# Young Physicists Program: March 2011
# Lab 6: Waves/Optics

## Laboratory: Sound and matter waves, lenses

**Introduction**

You will be introduced to two very established but very important topics in physics today: waves and optics! The two are a bit different in the contexts we are studying them in, but they are both quite interrelated, being based on the concept of a wave and what medium it travels in. Take a second before you start the lab to discuss: What is a **wave**? What are the criterion for calling something a wave- **energy content**, **coherence**, **wavelength** and **frequency**? How are sound waves different from the ocean waves you surf? What similarities are there? Now switching gears later in the lab, think about how light, which is a very special wave (an **electromagnetic wave**), behaves in various situations. What is a **convex** and a **concave** lens and what do they do to a beam of light? What kind of lens does your eye provide for incoming light?

**Transverse waves: string**

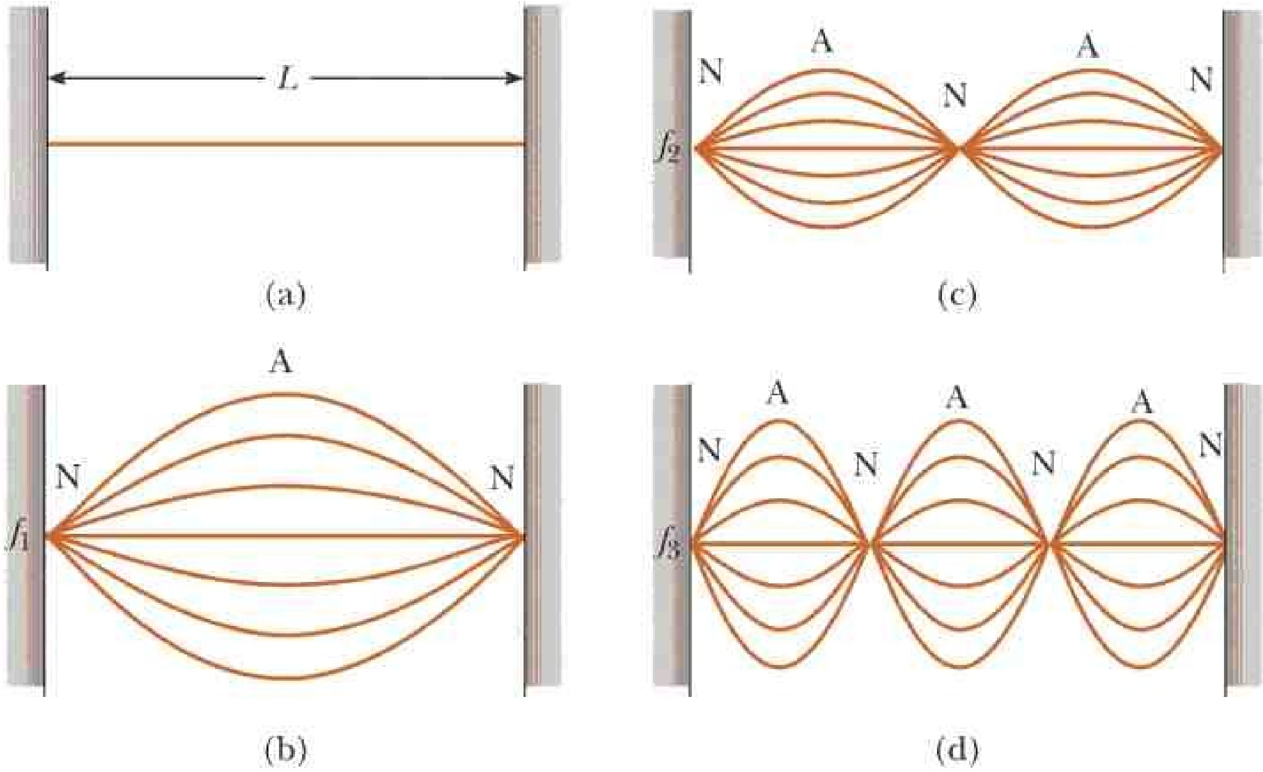
You should have a piece of rope several meters long. Next to your lab bench you will find a length of red tape on the floor. With a person at each end of the rope stretch it out straight on the floor so the center of the rope is at the tape and the rope is perpendicular to the tape. You don't need to pull on the rope, let it be a little slack. Send a pulse down the rope by quickly moving one end about 6 inches out and back.

