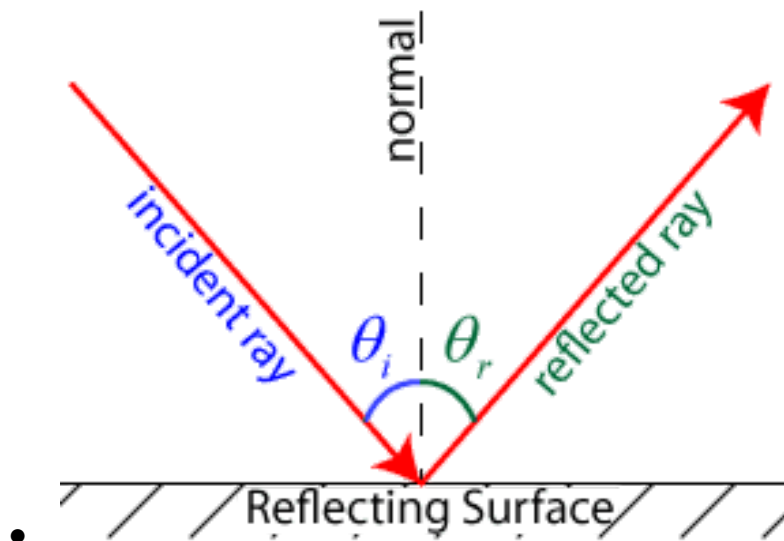


AP Physics 2 Unit 13:

Geometric Optics

13.1 Reflection

- Reflection is exactly as the name sounds, it reflects something
 - Let's go over some quick vocabulary:
 - **Surface Boundary**
 - The line where the material changes
 - **Normal Line**
 - Normal Line is the line that is perpendicular to the surface boundary
 - **Incident beam**
 - The incident beam, or anything with the word incident beam, is essentially what the heck the original beam is
 - **Incident Medium**
 - The original medium, the one that light goes through first
 - **Reflected beam**
 - The beam that hits the surface boundary is reflected
 - **Angle of incidence (θ_i)**
 - Original angle that the incident beam makes with the normal
 - **Angle of reflection (θ_r)**
 - The angle that the reflected beam makes with the normal



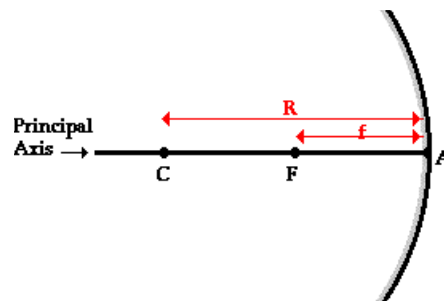
● Source: [Awesome Sauce](#)

- θ_i = Angle of Incidence

- θ_r = Angle of reflection
 - All angles from now on are the result between the rays and the normal line, NOT BETWEEN THE RAYS AND THE SURFACE
- **Law of reflection**
 - $\theta_1 = \theta_2$
 - θ_1 = Angle of Incidence
 - θ_2 = Angle of Reflection

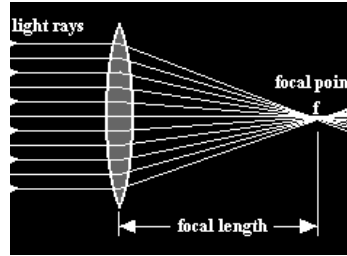
13.2 Images Formed by Mirrors

- **What do mirrors and lenses do?**
 - Mirrors and lenses change the direction of light, but do so in a way that can change the image we see.
 - Curved mirrors and lenses can make the image of the reflected object get bigger, smaller, or flip it.
 - We use a few words to describe mirrors and lenses:
 - The principal axis is an imaginary line perpendicular to the middle of the mirror or lens.
 - The vertex (A) is where the principal axis touches the mirror or lens.



