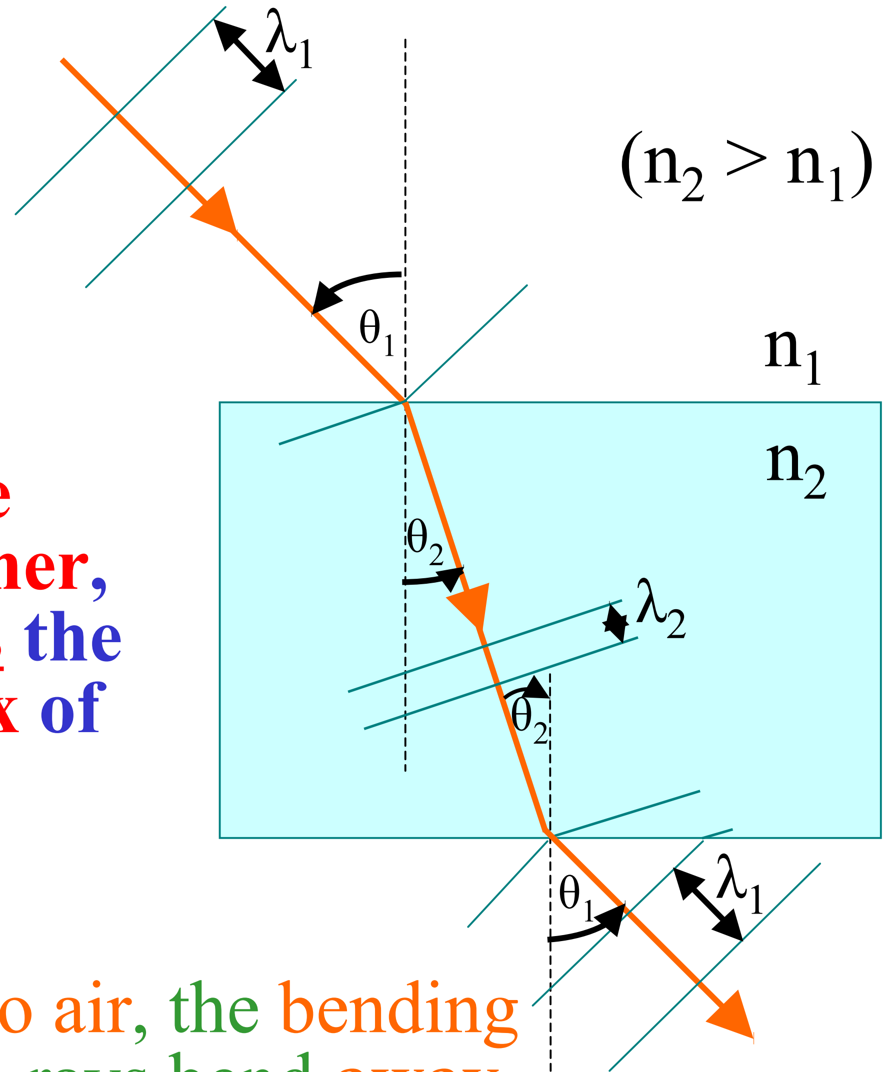
Recap: Refraction

- **Amount** of **bending** depends on:
  - **angle** of incidence
  - **refractive index** of medium



