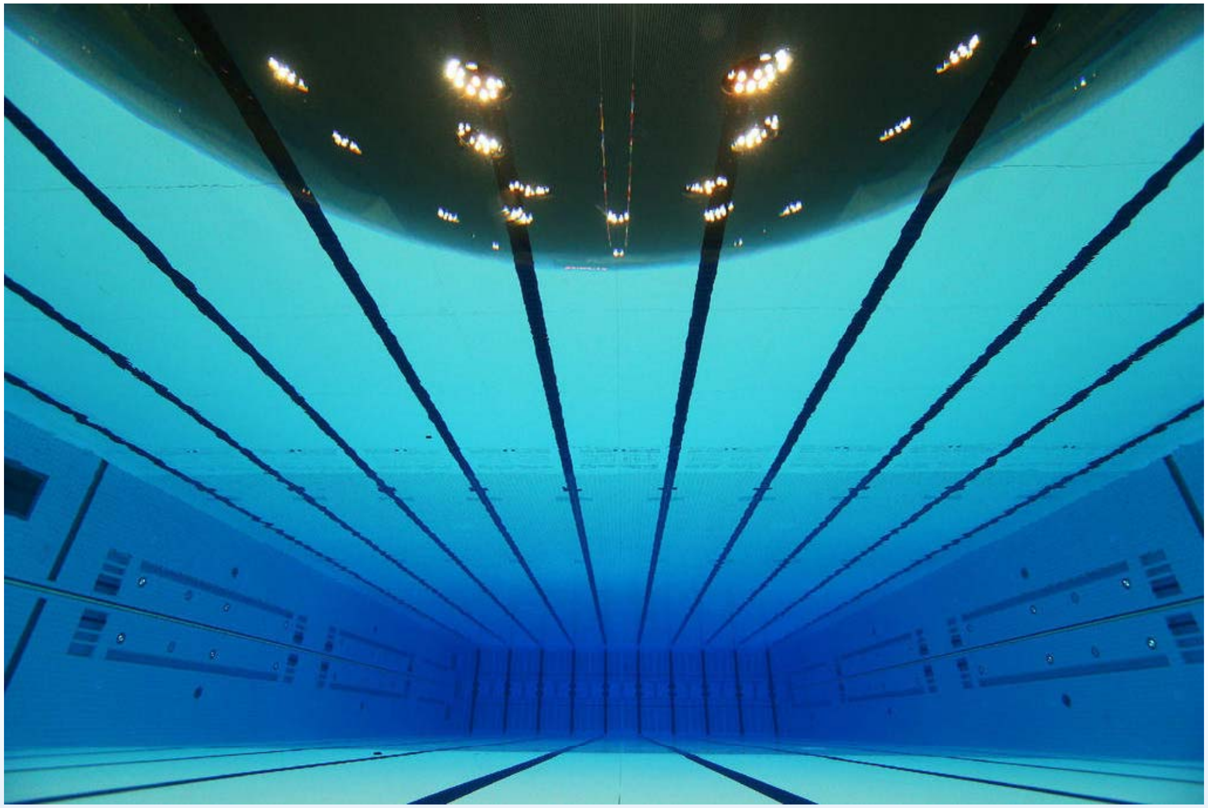


Phys 102 – Lecture 19

Refraction & lenses

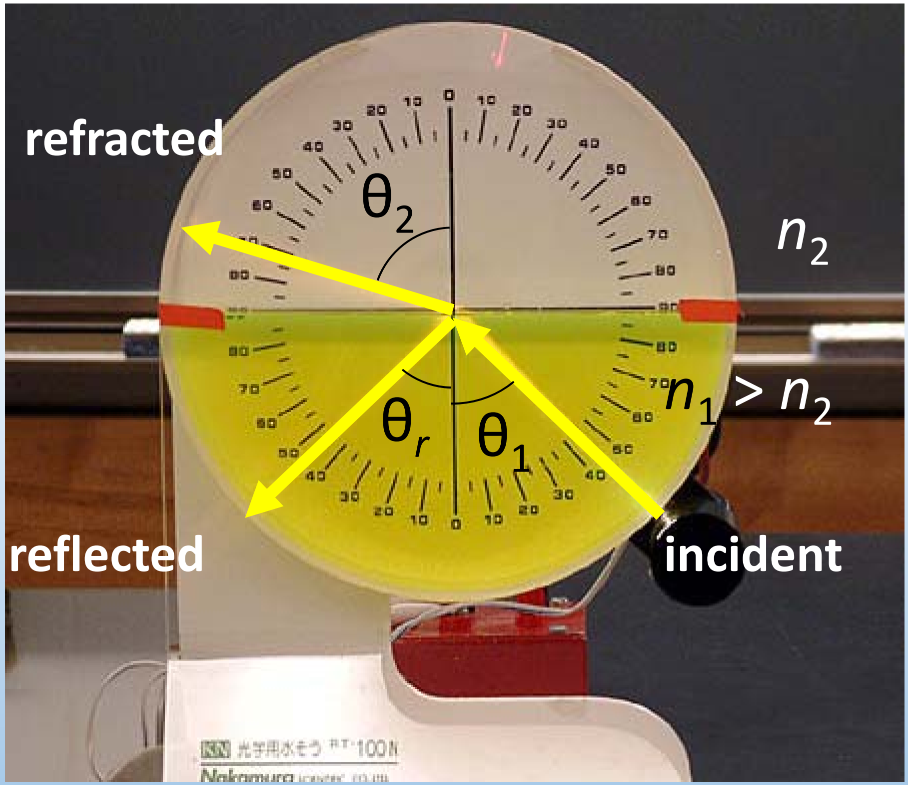
Today we will...

- Review refraction
  - Snell's law
- Learn applications of refraction
  - Total internal reflection
  - Converging & diverging lenses
- Learn how lenses produce images
  - Ray diagrams – principal rays
  - Lens & magnification equations

Review: Snell's Law

Light bends when traveling into material with different *n*

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$



If $n_1 > n_2$ then $\theta_2 > \theta_1$

Light bends <u>away</u> from normal as it goes into a medium with <u>lower</u> *n*