Source: [Wordpress](#)

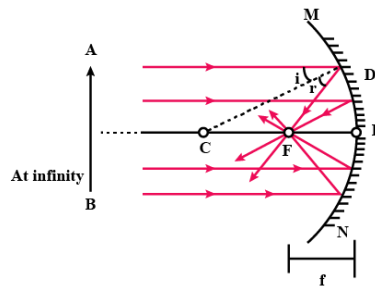
- Every curved mirror or lens will focus light on a specific point.
 - The focal point (f) is the place where the light focuses to a single point.
 - The focal length is the distance from the lens or mirror to the focal point.
 - C, or the curvature of the mirror, is essentially just 2F (This is important for drawing diagrams later)



Source: [Czarina](#)

- **Real or Virtual**

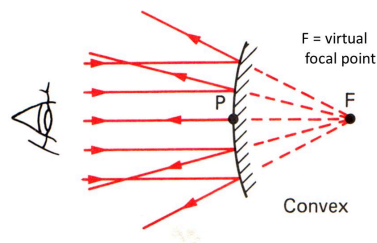
- We call something optically real if it happens in light we can see, or virtual if it does not.
 - In the mirror below, the light gets focused to a single point. This is a real focal point.



Source: [byjus](#)

- In the second mirror, the light gets spread out, but we can imagine where they would come together if they went behind the mirror.
 - This is a virtual focal point.

Reflection off a **convex** mirror



Source: [byjus](#)

- **Real images**

- If the image is real, it can be projected onto a screen.
- That is because there is light where the image is.
 - Real images are always inverted (upside down).

- **Virtual images**

- If the image is virtual, there is no light where the image is, so it doesn't exist.

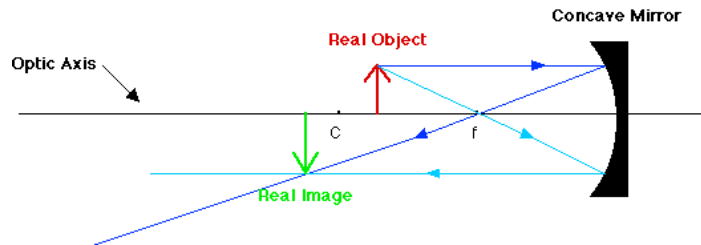
- Virtual images are never inverted; they are always upright.

- **Flat Mirror**

- The image in a flat mirror is always virtual.
- It appears you are behind the mirror, but you know there is no light behind it.

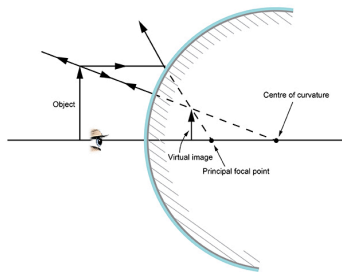
- **Curved Mirrors**

- In mirrors, real images are always in front of the mirror



Source: [Careers 360](#)

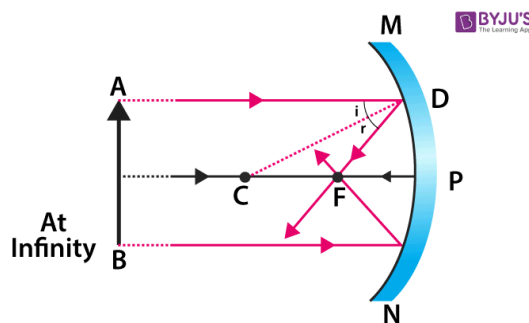
- Virtual images are behind the mirror.



Source: [Mammoth Memory](#)

- **For Curved mirrors, mirrors can either be concave or convex**

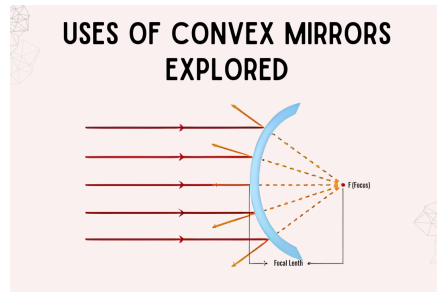
- **Concave mirrors** are like looking at the inside of a sphere.
 - Think like a cave: Concave means the mirror is being CAVED IN!



