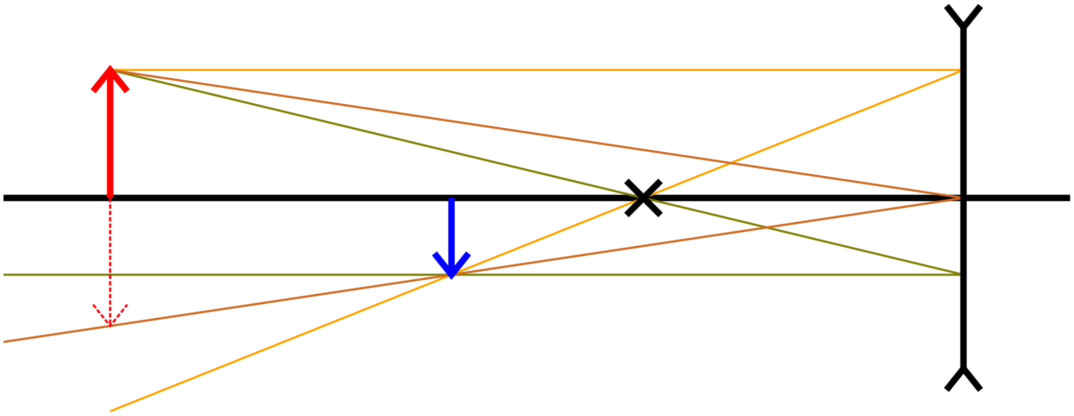
Ray Tracing to Find Where Images Will Form

When you make an image of an object with a lens or a mirror the object emits an infinite number of light rays in an infinite number of directions. But there are three special rays that you can draw to figure out where an image will form and how tall it will be (you get a fourth line for mirrors - lines through the center of curvature return to the center of curvature - but I will ignore this line in these examples). Three rays is just enough - it takes two rays tell you where the image forms, and one more to be sure that you didn't make a mistake. Below are some examples of how to use these special lines under various conditions.

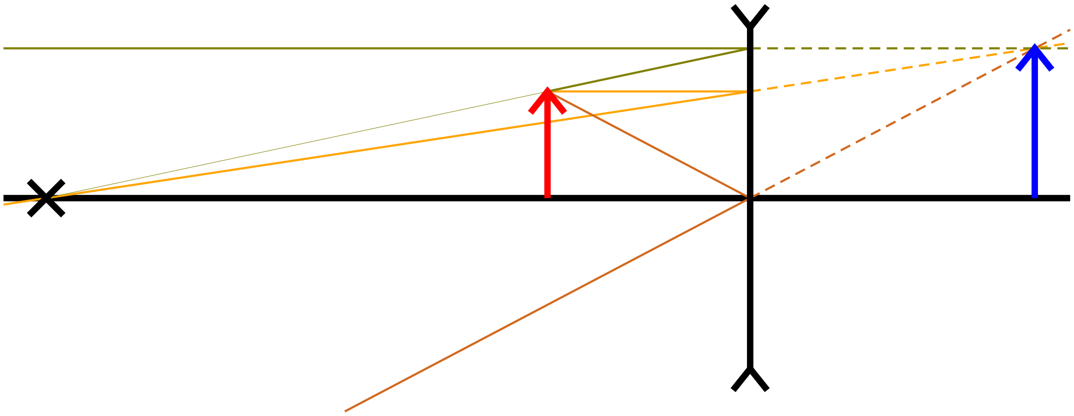
I. CONCAVE MIRROR MAKING A REAL IMAGE

A concave mirror has a positive focal length (i.e., it focuses collimated light). In the image below, the red arrow is the object. The orange line is a ray of light leaving the source traveling parallel to the optical axis. After striking the mirror, it travels a path that takes it through the mirror's focal point, marked with an x. The brown line strikes the mirror at it's center. Because the surface of the mirror is vertical at the center of the mirror, this ray reflects symmetrically about the optical axis. To draw this line accurately, we draw the object flipped upside down (shown as a dotted red arrow) and draw a line from the center of the mirror which passes through the tip of the inverted object. The green line passes through the focal point of the mirror, so when it reflects off of the mirror, it comes off parallel to the optical axis. All three of these lines cross at the position of the blue arrow. As such, the blue arrow represents the real image formed by the mirror.



