Al-Mustansiriyah J. Sci **Vol. 22, No. 5, 2011**

Determination of the Maximum Quantum energy of X-ray radiation independent on the molybdenum anode using LiF & NaCl crystals

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Received : 30/03/2011 Accepted: 29/05/2011

الخلاصة

تم دراسة طيف الانبعاث للاشعة السينية من انود الموليبدنيوم باستخدام بلورتي NaCl & (LiF) لحساب الطاقة الحركية للالكترونات المعجلة بفولتية (35Kv) و الطاقة العظمى للالكترونات بعد التصادم والمنعكسة من البلورتين اضافة الى سرعة الالكترونات المغادرة من القشرة (K) الى القشرتين (L ,M). اظهرت النتائج بان الطاقة الحركية للالكترونات المنبعثة من انود الموليبديوم تقدر (56KeV) وسرعة الالكترونات (1.1 Mm/sec) وان الطاقة الكمية العظمى المنبعثة من الانود والمنعكسة من خلال بلورة (NaCl) تقدر (50.8KeV) واقصر طول موجي (0.02nm) اما في بلورة (LiF) فتقدر الطاقة (44.3KeV) واقصر طول موجي (0.014 nm).

ABSTRACT

The aim of this research is to determine X-ray emission spectrum of molybdenum anode by using LiF and NaCl Crystals to calculate the Kinetic Energy for accelerated electrons in (35KV), The maximum Energy of electron after collision and reflected from crystals and The velocity of electron which travels from the (K-shell) to the (L-M shell). The results showed that the max. Kinetic energy of electrons emitted from the anode Molybdenum estimated (50.8KeV) and the speed of electrons (1.1Mm/sec). Maximum Quantum energy of x-ray radiation energy which emitted from anode and reflected by NaCl crystal (50.8KeV) and the shortest wavelength (0.02nm) either in LiF crystal estimated energy is (44.3KeV) and the shortest wavelength (0.014nm).

INTRODUCTION

X-rays were discovered in 1895 by William Roentgen and their uses and benefits were recognized before their risks. The problems caused by X-rays are due to their ionizing ability. This means that X-rays are capable of initiating chemical changes on the atomic level [1].

X-rays primary interact with electrons in atoms. When X-ray photons collide with electrons, some photons from the incident beam will be deflected away from the direction where they originally travel, much like billiard balls bouncing off one another. If the wavelength of these scattered x-rays did not change (meaning that X-ray photons did not lose any energy), the process is called elastic scattering (Thompson Scattering) in that only momentum has been transferred in the scattering process. These are the x-rays that we measure in diffraction experiments, as the scattered X-rays carry information about the electron distribution in materials. On the other hand, in the inelastic scattering process (Compton Scattering), x-rays transfer some of their energy to the electrons and the scattered x-rays will have different wavelength than the incident x-ray [2].

Diffracted waves from different atoms can interfere with each other and the resultant intensity distribution is strongly modulated by this interaction. If the atoms are arranged in a periodic fashion, as in crystals, the diffracted waves will consist of sharp interference maxima (peaks) with the same symmetry as in the distribution of atoms. Measuring the diffraction pattern therefore allows us to deduce the distribution of atoms in a material [3].

X-ray can be produced in two ways:

By acceleration the charged particles are usually electron-these rays are bremsstrahung as forms continuous spectrum (a mixtures of electromagnetic waves is very short and short) .or when the electron transition in the cover of atom from Avery high level. X-ray will then show a certain wavelength, and have a specific energy. Both cases above occur in the cavity X-ray, where the electrons arise from anode (fuse molybdenum) and speed by voltage to collision by the surface of cathode and then produce X-ray and heat. 99% of the electricity used appears as temperature is not helpful and only 1%of the energy converted to X-rays [4].

