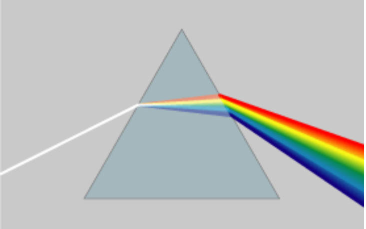
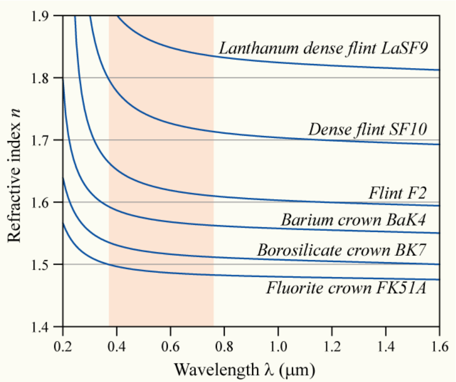
Dispersion (23.5)



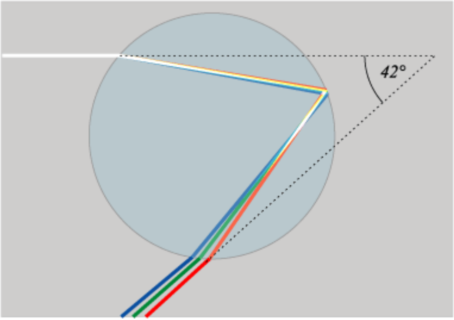
- The speed of light in a material depends on its wavelength
- White light is a mixture of wavelengths and colours.
- Different colours refract at different angles when a ray of white light crosses a boundary between two transparent media.
- Thus the colours are separated.
- Notice that blue light is bent more than red.

Dispersion



- The index of refraction in most materials is larger at lower wavelengths. The shaded region is visible light.
- Short wavelength light travels more slowly in glass, water, etc.
- This effect is called dispersion and depends on the chemical composition of the material.

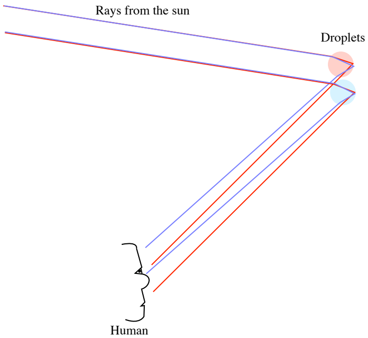
Rainbows



- Rainbows are caused by light refracting in water droplets in the air.
- White light from the sun enters a droplet and reflects off the back.
- When entering and leaving a droplet, the beam refracts and different colours leave the droplet going in different directions.
- Red light is bent leaves at a steeper downward angle than blue.

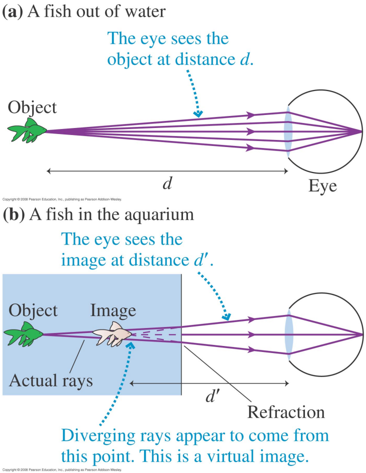
Rainbows

- When you look up in the sky with your back to the sun.
- Rays from the sun are reflected by all the droplets in the sky
- Some of the droplets reflect visible light to your eye.
- The droplets that reflect red light are higher than the ones that reflect blue because red light goes down at a steeper angle.



