LABORATORY 1

PRODUCTION AND DETECTION OF X-RAYS, CONTINUOUS AND CHARACTERISTIC SPECTRA, FILTERING OF X-RAYS

In this laboratory, an X-Ray tube (Cu X-ray tube) will be examined to give an idea about how the production of X-rays is achieved in practice. The tube is cut in order to facilitate the visual examination. In addition, Philips (PW/1050) X-ray generator together with units used in the detection and measurement of X-rays will be demonstrated.

The other purpose of this laboratory is to examine the spectrum of radiations produced in an X-ray tube. You will examine a chart, wavelength vs. intensity, recorded from an X-ray tube at a certain applied voltage (X-ray tube in use will not be disclosed so one of your aims is to identify the X-ray tube, i.e. the target metal, from which the spectrum is obtained.). Here the aim is to identify a suitable filter material in order to produce monochromatic radiations from the tube.

1.1. Production and Detection of X-Rays

1.1.1. Production of X-Rays

X-rays are produced whenever high-speed electrons strike to metal target. Any X-ray tube must therefore contain:

a. A source of electrons
b. A high accelerating voltage, and
c. A metal target.

All X-ray tubes contain two electrodes, an anode (the metal target) maintained at ground potential, and a cathode maintained at a high negative potential, normally of the order of 30000 to 50000 volts (30-50 kV) for diffraction work.

Most X-ray tubes in current use are of filament type as the present one under examination in this laboratory, see Fig.1.1. Such tubes consist of an evacuated glass envelope, which insulates the anode at one end from the cathode at the other. The cathode is a tungsten filament. The anode is the desired target metal placed as a small insert in a water-cooled copper block. One lead of the high voltage transformer is connected to the filament and the other to the ground.

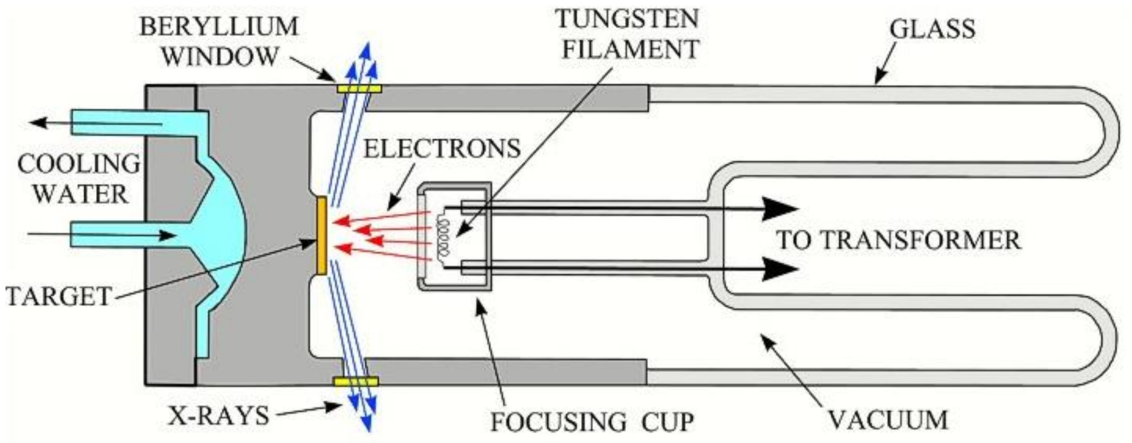


Fig. 1.1 Schematic cross-section of an X-ray tube (filament type).
[src= 'http://pubs.usgs.gov/of/2001/of01-041/htmldocs/images/xrdtube.jpg']

The filament is heated by passing a current of about 3A through it. The filament emits electrons, which are rapidly drawn to the target by the applied high voltage across the tube. Surrounding the filament is a small metal cup maintained at the same high (negative) voltage as the filament. It therefore repels the electrons and tends to focus them into a narrow region of the target, called the "focal spot". X-rays are emitted from the local spot in all directions and escape from the tube through windows, which are usually made of beryllium, aluminum, or mica in the tube housing.

