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

162sp25t3a – 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.

$1\ \text{kg}\cdot\frac{\text{m}}{\text{s}^2}=1\ \text{N}$	$1\ \text{N}\cdot\text{m}=1\ \text{J}$	$1\ \text{Pa}=1\frac{\text{N}}{\text{m}^2}$	$1\ \text{W}=1\ \frac{\text{J}}{\text{s}}$
$c=2.998\times10^{8}\frac{\text{m}}{\text{s}}$	$h=6.626\times10^{-34}\ \text{J}\cdot\text{s}$	$h=4.136\times10^{-15}\ \text{eV}\cdot\text{s}$	$e=1.602\times10^{-19}\ \text{C}$
$hc=1240\ \text{eV}\cdot\text{nm}$	$\hbar=\frac{h}{2\pi}=1.0546\times10^{-34}\ \text{J}\cdot\text{s}$	$\hbar=\frac{h}{2\pi}=6.583\times10^{-16}\ \text{eV}\cdot\text{s}$	$1.602\times10^{-19}\ \text{J}=1\ \text{eV}$
$\omega=\frac{2\pi}{T}=2\pi f$	$k=\frac{2\pi}{\lambda}$	$c=f\lambda \qquad E=hf=\frac{hc}{\lambda}$	$I_{avg}=\frac{\mathcal{P}}{A}$
$p=\frac{E_\gamma}{c}=\frac{h}{\lambda}=\hbar k$	$c=nv \quad \lambda_n=\frac{\lambda}{n} \quad f_n=f$	$\theta_{min\ slit}\approx\frac{\lambda}{a}$	$2n_{film}t=m\lambda_{vacuum}$
$\sin^2 x=\frac{1-\cos 2x}{2}$	$\cos^2 x=\frac{1+\cos 2x}{2}$	$\theta_{min\ circle}\approx 1.22\frac{\lambda}{d}$	$2n_{film}t=\left(m+\frac{1}{2}\right)\lambda_{vacuum}$
$2\sin\theta\cos\theta=\sin 2\theta$	$\cos(90°-\theta)=\sin\theta$	$\sin(90°-\theta)=\cos\theta$	for $m=0,1,2,\ldots$
$\sin(a\pm b)=\sin a\cos b\pm\cos a\sin b$		$\cos(a\pm b)=\cos a\cos b\mp\sin a\sin b$	
$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f}$	$\theta_i=\theta_r \quad n_1\sin\theta_1=n_2\sin\theta_2$	$d\sin\theta_{bright}=\pm m\lambda$	$a\sin\theta_{dark}=\pm m\lambda$ 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

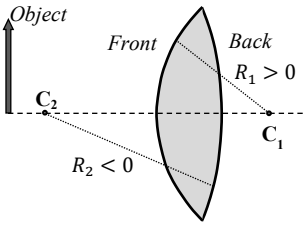
Variable	Positive if…	Negative if…
d_o	Object is *in front of* mirror (*real* object).	Object is *behind* mirror (*virtual* object).
d_i	Image is *in front of* mirror (*real* image).	Image is *behind* mirror (*virtual* image).
f & R	Mirror is *concave*.	Mirror is *convex*.
h_i	Image is *upright*.	Image 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.	

