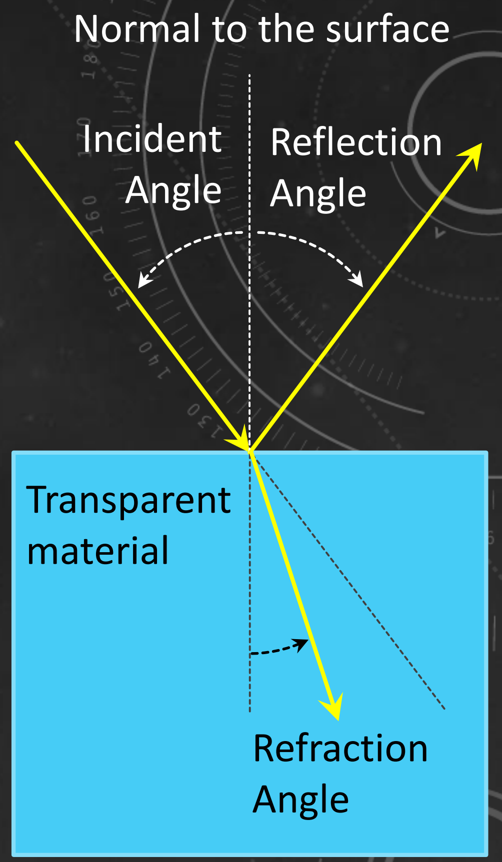
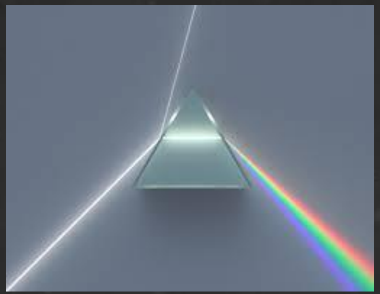
REFRACTION AND LENSES

PES 1000 – PHYSICS IN EVERYDAY LIFE

THE LAW OF REFRACTION

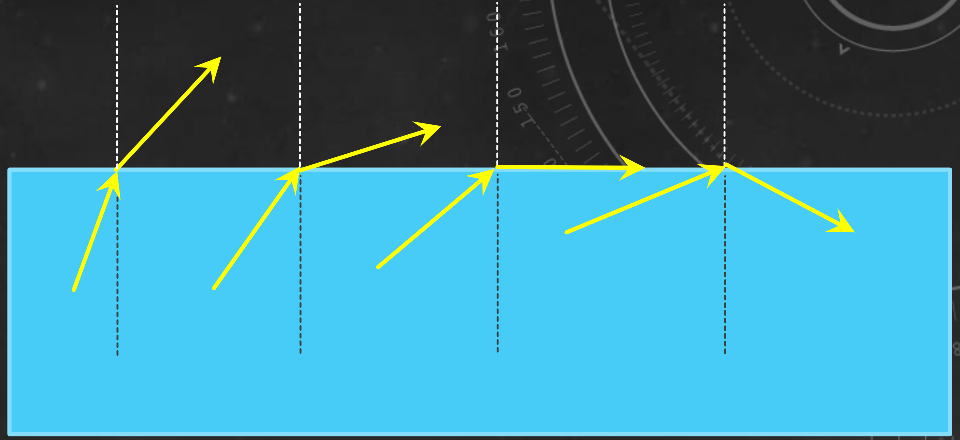
- When a light ray strikes a transparent material, the part of the light that is transmitted (passes through the material) is bent away from its original path.
  - If the light ray passes from a less dense material to a more dense material, the refracted ray bends toward the normal.
  - If the light ray passes from a more dense material to a less dense material, the refracted ray bends away from the normal.
- The amount of the bending depends on *n*, the index of refraction (related to the density and the speed of light in the material).
  - Snell's Law tells us how much: $n_i * \sin(\theta_i) = n_{refr} * \sin(\theta_{refr})$
  - The index of refraction is slightly different for different wavelengths of light (this is what lead to dispersion, or the prism effect.)

