Name Partners Date

Electron Diffraction

Goal
To gain an understanding of the wave behavior of electrons.

Introduction

In quantum mechanics, we create models using waves. But why do we have to do so? Why can't we just use Newtonian mechanics to study topics in quantum mechanics? Actually, researchers started with this classical approach and found that it did not work. They found that when things become extremely small, many physical features can no longer be precisely determined and thus need to be studied with probabilities and waves. In this tutorial, we will explore the wave and particle features of matter. Using electrons as the example, we will do experiments looking for evidence that supports our model that an electron can be a wave as well as a particle. If you can prove this model wrong, please do so!

A. Diffraction of Photons

Suppose a parallel beam of light with wavelength λ is incident on two slits where the separation distance between the slits is d. The width of the light beam, h, is much greater than d. A screen is placed beyond the slits at a distance L. The center of the screen and the mid-point between the slits are set at x = 0.

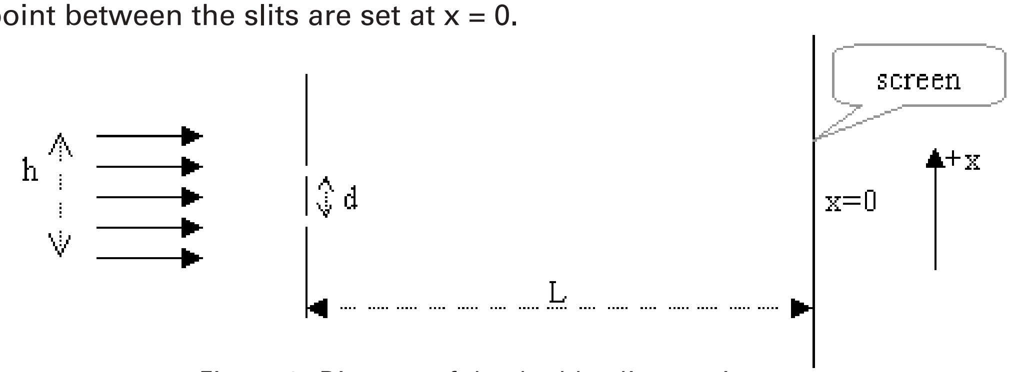

Figure 1. Diagram of the double-slit experiment

A-1. In the space below, sketch what you expect to observe on the screen. Explain your reasoning.

A-2. Now consider what would happen if the slit separation, d, is doubled. Sketch what you would expect to observe on the screen and explain your reasoning.

A-3. Instead of doubling the separation distance, consider what might happen to the pattern on the screen if the double-slit is shifted upward by a small distance a such that the mid-point between the slits is at x = a. Assume a is less than h, as shown in Figure 2 below. Sketch and explain.

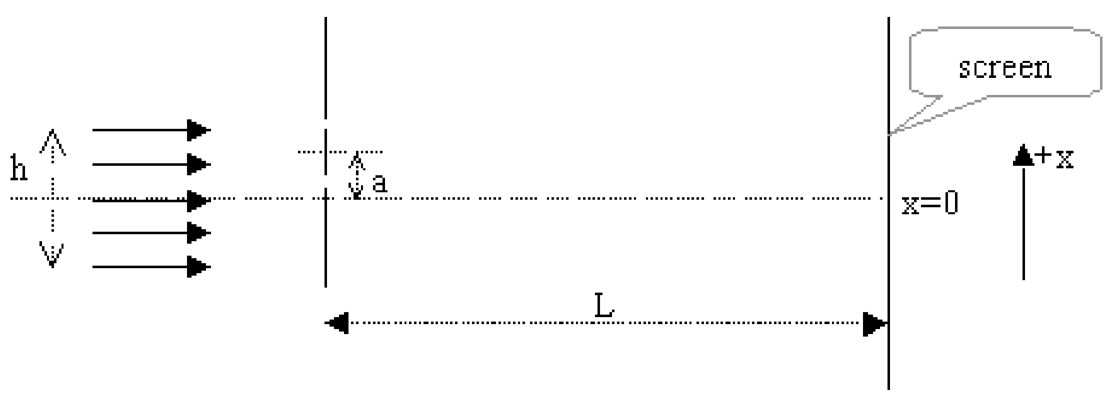

Figure 2. Diagram of double-slit shifted up a distance a

A-4. Now suppose a point light source of the same wavelength is used instead of the parallel beam of light. The point source is a distance S from the double-slit and lies on the x-axis. Assume the double-slit is still shifted up a distance a as shown in Figure 3. Sketch the patterns you would expect to observe and explain your reasoning.

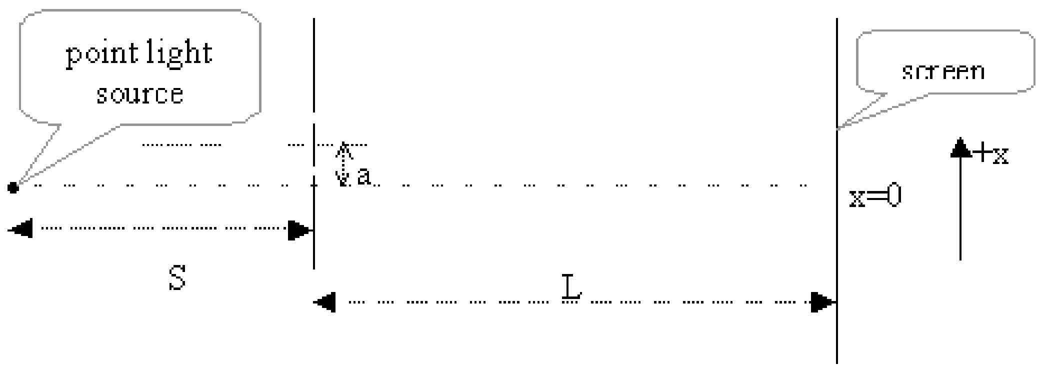

Figure 3: Diagram of double-slit with point source.

