2. X-ray Physics

Concepts

- This is the second part of the experiments dealing with the creation and measurement of X-rays. Production of X-rays by high-energy electron bombardment of metal targets. Bragg Diffraction; Characteristic X-ray energies; Brehmstrallung radiation; Absorbtion edge energy-filter; X-ray projection image; Tomography.

Background Reading

- The Leybold notes provide detailed quantitative discussions of the various experiments we will do with X-rays. These are posted on the BB site. You should consult all of these! Here we simply summarize the main points for a quick reference. Figures in this appendix refer to those in the respective Leybold documents. Leybold-Didactic Handouts (posted on BB): Bragg Reflection (p6331); Laue Diagrams (p7122); Fine-Structure (p6334); Flourescence – projection image (p6311).
- Notes for ImageJ program (see BB hand-out)

Special Equipment and Skills

- Klinger X-ray Apparatus, including: 35kV Mo and W X-ray sources; Two-axis (θ-2θ) goniometer; high-resolution diffraction slit/software; Tomography unit; Image Plate sensor. ImageJ program.

Precautions

- The X-ray tube, sample, detector and phosphor screen are fully enclosed and interlocked to allow safe viewing while operating (< 1μS/hr at 10cm from windows).
- Do not restrict or manually force the sample or detector positions (strips the stepper-motors).
- TA-assist is required to remove the X-ray tube, goniometer, sample and detector assemblies.
- Replace the scratch-cover on the phosphor screen when not in use.

Procedures

1. Bragg diffraction: (see p6331.pdf)

TA-assistance is required for all set-up steps (items a-d below).

a. Mount collimator slit (item 1 in Figure 1)
b. Set NaCl sample (item 2) at 5 cm from the collimator slit.
c. Set exit slit and detector (item 3) at 6 cm from the sample.
d. Mount NaCl sample. Handle with gloves by edges only. Replace in dessicator.
e. Press ZERO, and observe horizontal orientation of sample and detector.
f. Plug in USB cable and start "X-ray apparatus" program.
g. Set: U = 35keV; I = 1mA; dt=1sec; dB=0.2deg; B = 3-30 deg;
h. Do SCAN (COUPLED).

   The source anode material is Molybdenum. You should obtain a spectrum something like Figure 2 below. Note the sharp peaks, with the strongest peak near θ =7°. If this looks OK, then repeat with slower scan (smaller step, longer time). This “rocking curve” scan effectively yields an energy spectrum of the radiation, following Bragg's law: $n\lambda = 2d\sin\theta$, with energy increasing to the left, that is, the energy is inversely related to λ and theta. The broad distribution in intensity that is highest for low angles is continuous Brehmstrallung distribution and has a cut-off near the tube energy (U=35keV) and a broad peak at ~ 0.8°. The sharp features are the characteristic X-ray lines (including K_α,

K_β doublets) for the anode material of the source. The energy values for these "lines" can be found in tables of X-ray characteristic energies.
Analysis: Look up the energies of the K_α and K_β X-ray lines for Molybdenum and confirm that the angle where the peaks occur corresponds to Bragg diffraction of the X-rays from the (2,0,0) spacing of NaCl (d_{200} = 2.82 x 10^{-10}m). [The (2,0,0) notation are the "Miller Indices" of a crystal and indicates a spacing that is ½ the unit cell size.] Repeat for the n=2 and n=3 pairs of Bragg diffraction peaks from the Mo X-rays.

i. Repeat the scan for U=30keV and explain the changes. To what energy does the 30keV refer? How is this related to energy of the peaks in the scan profile? At what energy would you expect not to see the Mo characteristic X-ray lines.
j. (option). Repeat the experiment and analysis with the tungsten source.

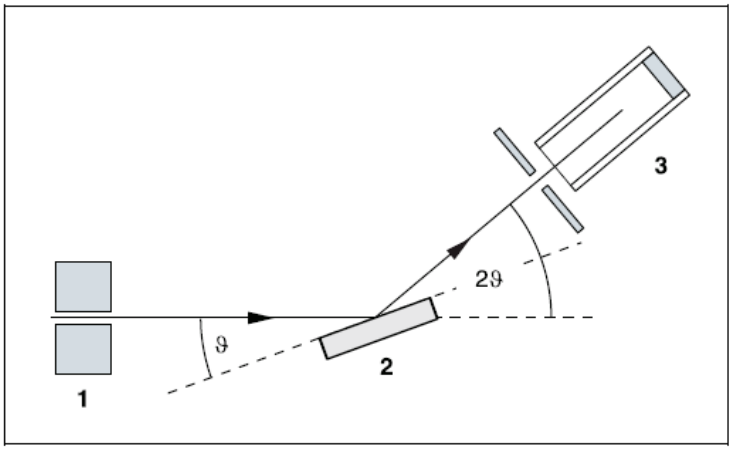

Fig. 1 Schematic for θ-2θ setup showing collimator slit (1), sample(2) and detector (3).

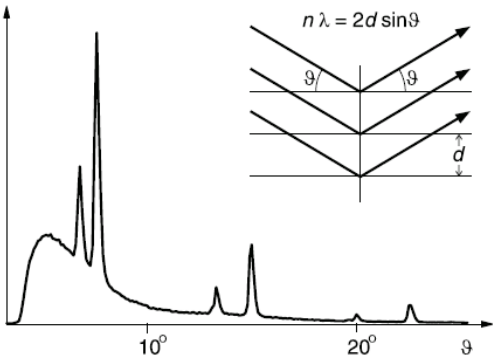

Fig. 2 Schematic of spectrum for single-crystal diffraction showing n=1, 2, and 3-order Bragg peaks, each as a doublet (K_α and K_β).

2. Zr-foil "monochromator" (Energy Edge-filter)

The doublet structures are distracting for diffraction or spectroscopy measurements. They can be suppressed using a simple/clever "edge-filter" for the incident beam. For a Mo (Z=42) source, we use a Zr filter (Z=40), which has an absorption edge just between the K_α-K_β doublets, causing selective suppression of the high-energy line.

a. Add the Zr filter and repeat the scan with U=35 keV. What are the energies of the characteristic X-ray lines for Kr? What is the effect on scan for the Mo source. What is happening This filter as a primitive "monochromator" for the X-ray source.

b. Using the tungsten source, repeat the scan with and without the Zr filter. Discuss the difference between the effect when a Mo source is used and when the W source is used.

3. X-ray projection image: Flouroscope (see p6311.pdf)*

(TA assist): Carefully remove the NaCl sample (replace in dessicator); collimator slit, detector and goniometer. In this configuration, the X-rays form a wide-angle beam from a "point source" ($2mm^2$ hot region of the Mo anode). An object placed in this beam will form an image on a screen downstream, with denser regions of the sample appearing darker. This comprises the famous "fluoroscope" used for medical diagnostics. For biological samples, the quantitative absorption behavior is the subject of "dosimetry", of vital importance in the medical field. Make projection images of a few interesting items: small calculator, Einstein bobble-head, etc. The object should be placed close to (but not touching!) the fluorescent screen for best resolution. Support the object carefully to avoid tipping.