The size and shape of the focal spot an X-ray tube is one of its most important characteristics. Within limits, it should be as small as possible in order to concentrate the electron energy into a small area of the target and so produce an X-ray source of high intensity. The best value of target-to-beam angle is about 6^o and a good tube will have a projected focal-spot size at this angle about $1mm^2$.

1.1.2. Detection of X-Rays

The principal means used to detect X-ray beams are fluorescent screens, photographic film and ionization devices.

> <u>FLOURESCENT SCREENS:</u> They are made of a thin layer of zinc sulfide, containing a trace of nickel, mounted on a cardboard backing. Under the action of X-rays, this compound fluoresces in the visible region, i.e. emits visible light, in this case yellow light. They are widely used in diffraction work to locate the position of the primary beam when adjusting the apparatus.

> <u>PHOTOGRAPHIC FILM:</u> Detection of X-rays with photographic films is similar to the recording of the visible light with ordinary film. The films used with X-rays, however, have thicker emulsion and larger grain sizes. Therefore, when developed the X-ray films are grainy and do not resolve fine details.

> <u>IONIZATION DEVICES:</u> They measure the intensity of X-ray beams by the amount of ionization. They produce in a gas (Geiger counter and proportional counter) or in a solid (scintillation counter and semiconductor counters). X-ray quanta can cause ionization by knocking an electron out of a gas or solid atom and this makes the basis of intensity measurements.

In the case of Geiger counters, an X-ray beam is passed through a chamber containing a suitable gas and two electrodes having a potential difference between them (in the order of 1500 volts), see Fig.1.2. When an X-ray photon enters, it ionizes an atom of a gas, somewhere within the chamber. Therefore, the atom ejects electrons. Because of the applied voltage, these electrons are accelerated and collide with other atoms ejecting new electrons in the process. The ejected electrons under the influence of the applied voltage move towards the wire anode where produce a pulse of current (1-10 V in height), which can be detected by the external circuitry. The Geiger counter can be used in measurements if the rate is not higher than several hundred counts per second (cps). If faster, the counter is "chocked" and the other fast responding (proportional or scintillation counters) should be used.

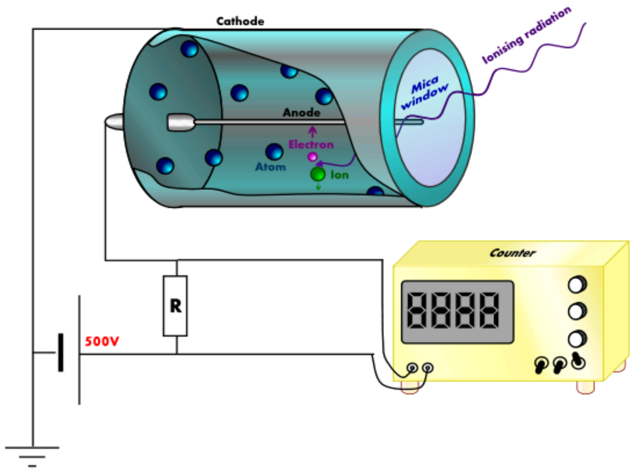


Fig. 1.2 Schematic cross-section of a Geiger Counter (*Micra window is the insulator.)
[src=' http://lakatom.blogspot.com.tr/2011/04/geiger-muller-counter_14.html']

1.1.3. X-Ray Generator and Measuring Electronics

Generator in use in the laboratory is a twin tube Philips X-Ray generator. This consists of control cabinet and a unit that contains two X-ray tubes and also houses the transformer. Through the control cabinet, high tension can be applied to the X-ray tube and the current can be adjusted. Measuring electronics in its simplest form involve (see Fig.1.3):

- A DETECTOR (e.g. GEIGER detector) pulses of which are fed to
- A SCALER (counters), the purpose of which is to count the pulses received. If the detector is a proportional or scintillation type, pulses which are weaker and irregular in shape are fed through an AMPLIFIER-ANALYZER and to a PULSE SHAPER and then to the scaler. Because counts should be collected over a time base measuring electronics also involve
- A TIMER. One use of this timer is in conjunction with
- A RATEMETER. This unit generates a voltage (in mV) proportional to the count accumulated over a certain period. This period is called TIME CONSTANT (in seconds) and can be adjusted to suit the purpose. The output of the ratemeter is fed to
- A CHART RECORDER, which involves a drive mechanism that feeds the recording paper and a pen, the position of which depends on the voltage generated by the ratemeter.