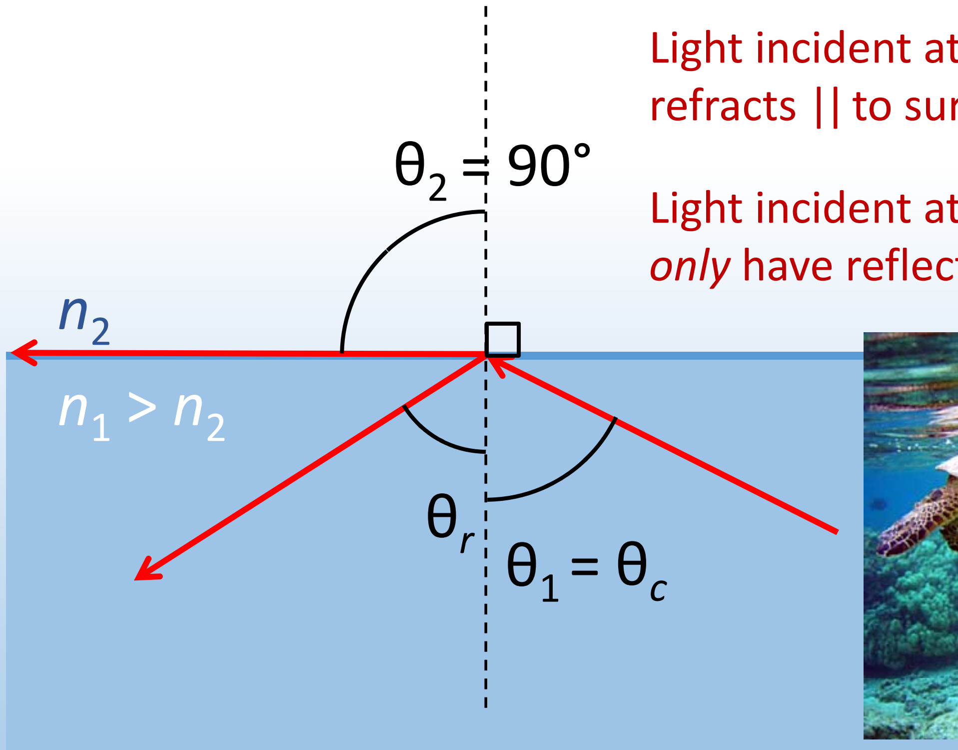
Total internal reflection

From Snell's law, if $n_1 > n_2$ then $\theta_2 > \theta_1$

$$n_1 \sin\theta_c = n_2 \sin 90° \qquad \text{So,} \quad \theta_c = \sin^{-1}\frac{n_2}{n_1}$$

Light incident at *critical angle* $\theta_1 = \theta_c$ refracts || to surface ($\theta_2 = 90°$)

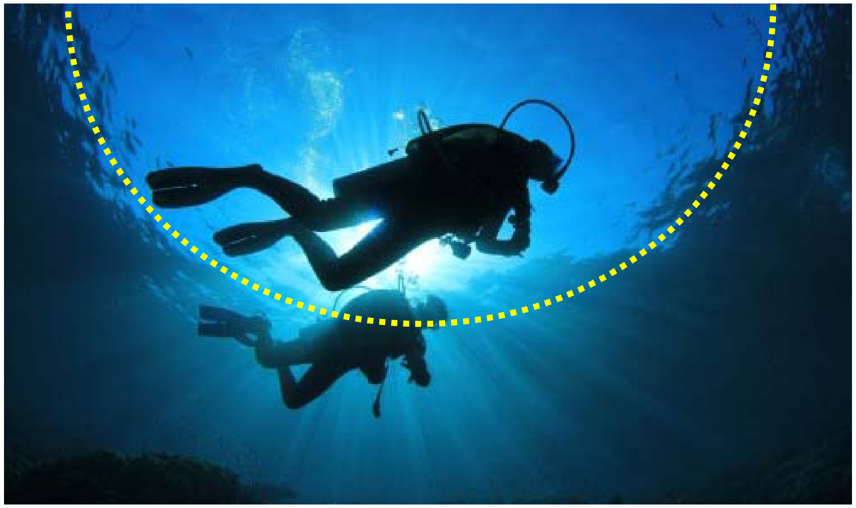
Light incident at angle $\theta_1 > \theta_c$ will *only* have reflection ($\theta_1 = \theta_r$)!

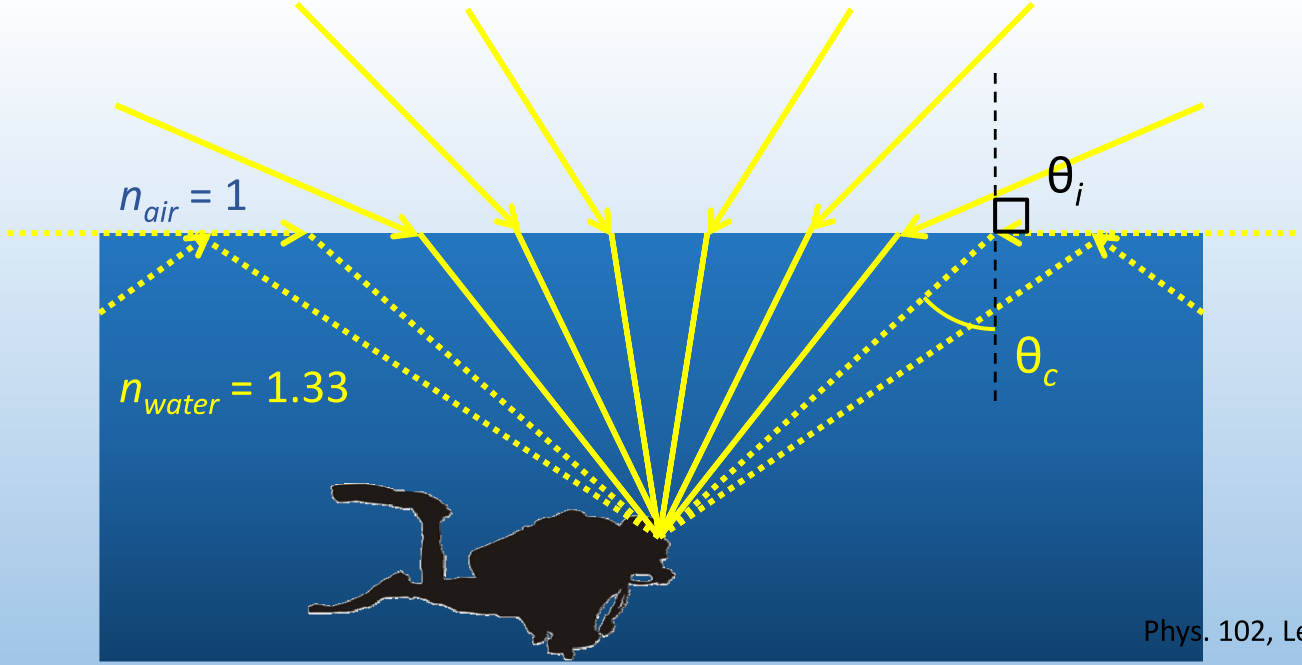


Calculation: underwater view

Explain why the diver sees a circle of light from outside surrounded by darkness

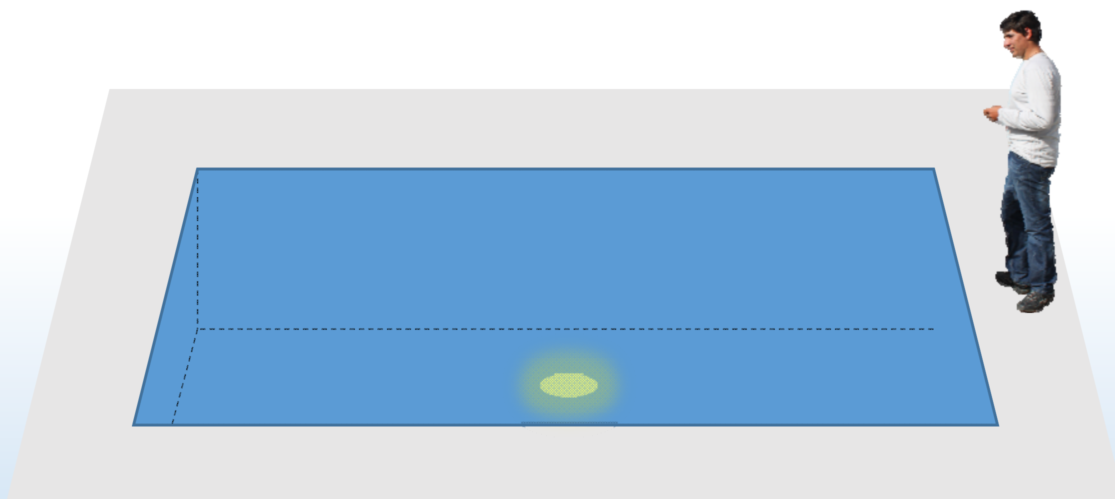
$$\theta_c = \sin^{-1}\frac{n_{air}}{n_{water}}$$





ACT: CheckPoint 1.1

Can the person standing on the edge of the pool be prevented from seeing the light by <u>total internal reflection</u>?

