

### Assignment Three:

Due Week 14 Fri. Feb. 3 by 5 pm to Krishna's office (Lab 2 3255)

Address relevant material from discussion, lab, and reading from Weeks 11, 12, and 13; you may include material from Week 14 as you choose

Tell stories (either new ones or expand your previous stories) that combine words, graphs, pictures, and/or equations to:

- demonstrate **connections** between what you have **learned about physics** through discussions, observations, and reading (make sure to **address lecture/seminar, lab, pre-class assignments, and reading**)
- show your **changed understanding** of the **natural** and/or **human-constructed worlds**
- describe your **surprise with the story** that Kumar (and/or Frayn) is telling.

### General Outline For Today

There are four separate activities for today's work:

- 1) Patterns of Light
- 2) Scattering off Shapes
- 3) Spring Waves
- 4) Calculating Hydrogen Energy Levels

### Goals

- Improve communication and teamwork capacities
- Gain confidence in scientific investigation, including appropriate use of equipment
- Keep careful records of observations
- Observe the patterns formed by light as it passes through different openings
- Deduce the shape of an unknown hidden object by scattering marbles off it
- Create and observe traveling waves, standing waves, and wave superposition on a long spring
- Use the Bohr model of hydrogen to calculate energy levels of the atom and the energy and wavelength of the emission spectrum

## Patterns of Light

**Equipment – make sure to return all equipment to location you borrowed it from, especially optics drawers**

- Lab stand & clamps
  - Optics mount (in optics drawer)
  - Screen (in optics drawer)
  - Flashlight (in optics drawer)
  - Ruler (cart)
  - Laser levels (cart) – **caution: don't shine or reflect the laser directly into your eye**
  - Cornell Slitfilm (cart) – **caution: made of glass**
  - Cornell Slitfilm schematic (cart)
- There's an example station demonstrated in the front of the room. Set up your station in a similar fashion. Please spread out, with one lab group per table; use both rooms.
  - Mount and orient the Cornell slitfilm so that the writing is upright, with the writing facing the laser.
  - Set up the laser at one end of your table with the Cornell slitfilm at such a distance that the laser spot goes through one pattern at a time. Set up your white screen at the other end of your table, as far from the slit as possible. You may find that you need to bring the screen closer, but start there.
  - In the upper left corner (marked A) is a single window, or opening, or slit. B, C, D, and E are also single slits, but get narrower as you go down the row. Shine the laser spot through the upper left single slit, and observe the pattern on the screen. If needed, use a notebook to shade the projected spot on the screen so that any overhead room light is blocked from the screen.
  - Record your observations. Use a ruler to determine the width of the spot on the screen.
  - Make your best guess before carrying out the experiment: Slit C is also a single slit, but it is narrower than slit A. What do you think will happen to the shape of the spot when you shine the laser through slit C? Do you think the pattern will become wider or narrower (compared to slit A)? Brighter or darker? Other changes?

- g) Now, test your guess by shining the laser through slit C. What do you observe? Use your ruler to make measurements if needed.
- h) Slit E is also a single slit, but it is narrower than slit C. Shine the laser through slit E. What do you observe? Use your ruler to make measurements if needed.
- i) Previously, you had a single window, or opening, or slit. Next, you will explore what happens if you “open another window”, in other words, what happens if you have two slits. Look at the upper right hand corner (marked E), which is a single slit, just like the single slit E in the lower left hand corner. Below this slit E in the upper right hand corner are a series of two slits, with the same width for each slit, but with increasing space between the slits (these are like two windows each of the “same size but with increasing distance between the windows.) Shine the laser through slit E in the upper right hand corner.
- j) Make your best guess before carrying out the experiment: What do you think will happen to the shape of the spot if you “open another window” when you shine the laser through G? H? I? J?
- k) Now, test your guess by shining the laser through each of G, H, I, and J. What do you observe? Use your ruler to make measurements if needed.
- l) F, K, L, M, and N are identical slits, evenly spaced, but increasing in number (so this is like opening more and more windows that are the same shape and size and evenly spaced). Shine the laser through each of F, K, L, M, and N. What do you observe? Use your ruler to make measurements if needed.
- m) The middle row varies, with different numbers of slits, widths, and spacing. Choose at least 2, and shine your laser through each. What do you observe? Use your ruler to make measurements if needed.
- n) Choose the configuration that you gave you the most interesting pattern. What do you think would happen if you use a green laser instead of a red laser? Set it up with the red laser. Krishna and Sina each have a green laser. Have them also shine the green laser through your chosen configuration so you can compare the two colors. What do you observe?
- o) Return all equipment (well, keep the ruler).