Theoretical part:

The difference between the energy of electron accelerated before and after the collision can be written by the flowing equation:

$$E = e\,U = 1/2\, m_e v_1^2 = E_{Ph} + 1/2\, m_e v_2^2 \qquad (1)$$

e : elementary charge of the electron ($e=1.602*10^{-19}$ C).
U : anode voltage.
m_e : electron mass.
v_1 : velocity of the electron before the collision.
v_2 : velocity of the electron after the collision
E_{ph} : energy of the photons (energy of an X-ray quantum).
The energy of radiation quantum is:

$$E_{Ph} = h \, . \, f = h \, \frac{c}{\lambda} \qquad (2)$$

h: Planck's constant ($h = 6.625*10^{-34}$ W. sec).

c : light velocity in vacuum ($c = 2.998*10^{8}$ m . sec^{-1}).
f : frequency.
λ : Wavelength.

The bremsstrahlung has a continuous spectrum with an edge at short wavelengths. This corresponds to those electrons which transpose their whole kinetic energy into an X-ray photon (total slowdown, v_2=0). The photon has then a maximum energy; hence its wavelength is minimum in this case [4]:

$$E_{Ph} = eV = h \, . \, f = h\, c/\lambda_{min} \qquad (3)$$

Wavelengths below λ_{min} can't occur at a given anode voltage because the entire kinetic energy of the electrons is already transformed in X-ray quanta. Equation (3) represented the maximum energy of electrons accelerated to the shortest wavelength.

Electron Shells:

As a simple model, an atom may be considered to be a positive charged nucleus surrounded by shells of negative charged electrons. The shells are termed K, L, M, and N (starting from the innermost, most strongly bound shell). More accurately, an atom consists of a nucleus surrounded by electrons that occupy volumes of space (orbital's) around it (Figure 1) only some of which are spherical.

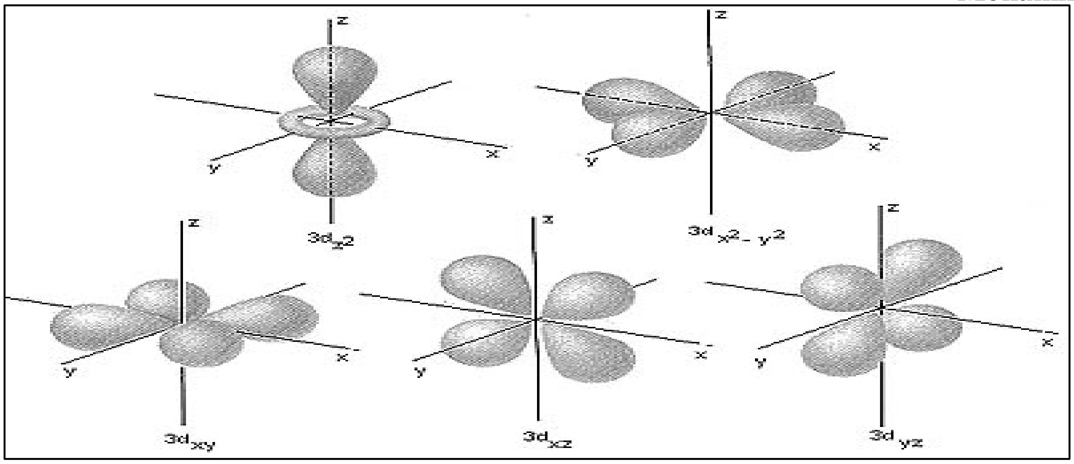

Fig.-1: Actual probability distributions for electron clouds, which are considered as shells in this discussion.

When a sample is bombarded by an electron beam, some electrons are knocked out of their shells in a process called inner-shell ionization. About 0.1% of the electrons produce K-shell vacancies; most produce heat. Outer-shell electrons fall in to fill a vacancy in a process of self-neutralization (Figure 2). The energy required to produce inner-shell ionization is termed the excitation potential or critical ionization potential (E_c) [5].

