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# A Unique Application of Pnccd X–Ray Detector in Material Characterization

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#### Abstract

In the current work, the principle focus is to analyze the measurements of X-rays by the application of Fast Readout Charge-Coupled Device (pnCCD), which is a special form of CCD developed for the purpose of spectroscopy and imaging of X-radiation with high time resolution. As a part of this work, two phases are taken into consideration. In the first phase, highly accelerated electrons induced by high voltage are collided with a metal target (anode material-Mo in this case) in X-ray tube and emitted X-rays from the tube are measured by pnCCD. In this phase, the X-ray spectrum depends on the anode material and accelerating voltage. During the phase 1 experiment, various elements are noticed in the X-ray spectra, which are originated from the experimental apparatus (X-ray tube only) and its surrounding materials. Through proper energy calibration technique, elemental composition of the materials has been determined. In the second phase, fluorescence X-radiation (secondary radiation), emitted by the secondary target source (MnO<sub>2</sub>) is measured by pnCCD where, Mn is excited by being bombarded with high energy X-rays from X-ray tube. It is to be noted that MnO<sub>2</sub> source is guarded by pure Al sheet foil that protects X-rays from other materials. That is why background radiation is decreased and as a result, clean Mn spectrum is observed. To avoid distortion of the intensity determination, the detector's degree of illumination is maintained less than 2% in both phases by using Al filters with required thickness. In terms of intensity, it can be concluded that the intensity of K X-rays released from MnO<sub>2</sub> source is approximately 0.06% in compare to the total intensity of direct emission spectra from experimental apparatus (X-ray tube) for 25 keV.

Keywords: Fast Readout Charged Couple Device (pnCCD) • X-ray Tube • X-ray source • Atomic research • Fluorescence radiation • X-ray characteristics • Energy spectrum

## Introduction

Since its inception, X-ray technology is being used as one of the key analytical technique for determining elemental compositions of materials in both industrial and medical research (producing visual and quantitative information about anatomy by imaging) and development laboratories [1]. It also belongs to a family of atomic research as emitted atomic spectrum expose details of inner structure of atoms like atomic energy transitions in multi-electron atoms, species of atoms in a range of objects [2]. Due to the specific set of energy levels, each type of atom (or element) has its own characteristic electromagnetic spectrum. Therefore, each element produce X-rays characteristic of the atomic element and X-ray fluorescence technique could be applied to determine the species of elements in an unidentified material composition.

X-rays are a part of the electromagnetic spectrum having wavelengths ranging from 0.01 to 10 nm with frequencies ranging from 3 x 1016 to 3 x 1019 Hz with corresponding energies ranging from 120 eV to 120 keV (Figure 1) [3]. X-rays bridge the wavelength range between ultraviolet light and  $\gamma$ -rays appearing in nuclear decay. Electromagnetic radiation not only behaves like waves but show also properties like a particle (photons).

The first law concerning characteristic X-rays was published by a British

physicist Moseley in 1913 that shows the X-ray region may be taken to be in the range of wave lengths from 0.1 to 10 Å corresponding to photon energies from a few keV to several hundreds of keV. Spectra observed were found to be characteristic of the element that is used as the target. Moseley studied the line spectra of 39 elements from the lightest to the heaviest elements. All spectra were remarkably similar. The spectrum consists of groups of lines where the K series and the L series have highest energy. Moseley found that that the square root of the frequency v of a spectral line of the characteristic radiation of an element is a linear function of its atomic number (Figure 2) [4].





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Figure 2. Moseley plot of characteristic X-rays [4].

One of the X-ray generation techniques is X-ray tube, where electrons released from a hot cathode are accelerated by a high voltage. Highly accelerated electrons hit the anode target metal inside X-ray tube. Typical high voltages are 30 to 150 kilovolts (kV). The X-ray spectrum in this case depends on the anode material and the accelerating voltage. The maximum energy of the produced X-ray photon is limited by the energy of the incident electron, which is equal to the high voltage of the tube, so an 80 kV tube can't create X-rays from bremsstrahlung with energy greater than 80 keV [5].