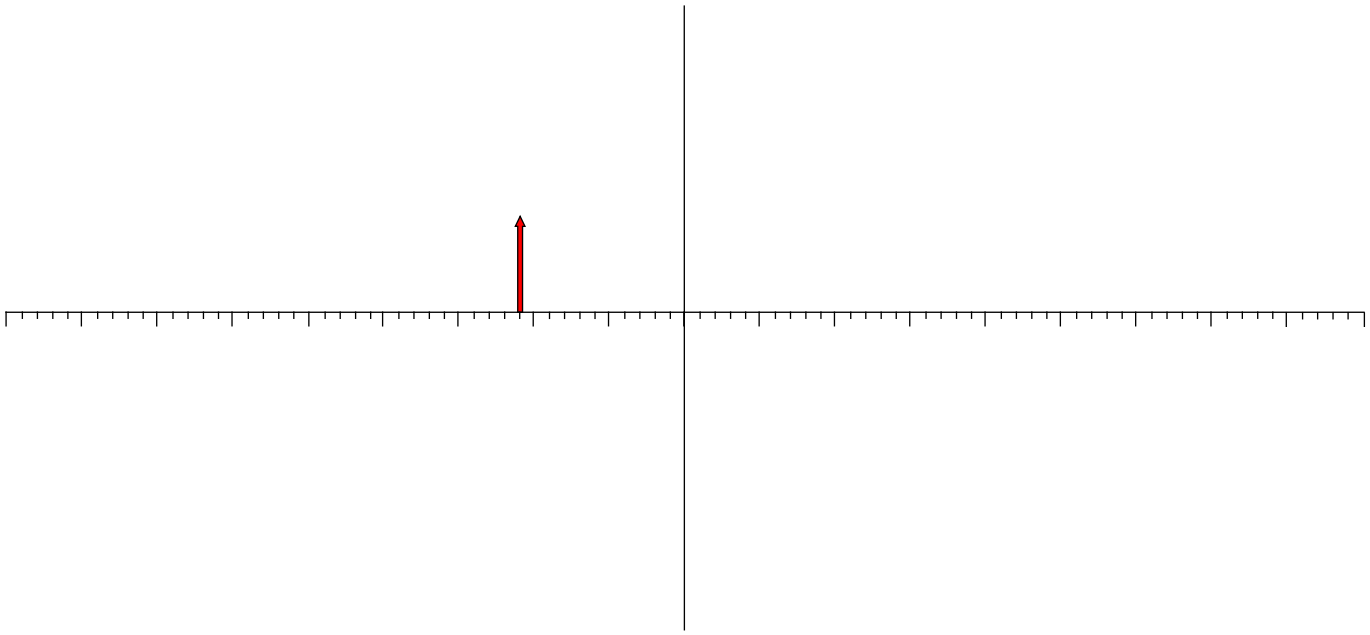
Indices of Refraction	
Vacuum	1
Air	$1.00029\approx1$
Water	1.333
Crown Glass	1.50-1.60
Flint Glass	1.45-2.00
Sapphire	1.77
Diamond	2.42

Radii & Centers of Curvature for a Biconvex Lens



Name: _____

An object & a bi-convex lens are placed at the positions shown below. Assume each minor tick mark on the diagram below corresponds to 1.0 cm. Focal points are located 25.0 cm from the lens (shown as a line).
**1a) Draw the ray diagram (using at least two rays) including labels for the focal points and the image.



Your answers to the following must be correct for the situation described above.
You can always do the math if you do not trust your ray diagram…

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

Upright	Inverted	Neither	Impossible to determine without more info

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

Enlarged	Diminished	Neither	Impossible to determine without more info

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

Real	Virtual	Neither	Impossible to determine without more info

A convex mirror with a 40.0 cm radius of curvature forms an upright image 2.22 times *smaller* than the object.

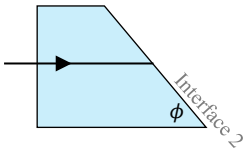
2a) Which of the following best describes magnification associated with the image formed by the mirror?

$M = +1$	$0 < M < 1$	$M > 1$	Impossible to determine without more info.
$M = -1$	$-1 < M < 0$	$M < -1$	

****2b) Determine object distance.

2b	

White is incident upon an acrylic prism (shown at right). The prism is surrounded by air. Total internal reflection does not occur at interface 2. For the following questions, circle the best answer.



3a) When light exits the prism (at interface 2), which best describes how the light ray is bent?

Deflected upwards	No deflection	Deflected downwards	Impossible to determine without more info

3b) Which color light experiences more deflection at interface 2: red light or blue light?

Red light	Same deflection (includes no deflection)	Blue light	Impossible to determine without more info

3c) A similarly shaped 2nd prism with different apex angle ϕ' is used. Light still enters perpendicular to the left face & parallel to the bottom face. TIR occurs at the new interface 2. Which best describes the relationship between ϕ' & ϕ?

$\phi' > \phi$	$\phi' < \phi$	Impossible to determine without more info

Below I show three images of interference patterns produced on flat screens. Each pattern was produced by sending monochromatic light though one of the following: a single slit, a double slit, or a diffraction grating.

Pattern 1

Pattern 2

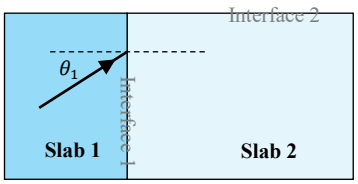
Pattern 3

4a) Which patterns (or pattern) were created by a diffraction grating? Circle the best answer.

1 only	2 only	3 only	None of them	Impossible to determine without more info
1 & 2	2 & 3	1 & 3	All three of them	

4b) What is the most plausible explanation of the large gaps in Pattern 3 (adjacent to the third bright fringes)? Your explanation should be clear, concise, and complete for credit. It should also fit in the space below.

Slab 1 is made from cubic zirconia with index of refraction 2.14.
Slab 2 is made from an unknown material with index 1.450.
The region surrounding the two slabs is a gas with index 1.234.



