L33 - Introduction To Teltron Tel-X-Ometer System

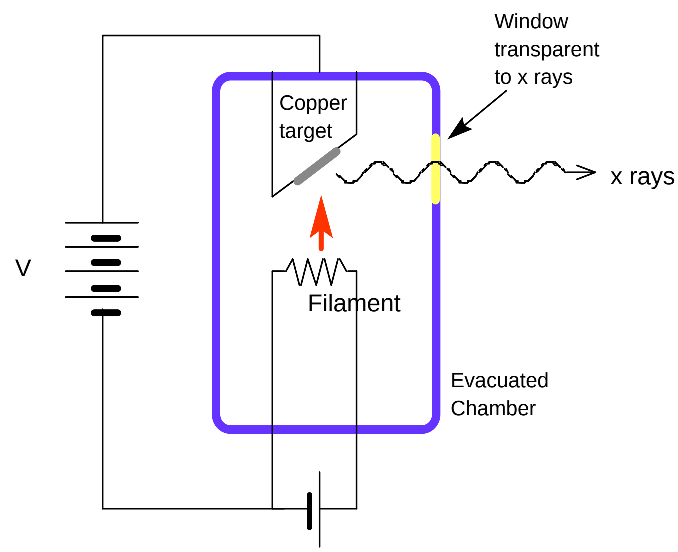
In today's lesson, you will be introduced to the function of the Teltron Tel-X-Ometer x-ray system. This system has been designed specifically for use by students in an introductory laboratory setting. It will allow you to study x-ray phenomena safely - as long as you follow all required safety procedures! Due to the potential dangers that always exist when using x-rays, you will be given an experimental protocol that must be followed. If at any point during this lab you have questions about the protocol or questions regarding the safe use of this equipment, then immediately stop what you are doing and consult with your instructor.

Producing X-rays

This diagram shows a common arrangement for producing x-rays with an x-ray tube.

A filament is heated to produce electrons. These electrons are accelerated through a potential difference V. In today's experiment, this potential difference will be 30,000 V!

These high-energy electrons strike a metal target inside an evacuated chamber. X-rays are produced and are able to leave the chamber through a window made of a material that is transparent to x-rays.



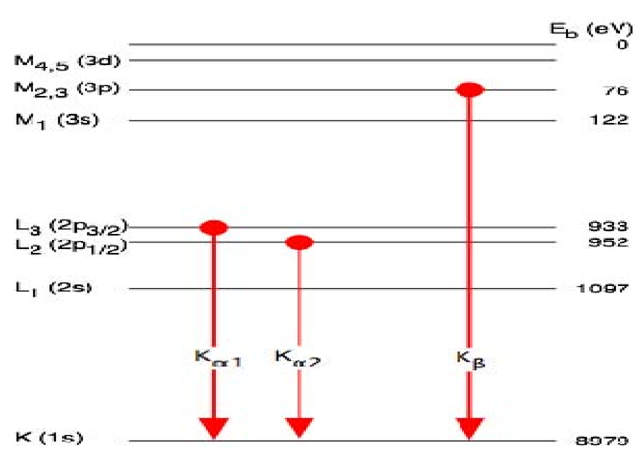
Q1. Based on this information, what would be the highest energy possible for an outgoing x-ray produced from this tube? How do you know?

Q2. What would be the wavelength and frequency corresponding to this x-ray?

Q3. Considering that a copper metal target produces the x-rays, do you think there will be x-rays produced with a continuum of frequencies or do you expect that there will be certain specific values determined by the properties of copper. Briefly justify your thinking.

Any electron from the x-ray tube filament having sufficient energy to eject a K electron in a collision process will ionize a copper atom. The ionized atom will revert to its stable state through electron transitions where each transition is accompanied by the emission of a photon of equivalent energy.

