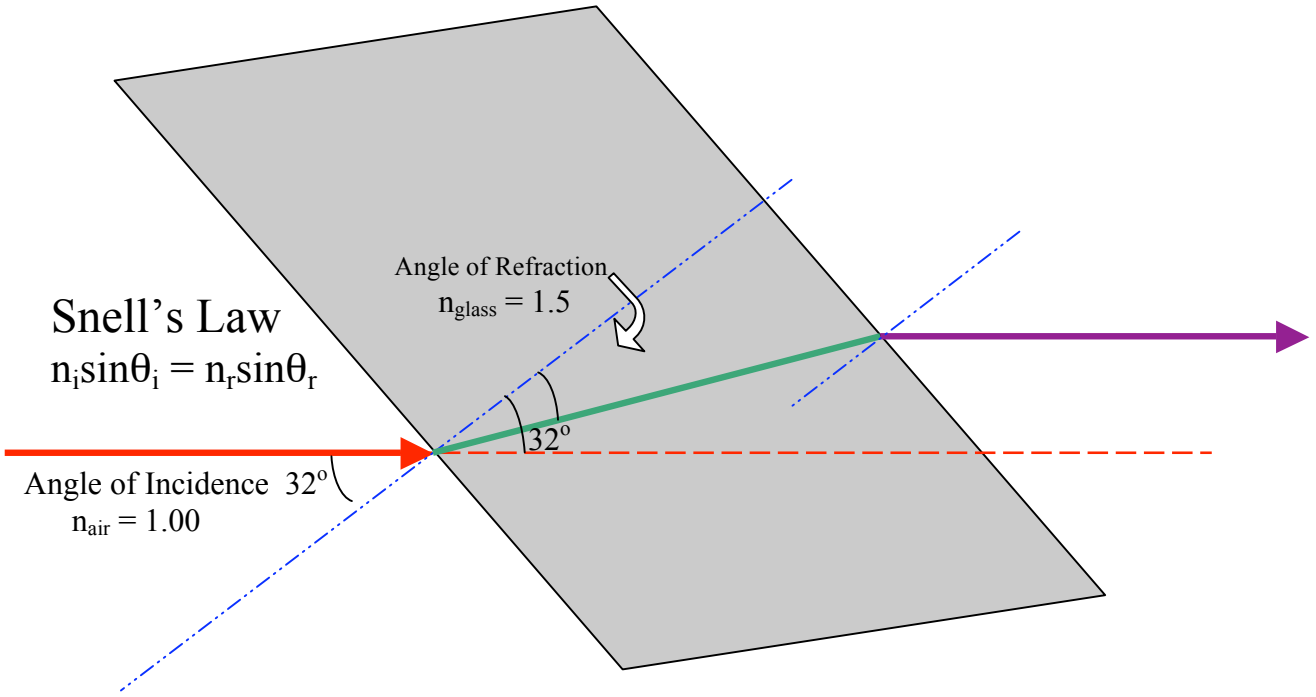

Snell's Law
$n_i \sin\theta_i = n_r \sin\theta_r$
Angle of Refraction
$n_{glass} = 1.5$
32°
Angle of Incidence 32°
$n_{air} = 1.00$

THE LAW OF REFRACTION

index of refraction

the ratio of the speed of light in a vacuum to its speed in a given transparent medium

An important property of transparent substances is the **index of refraction.** The index of refraction for a substance is the ratio of the speed of light in a vacuum to the speed of light in that substance.

INDEX OF REFRACTION

$$n = \frac{c}{v}$$

$$\text{index of refraction} = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$$

From this definition, we see that the index of refraction is a dimensionless number that is always greater than 1 because light always travels slower in a substance than in a vacuum. **Table 15-1** lists the indices of refraction for some representative substances. Note that the larger the index of refraction is, the slower light travels in that substance and the more a light ray will bend when it passes from a vacuum into that material.

Imagine, as an example, light passing between air and water. When light begins in the air (high speed of light and low index of refraction) and travels into the water (lower speed of light and higher index of refraction), the light rays are bent toward the normal. Conversely, when light passes from the water to the air, the light rays are bent away from the normal.

Note that the value for the index of refraction of air is nearly that of a vacuum. For simplicity, *use the value $n = 1.00$ for air when solving problems.*

Did you know?

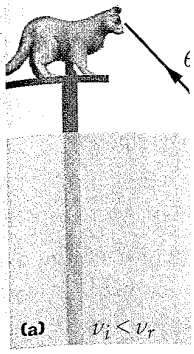
The index of refraction of any medium can also be expressed as the ratio of the wavelength of light in a vacuum, λ_0, to the wavelength of light in that medium, λ_n, as shown in the following relation.

$$n = \frac{\lambda_0}{\lambda_n}$$

Table 15-1 Indices of refraction for various substances*

Solids at 20°C	n	Liquids at 20°C	n
Cubic zirconia	2.20	Benzene	1.501
Diamond	2.419	Carbon disulfide	1.628
Fluorite	1.434	Carbon tetrachloride	1.461
Fused quartz	1.458	Ethyl alcohol	1.361
Glass, crown	1.52	Glycerine	1.473
Glass, flint	1.66	Water	1.333
Ice (at 0°C)	1.309		
Polystyrene	1.49	**Gases at 0°C, 1 atm**	**n**
Sodium chloride	1.544	Air	1.000 293
Zircon	1.923	Carbon dioxide	1.000 450

*measured with light of vacuum wavelength = 589 nm



Objects appear t

When looking at a
be closer to the wa
Conversely, the fis
water's surface tha

Because of the
the same path. H
angle with respec
water's surface. Th
from a medium w
index of refractio
the cat's image to

On the other h
face forms a large
from the fish trav
with a lower ind
water's surface th
air above appears
same size as the o

Concep

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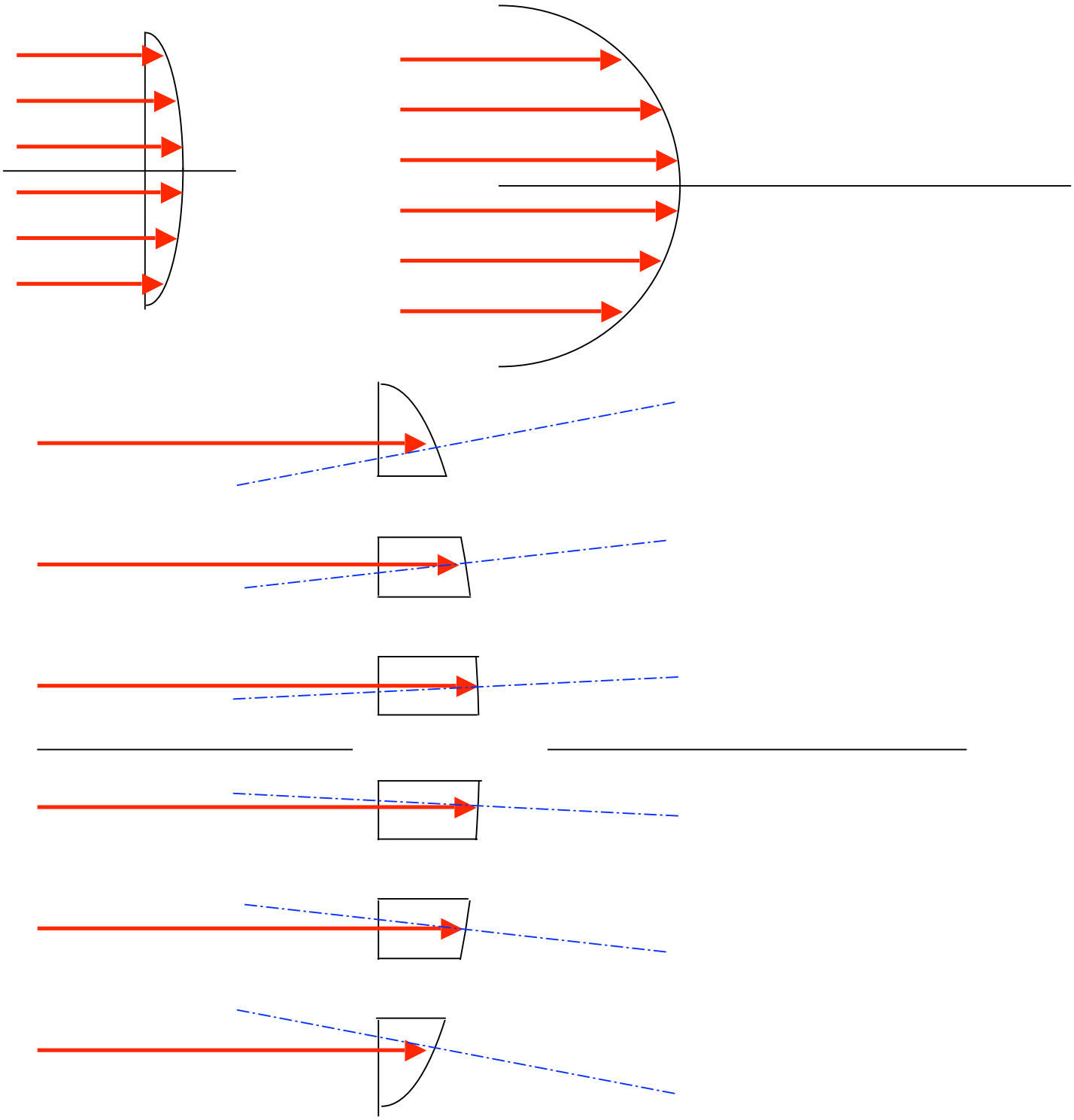

