This week's schedule

- Homework 9
  - Now due Thursday, Mar. 28
- Office hours
  - Make-up office hours Wednesday, Mar. 27
- Lab 6
  - Students with cancelled Monday lab get an 'EX'
- Lecture 18
  - Will be covered today with part of Lect. 19
- All other course events will go on <u>as scheduled</u>

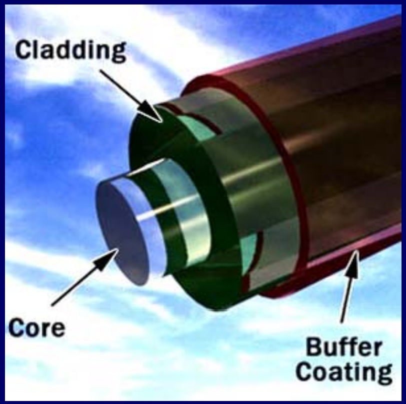
Physics 102: Lecture 18 & 19

Refraction!

Snell's Law, Total Internal Reflection, Dispersion, Lenses

Summary of today's lecture

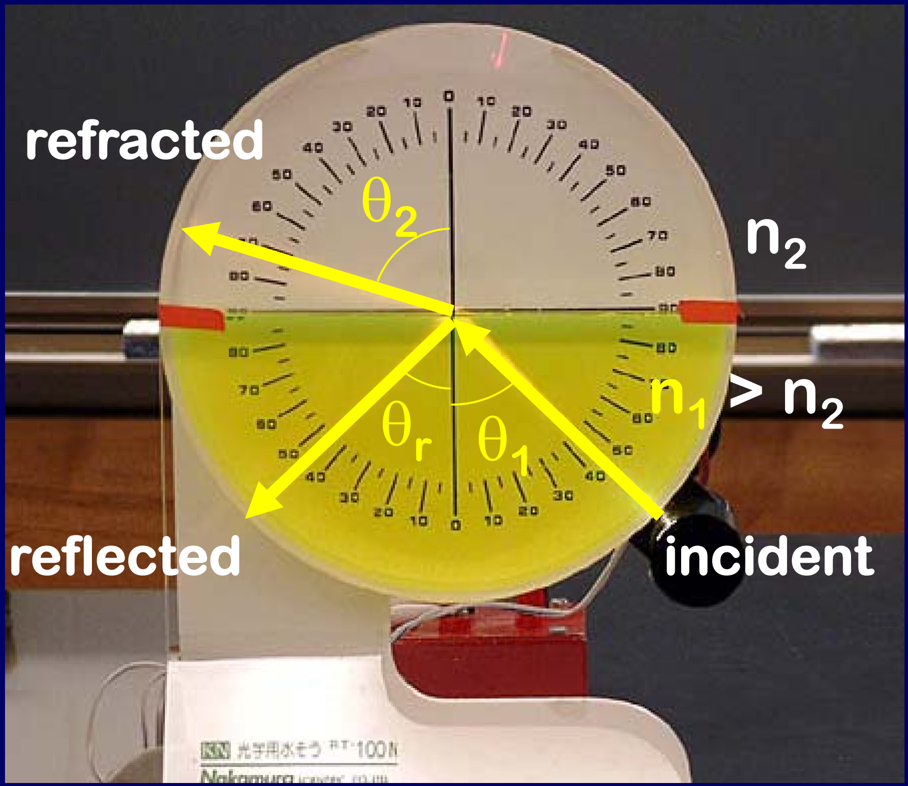
- Examples of refraction
  1) Total internal reflection
  2) Brewster's angle HW
  3) Dispersion (rainbows)
  4) Lenses



Refraction: Snell's Law

When light travels from one medium to another the speed (and wavelength) changes v=c/n, but the frequency is constant. So the light bends:

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



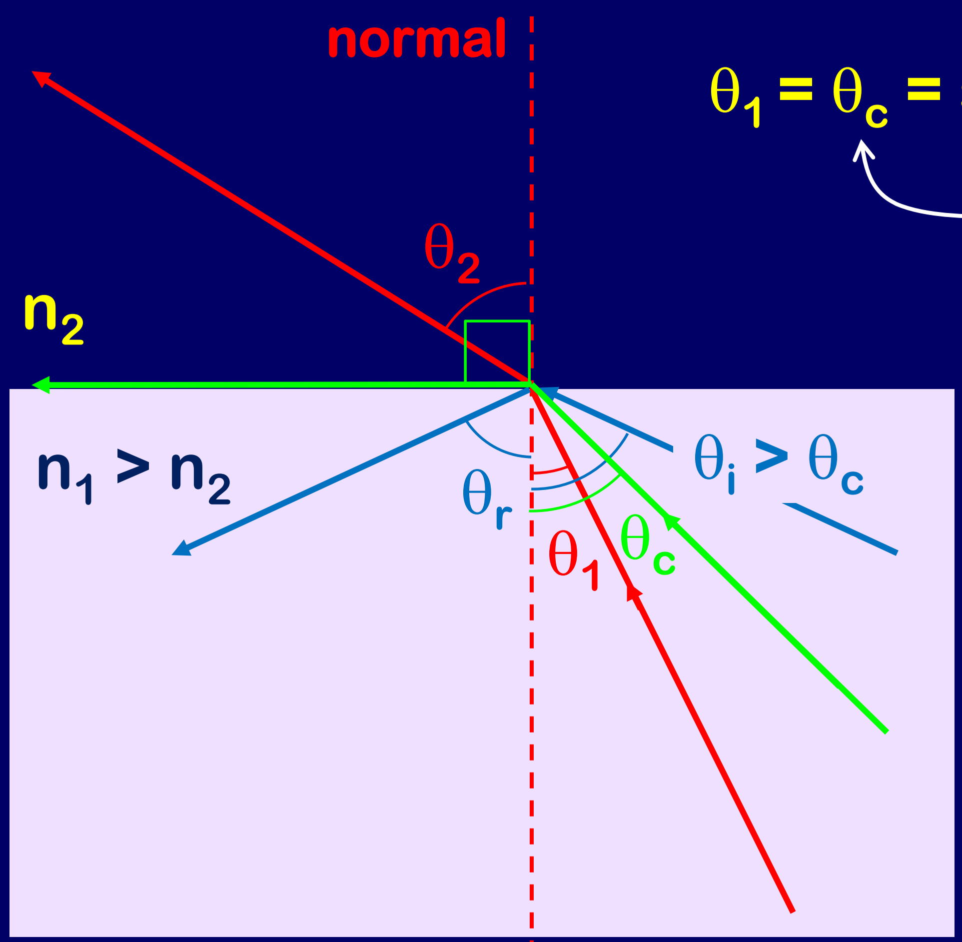
$n_1 > n_2 \Rightarrow \theta_2 > \theta_1$