Source: [BYJU](#)

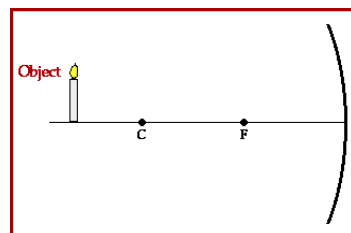
- These concave mirrors are converging.
- The images by a concave mirror can be real or virtual
 - If the object is in front of the focal point, the resulting image will be behind the mirror, upright, and virtual

- If the object is behind the focal point but in front of the $2f$ point, the resulting image will be past the $2f$ point on the same side of the mirror, inverted, and real
- If the object is behind the $2f$ point, the resulting image will be between f and $2f$, same side of the mirror, inverted, and real
- Concave mirrors tend to magnify objects and make them look bigger
- **Convex mirrors** are like looking at the outside of a sphere.



Source: [Texas International](#)

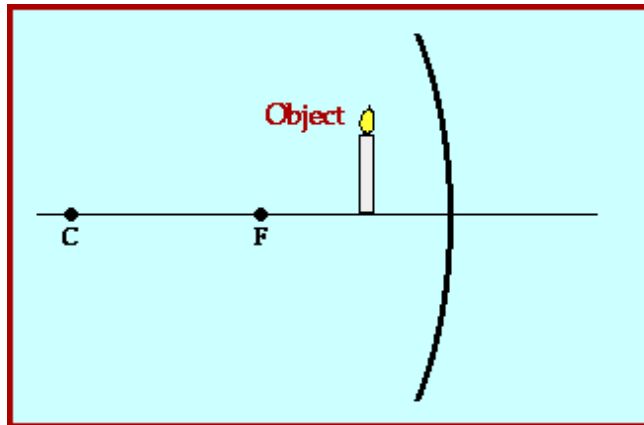
- Convex (aka diverging) mirrors are like looking at the outside of a sphere.
- They spread light out.
 - The focal points and images in convex mirrors are always virtual, no matter where the object is about the focal point.
 - The image will always be between the f and the mirror.
 - A convex mirror makes the objects appear farther away
 - The images created by a convex mirror are always virtual
- **Constructing an image used by a ray diagram**
 - We do this to find the image of the object
- **Concave Mirrors (Real)**
 - When the object is behind the focal point, it makes a real image
 - First, draw a line from the top of the object to the mirror, then from that point, draw a line angled straight to the focal point
 - Second, draw a line straight from the top of the object to the focal point, and keep going until you hit the mirror. From the mirror, draw a straight line
 - Where the lines meet is your real inverted image.



Source: [Study.com](#)

- **Concave Mirrors (Virtual)**

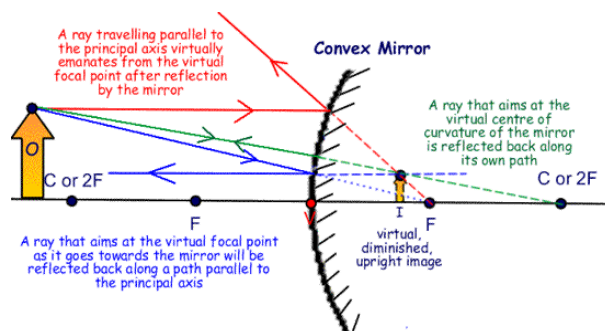
- When the object is in front of the focal point, it makes a virtual image
 - First, draw a line from the focal point to the top of the object to the mirror. Make that line straight past the mirror.
 - Next, draw a line from the top of the object straight to the mirror. Reflect that line to the focal point. That reflection should continue to be drawn.
 - The intersecting lines are the virtual upright mirror



Source: [Facebook](#)

- **Convex Mirrors**

- Convex mirrors are always virtual, so they will always be upright and virtual.
 - First, from the top of the object, draw a line straight forward; afterwards, draw a line angled towards the focal point.
 - Draw a line straight from the top of the object to the 2f point (curvature point)
 - Draw a line straight to the focal point, but stop at the mirror. At the mirror, draw a straight line.
 - Where the lines intersect is the virtual image



Source: [Univ of Alabama](#)

- Summary:

	Type	Shape	Object Location	Image Loc	Image type	Magnification
Mirrors	Converging	Concave	Past C (2f)	Between f and 2f	Real	Smaller
			Between f and C	Past 2f	Real	Larger
			Between f and mirror	Anywhere	Virtual	Larger
	Diverging	Convex	Anywhere	Between f and mirror	Virtual	Smaller