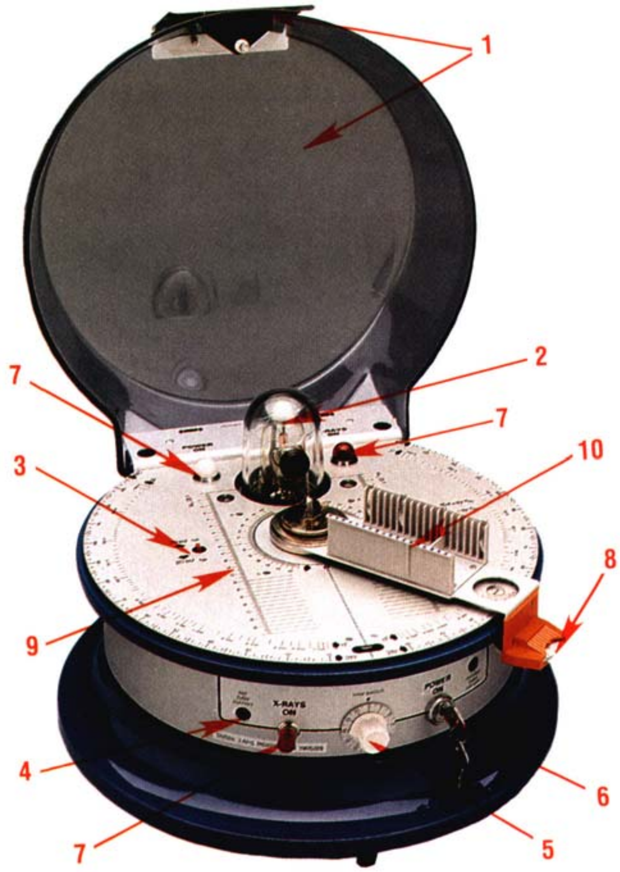
Q4. Will the K_α or the K_β photons be more energetic? Why?



The Tel-X-Ometer

You will be using a Teltron Tel-X-Ometer to study x-ray physics. This unit is pictured here. Read the following list of the major features and identify each component on the machine in front of you. In addition, you should identify visually the major components of the x-ray tube as described on page 1.

1. The experimental zone is covered with a 4 mm thick plastic cover containing a high percentage of chlorine to absorb scattered radiation. There is also a lead backstop on the cover to absorb direct beam rays.
2. The x-ray tube is mounted inside a transparent lead-glass dome, which absorbs x-rays except for those that will pass through the port to the experimental zone.
3. 20 kV/30 kV selection switch.
4. Tube current adjustment which can vary the tube current from 20-100 μA.
5. Electrical timer knob, which varies from 0-55 min. The filament cannot be turned on unless the timer is set.
6. Key switch. The x-ray unit cannot be operated without a key. The key must be returned to the instructor at the end of the lab.



7. Warning lights which illuminate to signal when the power is on (white light) and when x-rays have been turned on (red light).

8. Vernier scale to provide for making precise angle measurements.

9. 2:1 spectrometer drive so that a sample crystal placed at the center is rotated appropriately by θ when the carriage arm is rotated by 2θ

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10. Slide carriage arm, which allows for the positioning and rotating of experiment accessories such as a G-M tube detector.

Now that you have had a basic introduction to this system, you are ready to begin using it. On the following page is an experimental protocol checklist. Be sure that each person in your group participates in and checks each step. This list will take you through operating the machine and allow you to verify the operation of all important safety features.

Protocol for Starting the Experiment & Safety System Maintenance

Complete each of the following items in the order listed below. Place a check next to each item when you have verified its completion.

_______ 1. Sign into the x-ray log book. Record the ID of the x-ray machine you are using.

_______ 2. Verify that a sign has been posted at eye level on the door(s) to the lab room warning that x-rays can be produced in this location.

_______ 3. Check that the power strip is turned off at your lab station. Check that the Tel-X-Ometer and the scalar meter power supply are plugged into the power strip.

_______ 4. Physically inspect the plastic scatter shield cover. Examine the entire shield to make sure that no cracks or chips are present. Make sure that the aluminum/lead backstop is securely in place.

_______ 5. Gently check that the cover hinges slide freely in both directions. When you are using the x-rays later in this lab, you can turn them off simply by sliding the cover to one side. This will break the interlock and turn off the x-rays. When the carriage arm is rotated to one side, then always slide the cover to the same side as the carriage arm.

_______ 6. Check that the lead-glass dome containing the x-ray tube is entirely free of chips or cracks. The x-rays will be emitted through the port. Verify that the port is firmly attached to the dome.

_______ 7. Verify that both the Indicator Lamp next to the lead-glass dome and the red push-button on the Control Panel are legibly labeled “X-RAYS ON”.

