AFTER I GIVE THE SIGNAL TO BEGIN YOU CAN REMOVE THIS SHEET. DO NOT TURN IT IN!

162sp26t3b – Once the exam has officially started, remove the top sheet. The remaining sheets comprise your exam. It is each student's individual responsibility to ensure the instructor has received her or his completed exam. Any exams not received by the instructor earn zero points. Smart watches, phones, or other devices (except scientific calculators) are not permitted during the exam.

$1\ \text{kg}\cdot\frac{\text{m}}{\text{s}^2}=1\ \text{N}$	$1\ \text{N}\cdot\text{m}=1\ \text{J}$	$1\ \text{Pa}=1\frac{\text{N}}{\text{m}^2}$	$1\ \text{W}=1\ \frac{\text{J}}{\text{s}}$
$c=2.998\times10^{8}\frac{\text{m}}{\text{s}}$	$h=6.626\times10^{-34}\ \text{J}\cdot\text{s}$	$h=4.136\times10^{-15}\ \text{eV}\cdot\text{s}$	$e=1.602\times10^{-19}\ \text{C}$
$hc=124\underline{0}\ \text{eV}\cdot\text{nm}$	$\hbar=\frac{h}{2\pi}=1.0546\times10^{-34}\ \text{J}\cdot\text{s}$	$\hbar=\frac{h}{2\pi}=6.583\times10^{-16}\ \text{eV}\cdot\text{s}$	$1.602\times10^{-19}\ \text{J}=1\ \text{eV}$
$\omega=\frac{2\pi}{T}=2\pi f$	$k=\frac{2\pi}{\lambda}$	$c=f\lambda \qquad E=hf=\frac{hc}{\lambda}$	$I_{avg}=\frac{\mathcal{P}}{A}$
$p=\frac{E_\gamma}{c}=\frac{h}{\lambda}=\hbar k$	$c=nv \quad \lambda_n=\frac{\lambda}{n} \quad f_n=f$	$\theta_{min\ slit}\approx\frac{\lambda}{a}$	$2n_{film}t=m\lambda_{vacuum}$
$\sin^2 x=\frac{1-\cos 2x}{2}$	$\cos^2 x=\frac{1+\cos 2x}{2}$	$\theta_{min\ circle}\approx 1.22\frac{\lambda}{d}$	$2n_{film}t=\left(m+\frac{1}{2}\right)\lambda_{vacuum}$ for $m=0,1,2,\ldots$
$2\sin\theta\cos\theta=\sin 2\theta$	$\cos(90°-\theta)=\sin\theta$	$\sin(90°-\theta)=\cos\theta$	
$\sin(a\pm b)=\sin a\cos b\pm\cos a\sin b$		$\cos(a\pm b)=\cos a\cos b\mp\sin a\sin b$	
$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}$	$\theta_i=\theta_r \quad n_1\sin\theta_1=n_2\sin\theta_2$	$d\sin\theta_{bright}=\pm m\lambda$	$a\sin\theta_{dark}=\pm m\lambda$ for $m=1,2,3,\ldots$
$M=\frac{h_i}{h_o}=-\frac{d_i}{d_o}$	$\theta_{critical}=\sin^{-1}\left(\frac{n_2}{n_1}\right)$	$d\sin\theta_{dark}=\pm\left(m+\frac{1}{2}\right)\lambda$ for $m=0,1,2\ldots$	$\sin\theta\approx\tan\theta=\frac{y}{L}$ if $y\ll L$
$\frac{n_1}{d_o}+\frac{n_2}{d_i}=\frac{n_2-n_1}{R}$		$I=4I_0\cos^2\frac{\phi}{2}=I_{max}\cos^2\frac{\phi}{2}$	$I=I_{max}\left[\frac{\sin\beta}{\beta}\right]^2$
$f_{mirror}=\frac{R}{2} \qquad \frac{1}{f_{lens}}=\left(\frac{n_{lens}-n_{medium}}{n_{medium}}\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$		$\phi=\frac{2\pi d}{\lambda}\sin\theta$	$\beta=\frac{\pi a}{\lambda}\sin\theta$
$I=I_0\cos^2\theta$	$\theta_{Brewster}=\tan^{-1}\left(\frac{n_2}{n_1}\right)$	$d_{grating}=\frac{1}{n}$ where $n=\frac{\text{lines}}{\text{m}}$	

