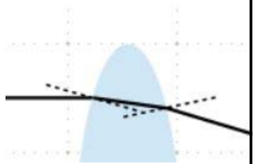
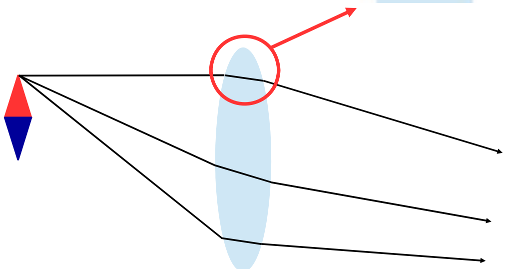
## Lenses

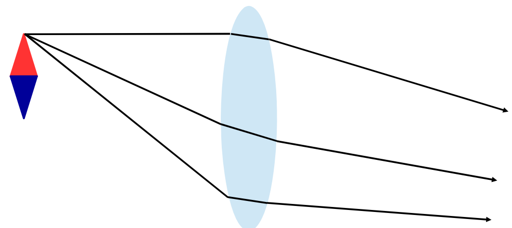
Light refracts at both surfaces.
Non-parallel surfaces results in net "bend".





## Lenses

Focusing power of the lens is function of
- radius of curvature of each surface and
- index of refraction of lens.



## Lenses

Converging lenses are thicker in the center of the lens.

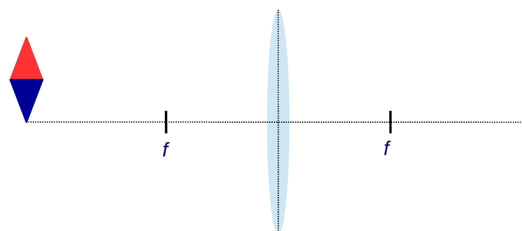


Diverging lenses are thinner in the center of the lens.



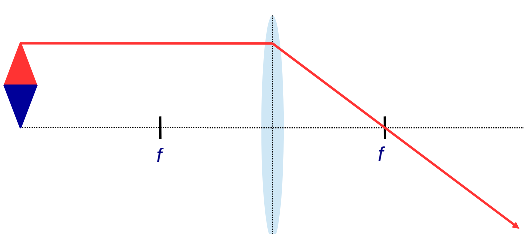
## Symmetric Thin Lens Approximation

Assume all bend occurs along a line through the lens.
Assume the same focus on each side of the lens.



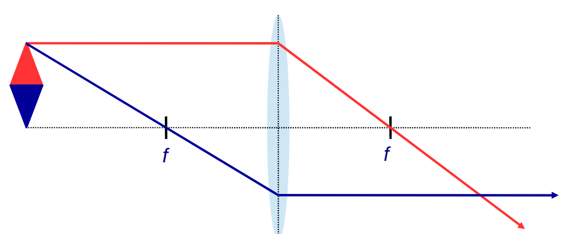

## Use geometric ray diagram to determine image location.

- From the object to the lens, parallel to the principle axis
  From there (lens) through the far focal point



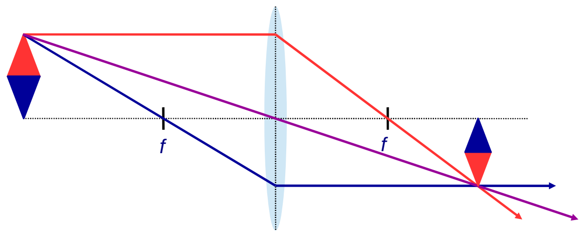

## Use geometric ray diagram to determine image location.

- From the object through the near focal point to the lens
  from there (lens) parallel to the principle axis



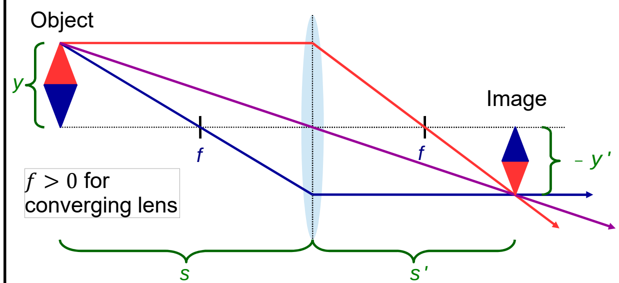
### Use geometric ray diagram to determine image location.