_______ 8. In addition, establish that underneath the red push-button on the Control Panel there is a clearly legible and visible label bearing the statement “CAUTION: X-RAYS PRODUCED WHEN ENERGIZED”.

_______ 9. There should be a GM tube mounted in the carriage arm of the Tel-X-Ometer. This GM tube should be connected to the scalar meter through a BNC connection.

_______ 10. Obtain a Tel-X-Ometer key from the lab instructor. Insert the key into the switch to free the controls. Check that the key can only be removed when the control is in the off position.

_______ 11. Check that the voltage switch is set to 30 kV.

_______ 12. Turn on the power strip. Turn the timer knob to ~30 and turn the key to the on position. Verify that the Power On Indicator Lamp (white) is illuminated and that the x-ray tube filament is illuminated at the same time. The Scaling Ratemeter may start beeping on occasion - this is perfectly normal.

_______ 13. It is possible for condensation to form inside the lead-glass dome. Therefore, you must let the system “warm up” for at least five minutes with only the filament operating. Note the current time so you can be sure when sufficient time has passed before turning on the x-rays.

Filament turned on: ____________________

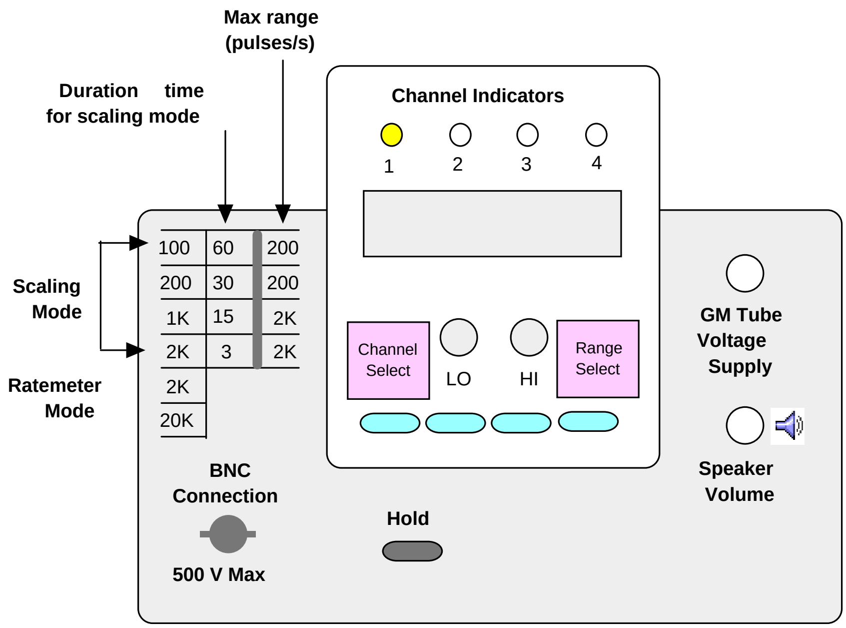
_______ 14. Verify the location of the dosimeter provided in the room. Prepare to keep track of the amount of time (in minutes) that the x-rays are on for the lab.

While you are waiting for the filament and electronics to warm up sufficiently, you can become more familiar with the GM tube and its accompanying electronics. This GM tube works exactly in the same manner as the tube you used in the Introduction to Radiation lab. Refer to that handout if you want to review the operation of this common detector.

The GM tube is operated with the scaling ratemeter. They should be connected together through the BNC connection already.

Using the Channel Select button, select Channel 3. This channel displays the voltage applied to the GM tube. Using the GM Tube Voltage Supply control knob, turn up the voltage to about 450 V.

This scaling ratemeter can operate in two modes: Scaling Mode and Ratemeter Mode. Counts will be displayed by selecting channel 1. The mode is determined by the switch position in the upper left corner of the unit.



Scaling Ratemeter

Ratemeter Mode: In this mode, the count rate (pulses/s) is displayed on channel 1. The counts can be displayed in two ranges of 2 k and 20 k pulses per second depending on the switch selection.

Scaling Mode: In this mode, the instrument is used as a scalar. Set the switch to the t = 3 s position. You will notice that the instrument now counts for three seconds. As it is counting the green LED marked RUN is illuminated. After the time t has passed, the instrument will stop counting, beep, illuminate the red LED marked STOP, and display the output (pulses/s) at channel 1 for 10 s. After 10 s, the unit resets to zero and the cycle repeats. You can push the HOLD button to stop the unit from counting. Press the HOLD button again to release and start the cycle over again.