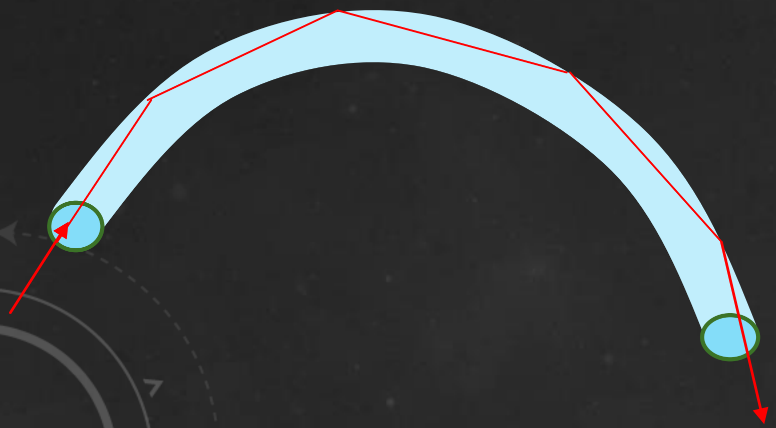


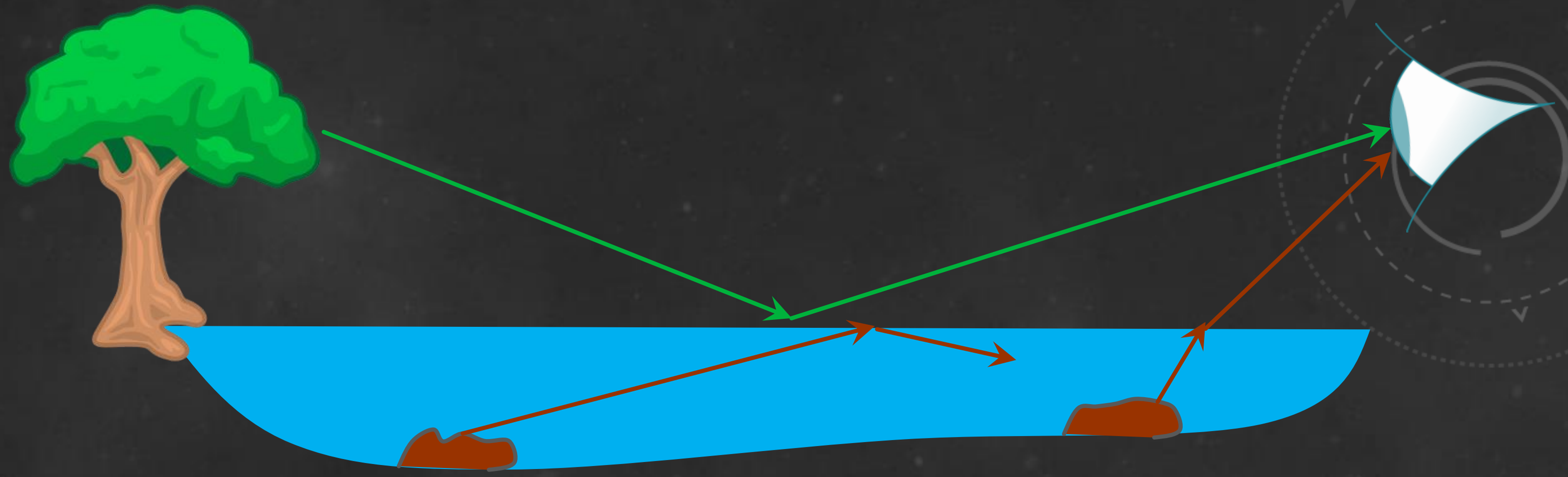


TOTAL INTERNAL REFLECTION

- If a ray of light is leaving a transparent material, it will bend away from the normal.
- At a certain angle, it won't be able to exit the material. This is called total internal reflection.
- Applications:
  - Light from objects in and around a lake.
  - Fiber optics