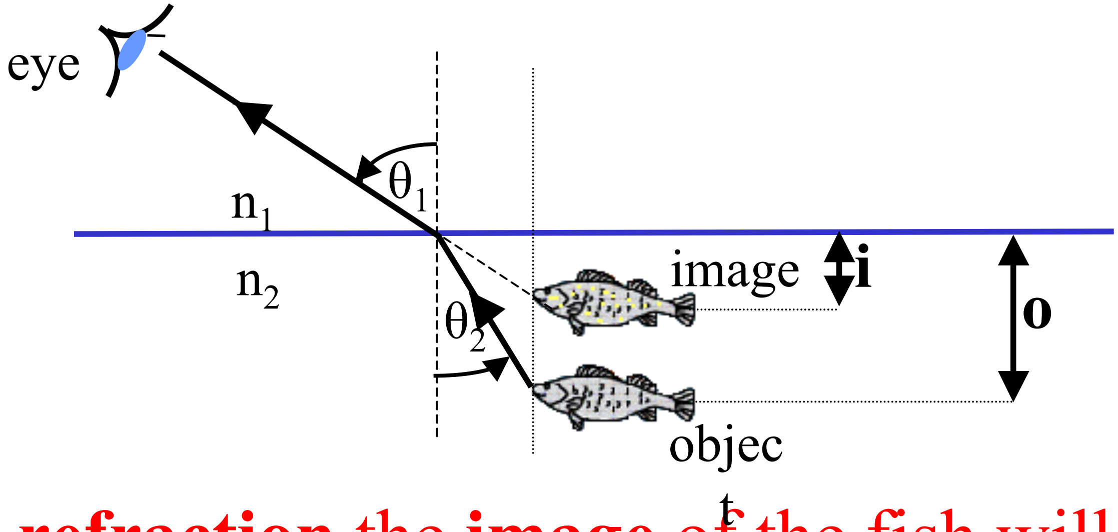
Snell's Law:

❖ **When light passes from one transparent medium to another, the rays will be bent <u>towards</u> the normal if the refractive index of medium is larger.**

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

- When light travels from glass to air, the bending is in the **opposite direction** (i.e. rays bend **away** from normal when going from high to low 'n' medium).

- **Example of refraction**: Viewing objects **under water**…



- Due to **refraction** the **image** of the fish will **appear closer** to the surface than it actually is.
- **Relationship for apparent depth:**

$$\mathbf{i = o\left(n_1/n_2\right)} \qquad \text{(provided } n_2 > n_1\text{)}$$

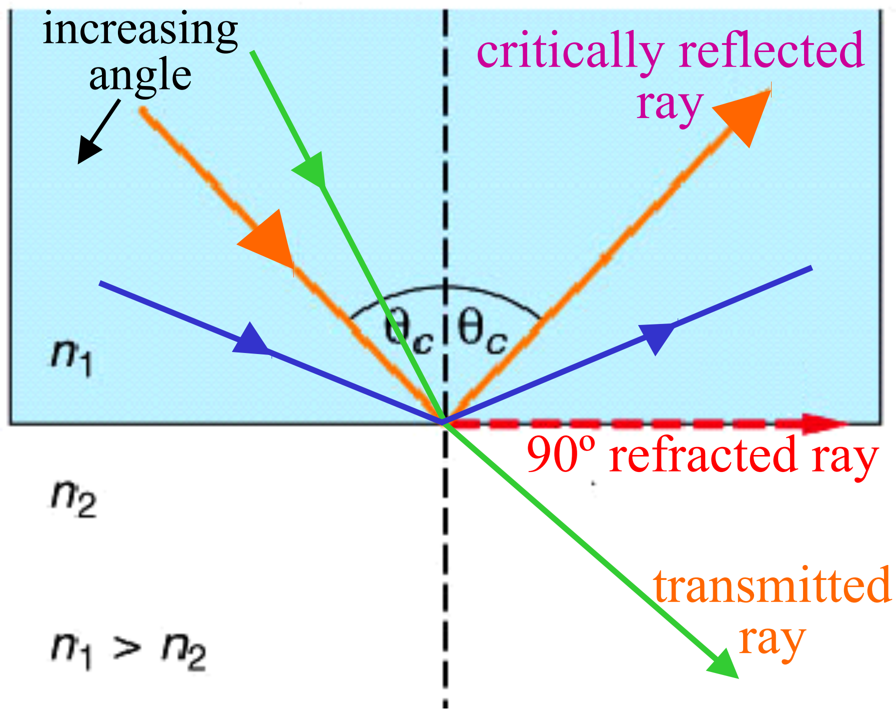
- E.g. If n_2 (water) = 1.33 what is the apparent depth of a fish at 2 m depth?

$$i = 2 \times \left(1/1.33\right) = 1.5\ \text{m}$$

- The fish is 0.5 m below its image (virtual image) and is safe!