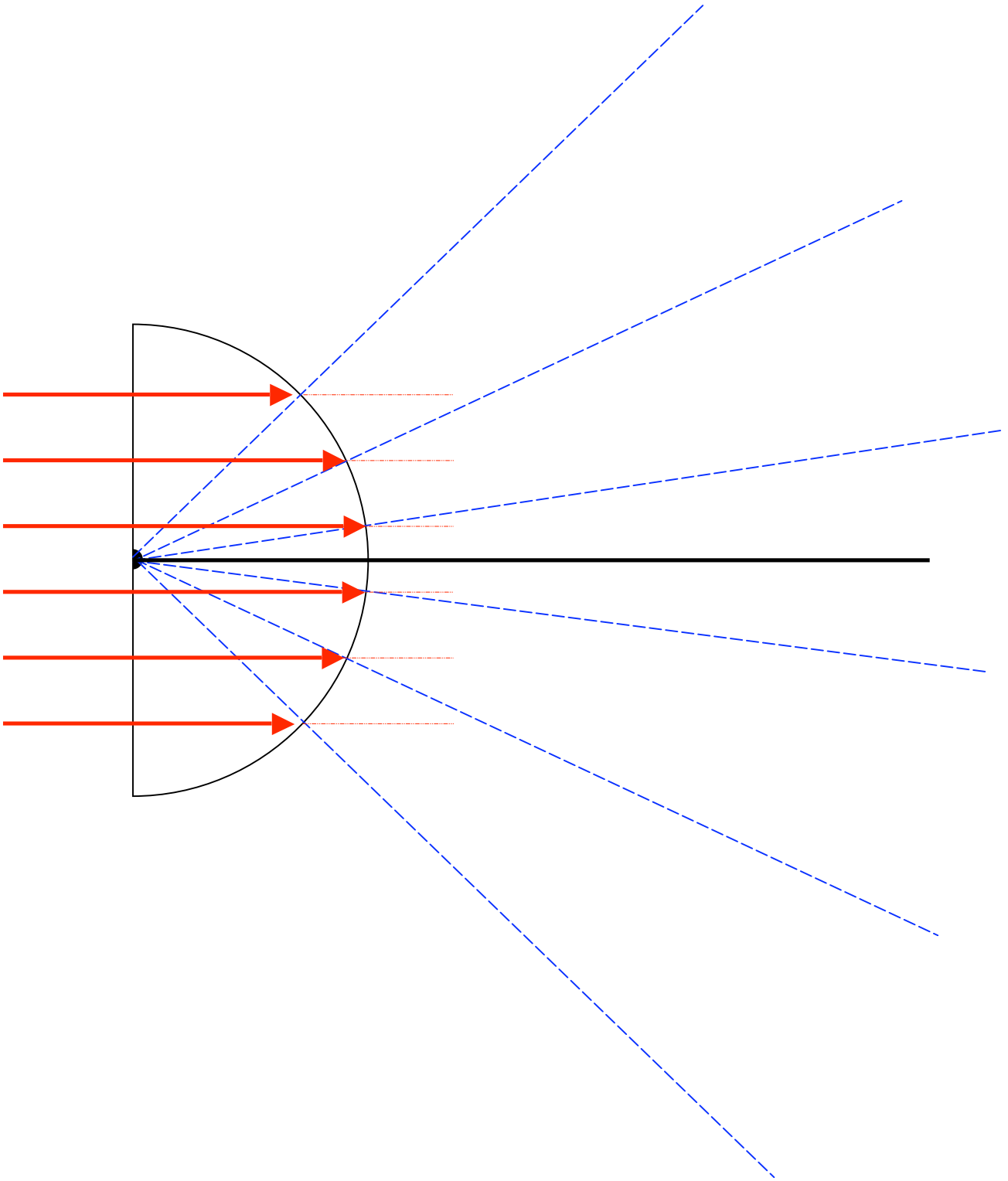

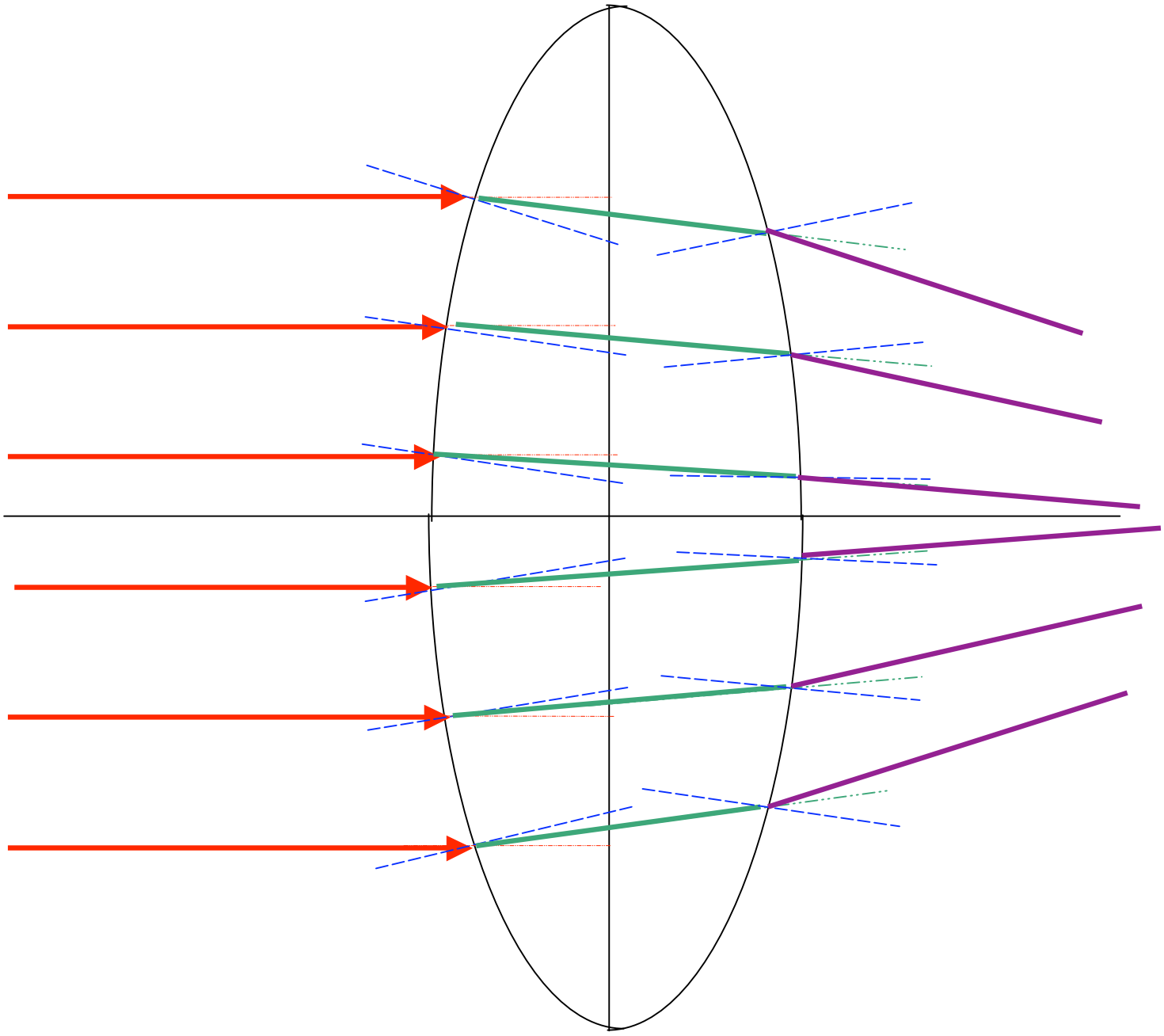

Name: _____
HR: _____
Date: _____
Grade 10 Science

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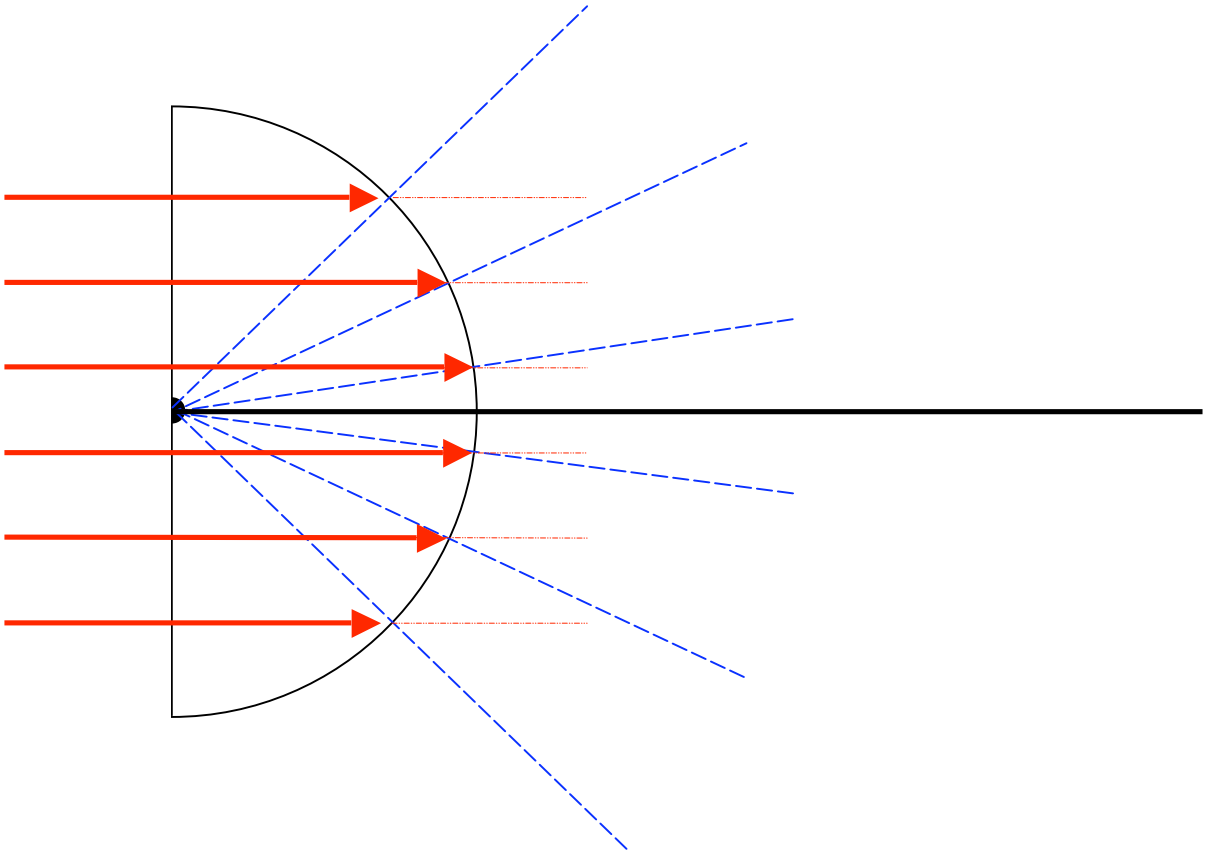
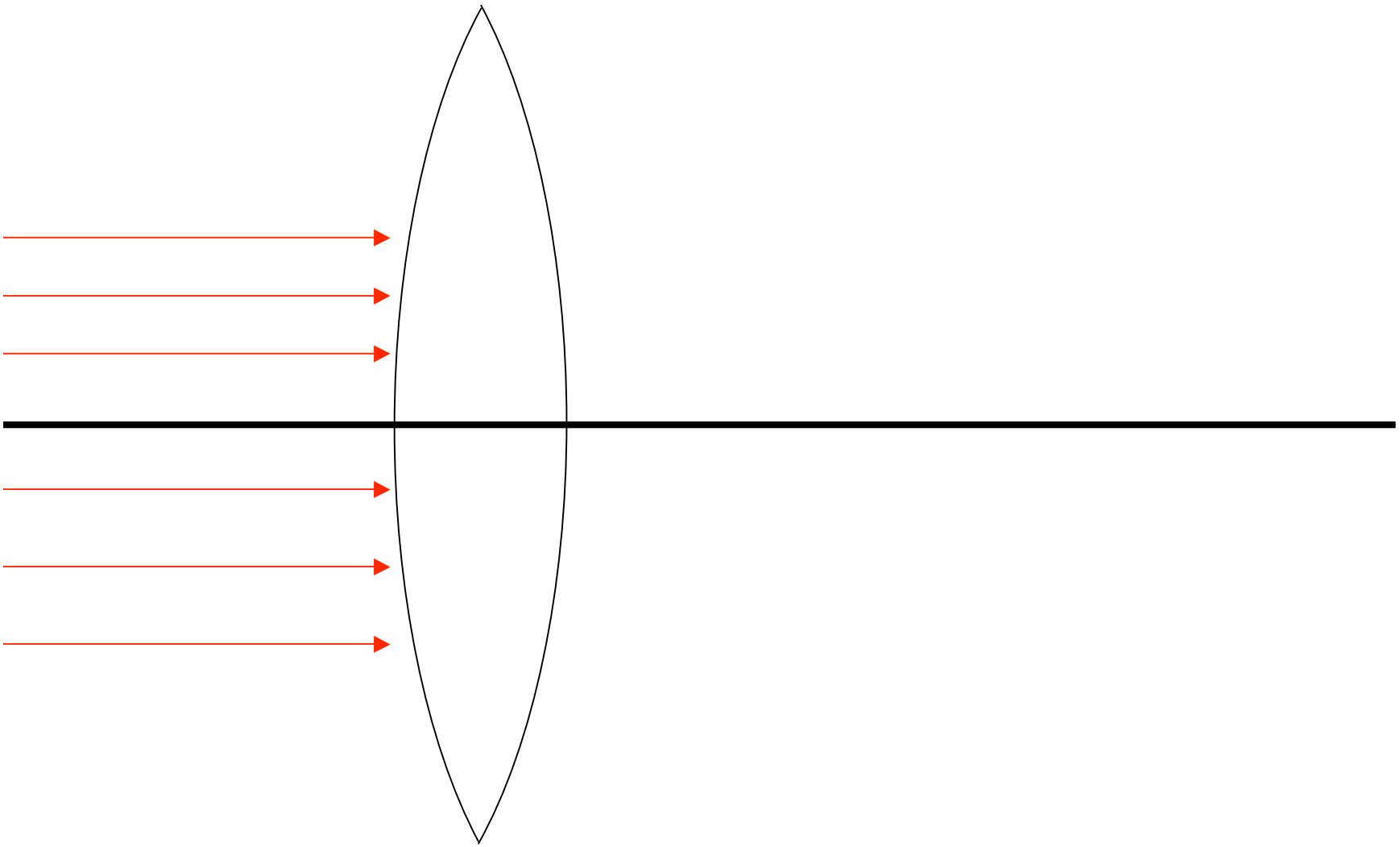
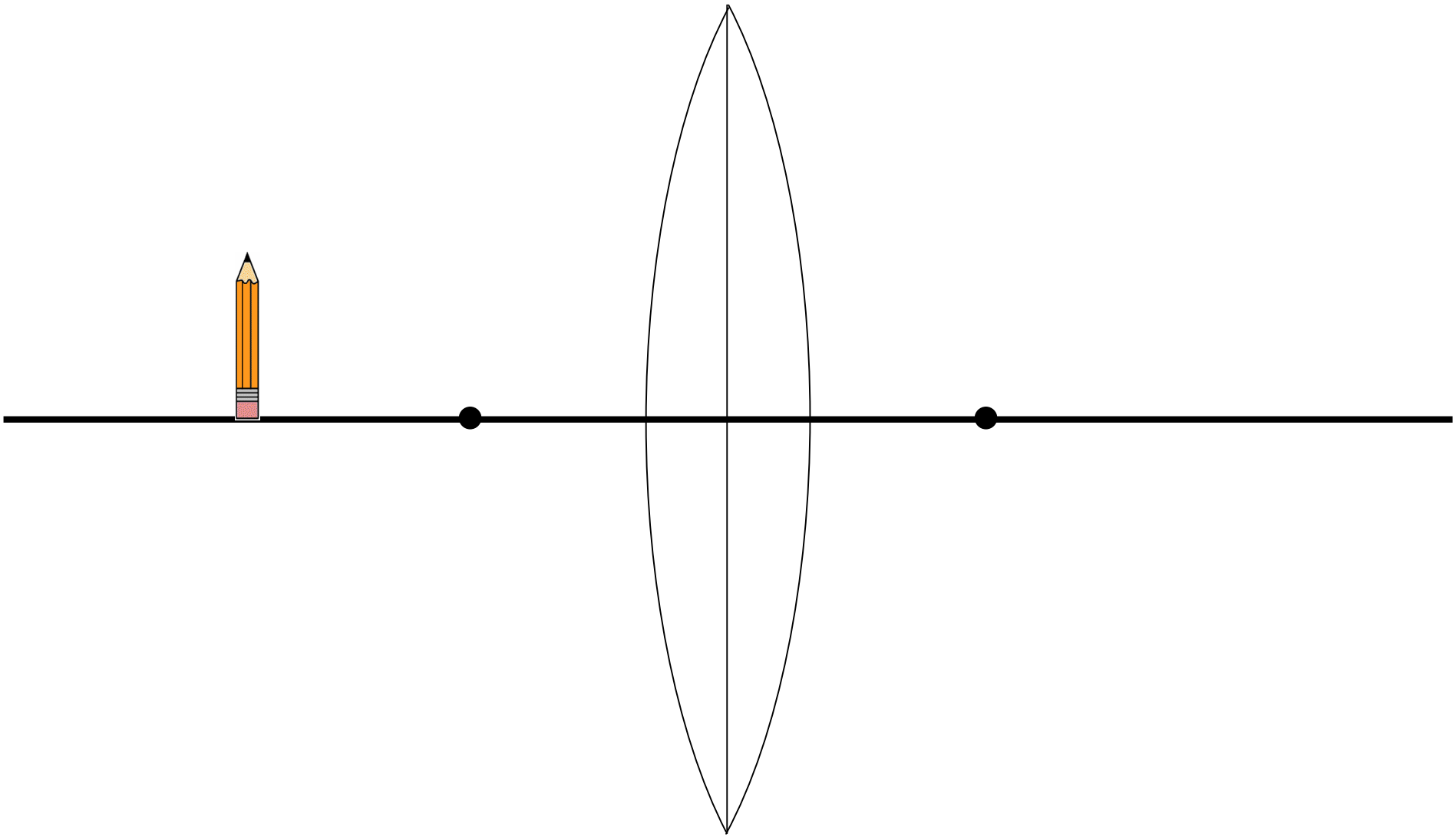
Converging Lenses