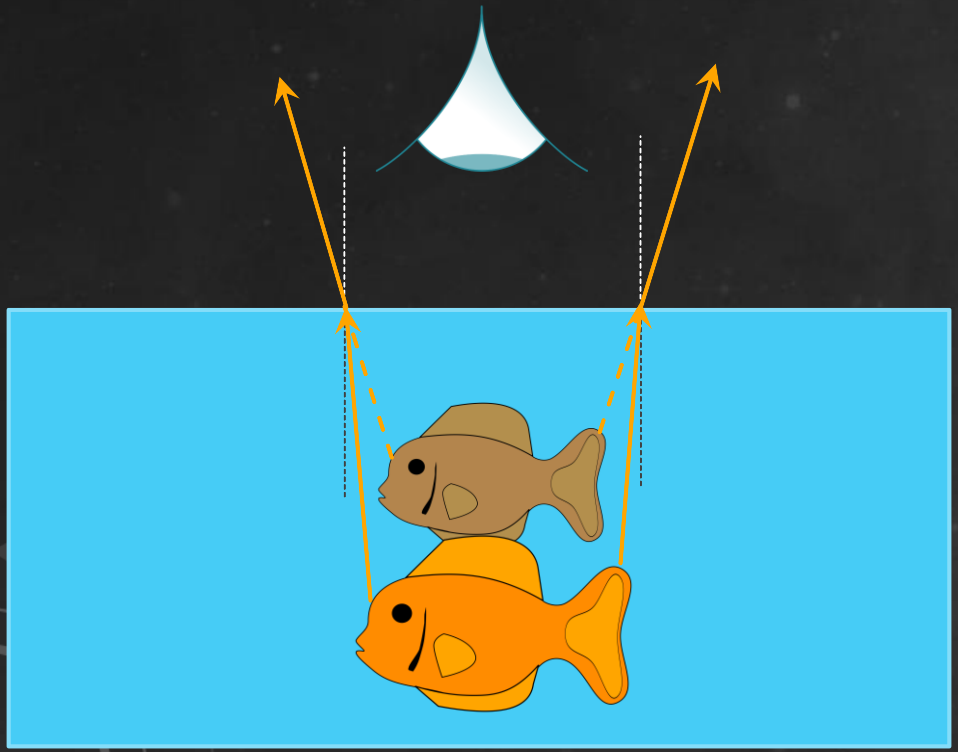


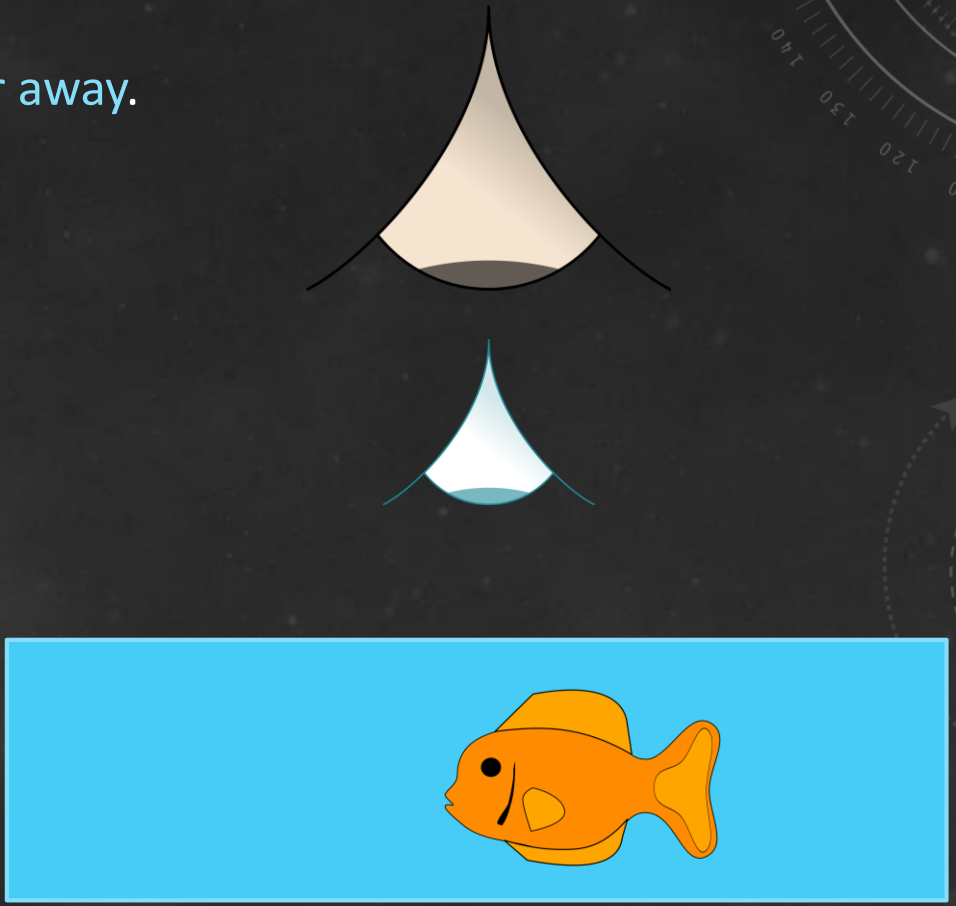
REVIEW OF IMAGE FORMATION

- Images can be formed by converging or diverging light rays emanating from an object.
- If the image is formed from converging rays, it is a real image. If the image is formed by projecting diverging rays back to an apparent source, it is a virtual image.
- Magnification (M) occurs if the image is larger or smaller than the source. Images with $|M|>1$ are larger.
