Instruction Sheet

Purpose of the project

This project examines the Compton scattering of X-rays by an electron. The project studies experimentally the angle dependency of the energy of scattered radiation. The scatterer used in the experiment is an aluminum plate. The angle of scattering can be freely changed in the equipment between 110°-150°. The source used will be a radioactive ^{241}Am sample, the detector a semiconductor crystal and the recorder a multichannel analyzer. The task is to collect spectrums using different angles of scattering. The shape of the scattering distribution is determined from the spectrum and the energy corresponding to the scattering spike's maximum, which is compared to the theoretical energies for the photon. Additionally, curve fitting methods will be used on the Compton scattering spike and its area will be integrated numerically. All calculating and modeling problems will be done using the Matlab program. Before measurements a pre-lab assignment will be written on the project. The measurement results will in turn be presented orally in the final seminar. The duration of the presentation is roughly 15 minutes.

Pre-lab assignment requirements

Before the lab portion of the project, a pre-lab assignment is made. The purpose of the pre-lab assignment is to make the student understand the basis of the phenomenon, what is happening during measuring and to get a feel for real lab work by considering possible errors in advance.

1) Review Compton's relativistic theory and derive the equation (1) presented in the handout for the change of wavelength in Compton scattering. Derive equations for the energy of a scattered photon and the scattering electron's kinetic energy as a function of the energy of the incident photon and the angle of scattering. Draw a picture of the energies as a function of the angle of scattering. Use the most probably gamma energy of the ^{241}Am sample as the energy of the incident photon.

2) Get familiar with the properties of two common distribution functions, normal (or Gaussian) and Cauchy (or Lorentz) distributions. Pay attention especially to the cumulative distribution functions. Draw a few representative pictures for each case.

3) Get familiar with the experimental procedure and prepare are measuring plan. In the plan answer the following questions:

   What is the measurement based on? How is the particle-like nature of light proven? How are the properties of the measured energy spectrum connected to the analytical theory of the Compton effect? What is the operating principle of the measuring equipment (shortly)? How does the energy spectrum collection time affect the end result?

During the measurement an energy calibration for the Compton scattering spectrums has to be done, in which a channel of the multichannel analyzer is calibrated to receive a certain value of energy. Explain how the energy calibration is done. Find a picture of the gamma spectrum of the ^{241}Am sample and find reference values for some gamma spikes found between 0-70 keV.

Instructions for the measurements done in the lab

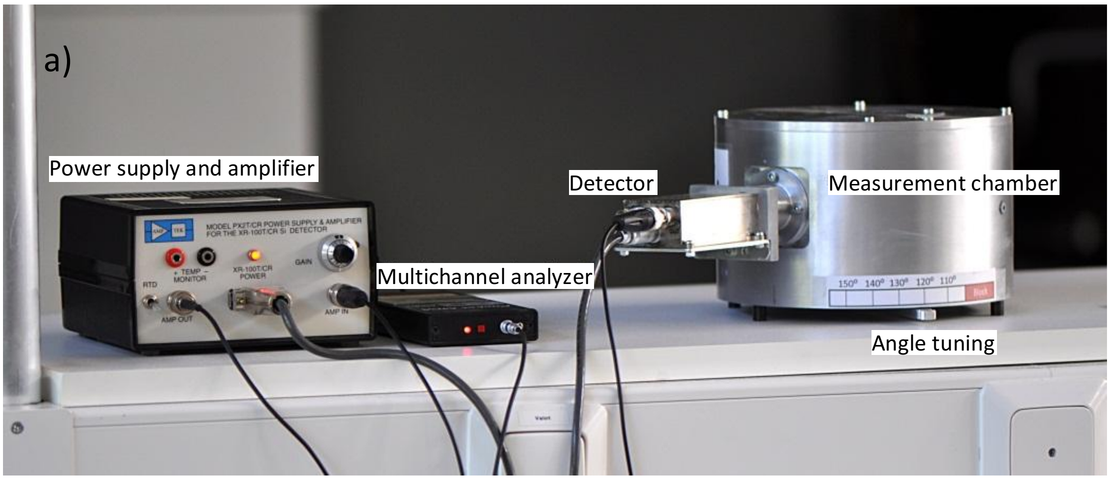
<u>NOTE!</u> The measurement chamber contains a ^{241}Am gamma source. The radioactivity of the source is 1670 MBq. Opening the chamber is forbidden! In regular use the equipment causes no radiation exposure to the user or the surroundings (0,3 μSv/h).