X-rays are emitted after vacancy refilling in inner electron shells (characteristic X-radiation) or as bremsstrahlung spectrum so called "braking radiation" when charged particles are decelerated (Figure 3) [6]. X-rays from X-ray tube are generated by two ways.



**Figure 3.** Illustration of the electron-atom interaction for 100 kV electrons that Produce a characteristic X-ray photon or bremsstrahlung photons from a tungsten atom [6].

#### **Characteristic X-radiation**

This is produced when outer-shell electrons fill a vacancy in the inner shell of an atom and photons are emitted. This process produces an emission spectrum of X-rays at discrete frequencies corresponding to the discrete binding energies of the electrons. As the energy of these spectral lines depends on the target (anode) element, they are called characteristic lines. The transitions stem from filling a K hole in the most inner shell (K shell) or in the L hole in the L shell and so on. The ionization cross section of photon (probability of interaction) depends on the electrons energy. If the initial energy of photon is too high, there will be less probability of interaction with the orbital electron.

#### Bremsstrahlung radiation

It is also called braking radiation. This electromagnetic radiation is produced by the deceleration of a charged particle when deflected by another charged particle, typically an electron by an atomic nucleus. The moving particle loses kinetic energy, which is converted into photon energy and the nucleus recoil.

However, due to high flux of X-rays in the X-ray tube technique, only a few detectors are suited for the precise detection of X-rays with high resolution. pnCCDs have been proven to be a suitable detector and can be used for the measurement of X-rays both with high rates and good energy resolution [7,8]. Its unique application started with the successful lunching of XMM-Newton satellite with the installation of pnCCD detector in it. No degradation in energy resolution is found since launch. It is not only used for the detection of X-rays, but also infrared and optical photons.

Unfortunately, so far, few studies are carried out in the area of pnCCD application for spectroscopy and imaging of X-rays. In the current work, the principal focus is to analyze the measurements of X-rays by the application of Fast Readout Charge-Coupled Device (pnCCD), which is a special form of CCD developed for the purpose of spectroscopy and imaging of X-radiation with high time resolution. As a part of this work, two phases are taken into consideration.

**Phase-I**: Electrons are emitted from a hot cathode are accelerated by a high voltage. Highly accelerated electrons are then collided with a metal target (anode material-Mo in our case) inside X-ray tube and emitted X-radiation from the tube are measured by pnCCD silicon detector. In this phase, the X-ray spectrum depends on the anode material and accelerating voltage. During the phase-I experiment, various elements are noticed in the X-ray spectra, which are originated from the experimental apparatus (X-ray tube only) and it's surrounding materials. Through proper energy calibration technique, elemental composition of the materials has been determined.

**Phase-II:** Fluorescence X-radiation (secondary radiation), emitted by the secondary target source (MnO2) is measured by pnCCD where, Mn is excited by being bombarded with high energy X-rays from X-ray tube. It is to be noted that MnO2 source is guarded by pure AI sheet foil that protects X-rays from other materials. That is why background radiation is decreased and as a result, clean Mn spectrum is observed. To avoid distortion of the intensity determination, the detector's degree of illumination is maintained less than 2% in both phases by using AI filters with required thickness.



Figure 4. Geometric view of the experimental apparatus [8]

The current experimental investigation in this research is structured as follows: Section 2 presents a brief introduction of production techniques of X-rays by X-ray tube and working principle of some X-ray CCD detectors. Section 3 gives an overview of the experimental setup of X-ray tube and pnCCD detector, MnO2 target, high voltage generator as well as activation of pnCCD detector data-acquisition programs. Section 4 presents the detector calibration using a radioactive source (Fe-55), setup optimization, and analysis methods applied to the spectra measured with the pnCCD. Section 5 presents analysis of the results. Section 6 summarizes and concludes on the experimental results (Figure 4).