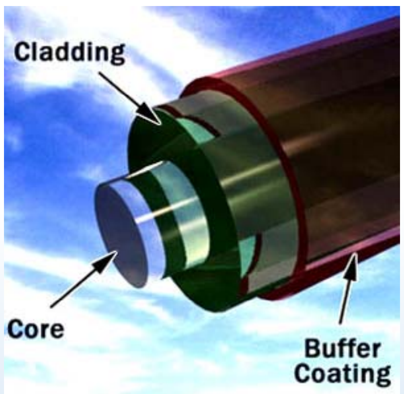


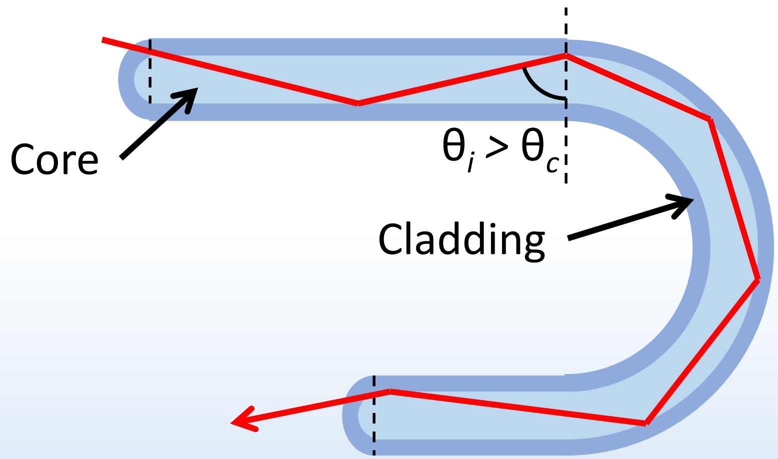
A. Yes

B. No

Fiber Optics

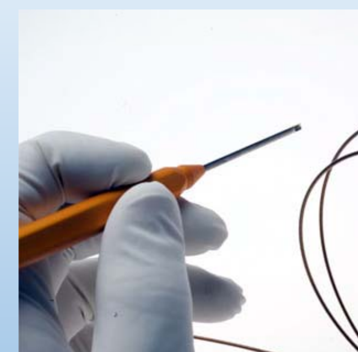
Optical fibers consist of "core" surrounded by "cladding" with $n_{cladding} < n_{core}$. Light hits core-cladding interface at $\theta_i > \theta_c$, undergoes total internal reflection and stays in the fiber.





Only works if $n_{cladding} < n_{core}$

- Telecommunication
- Arthroscopy
- Laser surgery

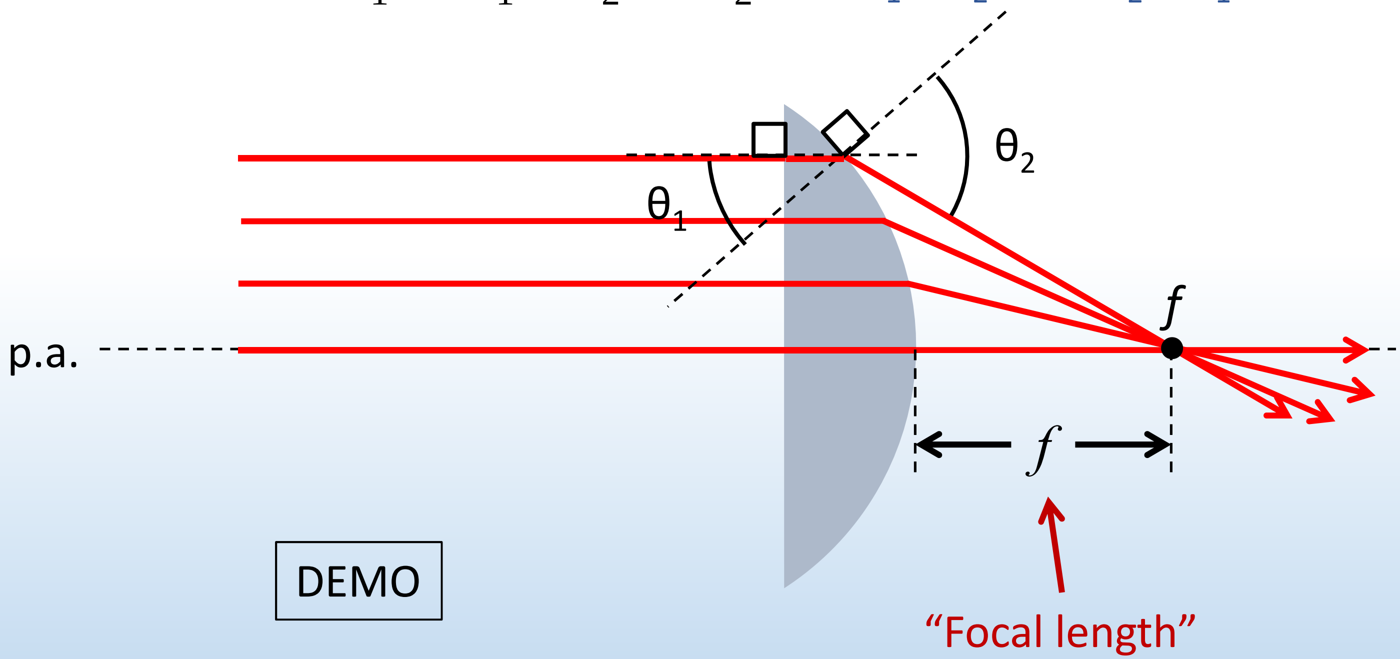


Converging lens

Lenses use refraction and curved surface(s) to bend light in useful ways

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

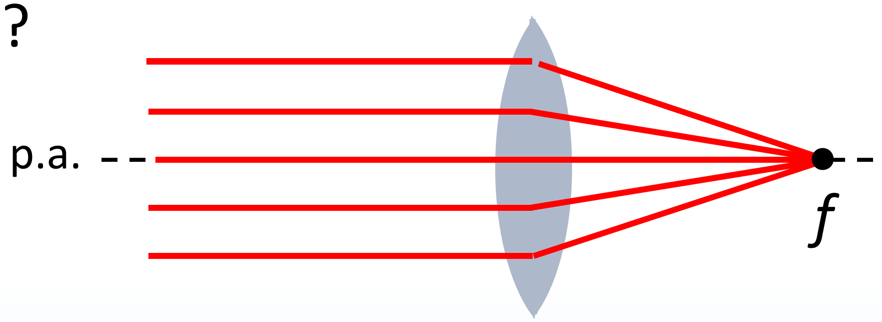
If $n_1 > n_2$ then $\theta_2 > \theta_1$