Source: Mr.Aghassi

- How to find the focal point

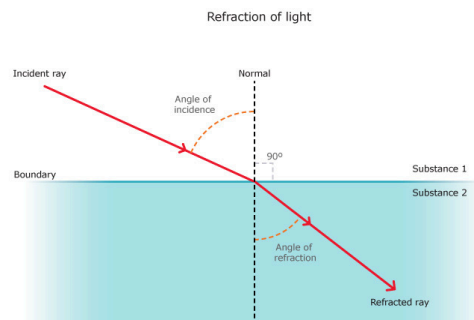
- $1/f = 1/d_i + 1/d_o$
 - f = Focal Point
 - d_i = Distance between the mirror and the image
 - d_o = Distance between the mirror and the object

- How to find magnification

- $M = h_i/h_o$
 - M = Magnification
 - h_i = Height of image
 - h_o = Height of object

13.3 Refraction

- Wave speed is always the same unless the medium changes
 - When waves move through different materials, the speed changes.
 - The speed changes are called refraction.
 - Refraction is when the wave slows down, causing its wavelength and speed to change.
 - At the same time, some of the energy is reflected.



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Source: [Super Prof](#)

- Light moves at speed C through space (3×10^8)
 - However, because of different media, light moves through different speeds

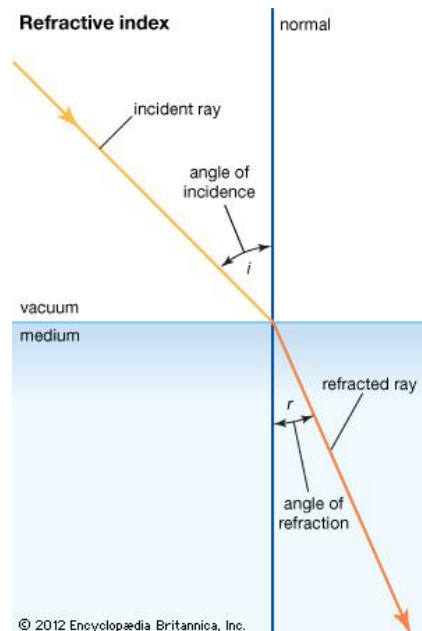
- How much an object refracts is because of its index of refraction
 - This is marked by symbol n
 - The slower the light moves in a material, the higher the index of refraction
 - ★ Air has the lowest index (1)
 - ★ Diamond has the highest index (2.4)
- How to calculate the index of refraction

$$n = \frac{c}{v}$$

index of refraction *velocity of light in vacuum*
velocity of light in the medium

Source: [Arun Joshi](#)

- n = Index of refraction
- c = velocity of light in vacuum (3×10^8)
- v = velocity of light in the medium
- Refracted Rays
 - When light moves from one material to another, the amount it bends depends on the difference in refractive indices between the two materials.
 - The bigger the difference, the more it bends.
 - Like the incident and reflected angle, in refraction, we also have the incident and refracted angles.
 - Both are angled to the normal line, NOT THE SURFACE.



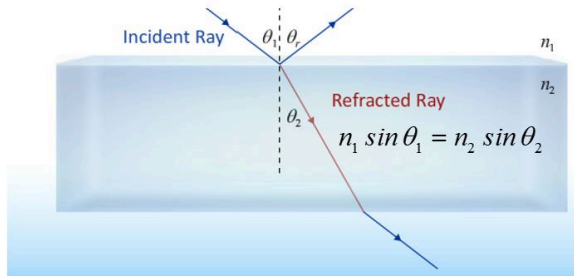
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Source: [Britannica](#)

- The light beam will always be closer to parallel to the surface in the material with the lower refractive index.
- The light beam will always be closer to perpendicular to the surface in the material with the higher refractive index.

■ This is only for vertical incident rays

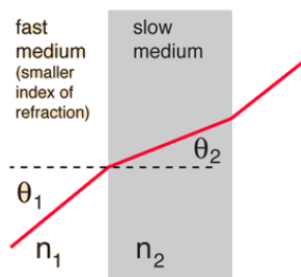
- **This is marked by Snell's Law**



Source: [Oregon State](#)

- n_1 = Index of refraction for material 1
 - n_2 = Index of refraction for material 2
 - $\sin\theta_1$ = Sin of the incident ray
 - $\sin\theta_2$ = Sin of the refracted ray
- This makes sense because the bigger the index of refraction, the smaller the angle between the refracted ray and the normal line is.