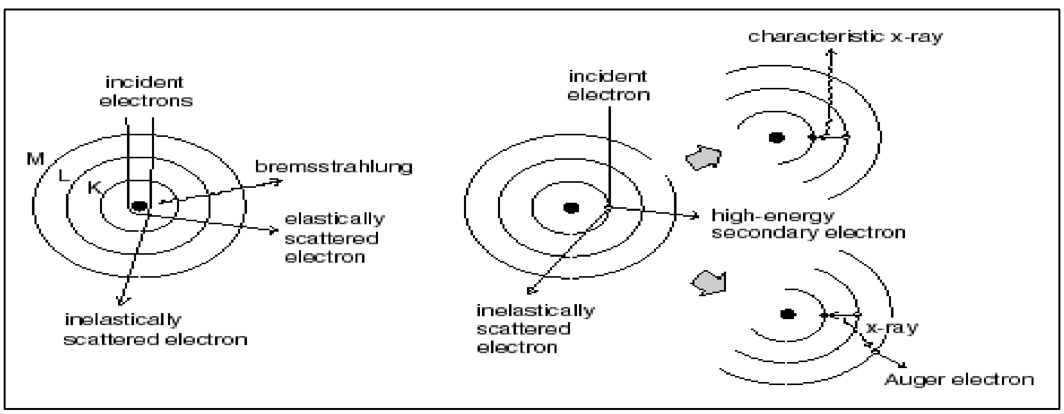

Fig.-2: Classical models showing the production of bremsstrahlung, characteristic X-rays, and Auger electrons.

(Left) Electrons are scattered elastically and in elastically by the positively charged nucleus. The in elastically scattered electron loses energy, which appears as bremsstrahlung. Elastically scattered electrons (which include backscattered electrons) are generally scattered through larger angles than are in elastically scattered electrons. (Right) An incident electron ionizes the sample atom by ejecting an electron from an inner-shell (the K shell, in this case). De-excitation, in turn, produces characteristic X-radiation (above) or an Auger electron (below) [5].

When outer-shell electrons drop into inner shells, they emit quantized photon "characteristic of the element". The energies of the characteristic X-rays produced are only very weakly dependent on the chemical structure in which the atom is bound, indicating that the non-bonding shells of atoms are the X-ray source. An atom remains ionized for a very short time (about 10^{-14} second) and thus the incident electrons that arrive about every 10^{-12} second can repeat atom ionization. However, not all outer-shell electrons can fall in to produce X-rays [6].

From fig.2 the photons (energy quantum) which are emitted during these electron jumps are called k_α *and* k_β,respectively. The corresponding wavelength can calculated from:

$$\lambda_{k_\alpha} = \frac{h \;.\; c}{E_L - E_K} \quad and \quad \lambda_{k_\beta} = \frac{h \;.\; c}{E_M - E_K} \qquad (4)$$

$E_L - E_K$ The difference in electron energy between the L and K –shell.

$E_M - E_K$ The difference in electron energy between the M and K –shell.

Because this energy difference is a characteristic of the material, the radiation is called "characteristic radiation". This radiation exhibits a line spectrum.

Bragg diffraction:

Bragg diffraction occurs when electromagnetic radiation or subatomic particle waves with wavelength comparable to atomic spacing's are incident upon a crystalline sample, scattered in a specula fashion by the atoms in the system, and undergo constructive interference in accordance to Bragg's law. For a crystalline solid, the waves are scattered from lattice planes separated by the linear distance *d*. Where the scattered waves interfere constructively; they remain in same phase since the path length of each wave is equal to an integer number of multiple of the wavelength [4, 5, 6].

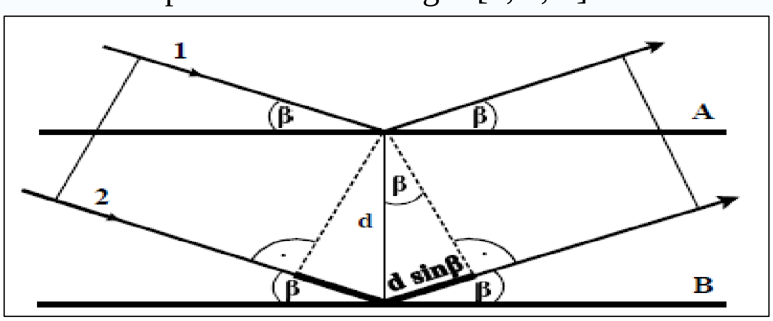

Fig.-3: Bragg reflection of x-ray [6].