## Scattering off Shapes

### Equipment – make sure to return all equipment to location you borrowed it from

- Masonite board, labeled with a letter (table) – **caution: don’t turn the board upside down**
- Two marbles of different sizes (cart) – **caution: these are likely to roll away, so use meter sticks as barriers**
- Ruler & 2 meter sticks
- Blank piece of paper & some pieces of tape to attach the paper to the top of the masonite board

- a) Try not to flip the masonite board over.
- b) Place the masonite board on your table. Write the letter on the board in the corner of your blank piece of paper, and tape the paper to the top of the masonite board.
- c) Roll the larger marble underneath the masonite board, through the “curtain”. The marble will either miss the “hidden” object and continue in a straight line, or deflect (“scatter”) off the “hidden” object and change its straight line motion. You need to make sure that the incoming marble is coming in fast enough that it moves in a straight line before and after the scattering, but not so fast that you can’t see where it came out.
- d) Draw the incoming and outgoing straight line trajectories of the marble directly on the paper. You may want to use the ruler to guide the marble in, and also use the ruler to draw the straight incoming and outgoing lines. Extend the lines until they intersect so that you have the incoming line, the collision location, and the deflected outgoing line. Label this first incoming and outgoing line with a small number 1.
- e) Do this for a series of incoming lines spaced an even distance apart, all on one side of the masonite board, drawing the incoming and outgoing lines. Label each set with a consecutive small number (the second incoming and outgoing line with a 2, the third incoming and outgoing line with a 3, etc.)
- f) Repeat for each side of the masonite board.
- g) By the end, you should have multiple incoming/outgoing lines for each side of the masonite board. Remove the paper. Can you use this information to determine the shape of the “hidden” object? Draw your best guess for the shape of the “hidden” object.
- h) When done, flip the board over to “reveal” the shape. How close did you come?
- i) Return all equipment.
- j) Make sure to make copies of your paper for each member of your group (there are photocopiers in the library, or you can scan it and email it, or you can take a picture and share it, etc.)

# Slinky Waves

**Equipment – make sure to return all equipment to location you borrowed it from**

- Slinky/Flat Coil Spring
  - Meter stick
- Sina and Krishna have demonstrated how to make standing waves on the slinky. Have two people (person A and person B) hold each end of the slinky and stand a fixed distance apart, stretching the slinky between them. Measure and record this distance, which you should hold fixed for the duration.
  - Person A should hold her/his end stationary, while Person B moves her/his end. Make a standing wave with one bump.
  - Switch roles, so that Person B is holding the stationary end, and Person A is moving the end. Again, make a standing wave with one bump. We'll call this the fundamental or the first harmonic.
  - Repeat, but this time make a standing wave with two bumps and a node in the middle. We'll call this the second harmonic or the first overtone.
  - Repeat, but this time make a standing wave with three bumps and nodes 1/3 of the way and 2/3 of the way. We'll call this the third harmonic or the second overtone.
  - What is the maximum number of bumps you can make?
  - Sketch the wave patterns you made. What was the wavelength of each of the standing waves you made? Note that you know the distance between the two ends of the standing wave.
  - Each standing wave you made had a distinct wavelength. What can you say about the location of the wave?
  - This next will take some patience and practice. Person A should identify the frequency required to get a standing wave with one bump (the first harmonic). Then, Person B should identify the frequency required to get a standing wave with two bumps (the second harmonic). Paying careful attention to just the frequency each person should drive at, Person A should drive at the first harmonic frequency while at the same time Person B should drive at the second harmonic frequency. It might be easier if the Persons don't look at the wave pattern. The remaining partner should describe what she or he sees as a result of trying to add together the first harmonic and second harmonic on the same slinky.
  - Again, stand with the slinky stretched out between two people. One person should give the slinky a sharp jerk, trying to send a well defined wave pulse down the slinky. What can you say about the location of the wave pulse? What can you say about the wavelength of the pulse?

## Calculating Hydrogen Energy Levels

**Equipment – none to borrow, but you'll want a calculator. Complete after lab if you run out of time.**

In this computationally intensive exercise, you will use: the relationship between wavelength, frequency, and speed of light; the Einstein-Planck relationship between frequency and energy of light; and the Bohr model of hydrogen's prediction of energy levels; to calculate theoretical values for the wavelengths of light emitted by a hydrogen atom, and compare this to your measured values for the wavelengths of light emitted by hydrogen from the Week 11 Lab.

