

VIII. Optics

Warm-Up Exercises

Conflicting Contentions

1. Lens cover-up
2. How long is a full length mirror?
3. How to spear a fish

Qualitative Reasoning

1. How many reflections?
2. Image in a spoon
3. Rainbow order
4. Approaching a concave mirror
5. Approaching a convex mirror
6. Diffraction gratings

Can You Explain This?

1. Disappearing Eyedropper
2. Re-appearing light
3. Fish tank reflection
4. Real and virtual images?
5. Poisson's bright spot
6. Optical fibers

WARM-UP EXERCISES

1. Why is the sky blue? What does that have to do with the fact that the setting sun appears red-orange?
2. The index of refraction of diamond is about 2.45, which is quite large. What does that have to do with the fact that diamond sparkle?
3. How does a diffraction grating turn white light into a rainbow?
4. How does a prism turn white light into a rainbow?

CONFLICTING CONTENTIONS

1. Lens Cover-Up

The Situation

“Here’s another classic concept question that the majority of the people get wrong,” Mr. Nicholls said. “After I give you the set-up, I’m going to tell you what the wrong answer is. I’m looking for two volunteers – one to come up with a plausible explanation for the wrong answer, and a second person to explain what’s wrong with the logic.”

Mary’s hand went up in the air. “I’ll help,” she said, “I usually choose the wrong answer anyway.” “Well then I better volunteer, too,” said John, “to maintain our family honor.”

“Okay,” said Mr. Nicholls, “Here’s the situation. I’ve set up an optical bench with a light, a converging lens, and a screen with the focused image projected on it.” The class could see the phrase ‘60 Watts’ printed on the surface of the light bulb projected on the screen, but written backwards.

“Now here is the question,” he continued. “What would happen to the image if I covered up the lower half of the lens with a sheet of paper?”

“I bet I know what the wrong answer is,” said Mary.

“Why do you say that?” asked Alonzo.

“Because it’s the answer I would give, it’s the most obvious answer, and it makes sense to me. So it must be wrong,” she replied.

“Okay,” said Mr. Nicholls, “Give it a try.”

“When you cover up the lower part of the lens, then the lower part of image will disappear,” she replied.

“Yes, Mary, that is the wrong answer that the majority of people would give. As you will all see in a minute, when I cover up the lower half of the lens, the lower half of the image does not disappear. So can you tell me why you would think that way?”

Can you come up with a response before reading Mary’s?

Mary’s Response

“Here’s what I think,” she said, “I know that if I cover up the lower half of a picture, I can’t see that part of the picture anymore. So If I put my hand over the lower part of the bulb, I would see the top part of the bulb on the screen, plus my hand covering up the lower part. So, naturally, I would think covering up the lower part of lens would work in a similar way. Only, I wouldn’t see an image of my hand if I covered up the lower half of the lens, because the lens isn’t

focusing light rays from my hand, only from the bulb. So the bottom half of the image just disappears.”

“That’s pretty good logic,” said Mr. Nicholls. “Wrong, of course, but logical.”

“Okay, I’m ready,” said John. “I can explain why that argument isn’t correct.”

Can you figure out the holes in Mary’s reasoning before reading John’s answer?

John’s Response

“This is what we learned about light rays,” John began. “The light rays travel from the object, pass through the lens, where they shift direction, then converge again at the screen. We learned that thousands of light rays are leaving all points of the object and passing through all parts of the lens before being re-focused on the screen. The assumption that my darling wife made is that the top half of the image is formed by light rays traveling through the top half of the lens, and the bottom half of the image is formed by light rays traveling through the bottom half of the lens, but that isn’t true. Light rays from the top half of the object are traveling through all parts of the lens, and the same for light rays from the bottom half of the lens. So light rays from all points of the object are still reaching the screen.”

“Very good,” said Mr. Nicholls. “That is absolutely correct. I would also like to add that the image isn’t formed at the lens; it’s formed at the screen. The lens, or a curved mirror, just redirects the light rays that meet it. That is why covering up the lower half of the lens is not the same as covering up the lower half of the object.

“But I still have one final question for you. If covering up the lower half of the lens doesn’t eliminate part of the image, what effect, if any, does it have on the image?”

What do you think?

Here were some responses from the class:

The image is dimmer.