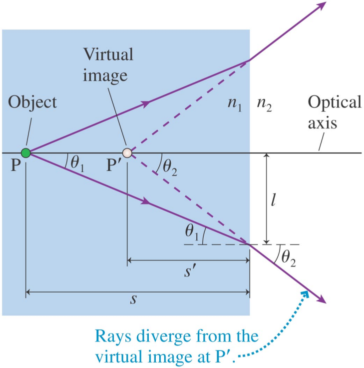
Rainbows

Image Formation by Refraction (23.4)



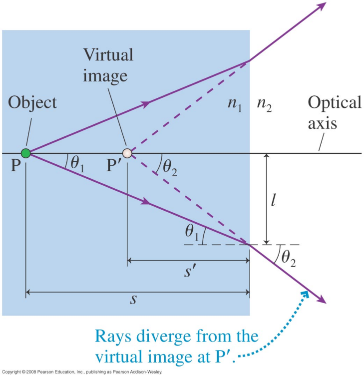
- Your brain determines how far away something is by how much the images in both eyes differ: parallax.
- However, your brain can be fooled! The fish on the left looks different when it is in water compared to when it is in air.
- In water the rays reflected from the fish refract at the air/water boundary.
- Water has a higher n than air, so the rays refract away from the normal and the projected rays converge in front of the actual position of the fish.
- We actually see a virtual image of the fish.

Image Formation by Refraction



- Analyzing the effect, for object P we see a virtual object P'.
- Distance s is called the object distance, s' is known as the image distance.
- A line perpendicular to the boundary is the optical axis
- Using two triangles with common side l we have $l = s \tan\theta_1 = s' \tan\theta_2$ and

$$s' = \frac{\tan\theta_1}{\tan\theta_2} s$$



- Remembering

$$s' = \frac{\tan\theta_1}{\tan\theta_2} s$$

- We can use Snell's Law

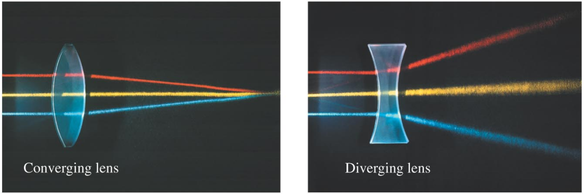
$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

- Angles are small and the rays nearly parallel (paraxial rays), so $\sin\theta \approx \theta \approx \tan\theta$:

$$\frac{\tan\theta_1}{\tan\theta_2} = \frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

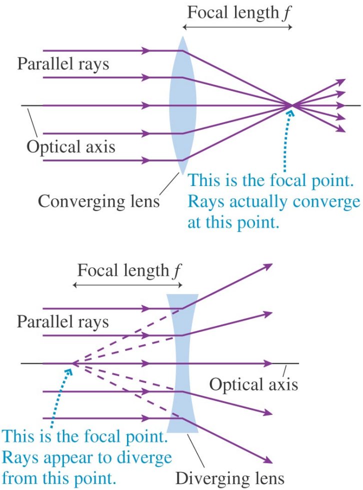
$$s' = \frac{n_2}{n_1} s$$

Thin Lenses: Ray Tracing (23.6)



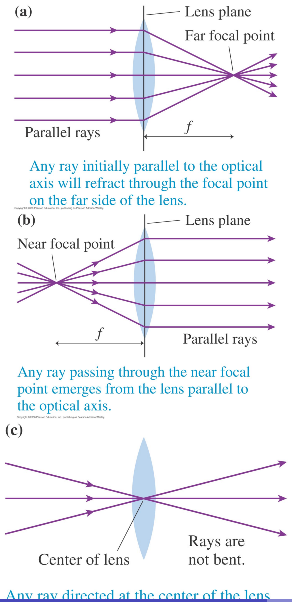
- A lens is a transparent material that uses refraction to form an image from diverging light rays.
- The geometrical method for understanding the effect of a given lens is known as ray tracing
- A converging lens causes parallel rays to refract toward the optical axis. A diverging lens causes parallel rays to refract away from the optical axis.

Thin Lenses: Ray Tracing

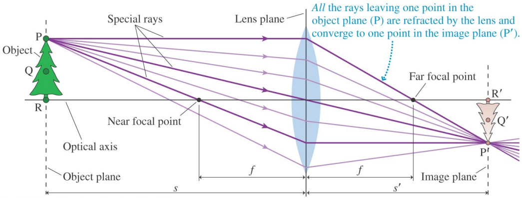


- For a converging lens the focal point of the lens is where all initially parallel rays meet. The focal length is the distance from the lens to this point.
- The focal point of a diverging lens is on the same side of the lens as the parallel rays.
- The focal length is a property of the lens.