Converging Lenses

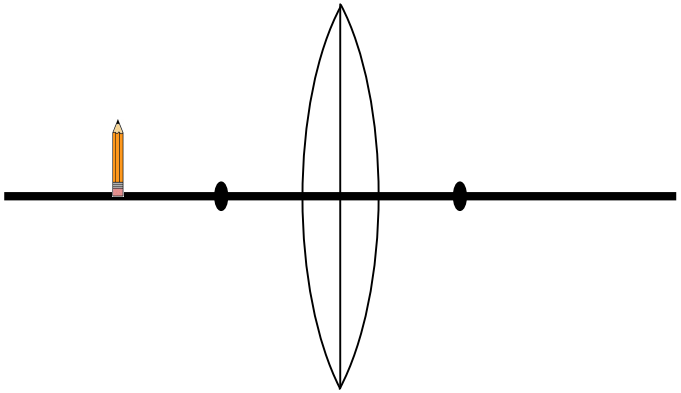


Converging Lenses

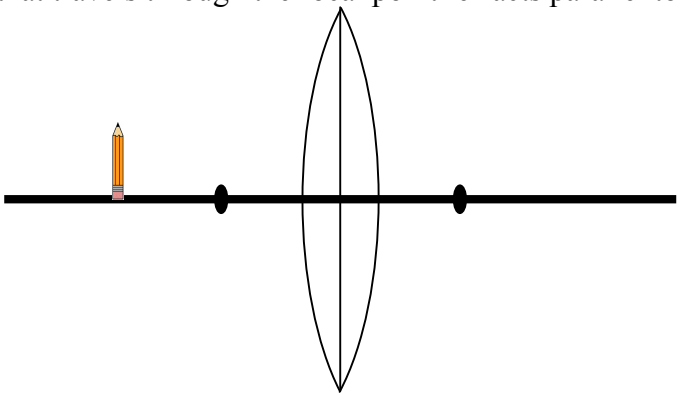


Converging Lenses

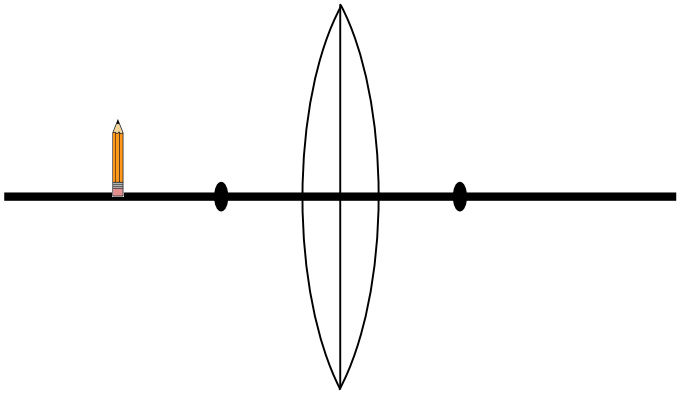
1. Any ray that travels parallel to the principal axis refracts through the focal point



2. Any ray that travels through the focal point refracts parallel to the principal axis



Any ray that travels through the center continues straight.