- Direction of the image relative to the source can be either upright (same direction) or inverted (opposite direction). The sign of magnification lets us specify which is which.
    - $M>0$ is upright.
    - $M<0$ is inverted.

FLAT SURFACE

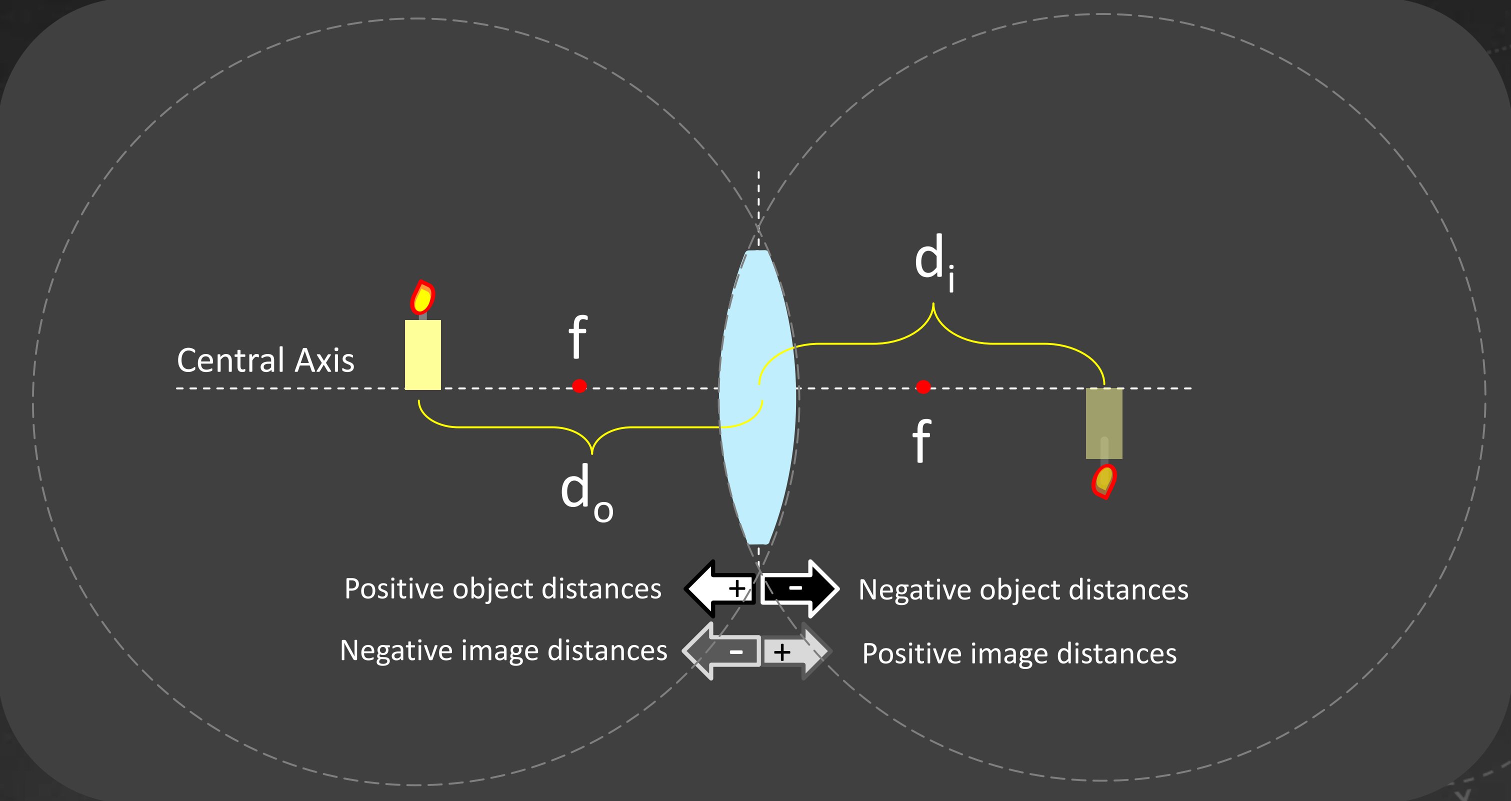
- Viewing a fish under water: The fish appears smaller and shallower than it really is. Viewed at an angle, it is also not where it appears to be.
- Conversely, the fish would see us larger and farther away.