The image is fuzzier, and the screen has to be brought in closer to re-focus it.

The image is fuzzier, and the screen has to be moved farther back to focus it.

Which answer do you think is correct, and why?

The Answer

Mr. Nicholls covered up the lower half of the lens, and the full image of the light bulb was just as sharp as before, but not as bright.

Can you explain why the image wasn’t fuzzy, and why it was dimmer?



2. How Long is a Full Length Mirror?

“Cathy, could you come up here, please? I want to see how tall you are,” Mr. Nicholls asked. Cathy came to the front of the room, and using meter sticks, Mr. Nicholls measured her to be exactly 156 centimeters tall.

“Okay, here is the question,” he said. “How tall does a full length mirror have to be for Cathy to see all of herself, from head to toe?”

“That’s easy,” said Daniel, “156 centimeters, of course.”

“I don’t trust ‘easy’, anymore; not after this class”, Beth interjected. “There’s got to be a catch.”

“Not a catch,” added Alonzo, “Logic. Why do you think the mirror has to be 156 centimeters?”

“Because that’s how tall she is,” Daniel replied.

“So what does that have to do with how light rays behave?” asked John.

“So then every full length mirror has to be tailor-made for the person who wants to use it?”, Mr. Nicholls added.

“Of course not,” Frank replied, “If a mirror is too long, you just see some of the floor or some of the wall above your head. Like when I try on new shoes. I see the floor as well as my shoes.”

“So then, I guess we’re back to the original question. How long does Cathy’s mirror have to be for her to see herself from head to toe?”

“Doesn’t it depend on how far away she is from it?” John questioned.

“How so?”

“Well, if she is farther away from the mirror, then the image is smaller, so the mirror can be smaller. But if she is right up next to it, it will have to be as tall as her, won’t it?”

“Got it!”, Beth shouted. “I know the answer! The mirror has to be 78 centimeters, or exactly half her height. Doesn’t it, Mr. Nicholls?”

“Yes,” he said, “That is correct.”

“And it doesn’t matter how far away she is from the mirror, right?”

“Right again,” he said, “As long as it is perfectly vertical. But it does matter where you put the mirror on the wall.”

“Okay,” said Frank, “How did you figure it out?”

“It’s all in what John said,” she replied. “I drew the light rays.”

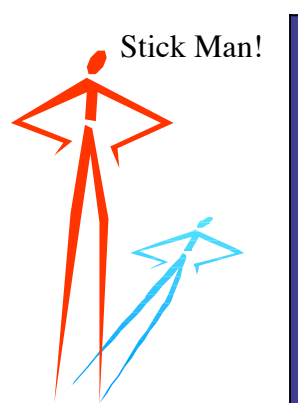
Can you draw a ray diagram using the law of reflection to show why a mirror only has to be half your height in order to see all of yourself from head to toe?

Can you also discover where the mirror must be placed on the wall? (Hint: light rays must reach your eyes. It depends on how far your eyes are from the top of your head or the soles of your feet.)

Can you draw a second diagram demonstrating that the distance from you to the mirror has no effect on how much of you is visible?

Can you also identify the errors in the explanations given by your classmates?

Suggestion: Stand in front of a full length mirror. Have a friend mark with masking tape on the mirror where you see the top of your head and the soles of your feet. Move towards and away from the mirror, and the location of the tape doesn’t change (as long as the mirror is vertical on the wall).