A-5. How and why is the point source pattern similar to and/or different from the light beam pattern?

A-6. Suppose the intensity of the light of the point source is dramatically reduced so that only one photon is emitted at a time and we replace the screen with a photographic plate. Sketch the image you would expect to observe on the plate after a long time has passed and explain why.

A-7. Suppose we exchange the point light source with a point electron source which emits only one electron at a time. Now what image would you expect to observe on the plate after a long time has passed? Sketch and explain.

A-8. Turn to the computer, open the *Diffraction Suite* program and choose *Double-Slit Diffraction*. The program has several possible sources to use with the double-slit. Run the experiment using both photons and electrons at different energies and slit separations and sketch the patterns you observe with the different settings.

A-9. Using your simulated results, write a short paragraph summarizing how the size of the double-slit and the energy of the photons/electrons affect the patterns.

B. Experiment with Photon Diffraction

In this experiment, we will use a red laser and several different diffraction gratings.

Using the available equipment, design and perform an experiment to determine the wavelength of the light from the laser. Describe your experimental design and record your procedures, data, and analysis results.

C. Electron Diffraction

The schematic of the electron diffraction tube is shown in Figure 4. When in operation, the electron "Gun" emits a continuous stream of fixed energy electrons which are controlled by the acceleration anodes inside the "Gun". For example, if an acceleration voltage of 2500 volts is applied, the electron beam will have an average kinetic energy of 2500eV. The beam of electrons is then shot through a target and finally lands on a screen coated with fluorescent materials to show the tracks of the electrons. The experiment will be set up with an acceleration voltage equal to 2500 V.

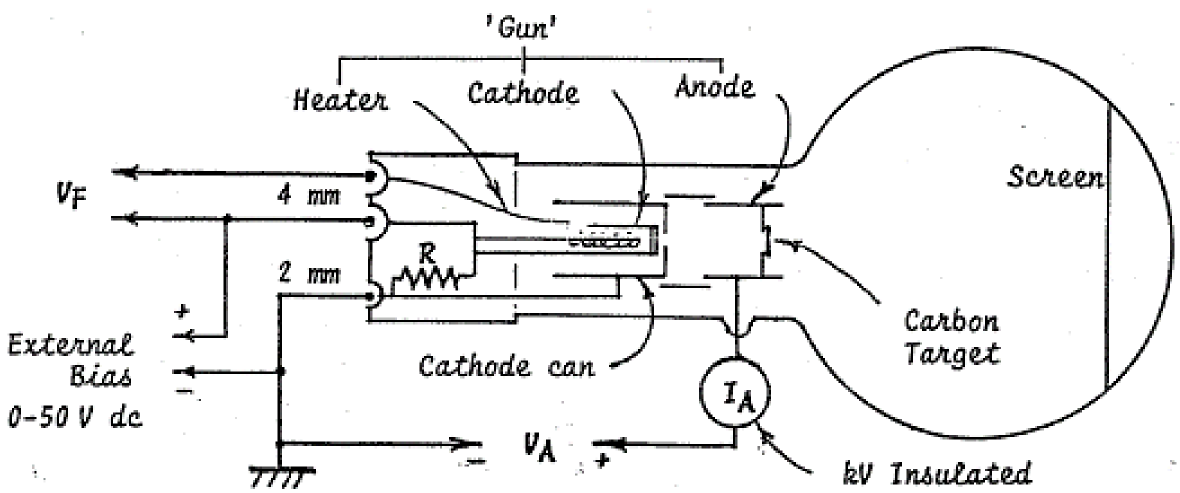

Figure 4. Schematic of the electron diffraction tube.

C-1. Carefully observe the pattern on the screen and make note of the features that you consider important. Sketch the pattern and label it with the data you observed.

C-2. Based on your observations, what do you think is the structure of the target? Explain your reasoning.

C-3. Describe what possible changes could occur to the pattern if the acceleration voltage is increased to 3000 V and explain why.

The instructor will now set the tube to an acceleration voltage of 3000 V.

C-4. Carefully observe the pattern on the screen and make note of the features that you consider important. Sketch the pattern and label it with the data you observed.

C-5. Using your data, try to estimate the structure of the target. Show all calculations and diagrams you use to do this.

D. Investigating Electron Interference

Now, you will complete a simulation of a double slit experiment using electrons. This experiment is a simplified version of the one that you just completed. It is less complex than the real experiment because only two openings are available. Thus, this simulated experiment is very similar to the one that you did with light. A real two-slit experiment with electrons can be done, but the equipment is rather expensive. **[See DZ - Insert Reference]**

D-1. Open the *Diffraction Suite* program, select *Double Slit* and click on the source tube labeled *Electrons* on the left side of the screen. Click *Start* to see what happens. Describe the pattern below.

D-2. Describe how the pattern for electrons is similar or different from the one for light.

D-3. Desribe how this pattern is similar to and different from the one for real electrons.

D-4. What can you conclude about the behavior of electrons in a Double Slit experiment?

D-5. In the simulated experiments we have much more control over variables than in the real one. So, let us see how this pattern changes with the energy of the electron. Keeping other variables fixed try at least four different energies and record the distance between consecutive dark areas on the screen.

Electron Energy (eV)	Distance between dark areas

D-6. How does the distance between dark areas change as the energy increases?

D-7. Use the information above to describe how the electron's wavelength changes as the energy increases.

E. Conclusion

E-1. In conclusion, write a short paragraph to summarize what you have discovered about the behavior of the electrons and how that behavior is related to the behavior of waves.