

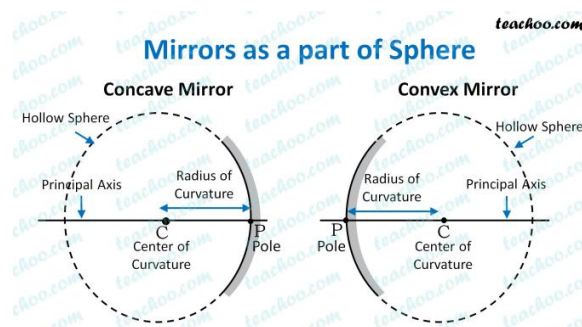
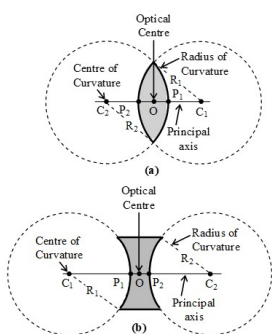
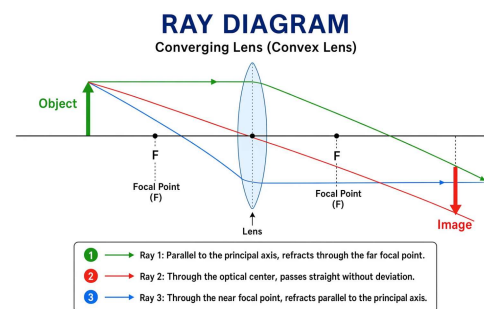
Ray Tracing for Astronomy

Terms to note:

- **Ray tracing:** Computing the path of light through a system of refracting or reflecting surfaces.
 - In our case, through telescopes and eyepieces.
 - Full ray tracing has many beams, including off-axis beams, to show the performance of the system. For this demo, I'm using simplified 3-ray traces and demos.
- **Rays** - A single light beam that interacts with the system.
- **Path** - The path a ray takes through the system.
- **Law of Reversibility** - Light follows the same path when its direction is reversed. The behavior of a light ray is consistent in either direction.

Trace Diagram Terminology:

- **Axis** - Center of the lens. On a normal convex or concave lens, this is the center of the round shape, like a hub of a wheel.
- **Center line** - The slice of the lens that bisects the side.
- **Center point** - Where the axis and center line intersect.
- **Focal point** - The location where the light from a distant object comes to a point. This is NOT the point where the image forms.
 - **Point F** is the focal point.
 - **Point 2F** is twice the distance from the focal point to the center point. This is also the center of the sphere defined by the lens's curvature.
 - **Point C** is the center of the lens's curvature. (Not always shown.)
- **Parallel ray** - A light ray that runs parallel to the axis of the lens.
- **Chief ray** - A light ray that passes through the center point of the lens.
- **Focal ray** - A light ray that passes through the focal point of the lens.
- **Focal length** - The distance from the center line to the focal point. This is not where the image forms, but where all rays converge to a point.
- **Image plane** - A plane that extends parallel to the centerline, fixed at the point where the parallel rays, chief rays, and focal rays meet.
- **Image orientation** - As the rays pass through a system, the image is modified:
 - **Inverted** - An even number of element groups will invert the image. Newtonian telescopes produce an inverted image thanks to the two mirrors.
 - **Reversed (left-right)** - An odd number of element groups will reverse the image. A refractor with a 90° diagonal produces an image that is upright, but reversed, just like your
 - **Both Inverted and Reversed** - A refractor or finder scope without the diagonal shows an image that is both inverted and reversed.
 - **Correct(ed)** - Binoculars, spotting scopes, 45° diagonals, and Amici prism diagonals have correcting optics that give a corrected upright, not reversed, image. Celestron also makes a 20mm eyepiece with a prism to give you a corrected image.
 - Celestron explains image orientation: <https://www.youtube.com/watch?v=D03oxOu1EQw>



<https://cbselibrary.com/types-of-spherical-lenses/>

<https://www.teachoo.com/10825/3118/Parts-of-Concave-and-Convex-Mirror/category/Concepts/>

Sample Diagrams- Converging (Convex) Lens & Focal Length

<https://conceptviz.app/tools/ray-diagram-generator>

I'll keep the object distance set at 30 cm and the object size at 6 cm for this set and only change the focal length to show how the focal length of the lens affects the image.