- Observe the motion of the mid point of the rope as the pulse passes though it. Wrap the rope with a small piece of colored tape at its mid point. This is also where the rope reaches the tape on the floor. Observe the motion of the tape on the rope at this point with reference to the tape on the floor.
- Which way does the pulse move? Which way does the piece of tape on the rope move? Are they in the same directions?
- Describe in words how the rope moves. What actually moves down the rope?
- Observe the reflection at the end. After reflection, is the pulse the same way up or is it upside down?

Now try to see if you can observe what happens when two pulses pass each other going in opposite directions. Both people holding the rope should now send pulses at the same time. This will take some practice.

- Talk about the "principle of superposition" and how this is being demonstrated in your lab
- If both pulses have displacements in the same direction would you expect the displacement where the pulses overlap to be larger or smaller than the individual pulses?
- Try making one positive displacement pulse and one negative displacement pulse in the same fashion

Finally, see if you can create "standing waves" on the rope. How are these formed? Hold the rope fairly loosely on the floor as you did before. Move one end of the rope backwards and forwards with a smooth periodic motion, and hold the other end still. Now you should have waves that are almost sine waves traveling down the rope all the time. They are reflected at the end and move back along the rope in the opposite direction and with inverted displacement.




Try making standing waves like those in the image above. The figure in (b) of the image is called the fundamental and is easiest to make. What is required to establish the standing waves in (c) and (d)? How are the concepts of frequency ($\nu$) and wavelength ($\lambda$) being demonstrated and which changes in each of the figures? How $\lambda$ and $\nu$ related?

**Longitudinal waves: slinky**

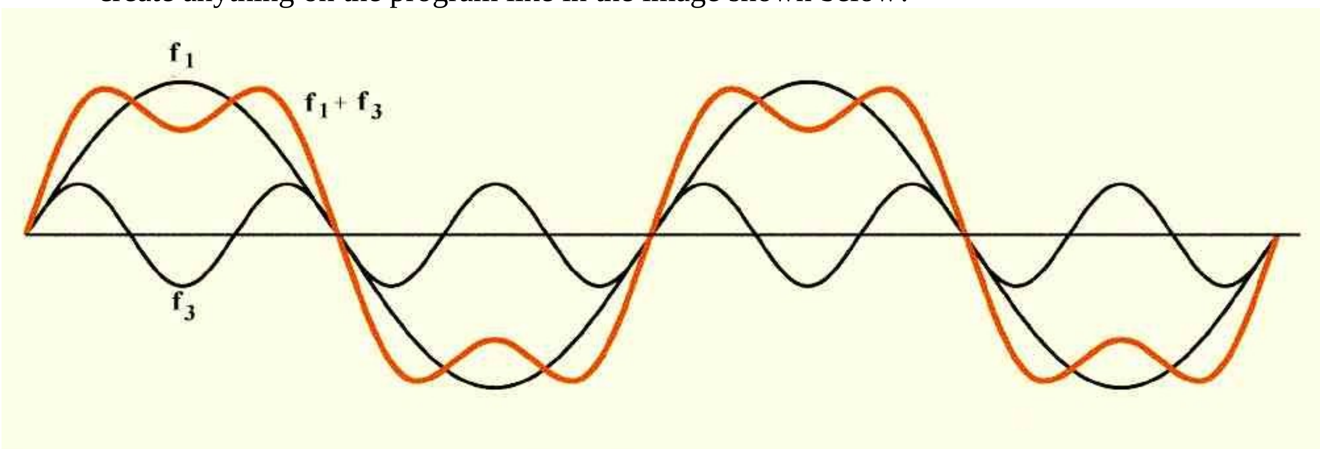
- Gently stretch the slinky across the length of the lab bench with a person holding each end. Use the full length of the table and the full length of the slinky. Are the coils evenly spaced?
- Keeping one end fixed, move the other end about 5 cm (2 inches) in and then back out. Do this as quickly as you can. The motion shortens the slinky for a very short period of time and sends a pulse down the slinky. How can you tell a pulse is traveling along the slinky? Does the pulse reflect off the fixed end?
- Attach a small piece of colored tape to a coil near the middle of the slinky. Watch what happens to that coil as the pulse passes. Which way does it move first? Does it end up in the same position where it started? What is it that has actually traveled down the slinky?
- How are these waves different from the ones you created with the rope? How are they similar? You've seen frequency and wavelength in transverse waves- how do you identify them here?
- What are some examples of transverse and longitudinal waves in nature?

