Lab 6: Bragg Scattering and Double Slit Diffraction

(Based on Pasco Instruction Manual and Experiment Guide for Microwave Optics)

Purpose: - to verify Bragg's equation for constructive interference
- to study double-slit diffraction

Equipment:

Transmitter unit with power supply	Receiver unit
Cubic lattice and rotating table	Component holder
Goniometer, rotating	Slit Extender Arm
Narrow Slit Spacer	Wide Slit Spacer
Metal reflector (2)	

In this experiment we will verify Bragg's equation for constructive interference of electromagnetic (EM) waves from parallel planes:

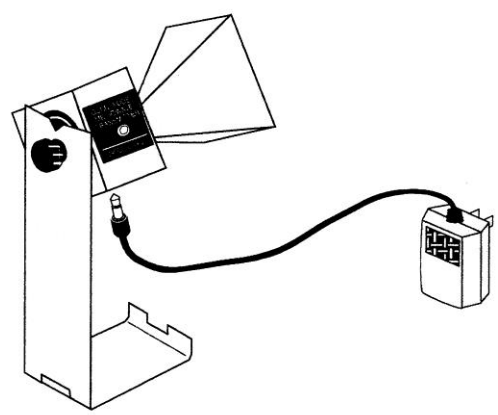
$$2d\sin\theta = n\lambda$$

where d is the plane separation, θ the scattered angle with respect to the interface, n a positive integer, and λ the wavelength of the EM waves. We will use microwaves as the EM waves.

Introduction to Microwave Optics System

This experiment gives a systematic introduction to the Microwave Optics System and may prove helpful in learning to use the equipment effectively and in understanding the significance of measurements made with this equipment.

Figure 1
Microwave transmitter
with power supply

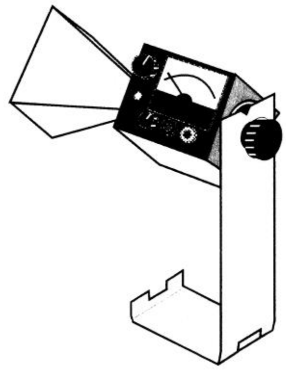


The Gunn Diode Microwave Transmitter (Fig. 1) provides 15 mW of coherent, linearly polarized microwave output at a wavelength of **2.85 cm**. The unit consists of a Gunn diode in a 10.525 GHz resonant cavity, a microwave horn to direct the output, and an 18 cm stand to help reduce table top reflections. The Transmitter may be powered directly from a standard 115 or 220/240 VAC, 50/60 Hz outlet by using the provided power supply. Other features include an

LED power-indicator light and a rotational scale that allows measurement of the angle of polarization. The Gunn diode acts as a non-linear resistor that oscillates in the microwave band. The output is linearly polarized along the axis of the diode and the attached horn radiates a strong beam of microwave radiation centered along the axis of the horn.

The Microwave Receiver (Fig. 2) provides a meter reading that, for low amplitude signals, is

Figure 2
Microwave receiver



approximately proportional to the intensity of the incident microwave signal. A microwave horn identical to that of the Transmitter's collects the microwave signal and channels it to a Schottky diode in a 10.525 GHz resonant cavity. The diode responds only to the component of a microwave signal that is polarized along the diode axis, producing a DC voltage that varies with the magnitude of the microwave signal. Special features of the Receiver include 4 amplification ranges (from 1 to 30) with a variable sensitivity knob that allows fine tuning of the amplification in each range. Banana connectors allow that a signal be examined using an oscilloscope. The receiver is battery powered and has an LED battery indicator. If the LED lights when you turn on the Receiver, the battery is working. As with the Transmitter, an 18 cm high mount minimizes table top reflections and a rotational scale allows measurements of polarization angles.

To Operate the Microwave Receiver:

Turn the INTENSITY selection switch from OFF to 30X, the lowest amplification level. The battery indicator LED should light, indicating that the battery is working. The INTENSITY selection settings (30X,10X, 3X, 1X) are the values by which you must multiply the reading to normalize your measurements. For example, 30X means that you must multiply the reading by 30 to get the same value you would get with the INTENSITY set to 1X. But, this is true only if you do not change the position of the VARIABLE SENSITIVITY knob between measurements.