#### **Experimental Approach**

#### Two phases are considered during the experiment

**Phase-1:** Measurement of X-radiation spectrum, released from experimental apparatus (X-ray tube) itself where, highly accelerated electrons hit the anode material (Mo) inside X-ray tube and emitted X-rays from the tube are measured by pnCCD. The range of applied voltage is 5-60 keV.

**Phase-2:** Fluorescence X-radiation (secondary radiation), originated by the secondary target source (MnO2) is measured by pnCCD where, Mn is excited by being bombarded with high energy X-rays from X-ray tube with the same accelerating voltage in the first phase.

#### Experimental setup for measurement of emitted spectrum

As shown in Figure 5 (in our case), electrons emitted from the spiral formed cathode hit the anode at the bottom which is thermally coupled to a water cooling circuit. The X-ray tube is a commercial device manufactured in 2002 by Rich. Seifert Co. GmbH, Ahrensberg (Table 1). The assembly of the facility is presented in Figures 6-9. The emission of spectrum from X-ray tube is in line with the main axis of pnCCD (detector). There is a gap between X-ray tube and detector, which is measured about (1500.5  $\pm$  10) mm.

High Voltage generator	Isovolt 3003
X-ray tube	DX-µ012x0.4-S
Anode material	Molybdenum
Tube voltage	2-60 kV
Filament Current	2-50 amps
Be window	0.25 mm thickness
Cooling water requirement	4.5 liters per minute
Cooling water intake temperature	Maximum 35 degree Celsius
Cooling water pressure	Maximum 7 bar
Maximum power consumption	3.5 kW

#### Table 1. Parameters of the X-ray generator



Figure 5. General view of the experimental facility 1) X-ray tube housing,

location of the Kapton window, 3) tube maintaining vacuum condition,
generator to supply high voltage, 5) location of Be window, 6) turbo molecular pump, 7) liquid nitrogen tank, 8) X-ray tube water cooling distributor, 9) computer for data acquisition. A crystal spectrometer setup alongside of the X-ray tube is not used in these measurements.



**Figure 6.** Diagram of the cross section of the setup for phase 1: 17) X-ray tube chamber with open window, 18) cabling port, 20) X- ray tube & Kapton window with air gap, 10) position of Kapton window, 19) location of detector, 6) turbo molecular pump for detector.



**Figure 7.** Vacuum tube: 4) generator to supply high voltage for the X – ray tube, 6) turbo molecular pump, 10) Kapton window, 11) dosimeter to measure radiation, 12) pressure gauge.



Figure 8. X-ray tube mountings: 1) X-ray tube housing, 25) position for secondary target source, 13) turbo pump for vacuum tube, 24) flexible tubes

for water cooling.



#### Figure 9. Operator panel of the high voltage generator

There are two plastic collimators (20 mm thickness and opening diameter 30 mm) are positioned inner side of coupling tube. To keep background radiation to a minimum level from scattered radiation, one collimator is placed after the Kapton window and another is located between X-ray detector and tube. To reduce absorption losses, the tube is evacuated.

Once the installation and testing of X-ray tube and pnCCD detector are properly done, set up voltage needs to be fixed manually using the F7 button, shown in Figure 10. It is to be noted that maximum set up voltage in our case is 60 kV must be greater than the applied voltage. There are some other precautionary measures are needed to be taken during the experiment like constant circulation of the water coolant around the anode, checking connection of warning lamp to the control unit. Otherwise, the generator control disables the operation of the X-ray tube.



Figure 10. General view of the pnCCD detector connections: 5) location of Be window (30  $\mu$ m), 6) detector turbo molecular pump, 7) liquid nitrogen storage tank for detector cooling, 18) cabling port to the data acquisition system

#### pnCCD detector installation

The following Figure 11 represents interconnection among different major components of pnCCD and X-ray tube. Incoming X-radiation generated from the X-ray tube is directed to pnCCD detector via the source. With the aim to reduce absorption losses, the detector tube is kept evacuated by the pump marked with '13' at Figure 9. At the time of experiment, the detector

gets overheated and therefore, liquid nitrogen marked with '7' in Figure 11 is used before the operation so that the detector remains cold. The measured distance between the 30  $\mu m$  thick Beryllium window of the detector cryostat and the pnCCD chip is 5 mm.