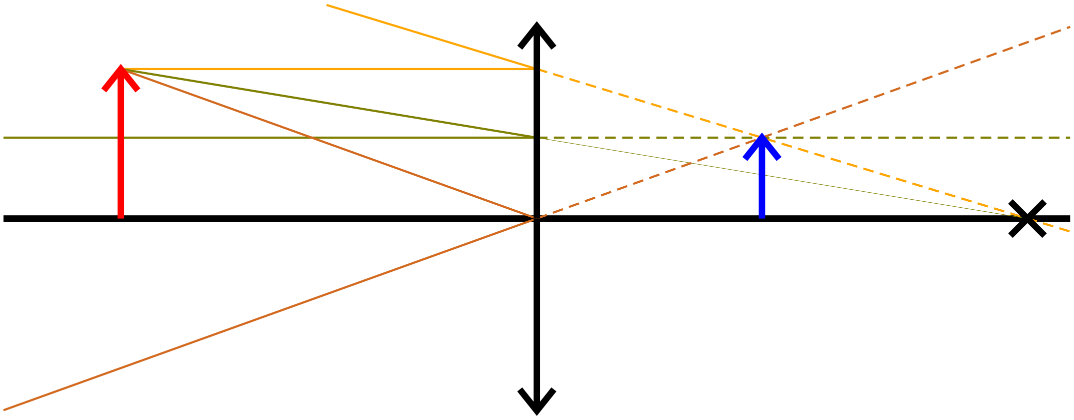
II. CONCAVE MIRROR MAKING A VIRTUAL IMAGE

In this case the lines do the same thing as in the example above, but with two subtle differences. First, because the object is between the mirror and its focal point, the green line doesn't travel from the object, through the focal point, and then to the mirror. Instead, it travels from the object as if it had come from the focus. Second, after reflecting off of the mirror, the three rays don't cross to form a real image. Instead, they diverge as if they were coming from a point behind the mirror. The dotted lines trace these rays backwards to show us where the light appears to be coming from. The dotted lines cross at the blue arrow, which represents the virtual image formed by the mirror.