Light bent away from normal as it goes into a medium with lower n

1) Total Internal Reflection

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

$(n_1 > n_2 \Rightarrow \theta_2 > \theta_1)$



$\theta_1 = \theta_c = \sin^{-1}(n_2/n_1)$ then $\theta_2 = 90°$

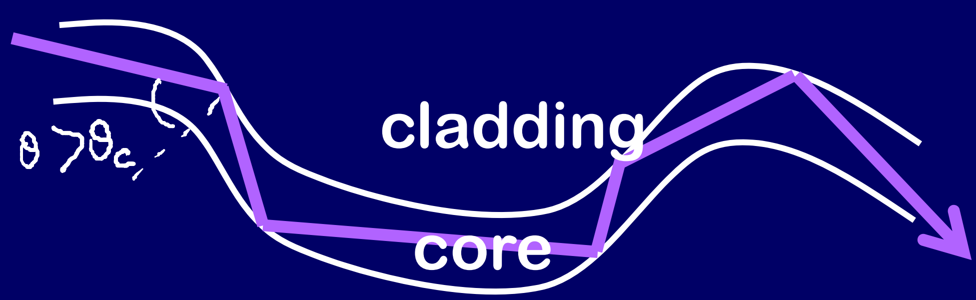
"critical angle"

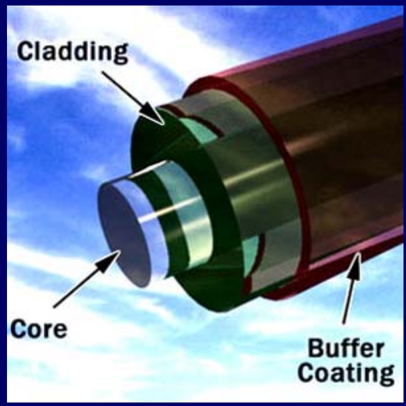
Light incident at a larger angle will only have reflection ($\theta_i = \theta_r$)

For water/air:
$n_1 = 1.33$, $n_2 = 1$
$\theta_c = \sin^{-1}(n_2/n_1)$
$= 48.8°$

Fiber Optics

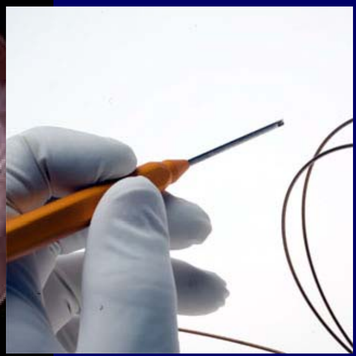
At each contact w/ the glass air interface, if the light hits at greater than the critical angle, it undergoes total internal reflection and stays in the fiber.



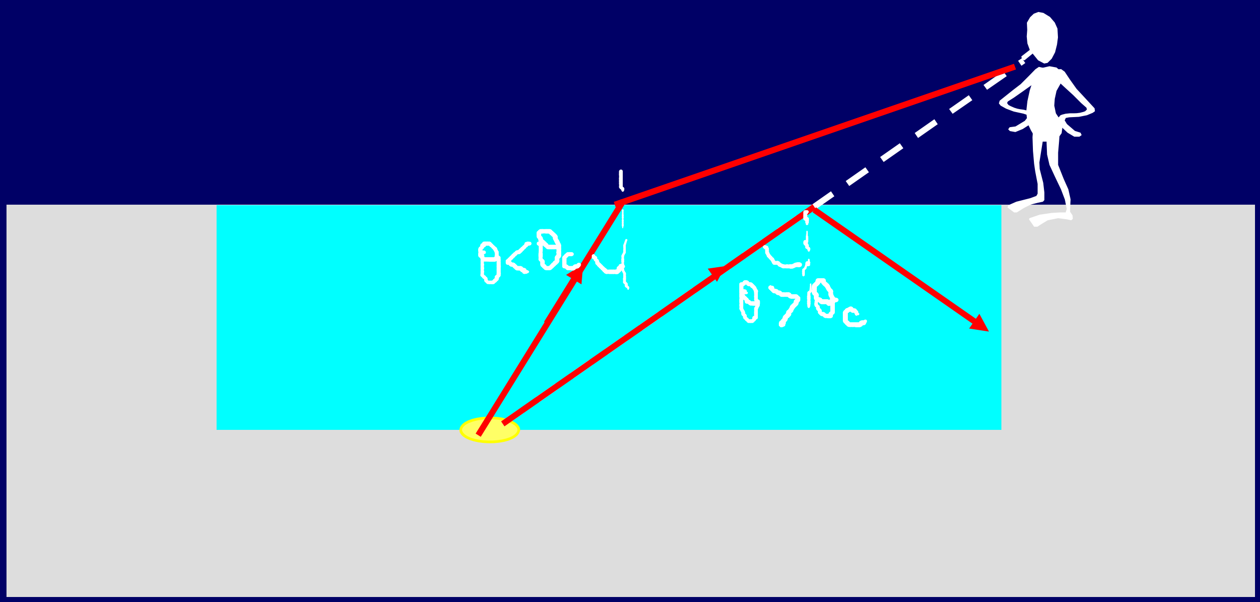


Total Internal Reflection only works if $n_{cladding} < n_{core}$

- **Telecommunications**
- **Arthroscopy**
- **Laser surgery**



Checkpoint 1.1



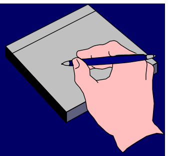
Can the person standing on the edge of the pool be prevented from seeing the light by total internal reflection?

