Optic Fiber

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Introduction

Almost all the light gathered by HET's enormous 10 by 11 meter mirror falls at PFIP (prime focus instrument package) into a tiny point, the size of George Washington's eye on a U.S. quarter. But this light is useless until it is processed and recorded by an instrument, then examined by an astronomer. Two instruments, the medium- and high-resolution spectrographs, are located in a basement beneath the telescope because they are too large and heavy to ride on the tracker inside the PFIP. Since the starlight comes to a focus at PFIP, some type of light-tight linkage must direct the light down to the spectrographs. Flexibility is another important property of the linkage. In order to follow the astronomer's target celestial object, the tracker and PFIP move during the observation. An optic fiber offers a simple and inexpensive solution to this complex problem.

From the outside, an optic fiber cable resembles and shares properties with an electrical cable. Both are flexible, coated with protective jackets, and able to carry digital signals. But on the inside, the optic fiber is quite different. Light travels through a narrow glass or clear plastic fiber instead of an electric current along a metal wire. Total internal reflection confines the light inside the fiber as it travels a crooked path from beginning to end. From the perspective of the light rays, the fiber walls are perfect mirrors. Today, optical fibers are quickly replacing copper wire as the medium for digital communication. TV cable and telephone companies can pack more information encoded as laser light pulses through optic fiber than electrical pulses through copper wire. For the HET, an optic fiber guides light from the PFIP all the way down to the basement and into the large spectrographs. From beginning to end, the light travels through 35 meters of optical fiber and suffers little intensity loss.

Materials

For each investigation group:

1. HET diagram.
2. 1 penlight or laser pointer, 2 inches of electrical tape, and four flat mirrors.
3. Barrier (e.g., shoe box, stack of books).
4. Target (e.g., tissue box, CD jewel box, or index card).
5. One hex jar, one black crayon, one protractor, and one pinch of nondairy coffee creamer. A two-liter clear bottle serves as an excellent alternate for the hex jar.

Texas Essential Knowledge and Skills

SCIENCE TEKS PROCESS SKILLS

- plan and implement investigative procedures (6.2, 7.2, 8.2, IPC, Physics, Astronomy)
- relationships between science and technology (8.5)

SCIENCE TEKS CONCEPTS

- Systems (6.5, 7.5)
- Characteristics and behavior of waves (Physics)
- Effects of waves in everyday life (IPC)

MATH TEKS

- Measurement (6.8)
- Underlying processes and mathematical tools (6.11, 6.13, 7.13, 8.14)

Preparation

Introduce the problem to the students by telling them that they are the optical team assigned to develop some way of getting the light from the PFIP to the spectrographs in the basement. The teams will evaluate a mirror-based solution and compare it with an optic fiber solution. Finally, divide students into investigation groups.

Challenge 1: Beam Bounce

Goal: Direct the beam from the penlight or laser pointer (the source) to the target, using a series of mirrors.

The goal is to direct the light beam around a barrier to a target on the other side, using a minimum number of mirrors. The barrier can be any solid, opaque shoebox-size object such as a stack of books or cardboard box. The barrier represents the obstacles between PFIP and the spectrographs in the basement (the target). The light beam models the light collected by the telescope. The students should also consider the path length of the beam. As the path length increases, more light is scattered out of the beam and the beam grows wider.