- From the object through the center of the lens



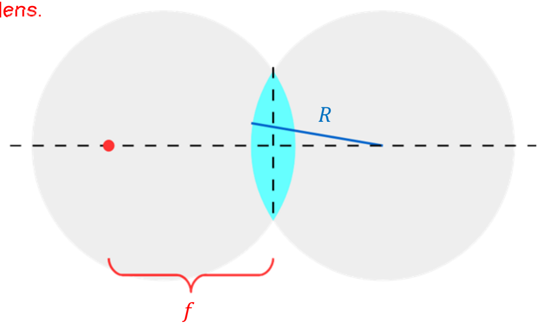

### Calculation

$$\frac{1}{s}+\frac{1}{s'}=\frac{1}{f} \qquad m=\frac{y'}{y}=\frac{-s'}{s}$$



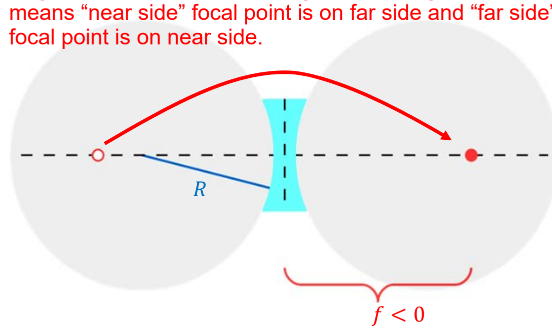

### Sign Conventions

Positive $f$ associated with positive $R$ on opposite side of lens.

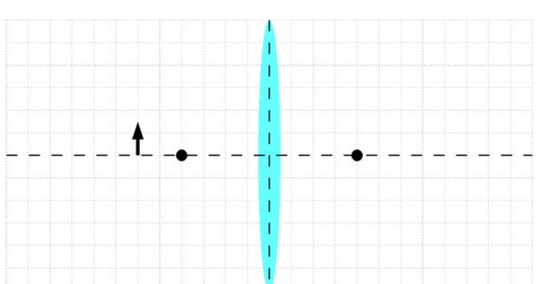



### Sign Conventions

Negative $f$ associated with negative $R$. Negative $f$ means "near side" focal point is on far side and "far side" focal point is on near side.




Example: A 3cm tall object is placed 12cm from a converging thin lens with a focal length of 8cm. (a) Where would the image be? (b) How tall would the image be?



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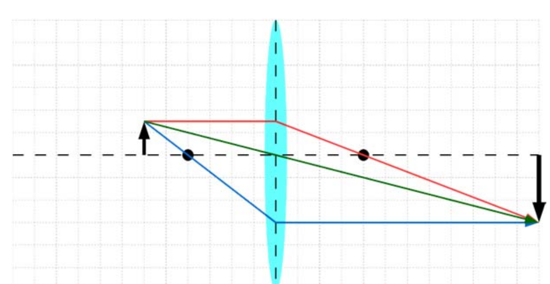
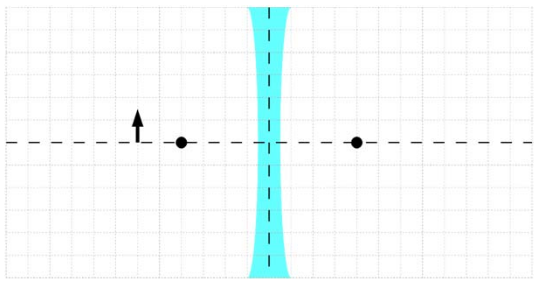


Example: A 3cm tall object is placed 12cm from a diverging thin lens with a focal length of $-8\text{cm}$. (a) Where would the image be? (b) How tall would the image be?



