

**Physics 220, spring 2009**  
**Lab 4 (or 5): Bragg diffraction with electrons**

Background:

You have already studied Bragg diffraction using electromagnetic waves (microwaves). Now you will do a similar experiment, but with electrons, following Louis deBroglie's revolutionary claim that particles have wave properties, and that the wavelength of an electron with momentum  $p$  is given by

deBroglie's relationship  $\lambda = \frac{h}{p}$ , where  $h$  is Planck's constant. According to this equation, electrons accelerated through a few thousand volts have wavelengths which are comparable to those of x-rays--that is, on an atomic scale. Since x-rays are used to study the nature of crystals through Bragg scattering, it is reasonable to expect that the wave properties of electrons can be studied by scattering them from crystals.

The electron diffraction tube is a device which will allow us to study electron waves via Bragg scattering, by accelerating electrons through a known voltage, and scattering them from two different types of crystals: graphite and aluminum. The graphite is a single crystal; the aluminum is made up of many crystals, randomly oriented. More information about the apparatus and the theory is in the other handout, which is a copy of the manual for the electron diffraction apparatus.

**Prelab questions** (to be done in your lab book):

1. Starting with equations (1) and (2), derive the electron diffraction tube manual's equation (4).
2. a) Calculate the wavelength (in nm) of an electron that's been accelerated through a potential difference of 10 kV. Use non-relativistic approximations.  
b) Show why the non-relativistic approximations can be used here (the electron tube uses accelerating voltages of 0-10 kV). Be quantitative (that is, how much error in the wavelength is introduced by using the non-relativistic approximation? is this likely to be significant?).  
c) Based on your answer to a), explain why crystals are good "diffraction gratings" for electrons of 10 keV kinetic energy.
3. In this experiment, you will be taking measurements as you vary the accelerating voltage of the electrons.
  - a) How does the wavelength of the electrons change as the accelerating voltage is increased?
  - b) What will happen to the Bragg angle,  $\theta$ , for an increased accelerating voltage?

Procedure:

The general operating procedure for the apparatus is given on pp. 4-5 of the manual. Ask me to show you how the apparatus works and where to steer the electron beam to find the two targets. You should be sure to take the following precautions which will keep the electron tube from being damaged:

1. Always turn the intensity and anode voltage all the way down before turning the tube on or off. Don't move the tube while it's on.
2. Keep the current as low as possible, and always keep it under  $10\ \mu\text{A}$ .

You will do variations of Experiment 1 and Experiment 3 which are described in detail in the other handout.

A) Experiment 1: Follow the instructions in the handout, but you don't need to do step 3. Take measurements at at least 4 different energies distributed over the range from 7.0 kV to 9.0 kV. (The lower voltages are more difficult; you may wish to start with higher voltages.) You will probably see 4 rings. For each ring, you should take measurements of  $r$  across several different diameters. Design your own procedure for doing this, but I suggest that you don't take all of your measurements of  $r$  at the same time. Be sure to describe in your lab book how you're measuring  $r$ . Note that you may see more than 4 rings at each energy; if you measure additional rings, ask me for help in interpreting which crystal planes they correspond to.

The accepted value for  $a^*$  is  $0.4049\ \text{nm} = 4.049\ \text{\AA}$ .

Do the analysis as they suggest, and compare the values of the electron wavelength you get from the Bragg relationship ( $\lambda^*$ ) to the ones you get from the deBroglie relationship ( $\lambda$ ).

In addition, choose one of the rings and analyze the data by plotting  $1/\sqrt{V}$  vs. the average  $r$ . Include error bars on the  $r$  values (ask if you're using Excel and don't know how to do this). From the slope of the best-fit line to these data, obtain a value for  $a^*$  (hint: combine equations (4) and (10) to get a relationship between  $1/\sqrt{V}$  and  $r$ ). Also estimate a lowest-possible and a highest-possible value for  $a^*$ , using the uncertainty in the slope. (Again, ask me how to do this in Excel or Graphical Analysis if you're not sure.) Does the accepted value of  $a^*$  lie within this range?

B) Experiment 3: Follow the instructions in the manual, measuring  $r$  to each of the six innermost maxima. Again, use accelerating voltages from 7.0 to 9.0 MeV. Do the analysis as they suggest. In addition, plot  $1/\sqrt{V}$  vs. the average  $r$  and interpret the results as you did above.