Total Internal Reflection

- When **light travels** from a **high** to a **lower refractive index** medium (as with the fish looking at us) the **ray** is **bent away** from normal.
- Depending on 'n', a critical angle of incidence (θ_c) can be reached where the **angle of refraction = 90º.**

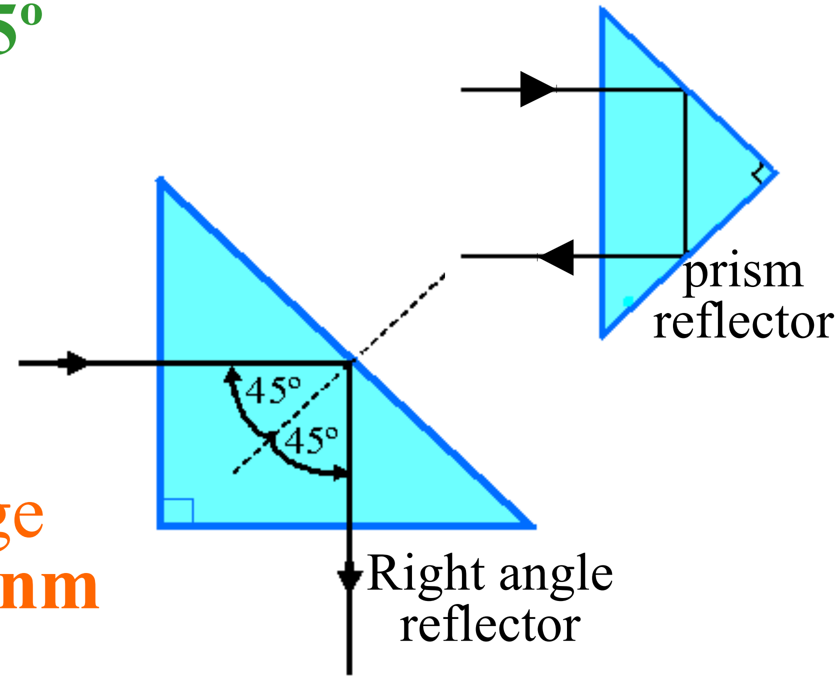


- When the angle of **refraction equals 90º,** the ray is **no longer transmitted** but is instead **<u>totally internally reflected</u>** at the interface.
- At angles **equal** or **greater** than **critical value** (~42º for glass, n=1.5) **100%** of **light** is **reflected** creating a **<u>perfect mirror</u>**!

Note: On **transmission** some light is always lost to **reflection** within the medium.