The path difference between two waves undergoing constructive interference is given by $2d\sin\theta$, where θ is the scattering angle. This leads to Bragg's law which describes the condition for constructive interference from successive crystallographic planes (*h, k, l*) of the crystalline lattice [6]:

$$2d \sin \theta = n \lambda \quad (5)$$

Where n is an integer determined by the order given, and λ is the wavelength. A diffraction pattern is obtained by measuring the intensity of scattered waves as a function of scattering angle. Very strong intensities known as Bragg peaks are obtained in the diffraction pattern when scattered waves satisfy the Bragg condition.

Selection rules and practical crystallography

Bragg's law, as stated above, can be used to obtain the lattice spacing of a particular cubic system through the following equation:

$$d = \frac{a}{\sqrt{h^2 + k^2 + l^2}} \quad (6)$$

where *a* is the lattice spacing of the cubic crystal, and *h*, *k*, and *l* are the Miller indices of the Bragg plane. Combining this relation with Bragg's law [6]:

$$\left(\frac{\lambda}{2a}\right)^2 = \frac{\sin^2\theta}{h^2 + k^2 + l^2}. \quad (7)$$

One can derive selection rules for the Miller indices for different cubic Bravais lattices; the selection rules for several will be given at table -1.

Table -1 : Allowed and Forbidden Reflections of Different Bravais Lattices

Bravais lattice	Allowed reflections	Forbidden reflections
Simple cubic	**Any *h, k, l***	**None**
Body-centered cubic	**(*h* + *k* + *l*) even**	**(*h* + *k* + *l*)odd**
Face-centered cubic	**(*h, k, l*)all odd or all even**	**(*h, k, l*) mixed odd and even**
Diamond F.C.C.	**all: odd, or even &(*h*+*k*+*l*) = 4n**	**above, or even &(*h*+*k*+*l*)≠ 4n**
Triangular lattice	***l* even, *h* + 2*k* ≠ 3*n***	***h* + 2*k* = 3*n* for odd *l***

To overcome this difficulty, Niels Bohr proposed, in 1913, what is now called the *Bohr model of the atom*. He suggested that electrons could only have certain *classical* motions [11, 12]:

1. The electrons can only travel in special orbits at a certain discrete set of distances from the nucleus with specific energies.
2. The electrons do not continuously lose energy as they travel. They can only gain and lose energy by jumping from one allowed orbit to another, absorbing or emitting electromagnetic radiation with a frequency (f) determined by the energy difference of the levels according to the *Planck relation*.
3. The frequency of the radiation emitted at an orbit of period (T) is as it would be in classical mechanics; it is the reciprocal of the classical orbit period[7,9]:

$$T = \frac{1}{f} \qquad (8)$$

The particle side:

1- Description of the X-ray device with diffract meter:

The case of the X-ray device shown in figure 4 [The device is made by LD didactic company, Germany] shielded from radiation consists of three separated chambers. The largest (right-hand side) chamber is the experimental space. It contains the geometry (facility for controlling and measuring angles) that holds the LiF crystal and the detector (Geiger-Muller counter tube). The X-ray tube is placed in the middle chamber. The left chamber contains the microprocessor controlled electronics, the controls and displays. The mechanism of X-ray is excluded because the high voltage at the X-ray tube is only present when the two sliding doors of the experimental and the tube chamber are closed. The doors and windows consist of lead glass, which prevents any escape of inadmissible radiation. Lead glass is soft, be careful for not to scratch it. The same happens to the LiF crystal fixed on the geometry [8].