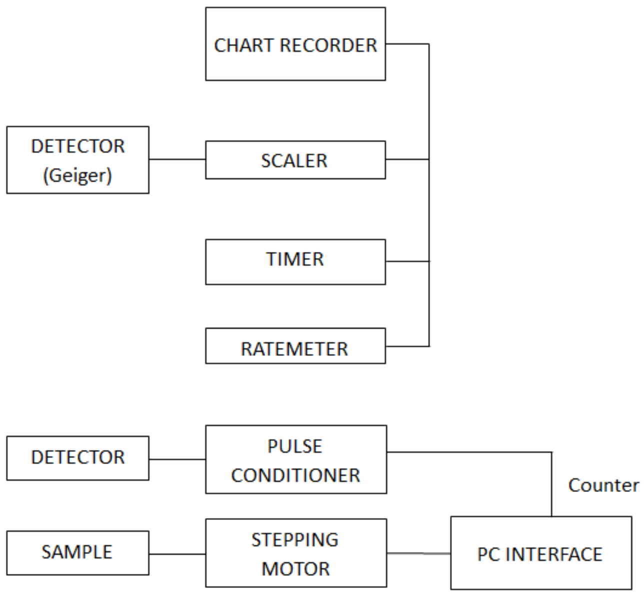


Fig. 1.3 Simple block diagrams of units used in counting X-rays.

1.2. CONTINUOUS AND CHARACTERISTIC SPECTRA

1.2.1. Continuous and Characteristic Radiations

When electrons with high kinetic energy hit a metal target, X-rays are produced in various wavelengths. See Fig.1.4.

CONTINUOUS SPECTRUM: At relatively low accelerating voltages, the metal target gives off continuous spectrum of X-rays. This occurs because not all electrons are decelerated in the same way. Some are stopped in one impact and give up all their energy at once, while others lose their energy after a number of impacts in each losing only a fraction of their energy. The electrons that are stopped in one impact will give rise to X-rays of minimum wavelength.

CHARACTERISTIC SPECTRUM: If the voltage applied to X-ray tube exceeds a certain critical value, sharp intensity maxima appear at certain wavelengths superimposed on continuous spectrum. The wavelengths at which these maxima appear are characteristic of the target metal. The electrons at this high voltage become so energetic that they have sufficient energy to knock out electrons from metal target. As a result, such atoms in the target are in excited or high-energy state. One of the outer electrons falls immediately into the energy state from which the electron is removed. The atom then emits a photon of radiation. The target metal in this way generates a set of radiation Kα, Kβ, Lα, etc. For instance, if an electron is removed from K-shell and L-shell electron fills this vacancy, the atom produces Kα radiation. It occurs with a precise wavelength because the energy of this radiation must be equal to the energy difference between L-shell and K-shell. As such, the characteristic radiation reflects the atomic structure of the target metal.