DEFINITIONS: GEOMETRY

- Central axis: The perpendicular line through the center of the lens
- Centers of curvature: Each lens surface can have its own curvature.
- Focal point/length: Each surface of the lens can have its own focal length. (f = ½ R). Focal lengths can be positive or negative.
- Sign conventions: Distances on the side of the lens where the light enters the lens are considered positive distances *for the object*. Distances on the side of the lens where the light has left the lens are considered positive *for the image*.
- We will usually deal with *symmetric* lenses.



TWO-SURFACE LENSES

A lens is composed of two refractive surfaces, each with possibly different shapes.

- Symmetric: Both surfaces are identically shaped.
  - Both could be convex or concave.
  - Both could be flat, in which case the lens is just a pane of glass.
- Asymmetric: The two surfaces differ in curvature
  - Only one surface could be flat, and the other convex or concave.
    - Plano-convex or plano-concave
  - Meniscal: Both surfaces curve in the same direction
    - Meniscal lenses can be diverging or converging.
    - These are the lenses used in vision correction.

RAY DIAGRAMS FOR LENSES

- We'll only consider symmetric lenses.
- Although the light bends only at each surface, we'll simplify by having a single bend at the center plane of the lens.
- Focal point definitions:
  - For a convex lens (converging lens), both focal lengths are positive.
  - For a concave lens (diverging lens), both focal lengths are negative.
- Image location – for a thin lens, the equation is the same as for mirrors: $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$
- Image magnification - the equation is the same as for mirrors: $M = -\frac{d_i}{d_o}$
- Here are a couple of easy rays to draw and their rules for thin, symmetric, converging lenses:
  - In parallel, out through the focus on the other side from the object.
  - In through the focus on the object side, out parallel.

EXAMPLES: CONVERGING LENSES

- Here are the ray diagrams for some interesting configurations for a concave mirror.