1) Yes 49%

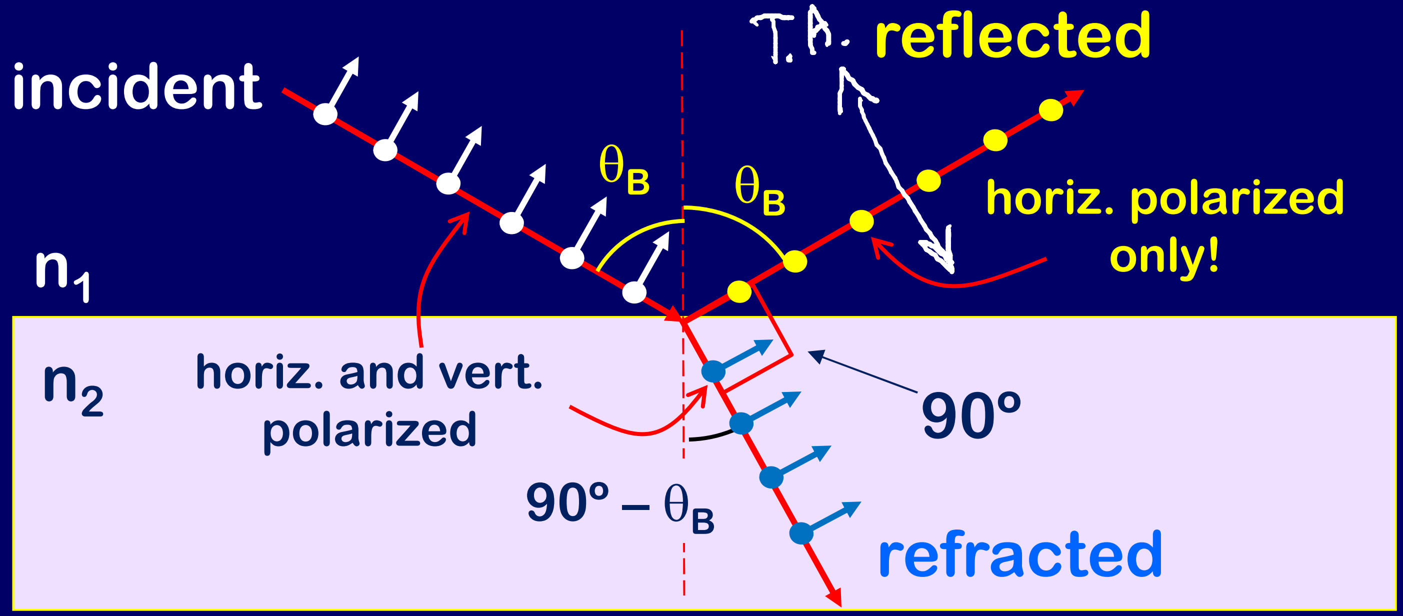
2) No 51%

"There are millions of light 'rays' coming from the light. Some of the rays will be totally reflected back into the water, but most of them will not."

2) Brewster's angle HW



Reflected light is usually unpolarized (mixture of horizontally and vertically polarized). But…



When angle between reflected beam and refracted beam is exactly 90°, reflected beam is 100% horizontally polarized !

$$n_1 \sin \theta_B = n_2 \sin (90-\theta_B)$$

$$n_1 \sin \theta_B = n_2 \cos (\theta_B)$$

$$\tan \theta_B = \frac{n_2}{n_1}$$

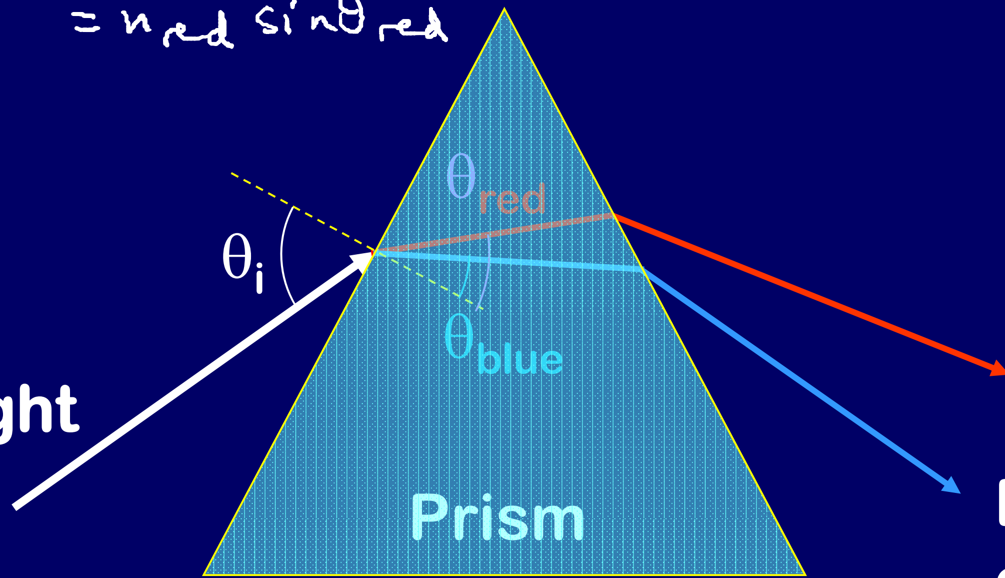
3) Dispersion

The index of refraction **n** depends on color!