Now switch the unit to the 15-s setting and verify that you understand its operation.

Now you are ready to do some physics!

Geiger-Mueller Tube LND712 Characteristics

Sensitivity	α, β, γ, X-ray
Window thickness	2.0 to 3.0 mg/cm^2 (mica)
Starting Voltage	250 V DC
Operating Voltage	~420 - 450 V DC
Dead time	100 microseconds
Dose rate range	10^{-3} to 10^2 mGy/h

Bragg Diffraction with X Rays

Q5. Record the wavelengths of the Cu K_α and the Cu K_β x-ray radiation as listed on the Tel-x-Ometer face. Determine the corresponding frequency and energy values for these x-rays.

Q6. How do the Cu K_α and Cu K_β x-ray wavelengths compare to those for visible light?

Q7. Do you think a diffraction grating like the one you used previously (like in the spectrometer experiment) would be appropriate for x-rays? Why or why not?

In 1912, Professor Max von Laue (1914 Nobel Prize winner) postulated that the wavelength of x-rays was much shorter than most experimenters of the day believed. He suggested that the basic granularity of matter imposed restrictions on the construction of a grating fine enough to cause x-ray diffraction. He proposed that this very "granularity" might provide a three-dimensional grating for the diffraction of x-rays.

Sir Lawrence Bragg (1915 Nobel Prize winner) was the first to presume that the atoms in a crystal were arranged in a cubic and regular three-dimensional pattern. He then derived the diffraction relation $n\lambda = 2d \sin\theta$ (where 2θ is the angle between the incident and diffracted x-rays). You have already investigated this relation using a simulated crystal and microwaves. Today, you will apply this expertise to measure the separation distance *d* between adjacent atoms in this crystal.

Experimental Procedure

- Check that the filament light is still glowing inside the x-ray tube. You may want to increase the setting of the time switch.

- Ask your instructor to place the NaCl crystal in the sample holder. Do not touch the wider sides of the crystal.

- Check that the Primary Beam Collimator #582.001 has been placed over the basic port with the 1 mm slot positioned vertically.

- Mount the Slide Collimator (3 mm) #562.016 at slot 13 on the carriage arm. In addition, mount the collimator (1 mm) #562.015 at slot 18 on the carriage arm.

- Sight through the collimating slits and observe that the primary beam direction lies in the surface of the crystal.

- Mount the GM tube and its holder at slot 26 on the carriage arm.

Now you are ready to begin collecting data! Move the carriage arm off to one side and close the lid completely. Slide the cover so that it is centered and all interlocks are engaged. Press the x-ray on button. If it works, then the red lights should be illuminated and you should be able to hear the high frequency pitch of the electronics. This sounds also serves as an indication that x rays are being produced. **Don't forget to note the time as the x-rays are now being emitted.**

If you are unable to turn on the x-rays then your instructor will help. The interlocks are very sensitive and must be positioned precisely.

Your instructor can demonstrate the technique for taking precise data. X-rays are now leaving the tube and are incident on the NaCl crystal. Using the scaling or ratemeter setting for the GM tube, move the carriage arm from its minimum angle (about $2\theta = 11°$) to the maximum allowed angle (about $2\theta = 124°$). Record the count rate at 1° intervals. If you are in ratemeter mode, be sure to allow enough time at each reading to estimate the average count rate value. If you are in scaling mode, be sure you were on the correct degree setting for the entire time interval. Where there are peaks in the data, then take data for ~10' intervals using the thumb wheel. Be sure to record the maximum count rate and peak location as precisely as possible.

Q8. Describe the nature of the counts at locations with very low count rates. Are they regular like the ticking of a clock? Should they be?

Turn off the x-rays by sliding the cover to the side with the carriage arm when you are finished collecting the data. Ask your instructor to remove the NaCl crystal.

Make a graph of count rate vs. 2θ for the 30 kV setting and a NaCl crystal.

You should have been able to obtain data for three orders of diffraction for the Cu K_α and Cu K_β x-rays. <u>Make a table</u> giving the location of the peaks and use this information to determine six different values for the spacing distance between the atoms in the NaCl crystal.

Q9. Based on your data, what single value would you give for the spacing in a NaCl crystal?

