# Teacher's Preparatory Guide

## Part 2: Jell-O® Waveguide and Power Loss

**Purpose:** This lab simulates how fiber optic cables transmit electronic data (such as email). Students will make a Jell-O® waveguide that will be used to guide a laser beam from one point to another and they will measure the power loss over distance. Students will learn:

- how light transmits through an optically transparent medium, such as a fiber optic cable or a waveguide
- how to measure the energy transmitted through a waveguide
- that a waveguide can be bent and still contain light
- if the waveguide bends too far, light can escape through the sides

Students should already be familiar with the concept of index of refraction, incident & reflected rays, and critical angle before beginning this lab.

**Level:** Middle school or high school physical science or physics

**Time required:** One and a half 50-minute class periods. If students make their own Jell-O®, they can do the Slinky®/Snaky® lab (*Part 1: Understanding Wave Motion*) for part of the class period and make the Jell-O® for the other part of the class period.

Day 1: Make the Jell-O® (20 minutes: 5 min. instructions & hand out supplies; 10 minutes making the Jell-O®; 5 minutes clean up).

Day 2: Make the Jell-O® waveguide and read the energy through the waveguide.

**Teacher Background:**

**Did you know?**

The wavelength of the visible light spectrum is between 400 nm–700 nm.

The nanoscale is defined as being 1 nm–100 nm.

Nanoscale objects are much smaller than the wavelength of light, which is why we cannot see nanoscale objects with optical microscopes.

When an email is sent, it goes through a computer network. Like highways, these networks are cables that span across the United States (and across most of the world). Just as regular mail is sorted and routed through post offices, email is sorted and routed through a computer called a *server*. The computer servers and cables together form a *computer network.*

To make information travel quickly, the data travels through *fiber optic cables.* The trouble is that data transfer slows down when it reaches the computer server, because the computer is using metallic wires instead of fiber optic cables. To speed things up, researchers are finding ways to use infrared light (heat or heat radiation; 0.7 - 300μm wavelength) control switching mechanisms in the servers. Infrared light can travel through *waveguides.* A waveguide

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is nothing more than an object or device that guides waves. Each one is specific for a specific frequency of wavelength. For example, optical fiber will guide light but not sound.

To do this, infrared light can be turned into lasers by amplifying the wave through internal reflection and then emit it at higher power. How does this work? A *standing wave* is what is generated inside a laser to amplify the wave—it resonates, gets stronger, and emits the strongest part. A musical instrument creates a *standing wave*. Light is a *transverse wave*. If you get a *transverse wave* to resonate so that its nodes are standing still, it becomes a *resonating standing wave*—similar to what is found inside a laser.

Why is this useful? Electrical signals traveling through coaxial cable (cable TV) loses half of its supplied power in 500 m, copper wires lose half of its supplied power in ½ to 1 mile (0.8–1.6 km), but fiber optics require 100 kilometers to lose half of its supplied power.

The way to make data transmission more efficient is by moving from electrical to optical media. Currently the connections between the nodes in the World Wide Web are all optical, but from the computer that serves as an internet provider (our ISP) to our home computer we're still using electrical connections. Nanotechnology, specifically nanophotonics, is examining the behavior of light at sub-wavelength scales to develop technology which will allow the interconnection of optical and electronic components.

The implications are that the entire computer system, from internet to our CPU, will end up optical rather than electrical so that it can continue to follow Moore's Law (http://en.wikipedia.org/wiki/Moore's_law) and bring us improved computer speeds ever faster, better, and cheaper.

**Teaching Strategies:** This activity works best in groups of 2 students. The information in the *Teacher Background* section above is a great lead-in to the activity. Students will be simulating a waveguide in a computer network with Jell-O®. Ask the questions in the *Guided Dialog* section below before beginning the lab. Review the materials and procedure *before* handing out the materials.

**Materials per class:**

- plastic food wrap (like Saran Wrap®), to line the bottom of each aluminum cake pan
- roll of scotch tape
- 2 cups water
- metal pot(s) or kettle to boil water
- heat source(s) to boil water
- measuring cup (1 cup)
- mixing bowl, 3 quart
- mixing spoon
- long, sharp knife to cut and trim Jell-O®
- plastic chopping board larger than the aluminum cake pan
- refrigerator large enough to contain the Jell-O® pans
- 2 tablespoons of powered sugar or finely ground salt

**Materials for each group of 2 students:**

- 6 oz. package of Jell-O® Gelatin Dessert, Lemon, (can be shared by two groups)
- aluminum square cake pan, 8 in. × 8 in. × 1.5 in. (can be shared by two groups)
- laser light pen, visible red light at 650 nm, common retail grade

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- photo cell (photodetector)
- 3 × 5 in. index card
- multimeter with leads
- set of alligator clips with a pair of leads (i.e., two wires with alligator clips at each end)
- sheet of graph paper
- pencil
- protractor
- metric ruler
- masking tape

**Safety Information:** Remind students to never shine laser light into anyone's eyes—including reflected laser light—it will harm a person's retina and can cause permanent blindness. Caution students when boiling water so that no one gets burned. Point out that water vapor can also cause burns.