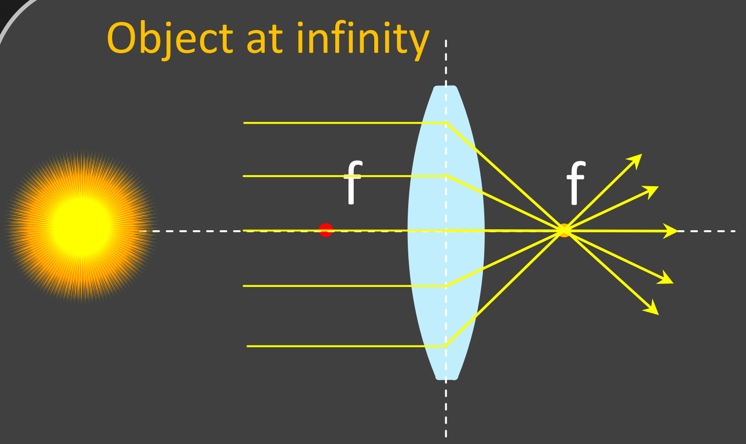


Image is a point and it is real

#1

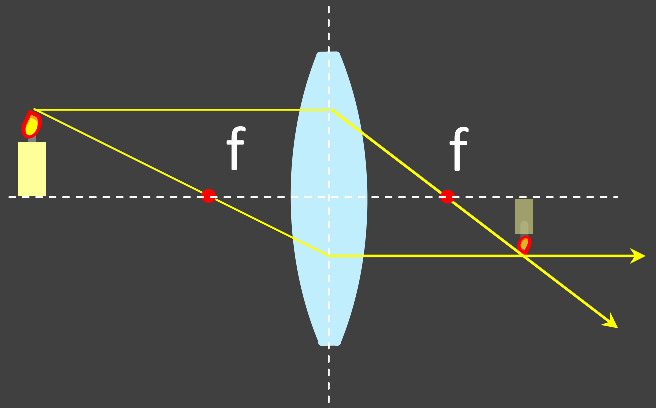


Image is smaller, inverted, and real

#2

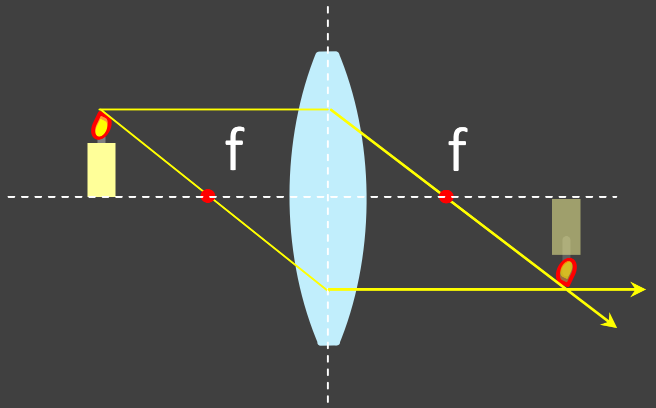


Image is same-sized, inverted, and real

#3

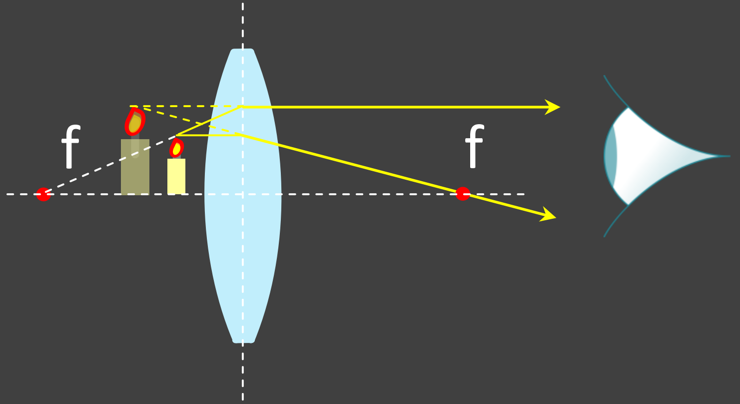
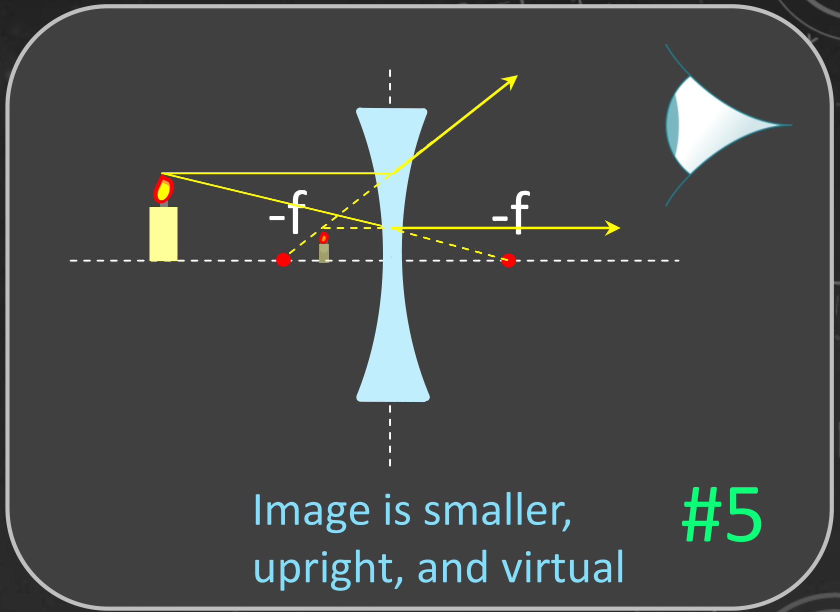