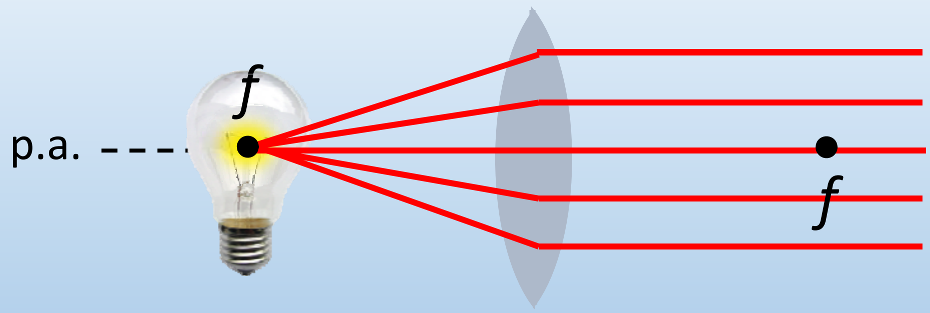


Converging lens – rays || to p.a. refract through focal point *f* ***after*** lens

CheckPoint 2.1

A beacon in a lighthouse produces a parallel beam of light. The beacon consists of a bulb and a converging lens. Where should the bulb be placed?





A. At *f*

B. Inside *f*

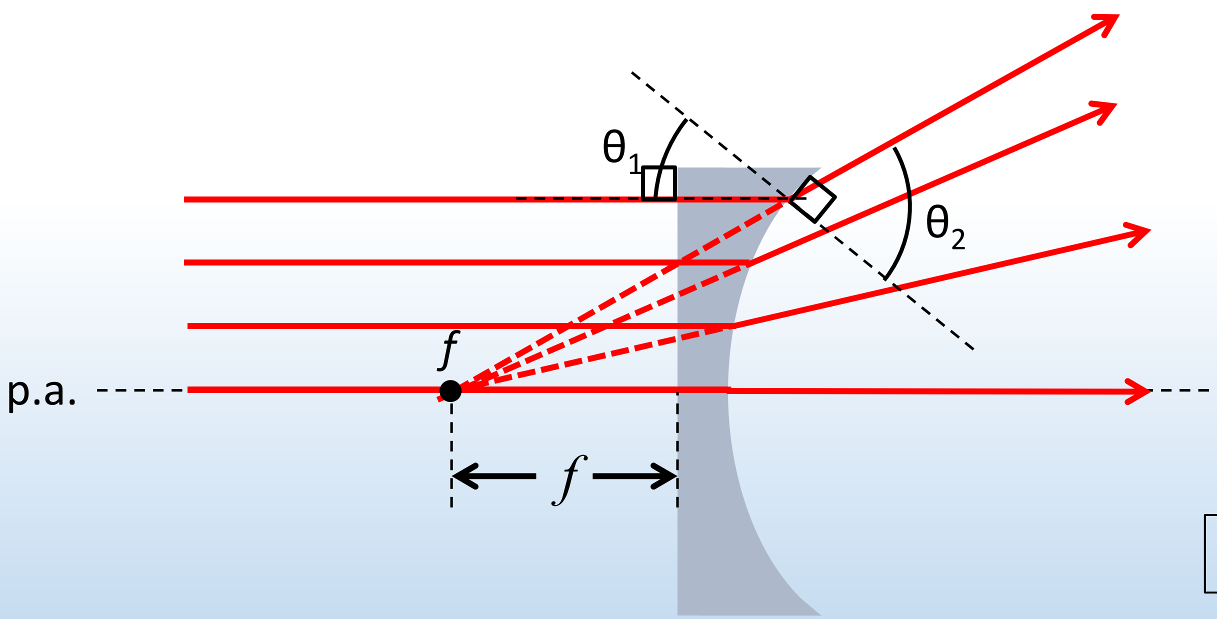
C. Outside *f*

Diverging lens

Lenses use refraction and curved surface(s) to bend light in useful ways

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

If $n_1 > n_2$ then $\theta_2 > \theta_1$



DEMO

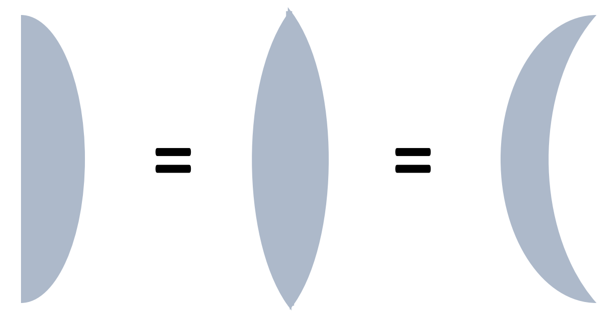
Diverging lens – rays || to p.a. reflect as if they originated from focal point *f* <u>*before*</u> lens

Converging & diverging lenses

Converging lens:

Rays parallel to p.a. converge on focal point after lens

Converging = thick in the middle

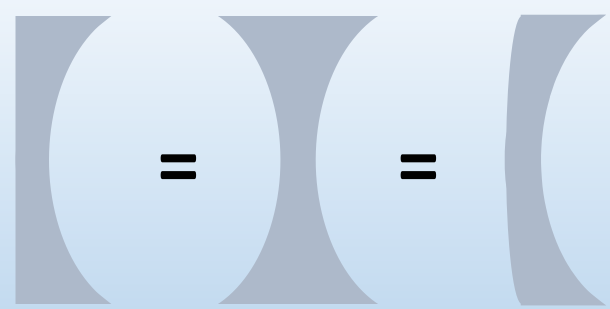


"Plano-convex" = "Double convex" = "Concave-convex"

Diverging lens:

Rays parallel to p.a. diverge as if originating from focal point before lens

Diverging = thin in the middle



"Plano-concave" = "Double concave" = "Convex-concave"

ACT: Lens geometry

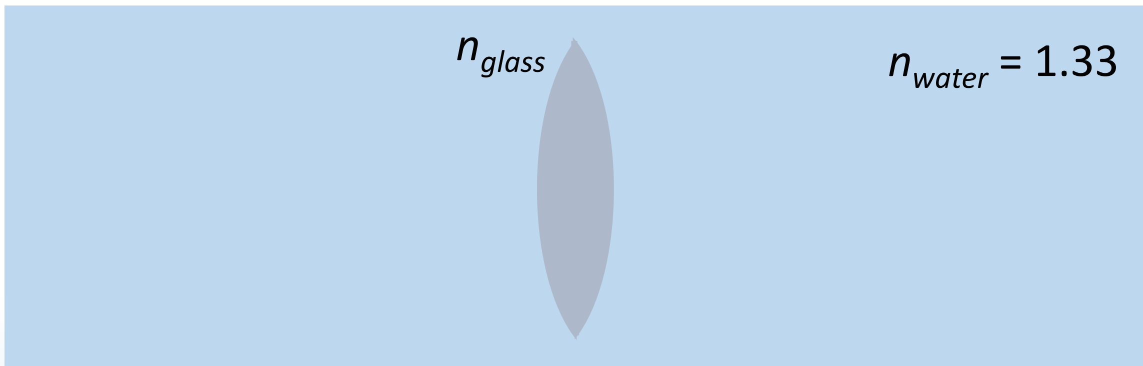
The following lenses are all made from the same material but have different geometry

Which lens has the shortest (positive) focal length?