$\text{T}=10^{12}$	$\text{G}=10^{9}$	$\text{M}=10^{6}$	$\text{k}=10^{3}$	$\text{c}=10^{-2}$	$\text{m}=10^{-3}$	$\mu=10^{-6}$	$\text{n}=10^{-9}$	$\text{p}=10^{-12}$	$\text{f}=10^{-15}$	$\text{a}=10^{-18}$

Sign Conventions for Spherical Mirrors

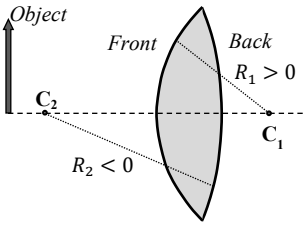
Variable	Positive if…	Negative if…
d_o	Object is *in front of* mirror (*real* object).	Object is *behind* mirror (*virtual* object).
d_i	Image is *in front of* mirror (*real* image).	Image is *behind* mirror (*virtual* image).
f & R	Mirror is *concave*.	Mirror is *convex*.
h_i	Image is *upright*.	Image is *inverted*.
M	Image is *upright*.	Image is *inverted*.
	$\lvert M\rvert>1$ implies an *enlarged* image.	
Ray 1	Leaves object *parallel to optic axis*, reflects (or back extends) through focal point.	
Ray 2	Leaves object *towards (or away from) focal point*, reflects parallel to optic axis.	
Ray 3	Leaves object *towards (or away from) the center of curvature*, reflects back on itself.	

Sign Conventions for Thin Lenses

Variable	Positive if…	Negative if…
d_o	Object is *in front of* lens (*real* object).	Object is *behind* lens (*virtual* object).
d_i	Image is in *behind* lens (*real* image).	Image is *in front of* lens (*virtual* image).
f	Lens is *convex* (*thickest in the middle*).	Lens is *concave* (*thinnest in the middle*).
R	Center of curvature is *behind* lens.	Center of curvature is *in front of* lens.
h_i	Image is *upright*.	Image is *inverted*.
M	Image is *upright*.	Image is *inverted*.
	$\lvert M\rvert>1$ implies an *enlarged* image.	
Ray 1	Leaves object *parallel to optic axis*, refracts (or back extends) through focal point.	
Ray 2	Leaves object *towards (or away from) focal point*, refracts parallel to optic axis.	
Ray 3	Leaves object *towards the center of lens*, passes through undeflected.	

Indices of Refraction	
Vacuum	1
Air	$1.00029\approx1$
Water	1.333
Crown Glass	1.50-1.60
Flint Glass	1.45-2.00
Sapphire	1.77
Diamond	2.42

Radii & Centers of Curvature for a Biconvex Lens



Name:_____

An object is placed 40.0 cm from a convex mirror with a ± 50.0 cm radius of curvature. Note: you are expected to know which sign to use. You might do parts d & e first then come back to answer parts a, b, & c.

1a) Which of the following best describes the final image? Circle the best answer.

Virtual	Real	Neither	Impossible to determine without more info

1b) Which of the following best describes the final image? Circle the best answer.