- **So what happens when we have a horizontal incident ray?**



Source: [Punch List](#)

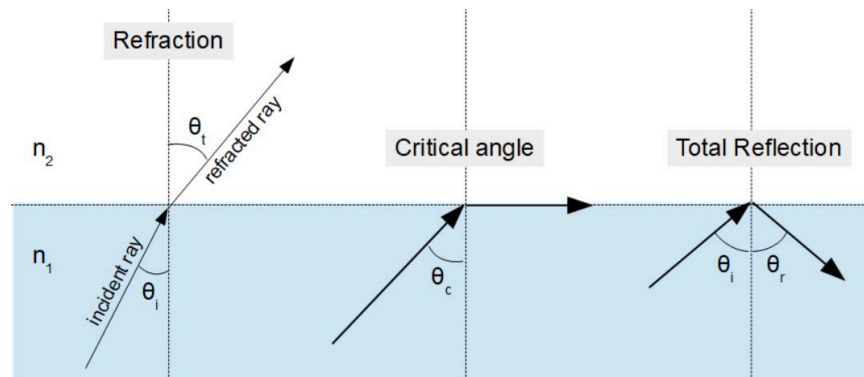
- Now the angles of refraction and incidence are between the normal line, but the normal line is now horizontal.
- Very important to note

- **Total Internal Reflection**

- When light is moving from a slow medium (like water) into a fast medium at a large angle, almost all of the light is reflected, and it stays in the slow medium.
- We use this in our communication technologies to communicate using light beams confined to fiber optic (glass) cables. This

communication works significantly faster than electricity and is the basis for the internet.

- **Total internal reflection** happens when light is going from a higher index medium to a lower index one at an angle higher than the critical angle.
 - Think about it this way:
 - Due to Snell's Law, we know that the bigger the θ_1 , the smaller the θ_2 .
 - However, there has to be a point where θ_1 gets big enough that it makes θ_2 zero.
 - This θ_1 is called the critical angle.



Source: [Vcalc](#)

- We can solve this critical angle as

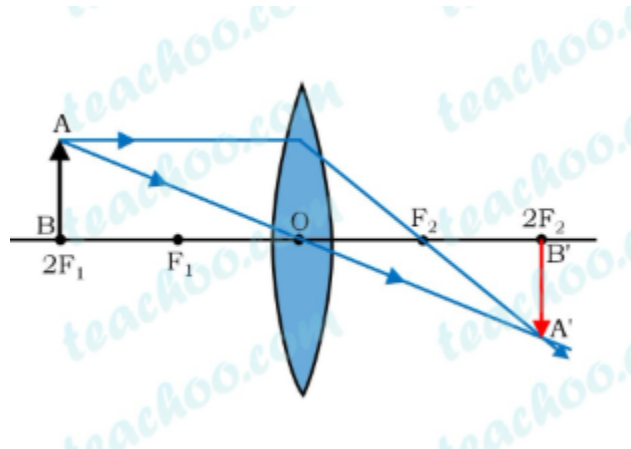
$$\sin \theta_c = \frac{n_2}{n_1}$$
$$(n_1 > n_2)$$

- Where $\sin \theta_c$ is the sin of the critical angle
- n_2 is the fast medium's index of refraction
- n_1 is the slow medium's index of refraction
 - Total reflection happens at the exact moment that our θ_1 is bigger than the critical angle.
 - Total reflection is the same as regular reflection mathematically