In glass: $n_{blue} = 1.53$ $n_{red} = 1.52$

$n_{air} \sin\theta_i = n_{blue} \sin\theta_{blue}$

$= n_{red} \sin\theta_{red}$



White light

$n_{blue} > n_{red}$

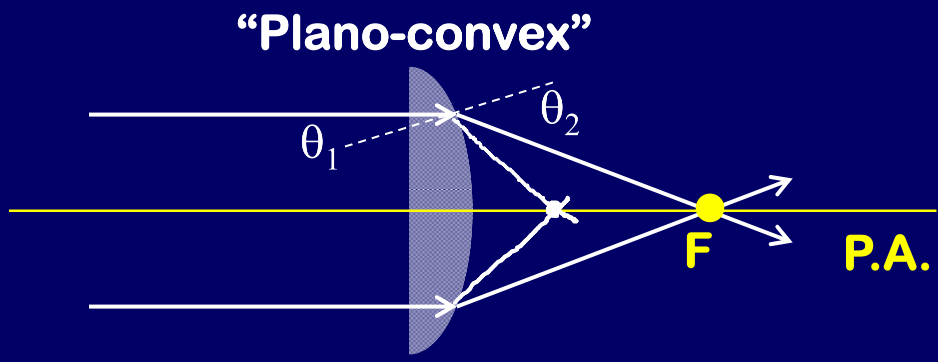
$\theta_{blue} < \theta_{red}$

Blue light gets deflected more

4) Lenses

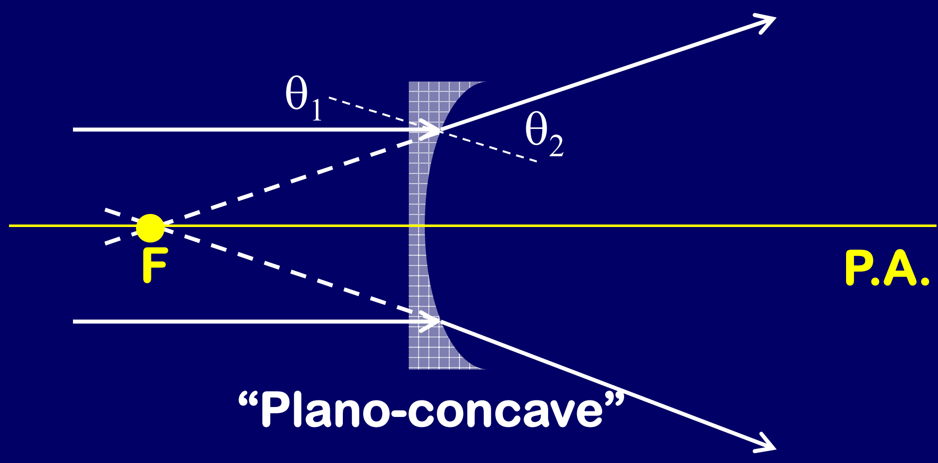
Converging lens:

– Rays parallel to P.A. converge on focal point



Diverging lens:

– Rays parallel to P.A. diverge as if emerging from focal point behind lens



Focal point determined by geometry and Snell’s Law: $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$

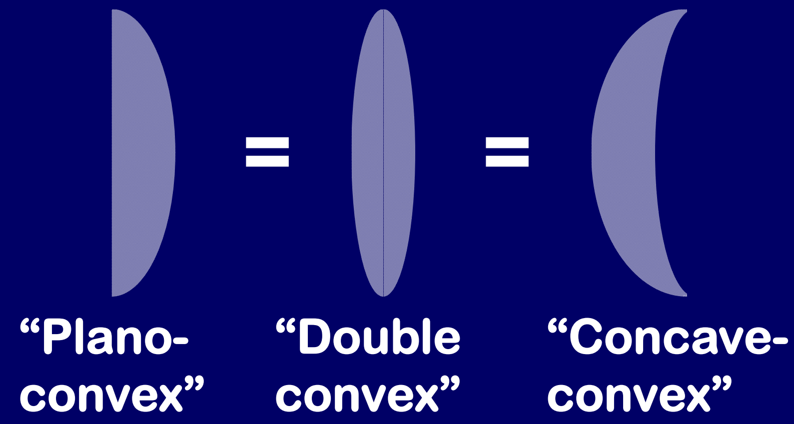
Larger n_2/n_1 = more bending, shorter focal length.
Smaller n_2/n_1 = less bending, longer focal length.

Converging & Diverging Lenses

Converging lens:

– Rays parallel to P.A. converge on focal point

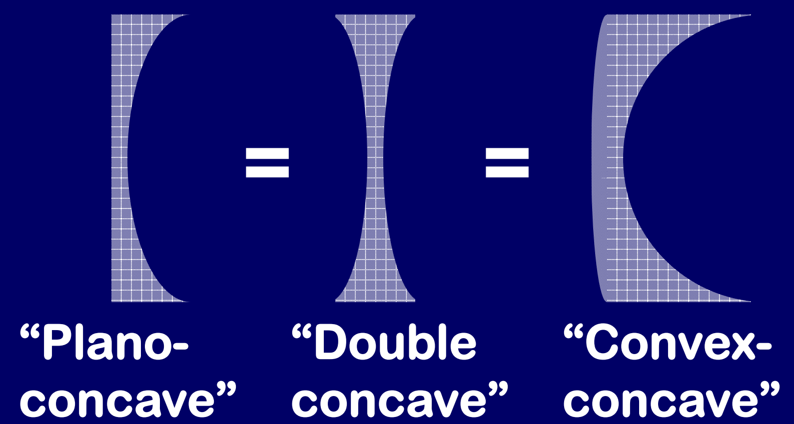
Converging = fat in the middle



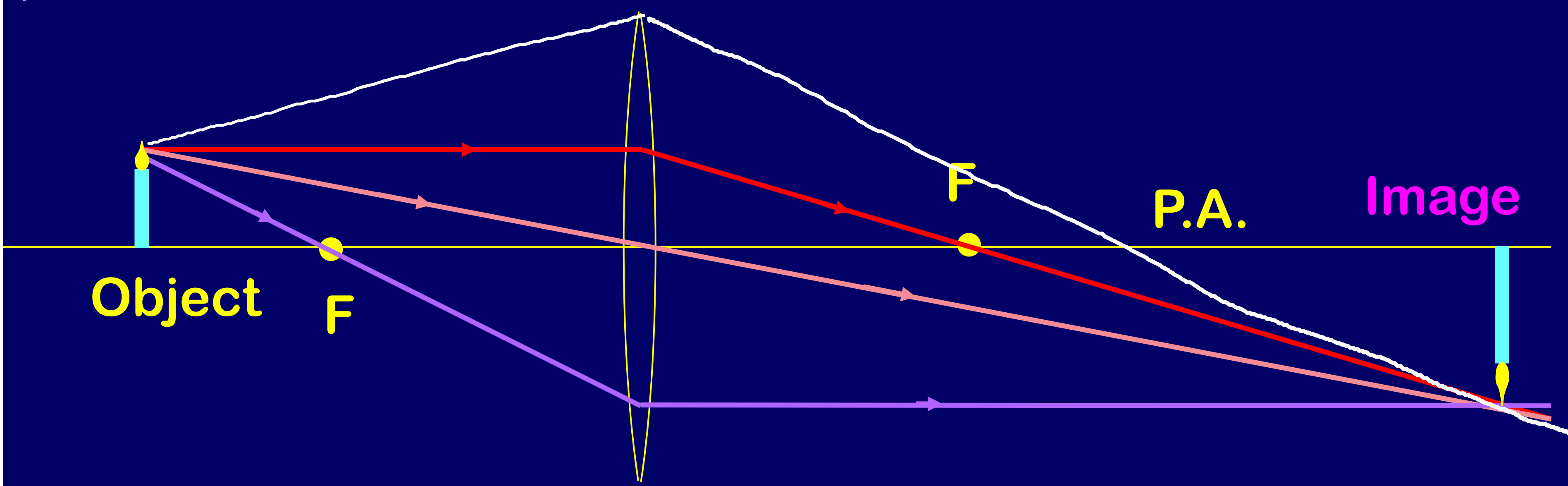
Diverging lens:

– Rays parallel to P.A. diverge as if emerging from focal point behind lens

Diverging = thin in the middle



Example Converging Lens Principal Rays



1) Rays parallel to principal axis pass through focal point.

2) Rays through center of lens are not refracted.

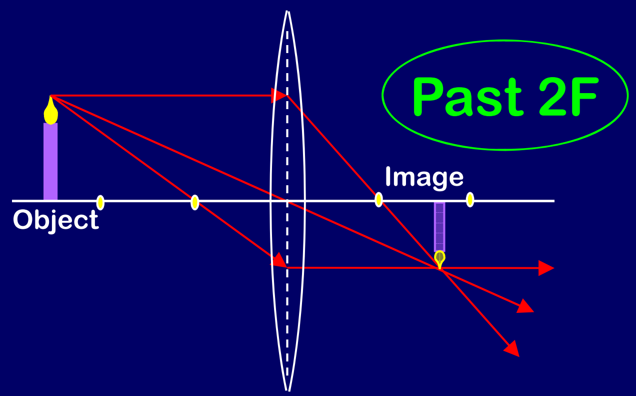
3) Rays through F emerge parallel to principal axis.

Image is: real, inverted and enlarged (in this case).

Key assumptions:

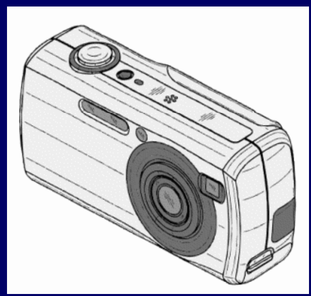
- monochromatic light incident on a thin lens.
- rays are all "near" the principal axis.

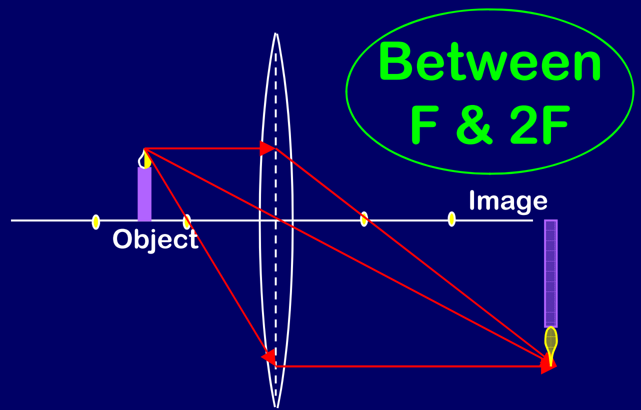
3 Cases for Converging Lenses



Inverted
Reduced
Real

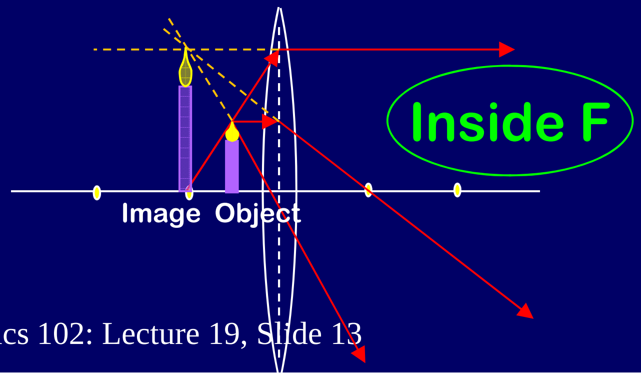
This could be used in a camera.





Inverted
Enlarged
Real

This could be used as a projector.

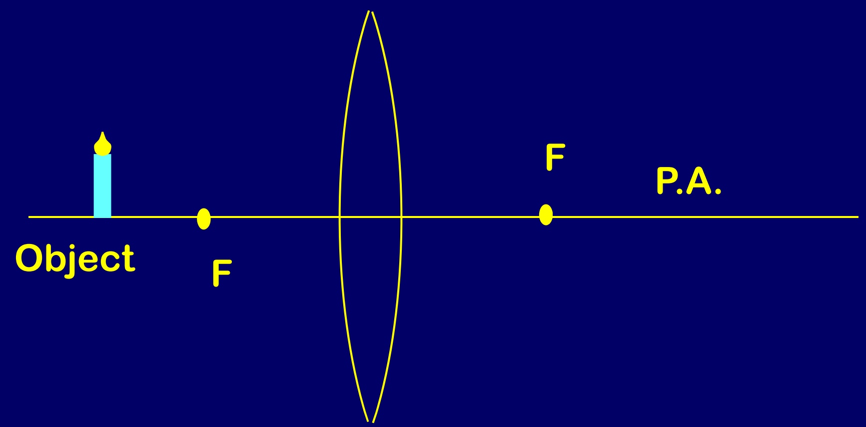


Upright
Enlarged
Virtual

This is a magnifying glass.