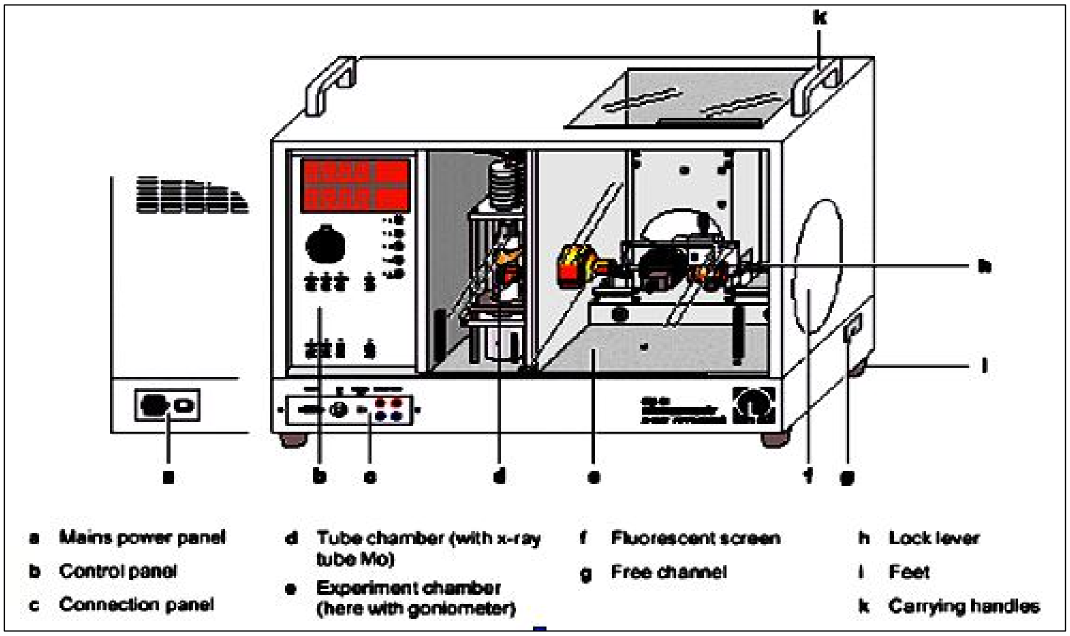

Fig.-4: X-Ray device with goniometry [8].

2- For recording the X-ray spectrum in the Bragg arrangement the following working parameters should be set up: Tube current: I = 1 mA , High voltage: *U* = 35 kV , Measuring time: *t* = 5 s **,** Initial angle = 5^o ,Final angle max. = 40^0

3- Determine the wavelength and quantum energies for the characteristic lines K_α and K_β of the Mo anode for NaCl and LiF .

4- Calculate the maximal quantum energy for each experimental value of the anode voltage U from the angles belonging to the corresponding short-wave edge using equation (3). List the energies in a table and compare them with the kinetic energy E = eU of the electrons accelerated by the voltage U.

5- Calculate the $E_L - E_K$ The difference in electron energy between the L and K –shell and $E_M - E_K$ The difference in electron energy between the M and K –shell by using equation (4).

6- Using equation (1) to find the velocity and interval time of electron and the displacement between the orbits.

RESULTS AND DISSECTION

1- The kinetic energy of accelerated electrons valued before collision (56keV) and velocity (1.1Mm/sec).

2-The maximum energy for estimation after collision and reflected from NaCl crystal (50.8KeV) with wavelength (λ_{min}=0.0214nm) for first order of diffraction (k=1), $E_L - E_K$=14.16KeV i.e. λ_α =0.0876nm and $E_M - E_K$=6.53 KeV i.e. λ_β = 0.19nm.