Point the microwave horn toward the incident microwave signal. Unless polarization effects are under investigation, adjust the polarization angles of the Transmitter and Receiver to the same orientation (e.g., both horns vertically or both horns horizontally).

Adjust the VARIABLE SENSITIVITY knob to attain a meter reading near midscale. If no deflection of the meter occurs, increase the amplification by turning the INTENSITY selection switch clockwise. Remember, always multiply your meter reading by the appropriate INTENSITY selection (30X, 10X, 3X, or 1X) if you want to make a quantitative comparison of measurements taken at different INTENSITY settings.

IMPORTANT: Reflections from nearby objects, including the table top, can affect the results of your microwave experiments. To reduce the effects of extraneous reflections, keep your experiment table ***clear of all objects****, especially metal ones, other than those components required for the current experiment.*

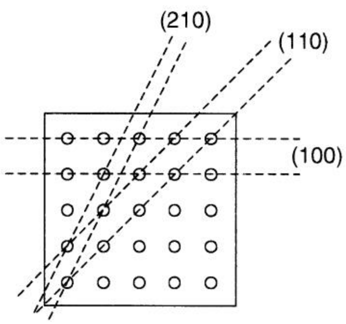
Procedure:

Part I - Bragg Diffraction

Bragg's Law provides a powerful tool for investigating crystal structure by relating the interplanar spacings in the crystal to the scattering angles of incident x-rays. In this experiment, Bragg's Law is demonstrated on a macroscopic scale using a cubic "crystal" consisting of 10-mm metal spheres embedded in a cube. The size of the "crystal" allows us to use microwave radiation, since its wavelengths are on the order of magnitude of the spacings in the crystal.

Three families of planes are shown in Fig. 3. (The designations (100), (110), and (210) are the, so called, Miller indices for these sets of planes.)

Figure 3
"Atomic" planes of the Bragg crystal



1. Place the Transmitter and Receiver on the Goniometer, with the **Transmitter** attached to the **fixed** arm. Be sure to adjust both the Transmitter and Receiver to the same polarity (the horns should have the same vertical or horizontal orientation). Adjust the Transmitter and Receiver so that they directly face each other (the angle should be 180^{o}).
2. Place the cubic lattice on the rotating table as shown in Fig. 4. Position the Transmitter and Receiver as close as possible to each other (to increase the signal), but leave enough space so that the cube can be rotated freely. Align the crystal so that the (100) planes are parallel to the incident microwave beam (see Fig. 4). Adjust the Receiver controls to provide a readable signal. Record the meter reading.

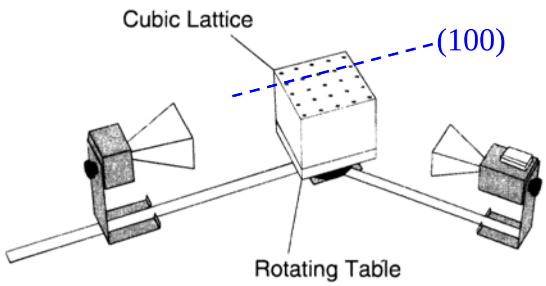
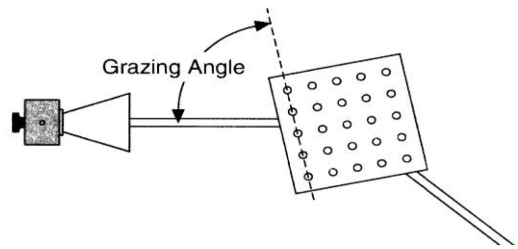


Figure 4
Equipment setup

3. Rotate the cube (with the rotating table) 12^o counterclockwise (CCW) and the Rotatable Goniometer arm 24^o CCW. Record the grazing angle of the incident beam and the meter reading. (The grazing angle is the complement of the angle of incidence. It is measured with respect to the plane under investigation, **NOT** the face of the cube; see Fig. 5.) Rotate the Goniometer arm two degrees CCW for every one degree CCW rotation of the crystal. In Table 2, record the angle and meter reading at each position. (If you need to adjust the INTENSITY setting on the Receiver, be sure to indicate this in your data.)

