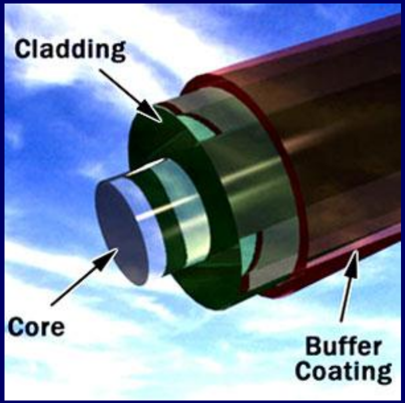
Physics 102: Lecture 18

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

Summary of today's lecture

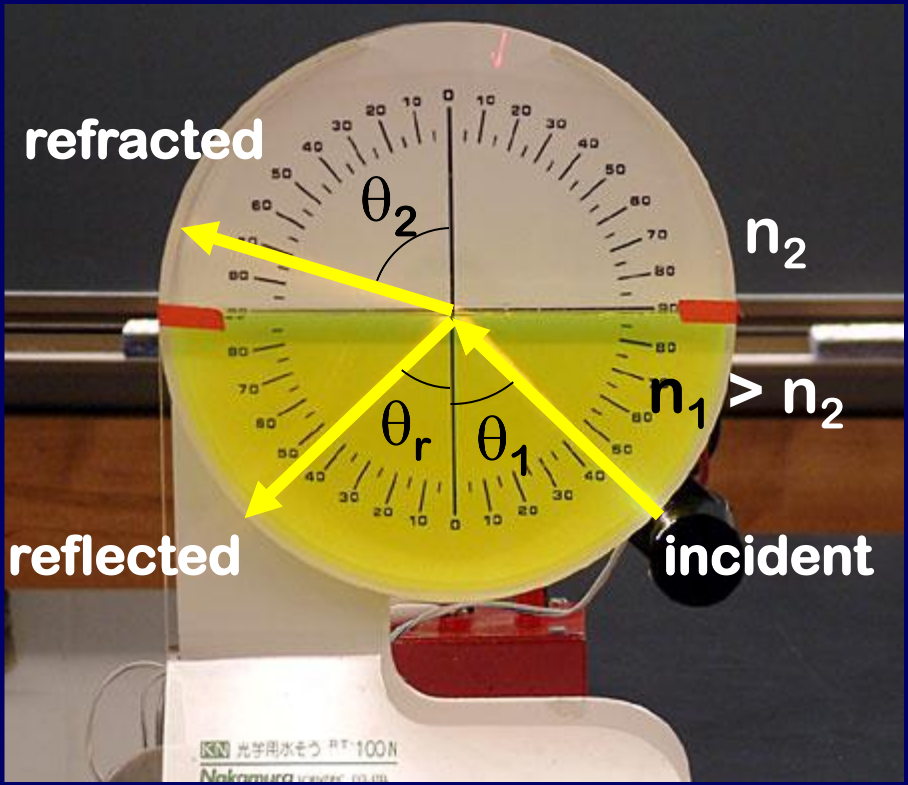
- Examples of refraction
  1) Total internal reflection
  2) Dispersion (rainbows)
  3) Lenses



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:

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

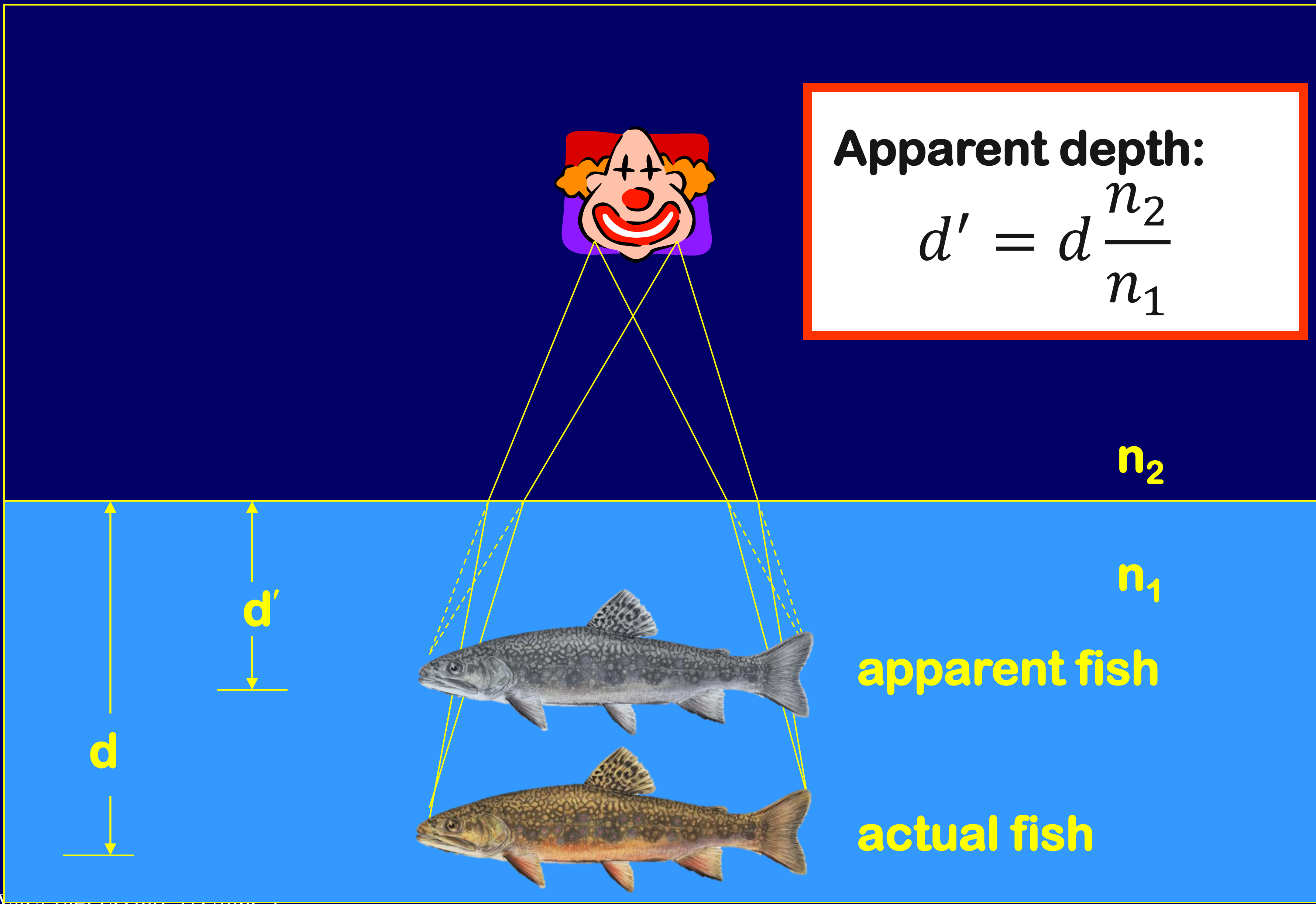


$n_1 > n_2 \Rightarrow \theta_2 > \theta_1$

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

Apparent depth:

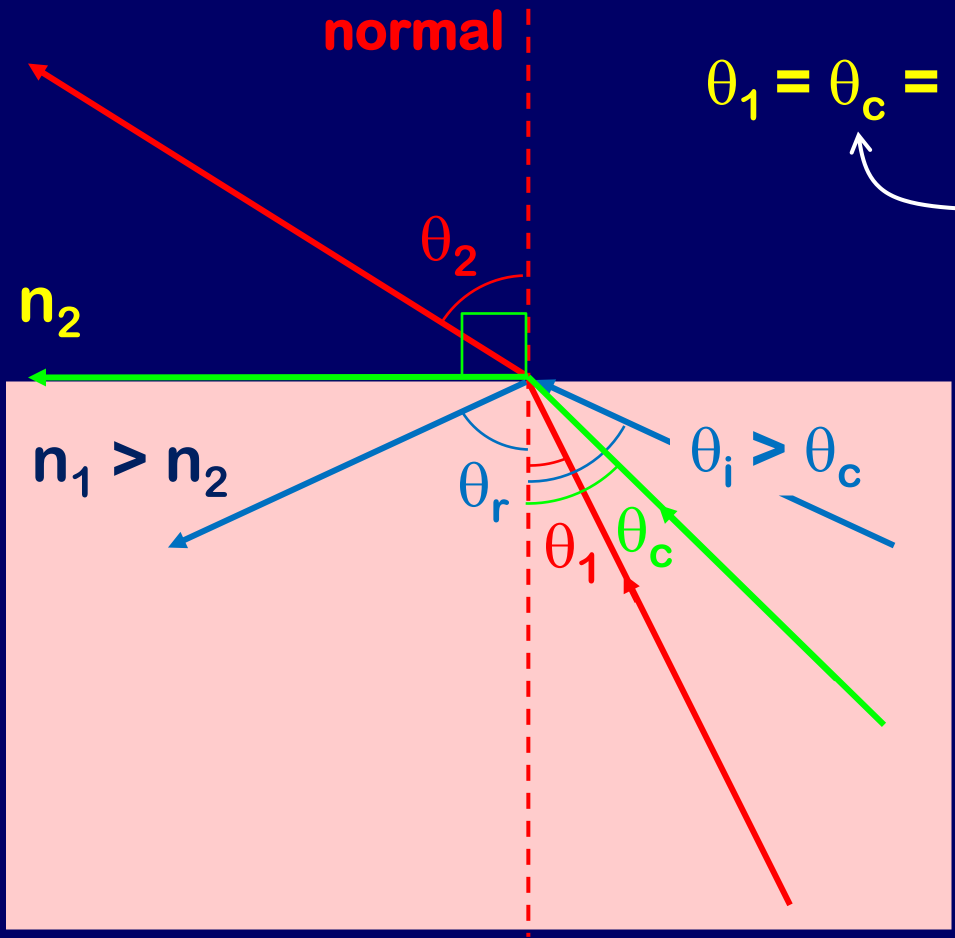
$$d' = d\,\frac{n_2}{n_1}$$



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 $\theta_2 = 90$

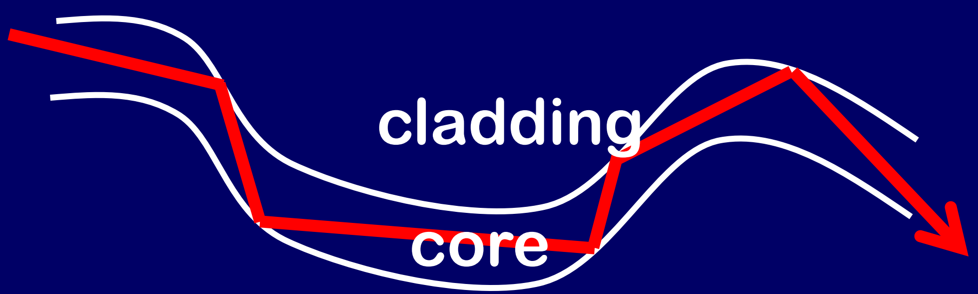
"critical angle"

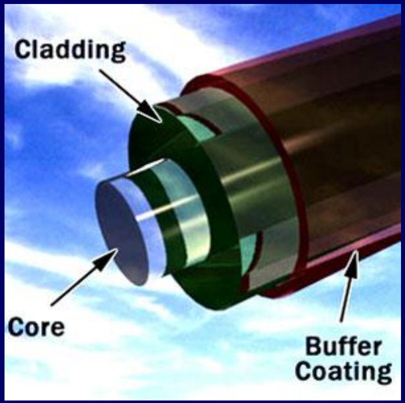
Light incident at a larger angle will only have reflection ($\theta_i = \theta_r$)

For water/air:
$n_1=1.33$, $n_2=1$
$\theta_c = \sin^{-1}(n_2/n_1)$
$= 48.8^0$

Fiber Optics

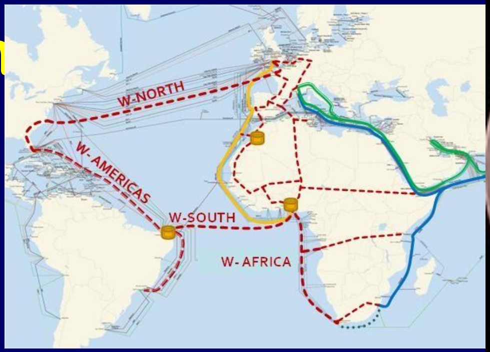
At each contact w/ the glass air interface, if the light hits at greater than the critical angle, it undergoes total internal reflection and stays in the fiber.

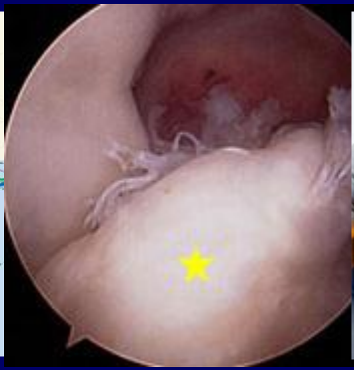




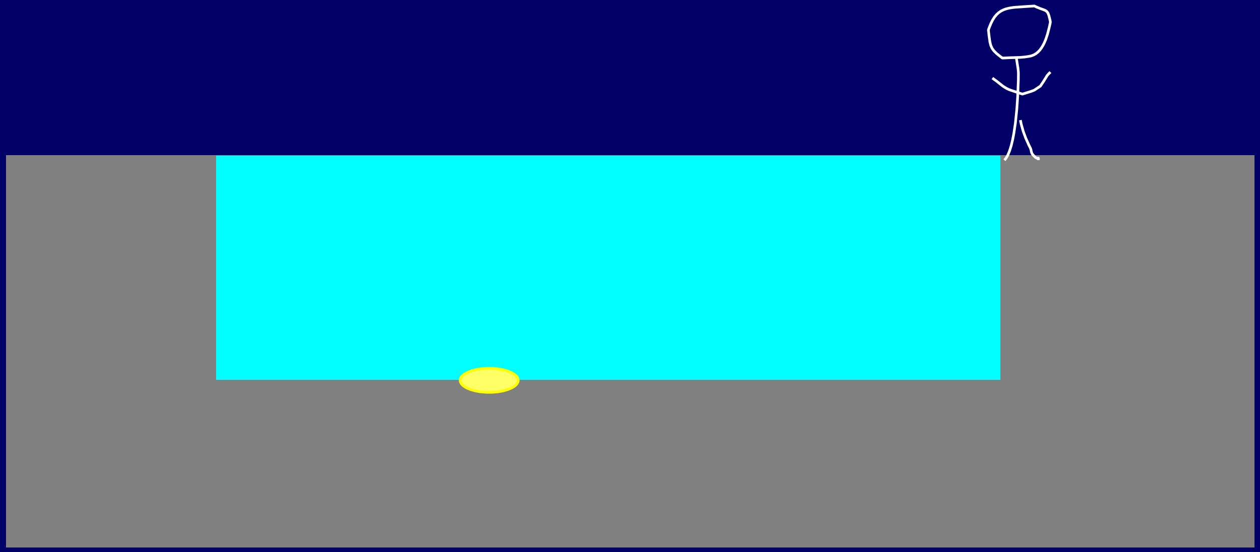
Total Internal Reflection only works if $n_{cladding} < n_{core}$