**Harmonic content and frequency**

You may have noticed the curve of the standing waves you created a bit back- they were sine waves. One can always represent a wave as a sine wave- whether the displacement is in time or in position (like with the string). However, this only applies if the wave has only ONE frequency. Most things in nature, like the music you listen to or your own voice- which are both just pressure waves of the nature

we talked about before (longitudinal or transverse!?) - are a bunch of frequencies of sound on top of one another. There is a very famous theorem that states that any of these really complex waves are just a bunch of simple sine waves added on top of one another.
Let's check this out with tuning forks. Tuning forks vibrate at only one frequency- so we will get a nice clean sine wave out of them. However, we can put two tuning forks together that vibrate at different frequencies and see something a bit more complicated.

- Start the “Mathematics of Music” file. Just search for this file on your computer in the Spotlight feature, or ask how to find it.
- What are the frequencies of each of your tuning forks, individually? You can change the frequency of one of your tuning forks by moving the metal clamp on it. Check on the program running on the computer.
- What does the program read when you play both tuning forks at the same time? See if you can get both vibrating at the same frequency. What happens as you change the adjustable tuning fork's frequency? What if the two frequencies are very different? What if they are *almost* the same but not quite? Can you establish a “beat” frequency and describe what it is? Can you create anything on the program like in the image shown below?




- What does the “harmonic content” of your voice look like? What do I mean by “harmonic content”? How close can you get your voice to only playing one frequency, and what will this look like on the program? What happens if you sing “aaaaaaaaaaaa” versus “eeeeeeeeeeeee” or “qqqqqqqqqqqqqq”? (I am interested in seeing the results of the last test) Are you the next AMERICAN IDOL?

**Switching gears: An Introduction to Optics**
We are going to gain a basic understanding for the equation

$$\frac{1}{S_1}+\frac{1}{S_2}=\frac{1}{f}$$

(sometimes called the “Lensmaker's equation”) and its relation, for example, to the following diagrams.

- Set up your optics workbench so that you have your target screen and your lightbox clipped in.
- This is only meant as an introduction, so place various lens in between the lightbox in the target:
  - First a (bi)convex (hereafter referred to as a convex lens) lens.
  - A concave lens.
  - A convex lens then a concave lens.
  - A concave lens then a convex lens. Does the order matter?
  - Two convex lenses; separately, to concave lenses.

- What happens in each case- does the image always come into focus at a certain distance? Over what range does the image form? When is the image inverted? Why does the order of the lenses in between the light source and the target matter?
- Which lens- concave or convex- causes light to “converge”? Which lens causes divergence? What is the focal length of a lens and what does it mean?
- How in the heck is the Lensmaker's Equation useful in these situations?
- What type of lens does your eye provide? How does your eye focus on objects? This is equivalent to changing the focal length of your eyeball!
- Finally, because we need to know how we set matches on fire with a lightbulb across the room, how are convex and concave mirrors, respectively, related to their cousins, convex and concave lenses? (Hint/answer: their properties are reversed, in a sense! What sense is this?)