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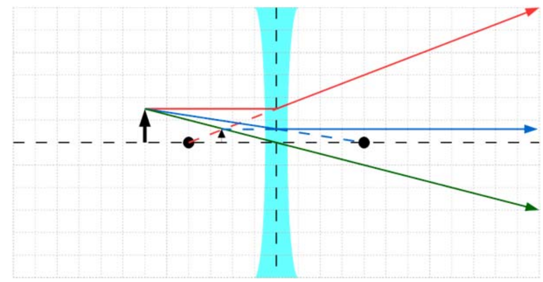
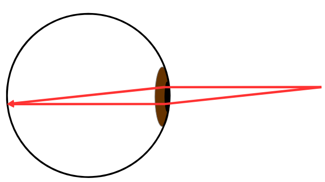


## Eyes and Corrective Lenses

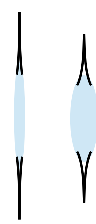
Lens causes light rays to converge on the back of the eye.



## Eyes and Corrective Lenses

Focal length of human eye is adjustable.

Muscles can pull lens, causing the lens to be thinner, less converging.



When muscles are relaxed, elasticity of lens restores lens to thicker shape, more converging.

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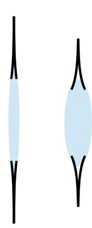
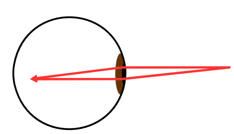


When muscles are relaxed, elasticity of lens restores lens to thicker shape, more converging.

The human eye eventually loses elasticity and loses some range in convergence, resulting in inability to focus on near objects. Typically, there is significant loss between 40 and 50 years of age.

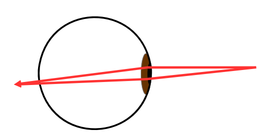
## Eyes and Corrective Lenses

Some eyes have lenses that are too converging or not converging enough and need corrective lenses.



Too converging

"Nearsighted"

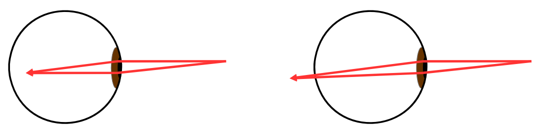


Not converging enough

"Farsighted

## Eyes and Corrective Lenses

Some eyes have lenses that are too converging or not converging enough and need corrective lenses.



Too converging

"Nearsighted"

Corrected with diverging lens.

Not converging enough
"Farsighted"

Corrected with converging lens.

---

Example: A student's natural lenses focus light from a distant object 0.1 cm in front of the back of the eye.
a. What kind of corrective lenses should the student use?
b. What should be the focal length of the corrective lenses?
[The back of the human eye is ~2.4 cm from the natural lens. Estimate the location of corrective lenses.]

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The image for the corrective lens will become the object for the natural lens.
- Determine the focal length of the natural lens.

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The image for the corrective lens will become the object for the natural lens.
- Determine the focal length of the natural lens.
- Determine an object distance for the natural lens that results in an image distance of 2.4 cm.

---

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The image for the corrective lens will become the object for the natural lens.
- Determine the focal length of the natural lens.
- Determine an object distance for the natural lens that results in an image distance of 2.4 cm.
- Determine the image distance for the corrective lens.

[The object for the natural lens is the image for the corrective lens, BUT the two distances are different because they are measured from different lenses.]