**Figure 12.** Diagram of the cross section of the setup for phase 2: 25) location of MnO2 target source, 23) pressure measurement device, 3) vacuum coupling tube, 6) detector turbo molecular pump, 18) cabling port to connect to the data acquisition system, 19) location of detector.

The cabling at the cryostat (Figure 12) connects the electronic modules located near the detector chamber, the so called 'Front End Control Unit'. It is realized as one crate containing modules for all DC power supplies, an I/O unit, the sequencer and the analog to digital converter (ADC).

The DC power supplies are fully controlled and parameterized through the I/O unit by software. The sequencer device is freely programmable with a time resolution of 10 ns and the program code is generated by special software on the LINUX workstation and can be uploaded at any time. The sequencer unit generates all digital control pulses for the whole system such as the shift pulses for the CCD, the timing for the CCD chip and the readout clock for the ADCs. The system is set up and controlled by a PC connected to the front end unit by a fiber optics cable.

## Experimental setup for the measurement of emission spectra of the $MnO_2$ target source

The experimental configuration for the phase 2 is shown in Figures 13-16. The space between source (MnO2) and detector is measured to  $(1840.5 \pm 10)$  mm. In this phase 2, MnO2 acts as a target source, which is surrounded by pure Aluminum foils (Figures 15 and 16) and that is why Mn X-rays only have been observed in the spectrum. To avoid the absorption loss, the detector is evacuated. As Aluminum (Al) and oxygen (O2) X-rays are too low energetic, that is why they are not registered in the detector.



Figure 13. X-ray source (MnO2 target) mounted on a pure AI support.



**Figure 14.** Top view of the X-ray tube along with source location, 1) X- ray tube, 25) position of MnO2 target



**Figure 15.** Housing of X-ray tube with source, connected to the detector by coupling tube, 1) location of X-ray tube, 25) secondary source position, 22) coupling tube acts as a bridge between X-ray tube and detector.



**Figure 16.** Housing of outer electronics: 14) detector bias voltage to be controlled by power supply 15) position of Sequencer button, 16) the PROFIBUS (inter connection standard for backplane modules).

#### Experimental set up for data acquisition

The data acquisition system of the pnCCD writes a binary data format. With the objective of filtration, correction and interpretation of the raw data, it is needed to have clear understanding of the measurement technique. It is to be noted that in line with the pnCCD detector, the readout electronics is also involved with entire measurement process. The following programs working together simultaneously in corporation with high tech hardware systems with the aim to readout data and acquisition from the detector (pnCCD) chip are briefly discussed.

Controlling power access: This is the program, responsible to supply power to outer electronic components serving for pnCCD. This crate contains sequencer, ADC units, preamplifier boards and all other devices interfacing the detector and the computer (Figure 17).



Figure 17. X-ray emission by the result of electron capture process of Fe-55 [09]

Controlling CCD: It is considered; as the principal software, which constantly interacts with the pnCCD detector during operation. It is mainly responsible for detector control (turning on and off, timing transfer, setting of ADC offsets, exposure time and so on).

#### pnData Display

After successive steps, it is needed to generate online spectrum, which is done by this program so called "pnData Display". To activate the pnCCD program while doing the experiment, the procedure needs to be maintained as follows:

A. Switch on the outer electronics crate manually. Green and blue LEDS must blink on a PROFIBUS card. When they are stable, reset the controller by pressing the RESET button at the PROFIBUS module.

B. Enter home/karotte/Projekte/pnccd-pnPlxHotl/bin folder from terminal and load the Power Control program by typing/Power Control.