Converging Lenses

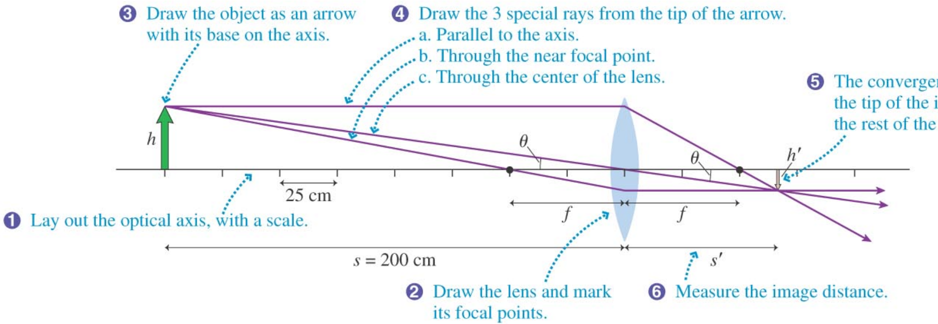


- We model our lenses as thin lenses - ignore their thickness. All refraction occurs as the rays pass the lens plane.
- The picture on the left shows three important types of rays to trace:
  1. Parallel rays converging at the focal point
  2. Rays from the focal point becoming parallel
  3. Rays passing through the center of the lens following a straight line
- You will become used to making use of these three special cases.



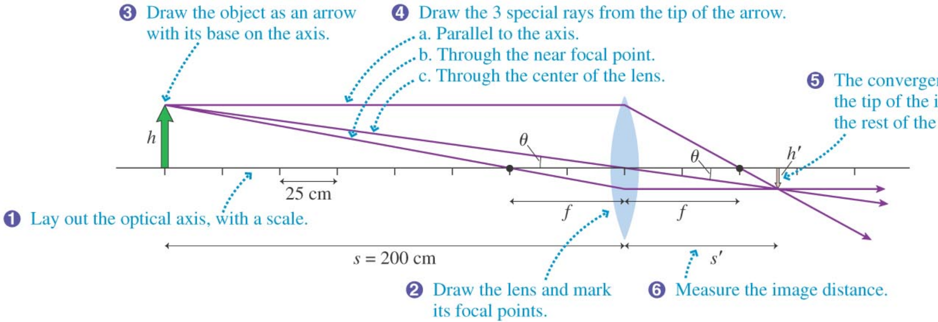
- If you place an object at a distance greater than the focal length away from a converging lens you will get a real image of the object on the other side of the lens.
- The real image is inverted and can be projected onto a screen.
- All points on an object which are in the same plane (the object plane) will have an image in the image plane.
- Rays strike the full lens surface. A bigger lens collects more light.
- The real image exists whether or not you put a screen there.

Ray Tracing Example



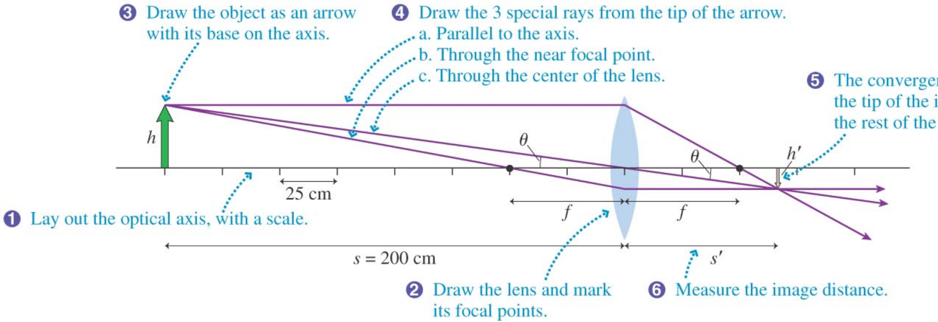
1. Draw and optical axis and center the lens on the axis
2. Represent the object with an arrow at distance s
3. Draw three "special" rays from the tip of the arrow: one parallel to the axis, one through the near focal point and one through the center of the lens.