Name: _____
HR: _____
Date: _____
Grade 10 Science

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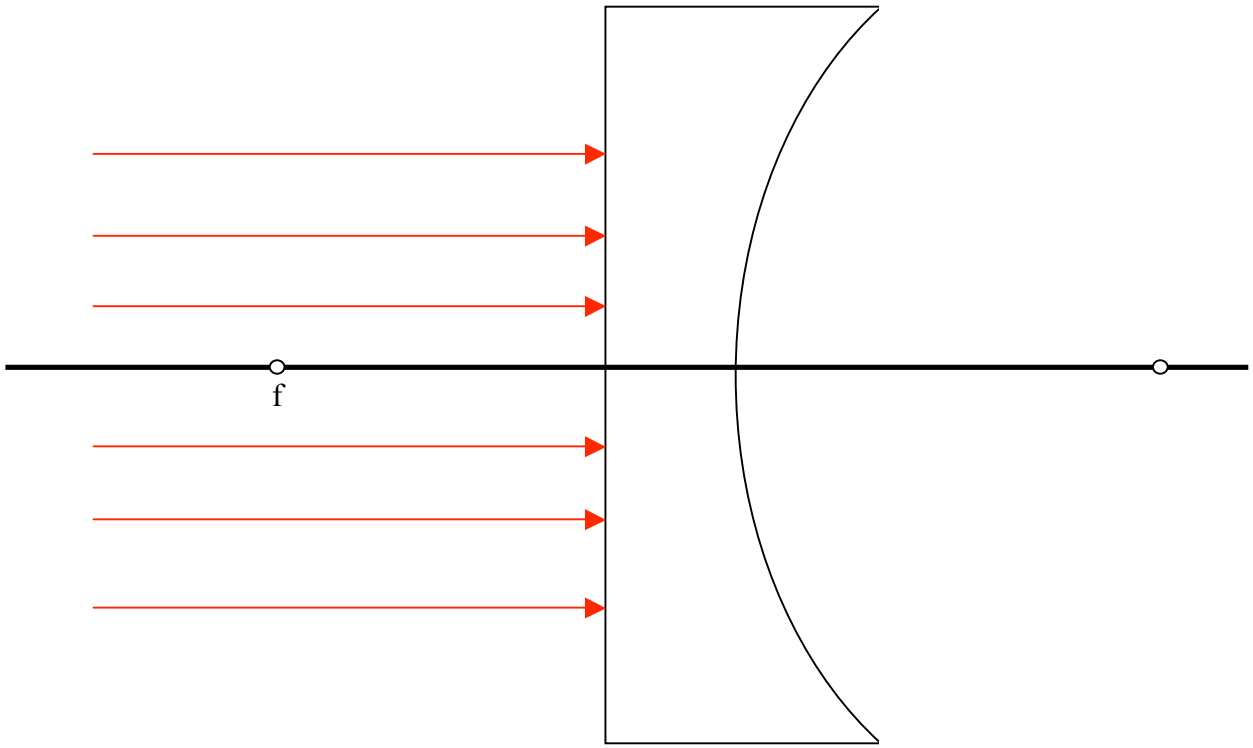
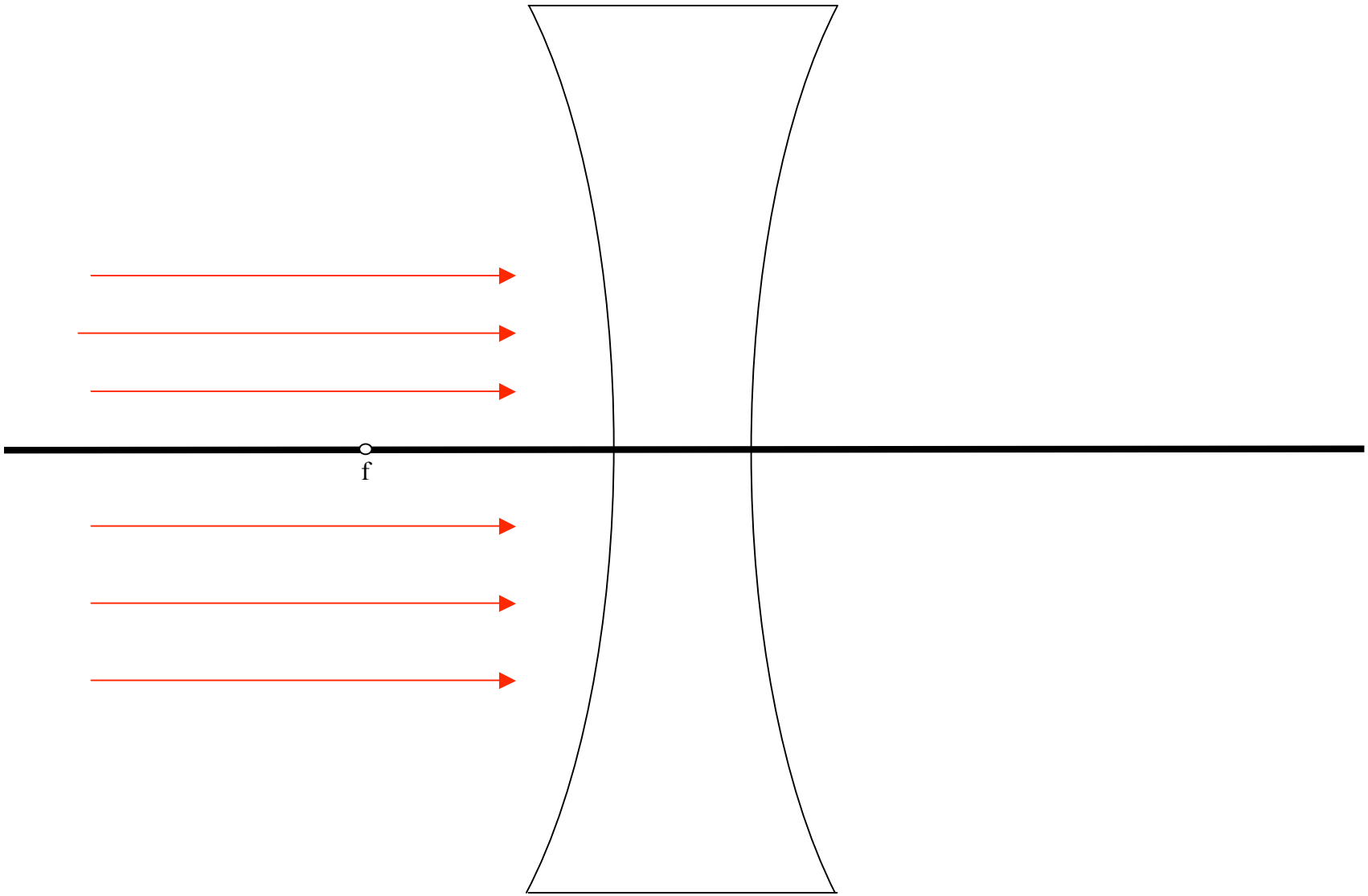
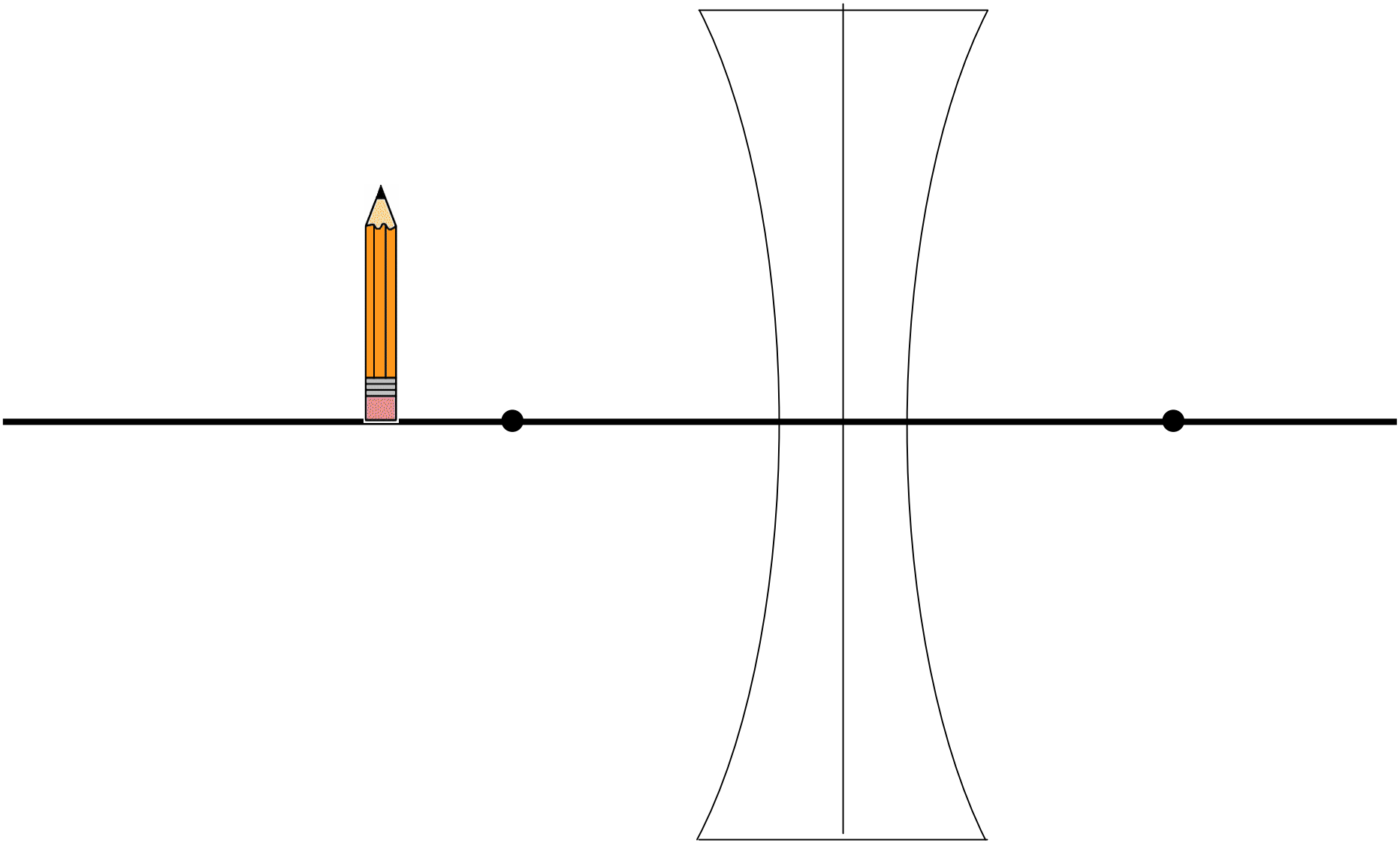
Diverging Lenses



Diverging Lenses

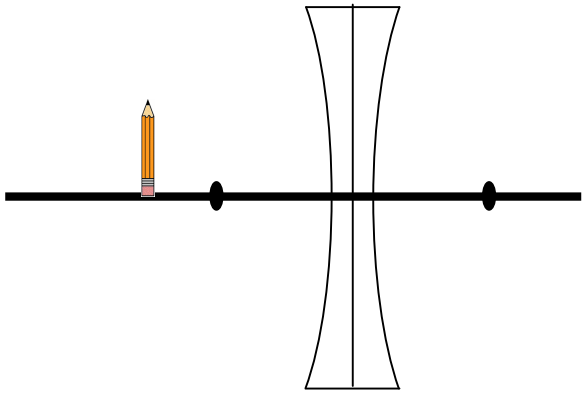


Diverging Lenses

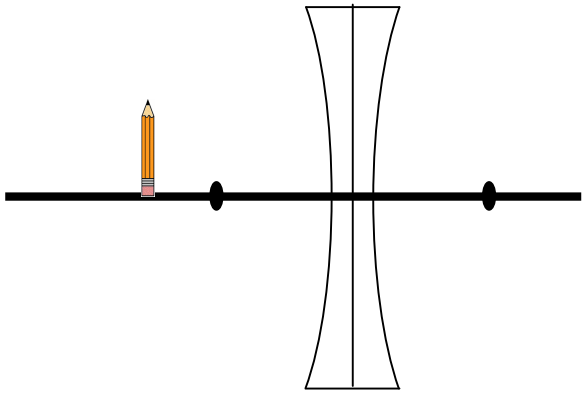


Diverging Lenses

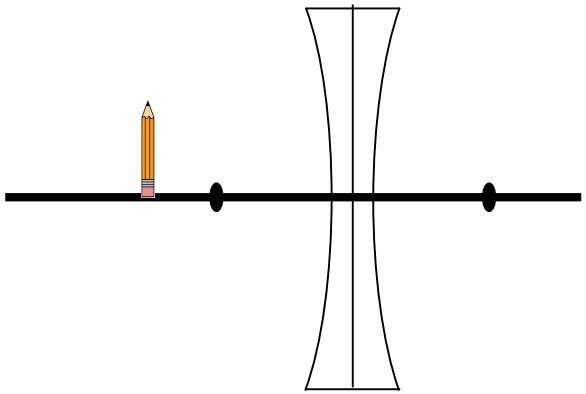
1. Any ray that travels parallel to the principal axis refracts upward, and is extended back to the focal point



2. Any ray that travels toward the *opposite* focal point refracts parallel to the principal axis, and is extended back parallel



3. Any ray that travels through the center continues straight.



Name: _____

Date: _____

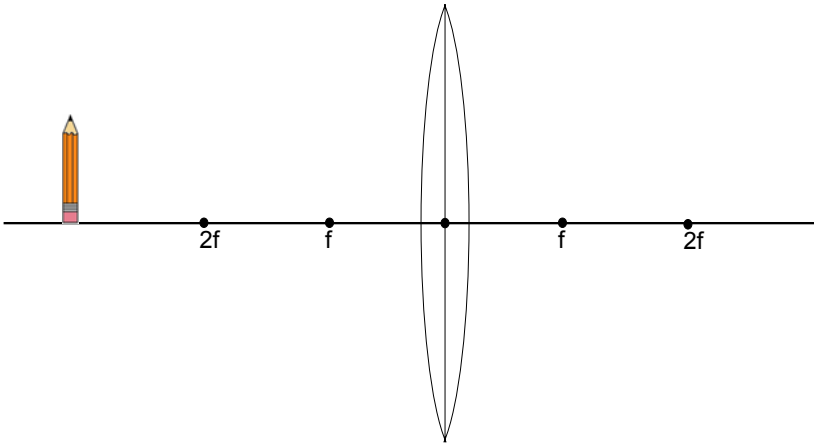
Section C D F

The Masters School
Mr. Alex Rawson
Physics

Refraction II: Ray Diagrams, Converging Lens
Real Images

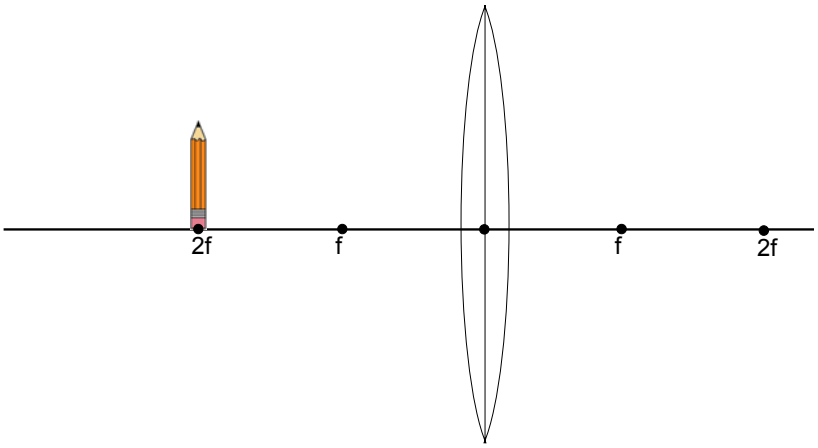
1. **For the following images, please draw the ray diagrams.**
2. The following slides illustrate an image being refracted by a converging lens. The only element that changes is the object distance, and from that the image distance changes, as well as the image height and magnification. Certain elements are the same, such as focal length and height of the object.
3. Remember the 3 rules of lenses:
   i. Any ray that travels parallel to the principal axis refracts through the focal point.
   ii. Any ray that travels through the focal point refracts parallel to the principal axis.
   iii. Any ray that travels through the center continues straight.
4. Rays must converge to create an image point.
5. Please consult the textbook pages 568-577 to ensure that your diagrams are correct.
6. Please use the "Links" page on *The Vault* for supplemental applets, diagrams, and explanations.