Focal length = 10 cm

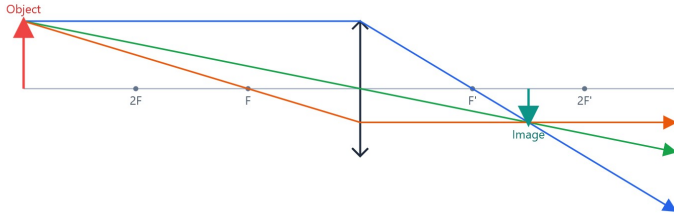


Image distance = 15 cm Magnification = 0.5x Real, inverted, reduced

Focal length = 15 cm

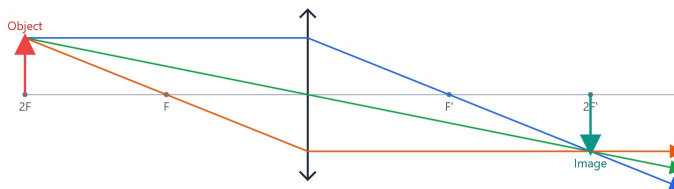


Image distance = 30 cm Magnification = 1x Real, inverted, same size

Focal length = 20 cm

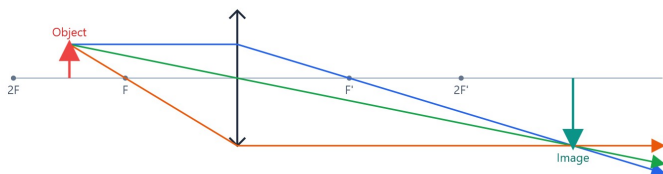


Image distance = 60 cm Magnification = 2x Real, inverted, magnified.

Focal length = 25 cm

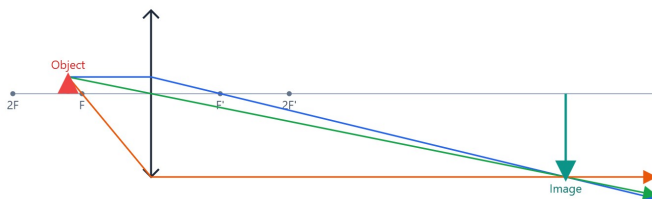


Image distance = 150 cm Magnification = 5x Real inverted, magnified

Converging (concave mirrors)

Like convex lenses, concave mirrors create a real image at the same distances as convex lenses, except that the mirror reflects while the lens refracts. Without a secondary mirror or a tilted primary mirror, your head would be in the way if you tried to see the object.