13.4 Images Formed by Lenses

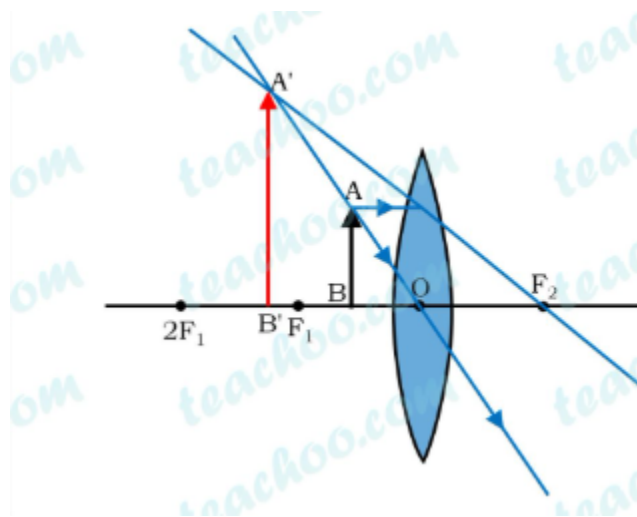
- The difference between mirrors and lenses is that mirrors use reflection, and lenses use refraction.

- In lenses, light goes through the lens, so real images are behind the lens, and virtual images are in front.
- Example of a real image down below for the lenses



Source: [Scipitutor](#)

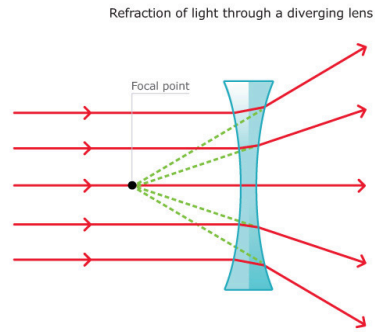
- Example of a virtual image down below for the lenses



Source: [Scipitutor](#)

● Concave Lenses

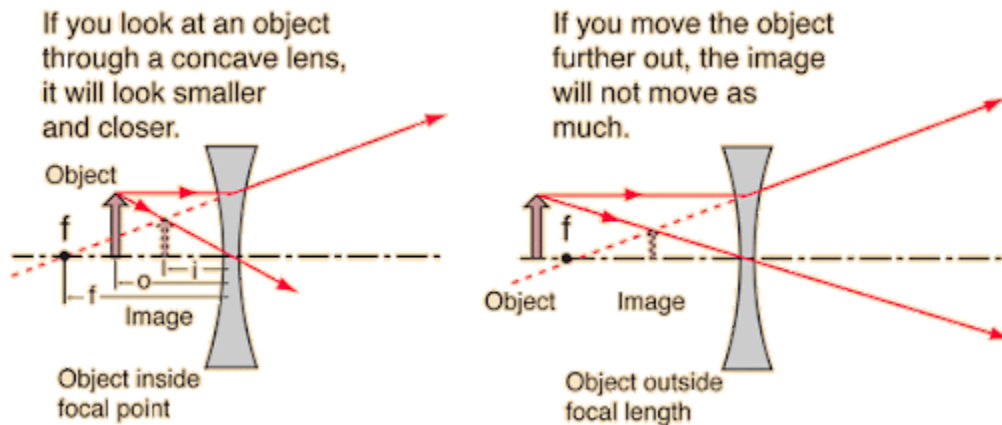
- Concave Lenses (Diverging) have the same shape as concave mirrors, but do the opposite.
 - Instead of causing light to converge on a single point, they cause light to spread out and diverge.
 - These lenses have a virtual focal point in front of the lens and tend to make virtual images in front of the lens.
- **The images are all virtual (Like convex mirrors!)**



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Source: [Fine Art America](#)

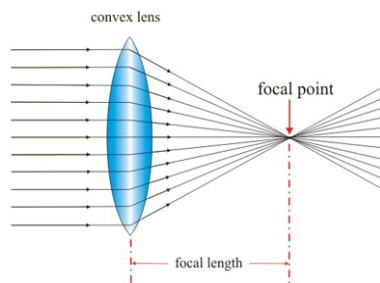
- For concave lenses, it doesn't matter where the object is.
 - No matter what, it will create an image that is virtual and upright on the side of the object



Source: [Quia Web](#)

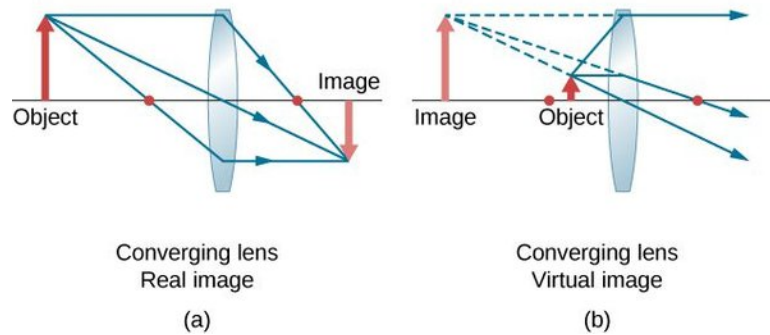
● Convex Lenses (Converging)

- Convex lenses have the same shape as convex mirrors, but they do the opposite.
 - Instead of causing light to diverge and spread out, they cause light to focus on a single point.
- They have a real focus point where they focus light, and they can create a real or virtual image.