Object Distance greater than 2f



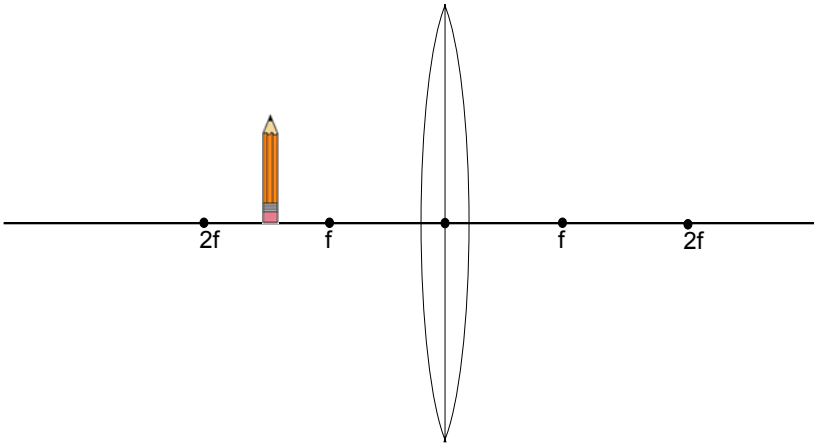
Converging Lenses

Object Distance at 2f



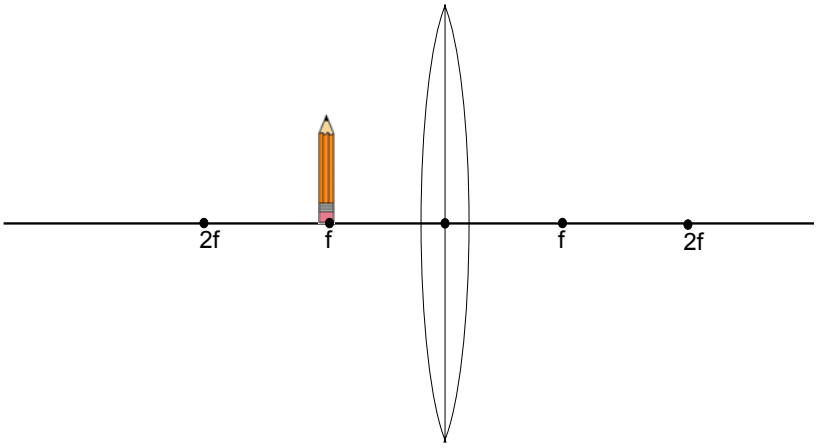
Converging Lenses

Object Distance less than 2f



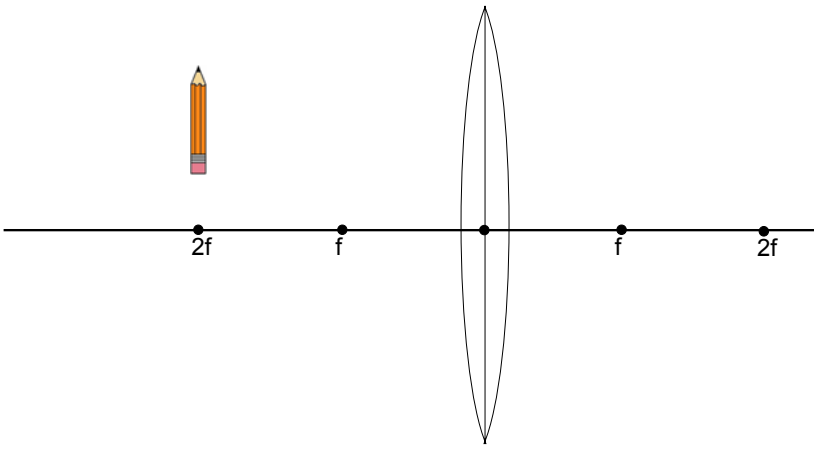
Converging Lenses

Object Distance at f



Converging Lenses

Object Distance at 2f



Converging Lenses

Name: _____

Date: _____

Section C D F

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Refraction III: Ray Diagrams
Virtual and 2D Images

1. **For the following images, please draw the ray diagrams.**
2. The following slides illustrate an image/object being refracted by a lens. The only element that changes is the object distance, and from that the image distance changes, as well as the image height and magnification. Certain elements are the same, such as focal length and height of the object.
3. Remember the 3 rules of lenses:
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   ii. Any ray that travels through the focal point refracts parallel to the principal axis.
   iii. Any ray that travels through the center continues straight.
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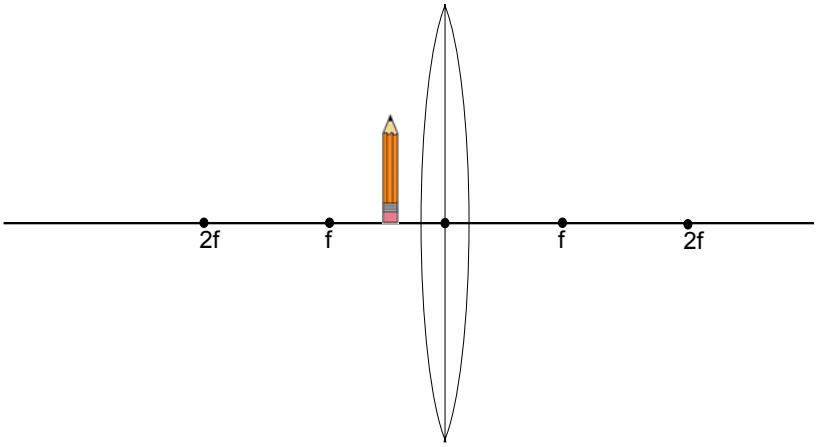
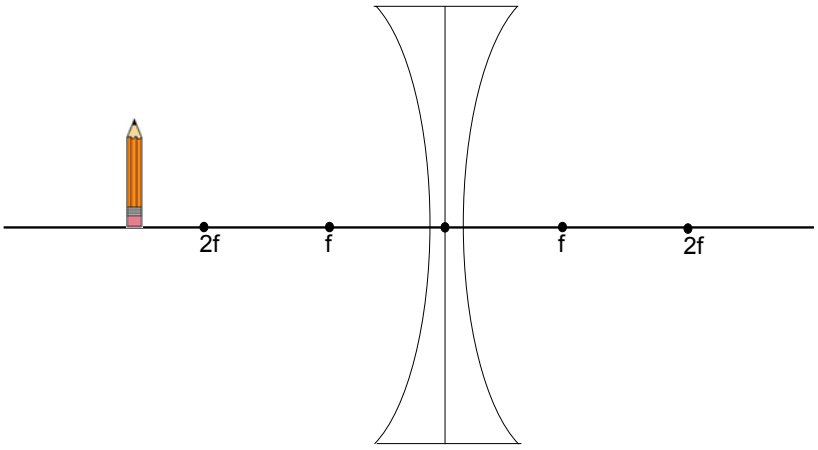
5. Please consult the textbook pages 568-577 to ensure that your diagrams are correct.
6. Please use the "Links" page on *The Vault* for supplemental applets, diagrams, and explanations.