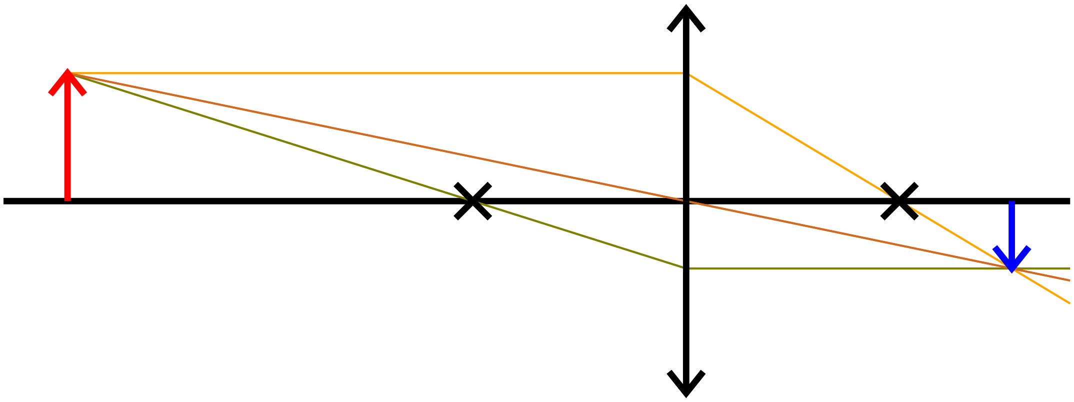
III. CONVEX MIRROR MAKING A VIRTUAL IMAGE

Below is an example of a convex mirror. A convex mirror has a negative focal length, and the focal point of the mirror is on the opposite side of the mirror. As before, the orange ray comes from the object traveling parallel to the optical axis. But instead of reflecting to go through the focal point, it reflects such that it appears to have come *from* the focal point. The green ray travels from the object toward the focal point . . . but it runs into the mirror before it gets there. This ray does what the orange one does but in reverse - it is traveling toward the focus, so when it reflects it travels parallel to the optical axis. The brown ray does just what it did in the two examples above. Again, the reflected rays do not converge to a point, but appear to be coming from a point. The dotted lines trace back to the virtual image where the light appears to be coming from, which is the point denoted by the blue arrow.



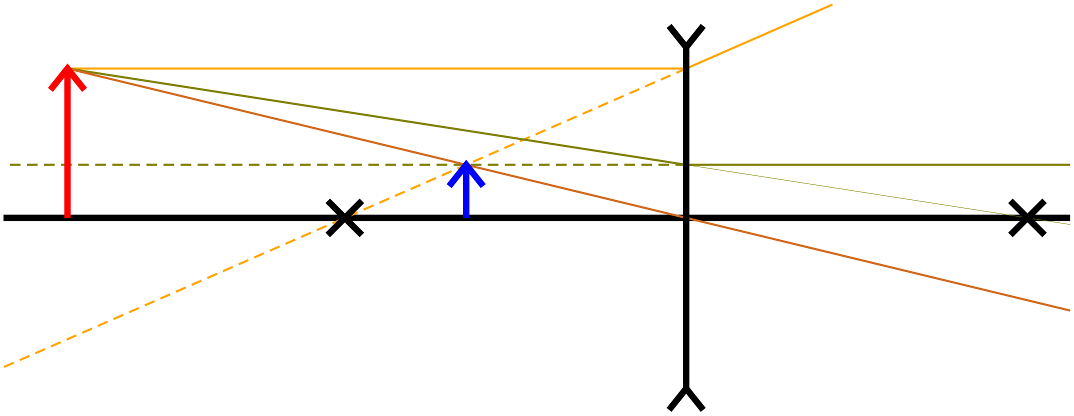
IV. CONVERGING LENS

Below is a ray diagram for a converging lens (i.e. one with a positive focal length). There are two focal points for lenses - one in front, and one behind the lens. For a converging lens, a ray traveling parallel to the optical axis bends and goes through the far focal point - this is shown with the orange line. A ray passing through the center of the lens is not deflected, passing straight on through. This is shown with the brown line. The green ray passes through the near focal point. As such, after going through the lens it travels parallel to the optical axis. The three rays meet at the location of the real image, denoted by the blue arrow.