A. B. C. D.

ACT: CheckPoint 3.1

A glass converging lens placed in air has focal length *f*.



Now the lens is placed in water. Its focal length:

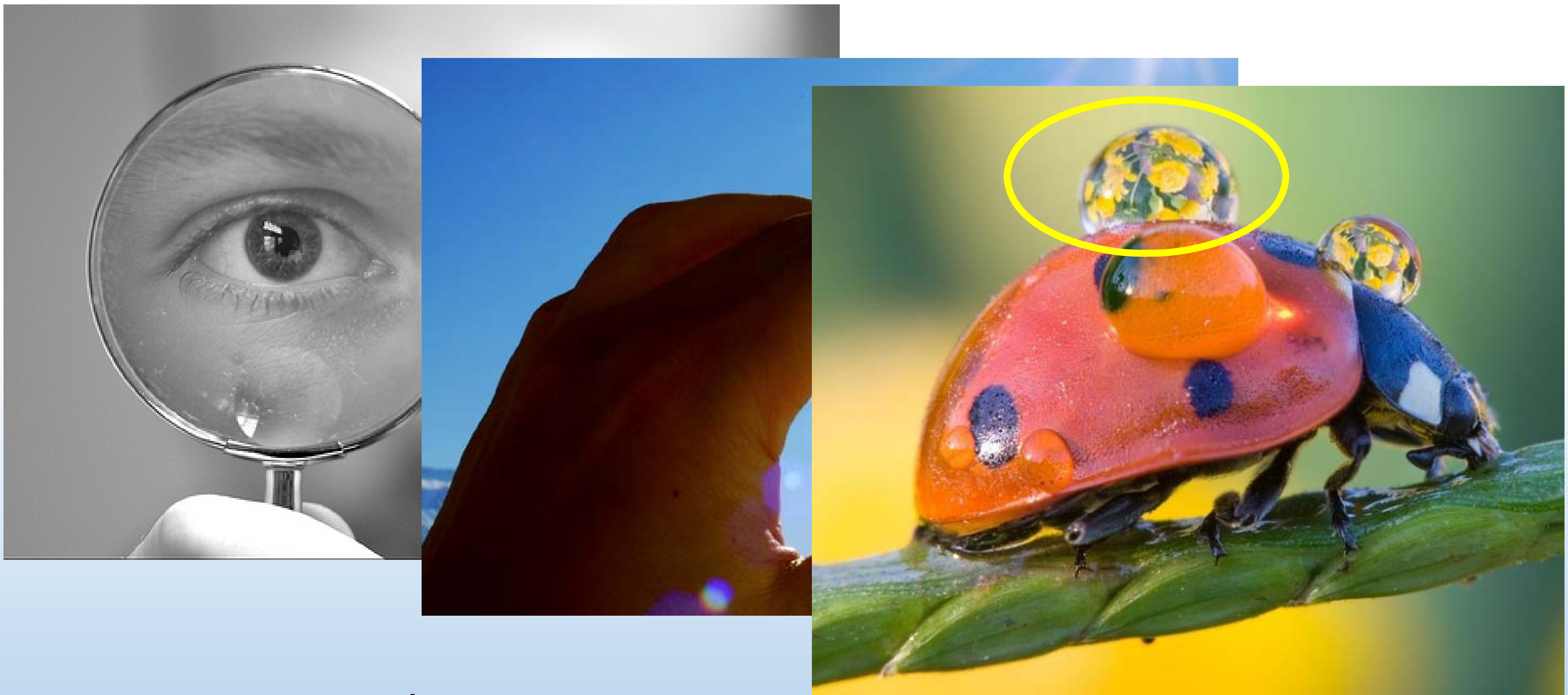
A. Stays the same

B. Increases

C. Decreases

Images & lenses

Like mirrors, lenses produce images of objects



Key approaches:

- Ray diagrams
- Thin lens & magnification equations

Principal rays – converging lens

Ray from object traveling:

1) parallel to principal axis, refracts through *f*
2) through *f*, refracts parallel to principal axis
3) through *C*, travels straight

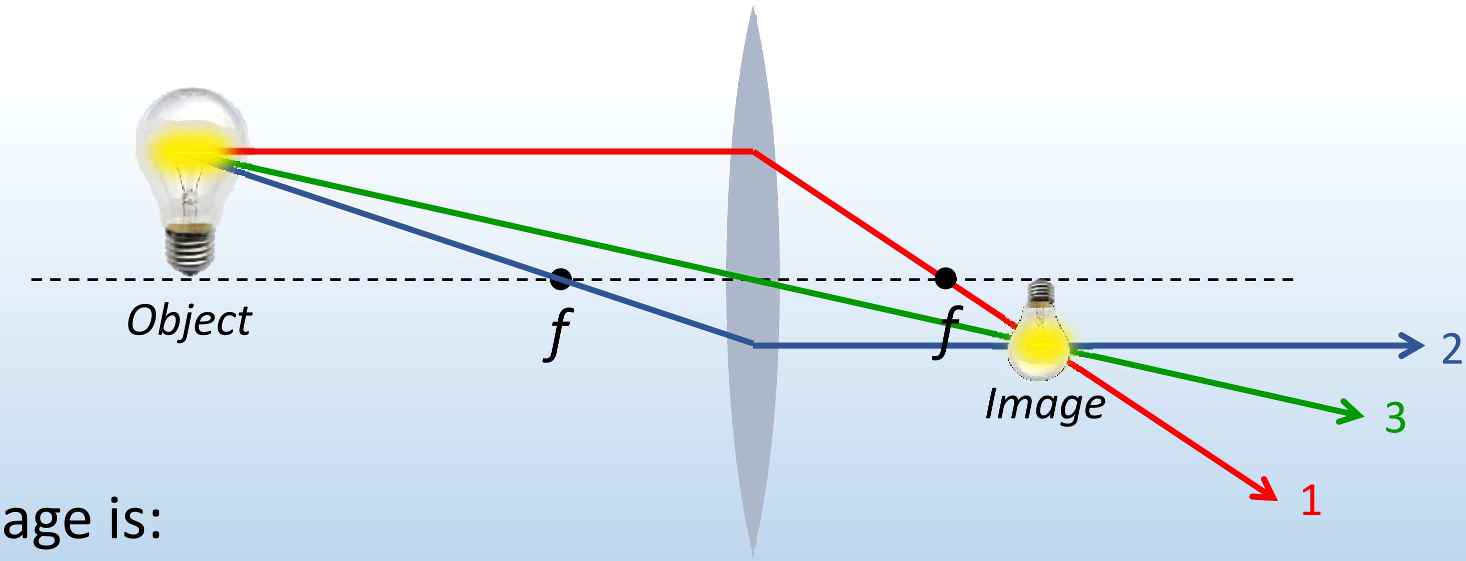


Image is:

Real (light rays cross)

Inverted (opposite direction as object)

Reduced (smaller than object)

Principal rays – diverging lens

Ray from object traveling:

1) parallel to principal axis, refracts through *f*
2) through *f*, refracts parallel to principal axis
3) through *C*, travels straight

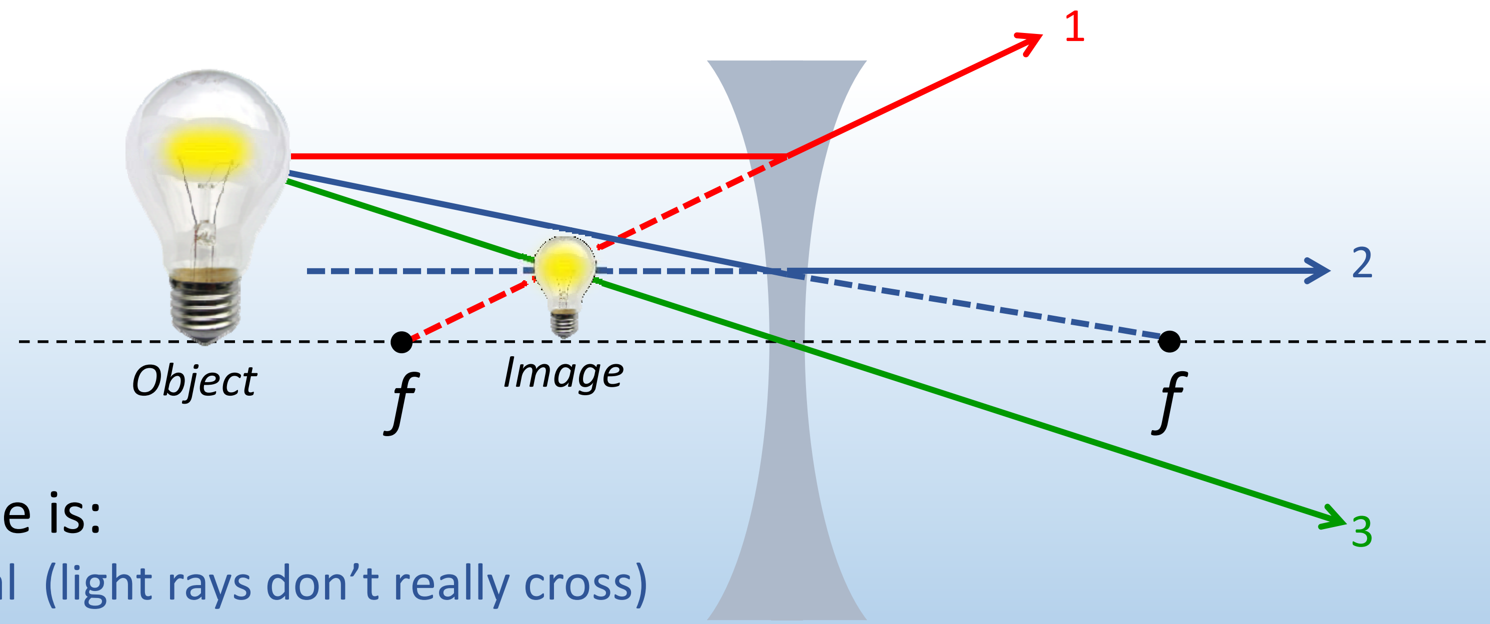
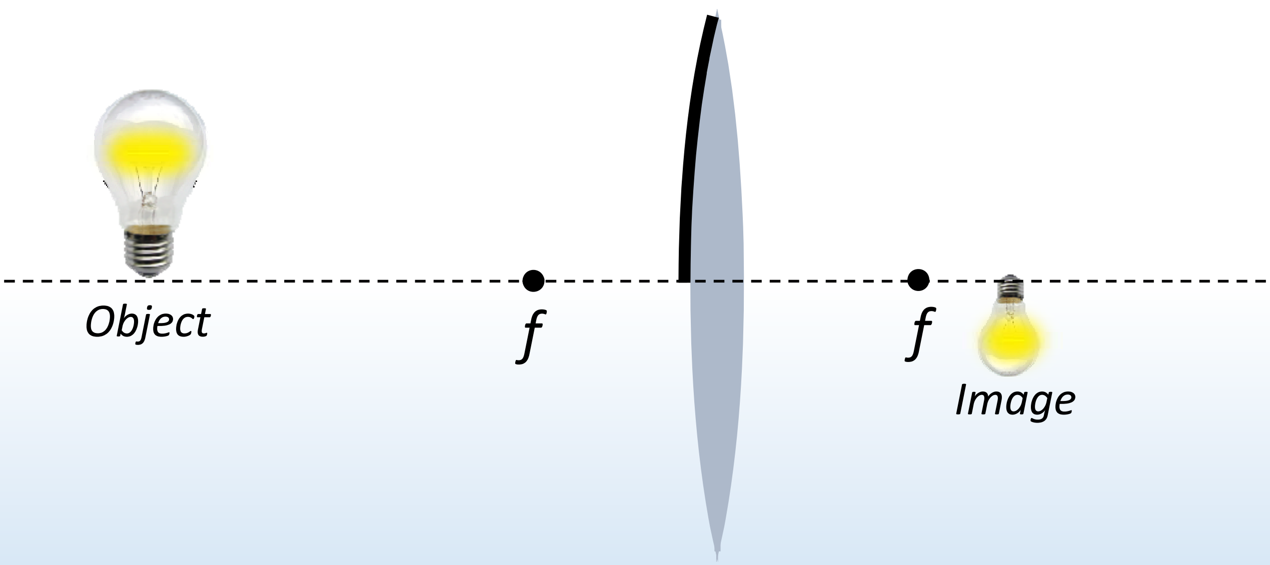


Image is:

Virtual (light rays don't really cross)
Upright (same direction as object)
Reduced (smaller than object)