C. In Power Control program menu enter 0 to switch the amplifier on (Red Led turns on a PROFIBUS) controller.

D. Connect the cables to detector chamber and turn on the high voltage (180 V) on a power supply.

E. Load the CCD control program by typing "./CCD Control".

F. After that load "pnDataDisplay" Program by typing "./pnDataDisplay" to start pnCCD detector readout and look at online spectrum.

Afterwards the user can see the online data plotted in a window on the screen. At the beginning, the noise peak appears and few seconds later (say 10 seconds), the source need to be placed in front of the detector. The user can see the changes immediately on a screen. When the measurement is finished, press the GNUPLOT bottom on an online window and then EXIT. This procedure saves the data on a/home/karotte/Projekte/pnccd-pnPlxHotl/Data folder. Data are saved as txt files which has the name entered before as measurement name.

#### Energy Calibration and Analysis Using Radioactive Source

To determine the energy corresponding to each single peak of the spectrum, we need to know each channel's corresponding energy. The calibration of pnCCD (in our case) is done by applying a source (55Fe) which is radioactive. It emits the 55Mn X-rays after capturing an electron: e-+55Fe 55Mn+v. The elementary process of the nucleons in the 55Fe nucleus is proton conversion to a neutron p+e-n+v. The beta decay process of 55Fe is occurred by electron capture to 55Mn (Figures 18 and 19) [9]. The electrons centering nucleus adjust themselves very quickly to the lowered charge without leaving their shell. Within a very short time after the

vacancy in the K shell left by the captured electron is filled by an electron from a higher shell under emission of a photon.



**Figure 18.** Mn X-ray spectrum after Fe-55  $\beta$ -decay, K $\alpha$  : Vacancy refilling from the L shell , K $\beta$  : Vacancy refilling from the M shell.

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#### Figure 19. Setup panel for filter transmission [10].

The level of the noise peak is set 250 to Analog to Digital unit (ADC) by software, corresponding to X-ray energy zero. In order to keep the amount of stored data to a minimum level, most of the peaks generated by noise are removed.

The rest of the tail of noise peak is observed as peak-1, starting from **Table 2.** Required degree of illumination for phase (i)

the left side of the spectrum. In order to ensure proper energy calibration, every channel must subtract the offset. The highest peak representing Ka line of Manganese (Mn) is detected at channel position 706. After offset subtraction, the true value of the channel becomes 456. It is found from literature that for Manganese (Mn) Ka energy is 5892 eV or 5.892 keV. Therefore, after offset correction the energy interval of each channel is 12.921 eV/channel (5892 eV/456) which is called energy gain factor or energy calibration factor. For the entire spectrum, it is assumed to be constant. Based on energy calibration factor (gain factor), one can easily calculate the corresponding energy of the peaks. Comparing the calculated values with the photon energies along with X-ray intensities, materials excited can be easily identified.

#### Degree of the detector illumination

The deposited charge in a single pixel of pnCCD detector can't be treated as one X-ray event. That is why, we need to avoid over illumination of the detector because in that case it can lead to the misinterpretation of counting rate. To be in a safe side, an illumination degree is kept 2% or less.

#### Calculation of the degree of illumination

To calculate the degree of illumination, we take all the counts per channel from ADC and sum them up. Afterwards this has been divided by the number of frames per measurement and the number of pixels per frame (in our case total number of pixels 4096).

Let's take an example in case of 25 keV X-ray energy In this case, the sum of the number of counts is 992,169 and the total number of frames is 110,000. So the fraction per frame is 992,169/110,000=9.02. So the degree of illumination per pixel is 9.02/4096=0.22%.

#### Determination of filter thickness

In phase (i), the degree of illumination is tolerable at an applied voltage of 5 keV, but in all the other cases, the illumination is over 2%. In those cases, we need to use a filter (Table 2). To get the aluminum filters with required thickness, a calculator referred by NIST (Figure 20) is used. For phase 2, the illumination is always well below 2% (Table 3).