Ray Tracing Example



4. Extend the rays until they converge
5. Measure the image distance s'

Ray Tracing Example

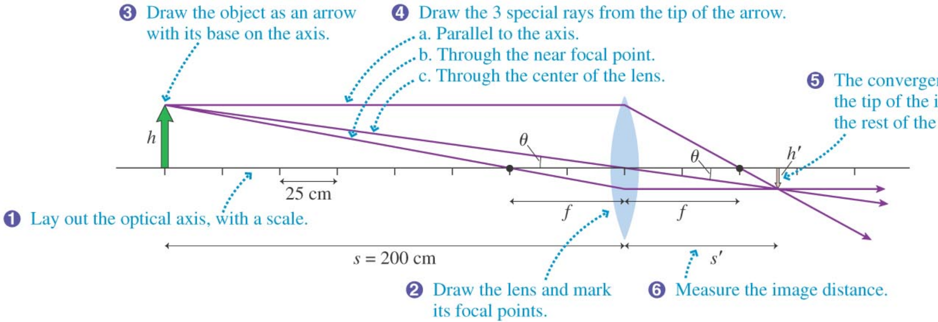


- From the geometry one can see that the following formula holds

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

- In our convention both s and s' are positive.
- and f is positive for a converging lens.

Ray Tracing Example

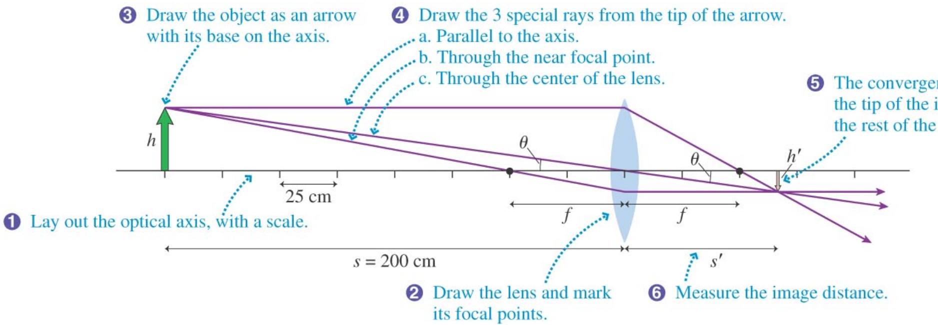


- In this case s = 200 cm and f = 50 cm

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

$$\frac{1}{200\text{ cm}} + \frac{1}{s'} = \frac{1}{50\text{ cm}}$$

Ray Tracing Example



$$\frac{1}{200\text{ cm}} + \frac{1}{s'} = \frac{1}{50\text{ cm}}$$

$$s' = \frac{200\text{ cm} \times 50\text{ cm}}{200\text{ cm} - 50\text{ cm}}$$

$= 66.7$ cm

Lateral Magnification

- Your textbook shows how the height of the image depends on the object and image distances:

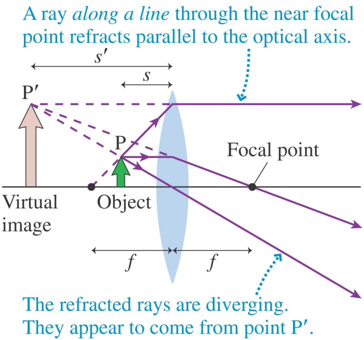
$$\frac{h'}{h} = \frac{s'}{s}$$

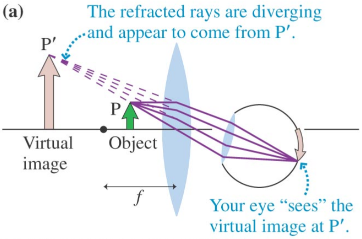
- We can then define the lateral magnification as

$$m = -\frac{s'}{s}$$

- A positive m indicates the image is upright, negative indicates inverted.
- The absolute value of m gives the ratio of the image height to the object height (hence the word “magnification”).

Virtual Images





- What happens if you put an object inside the focal length of the lens??
- You still get an image of the object but it is a virtual image
- The line through the near focal point must be projected back to reach that focal point.
- The rays diverge on the far side of the lens. Project all three back to see an enlarged upright image behind the lens.
- You have built a magnifying glass!!
- The image distance (s') for a virtual image is negative, making $m = s'/s$ positive (upright image).