Source: [Study Rankers](#)

- If the object is in front of the focal point, it creates a giant virtual image behind the object.
- If the object is between the focal point and the $2f$ point, it creates a real, larger image that's past $2f$
- If the object is past the $2f$ point, it creates an inverted real smaller image between f and $2f$.



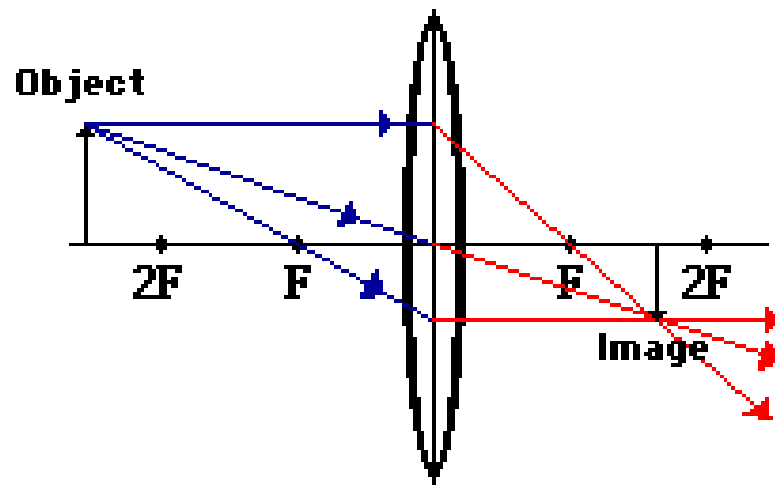
Source: [Florida State](#)

- **Ray Diagrams for Convex Lenses**

- These can be real or virtual

- **Convex diagram (Real)**

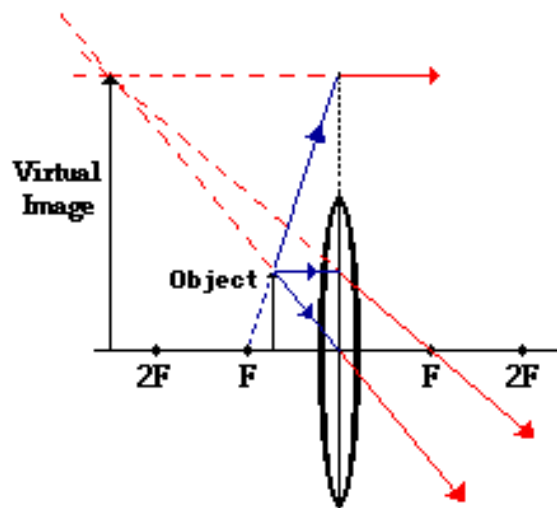
- These look like concave mirrors, but instead of bouncing off, they go through the lens.
 - When the object is behind the focal point, it creates a real inverted image.
 - First, draw a line from the top of the object straight to the lens. Then, angle the line to the focal point.
 - Second line, draw a line from the top of the object straight to the middle of the lens and keep going.
 - Third line, draw a line from the top of the object to the focal point on the same side as the object. Once you hit the lens, draw the line straight.
 - Where the 3 lines intersect is your real inverted image.