Applied voltage (KV)	5	10	15	25	30	40	50	60
Degree of illumination (%)	0.042	0.05	0.2	0.22	0.17	0.177	0.135	0.177
Thickness of Al filter (mm)		0.13	0.8	1	2	4	8	12

Table 3. Required degree of illumination for the measurements with the MnO2 target in phase (ii)

Applied voltage (kVA)	5	10	15	25	30	40	50	60
Degree of illumination (%)	0.012	0.026	0.16	0.17	0.23	0.36	0.475	0.58
illumination (%)		0.13	0.8	1	2	4	8	12

Table 4. shows spectra generated with 5 kV high voltages. As expected the electron energy (5 kV) produced with this voltage is not high enough to generate an X-ray spectrum by ionizing all the surrounding and anode materials as their ionization energy is higher than the maximum X-ray energy.

Applied Voltage (kV)	5	10	15	20	25	30	35	40	45	50	55	60
Current (mA)	3	3	3	3	3	3	3	3	3	3	3	3
Al filter thickness (mm)	-	0.1	2	0.5	1	2	3	4	6	8	10	12



Figure 20. Photon energy Vs Filter transmission at 50-micron filter thickness

On request, the transmission is returned as a function of X-ray energy. Approximately, over 50% photons (having energy less than 8 keV) (Figure 21) can penetrate (if the aluminum filter thickness is 50 micron) which can lead over illumination of the detector, but of course transmission also depends on the energy as well.



Figure 21. Photon energy Vs Filter transmission at filter thickness 1000 micron

If aluminum filter thickness having 1000 micron is used, around 70 percent photons can reach the pnCCD detector with highest possible energy (Figures 22 and 23) in case of 25 keV. Therefore, the optimum thickness of aluminum filter is found 1000 micron.



Figure 22. X-ray spectrum generated at 15 kV applied voltage with 3 mA



Figure 23. Display of the best fit to the spectrum obtained at15 kV high voltage

To illustrate analysis procedure of the X-ray spectra detected by pnCCD detector, let us first consider the final spectrum generated at 15 kV applied voltage.

Due to very narrow deviation between the peaks adjacent to each other, it seems like they overlaps each other. Therefore, the peaks are not obviously visible. In this case, applying fitting technique these problems can be solved, meaning by using fitting technique such obscure peaks can be properly analyzed, meaning this technique gives the final positions of every peak along with their spectral width, intensity and respective errors. A special fitting technique is applied in our case by using computer program so called "FITOS". This program requires initial input parameters like initial and end position of the fit range position, height and FWHM of each peak (start values) before starting. The peak form itself is assumed to be a Gaussian. Based on these input parameters, fittings are carried out. Here, is the image of the best fit after applying computer program oriented fitting technique in Figure 24. The corresponding values are shown in Figure 25.

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**Figure 24.** Corresponding values from the FIT to the spectrum shown in Figure 23: The last column shows elements corresponding to the peak energies.

From the Figure 25, the summation of peak intensities is 1,431,520 while the integral of all channels is 2,032,134. If we subtract total peak intensity from the integral of the channels we get 600,613.2 counts, which is the contribution of the continuous bremsstrahlung spectrum.



Figure 25. X-ray spectrum measured at 5 kV voltage: P1 (Ar K $\alpha$ 1), P2 (Ca K $\alpha$ 1), P3 (Ti -K $\alpha$ 1), P4 (Unidentified).

## **Analysis of Results**

#### Measurements overview

The measurement parameters are given in Table 4. X-ray spectra obtained by the X-ray tube to get the real identity of the elements, found from our experiments we need to match experimental value to the literature value, shown in (Table 5).