Figure 5
Grazing angle



4. Graph the relative intensity of the diffracted signal as a function of the grazing angle of the incident beam. At what angles does definite peak for the diffracted intensity occur?

   the angle where peak intensity occurs: ___________

5. Use your data, the known wavelength of the microwave radiation (2.85 cm) and Bragg's Law to determine the spacing between the (100) planes of the Bragg Crystal. Measure the spacing between the planes directly and compare with your experimental determination.

   d (measured by a ruler) = ______________________ (cm)

   d (using Bragg's Law) = _______________________ (cm)

   % difference = _________________

Table 1 - Plane (100)

Grazing Angle	Meter Reading (mA) (after adjusted INTENSITY, if applicable)
18	
20	
21	
22	
23	
24	
25	
26	
28	

6. Repeat the measurements for the (110) family of planes. Record in Table 2.

Table 2 - Plane (110)

Grazing Angle	Meter Reading (mA)
24	
26	
28	
29	
30	
31	
32	
33	
34	
36	
38	
40	

The angle where peak intensity occurs: ___________

d (measured by a ruler) = ________________

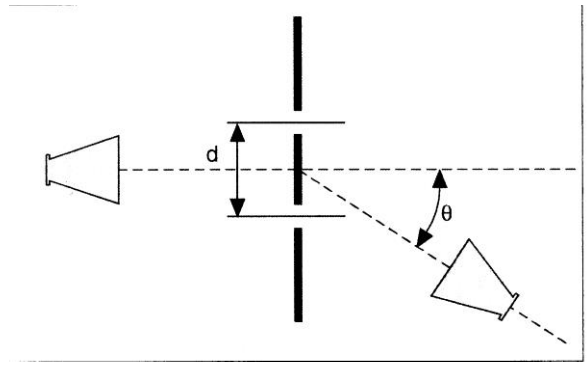
d (using Bragg's Law and n = 1) = _____________________ (cm)

% difference = _________________

Part II - Two Slit Diffraction

When an EM wave passes through a two-slit aperture the wave diffracts into two waves which superpose in the space beyond the apertures. Similar to the standing wave pattern, there are points in space where maxima are formed and others where minima are formed. With a double slit aperture, the intensity of the wave beyond the aperture will vary depending on the angle of detection. For two thin slits separated by a distance **d**, maxima will be found at angles for which $\mathbf{d \sin\theta = n\lambda}$. (Here, θ = the angle of detection, λ = the wavelength of the incident radiation, and **n** is an integer, which in this lab will be equal to 1. Notice that **d** is the distance between the middle of the openings.) (See Fig. 6).

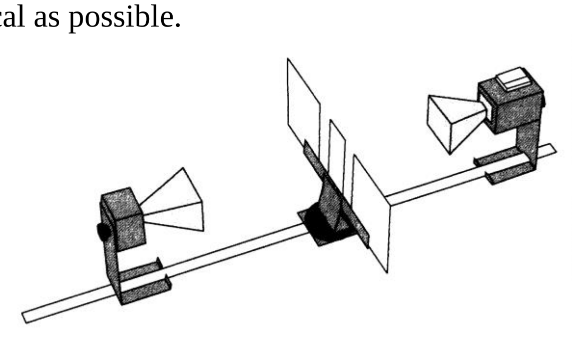
Figure 6
Two slit interference



Procedure

7. Arrange the equipment as shown in Fig. 7. Use the Slit Extender Arm, two Reflectors, and the Narrow Slit Spacer to construct the double slit. A slit width of about 1.5 cm is recommended. Notice that the slit width is not the same as "d". Be precise with the alignment of the slit and make the setup as symmetrical as possible.

Figure 7
Double slit interference setup



8. Set the Goniometer arm so the Receiver directly faces the Transmitter. Adjust the Receiver controls to obtain a meter reading as close as possible to 1.0 at the lowest possible amplification. Find the angles of constructive interference by scanning (slowly varying), the receiver's angle from 0^o to 60^o. First scan clockwise. Return the receiver to 0^o and then scan counterclockwise. Record your values in Table 3.

9. Compare your average values of the measured angles with those predicted by the maxima equation for two slit diffraction patterns (**dsin**θ **= n**λ). Record in Table 3.

Table 3

Maximum reading	CW (degrees)	CCW (degrees)	Average (degrees)	Theoretical prediction	% error
1st trial					
2nd trial					