Stages of Discovery
Wednesday February 1
Week 14 Physics Lab

Name:_____

General Outline for Today

There are five activities for today's work:

1) Wavefunctions and Probability (we'll do this together)
2) Calculating Energy Levels & Spectra (continues work from last week's lab)
3) Localizing Waves & the Uncertainty Principle
4) Quantum Wave Interference
5) Concept Mapping & Synthesis (see Calendar page)

Goals

- Connect wavefunctions to the probabilistic behavior of quantum particles.
- Use energy levels for different systems to determine the wavelengths of their associated spectra.
- Observe how localizing waves in space results in increased spread in wavelength, and connect this to the Uncertainty Principle.
- Explore the behavior of photons and electrons in the two-slit interference experiment.
- Construct a concept map of quantum mechanics concepts and connect it to scientists, historical experiments, and hands-on and computer activities.

1) Wavefunctions and Probability

a) Go to www.kcvs.ca then click on Visualizations, then Modern Physics, then scroll down to Particle in a 1-dimensional box and Run Applet.
b) Follow along with the class discussion.

2) Calculating Energy Levels & Spectra

a) Complete the final part of last week's lab (Calculating Hydrogen Energy Levels) if you have not already.
b) (You may still have this open from before). Run Applet for Particle in a 1-dimensional box as found in 1a) above.
c) Compare the transitions from n = 5 → n = 4 and from n = 5 → n = 1. Attempt to answer the following without doing any calculations. Which transition has the largest energy change associated with it? Which transition has the longest wavelength of emitted light associated with it?
d) Calculate the wavelength associated with these two transitions.
e) Simulate these two transitions. Use the mouse to point at the associated spectral lines, and compare to your calculated values (you will probably have to use the mouse to narrow down the wavelength range rather than getting a precise value).
f) For the Bohr model of hydrogen, we have a formula that allows you to calculate the energy of a level as related to its level number. Can you determine an energy level formula for this particle-in-a-box system? Try this: divide each energy level by 0.06 eV (which is the energy of the lowest level). In other words, calculate E_1/E_1, E_2/E_1, E_3/E_1, E_4/E_1, and E_5/E_1. Do you notice a pattern?
g) Let's see if this pattern is consistent. Change the width of the box to 1.605 nm, so that E_1 = 0.15 eV. You'll see that all the energy levels change as well. Do the same calculations as you did in f). What do you notice?
h) Can you use this to determine an energy level formula for the particle-in-a-box system?
i) Why does decreasing the width of the box increase the energy of the lowest level (and thus all the other levels)? If you are not sure, keep this question in mind and ask in class on Thursday.

3) Localizing Waves & the Uncertainty Principle

a) Go to http://phet.colorado.edu, then click on Play with sims…>, then Physics, then Sound & Waves, and then find Fourier: Making Waves. Click on Fourier: Making Waves. Read the description and then Run Now!
b) You can add different amounts of different harmonics together, by dragging the horizontal black bars in the Amplitudes section (Amplitude is the height of a particular wave, a negative amplitude gives a mirror reflection of the wave – try it out and see). Try out an interesting combination of Amplitudes. See what happens in the Harmonics box and the Sum box. You might want to turn on Auto scale.
c) Under *Preset Functions*, choose sine/cosine. Under *Graph controls*, try out the different options under Function of:. What do you notice? Return to Function of: space(x).
d) Under *Graph controls*, switch to cos. What do you notice about the Amplitudes, Harmonics, and Sum? Switch back to sin.
e) Under *Preset Functions*, choose triangle. What do you notice about the Amplitudes, Harmonics, and Sum?

f) Under *Graph controls*, switch to cos. What do you notice about the Amplitudes, Harmonics, and Sum? Switch back to sin.
g) Repeat for square and sawtooth under *Preset Functions*, also switching between sin and cos.
h) Finally, choose wave packet under *Preset Functions* and choose cos under *Graph controls*. In the Sum graph, what do you notice about the spatial extent (the spread) of the wave packet? Is the wave packet spread out or localized?
i) In order to have a localized wave packet, what do you notice about the spread of wavelengths? Do you need a narrow spread or a wide spread of wavelengths?
j) Here are some concepts and (suggestive) terminology: if the spatial extent (the spread in space) of a wave is very narrow, then we say that the uncertainty in its position is small. If the spatial extent is wide, then we say that the uncertainty in its position is large. Similarly, if there is a narrow spread of wavelengths, we say that the uncertainty in wavelength is small, and if there is a wide spread of wavelengths, we say that the uncertainty in wavelength is large. Given this terminology, would you say that the uncertainty in the position of the wave packet you looked at is small or large? Would you say that the uncertainty in the wavelengths associated with the wave packet is small or large?
k) Recall that the de Broglie relation relates wavelength and momentum. This means that a large uncertainty in wavelength tells us that there is a large uncertainty in momentum. What can you say about the uncertainty in the position and the uncertainty in the momentum of the wave packet you looked at?
l) Go back to Preset Functions, choosing sine/cosine. Is the uncertainty of the position of this wave large or small? Is the uncertainty of the wavelength of this wave large or small? Is the uncertainty of the momentum of this wave large or small?

4) Quantum Wave Interference

a) Go to http://phet.colorado.edu, then click on Play with sims…>, then Physics, then Quantum Phenomena, and then find Quantum Wave Interference. Click on Quantum Wave Interference. Read the description and then Run Now!
b) Make sure you in the High Intensity tab. Switch from Time-Averaged Intensity to E-Field. Turn on the gun (it should by default be set to Photons and some light blue color). What do you observe?
c) Turn off the gun, and use the Clear Wave and Clear buttons. What do you notice? You'll use those two buttons quite frequently.
d) Turn on Double Slits. Make the Slit Width as small as possible, the Slit Separation as large as possible, and adjust the Vertical Position to bring the slits as close to the gun as possible. Turn on the gun. What do you notice? (You may want to increase the Screen Brightness all the way up to 1.0). What, if anything, surprises you about the pattern on the screen? Leave the gun on.
e) Switch to Single Particles. Switch from Time-Averaged Intensity to E-Field. Turn on Rapid, and then click Auto-Repeat. Watch for about a minute and then turn off Auto-Repeat. What do you notice? What, if anything, surprises you about the pattern on the screen?
f) What do you observe that supports the claim that only one photon at a time is being fired from the gun?
g) If you add in double slits, but make no other change, will that affect the number of photons being fired at a time from the gun?
h) Here is one of the great questions in quantum mechanics. Make your prediction before testing it out. If you fire photons one at a time from the gun at double slits, what do you think the pattern on the screen will be?
i) Turn off Auto-Repeat, and use the Clear Wave and Clear buttons. Turn on Double Slits. As before, make the Slit Width as small as possible, the Slit Separation as large as possible, and adjust the Vertical Position to bring the slits as close to the gun as possible. Turn on Auto-Repeat, wait, and watch (be patient and watch for a while). What do you notice on the screen? How do you know that there is still only one photon at a time?
j) You may find it amusing to switch back and forth between High Intensity and Single Particles. Eventually, switch back to High Intensity. You will notice that you can put a detector on either slit. What do you think will happen to the pattern on the screen if you turn on the Detector on Left Slit? Make a prediction before testing it out. Then, try it and see what happens. What do you notice? What happens if you turn off the Detector on Left Slit?

5) Concept Mapping & Synthesis

a) Go to the Calendar page for today, and click on the link for Concept Map. Follow those instructions.
b) You likely will not complete your Concept Map during class time. The Concept Map serves as your Pre-Class Assignment for Thursday February 2, so bring it with you then.