Q10. Which of the x-rays (Cu K_α or Cu K_β) is more intense? Does this make sense?

Q11. What purpose do you suppose the collimators have in this experiment? How would your results have been different if the collimators hadn't been used?

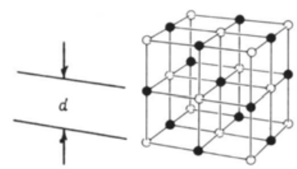
Q12. The mass of a NaCl molecule can be given by: $\frac{Molecular\ weight}{Avogadro's\ number} = \frac{M}{N}$ (g/molecule)

The number of molecules per unit volume can be given by: $\frac{\rho}{M/N}$ (molecules/cm^3)

Since NaCl is diatomic, the number of atoms per unit volume is: $\frac{2\rho N}{M}$ (atoms/cm^3)

Therefore, the distance between adjacent atoms, *d*, in the cubic lattice can be estimated as:

$$d^3 = \frac{1}{2\rho N / M}$$

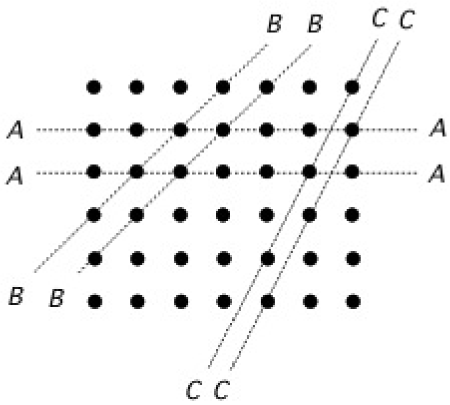


Using the provided values for sodium chloride, estimate the spacing distance *d* for this crystal. How does this value compare to your experimental measurement?

Sodium chloride (NaCl): Mol. Wt. = 58.443; density = 2.17 g/cm^3

Q13. Now replace the sample with the tube of unknown powder and produce a graph of Intensity v. 2θ for the unknown powder. Once you have this, evaluate the peaks you see. Are they coming from the spacing between crystals as they were with the NaCl?

It turns out that the physics for powder analysis is pretty similar to solid crystals, but with an extra twist! In the powder sample, the crystals are randomly oriented so that there are many different orientations of spacing. A graphical representation is below.