Inverted	Upright	Neither	Impossible to determine without more info

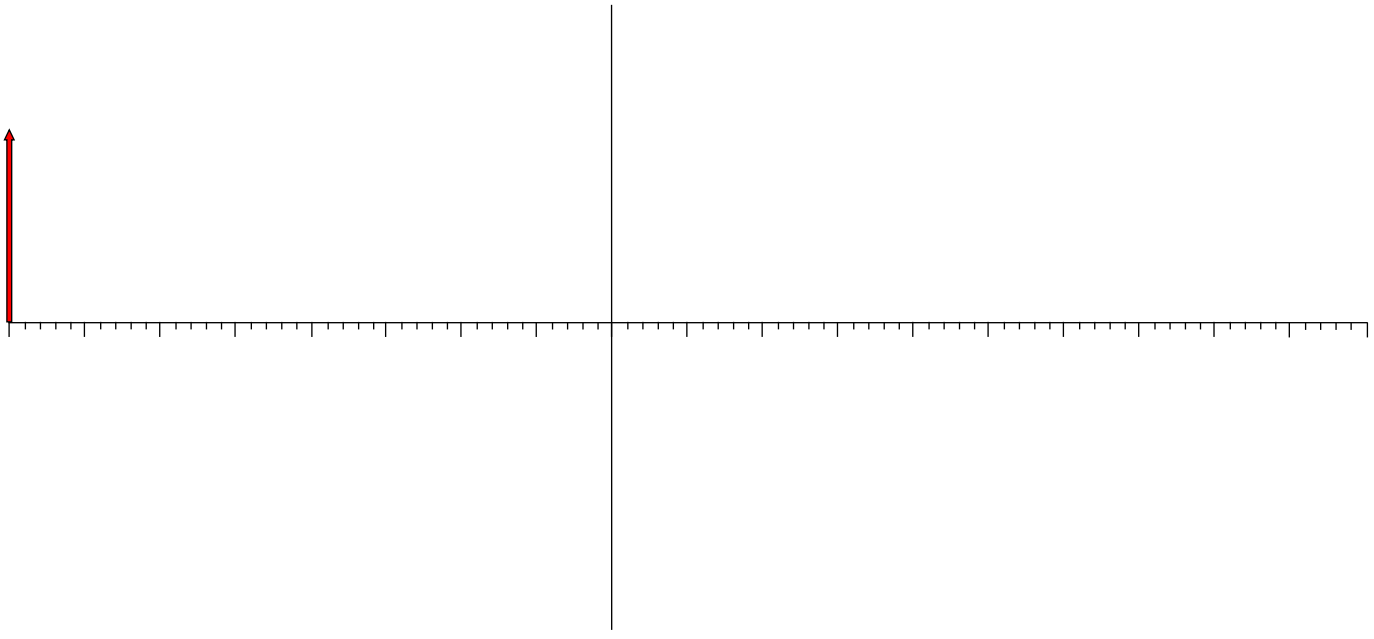
1c) Which of the following best describes the final image? Circle the best answer.

Diminished	Enlarged	Neither	Impossible to determine without more info

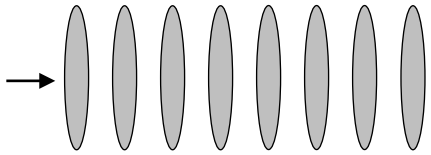
***1d) Determine magnification of the image. Because your result must be correct to three sig figs, avoid using parameters determined from your drawing!

1d	

**1e) Draw the ray diagram (using at least two rays). Include labels for the focal point and the image.



Unpolarized light is incident upon a series of 8 polarizers. The first polarizer is vertically oriented. The second polarizer is rotated from the vertical by unknown angle θ. The third polarizer is rotated from the vertical by 2θ. The next polarizer is rotated from the vertical by 3θ and so on. The final transmitted intensity (after passing through all 8 polarizers) is 33.3%.



*****2) Determine angle θ. List all possible angles if more than one exists.

2	

A diffraction pattern is formed on a screen located 3.85 m from a 540 μm wide slit. The first minima occurs at position **A** on the screen 4.44 mm from the middle of the central max. Notice the questions at the bottom of the page…

***3a) Determine the wavelength of light used to generate this single slit pattern.

***3b) Determine intensity on the screen 1.234 mm from the centerline.
Express your result as a percentage of maximum intensity.