Object Distance less than f



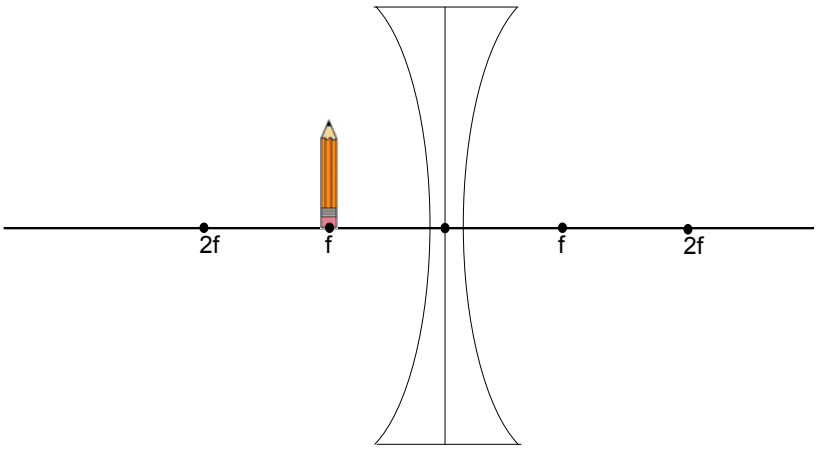
Converging Lenses

Object Distance greater than 2f



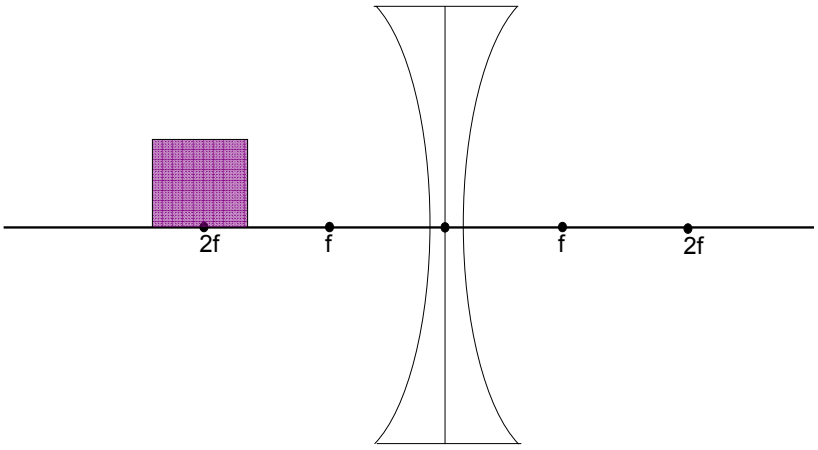
Diverging Lenses

Object Distance at f



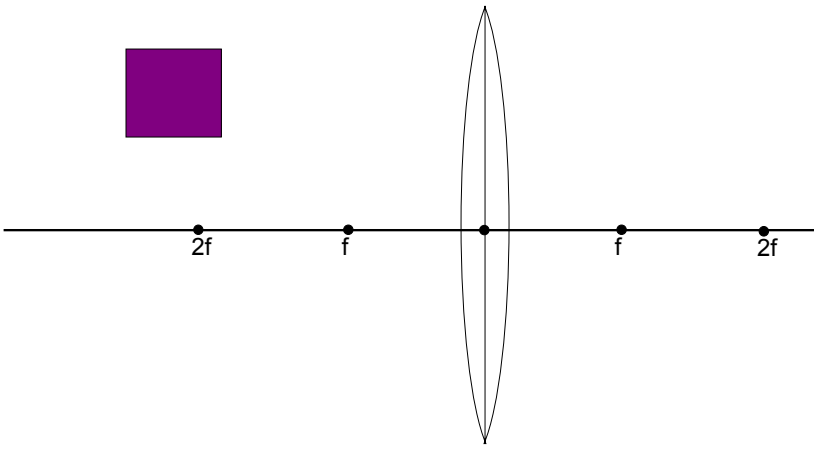
Diverging Lenses

2D Object on Principal Axis



Diverging Lenses

2D Object off Principal Axis



Converging Lenses

Name: _____

Date: _____

Section C D F

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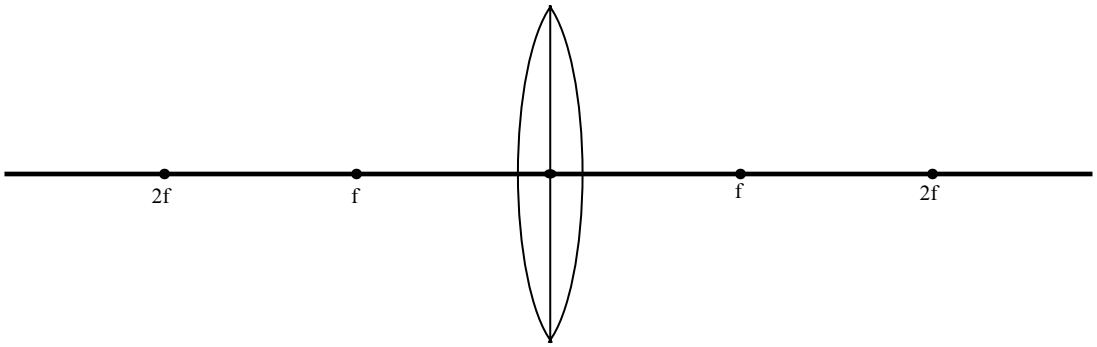
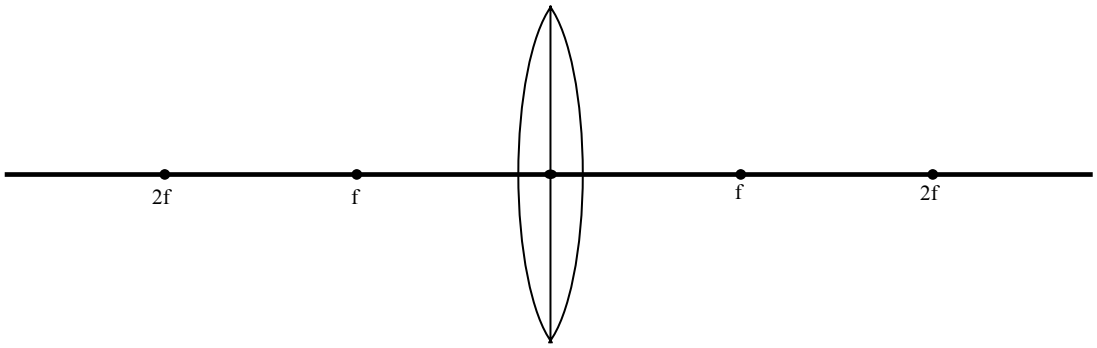
Refraction IV: Lens Calculations

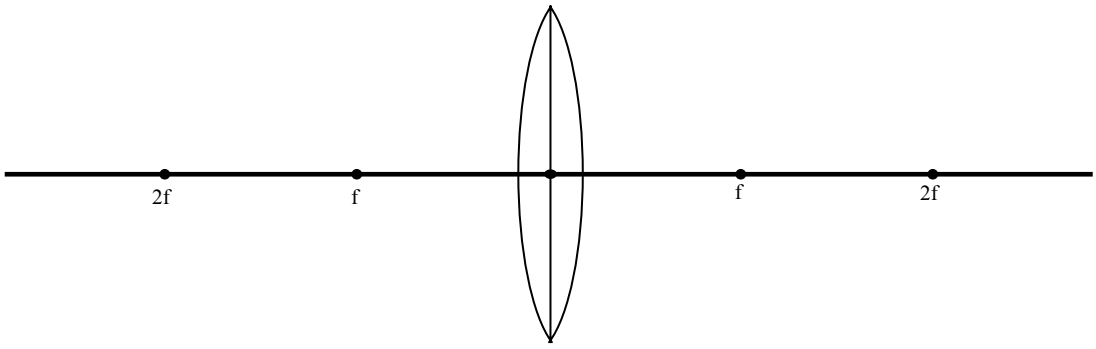
1. Determine image distance, image height, and magnification for a 5-cm tall object placed 45.0 cm from a converging lens having a focal length of 15.0 cm. Please draw a diagram.



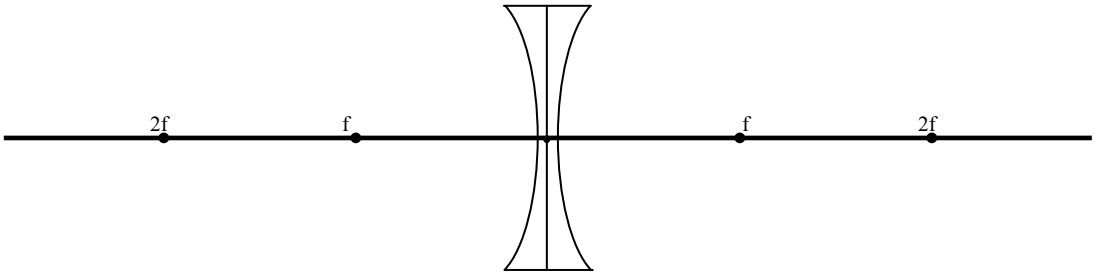
2. Determine p, h', and M for a 5-cm tall object placed 10.0 cm from a converging lens having a focal length of 15.0 cm. Draw a diagram.



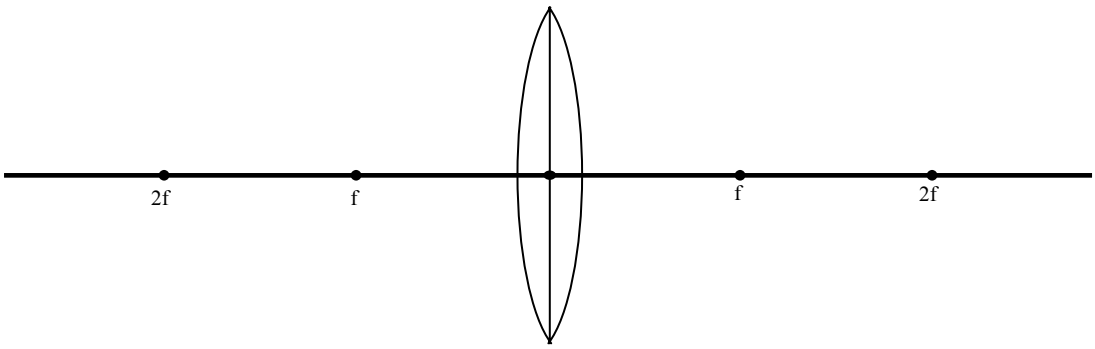
3. A magnified, inverted image is located a distance of 32.0 cm from a converging lens with a focal length of 12.0 cm. Determine the object distance and tell whether the image is real or virtual. After calculations, please fill in the diagram.



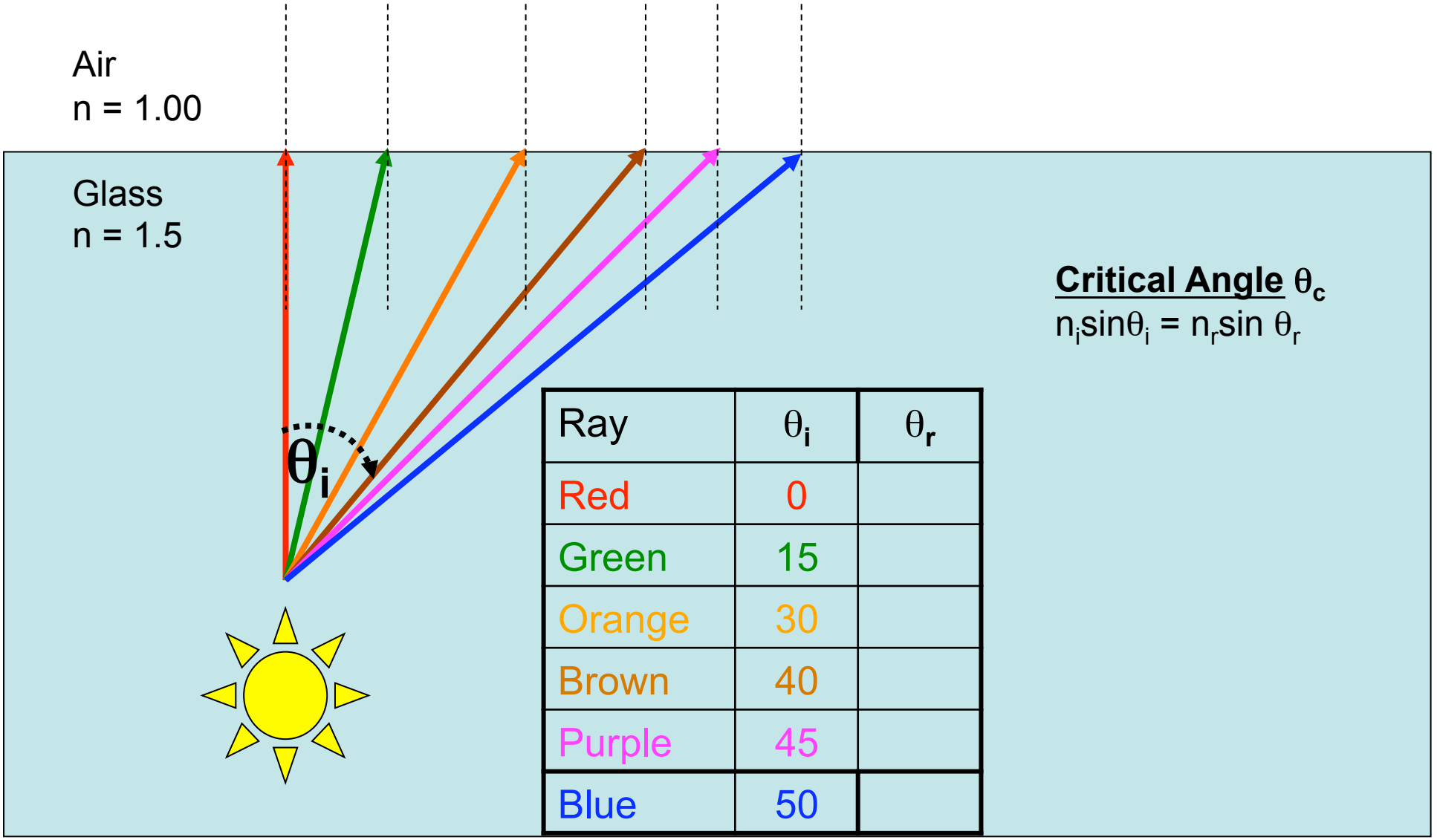
4. If a diverging lens has a focal length of -10.8 cm, find the image distance when an object is placed 32.7 cm from the lens's surface. Draw a diagram.



5. A person looks at a gem with a jeweler's microscope - a converging lens with a focal length of 12.7 cm. The microscope forms a virtual image 31.6 cm from the lens. Determine the object distance, and magnification of the image. After calculations, please fill in the diagram.