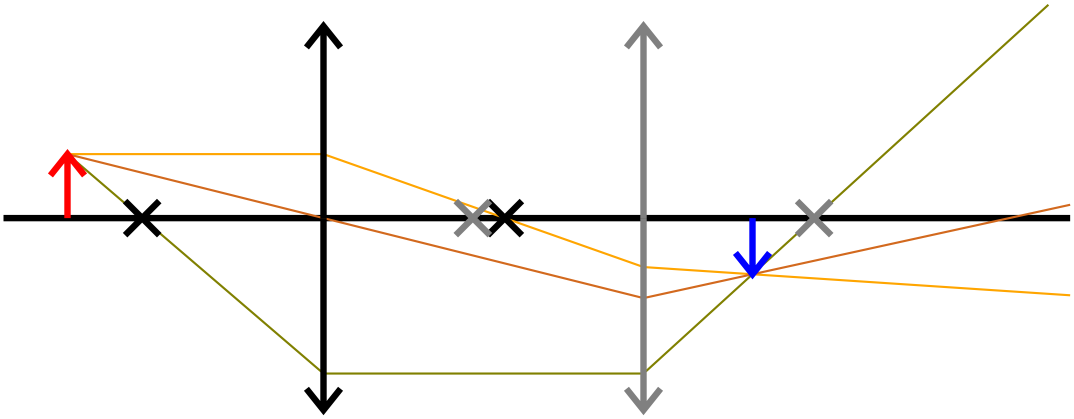
V. DIVERGING LENS

A diverging lens has a negative focal length. As such, the orange ray, which is initially traveling parallel to the principle axis, bends away as if it came from the near focal point after passing through the lens. The green ray, traveling toward the far focal point, hits the lens before it gets there. This ray bends to travel parallel to the optical axis after passing through the lens. This can be understood by imagining that the green line is propagating backwards, from right to left - a ray that hits the lens traveling parallel to the principle axis will bend as if it came from the focal point. The brown line does what it always does, and passes right through the lens. The three refracted rays don't cross, but appear to be coming from the virtual image indicated by the blue arrow.

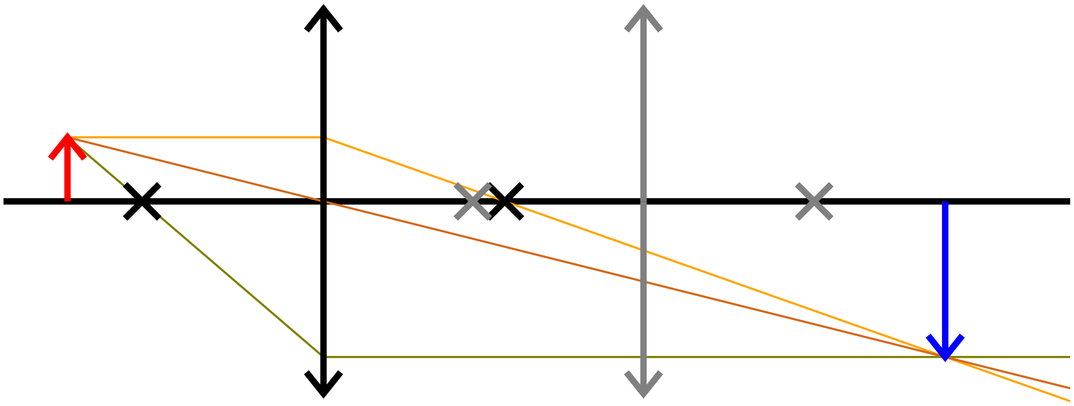


VI. TWO LENSES WITH A VIRTUAL OBJECT

Consider what happens when I put two lenses together, as shown below. The orange, brown, and green lines do just what they did in the example of the converging lens above. But now, before they form an image, they are intercepted by the second lens, shown in gray. When they pass through the second lens, they bend as shown to form the real image represented by the blue arrow. But how did I know how to draw those lines after the second lens? They are the special three rays for the first lens, but only the green line represents one of the special three rays for the second lens. So to find what they would do, I had to cheat - I calculated the position of the final image, and forced them to cross at that point.



So how would we find the location of the second image by just drawing rays (and not cheating and doing calculations)? We do this by first considering just the first lens, pretending that the second lens is not there. It makes an image, just as in the converging lens example above.



The image from the first lens in the figure above now becomes the object for the second lens. So in the figure below, I've replaced the blue arrow in the above figure with a red arrow, indicating that the image from the first lens is now acting as the *object* for the second lens. Once we draw the object arrow, we forget about all of the rays that we drew above to find it's location - we're done with those rays.

Note that the object for the second lens is on the wrong side of the lens! This means that p for this object is negative, and we have a *virtual object*. We have to treat virtual objects differently from real objects. Instead of thinking about light that comes from the object, for a virtual object we think of rays that are traveling *toward* the virtual object. The brown ray is one that is traveling toward the virtual object and happens to strike the center of the lens. As such, it passes right on through without deflecting. The green line passes through the focal point of the second lens on it's way to the virtual object. So when it strikes the lens, it will come out parallel to the optical axis. The orange line is traveling parallel to the optical axis on it's way toward the virtual object. As such, when it passes through the lens it is bent such that it will pass through the focal point on the opposite side of the lens. The rays cross where the blue arrow is located, so the final image formed by this system of two lenses happens to be real.