3a	
3b	

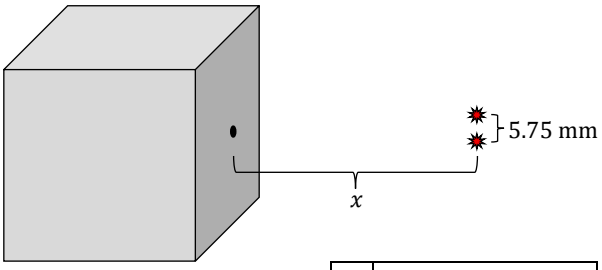
3c) Suppose single slit was exchanged with double slits with slit separation equal to twice the single slit's width. Assume each slit is 540 μm wide. Which best describes how the central max changes? Circle the best answer.

Central max 4 times as wide	Central max 2 times as wide	Central max same width	Central max $\frac{1}{2}$ as wide	Central max $\frac{1}{4}$ as wide	Impossible to determine without more info	None of the other answers is correct

3d) Again, suppose single slit was exchanged with double slits as in part 3c. Which best describes how the intensity at position **A** would change? Circle the best answer. I am asking about brightness relative to the *new* central max brightness…

Completely dark $I' = 0$	Half max brightness $I' \approx 0.5I'_{central\ max}$	Max brightness $I' \approx I'_{central\ max}$	Impossible to determine without more info	None of the other answers is correct

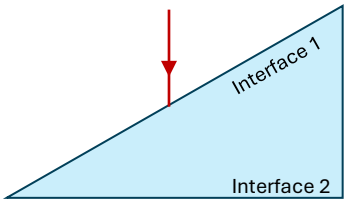
A pinhole camera is made by poking a hole of diameter 2.22 mm in the center of one side of a cardboard cube with side length 60.0 cm (figure not to scale). The hole forms an image inside the box on the *left* side. This camera just barely resolves two 650 nm light sources separated by the distance shown.



**4) Determine distance x shown in the figure.

4

A triangular slab of diamond is 2.00 cm tall by 3.40 cm wide is surrounded by air. Laser light is incident upon Interface 1 as shown in the figure (almost to scale).



5a) As the light passes through interface 1, which best describes the deflection of the ray? **To clarify your answer, draw the deflection in the figure at right.**

Deflection left	Deflection right	No deflection	Impossible to determine without more info

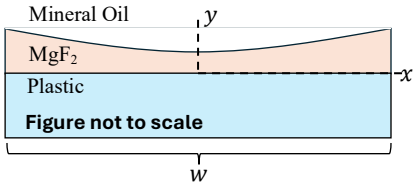
***5b) At what angle does the light impact Interface 2 (relative to the normal)?

5b

A thin layer of magnesium fluoride (index $n = 1.40$) is applied to a slab of plastic with index $n = 1.53$. The system is immersed in mineral oil with $n = 1.47$. The slab has width $w = 8.88$ cm. The height of the thin layer is modeled by

$$y(x) = a + bx^2$$

based on the coordinate system shown. In this equation a & b are unknown constants. This slab is illuminated from above with 800 nm light (normally incident).



- We want the film to be the *minimum* possible thickness to produce strong reflection at $x = 0$.
- We want film thickness at the right edge of the slab to be 7.00 times thicker than at the center.

****6a) Determine the constant a as a number with units.

6b) Determine the constant b in **scientific notation times a **unit *without* prefixes**.

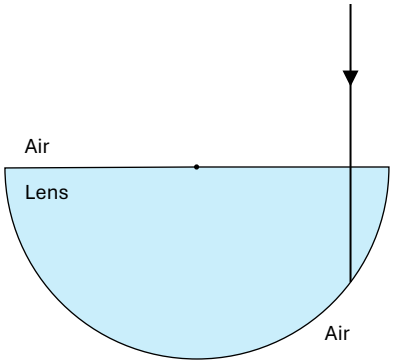
Notice there is a problem at bottom of page…

6a	
6b	

*6c) Which best describes the reflection at the right edge of the slab?