Total Internal Reflection



Critical Angle θ_c

$n_i \sin\theta_i = n_r \sin\theta_r$

Ray	θ_i	θ_r
Red	0	
Green	15	
Orange	30	
Brown	40	
Purple	45	
Blue	50	

Name: **ANSWER KEY**

Date: _____

Section C D F

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Refraction II: Ray Diagrams, Converging Lens
Real Images

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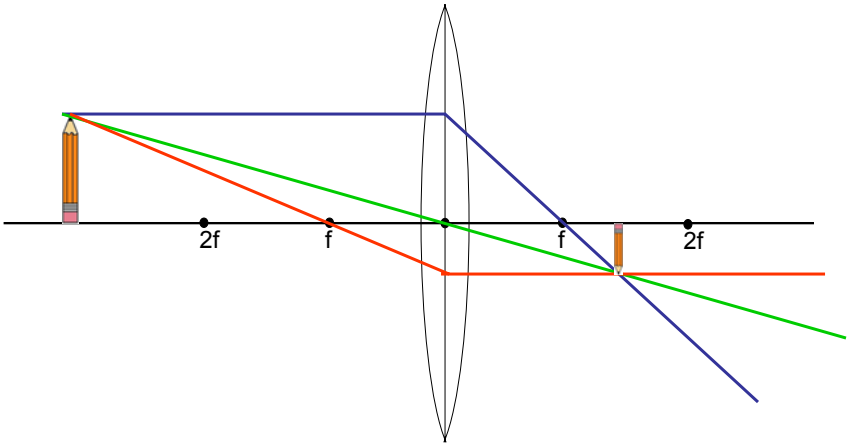
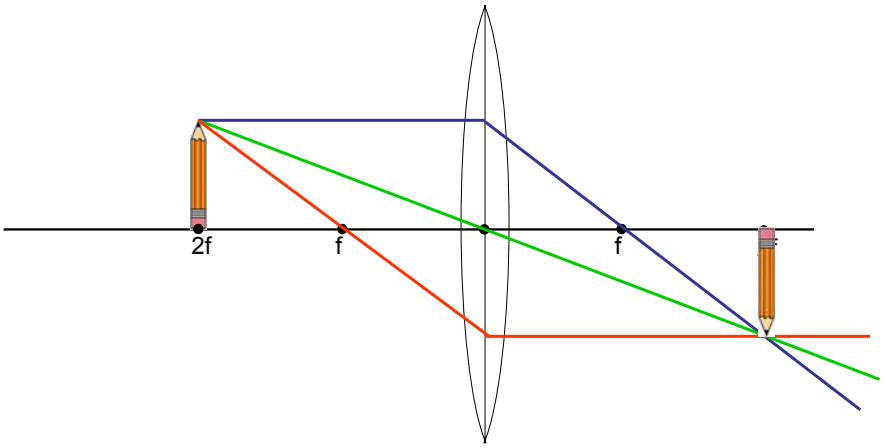


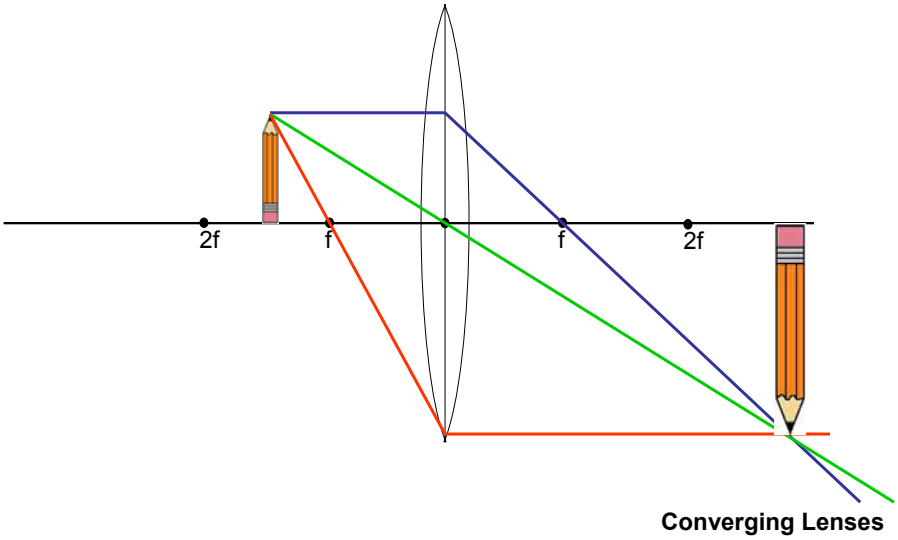
Converging Lenses

Object Distance at 2F



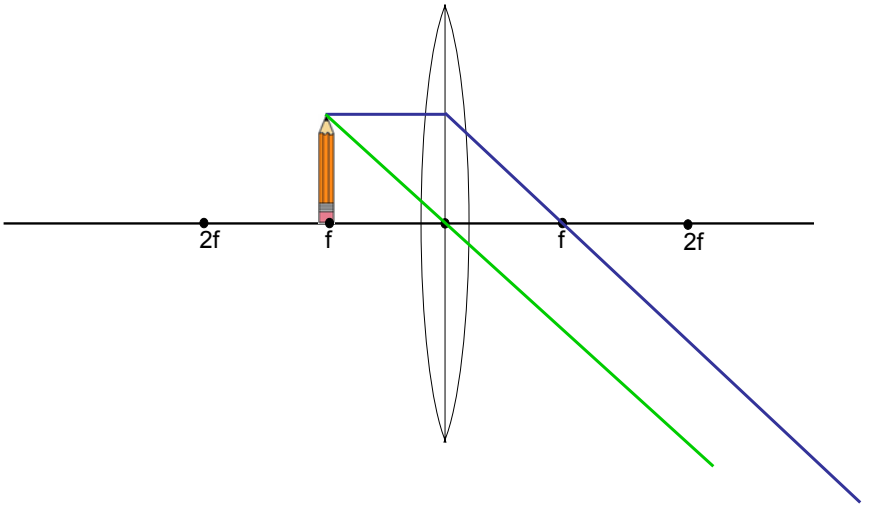
Converging Lenses

Object Distance less than 2f



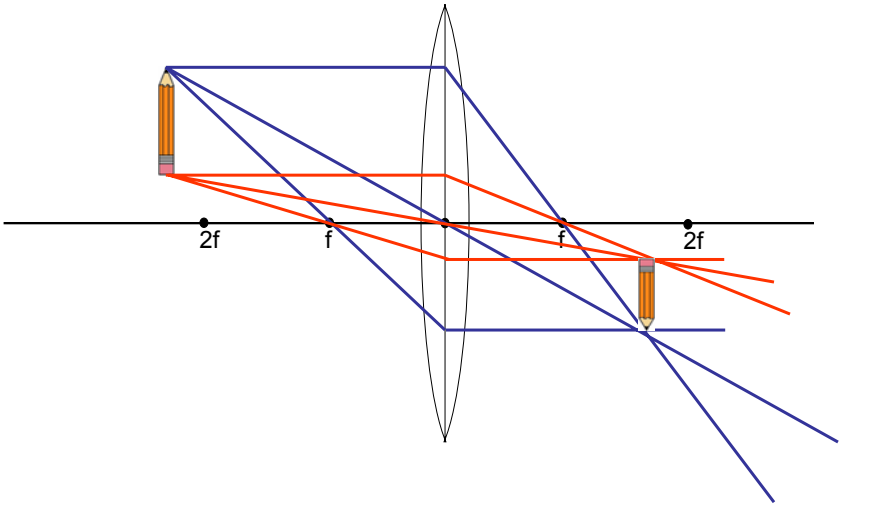
Converging Lenses

Object Distance at f



Converging Lenses

Object off Principal Axis



Converging Lenses

Name: _____

Date: _____

Section C D F

The Masters School
Mr. Alex Rawson
Physics

Refraction III: Ray Diagrams
Virtual and 2D Images

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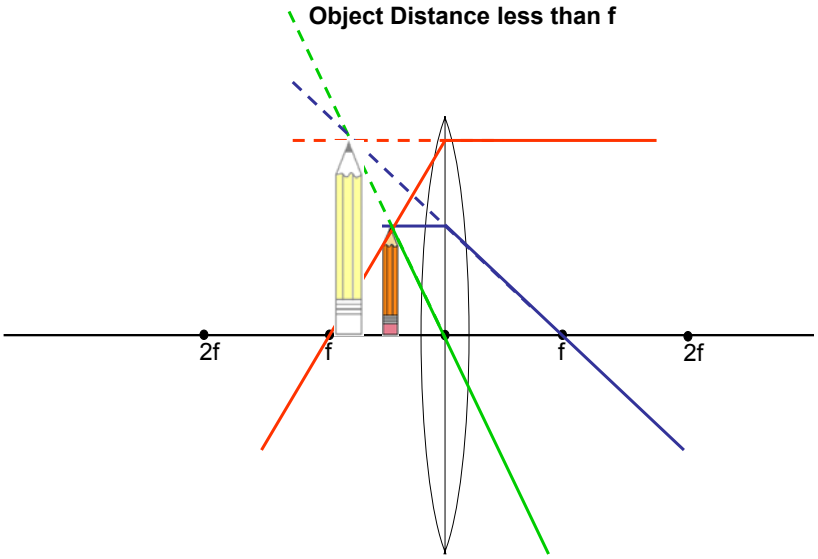
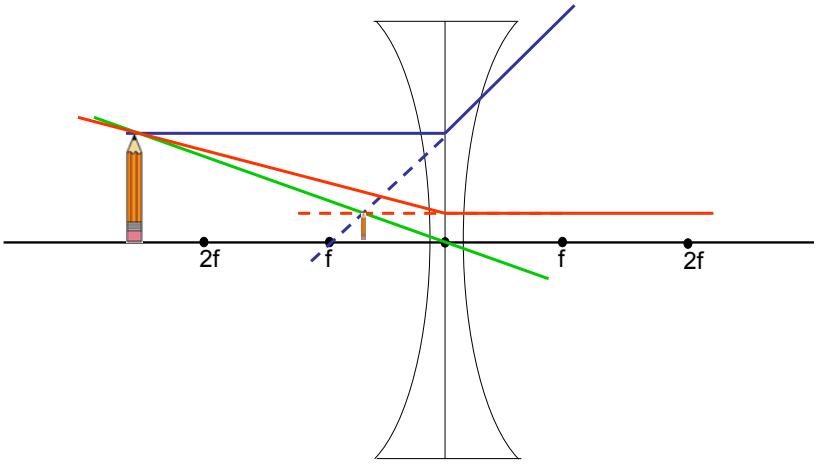