The relationship between wavelength ( $\lambda$ ), frequency ( $\nu$  or  $f$ ), and speed of light ( $c$ ) is:

$$\lambda \cdot \nu = c$$

Recall that (in vacuum) the speed of light  $c = 3 \times 10^8 \text{ m/s} = 3 \times 10^{17} \text{ nm/s}$  is a fundamental constant of nature.

The Einstein-Planck relationship between frequency ( $\nu$  or  $f$ ) and energy of light ( $E_{ph}$ ), where  $ph$  is short for photon, is:

$$E_{ph} = h \cdot \nu$$

where  $h$  is a fundamental constant of nature called Planck's constant.

We can combine these relationships  $\lambda \cdot \nu = c$  and  $E_{ph} = h \cdot \nu$  as follows (make sure you follow how this works):

$$\lambda \cdot \nu = c \Rightarrow \nu = \frac{c}{\lambda}$$

$$E_{ph} = h \cdot \nu = h \cdot \frac{c}{\lambda} = \frac{hc}{\lambda}$$

Since  $h$  and  $c$  are fundamental constants, then their product is also a constant, so we can

write  $E_{ph}$  as follows: 
$$E_{ph} = \frac{hc}{\lambda} = \frac{1240 \text{ eV} \cdot \text{nm}}{\lambda},$$

where eV is short for "electron volt", which is a unit of energy.

The energy levels of the hydrogen atom were predicted by Bohr's model, which combined some classical with some quantum aspects. Though Bohr's model is incorrect in many ways, it does predict the same principal energy levels as a full blown quantum mechanical treatment.

The principal energy levels of the hydrogen atom are given by:

$$E_n = \frac{-13.6 \text{ eV}}{n^2},$$

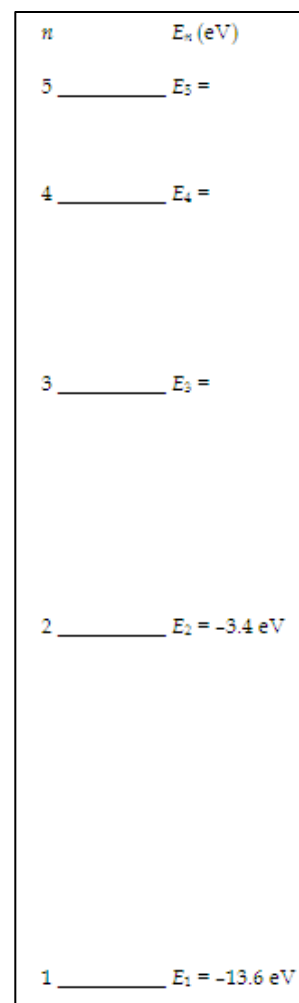
with  $n$  being the number of the energy level, which are the integers from 1 to infinity, and  $E_n$  as the energy of that level. The negative sign might be confusing (how can something have negative energy?) but its physical meaning here is that the electron is bound in the hydrogen atom. Here are two examples of how to use this formula:

For  $n = 1 \Rightarrow E_1 = \frac{-13.6 \text{ eV}}{1^2} = -13.6 \text{ eV}.$

For  $n = 2 \Rightarrow E_2 = \frac{-13.6 \text{ eV}}{2^2} = \frac{-13.6 \text{ eV}}{4} = -3.4 \text{ eV}.$

The boxed diagram above to the right shows a partial energy level diagram of hydrogen; note that the energy level spacings are not to scale and that  $E_1$  and  $E_2$  are already filled in.

Calculate the energies of levels  $n = 3, n = 4, n = 5$ , and label the level with its energy on the diagram.



Now, complete this table. I've filled in one row to show how it goes. Do the calculations separately (don't cram the calculations into the table) in your notes.

Compare your predicted spectral line wavelengths with your experimental results from the Week 11 Lab.

transition $n_i \rightarrow n_f$	$E_f$ (eV)	$E_i$ (eV)	$\Delta E =$ $E_f - E_i$ (eV)	$E_{ph} =  \Delta E $ (eV)	$\lambda$ (nm)
5 $\rightarrow$ 2	-3.4				
4 $\rightarrow$ 2	-3.4				
3 $\rightarrow$ 2	-3.4				
5 $\rightarrow$ 1	-13.6				
4 $\rightarrow$ 1	-13.6				
3 $\rightarrow$ 1	-13.6				
2 $\rightarrow$ 1	-13.6	-3.4	$-13.6 - (-3.4) =$ $-10.2$	10.2	$\lambda = \frac{1240 \text{ eV} \cdot \text{nm}}{E_{ph}}$ $= \frac{1240 \text{ eV} \cdot \text{nm}}{10.2 \text{ eV}}$ $= 122 \text{ nm}$