Brightest possible reflection	No reflection	Some reflection (but not brightest possible)	Impossible to determine without more info

A laser is incident upon a semi-circular lens 3.81 cm from its center (black dot). The lens has diameter 10.00 cm (figure not to scale…but somewhat close).
***7a) Determine the index is required to cause total internal reflection when the light ray first reaches the curved surface. Notice the questions at the bottom of the page…



7a	

7b) Suppose the laser is moved left or right while keeping the laser normally incident on the top surface. Which way should the laser be moved to allow some light to exit the curved surface? Circle the best answer.

Right	Neither works	Left	Either works	Impossible to determine without more info

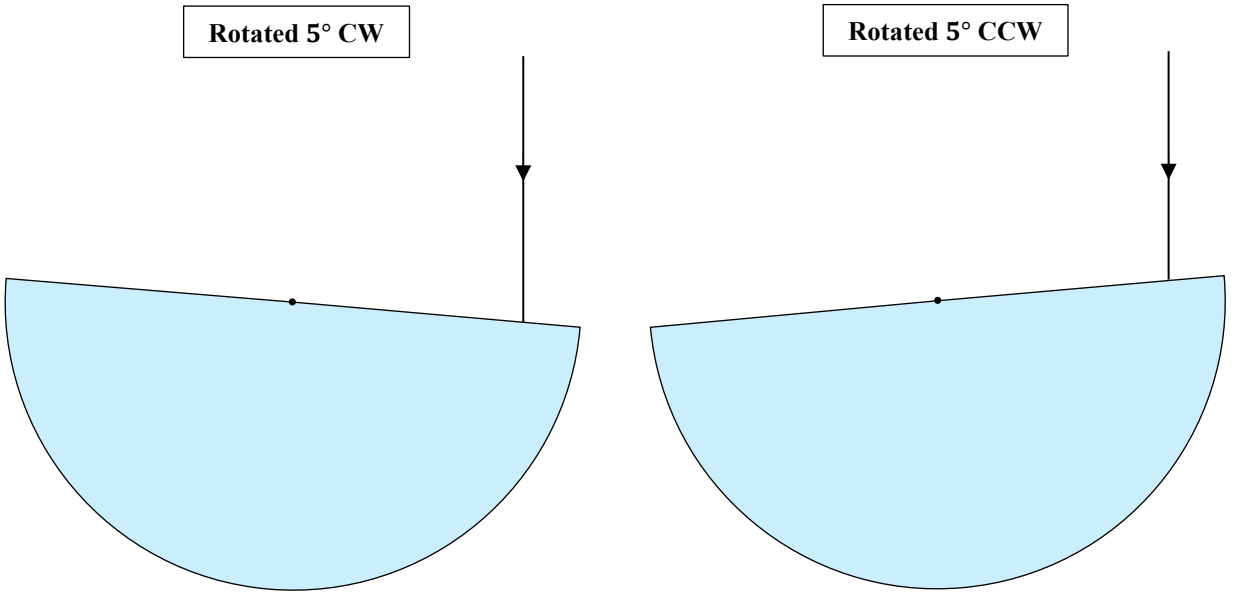
This is a tough page for only 2 points. Skip this unless you've finished the test & checked your work already.

***EC1)** In question 3c & 3d, we described replacing the single slit with a double slit. Assuming the same changes were made, how does max brightness of the double slit pattern compare to max brightness of the single slit pattern? Circle the correct answer AND clearly explain your reasoning for credit.

Half as bright	Same brightness	Twice as bright	Impossible to determine without more info	None of the other answers is correct

***EC2)** Reconsider problem 7. The laser is in the original location & the lens is *rotated* 5° about its center. Which way should the lens be *rotated* (about its center) to allow some light to exit the curved surface? **Circling an answer without showing your work on the diagrams below receives no credit.**

Clockwise	Counterclockwise	Either works	Neither works	Impossible to determine without more info



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