Physics 220, Spring 2009
Lab 3: Bragg scattering using microwaves

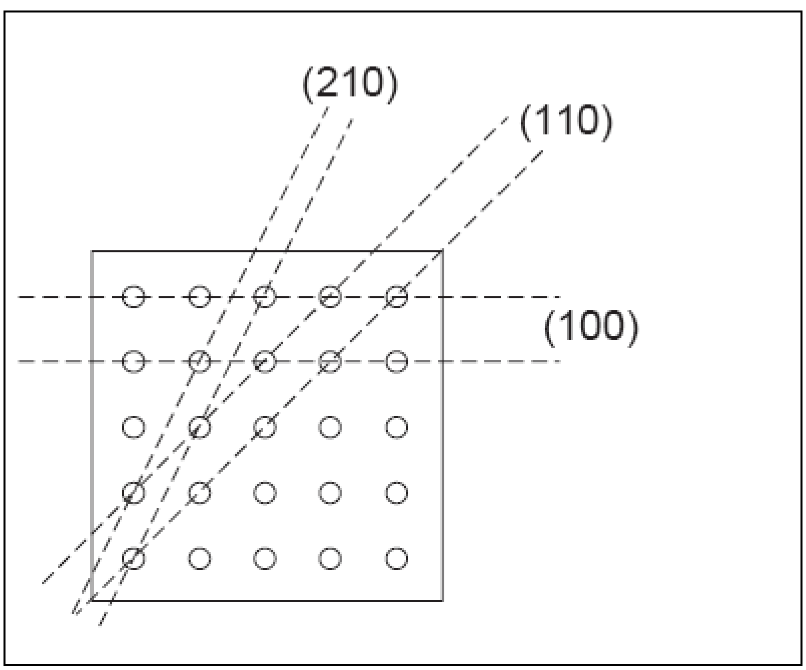
Background:
Bragg diffraction (or scattering) of waves such as x-rays, electrons, or neutrons provides a powerful tool for investigating crystal structure. Bragg diffraction can occur when there are planes of scatterers oriented such that the scattering from the planes creates constructive interference. This condition is described by Bragg's law: $2d \sin \theta = n\lambda$, where d is the distance between the scattering planes of atoms in the crystal, λ is the wavelength of the incident beam, θ represents the angle of incidence and also the scattering angle, both measured with respect to the crystal planes (i.e. grazing angle), and $n = 1, 2, 3, ...$ is the *order number*. Thus, the spacing of atoms in the crystal can be related to the angles at which scattering maxima are observed.

In this lab, we will do Bragg scattering on a larger scale, using a cubic "crystal" made of metal spheres embedded in Styrofoam (the metal spheres play the role of the atoms) and microwaves instead of the much-shorter-wavelength x-rays. You know the wavelength of the microwaves, having measured them with the Michelson interferometer, and so you will be able to determine the spacing of the "atoms" in the "crystal" by measuring the angles at which the microwaves interfere constructively.

Pre-Lab Preparation Questions (to be answered in logbook)

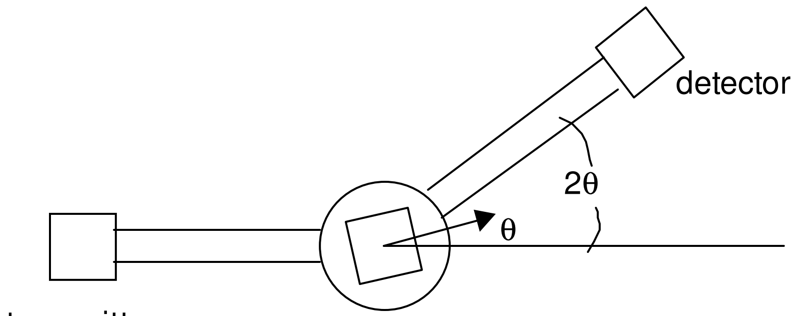
1. a) Some of the different planes of the cubic "crystal" are shown below, labeled by their Miller indices. The (100) planes have the largest spacing. Given that the (100) planes are separated by a distance D, calculate the spacing between the (110) planes in terms of D. Then calculate the spacing between the (210) planes in terms of D.

b) Based on the Bragg scattering relationship (Bragg's law), how does the angle of the n=1 scattering maximum for the (100) plane compare to that for the (110) plane?



2. Explain why when the "crystal" rotates through θ degrees for each measurement, the detector needs to rotate through 2θ degrees.

Procedure:



It is helpful to determine the beam profile before you start so that you have an idea of how broad an angular range the beam covers without scattering. To do so, place the detector and the transmitter as shown above, but do not place the Styrofoam "crystal" on the rotating drum. Now move the detector in one direction to get a feeling for how quickly the intensity falls off. Then go back and take careful readings of intensity vs angle, choosing the size of the angle steps based on how quickly the intensity drops off with angle. Record the meter reading at each step, until the intensity drops to nearly zero. Return the detector to the middle and do the same in the other direction. Plot the meter readings as a function of angle and determine the effective width of the beam when measured at half its maximum value (this is called the "full width at half max" (FWHM) value).

There's no point in trying to measure Bragg scattering at an angle smaller than that covered by the original beam, since you won't be able to distinguish between the original and the Bragg scattered beam. Given the beam width you found, what would be a good minimum angle at which to start trying to measure Bragg scattering (in other words, an angle beyond which you can be sure you won't see any of the original beam)?

Now you're ready to observe Bragg scattering. Place the "crystal" on the rotating platform so that the pointer on the cylinder is perpendicular to a flat face of the block. Bring the detector around so that the angle (2θ) between it and the transmitter is twice the minimum angle you decided to use. Set the normal to the "crystal" to bisect this angle (see figure above).

Again, get a feeling for what the intensity as a function of angle looks like by moving the crystal and detector to larger and smaller angles (don't forget that the detector must move through twice the angle of the crystal). Then take careful measurements of intensity vs. angle. Take larger steps for θ where the intensity is changing slowly and take smaller steps where the intensity is changing more rapidly. Continue until all maxima have been found. If you need to change meter scales at any time during the experiment, be sure to record what scales were used when.

Repeat your measurements for angles on the other side of the crystal.

Plot graphs of the relative intensity vs. the angle θ. Use your data and Bragg's Law to determine the spacing between planes of the "crystal" in this orientation and estimate an uncertainty in the spacing. Show how you did this.

Repeat the procedure in order to find the spacing between the planes of the "crystal" in the 45 degree orientation ((110) planes).

Would you expect to be able to measure any Bragg peaks for the (210) planes? Discuss with your instructor (be prepared to justify your reasoning). Carry out the measurement for that case, if possible.

By direct measurement, find the spacing of the "crystal" planes in the orientations you measured. (You should probably make a sketch in your lab book of the "crystal" to make clear what distances you're actually measuring here.) Estimate an uncertainty in your direct measurements. Compare with the results from the Bragg scattering analysis.

Embedded question: Suppose you did not know beforehand the orientation of the "inter-atomic planes" in the crystal. How would this affect the complexity of the experiment? How would you go about locating the planes?

Summarize your results. Are the values obtained by Bragg scattering in good agreement with the direct measurements (that is, do the two methods agree within the range of their uncertainties)? Comment on any possible systematic errors. What (specific) changes to the procedure and/or the apparatus would you suggest in order to improve the accuracy or the precision of this experiment?