ACT: Converging Lens

Which way should you move object so image is real and diminished?

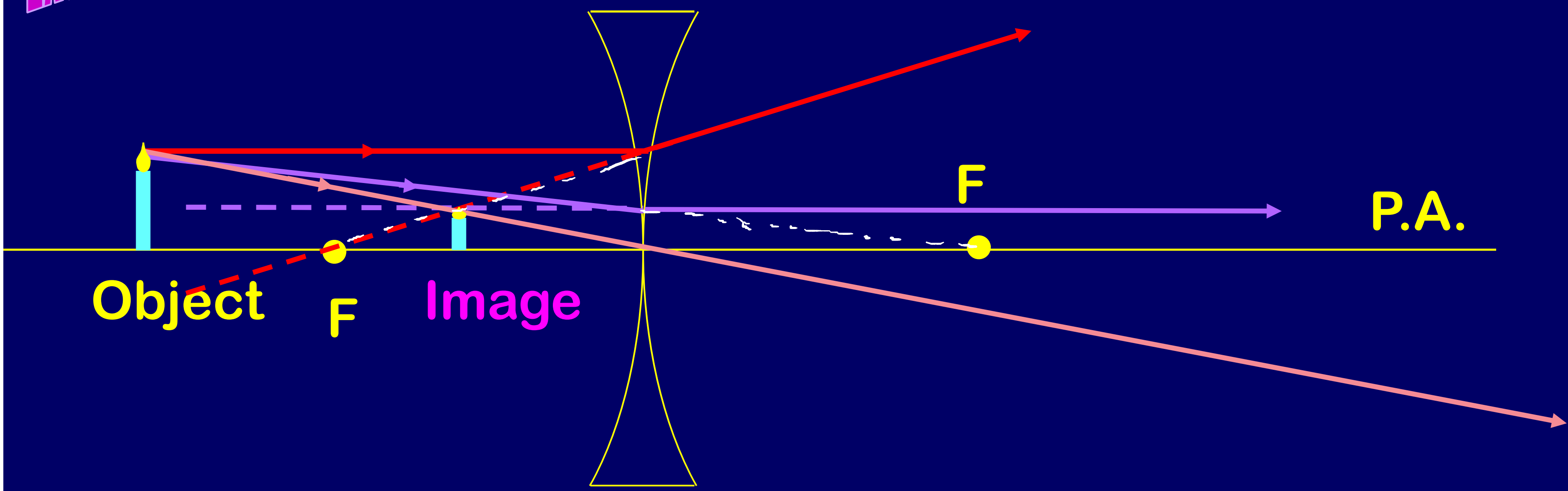


(1) Closer to lens

(2) Further from lens

(3) Converging lens can’t create real diminished image.

Diverging Lens Principal Rays



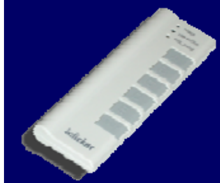
1) Rays parallel to principal axis pass through focal point.

2) Rays through center of lens are not refracted.

3) Rays toward F emerge parallel to principal axis.

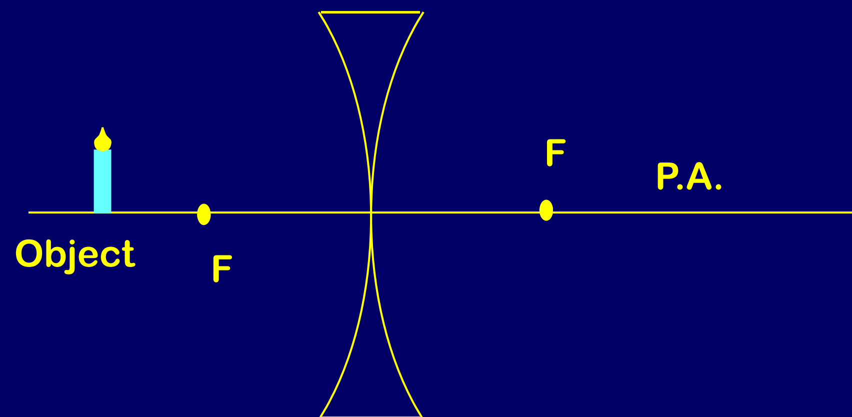
Only 1 case for diverging lens:

Image is always virtual, upright, and reduced.

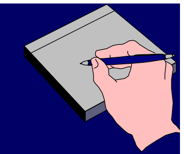


ACT: Diverging Lenses

Which way should you move object so image is real?



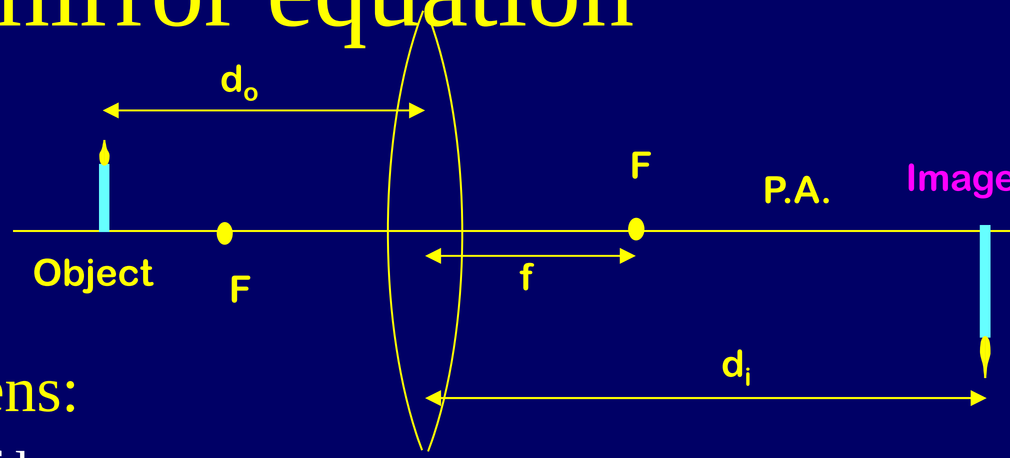
1) Closer to lens
2) Further from lens
3) Diverging lens can’t create real image.