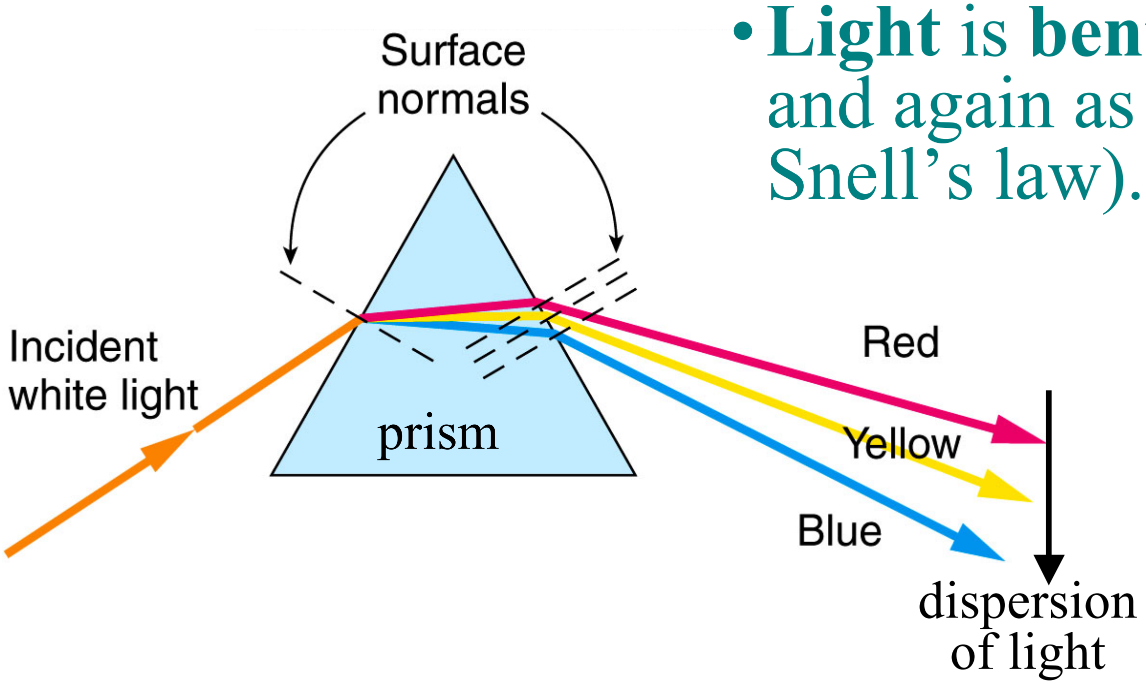
- A **right angle prism** cut with **45º angles** makes a **perfect mirror** using **total internal reflection**.

(As angle of incidence > 42º).



Dispersion and Prisms:

- **"White light" comprises** a range of **E-M waves** from **400** to **700 nm wavelength** (in air).

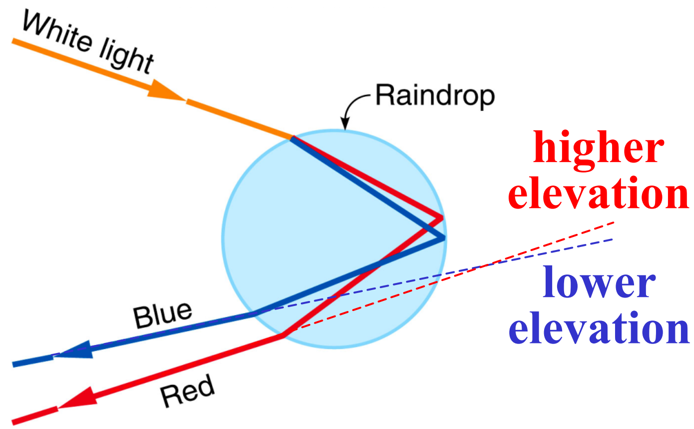


- **Light** is **bent** as it **enters** prism and again as it **leaves** prism (by Snell's law).

- Refractive index 'n' depends on color (i.e. freq. of light). It is **larger** for **blue,** which is **bent most -** creates **<u>dispersion of light</u>**.

Example: Rainbow Formation

From experience we all know that a rainbow is usually seen in the late afternoon when the Sun is at low elevation and there is rain nearby.

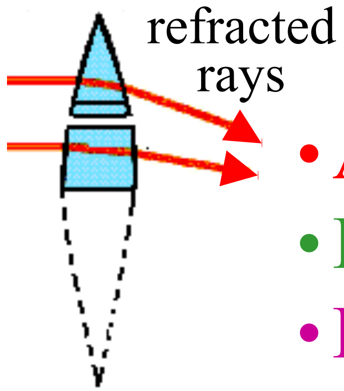


- Sunlight at **low elevation enters raindrop** and is **refracted** (blue refracted most).
- **Some of the light** that hits the **back** of the **raindrop** is **reflected back** towards **front**.
- This **light** is again **refracted** as it **exits** the **raindrop**.
- Net effect is **light** is **dispersed** into its **spectrum** and **rainbow** appears with **red at top** (larger angle from arc center) and **blue /violet** at **bottom**.
- **Sun** must be at **your back** to **see** a rainbow.