- **Telecommunication**
- **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

2) No

2) Dispersion

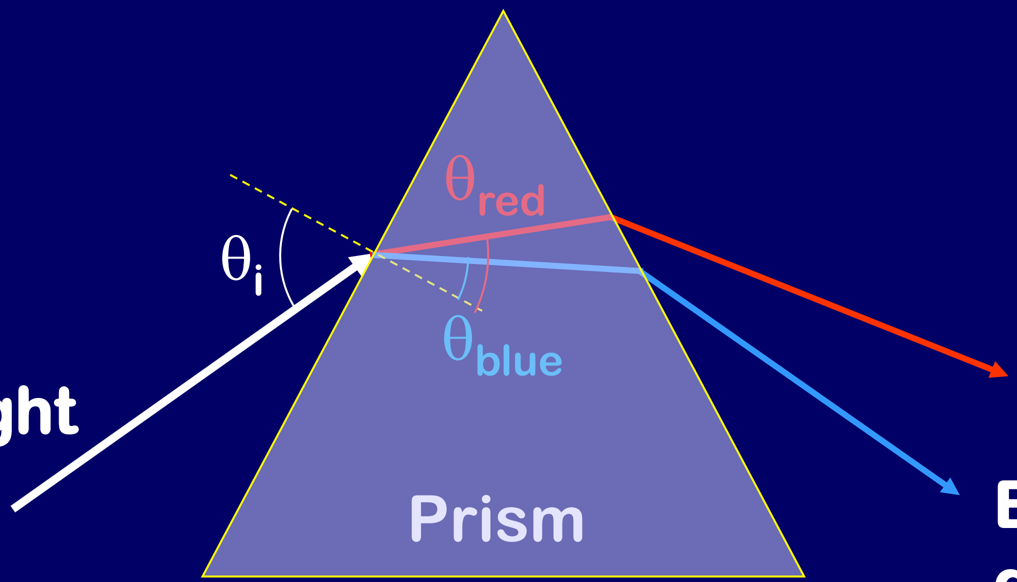
The index of refraction **n** depends on color!