Lens Equation

Same as mirror equation

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



- d_o = distance object is from lens:
  - Positive: object in front of lens
  - Negative: object behind lens
- d_i = distance image is from lens:
  - Positive: real image (behind lens)
  - Negative: virtual image (in front of lens)
- f = focal length lens:
  - Positive: converging lens
  - Negative: diverging lens

Example

$$\frac{1}{15\text{ cm}} + \frac{1}{d_i} = \frac{1}{10\text{ cm}}$$

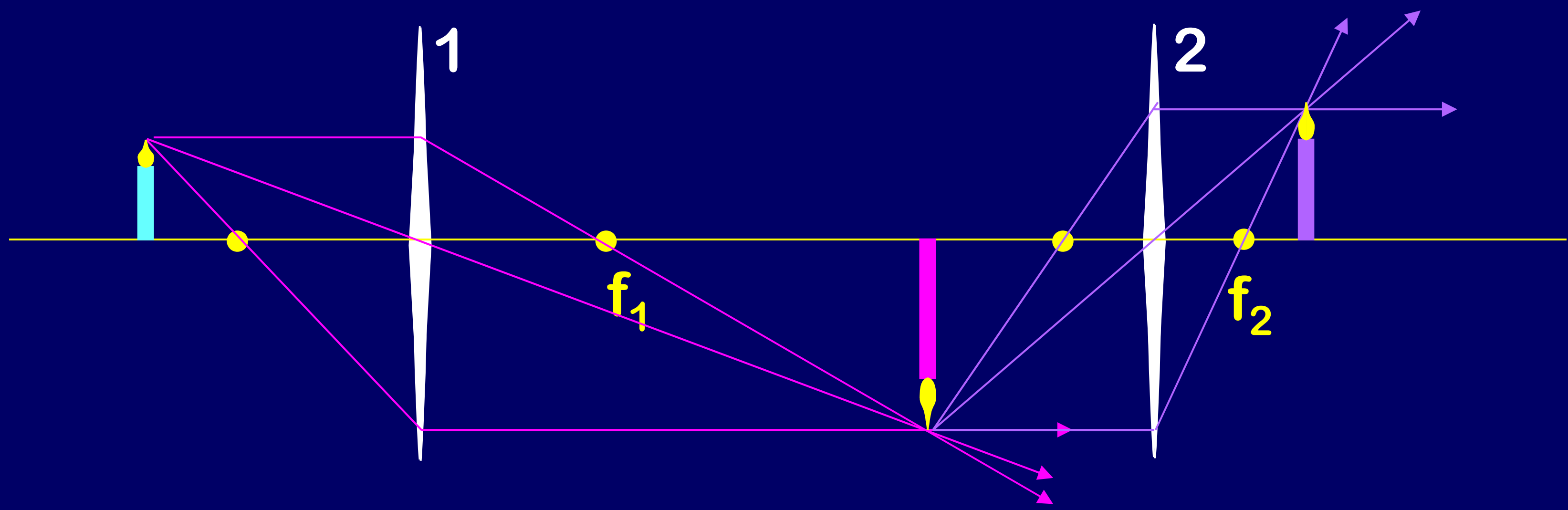
$$d_i = 30\text{ cm}$$

$$m = -\frac{d_i}{d_o} = -2$$

Example

Multiple Lenses

Image from lens 1 becomes object for lens 2

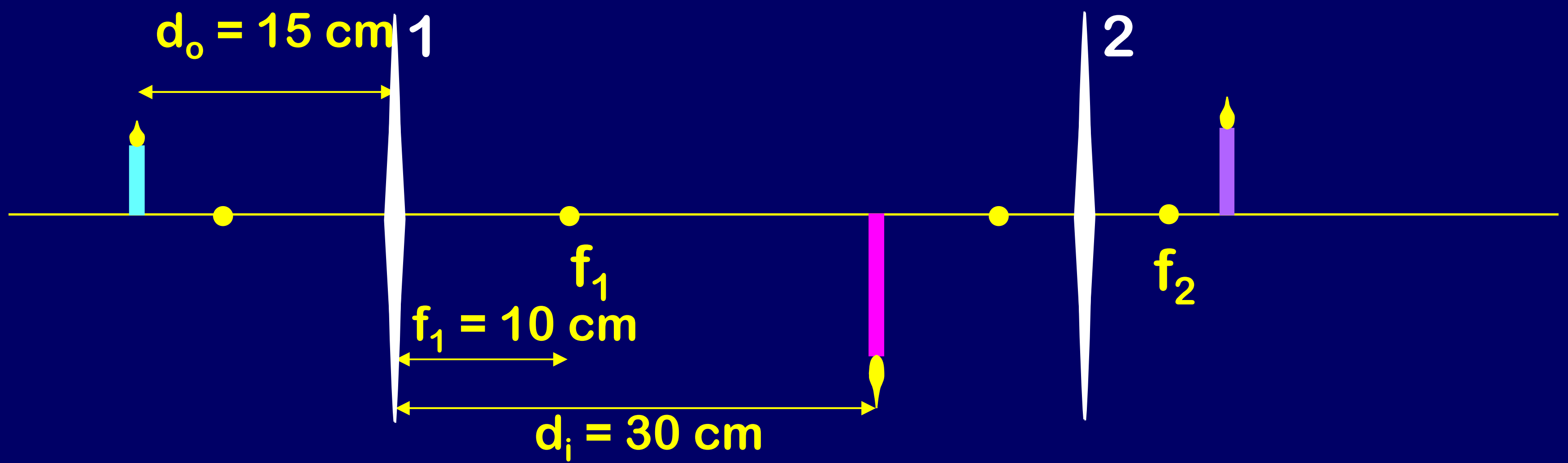


Lens 1 creates a real, inverted and enlarged image of the object.