Lenses

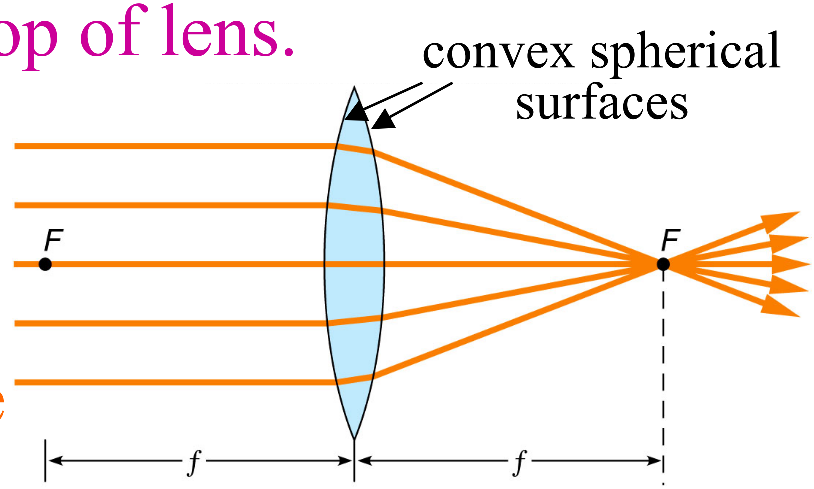
Question: How do lenses **form images**?

- Lenses are made of a transparent material: glass, quartz, etc.
- **Refraction** (bending) of **light rays** as they pass **through lens** is responsible for the resultant **size** and **nature** of the **image**.
- Two **types** of lenses: **positive** and **negative**.



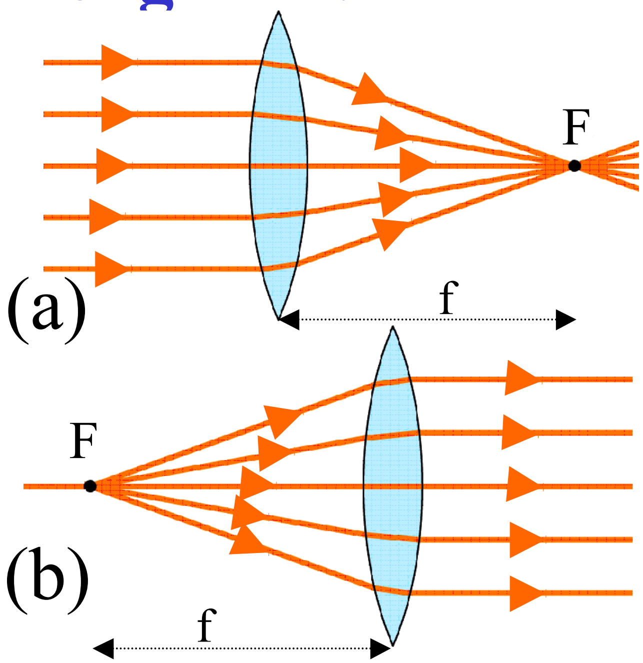
Positive lenses (convex):

- A positive lens causes the light rays to converge.
- Lens acts as a set of prisms.
- Prism angle larger at top of lens.



- Light at top of lens is bent more than light passing through it near the middle of the lens.
- Parallel rays are brought to a single point 'F' called the "**focal point**".

- Distance from **center** of **lens** to **focal point** is called **focal length 'f'**.