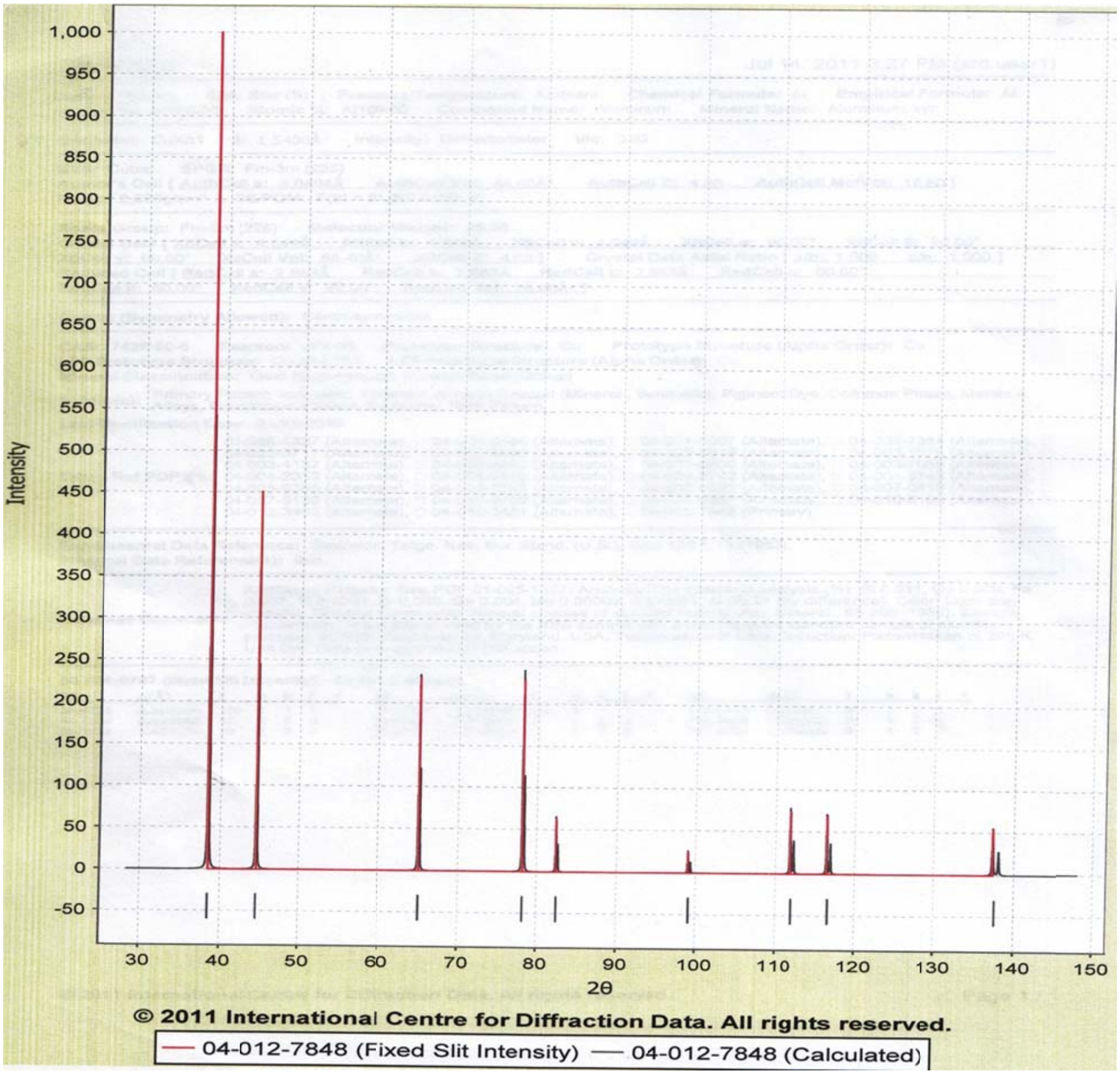


Here the planes AA, BB, and CC represent the various orientations the powder crystal could have. In a powder sample, each plain is equally likely to be in line with the X-ray beam. However some plains in various crystals will be less likely to forward scatter than others. Each powder sample has its own unique diffraction pattern depending on its plane spacing and lattice structure.

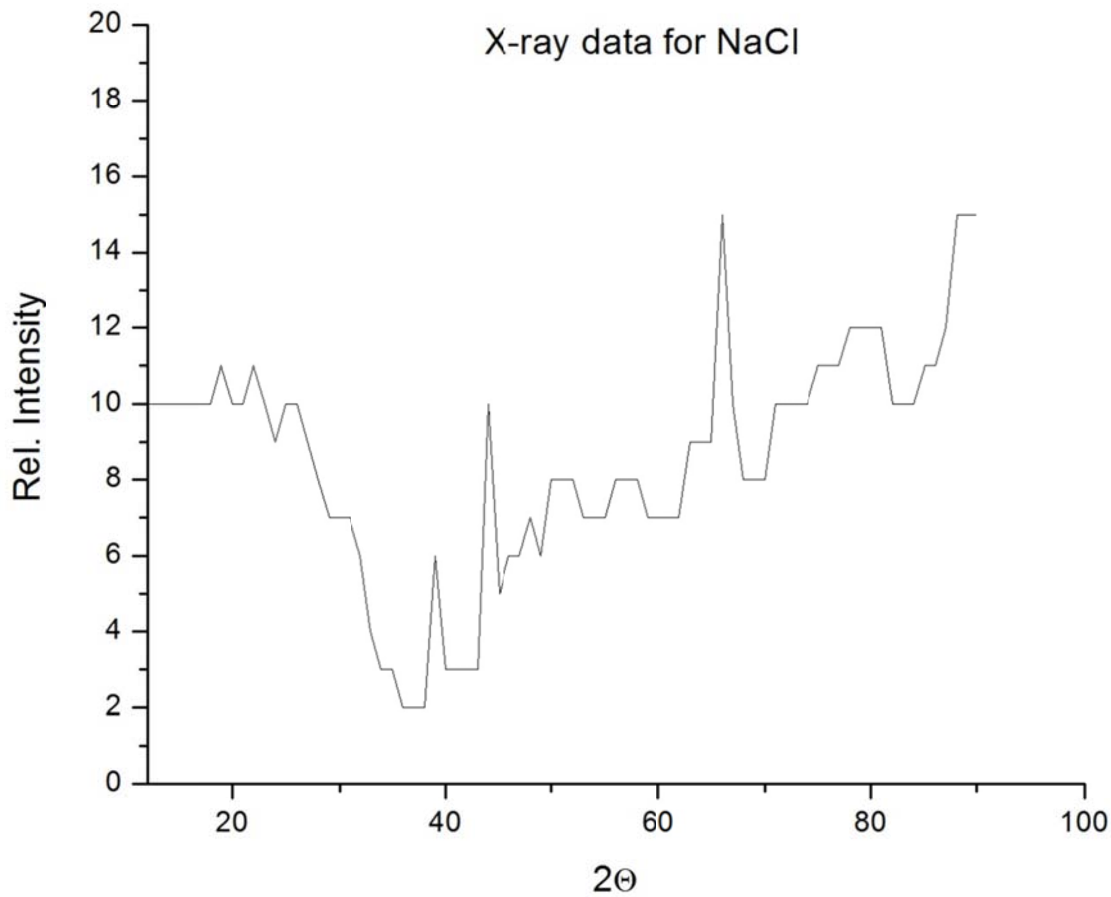
Q14. Compare your powder sample data with the theoretical diffractogram for Aluminum. How do they compare? Look at the sample holder and come up reasons why the background fluctuates as it does? Note: What is holding the sample to the sample holder?!