Image is larger, upright, virtual, and behind the lens

#4

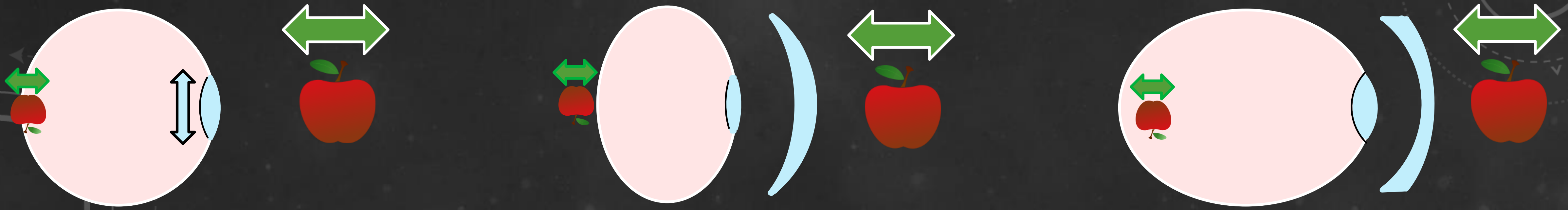
EXAMPLE: DIVERGING LENSES

- For diverging lenses, the ray rules are slightly modified. Here are the rules for thin, symmetric, diverging lenses:
  - In parallel, out *as if* through the focus on the *same side* as the object.
  - In *as if* through the focus on the *opposite* side, out parallel.
- Diverging lenses *always* make virtual, upright, smaller images.
  - This is analogous to diverging mirrors.



HUMAN VISION AND VISION CORRECTION

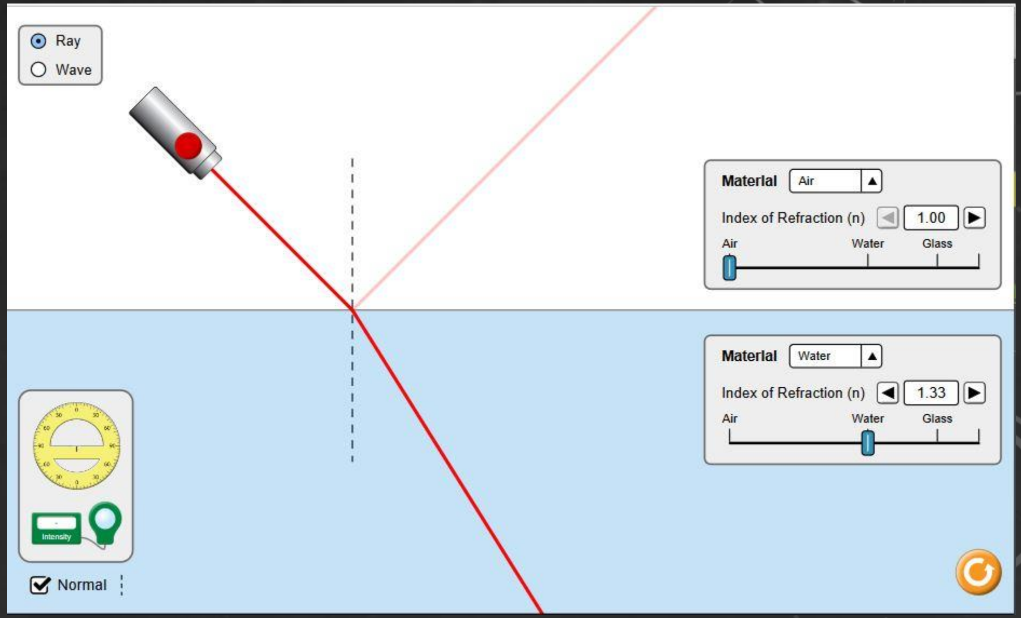
- The normal eye has a lens which will focus the diverging rays from an object into a real image projected on the retina in the back of the eye.
  - The image distance is fixed by the length of your eyeball, so as the object distance varies, the lens itself changes shape (changes its focal length) to keep the image focused on the retina.
- The condition known as *hyperopia* (far-sightedness) is caused by an shortened eyeball.
  - The near-focus range is behind the retina. The lens can't converge the incoming rays enough.
  - Correction: An additional lens that pre-converges the incoming rays, allowing the natural lens range to reach the retina.
- The condition known as *myopia* (near-sightedness) is caused by an elongated eyeball.
  - The far-focus range is in front of the retina. The lens can't diverge the incoming rays enough.
  - Correction: An additional lens that pre-diverges the incoming rays, allowing the natural lens range to reach the retina.
- Additionally, thin film coatings on the lenses can compensate for chromatic dispersion, glare resistance, etc.