- **Focal length** is a **property** of an individual **lens** and depends on its **curvature** and **index of refraction**.
- There are **two focal points**, one on either side of the lens.
- **Light** is **reversible**:
  (a) **Parallel light** brought to a **focus**.
  (b) **Point light** at **focal point** creates a **parallel beam** of light (flash light).

Negative Lens (concave):

- Acts like a set of **upside down prisms bending** light **away** from the optic axis.
- **Diverging rays** appear to **come** from a **common focal point** to the left of lens.

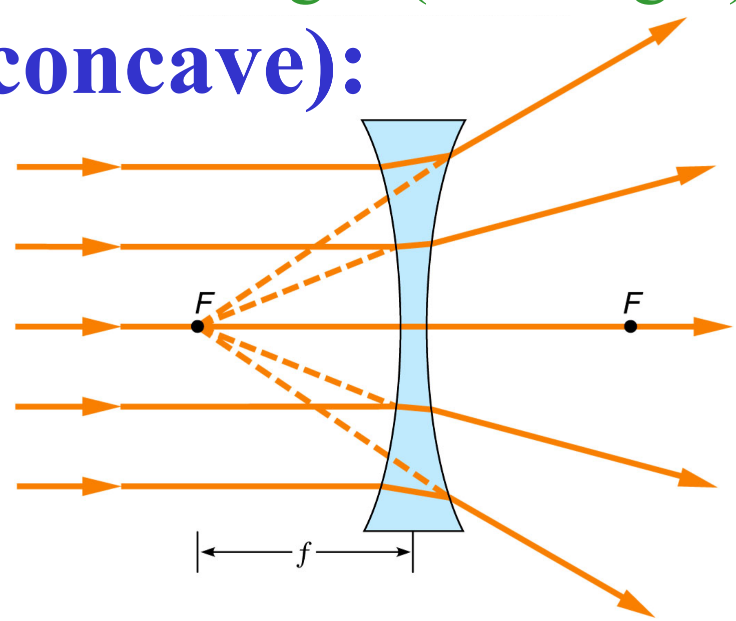
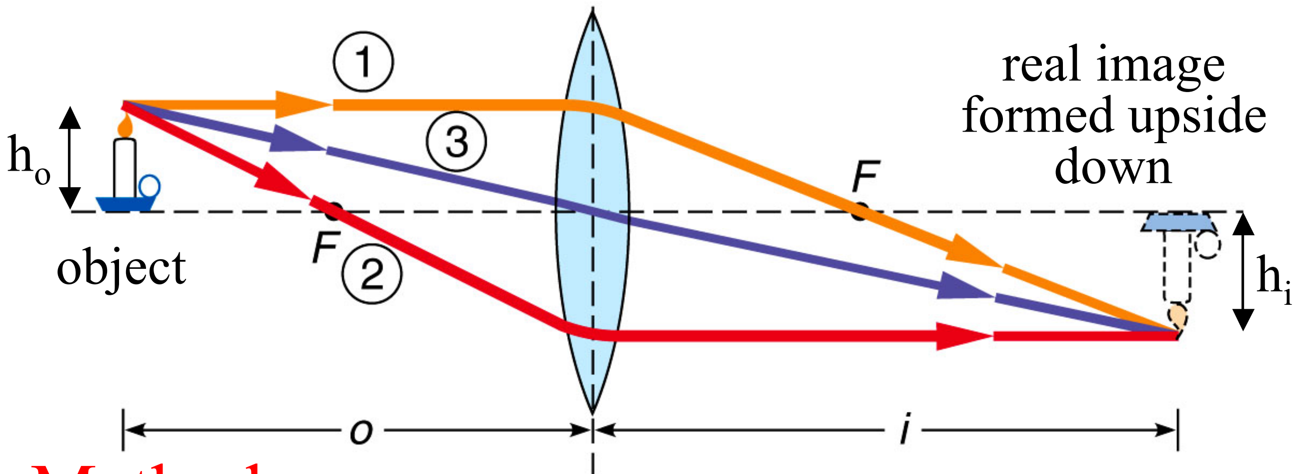


Image Formation Using Ray Tracing

- Simple ray tracing techniques can be used to tell us the position and size of the image formed by different lenses.