3. How to spear a fish

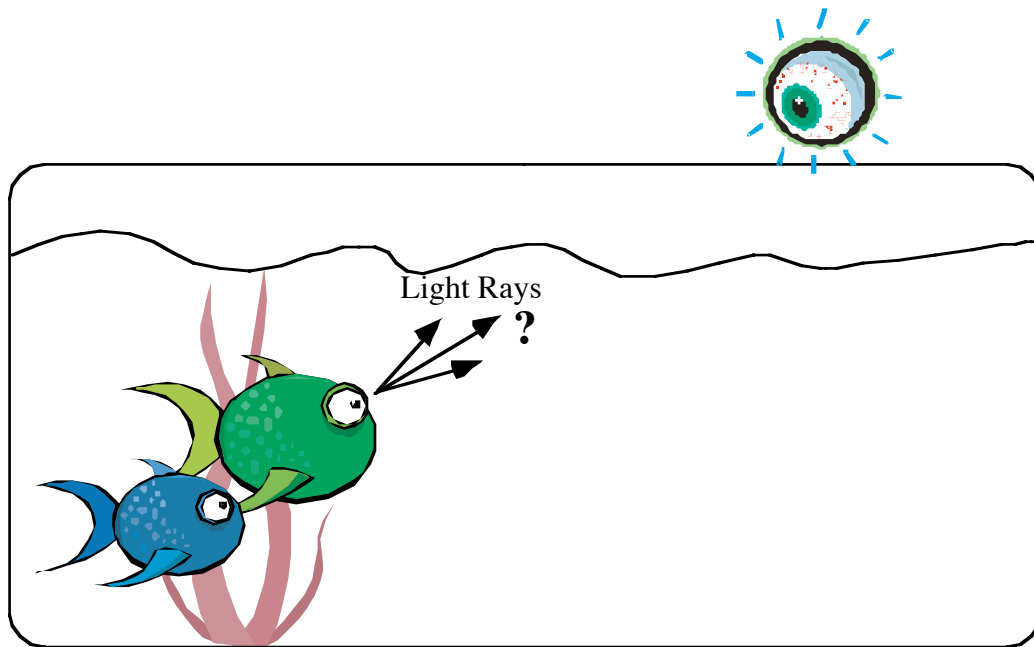
Mr. Nicholls set up a fish tank with a small plastic fish resting on the bottom.

“Let’s see what you learned about light rays,” he said. “Frank is going to be out fearless hunter. He is going to stand – actually, sit – in front of this fish tank and look as my plastic fish, Frederica, under the water.

“Fearless Frank is going to have a pencil in his hand, which he will use as a spear. His goal is to catch poor Frederica by spearing her with the pencil.

“Now here’s the question: From Frank’s point of view, should he aim directly at Frederica in the water, should he aim higher and past the image of Frederica that he sees, or should he aim lower and in front of the image of Frederica?”

Complete the ray diagram and provide an answer to the question.



Our intrepid hunter was asked by the instructor to point his pencil-spear directly at the image of Frederica that he saw. Everyone observed that the pencil was pointing well above and past the actual location of the fish, as viewed from the side.

Does your ray diagram demonstrate this fact? If not, how must it be changed to correctly show the law of refraction?

QUALITATIVE REASONING

1. How many reflections?

An object in front of a flat mirror creates one image. If two or more mirrors are placed next to each other with a common edge, then multiple images are possible. These types of mirrors are often found at clothing stores.

If two mirrors hinged together are set to a 90 degree angle, then three images are formed (try it for yourself). How many images would be formed if two mirrors are placed at a 60 degree angle?

Can you develop a general rule for the relationship between the number of images seen and the angle between two mirrors? (Then test your rule.)

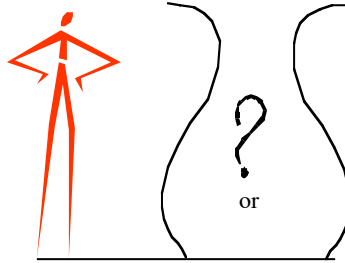
HINT: don't forget the position of the original real object in addition to the images seen when formulating your rule.

2. Fun House mirror

A fun house mirror distorts an image because the mirror surface is not flat. Suppose a mirror shows a person with very long legs and a short, squat torso. Draw the side view of the mirror

with the person on the right and the mirror on the left of your sketch. Does the mirror have an “S” shape, or a backward “S” shape? Use your knowledge of curved mirrors and their images to justify your answer.

Stick Man Returns!



3. Image in a spoon

It is possible to produce both upright and upside-down images in an everyday metal teaspoon. It is also possible for the upright image to be larger than or smaller than the object. Explain how to hold the spoon and where to put the object for each of type of image that may be produced by a metal spoon. Then test your answers with a real spoon.

4. Rainbow order

The order of colors of a rainbow are red, orange, yellow, green, blue, and violet. But is red on the outside of the rainbow arc, or on the inside?