ACT: CheckPoint 4.1

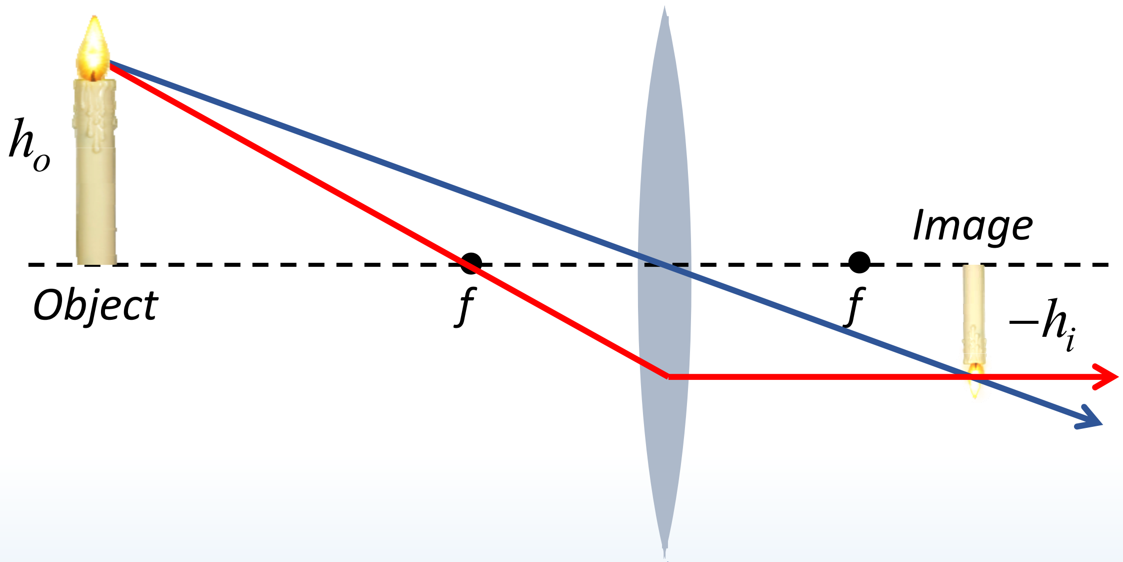
A converging lens produces a real image onto a screen. A piece of black tape is then placed over the upper half of the lens.



Which of the following is true:

A. Only the lower half of the object will show
B. Only the upper half of the object will show
C. The whole object will still show

Thin lens & magnification equations

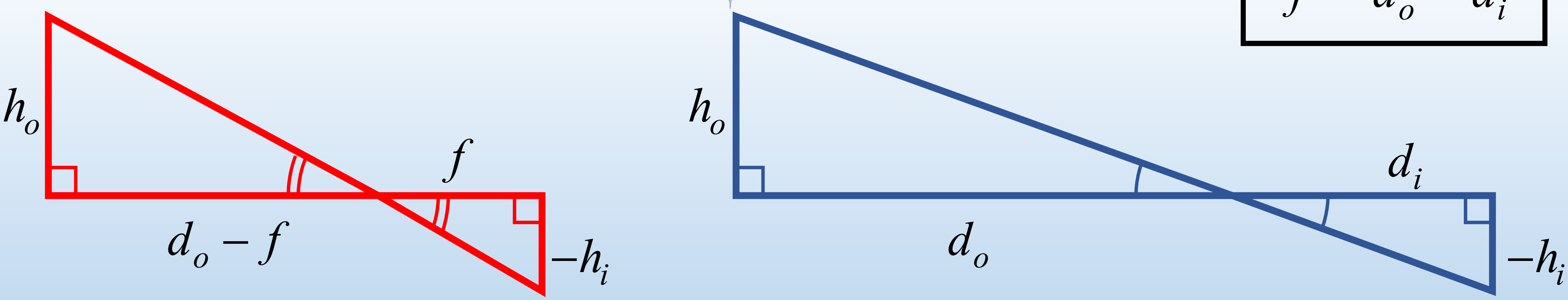


Magnification

$$m \equiv \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

Thin lens equation

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

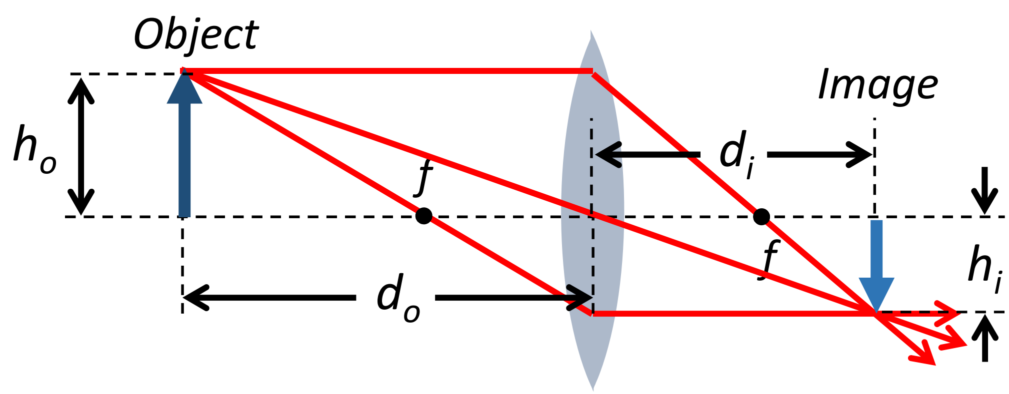


$$\frac{f}{d_o - f} = -\frac{h_i}{h_o} = \frac{d_i}{d_o}$$

So, $\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$

Same as mirror equations!

Distance & magnification conventions

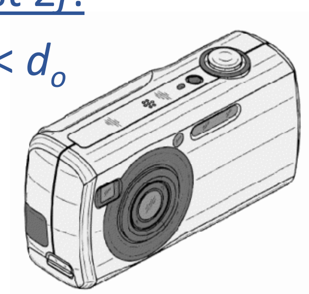


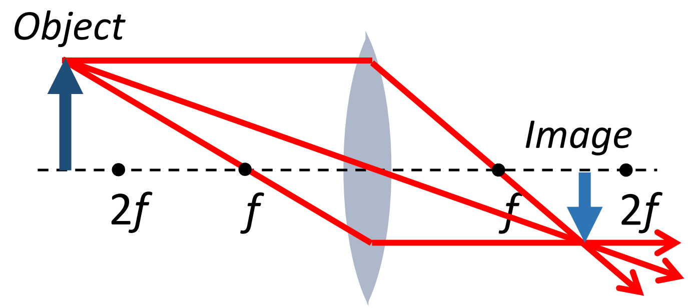
- d_o = distance object is from lens:
  - > 0: object before lens
  - < 0: object after lens
- d_i = distance image is from lens:
  - > 0: real image (after lens)
  - < 0: virtual image (before lens)
- f = focal length lens:
  - > 0: converging lens
  - < 0: diverging lens
- h_o = height of object:
  - > 0: always
- h_i = height of image:
  - > 0: image is upright
  - < 0: image is inverted
- $|m|$ = magnification:
  - < 1: image is reduced
  - > 1: image is enlarged