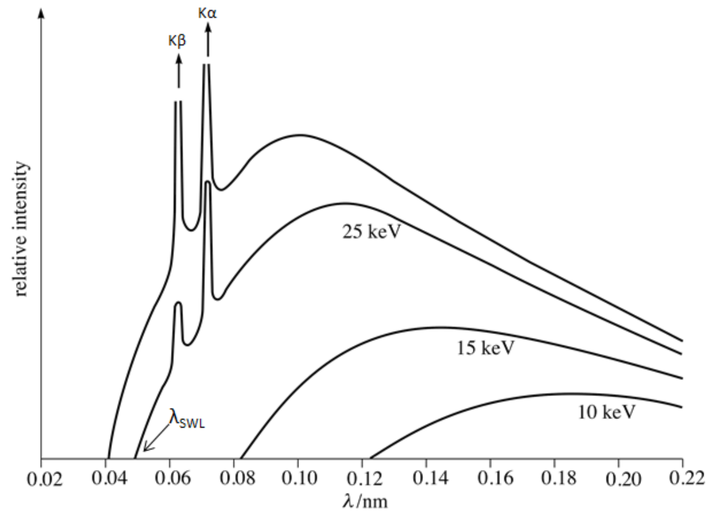


Fig. 1.4 X-ray spectrum for Mo (at different tube voltages) showing the continuous spectrum and the characteristic lines. [src='http://www.physics.brocku.ca/PPLATO/h-flap/phys8_3.html']

1.2.2. Filtering of X-Rays

Under normal conditions, an X-ray tube produces a continous spectrum of radiations superimposed on a spectrum of characteristic lines. Diffraction work, however, requires a monochromatic radiation. Kα lines of most metal targets are particularly suitable for this purpose if this can be separated from other radiations. The separation is normally achieved by filtering the X-rays through a metal sheet of a suitable mass absorption edge.

Experiment 1:

Experiments involve an X-ray tube. Radiations produced in this tube is analyzed with wavelength dispersive system, see Fig.1.5. This system consists of a single crystal sheet (e.g. silicon sheet), with a stack of parallel crystallographic planes with interplanar spacing of **d=1.441 Å**. The sheet is mounted on a system such that the single crystal on which the X-rays fall are tilted continuously and the detector (Geiger counter) placed some distance away (also tilted continuously) measures the intensity of the scattered radiation.

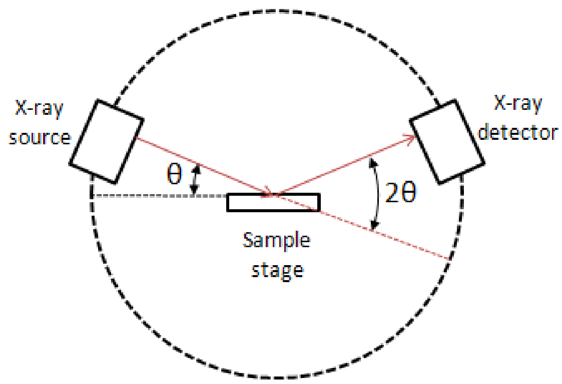


Fig. 1.5 Schematic representation of wavelength dispersive analyzer. In this example, single crystal silicon sheet is at the sample stage. [src='http://chemwiki.ucdavis.edu/@api/deki/files/232/xrd.png?size=bestfit&width=323&height=237&revision=1']

At different tilt angles (θ), the crystal "reflects" different wavelengths whose intensity is measured by a detector. At a given tilt angle, the wavelength (λ) analyzed is given by:

$$\lambda = 2\ \mathrm{d}\ \sin\theta$$

The charts obtained from an unknown X-ray tube are in the form of "intensity vs. 2θ", see Fig.1.6 and Fig.1.7. In order to identify the tube:

a. Convert the charts into intensity vs. λ.
b. The particular interest here is the wavelengths at which the characteristic lines occur.

Therefore determine these wavelength values, and then compare them with the values given in the Appendix 7: "X-Ray Wavelengths".

$\lambda(K\alpha_1)$ = ………………………………. Å
$\lambda(K\alpha_2)$ = ………………………………. Å
$\lambda(K\beta)$ = ………………………………. Å

Therefore, according to the wavelength values tabulated in the Appendix 7: "X-Ray Wavelengths", target metal is ………………………………. .

Minimum excitation voltage for this tube is ………………………………. .

HINT:

$$V_K = \frac{h.c}{e.\lambda_K}$$

The charts given in Fig.1.6 and Fig.1.7 (intensity vs. 2θ) are identical in terms of radiation (the same X-ray tube, the same conditions). The only difference is that: for recording the chart given in Fig.1.7, X-rays were filtered through an iron sheet.