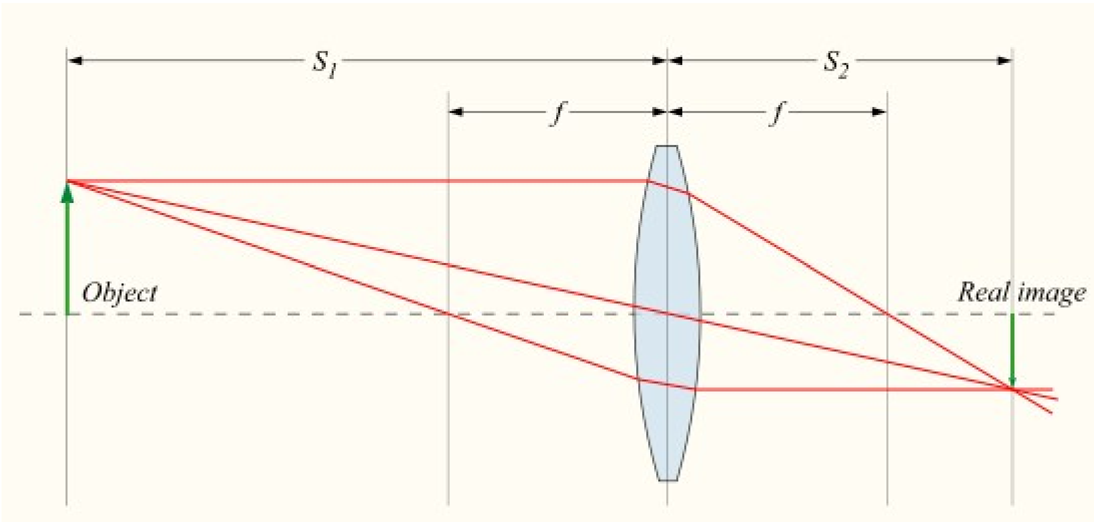



*Illustration 1: (Bi)convex lens.*

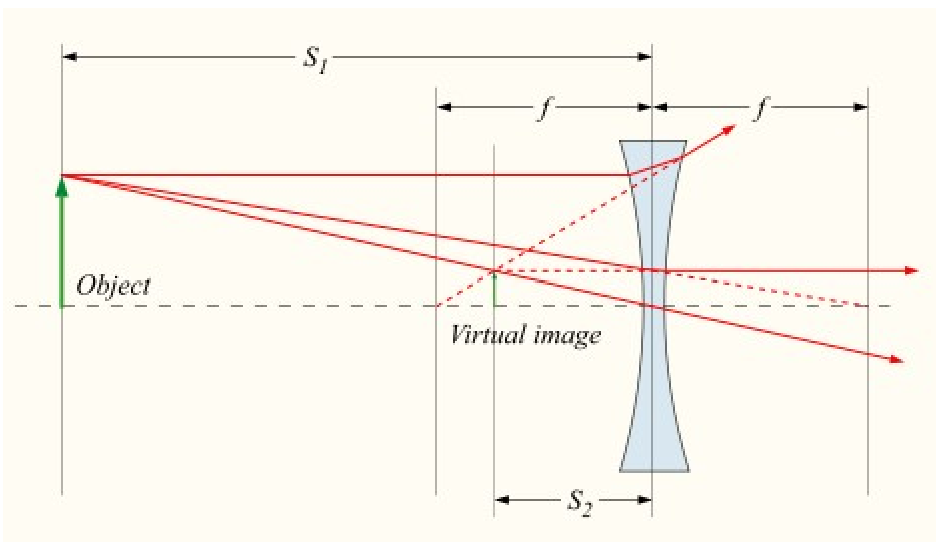



*Illustration 2: (Bi)concave lens.*

## Demonstrations: Singing tubes, defacing Abraham Lincoln's image, matches and mirrors

[performed during the YPP meeting]