Figure 1: Optics in a Washbasin

Optics at Home – in Washbasins, Aquariums and Pools

Begin with a simple experiment in a washbasin or sink. Start with an empty washbasin as shown on the left in Figure 1 and notice the drain at the bottom. You might even take a quick picture. Then fill the washbasin with water and wait until any bubbles disappear and the water is still. See the right side of Figure 1. Notice the drain appears to be higher than it was when the washbasin was empty. You might even take a second picture from the same vantage point and compare the two pictures side-by-side.

This is a phenomenon that is well-known to bow fisherman:

> In bowfishing . . . you can't aim directly at the fish. Light refraction in the water distorts what you see, ...[1]

Whenever light rays cross from one medium, like water, to another medium, like air, their path is bent. Their behavior is called "refraction" and is based on the almost anthropomorphic first rough statement of Fermat's Principle – light rays follow the fastest possible path between two points. When light rays are traveling in a single medium the fastest possible path is a straight line. Our brains use this simple fact to figure out where incoming light rays come from.

But, when two different mediums are involved, like water and air as in Figure 2, there is a complication. Light travels faster in air (30.0 centimeters per nanosecond) than it does in water (22.5 centimeters per nanosecond). This figure shows an aquarium that is 50 cm long. It is filled to a depth of 15 cm with water. An eye 15 cm above the surface of the

[1] https://bowhunting360.com/2019/04/17/bowfishing-making-the-shot/. Accessed 27 October 2020.

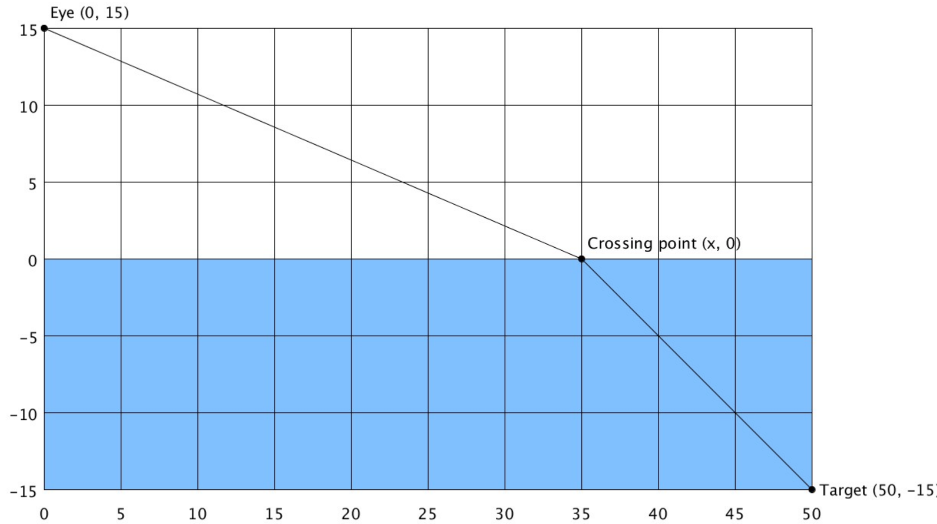

Figure 2: A Possible Path

water at one end of the aquarium is looking at a target on the bottom at the other end of the aquarium. This is like a bow fisherman looking at a fish underwater.

We draw this on graph paper with the x-axis along the surface of the water and the y-axis at the same end of the aquarium as the eye. The eye is at the point $(0, 15)$ and the target is at the point $(50, -15)$. Light rays traveling from the target at the point $(50, -15)$ to the eye will travel in a straight line from the target to a point $(x, 0)$ on the surface of the water and then in a second straight line from the point $(x, 0)$ to the eye at the point $(0, 15)$. We use the letter x to denote the x-coordinate of the crossing point because we don't know where this point is. Because light travels faster in air than in water our anthropomorphic light rays will travel further in the air than in the water. The function:

$$f(x) = \frac{\sqrt{x^2 + 15^2}}{30.0} + \frac{\sqrt{(50 - x)^2 + 15^2}}{22.5},$$

computes the total travel time for a light ray following the path shown in Figure 2. To determine the actual path followed by our light rays we must find the value of x that miniimizes the function $f(x)$. You can do this in various ways, for example, using a graphing calculator, using computer software or using the `Processing` program `interactiveRefraction` found in the Collaborative Computing Group. The answer is $x \approx 35.6$ and is shown in Figure 3.

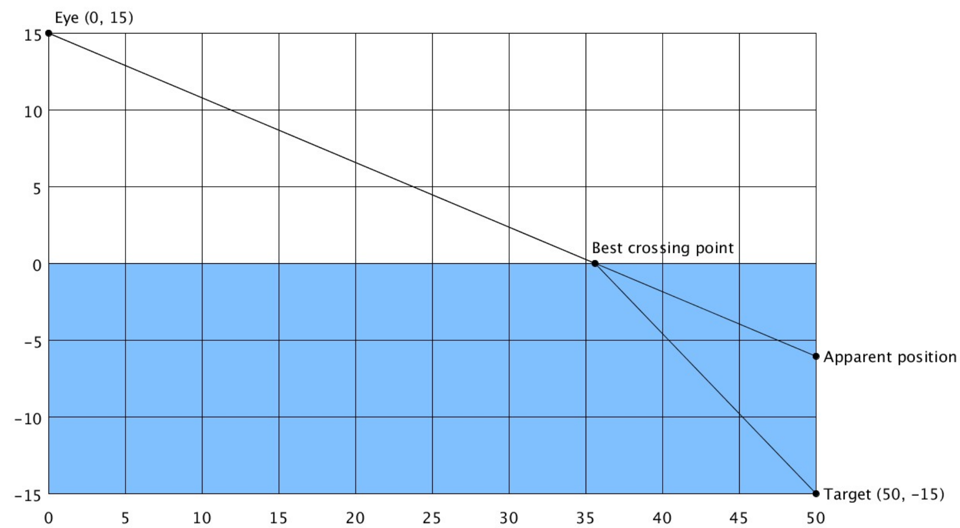

Figure 3: The Fastest Path, the Apparent Path and the Apparent Point

Your brain assumes that the incoming light ray is not bent but travels along single straight line extending the path between the eye and the surface of the water. This extended straight line is called the "apparent path" traveled by the incoming light ray and your brain believes that the target is located someplace on this line. Your brain receives the same information from your other eye and combining the information from the two eyes determines that the target is directly above its true position. The apparent position of the target is shown in Figure 3.

Question 1:

Find the apparent depth of the target in Figure 3 by using your knowledge of linear functions to find the y-coordinate of the apparent point.

Question 2:

Suppose a fisherman whose eye is five feet above the surface of a pool is looking at a fish 20 feet away at a depth of six feet. How deep does the fish appear to be?

Question 3:

Suppose the fish in Question 2 is 14 inches long and 3 inches tall. How long and tall does it appear to be?

Question 4:

Suppose the same fish is looking at a fisherman who is six feet tall and up to his waist in the water 20 feet from the fish. Draw a picture showing what the fisherman looks like to the fish. You may be surprised.