Questions: Refraction and reflection

Question 1: Part 1

A swimming pool looks less deep than it actually is.

a Explain what is meant by *optical path length* and show that the ratio of apparent depth D' over real depth D for normal incidence (when looking straight down into the water) is given by the ratio of refractive indices of air and water.

$$D'/D = n_{air}/n_{water}$$

$$D' = D/1.33$$

It is well known that a drinking stray or skewer appears to bend at the surface when placed at an angle in water.

b Explain briefly why the stick appears to bend at the water surface in the image above and why it appears to be thinner under the water.

c Explain briefly what is meant by saying that brine (concentrated salt solution) has a higher optical density than water.

d If the container in the image above were filled with brine to the same depth would the stick appear to bend a little more or a little less at the surface.

Question 1: Part 2

The figure shows a straight drinking straw in a bottle of water.

The drinking straw is straight but appears to be wildly distorted into a zigzag shape when seen through the sides of the bottle.

a Describe the surface of the water bottle in as much detail as you can.

b In one word, what physical principle is responsible for the zigzag appearance of the straw which is angled left to right in the bottle?

c Give a brief explanation of the effect in as much detail as you can.

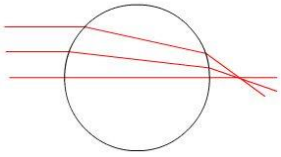
d Would the appearance of the straw be the exactly the same, or nearly the same, if the bottle was filled with brine (a concentrated solution of salt in water)?

e Give a brief explanation for your answer to question d above.

Question 2: Part 1

For this question you may require the lens maker's formula relating the refractive index of a lens material and the radius of curvature to the focal length of a single surface lens.

The diagram shows rays that refract at each surface of a ball lens.



a Rays are often shown with arrows to indicate the direction of light propagation. Why might the writer have chosen not to include arrows in this case?

b Partial reflections at each surface are not shown. Carefully redraw the diagram to include partial reflections. Locate any images formed by these reflections on your diagram.

c Explain why in general terms this ball lens will not have a well-defined focal length and will not form an image of the sun in a single plane when placed in sunlight.

d The image above (with a magnified inset) shows almost spherical water drops on a leaf in sunlight. Locate and describe the images.

Question 2: Part 2

A flower is imaged in a water drop.

It can be shown[1] that for the central portion of a ball lens in air the focal length is given approximately by …

$$f = \tfrac{1}{2}[n/(n-1)]r$$

… where r is the radius of curvature, and
n is the refractive index of the lens material.

The derivation is an exercise in geometry and approximation. The reference is very clear and recommended for those with a strong mathematical background.

[1] https://math.stackexchange.com/questions/345268/how-is-the-formula-for-the-focal-point-of-a-ball-lens-derived

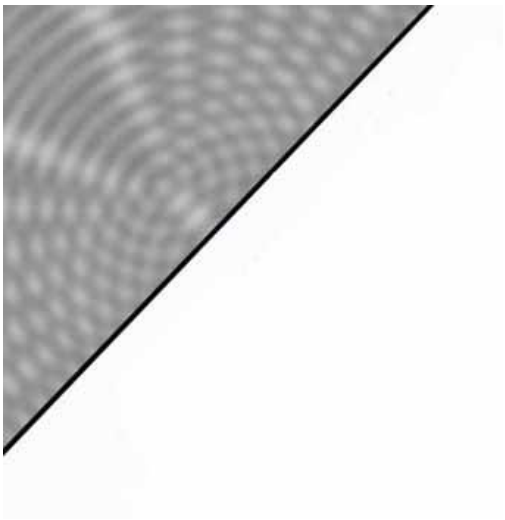
a Find the image distance (from the centre of the water drop to the inverted image) in terms of the radius of curvature of the drop given that the refractive index of water is 1.33**.**

b Explain any additional approximations involved in your answer to **a**.
[Why, for instance, are you justified in equating the image distance with the focal length and why is the radius of curvature only approximately half the lateral diameter of the drop in the image?]

c Since digital cameras with macro functions became common may people have taken water drop images (in particular of a distant flower imaged in a drop. Instructions found on the web recommend that the photographer use a tripod and focus very carefully on the drop. Why might this recommendation be slightly misleading?