References: *The Production, Properties, and Uses of X-rays*, Teltron, 1974.
Physics, 4th Ed., Halliday, Resnick, and Krane, John Wiley & Sons, 1992.
Handbook of Chemistry and Physics, 77th Edition, 1996, **4**-85.

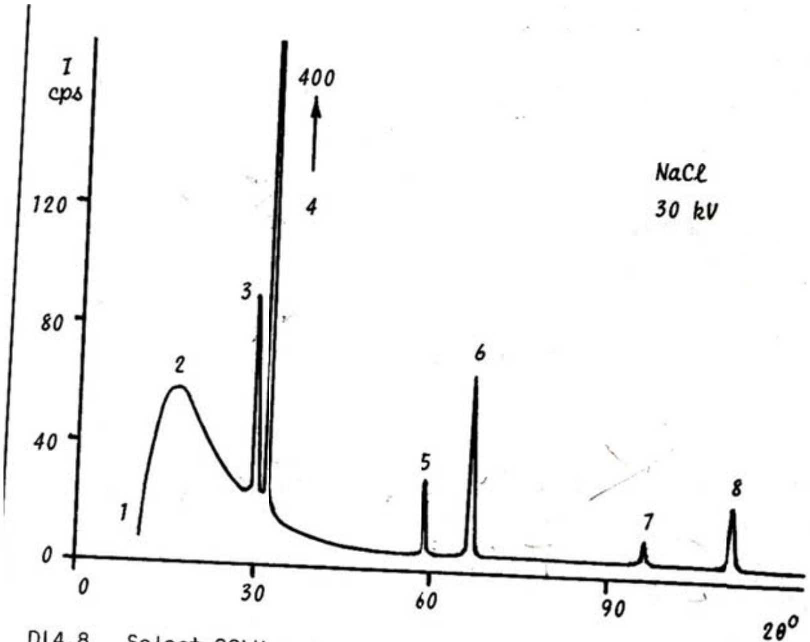
Theoretical Data Aluminum powder:



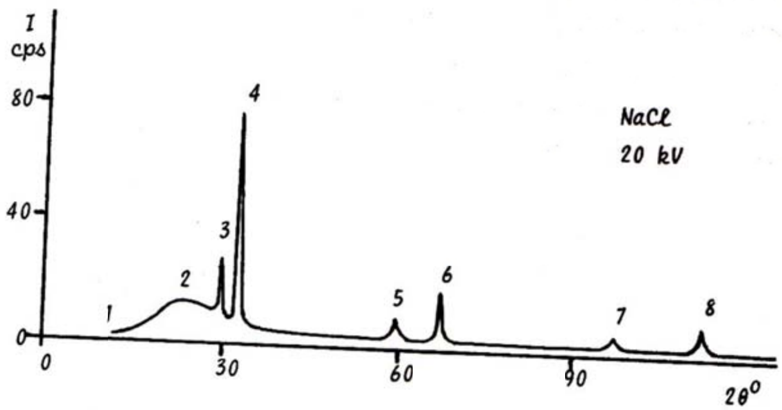
Experimental Data Al:



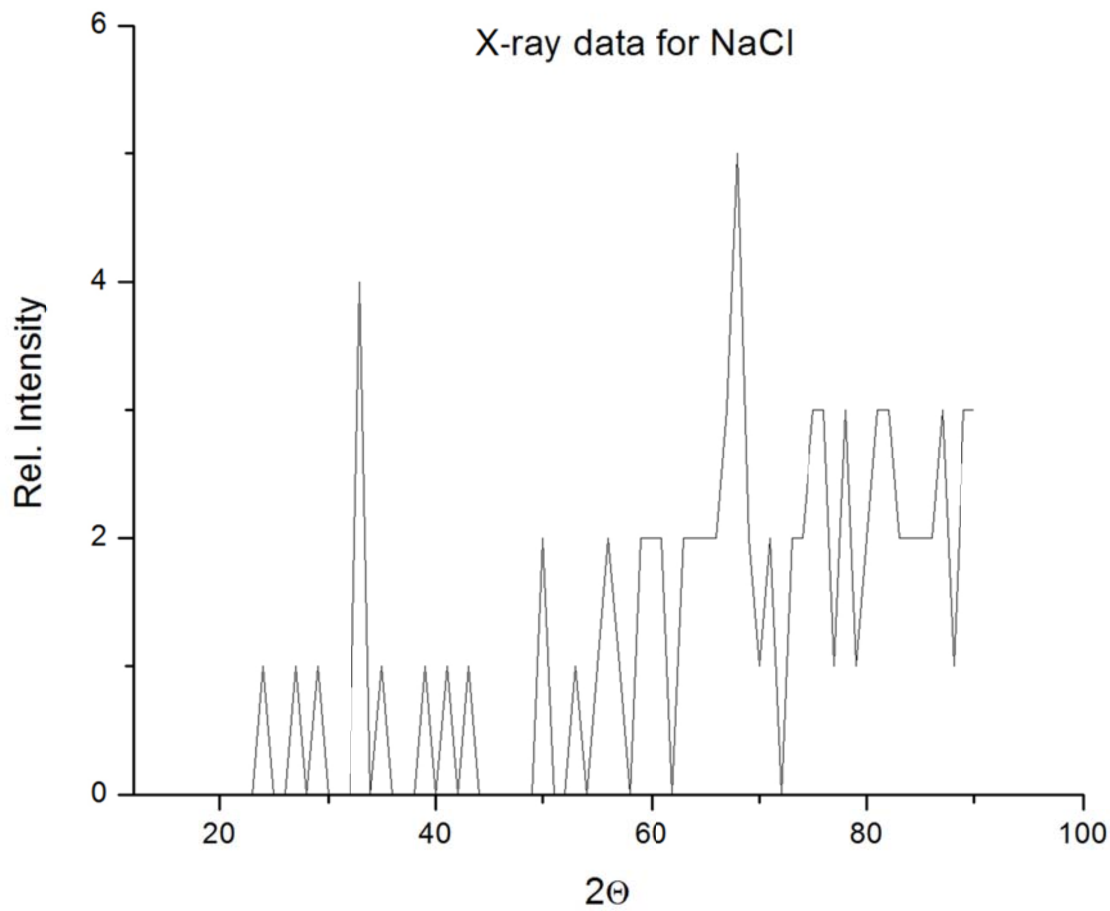
Theoretical Data: NaCl



DI4.8 Select 20kV and repeat DI4.7.



Experimental NaCl:



Pricing:

TEL 25819 TEL-X-Ometer® With Tube & TEL-X-Driver (motorized) - $11,287

Tel-Atomic NaCl crystal – $94

Al powder (tricky to rig a sample holder) – approx. $10

General Advice:

-Most states require dosimetry and other training for the primary user of these machines

-The motorized device priced above makes this entire lab possible in a three hour time limit. If one does not have the motorized Tel-X-Ometer, then this would need to be spread over two lab periods.

-Mounting an aluminum powder sample holder is tricky at best. One must try various types and see which fits best, most securely, and still gives reasonable data

-The NaCl crystals get too much moisture/dust after about 2 years so need to be replaced regularly