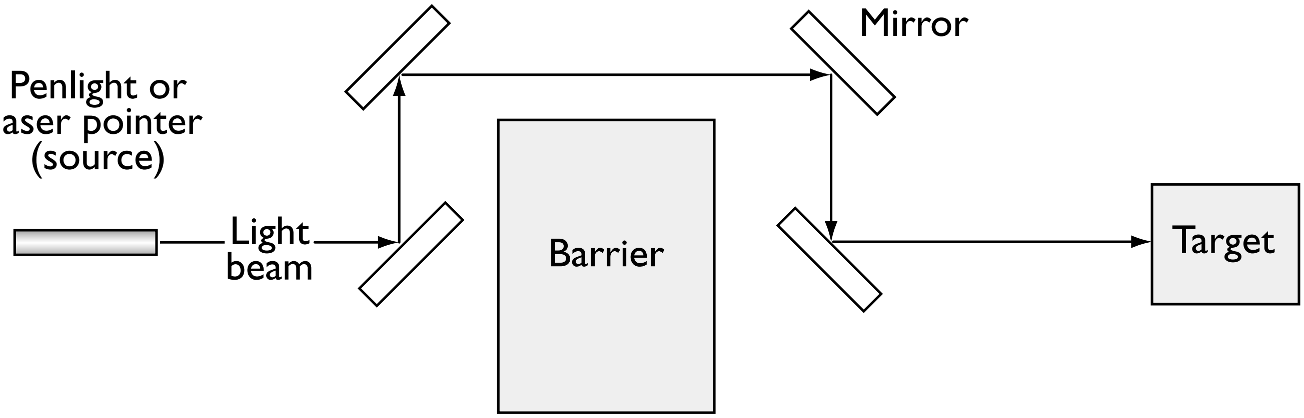
Measuring and Data

Each group should draw a diagram of its best solution after the group members experiment with placing their mirrors in different locations. The diagram should include information that would enable another group to reproduce the experiment:

1. Position and angle of the mirrors and the source.
2. Position of the barrier and target.

On the diagram, they should include a table to organize the following data:

1. Path length of the beam.
2. Number of mirrors.
3. Initial beam size. (Hint: Hold a paper in front of the source and trace the outside borders of the beam that illuminates it.)
4. Final beam size at the target. (Hint: Trace the outside of the beam at the target.)



Setup

Place the source facing center of the long side of the barrier. The source can pivot, but should point parallel to the table surface. The target should stand perpendicular to the table. It could be a block with a piece of graph paper covering the target side.

Solution

This is one solution. There is a two-mirror and possibly a single-mirror solution, depending on the size of the tabletop and barrier. Fewer mirrors mean that less light is lost due to scattering. During an astronomical observation, astronomers want as much light as possible flowing into their instruments.

You may extend the challenge by expanding the goal to include a minimum beam size at the target, compared with the beam size at the source. As the beam travels along the path, it diverges (gets wider) and scatters owing to particles in the air and imperfections in the mirror surface. The spectrograph at the target accepts only a narrow slit of light, not the whole beam. So, the longer and more complex the path, the less light enters the spectrograph.

Challenge 2: Beam Guide

Goal

Direct the light beam from the source to the target using an optic fiber.

There is another solution to Challenge 1 — use an optic fiber to carry the light from the source to the target. Instead of guiding the light with mirrors, each group must devise a way of getting the light from the source to the target via the optic fiber.

Setup

Include the electrical tape as a tool the groups can use. The source should lie on the tabletop and may pivot about its center. The target and source should lie on opposite sides of the barrier.

Measuring and Data

After experimenting, the students should draw a diagram of their best solution. They should include all the information they think is necessary to reproduce the experiment. They may want to comment about how they fastened the optic fiber to the source. In a table, students should record their data:

1. Size of the beam on the target. This will depend on the distance between the fiber end and the target.
2. Length of the optic fiber.
3. Optional: exit angle of the light from the fiber.

Analysis

Ask each group to compare their Challenge 1 and Challenge 2 data:

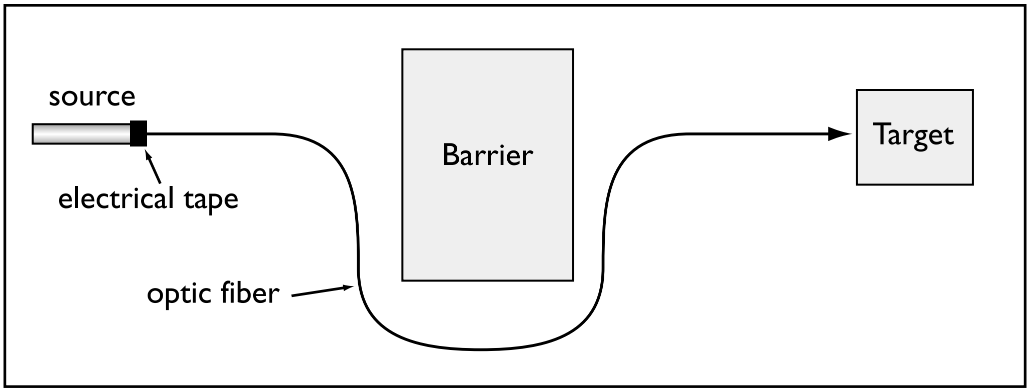
1. Beam size data.
2. Path length.

A few questions to consider:

1. What happens to the beam size as it travels to the target?
2. How would a change in the path length affect the beam size?
3. How much light enters the fiber from the source?
4. What would you suggest to increase the amount of light entering the fiber?
5. Over a long distance (across the classroom) separating the source and target, which solution would result in the brightest and most compact beam at the target? Assume you have a long optical fiber.
6. Which solution would an astronomer or telescope designer prefer, and why? What are the merits and limitations of each solution if applied to a telescope and instruments?

Solution

Fasten one end of the fiber to the source with the electrical tape. With the loose end, snake it around or over the barrier, bringing it as close to the target as possible.

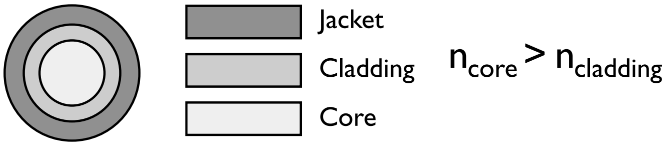


Challenge 3: Critical Angle

Goal

Set up an experiment to determine the critical angle for the model optic fiber.

The actual fiber that guides the light is two millimeters in diameter and is composed of three layers. The light actually flows through the central transparent plastic wire called the core. The cladding surrounds the core. It is a transparent material with an index of refraction (n) less than the core. The opaque durable jacket protects both the cladding and the core from outside light, weather, and abrasion.



Some students may think that the jacket "holds the light in." What does hold the light inside the fiber is total internal reflection. At the boundary between the core and cladding, light rays bend or refract back into the core all along the trip through the fiber.

In this challenge, the students seek the maximum incident angle for the beam to remain inside the core. This angle is called the critical angle; it is related to the indexes of refraction of both the core and cladding.

Instead of experimenting with a real fiber, the students will experiment with a model to determine the critical angle. In the model, the water is the core, and air is the cladding. Water's index of refraction is 1.33; air's is 1.00.

Setup

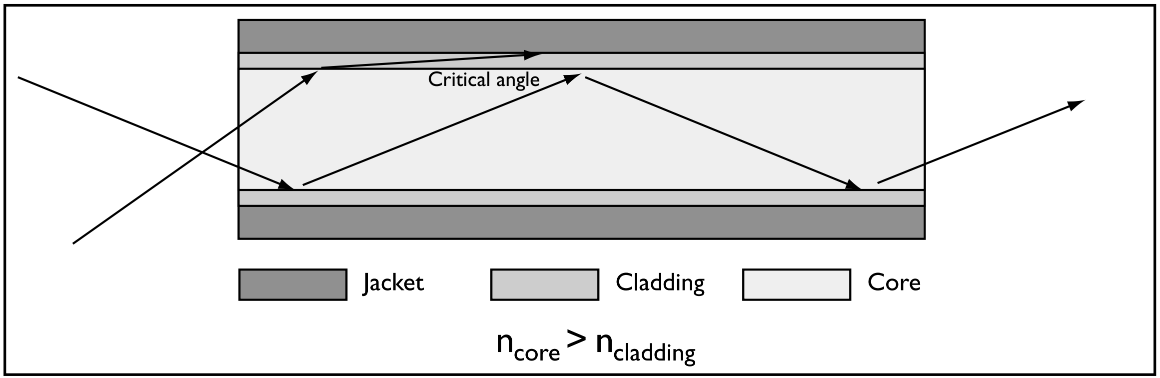
Each group needs a hex jar, penlight or laser pointer, protractor, and a black crayon. Add the smallest pinch of nondairy creamer to the hex jar, and then fill half way with water. The creamer should faintly cloud the water, so that the light beam shows up clearly inside the water. Set the hex jar on a tabletop, so that one angled end extends beyond the table. This makes it easy to shine the beam into the water toward the surface. Let the groups discover this on their own — it's part of the challenge to set up the experiment. Once the groups are set up, dim the lights so that the beams show up inside the water.