Focal length = 10 cm

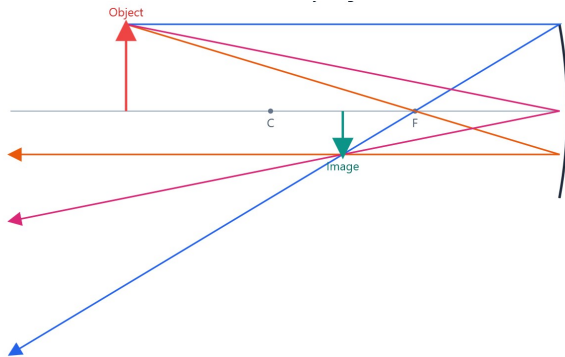


Image distance = 15 cm Magnification = 0.5x Real, inverted, reduced

Focal length = 15 cm

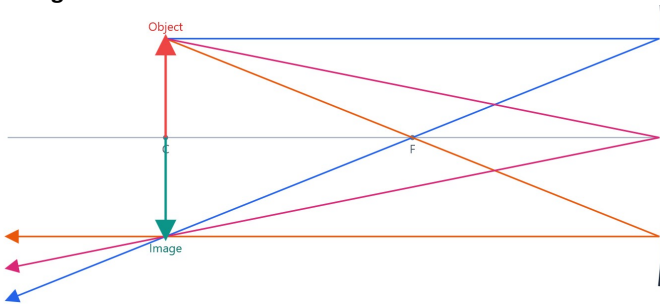


Image distance = 30cm Magnification = 1x real, inverted, same size

Focal length = 20cm

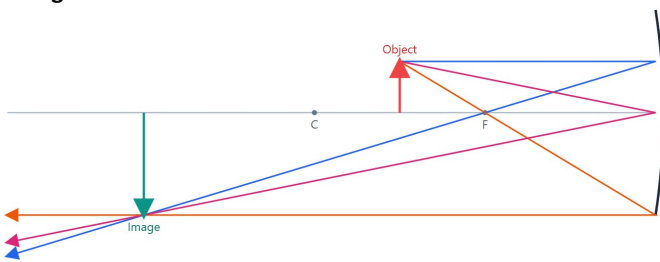


Image distance = 60cm Magnification = 2x Real, inverted, magnified

Focal length = 25

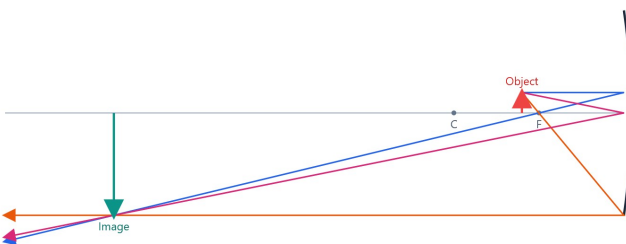


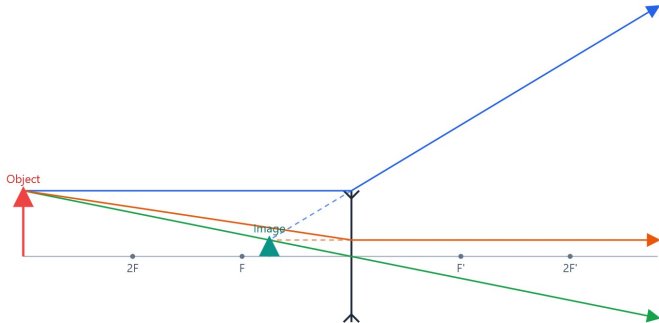
Image distance = 150 cm Magnification = 5x Real, inverted, magnified.

NOTE: If a converging mirror and a converging lens share the same focal length, they represent the same curvature (portion of a sphere) and therefore have the same magnification and image distance!

Diverging (Concave) Lens

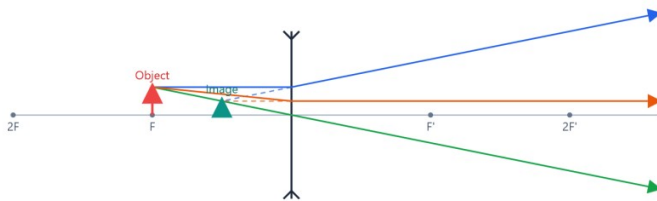
Note that the “image” as defined by the rays meeting is on the same side of the lens as the object and cannot be seen. It is therefore virtual.

Focal length = 10 cm



Virtual image distance = 7.5 cm Magnification 0.25x Virtual, upright, reduced.

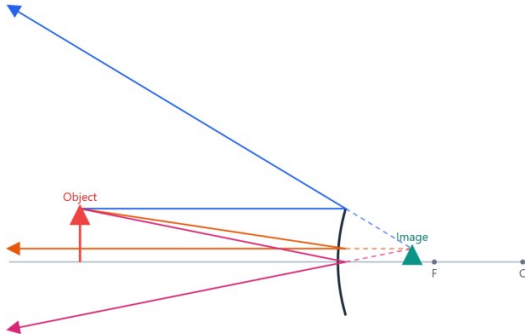
Focal Length = 30 cm



Virtual image distance = 15cm Magnification = 0.5x
With this calculator, you never reach 1x magnification.

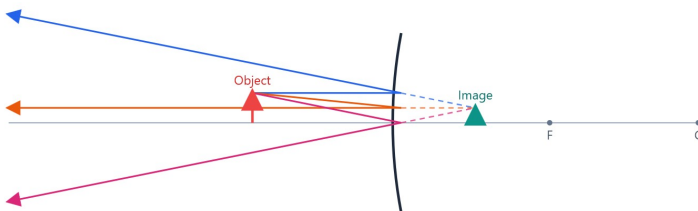
Diverging (Convex Mirror)

Focal length = 10 cm



Virtual image distance = 7.5 Magnification 0.25x Virtual, upright, reduced.