Source: [Manojsir](#)

- **Convex Diagram (Virtual)**

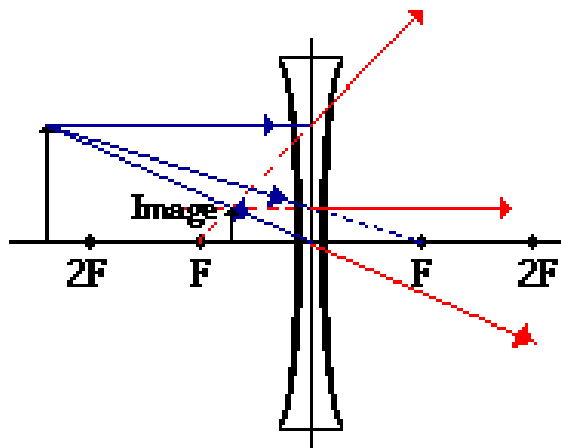
- This happens when the object is in front of the focal point
 - First, draw a line straight to the lens, then angle it to the focal point. That line is then continued to the same side as the object
 - The second line should be directly angled to the middle line of the lens. Again, that line should be drawn straight back to the same side as the object
 - Finally, the third line should be drawn from the focal point to the top of the object. Keep drawing that line until it hits the vertical line of the lens. After that, draw it straight
 - Where you're three lines meet is the virtual image



Ray Diagram for Object Located in Front of F

Source: [Univ of Louisville](#)

- **Ray Diagrams for Concave Lens (Always virtual)**
 - First, draw a line from the top of the object to the middle of the lens.
 - The second line should go straight from the top of the object to the other side's focal point. Once it hits the lens, draw it straight back.
 - The third line should go straight from the top of the object to the lens. Then another line from the focal point should go straight to the third line, where it hits the mirror.
 - Where all three lines intersect is the virtual image.



Source: [Univ of Louisville](#)

- **Quick Summary**

Lenses	Converging	Convex	Past 2f	Between f and 2f	Real	Smaller
			Between f and 2f	Past 2f	Real	Larger
			Between f and lens	Anywhere	Virtual	Larger
	Diverging	Concave	Anywhere	Between f and lens	Virtual	Smaller

Key Equations

- **Law of reflection**
 - $\theta_1 = \theta_2$
 - θ_1 = Angle of Incidence
 - θ_2 = Angle of Reflection
- **How to find the focal point**
 - $1/f = 1/d_i + 1/d_o$
 - f = Focal Point
 - d_i = Distance between the mirror and the image
 - d_o = Distance between the mirror and the object
- **How to find the magnification**

- $M = h_i/h_o$
- M = Magnification
- h_i = Height of image
- h_o = Height of object

- **Index of Refraction calculation**

$$n = \frac{c}{v}$$

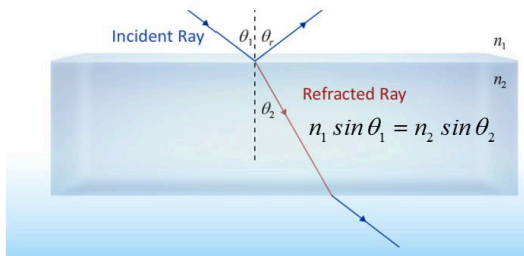
index of refraction

velocity of light in vacuum

velocity of light in the medium

- n = Index of refraction
- c = velocity of light in vacuum (3×10^8)
- v = velocity of light in the medium

- **Snells Law**



- n_1 = Index of refraction for material 1
- n_2 = Index of refraction for material 2
- $\sin \theta_1$ = Sin of the incident ray
- $\sin \theta_2$ = Sin of the refracted ray

- **Critical Angle for total internal reflection**

$$\sin \theta_c = \frac{n_2}{n_1}$$

$$(n_1 > n_2)$$

- Where $\sin \theta_c$ is the sin of the critical angle
- n_2 is the fast medium's index of refraction
- n_1 is the slow medium's index of refraction

- **Mirror and Lenses Review**

	Type	Shape	Object Location	Image Loc	Image type	Magnification
Mirrors	Converging	Concave	Past C ($2f$)	Between f and $2f$	Real	Smaller
			Between f and C	Past $2f$	Real	Larger
			Between f and mirror	Anywhere	Virtual	Larger
	Diverging	Convex	Anywhere	Between f and mirror	Virtual	Smaller
Lenses	Converging	Convex	Past $2f$	Between f and $2f$	Real	Smaller
			Between f and $2f$	Past $2f$	Real	Larger
			Between f and the lens	Anywhere	Virtual	Larger
	Diverging	Concave	Anywhere	Between f and the lens	Virtual	Smaller