SIMULATION – BENDING LIGHT

- URL: https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html

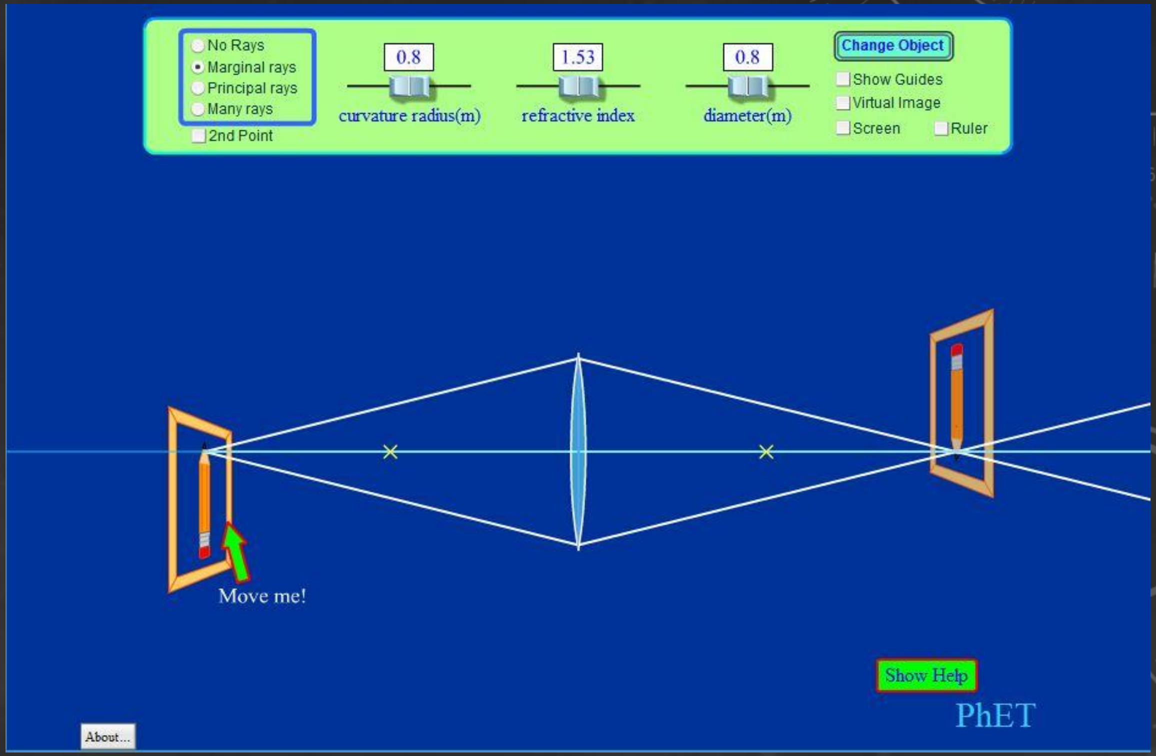
- Things to do on the 'Intro' page:
  - Center the protractor (from the bottom left) at the point where the light enters the water. Check the angles.
  - Change the bottom material to glass. See that the reflection doesn't change, but the refracted ray bends even more toward the normal. Glass is denser than water.
  - Change the top material to water and the bottom one to air. Find the angle that causes total internal reflection.
  - Experiment with different combinations of materials on top and bottom.



SIMULATION – GEOMETRIC OPTICS

- URL: https://phet.colorado.edu/sims/geometric-optics/geometric-optics_en.html

- Things to do:
  - Turn on ‘Principle rays’ and click the ‘Virtual Image’ box.
  - Re-create some of the ray diagrams from this presentation. Specifically, try:
    - Object at twice the focal length
    - Object at the focal length
    - Object less than the focal length
  - Experiment with different radii of curvature and refractive indices (at the top).



CONCLUSION

- Refraction occurs when light rays pass between materials of different density. The ray will bend away from its original path, depending on the index of refraction of the materials.
- If a ray going from a denser material hits the surface at a steep enough angle, it will not exit the material, but be completely reflected internally.
- Diverging or converging rays due to refraction can form images. Like mirrors, the images can be virtual or real, larger or smaller, upright or inverted.
- Lenses have two refracting surfaces that can be similarly or differently shaped. The shape affects the focal length, and the combination of the surfaces has an effective focal length.
- There are rules for tracing important rays from the object that let us easily reconstruct the image that is produced by a lens.
  - Generally, lenses can be classified as diverging lenses or converging lenses.
- We can use our knowledge of lenses to solve an ancient human problem: vision correction.

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