Example: (Convex lens)



Forms:

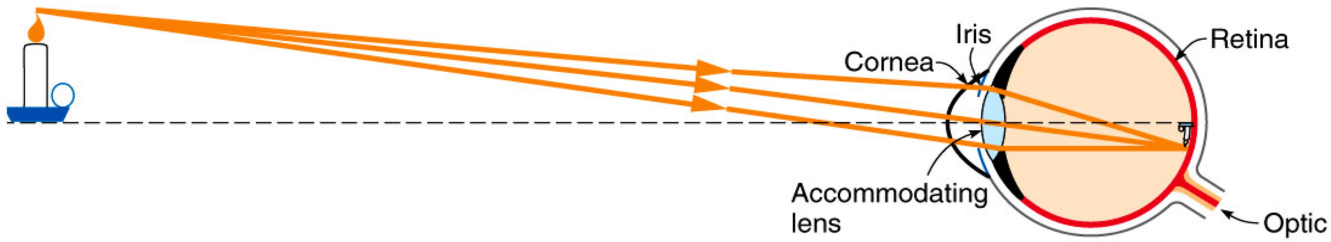
An **inverted real image** on the **opposite** side of lens.

Method:

1. Draw a ray from top of object parallel to axis and then bend it so it passes through focal point.
2. Draw a ray passing through the focal point on the object (near) side and then make it emerge from lens parallel to axis.
3. Draw a ray from top of object passing straight through the center of the lens (undeviated).

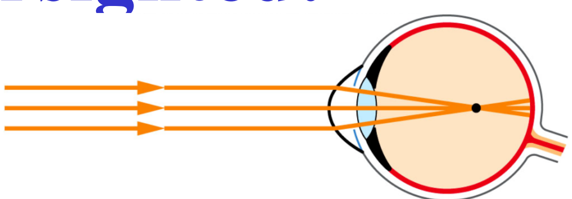
Eye Sight

- The **eye** contains **two positive lenses** (cornea) and accommodating lens.

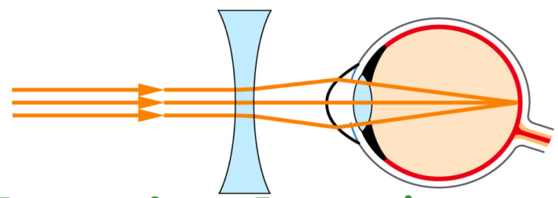


- A **real, inverted, minified** image is formed.

Nearsighted:

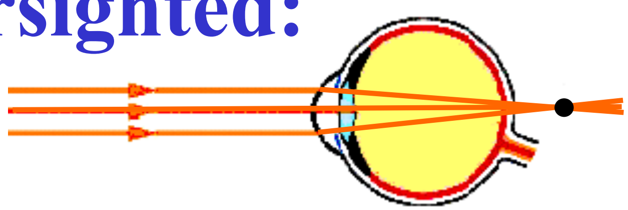


Parallel light focuses **in front** of retina

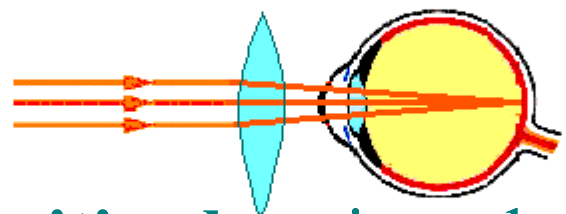


Negative lens introduces **divergence** to correct focus.

Farsighted:



Parallel light focuses **behind** retina



Positive lens introduces **convergence** to correct focus.