Focal length = 30 cm



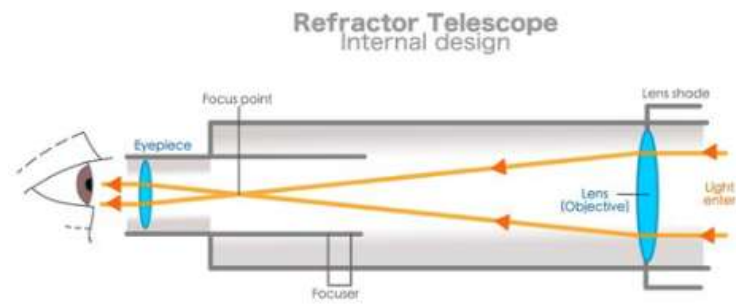
Virtual image distance = 15 cm Magnification = 0.5x Virtual, upright, reduced.

Again, the diverging mirror and lens share the same characteristics of magnification.

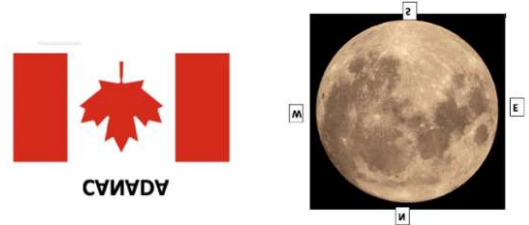
Telescope Tracing

Images <https://nseaa.ca/wp-content/uploads/2026/02/telescope-optical-design-and-how-the-viewed-image-appears.pdf>

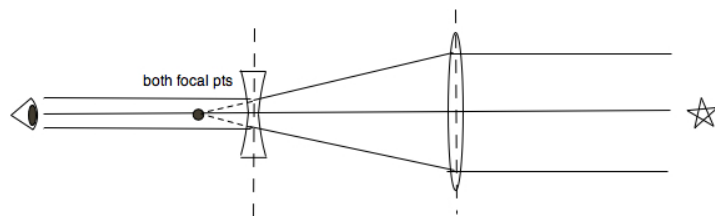
Basic Refractor - 2 lenses, Inverted



Basic Refractor Inverted (upside down)



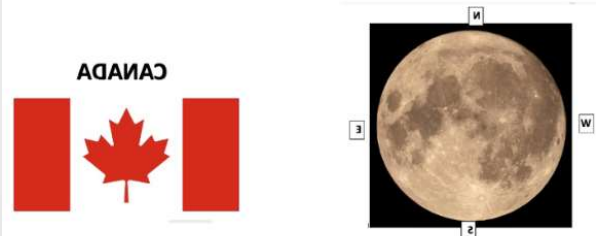
Galileo's telescope (diverging eyepiece lens)



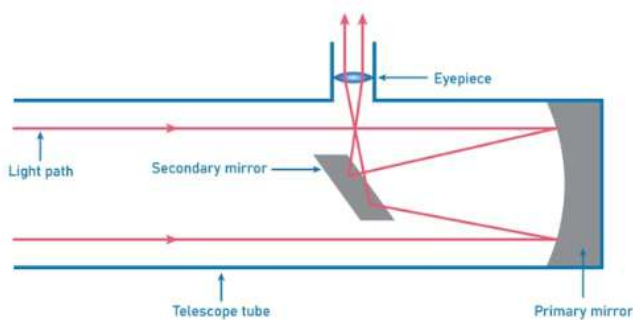
Refractor + Diagonal - 2 lenses + 1 mirror, upright, but mirrored



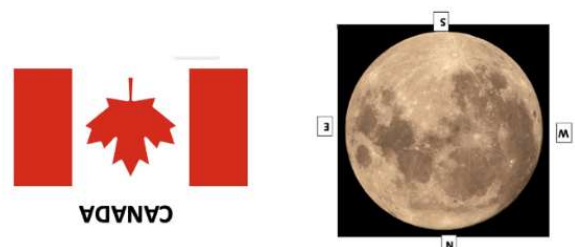
Refractor and Diagonal Upright but mirrored