Measuring and Data

Groups will measure the incident angle and refracted angle of the beam. They should measure several different incident and refracted angles, and record each pair on a data table. A diagram showing the incident and refracted angles plus a data table is an ideal way to document their experiment.

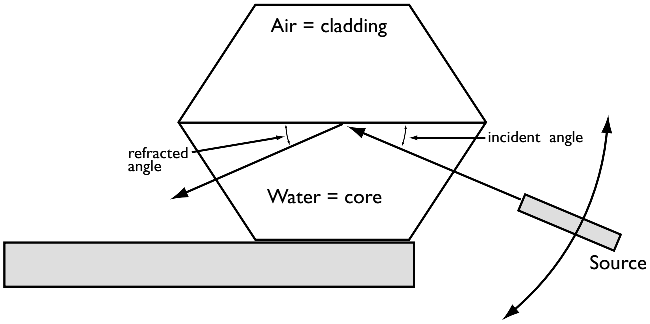
Analysis

1. Find the range of incident angles for which the beam remains in the water.
2. Determine the maximum angle. This is the critical angle.
3. Compare the incident angle with the refracted angle as the incident angle approaches the critical angle.
4. What would happen to a light beam with an incident angle greater than the critical angle?

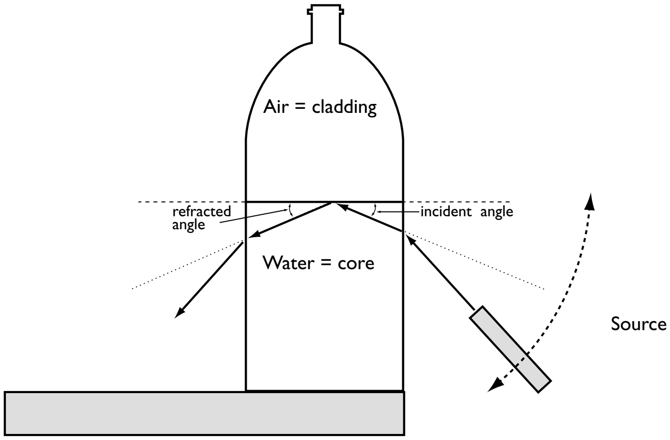


Solution

To determine the critical angle, students must solve several smaller problems such as measuring the light beam angle and recording and organizing data. The tools available are the hex jar, crayon, penlight or laser pointer, and protractor. The students may need some help getting their bearings in the problem space — identifying the subproblems and matching tools and techniques to a range of solutions.



The diagram above illustrates a possible way to set up the experiment using the hex jar. Tracing the beam with the crayon simplifies measurement of the angles. The students must be consistent with the method they use to trace the beam, since the beam is thicker than the crayon tracing. Shining the beam toward the same point on the water surface for each measurement trial also helps with consistency.



This alternative set up uses the 2-liter bottle instead of the hex jar. Since the bottle is curved, students must invent a way to measure the incident and refracted angles. Also notice what happens as the source beam enters and exits the bottle. Make sure that students are measuring the angles from where the beam hits the water surface at the water-air boundary.