5a) Which of the following best describes the behavior of the ray **at interface 1**?
Circle the best answer.

No reflection, ray *undeflected* as it travels towards interface 2	No reflection, ray deflected *upwards* as it travels towards interface 2	No reflection, ray deflected *downwards* as it travels towards interface 2	TIR at interface 1
Some reflection, ray *undeflected* as it travels towards interface 2	Some reflection, ray deflected *upwards* as it travels towards interface 2	Some reflection, ray deflected *downwards* as it travels towards interface 2	Impossible to determine without knowing θ_1

5b) Determine the critical angle **for interface 2**.
***5c) Determine the angle θ_1 required for the incident ray to impact interface 2 at the critical angle.

5b	
5c	

5d) Assume you correctly determined θ_1 such that the transmitted ray is incident at interface 2 at the critical angle. Which of the following answers best describes this value of θ_1? Circle the best answer.

Min value of θ_1 to cause TIR	Only value of θ_1 to cause TIR	Max value of θ_1 to cause TIR	Impossible to determine without more info

A double slit interference pattern is produced using 475 nm wavelength light & slit spacing 325 μm. The screen position is adjusted until the spacing between adjacent dark fringes is 10.00 mm. The intensity in the middle of the central maximum is $0.888\frac{\mathrm{W}}{\mathrm{m}^2}$.

****6a) Determine the distance to the screen.

**6b) Determine intensity 7.77 mm from the central max.

6a	
6b	

6c) Suppose this experiment was repeated with a *smaller slit spacing* but used the same wavelength & screen distance. Which best describes how the pattern would change? Circle the best answer.

No change to fringe spacing	Fringes closer together	Fringes farther apart	Impossible to determine without more info

A thin film of sapphire is adjacent to a thick slab of crown glass. The sapphire film is essentially a triangular wedge. Be aware, the maximum width w of the sapphire is much smaller than the height of the crown glass slab h. As such, the angled face of the sapphire is *almost* perfectly parallel to its other face. The angle in the picture is grossly exaggerated. Monochromatic visible light is incident from the right side, parallel to the x-axis.

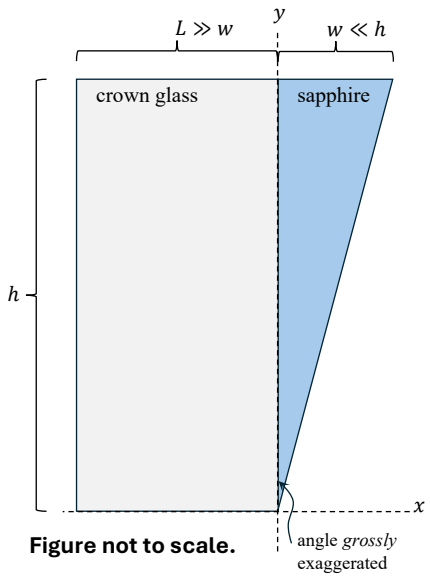


Figure not to scale.

7a) Will this system produce strong reflection or almost no reflection for points near $y = 0$? Circle the best answer.

Strong reflection	Almost no reflection	Impossible to determine without λ	Impossible to determine even if I knew λ	None of the other answers are true

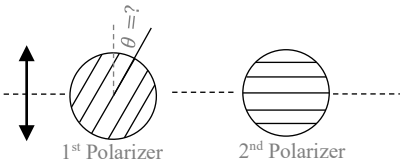
7b) Which best describes the appearance of the reflection from the system?

Strong uniform reflection over entire face	Pattern of fringes getting closer together as y increases.	Pattern of fringes with uniform spacing as y increases.	Impossible to determine without λ
Almost no reflection over entire face	Pattern of fringes getting farther apart as y increases.	Impossible to determine even if I knew λ	None of the other answers are true

****7c) Now assume $\lambda = 555\ \text{nm}, h = 20.0\ \text{cm}, \& L = 5.00\ \text{cm}$. An engineer observes the center of the 44th bright fringe appears at $y = 3.25\ \text{cm}$. Determine max width of the wedge.

7c	

Vertically polarized light is incident upon two polarizers.
The 1st polarizer has unknown angle θ from the vertical.
The 2nd polarizer is horizontal.
Exactly 12.34% of incident light is transmitted through this system.
******8) Determine *all possible* angles for θ between 0° & 180°.



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****Extra Credit:** Under what conditions (if any) is it possible for a diverging lens to produce an inverted image? Is it impossible? *Answering yes or no receives zero points.* I am interested in seeing clear work supporting your claim with math or drawings.

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