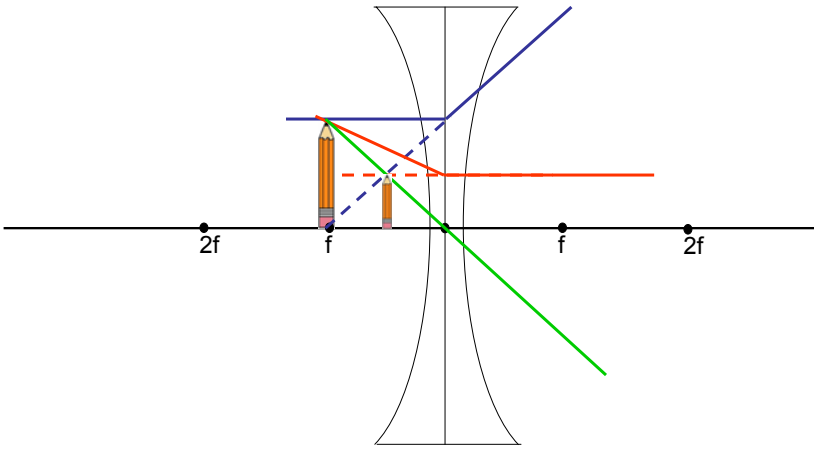
Concave Mirrors

Object Distance greater than 2F



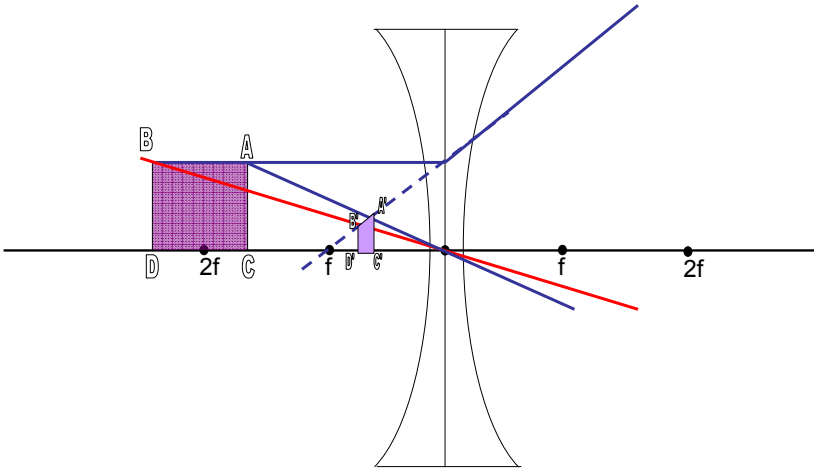
Diverging Lenses

Object Distance at F



Diverging Lenses

2D Object on Principal Axis



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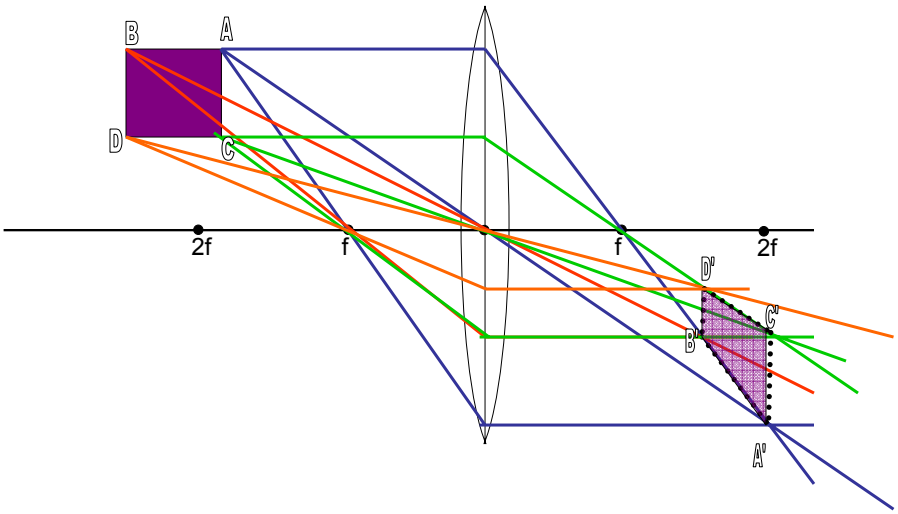


Converging Lenses

Name: _____

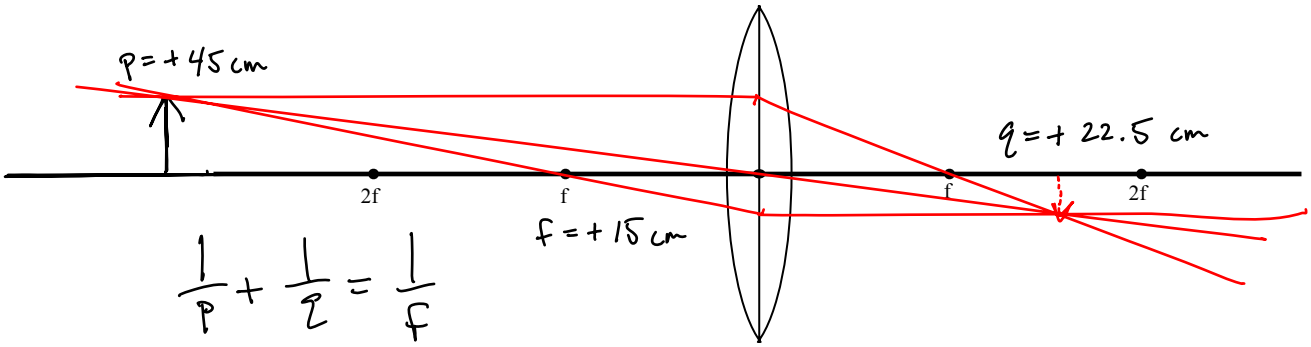
Date: _____

Section C D F

The Masters School
Mr. Alex Rawson
Physics

Refraction IV: Lens Calculations

1. Determine image distance, image height, and magnification for a 5-cm tall object placed 45.0 cm from a converging lens having a focal length of 15.0 cm. Please draw a diagram.



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

$$\frac{1}{q} = \frac{1}{F} - \frac{1}{p}$$

$$\frac{1}{q} = \frac{1}{15} - \frac{1}{45}$$

$q = 22.5$ cm

$$\frac{h'}{h} = -\frac{q}{p}$$

$$\frac{h'}{5} = -\frac{22.5}{45}$$

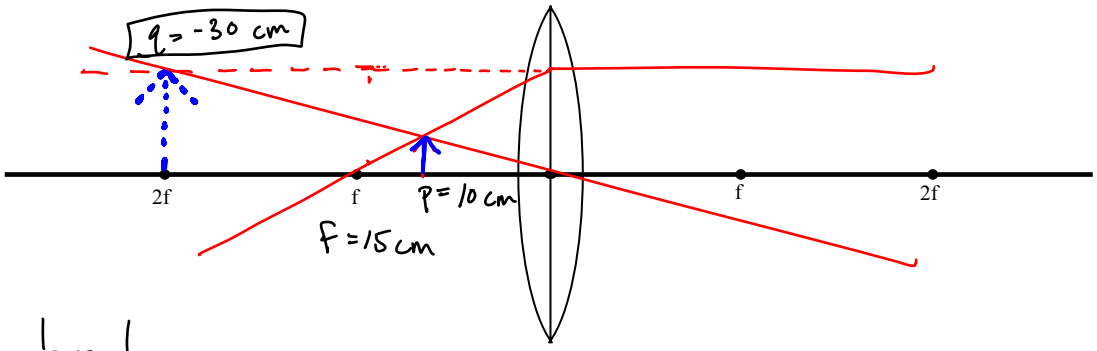
$h' = -2.5$ cm

$$M = \frac{h'}{h}$$

$$M = \frac{-2.5}{5}$$

$M = -.5$

2. Determine q, h', and M for a 5-cm tall object placed 10.0 cm from a converging lens having a focal length of 15.0 cm. Draw a diagram.



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

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

$$\frac{1}{q} = \frac{1}{15} - \frac{1}{10}$$

$$\frac{1}{q} = -.03\overline{3}$$

$q = -30$ cm

$$\frac{h'}{h} = -\frac{q}{p} =$$

$$\frac{h'}{5} = \frac{-(-30)}{10}$$

$h' = 15$ cm

$$M = \frac{h'}{h}$$

$M = \frac{15}{5} = 3$

3. A magnified, inverted image is located a distance of 32.0 cm from a converging lens with a focal length of 12.0 cm. Determine the object distance and tell whether the image is real or virtual. After calculations, please fill in the diagram.

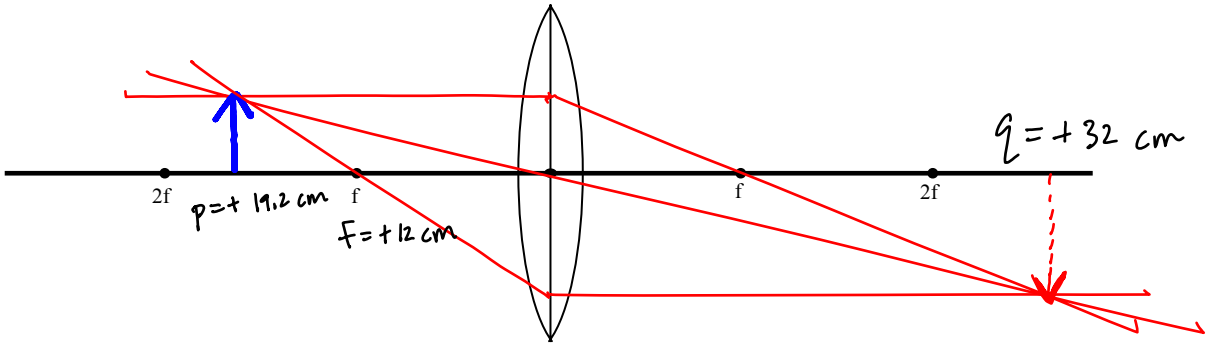
$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

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

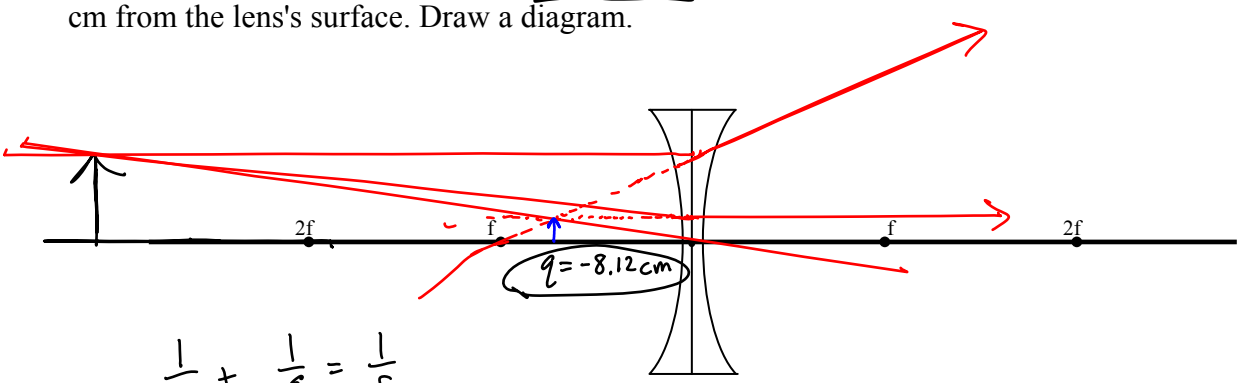
$$\frac{1}{p} = \frac{1}{12} - \frac{1}{32}$$

$$p = 19.2$$

Real Image



4. If a diverging lens has a focal length of -10.8 cm, find the image distance when an object is placed 32.7 cm from the lens's surface. Draw a diagram.



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

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

$$\frac{1}{q} = \frac{1}{-10.8} - \frac{1}{32.7}$$

$$\frac{1}{q} = -.123$$

$$q = -8.12 \text{ cm}$$

5. A person looks at a 5 cm tall crystal with a jeweler's microscope - a converging lens with a focal length of 12.7 cm. The microscope forms a virtual image 31.6 cm from the lens. Determine the object distance, and magnification of the image. After calculations, please fill in the diagram.

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

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

$$\frac{1}{p} = \frac{1}{12.7} - \frac{1}{-31.6}$$

$p = 9.06$ cm

$$\frac{h'}{h} = \frac{-q}{p}$$

$$\frac{h'}{5} = \frac{-(-31.6)}{9.06}$$

$h' = 17.44$ cm

$$M = \frac{h'}{h}$$

$$M = \frac{17.44}{5} = 3.49$$