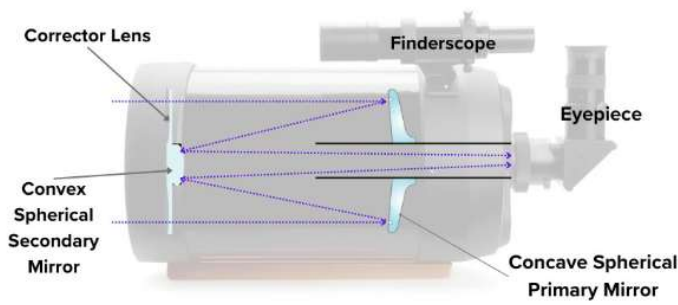
Newtonian 2 mirrors, inverted



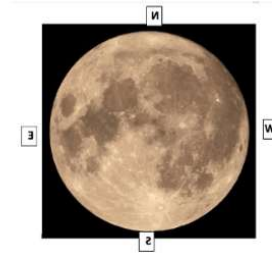
Newtonian Reflector Rotated 180 degrees



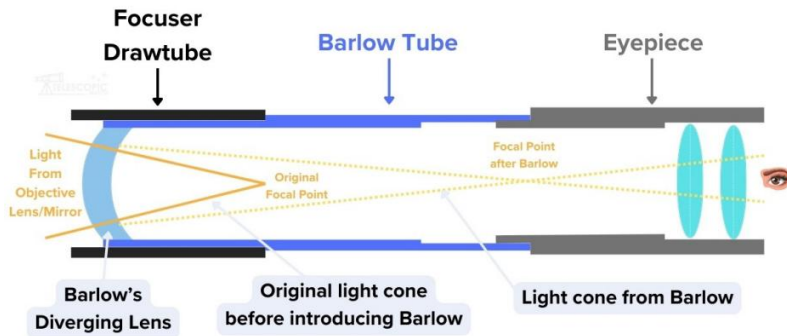
SCT - 1 lens + 2 mirrors, upright, mirrored



Schmidt-Cassegrain Upright but Mirrored



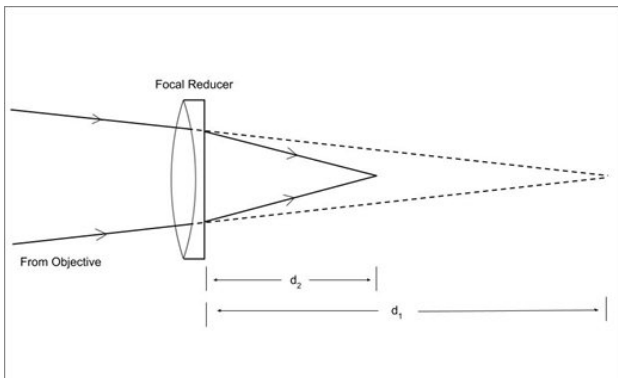
Barlow Lens



<https://telescopicwatch.com/how-to-use-barlow-lens/>

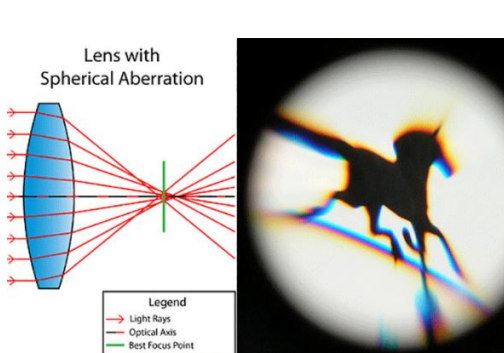
The Barlow lens extends the focal length, increasing magnification and decreasing the FOV.

Focal reducers

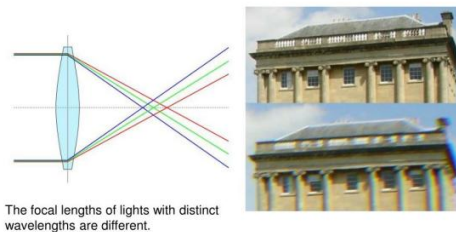


<https://agenaastro.com/articles/product-types/barlows-focal-extendors-and-reducers/focal-reducers-guide.html>

A focal reducer shortens the focal length with a diverging lens, decreasing magnification and increasing the FOV.



Chromatic Aberration



<https://www.allaboutvision.com/resources/human-interest/spherical-aberration/>

<https://www.slideserve.com/shilah/3-geometrical-optics>