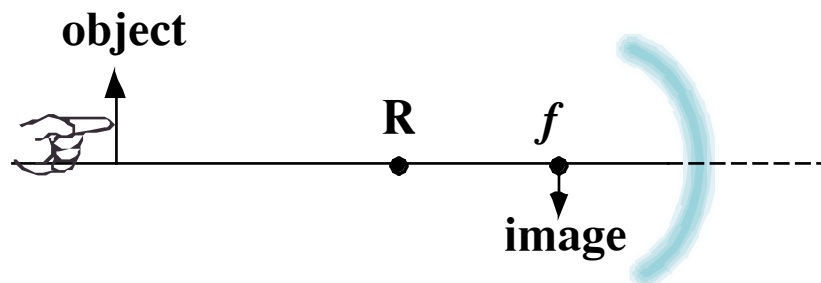
Hint: The index of refraction for red light is less than that of blue light.

Of course, be sure to include and explain the reasoning supporting your answer.

5. Approaching a concave mirror

Suppose you slowly bring an object in toward a concave mirror from a very great distance. Explain what happens to the image as you bring it closer – that is, describe its size (or magnification) relative to the size of the object, its location, and its orientation (upright or upside down).

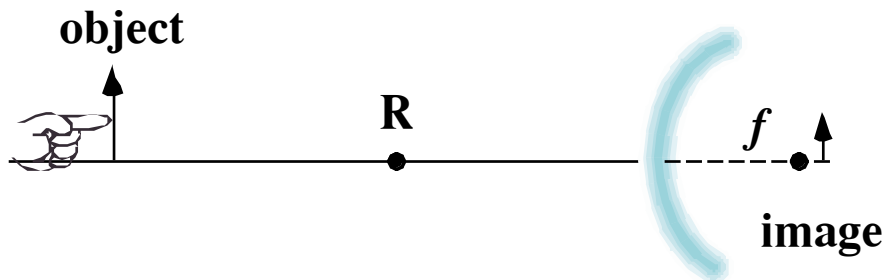
Hints: The image begins at the focal point of the mirror and is extremely small. Key distances from the mirror are the focal length (f) and twice the focal length, which is also called the radius of curvature (R).



6. Approaching a convex mirror

Suppose you slowly bring an object in toward a convex mirror from a very great distance. Explain what happens to the image as you bring it closer – that is, describe its size (or magnification) relative to the size of the object, its location, and its orientation (upright or upside down).

Hint: The image begins at the focal point of the mirror, which is on the opposite side of the mirror's surface compared to the object.



CAN YOU EXPLAIN THIS?

1. Disappearing Eyedropper

A glass eyedropper is put in a liquid that has an index of refraction the same as that of the glass. Air is squeezed out of the eyedropper, and when the bulb expands again, the eyedropper seems to disappear. Can you explain what is happening using the principles of refraction?

Would it be possible to create an 'invisible man' by this method?

2. Re-appearing light

A waterproof light is placed in the bottom of a tank, and a person is positioned so that the light is just below the edge of the tank, out of her line of sight. Water is added to the tank, and as it rises toward the top edge, she can see the light in the tank. Can you explain this?

Hint: compare this question to (3) Spearing a Fish.

3. Fish tank reflection

Why does the top surface of a fish tank look like a mirror when looking upward from the outside glass wall, but it never looks like a mirror when viewing the surface from above?

4. Magnifying glass

Why is it impossible to focus the image you see through a magnifying glass on a screen?

Hints: Is the image upright or upside down? Is it virtual or real? Where is the image located with respect to the magnifying glass lens and the object that is being magnified?

5. Poisson's bright spot

A small object, like a pin, is held near a very bright light, and the shadow of the pin is viewed on a screen. A bright spot can be seen in the center of the pin head's shadow.

Can you explain how the bright spot is formed? Which property of light is causing this behavior?

[By the way, Poisson predicted the existence of the bright spot in the middle of a shadow as proof that light did not possess the property that actually causes it. He thought the idea a bright spot in the center of a shadow region was a ridiculous impossibility, and therefore the theory must be wrong. But then another scientist, Arago, decided to check it out – and the bright spot did exist. So Poisson help prove a theory he didn't like.]

6. Optical fibers

Optical fibers use the principle of total internal reflection to send electromagnetic radiation (light) great distances down the Information Superhighway. Is it necessary to cover the fibers with a plastic coating for them to function correctly? Why or why not?

What would you see if you looked through an optical fiber without a protective coating?

Can you explain your answers using the principles of optics?