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

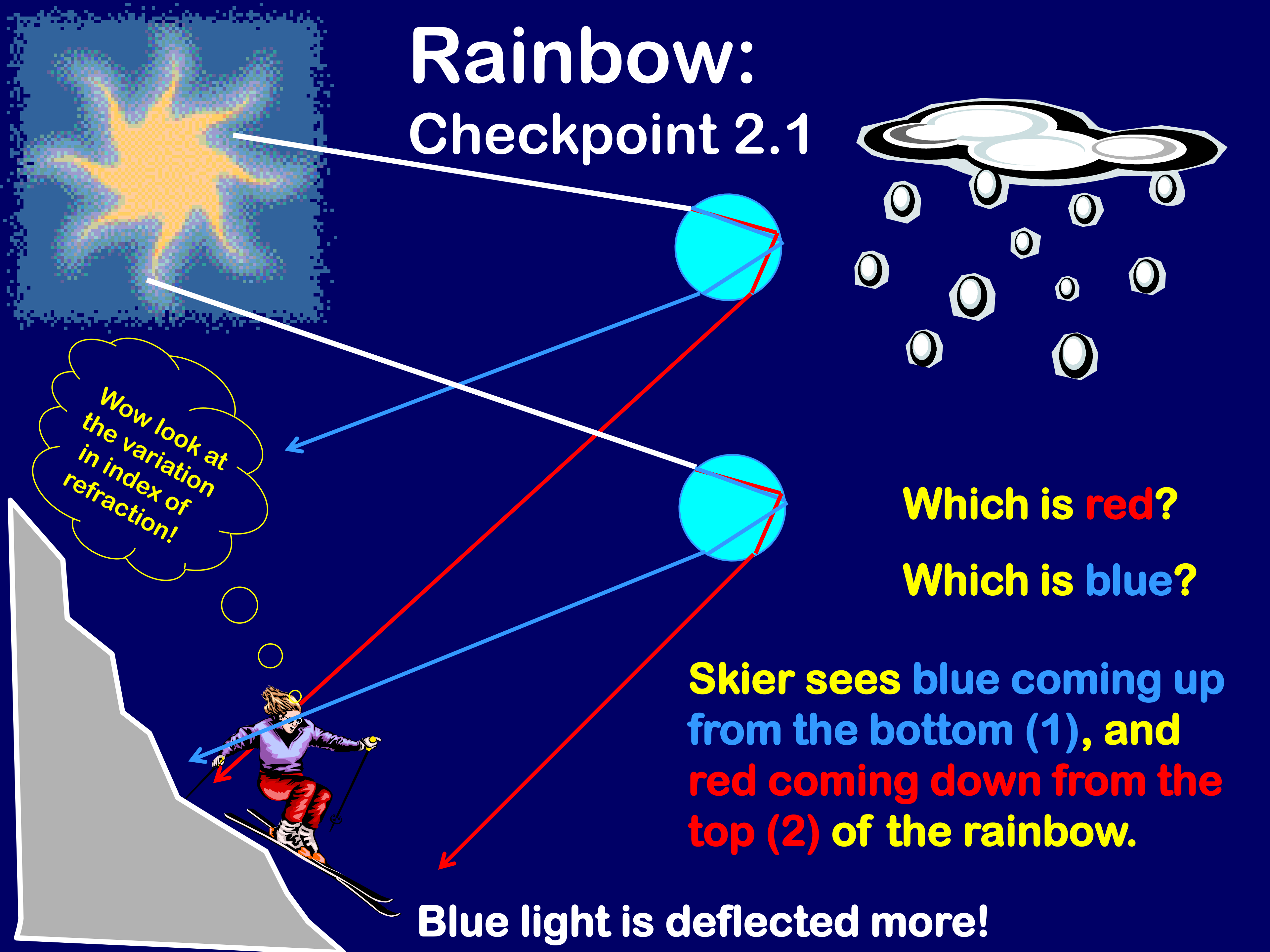
$n_{blue} > n_{red}$

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

White light



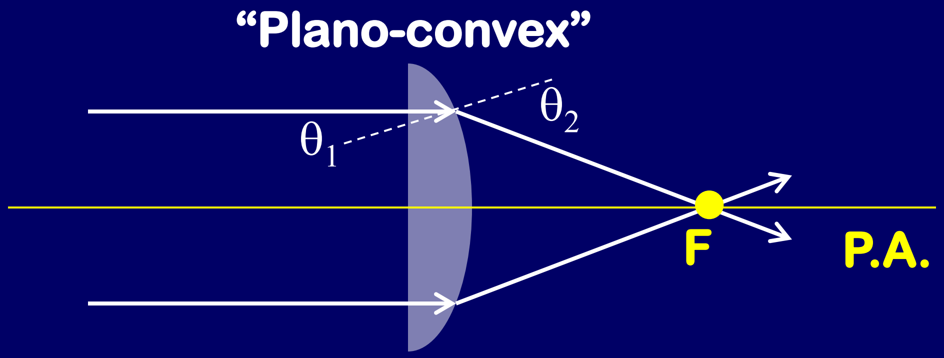
Blue light gets deflected more


Rainbow:
Checkpoint 2.1
Wow look at the variation in index of refraction!
Which is red?
Which is blue?
Skier sees blue coming up from the bottom (1), and red coming down from the top (2) of the rainbow.
Blue light is deflected more!

In second rainbow pattern is reversed

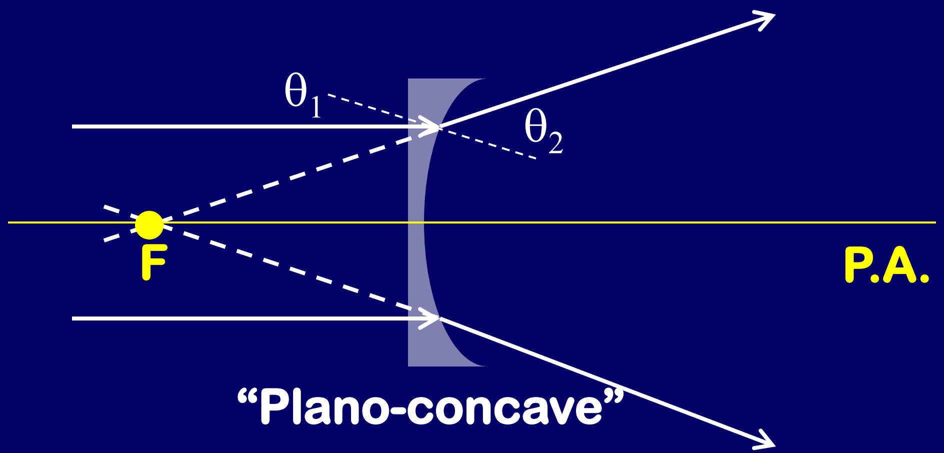
LIKE SO!