---

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a. What kind of corrective lenses should the student use?
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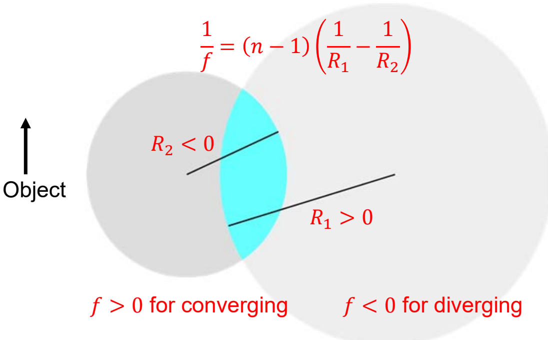
The image for the corrective lens will become the object for the natural lens.
- Determine the focal length of the natural lens.
- Determine an object distance for the natural lens that results in an image distance of 2.4 cm.
- Determine the image distance for the corrective lens.
- Determine the focal length for the corrective lens.

## More Complex Lenses
## Lensmaker's Equation

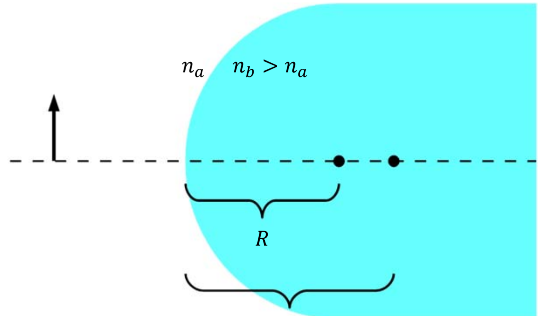
$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$




$f > 0$ for converging $f < 0$ for diverging

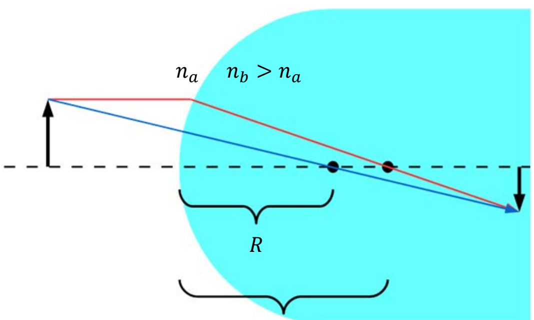
(Surface 1 is first surface hit by light.)

## Refraction at Spherical Surfaces




$$f = \left(\frac{n_b}{n_b - n_a}\right)R$$

## Refraction at Spherical Surfaces

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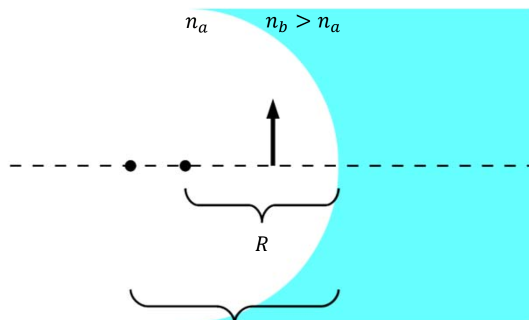
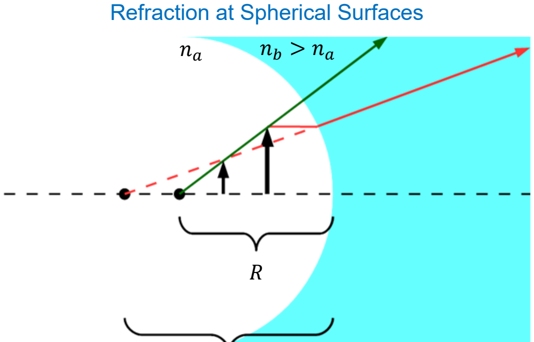
## Refraction at Spherical Surfaces




$$f = \left(\frac{n_b}{n_b - n_a}\right)R$$

## Refraction at Spherical Surfaces




$$f = \left(\frac{n_b}{n_b - n_a}\right)R$$

## Refraction at Spherical Surfaces
## Calculations (for $n_b > n_a$)

$$f = \left(\frac{n_b}{n_b - n_a}\right)R$$ (Note that $f > R$)

$$\frac{n_a}{s} + \frac{n_b}{s'} = \frac{n_b - n_a}{R}$$

$$m = \frac{y'}{y} = \frac{-n_a s'}{n_b s}$$