Elements	Atomic number (Z)	Energy/KV	Transition
Argon (Ar)	18	2.957	Κα
		3.192	Κβ
Chromium (Cr)	24	5.414	Κα
		5.946	Κβ
Ferrous (Fe)	26	6.403	Κα
		7.057	Κβ
Cobalt (Co)	27	6.93	Κα
		7.649	Κβ
Nickel (Ni)	28	7.47	Κα
		8.263	Κβ
Copper (Cu)	29	8.042	Κα
		8.904	Κβ
Zink (Zn)	30	8.638	Κα
		9.571	Κβ
Molybdenum (Mo)	42	17.47	Κα
		19.61	Κβ

Table 5. X-ray energies, taken from literature [12]

It can be seen from Figures 26-28 that X-ray energy (5 keV) produced with this voltage (5 kV) is not high enough to ionize all the anode material and the elements in the steel tube as their ionization energy is higher than the excitation X-ray energy.

**Figure 26.** X-radiation spectra generated at 25 kV high voltages: P1 (unidentified), P2 (Cr-Kα), P3 (Fe Kα), P4 (Fe-Kβ), P5 (Fe-Kβ), P6 (Zn-Kα), P7 (Mo-Kα), P8 (Mo-Kβ-backscattering), P9 (Mo-Kβ).



Figure 28. Spectrum measured at 5 kV voltages.



Figure 29. Spectrum generated at 25 kV applied voltages.



Figure 30. Spectrum produced at 60 kV voltages.

So with respect to the rough peaks, we can calculate the corresponding energy of each peak using the energy gain factor of Mn X-rays (Section 5.1). In this case, roughly four peaks we have. First peak corresponds to the energy of 3036 eV, which confirms the identity of the element Ar. Except peak 1, peaks 2-4 do not reappear at the high voltages. The reason might be because of bremsstrahlung continuum which might have some holes because of the absorption edges.

We receive completely different scenario in case of 25 kV applied voltage. Variety of elements have been excited at this excitation energy causing the respective peaks. Using energy calibration factor (similar procedure applied before), we can identify the existing elements available in the anode material by the corresponding peaks. In this case, the elements are identified as Cr, Fe, Ni, Zn, Mo. The most obvious phenomena occur at peak 7 where, Mo spectrum from anode material is visible.

The most interesting thing is that we experience data overflow at 60 kV and that is why no peak over 20 keV X-ray energy can be observed. The reason is that at this excitation energy, pnCCD is not capable to detect the X-rays, because in that case it crosses the maximum capacity of our experimental detector. The spectrum ends with the 20 keV peaks because of the range of ADC.

We get a few events at this voltage level (5 kV) representing aluminum (Al) but the interesting matter is that we experience no Mn spectrum (Figures 29 and 30), since 5 kV high voltage is not enough to ionize the manganese atom (ionization energy of Mn is 6 keV).

## Conclusion

In this experimental study, the main focus is to analyze the measurements of X-rays by the application of Fast Readout Charge-Coupled Device (pnCCD). As a part of the experiment, two phases are considered. The first phase is conducted using X-ray tube only where, highly accelerated electrons collide with the anode material (Mo) in the experimental apparatus (X-ray tube) that generates mainly a continuous braking spectrum (Bremsstrahlung spectrum). In this case, various elements are noticed in the X-ray spectra, which are originated from the experimental apparatus itself and its surrounding materials. Through proper energy calibration technique, elemental composition of the materials has been determined. The identified surrounding materials are mostly Cr and Fe.

In the second phase, fluorescence X-radiation (secondary radiation),

emitted by the secondary target source (MnO2) is measured by pnCCD where, Mn is excited by being bombarded with high energy X-rays from X-ray tube. It is to be noted that MnO2 source is guarded by pure AI sheet foil that protects X-rays from other materials. That is why background radiation is decreased and as a result, clean Mn spectrum is observed. To avoid distortion of the intensity determination, the detector's degree of illumination is maintained less than 2% in both phases by using AI filters with required thickness. In terms of intensity, we can come up with the conclusion that the intensity of K X-rays released from MnO2 source is approximately 0.06% in compare to the total intensity of direct emission spectra from experimental apparatus (X-ray tube) for 25 keV. The range of applied voltage is measured 5-60 keV in both phases.

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## **Conflict of Interest**

None

## Funding

None

## Ethical Approval

Not required.

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