**Advance Preparation:** Materials may be found at:

| | |
|---|---|
| **Digi-Key Corporation**<br>(800) 858-3616<br>http://search.digikey.com/scripts/DkSearch/dksus.dll?Detail?name=PDV-P5001-ND | • photodetectors (part number PDV-P5001; called CdS Photoconductive Photocells, made by Advanced Photonix, Inc.: http://www.advancedphotonix.com/ap_products/pdfs/PDV-P5001.pdf) |
| **SK Science Kit & Boreal Laboratories**<br>(800) 828-7777<br>http://sciencekit.com/key-chain-laser-pointer/p/IG0024470/ | • keychain red laser pointers |
| **All Electronics**<br>(888) 826-5432<br>http://www.allelectronics.com | • digital multimeters<br>• multiple colored jumper test leads with insulated alligator clips |
| **any grocery store** | • 6 oz. packages Jell-O® Gelatin Dessert, Lemon<br>• 8 in. × 8 in. × 1.5 in. cake pans<br>• plastic wrap<br>• measuring cups<br>• mixing bowl |

Note:
* Photodetectors purchased through Digi-Key Corporation are available with a good price break at 25 pieces, are the best size to work with, and will work well with a red laser.
* Keychain red laser pointers can be inexpensive. Avoid the long, laser pen lights—they have less power and cost too much. If the laser stops working, check to see whether the batteries are corroded. If they are, remove the corrosion from the batteries and the contact spring in the body of the pen light using a stiff pencil eraser. Then use a multimeter to measure the voltage across the batteries (it should be 1.5 V).
* An inexpensive multimeter and an inexpensive package of 10 multiple colored jumper test leads with insulated alligator clips can be bought from All Electronics.

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1. **Make Jell-O®**
   Make Jell-O® as described in *Procedure for Making Jell-O®* below.
2. **Cut Jell-O®**
   After the Jell-O® has set, but before the lab begins, put the Jell-O® onto a cutting board, cut opposite ends square, then cut it into 5 equal sections (about 7 in. × 1.5 in.) using a long, sharp knife. Put the Jell-O® back into the pan (use the plastic wrap to lift/lower the gelatin) to transport it.
3. **Mount photodetectors on index cards**
   Mount photodetectors on index cards as described in *Procedure for Mounting Photodetectors* below.
4. **Learn how to use the multimeter**
   Learn how to use the multimeter; i.e., test with ohms by touching the two leads together to get 1, or the highest reading, and also setting it to DCV and reading a 1½ volt battery.

## Procedure for Making Jell-O®

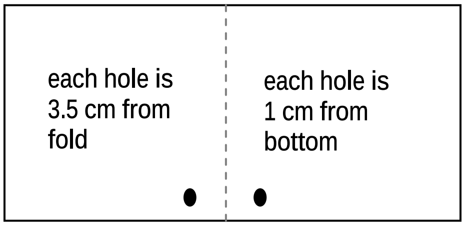
You can either prepare this beforehand for your students (one pan per group), or allow 20 minutes in class previous to this lab for each group to prepare their own pan of Jell-O®.

*(Note: If you follow the instructions on the Jell-O® box, do NOT add the final 2 cups of cold water to the mix.)*

1. Line a square pan with the plastic food wrap. Tape the plastic wrap to the sides to keep it in place while pouring the hot liquid Jell-O®. This lining will serve to easily lift the Jell-O® from the pan.
2. Boil 2 cups of water.
3. Put a 6 oz package of yellow Jell-O® into a mixing bowl. Gently stir the boiling water to mix well (about 3 minutes).
4. Pour this mixture into the square pan. Be sure the plastic wrap stays in place. Put all pans into a refrigerator to cool and set overnight.

## Procedure for Mounting Photodetectors

Students can be guided through this procedure if class time allows.



1. Fold the index card in half.
2. Measure and mark a dot 3.5 cm from either side of the fold and 1 cm from the bottom. Poke two tiny holes at the dots with a pen or other sharp object.
3. Put the wires (leads) of the photodetector through the holes.

