person adds a liquid having index of refraction $n = \sqrt{2}$. The height of the liquid in the tank is *h*. Because of refraction, the person then sees one of the rulers as he continues to look along the same line over the edge of the tank.



(a) Which ruler does the viewer see? Draw a sketch on the figure to the right to illustrate your conclusion.

(b) What mark on the ruler does the viewer see just over the edge of the tank? Your answer should be a function of no variables other than *H* and *h*.

5. For single **mirrors** the object distance is always positive, however, both the focal length and the image distance can be either positive or negative. If possible, for each of the following systems (a) draw a ray sketch and (b) **for each diagram you sketch**, characterize the image as real\virtual, erect\inverted, enlarged\reduced. If not possible, explain why.

(a) Positive focal length, positive image distance.

(b) Positive focal length, negative image distance.

(c) Negative focal length, positive image distance.

(d) Negative focal length, negative image distance.

6. A coating is placed on the lens of a camera to reduce reflection. It is designed to minimize the reflection of normally incident light of wavelength 500nm. The index of refraction of the coating is n = 1.25 and that of the lens is n=1.63.

(a) What are the possible thicknesses of the coating?

(b) For **each** of the three smallest (non-zero) values for the thickness of the coating you found in part (a), find the visible wavelengths (400nm − 700nm) for which the reflection is maximized.

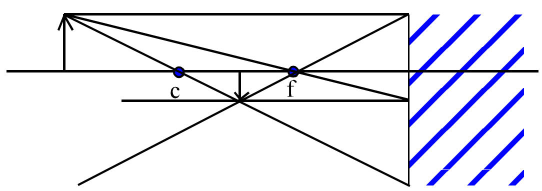
Answers

1. *C* 2. *A* 3. *C*

4. (a) *The beam coming out of the water bends away from the normal. The observer then sees the bottom of the tank.*

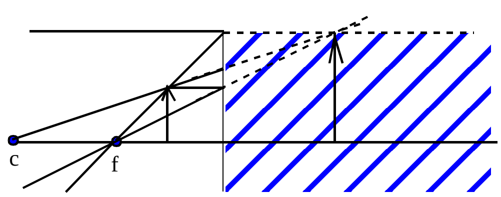
(b)
$$n_0 \sin\theta_0 = n_1 \sin\theta_1$$
$$1\times\sin 45^\circ = \sqrt{2}\times\sin\theta_1$$
$$\frac{\sqrt{2}}{2} = \sqrt{2}\times\frac{h-x}{\sqrt{h^2+(h-x)^2}}$$
$$\sqrt{h^2+(h-x)^2} = 2(h-x)$$
$$h^2+(h-x)^2 = 4(h-x)^2$$
$$h^2 = 3(h-x)^2$$
$$h = \sqrt{3}(h-x)$$
$$x = h-\frac{h}{\sqrt{3}}$$
$$x = 0.423h$$

5. (a)



The image is real, inverted, and reduced.

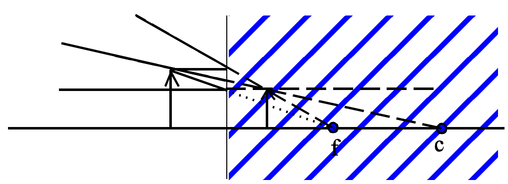
(b)



The image is virtual, erect, and enlarged.

(c) *If the image distance is positive, the image must be real; however, diverging lenses can never form real images.*

(d)



The object is virtual, erect, and reduced.

6. (a) *We see that there are two phase shifts, so the minima satisfy the expression:*

$$\left(m+\tfrac{1}{2}\right)\lambda' = \frac{\lambda}{n}\left(m+\tfrac{1}{2}\right) = 2t,$$
$$t = \frac{1}{4}\frac{\lambda}{n}(2m+1) = \frac{1}{4}\frac{500\text{ nm}}{1.25}(2m+1)$$
$$t = 100\text{ nm}(2m+1) = 100\text{ nm},\ 300\text{ nm},\ 500\text{ nm},\ldots$$

(b) *The condition for maxima is:*

7.

$$m'\lambda' = \frac{\lambda}{n}m' = 2t,$$

$$\lambda = \frac{2nt}{m'}$$

If $t = 100$ nm, $\lambda = \dfrac{250\text{ nm}}{m'} = 250\text{ nm},\ 125\text{ nm},\ 83.3\text{ nm},\ldots$ None are in the visible spectrum.

If $t = 300$ nm, $\lambda = \dfrac{750\text{ nm}}{m'} = 750\text{ nm},\ 375\text{ nm},\ 250\text{ nm},\ldots$ None are in the visible spectrum.

If $t = 500$ nm, $\lambda = \dfrac{1250\text{ nm}}{m'} = 1250\text{ nm},\ 625\text{ nm},\ 417\text{ nm},\ 313\text{ nm},\ldots$ 417 nm and 625 nm are in the visible.