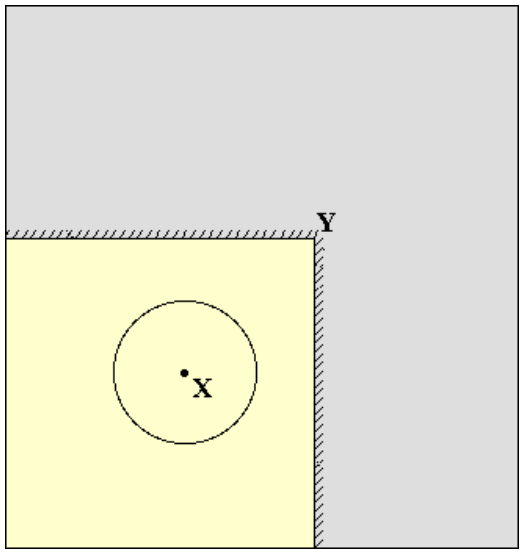
Question 3: Part 1

Circular waves expand from a point in a ripple tank and reflect from a straight surface. The photograph shows that is seen in the tank.



a Draw a diagram showing a single incoming wave and its reflection. Locate the image of the point source on your diagram.

The diagram below shows a single circular wave expanding from the point X about to encounter two reflecting surfaces that meet at right angles in a ripple tank at point Y.



a Draw the reflected waves as they pass through the point Y at time *t*.

b Draw the reflected waves at time 2*t* and locate all three images in the right angled corner.

Question 3: Part 2

Mirrors are fixed in a frame at right angles. The frame is hung in the corner of a square bathroom with the mirrors against the walls. A person looks into the mirrored corner and sees their face upright. They comb their hair and are surprised to see their hand and comb on the "wrong" side of their head.

a Explain why they are not seeing what they normally see when they look into a bathroom mirror.

They take the frame off the wall and hold it so that they see their head upside down.

b How are they holding the mirrors when their head appears to be inverted?

They now rotate the mirrors to the left like the steering wheel of a car.

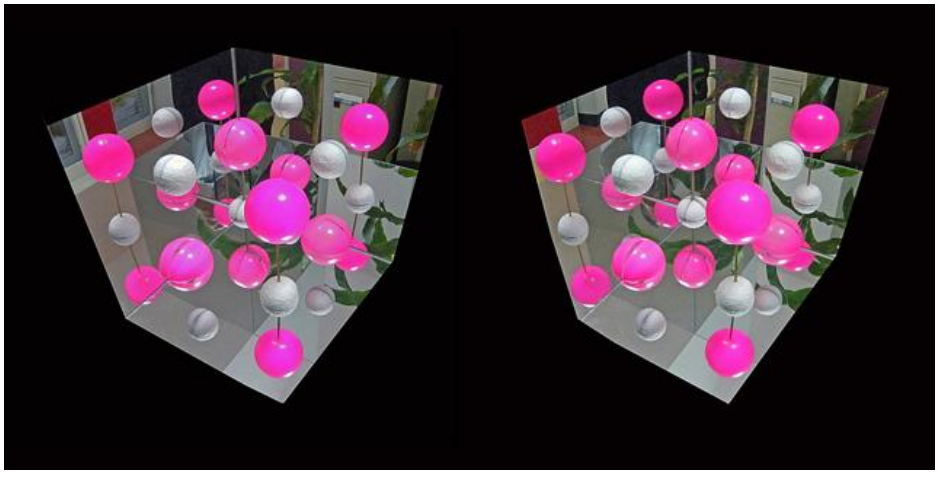
c In which direction do they see their head rotate and through what angle have the mirrors been turned when they again see their head upside down?

For a Physics open-day at KVIS I want to make an image inverter with four front-surfaced mirrors and a cardboard box. I want people to look into a short eye-tube on one side of the box and see an inverted image of what is in front of them.

d Why should I use front-surfaced mirrors for best effect in this case rather than cheap back-surfaced mirrors?

e How should the four mirrors be mounted inside the box? Diagrams please.

f* In a sentence, why is the inverted image seen through the box not laterally inverted, and why does the image stay upside down when the box is rotated?



https://www.flickr.com/photos/jacobs_ian/9442293670

b How many balls and part balls were needed to make this mirror-corner 3D cross view model of a sodium chloride crystal that appears to have 18 complete balls?