Required instruments

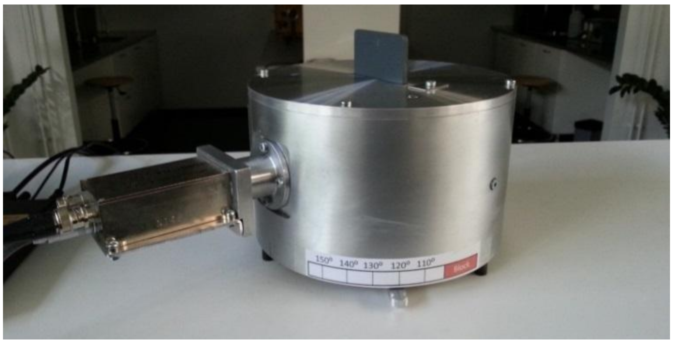
- Specimen chamber (contains an angle adjustable sample of Am-241)
- XR-100CR X-ray detector
- AmpTek PX2T/CR power supply and amplifier for the X-ray detector
- Pocket MCA 8000A multichannel analyzer
- AmpTek ADMCA measurement software
- Am-241 calibration sample
- Sample holder

Overview of the equipment

The measurement chamber contains an Am-241 gamma source with radioactivity of 1670 MBq. The radiation source is enclosed in the measurement chamber inside a metal cylinder, which acts as a collimator. A sample or a scatterer is placed into the chamber through the hole in the cover using the sample holders. The angle of the source of radiation is adjusted with the controller located on the bottom of the chamber. Moving the angle control to position *Block*, blocks the radiation from reaching the detector. The radiation is detected with a semiconductor crystal located at the edge of the chamber. An overview of the equipment is shown in pictures 1 a and b.



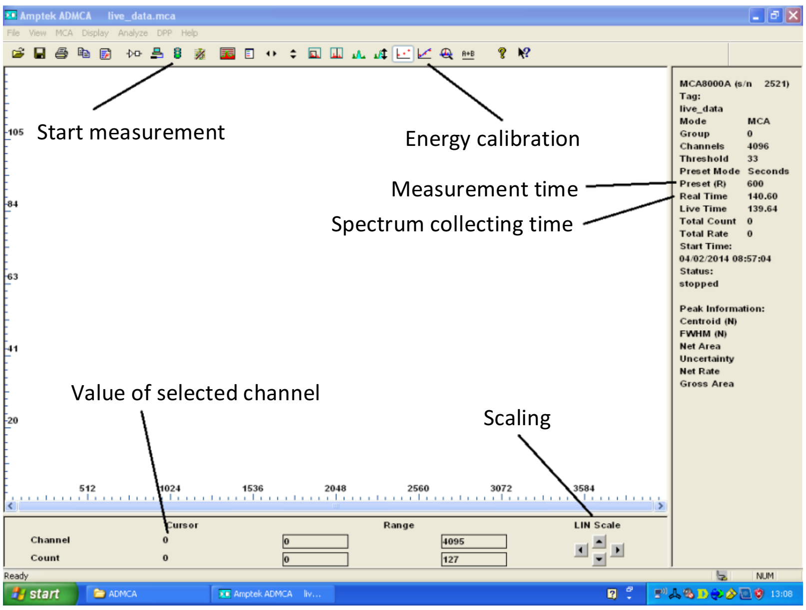
b)



***Picture 1** a) Overview of the equipment b) Sample holder in the measuring chamber*

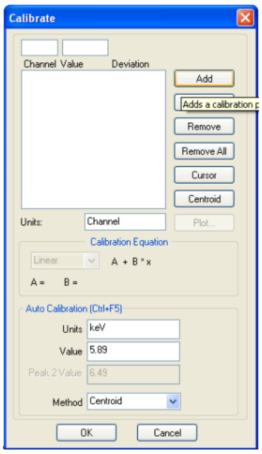
Using the measuring equipment

1) Turn on the amplifier (switch at the back) and the multichannel analyzer (red button on the front). When the power is turned on, a red light lights up on both machines. Make sure that the amplifier is set to 1,20.
2) Launch ADMCA2.0.exe
3) After the program has launched, choose *Device type:* MCA8000A and choose *Connect.*
4) If there's an old spectrum on the screen, clear the screen by choosing *Delete data* from the *MCA* toolbar.
5) In the *MCA* menu's *Acquisition setup* window you can control the collection time of the spectrum among other things.
6) The measuring can be started from either the *MCA* menu or the button on the panel. Picture 2 shows the central controls for the program.