Lens 2 creates a real, inverted and reduced image of the image from lens 1.

The combination gives a real, upright, enlarged image of the object.

Multiple Lenses: Image 1

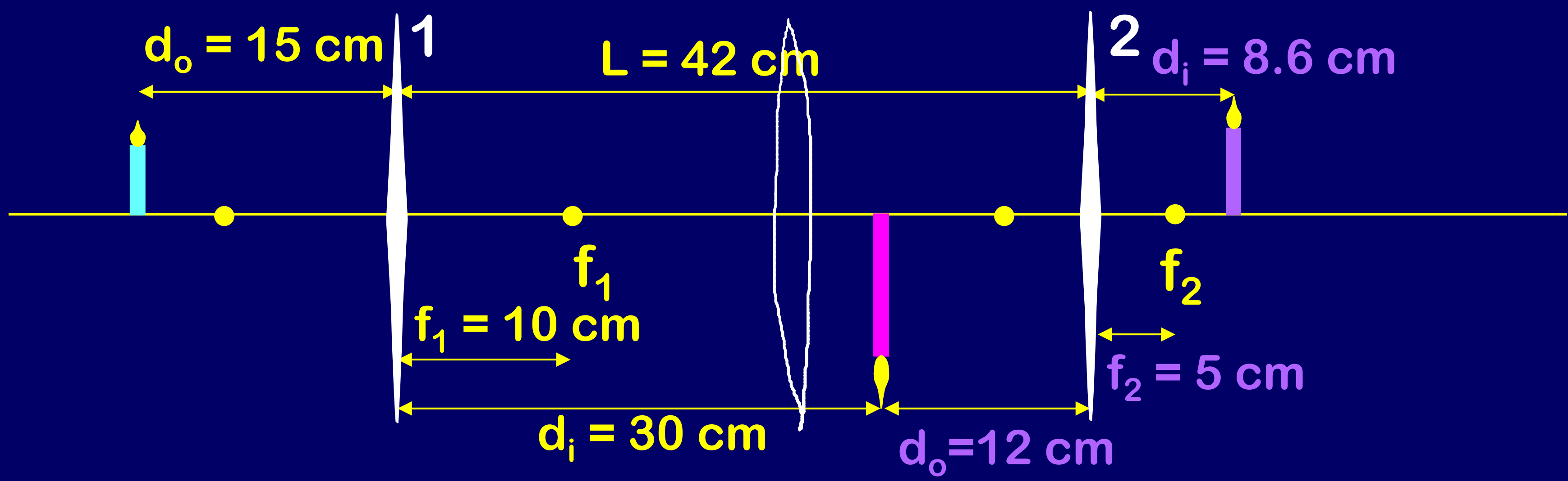


First find image from lens 1.

$$\frac{1}{15\text{ cm}} + \frac{1}{d_i} = \frac{1}{10\text{ cm}} \Rightarrow d_i = 30\text{ cm}$$

Example

Multiple Lenses: Image 2



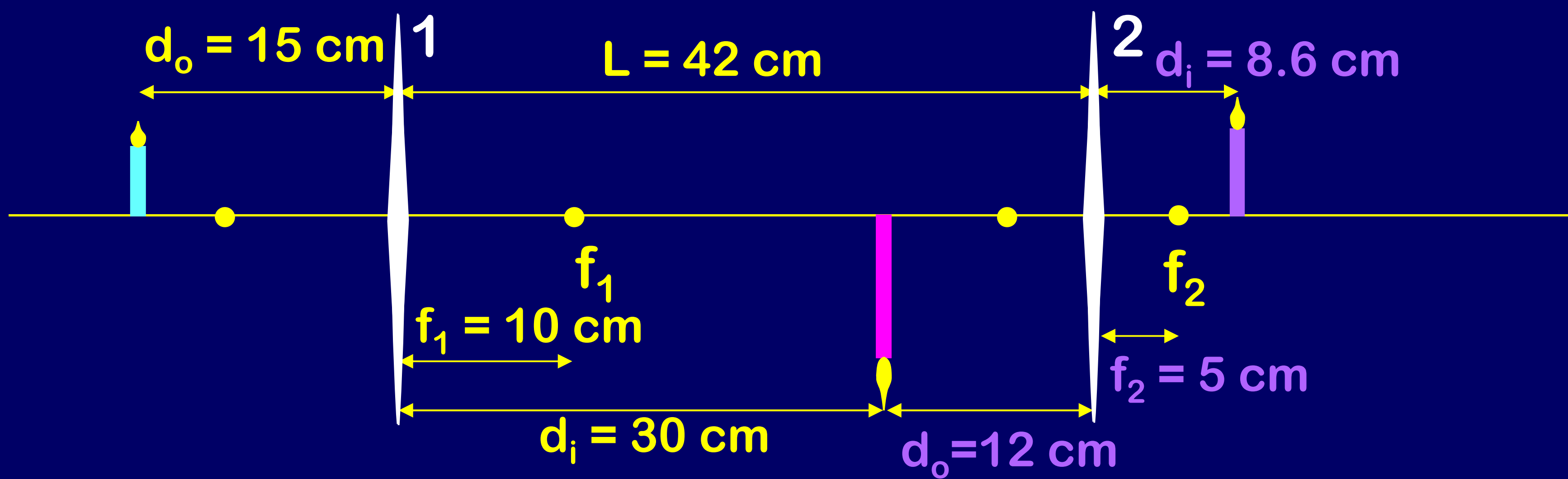
Now find image from lens 2.

$$\frac{1}{12\ \text{cm}} + \frac{1}{d_i} = \frac{1}{5\ \text{cm}} \quad \Rightarrow \quad d_i = 8.6\ \text{cm}$$

Notice that d_o could be negative for second lens!

Example

Multiple Lenses: Magnification



Net magnification: $m_{net} = m_1\ m_2$

$$m_1 = -\frac{30}{15} = -2$$

$$m_2 = -\frac{8.6}{12} = -.72$$

$$m_{net} = m_1 m_2 = +1.43$$

See you next week!