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

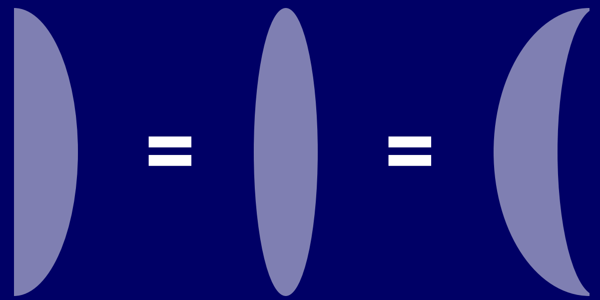
Larger n_2/n_1 = more bending, shorter focal length.
Smaller n_2/n_1 = less bending, longer focal length.

Converging & Diverging Lenses

Converging lens:

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

Converging = fat in the middle

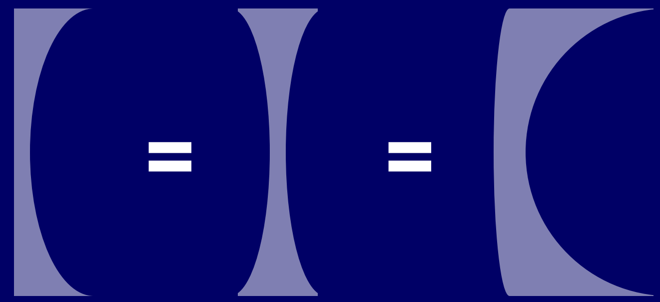


“Plano-convex” = “Double convex” = “Concave-convex”

Diverging lens:

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

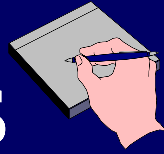
Diverging = thin in the middle

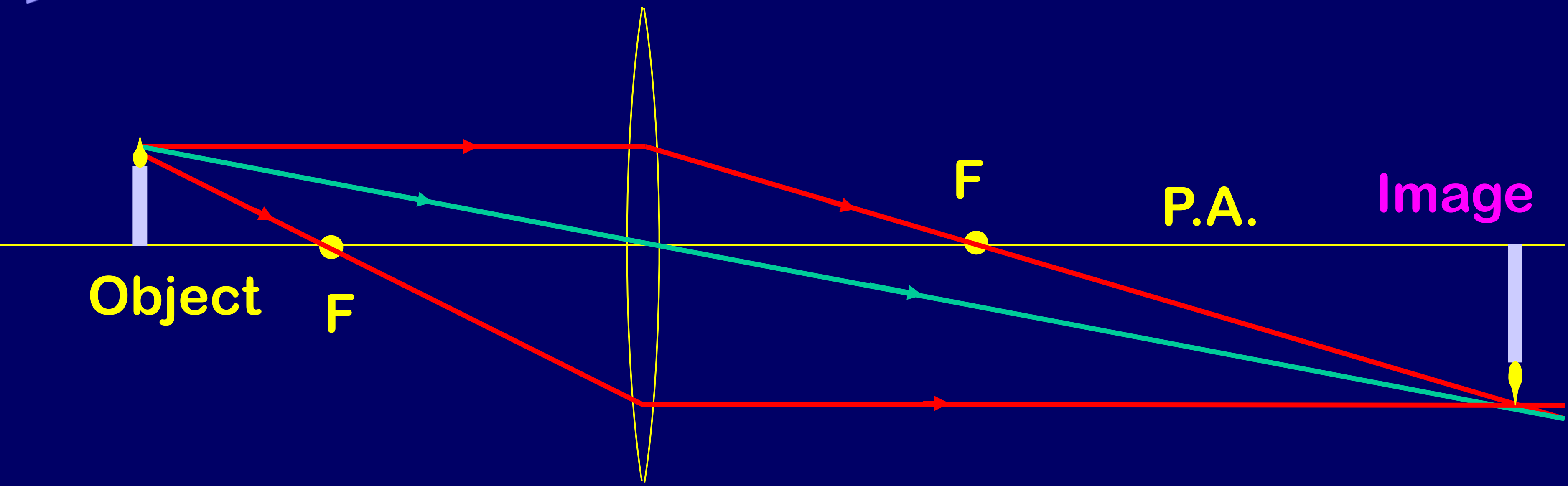


“Plano-concave” = “Double concave” = “Convex-concave”

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).

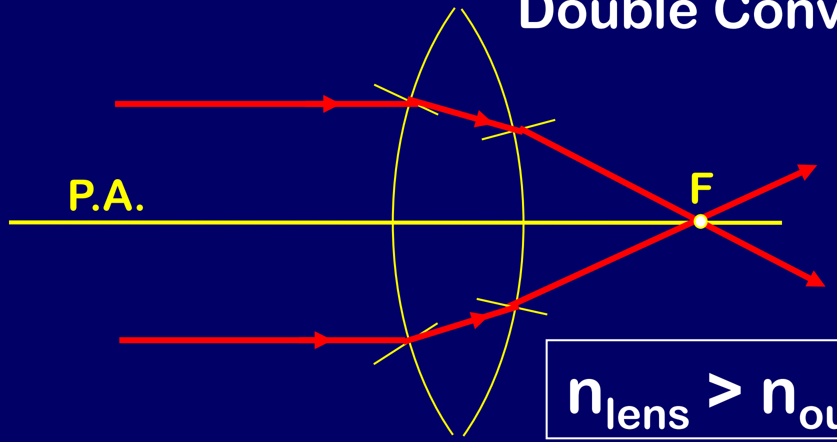
Key assumptions:

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

Converging Lens

All rays parallel to principal axis pass through focal point F.