With the data supplied in these charts, you should be able to calculate the thickness of the filter, x.

$$(\mu/p)_{Fe} = \underline{\hspace{3cm}}\ cm^2/\mathrm{gm}$$

Use Appendix 8: "Mass Absorption Coefficients μ/p (cm^2/gm) and Densities p".

HINT:

$$\frac{I_x}{I_0} = e^{-(\mu/p).p.x}$$

Therefore, the thickness of the filter, x = ………………………………. .

You should not that how intensities are affected with different filter materials. You should aim that identifying the most suitable filter material so that the tube in question can be used as a source of monochromatic radiation.

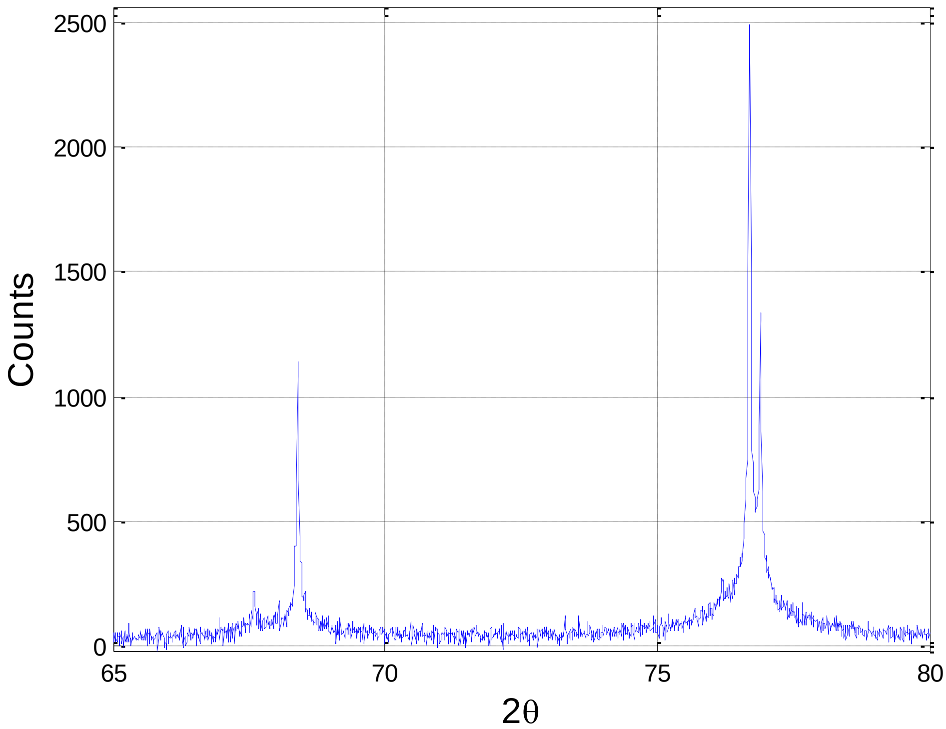


Fig. 1.6 Intensity vs. 2θ recorded from an X-ray tube at an accelerating voltage of 30 kV and 10mA.