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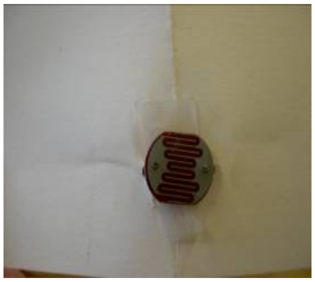
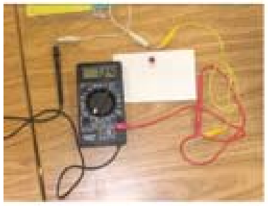
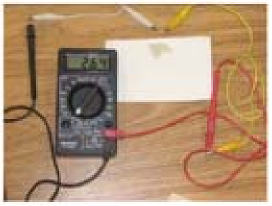
4. Roll a piece of tape and put it on the back of the photodetector. Press the photodetector to the card to hold it in place. Bend the wires away from each other so that they do not touch each other (and to help hold the photodetector in place).

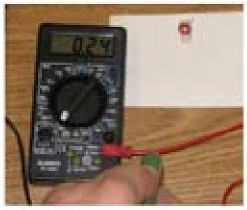

Above: photodetector taped to a folded index card

**Procedure:** The student worksheet has a simplified version of this detailed procedure. Demonstrate the procedure *before* handing out materials so that students will pay attention.

1. Attach the alligator clips to the photo detector wires and plug the other ends into the multimeter. The photo detector wires should not touch each other.
2. Set the multimeter to measure resistance (Ohms, Ω), and set the meter to 20 kΩ. The resistance will decrease as the illumination on the photodetector increases.
3. Measure and record the readings on the multimeter for ambient light (the light regularly in the classroom), with ambient light blocked by a piece of masking tape, and with laser light shining directly on the photo detector. ***Possible*** *multimeter readings are about 4,000 Ω (40 kΩ) in normal light, about 14,000 Ω (140 kΩ) when the photodetector is blocked, and about 800 Ω (0.8 kΩ) with the laser light shining on it. These will vary due to the intensity of the ambient light and the laser.*


ambient light


ambient light blocked


red laser light

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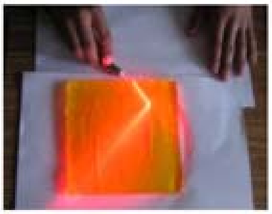
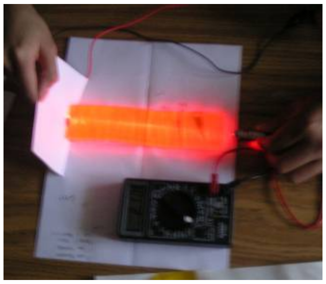
4. Lay the Jell-O® (that has already been cut into strips) flat on a sheet of paper and take the laser pointer and shine it through the width and length of the Jell-O® waveguide.

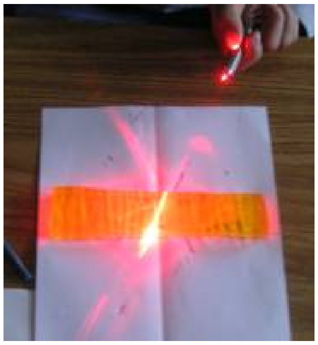

cutting the Jell-O®


refraction in Jell-O®


refraction & reflection
at slice



5. Place one section of Jell-O® on paper. Hold the photocell on one side of the waveguide. Shine the laser directly into the waveguide (Jell-O® ) so it strikes the photocell on the other side of the waveguide, and collect the data.
6. Repeat along the long side of the waveguide; then keep adding waveguides end-to-end, shining the laser through the waveguide material, and see how many you can add and still get a reading. Collect data from the multimeter each time and plot these results as resistance on the *y*-axis and distance on the *x*-axis to determine the loss of intensity over distance of waveguide material.



7. Draw an *x*-axis and *y*-axis on graph paper. Place a straight section of waveguide along the *x*-axis with the line along its edge.
8. Shine the laser into the intersection of these lines. Trace the path of the incident light beam. Mark where the refracted beam comes out of the Jell-O® waveguide on the other side.
9. Remove the Jell-O®. Use a protractor to measure the incident angle, $\theta_1$, and the refracted angle, $\theta_2$.
10. Calculate the index of refraction of the Jell-O® $n_2$, using Snell's law: $n_1\sin\theta_1 = n_2\sin\theta_2$. The value for $n_1$ of air = 1.

**Guided Dialog** Before beginning the lab, ask students questions to provoke thought and review what they already know. For example:
Ask students to raise their hands if they have used email. Then ask the following questions:

1. When you write an email to a friend, what happens to the email when you click *send*? *When an email is sent, it travels through a computer network to the friend.*

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2. How does the email get from one place to another? *Like highways, these networks are cables that span across the United States (and across most of the world).*
3. How is email similar to mail that is delivered through the post office. *Just as regular mail is sorted and routed through post offices, email is sorted and routed through a computer called a server. The computer servers and cables together form a computer network.*

Review the meaning of these terms:

**Critical angle** *An angle where all the internal transmitted light is kept inside the waveguide because the angle $\theta$ of the source wave (inside the waveguide) is greater than $\theta_c$ for that material and $\sin \theta_c = n_2/n_1$. At this point $\theta_1 = \theta_c$ and $\theta_2 = 90.0°$, which means the transmitted wave trying to get out of the waveguide is a t 90.0° to the normal and this keeps the light from escaping the waveguide.*

**Incident ray** *Incoming or source wave of light.*

**Index of refraction** *The measure of how easily light can move through transparent media, related to the substance rather than angles of the light, and known as Snell's Law of Refraction, where $n_1 \sin\theta_1 = n_2 \sin\theta_2$, and n is the index of refraction, 1 refers to the incident wave and 2 refers to the refracted or reflected wave.*

**Infrared** *Light with a wavelength of 600 nanometers.*

**Interface** *Where the two media meet, such as laser light and waveguide, or air and waveguide.*

**ISP** ***I**nternet **S**ervice **P**rovider*

**Laser** ***L**ight **A**mplification by **S**timulated **E**mission of **R**adiation*

**Micro** *Prefix using the symbol μ, which is $10^{-6}$, and when referring to micrometer, μm, this is one millionth of a meter, or it takes 1000 μm to equal 1 millimeter, mm.*

**Milli** *Prefix using the symbol m, which is $10^{-3}$, and when referring to millimeter, mm, this is one thousandth of a meter, or it takes 1000 mm to equal 1 meter, m.*

**Moore's Law**

- **1st law** *Chip size reduces by half every 18 months (i.e., the number of transistors on a chip doubles every 18 months); [this is the good news]*
- **2nd law** *Cost of building a chip manufacturing plant doubles every 36 months; [this is the bad news]*

**Nano** *Prefix using the symbol n, which is $10^{-9}$, and when referring to nanometer, nm, this is one billionth of a meter, or it takes 1000 nm to equal 1 micrometer.*

**Nanofabrication** *Building things at the nano scale.*

**Nano scale** *Refers to anything from 1 nm to 100 nm in size.*

**Normal** *An angle perpendicular to the surface the wave is striking.*

**Optronics** *Making use of optics and electronics in systems used to generate, control, and detect photons.*

**Photon** *Electromagnetic energy in a discrete particle with zero mass, no electrical charge, and an indefinitely long lifetime.*

**Photonics** *The application of electromagnetic energy, with a base unit of the photon, incorporating optics, lasers technology, and information storage and processing.*

**Reflected wave** *Wave that has bounced off an impenetrable surface or media, or a denser media, and the incoming wave either bounces straight back or at an angle equal to the angle it hit measured from the normal.*

**Refracted ray** *Light that has gone through a different media and has become bent according to Snell's Law.*

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**Source wave** *The wave generated by the laser pen and going into the waveguide.*
**Transmitted wave** *The wave moving through the waveguide, exiting the other end of the waveguide to the detector.*
**Visible light** *Red, orange, yellow, green, blue, indigo, violet (ROYGBIV) visible light; and wavelength extends from red light, with a wavelength of 700 nm, to violet light, with a wavelength of 400 nm.*
**Multimeter** *Reads volts, ohms and amps, and can be a digital meter or a simple analog meter that anyone can easily use; also known as volt-ohm meter.*
**Wavelength** *Length of one cycle of a wave measured between two consecutive parts of the wave, such as the crests, and measured perpendicular to its direction of motion.*

**Cleanup:** Have students deposit Jell-O® the in the lab waste bin. Collect all of the lasers, photodectectors, multimeters, alligator clips , and pans for future use.

## Assessment

At the end of this lesson, students will be able to explain that light can move through optically transparent material and that it can be bent and still stay within the material when it strikes the side greater than the critical angle.

The light intensity can be measured by how much it decreases over distance, and the light wave can also be measured by how it bends, refracts, using Snell's Law when the incident rays within one optically transparent material refract into another optically transparent material, and this is where the connection with the Slinky® and the Snaky® in *Part 1: Understanding Wave Motion* come in because they had different masses and tensions which are similar to different indexes of refraction.

This entire analogy is to compare visible light in Jell-O® with infrared light in Indium Phosphide (InP) semiconductor waveguides that will be used for internet communications processing at the nodes in routers on the internet and other communications processing systems.

## National Science Education Standards (Grades 5–8)

Content Standard A: Scientific as Inquiry
- Abilities necessary to do scientific inquiry

Content Standard E: Science and Technology
- Abilities of technological design

Content Standard F: Science in Personal and Social Perspectives
- Science and technology in society

## National Science Education Standards (Grades 9–12)

Content Standard A: Scientific as Inquiry
- Abilities necessary to do scientific inquiry

Content Standard E: Science and Technology
- Abilities of technological design

Content Standard F: Science in Personal and Social Perspectives
- Science and technology in local, national, and global challenges

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