Double Convex

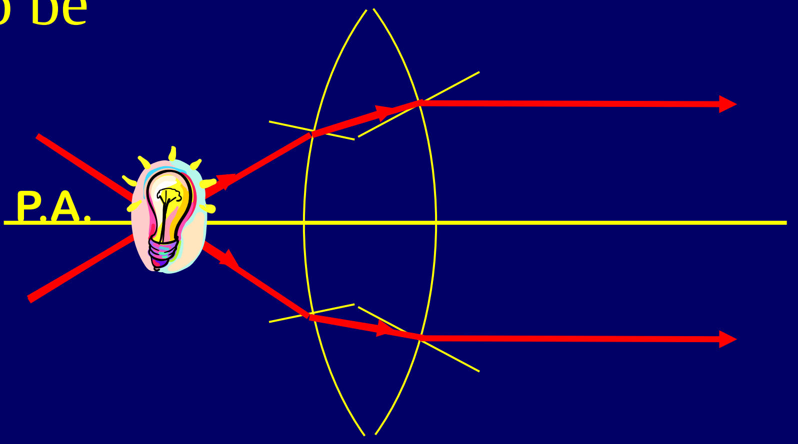


$n_{lens} > n_{outside}$

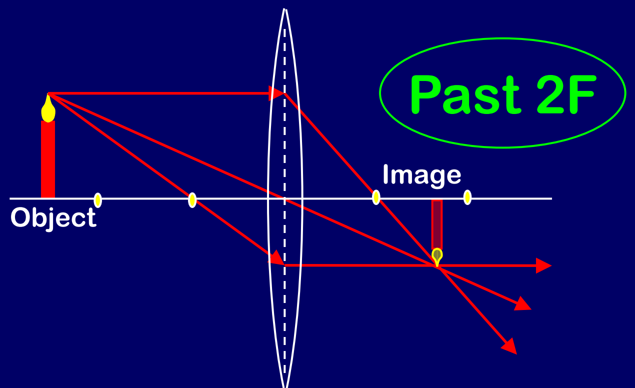
Checkpoint 3.1

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?

- **At F**
- **Inside F**
- **Outside F**

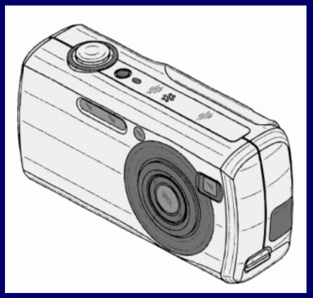


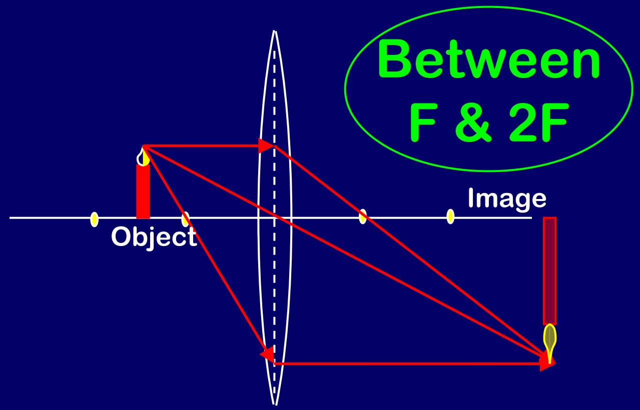
3 Cases for Converging Lenses



Inverted
Reduced
Real

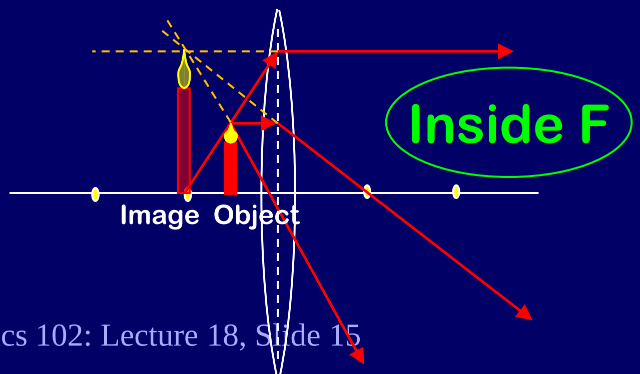
This could be used in a camera.





Inverted
Enlarged
Real

This could be used as a projector.