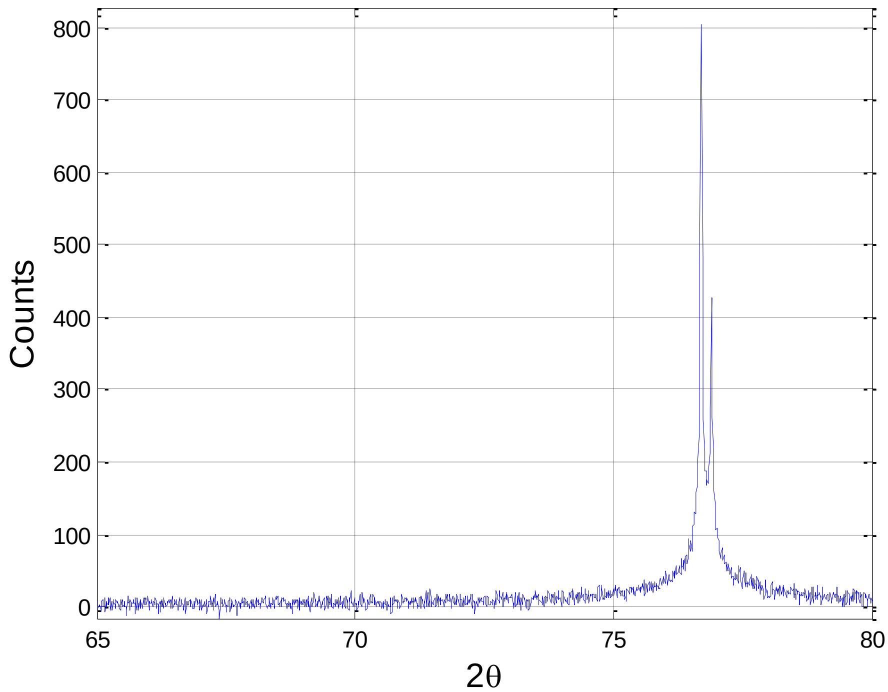
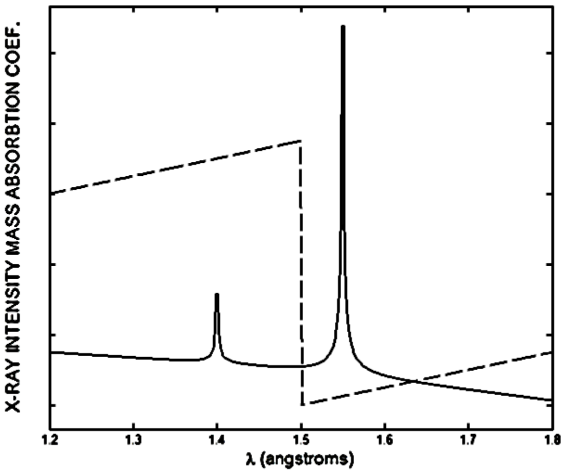


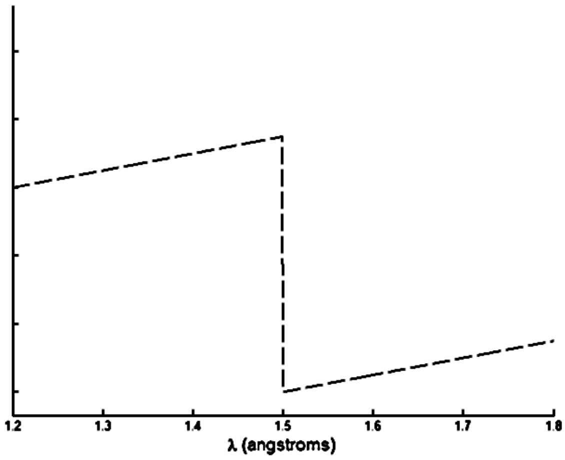
Fig. 1.7 Intensity vs. 2θ recorded from same conditions as given in Fig.1.6, but filtered through an iron sheet.

Self-Study Questions:

1. In figure (a) partial spectra of the unfiltered beams from a metal target and the mass absorbtion coefficient (the dashed lines) of the filter material are shown. Roughly draw the partial spectra of this material after passing through the filter in figure (b).



No Filter



After Filtering

2. Label the below statements as Ture (T) or False (F).

a. An increase in voltage above the critical voltage increases the intensities of the characteristic lines relative to the continuous spectrum but does not change their wavelengths. (......)

b. Mass absorption coefficient (μ/p) is a constant of the material and independent of its physical state (solid, liquid, or gas.) (......)

c. Flourescent screens are used both for detection of X-ray beams and measurement of intensity. (......)

d. The wavelengths of X-rays are longer than infrared. (......)

e. Any X-ray tube must contain a source of electrons, a high accelerating voltage, and a metal target. (......)

f. BONUS QUESTION
Electric and magnetic fields vibrate perpendicular to each other. Together they form an electromagnetic wave that moves through space at the speed of light. (......).