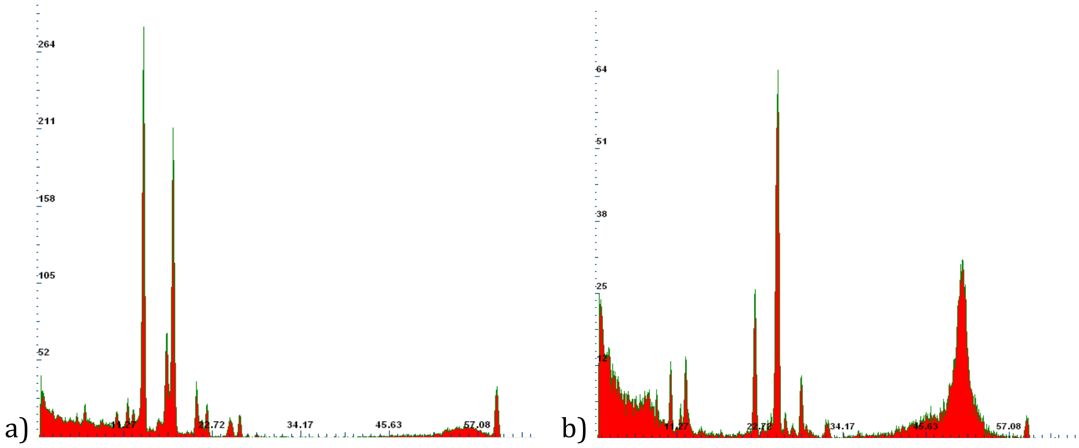
***Picture 2** The central controls for the measuring program*

7) The energy calibration spectrum is measured from a separate Am-241 sample, which is placed in the sample holder. Inside the chamber the radiation is blocked from reaching the detector. When the spectrum is collected, an energy calibration is done. The calibration requires at least two calibration points (channel and known reference value for the energy). Picture 3 shows the window used for entering the calibration points. Save the calibration data. (*File -> Copy spectrum data -> Open Wordpad and Ctrl + V -> Save).* Save the measurement itself too (*File -> Save*) in case it's still needed.



Picture 3 *Window used for energy calibration*

8) Place the aluminum plate inside the chamber as the scatterer and do the energy spectrum measurements according to your measuring plan with scattering angles of 110°-150° using for example steps of 5° - 10°. Pay attention to the quality of the data and the usable lab time. Even though the aim is to stop the primary radiation from reaching the detector, it will always get through enough that the primary gamma spectrum is shown with the scattering spectrum. Save every spectrum you measure for analysis. Picture 4 shows example spectrums for the calibration measurement and the measurement of the Compton spike.
9) Turn off the power from all the machines you used.



Picture 4 *Two example spectrums. a) Calibration spectrum and b) scattering spectrum. The scattering spike shown in spectrum b) moves towards the photo spike of the primary radiation as the angle of scattering diminishes.*

Analysing the results

Analysis of the measurements is done using the Matlab software. The project contains curve fitting, numerical integration and basic Monte Carlo - simulation. These methods will be taught separately during lectures and in lecture slides. The results are presented at the final seminar and the calculatory components of the project are in a significant role in the final evaluation. The results of the analysis are to be visualized into illustrative pictures for the final seminar.

Before analyzing load the spectrums you measured into Matlab using for example the *importdata* command. Change the channel scale into an energy scale using the calibration curve you measured. Perform the following analysis for the measured data:

1) Get familiar with the details of the measured energy spectrums in the frame of Compton's scattering theory using the handout and equations derived in the pre-lab assignment. Recognize the Compton scattering spike from the measured spectrums and crop the energy area examined to the surroundings of the spike.
2) Fit an analytic distribution function to each scattering spike measured with different angles of scattering using the *least-squares* method. Which curve best represents the distribution of the measured spike?
3) Using the fitting, define the energy of the scattered radiation with each angle of scattering and compare it to the analytic, theoretic photon energy.

Perform the following numerical integrations using simple Matlab scripts:

4) Integrate the area of the scattering spike for each angle of scattering both numerically from the measurement data and analytically from the fitted curve. You can find a suitable theoretical model for the scattering probability as a function of the angle and compare the measurements to the angle distribution predicted by the analytical model.
5) Choose one curve fitting for a scattering spike and integrate the area below it using the trapezoidal rule and Simpson's rule using different bin widths. Do the same integration using Monte Carlo integration algorithm. With each method compare the results to the precise analytical result and pay attention to the convergence of each method.
6) Evaluate how much of the radiation corresponding to the measuring sector 110°-150° hits between 117°-141°. Explain clearly the method you used.