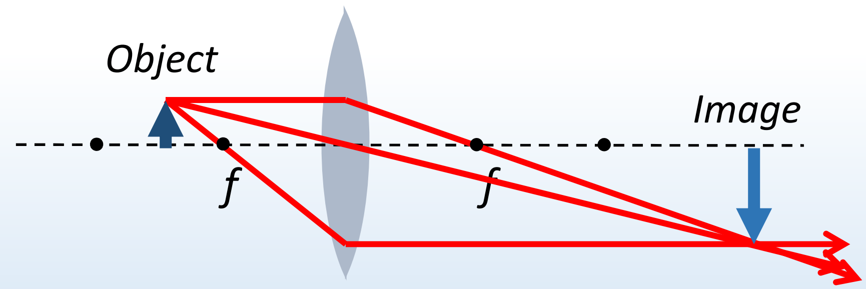
Note similarities to mirror conventions

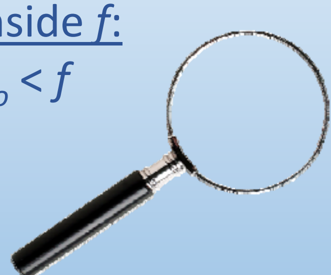
3 cases for concave mirrors

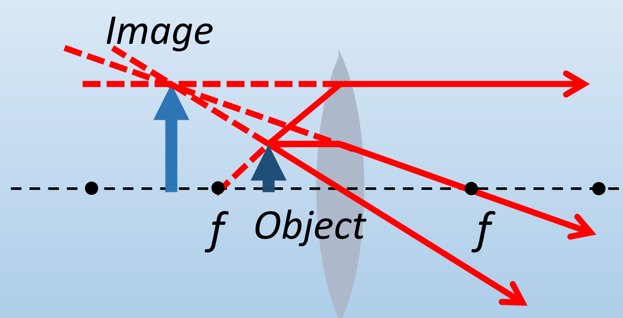
Object is:	Image is:
Past 2*f*: $2f < d_o$	Inverted: $h_i < 0$ Reduced: $m < 1$ Real: $d_i > 0$
Between 2*f* & *f*: $f < d_o < 2f$	Inverted: $h_i < 0$ Enlarged: $m > 1$ Real: $d_i > 0$
Inside *f*: $d_o < f$	Upright: $h_i > 0$ Enlarged: $m > 1$ Virtual: $d_i < 0$







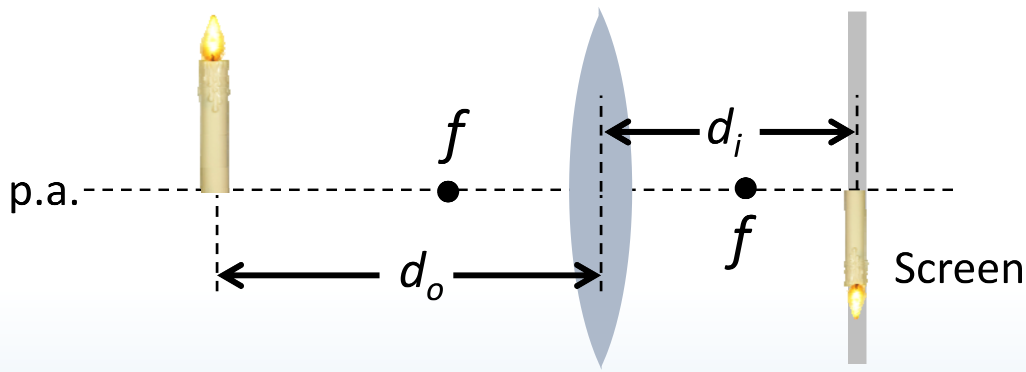




DEMO

ACT: Converging Lens

A candle is placed in front of a converging lens. The lens produces a well-focused image of the flame on a screen a distance d_i away.



If the candle is moved *farther* away from the lens, how should the screen be adjusted to keep a well-focused image?

A. Closer to lens
B. Further from lens
C. At the same place

Calculation: diverging lens

A 6-cm tall candle is placed 12 cm in front of a *diverging* lens with a focal length f = –6 cm. Determine the image location, size, and whether it is upright or inverted

$$\frac{1}{d_i} = \frac{1}{f} - \frac{1}{d_o}$$

$$m = -\frac{d_i}{d_o}$$

$$h_i = mh_o$$

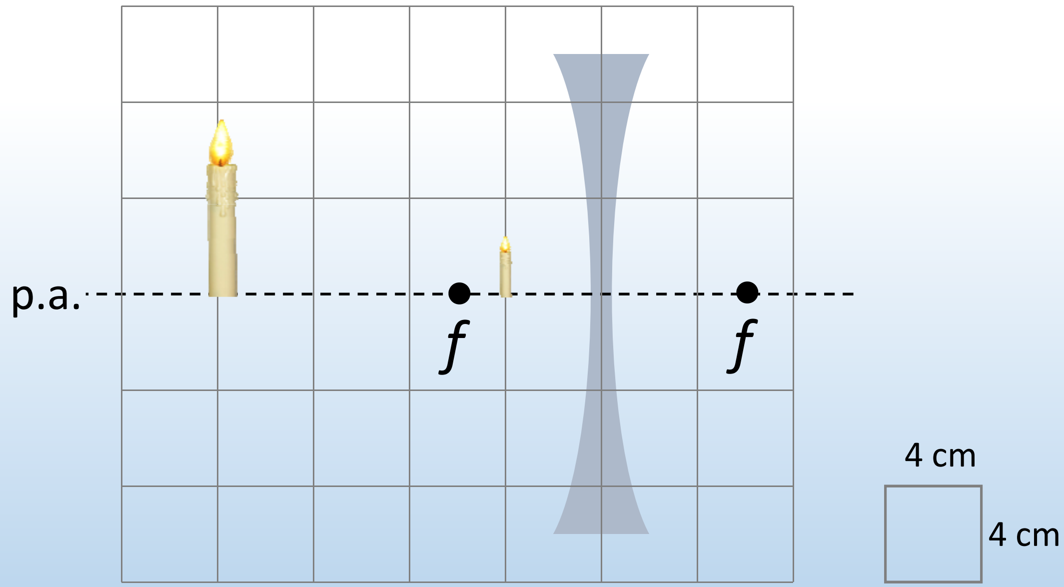
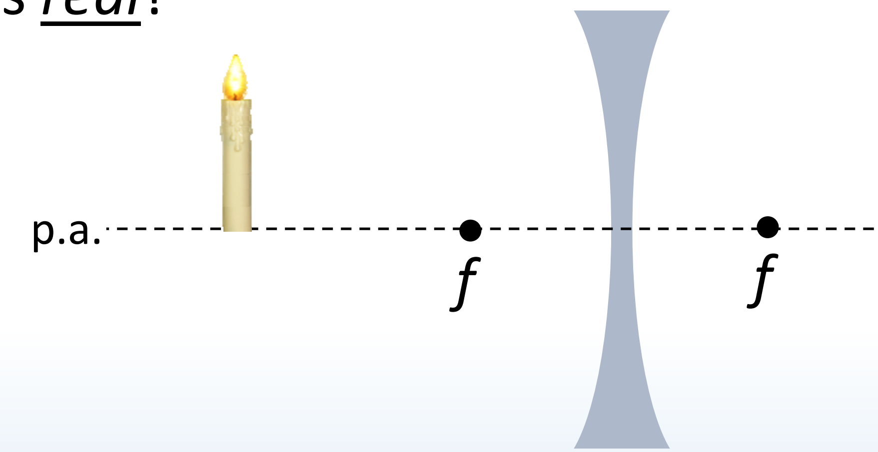


Diagram should agree!

ACT: Diverging Lenses

Where in front of a diverging lens should you place an object so the image is *real*?



A. Closer to lens
B. Further from lens
C. Diverging lens can't create real image

Summary of today's lecture

- Total internal reflection
- Lenses – principal rays

  Parallel to p.a. –> refracts through *f*

  Through *f* -> refracts parallel to p.a.

  Through *C* -> straight through

- Thin lens & magnification equations

  Numerical answer consistent with ray diagram

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \qquad m \equiv \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$