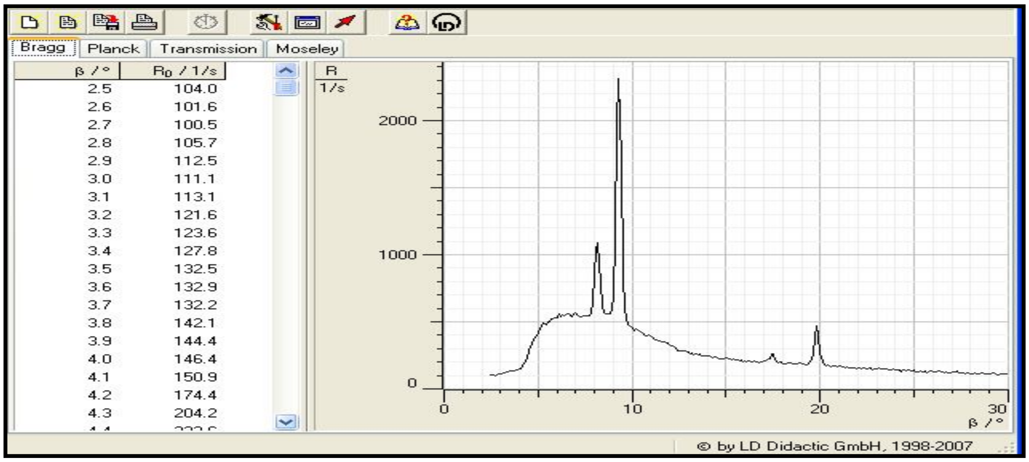

Fig.-5: spectrum of NaCl crystal

As can be seen from Figure (5) that the spectrum contains and three sharp lines which characterize the spectrum of X-ray for anode molybdenum reflected from a NaCl crystal with special angle and that can be determined theoretically from the equation (5)

The ratio (d/n) has meaning in the crystals science of to imagination surfaces. Taking into account that the linear spectrum cannot be done without voltage estimated at 35 KV and without that we will get a continuous spectrum of X-rays. But the electrons tend to have the movement of vibration energy generating heat where the electrons do not have the crust to leave (K-shall).

3-The maximum energy for estimation after collision and reflected from LiF crystal (44. 3 KeV) with wavelength (λ_{min} =0.014nm) for second order of diffraction (k=2), $E_L - E_K$=25.3KeV i.e λα =0.04899nm and $E_M - E_K$=14.16 KeV i.e λ_β = 0.097nm.

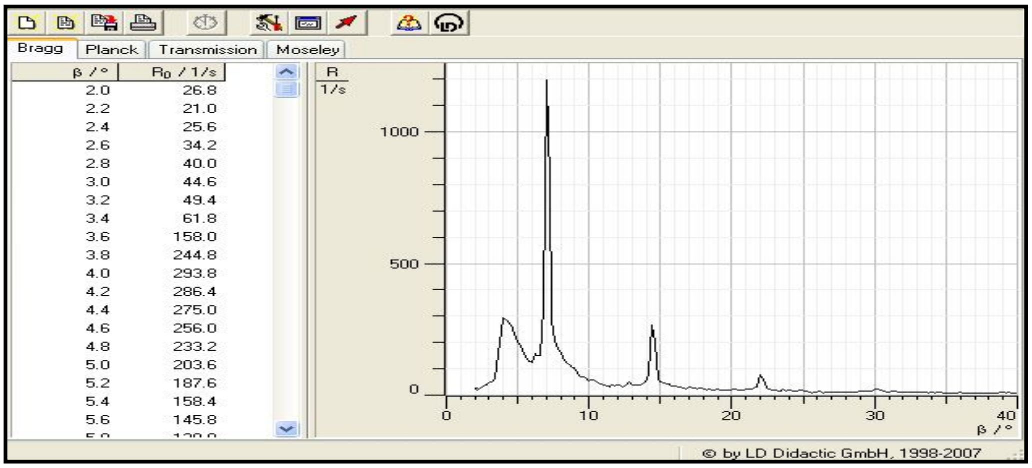

Fig.-6: spectrum of LiF crystal.

Figure (6) noted a linear spectrum and three peaks characteristic of crystal LiF. But the first peak is getting closer to the shorter wavelength compared to crystallize NaCl.

4-by using equation (1) to calculate the velocity of the electron after the collision and travel from $E_M - E_K$ represented as (v_β = 0.046Mm/sec) and $E_L - E_K$ as (v_α = 0.7Mm/sec) in NaCl crystal compare to the LiF (v_β = 0.67Mm / sec) and (v_α = 0.94Mm / sec).

Conclusions:

1- Increasing the voltage between the anode and cathode (accelerating voltage) is not the only factor that's causing the figure of the linear spectrum of X-rays but mainly depends on the type of anode material.

2- Most important features of the spectrum of linear high intensity in X-rays more than 90 times or more of the other rays that have the same wavelength.

3- X-ray radiation, especially (K- Line) plays a main rule in an important study the crystalline structure of solids.

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