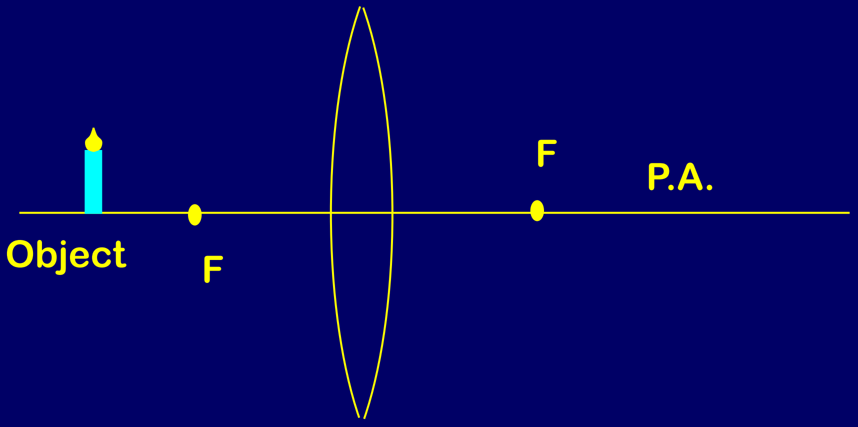


Upright
Enlarged
Virtual

This is a magnifying glass.

ACT: Converging Lens

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

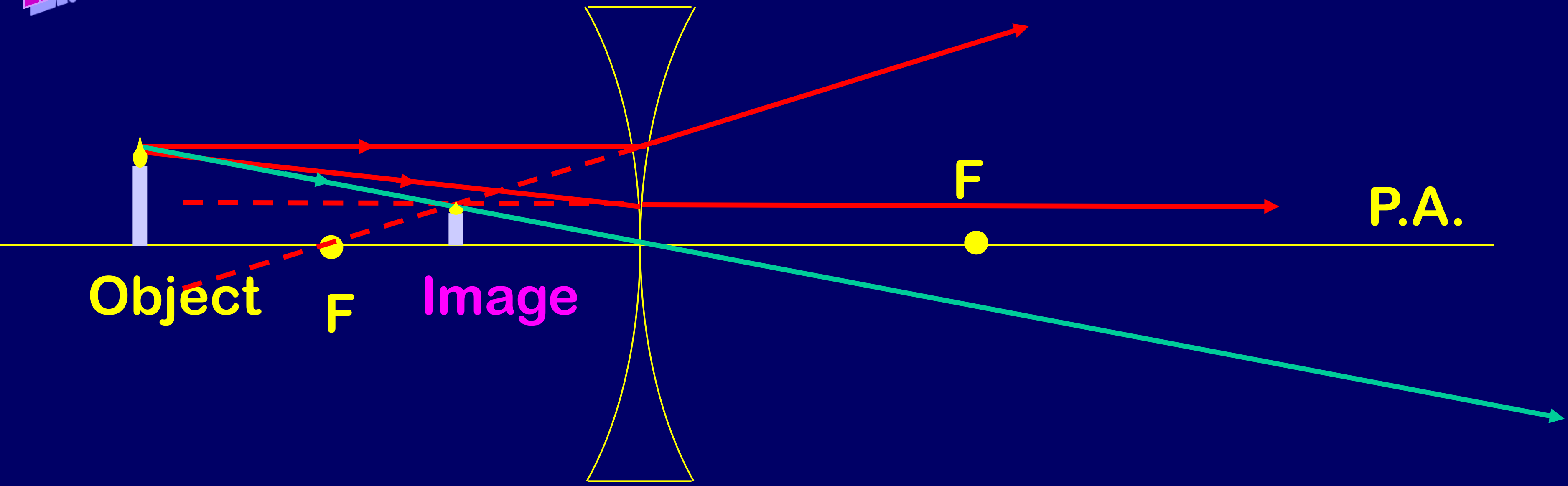


(1) Closer to lens

(2) Further from lens

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

Diverging Lens Principal Rays



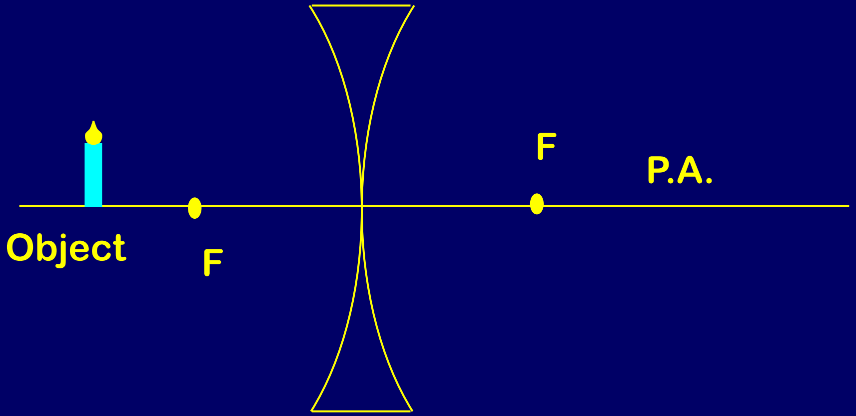
1) Rays parallel to principal axis pass through focal point.
2) Rays through center of lens are not refracted.
3) Rays toward F emerge parallel to principal axis.

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.