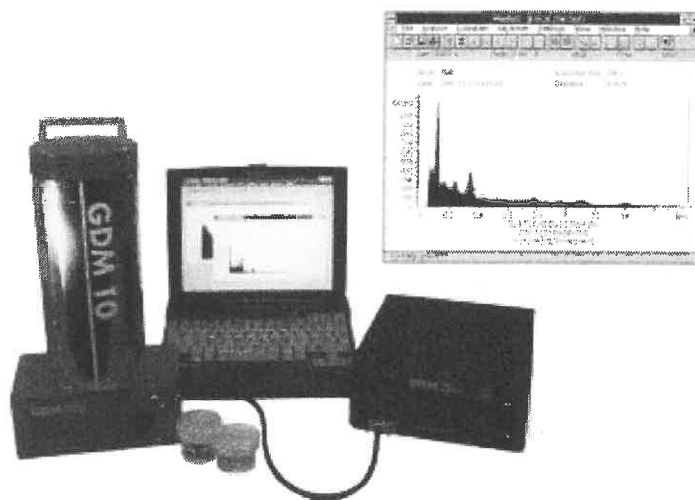


Teacher's Handbook GDM 10

Version 1.1



GAMMADATA

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Version 1.1

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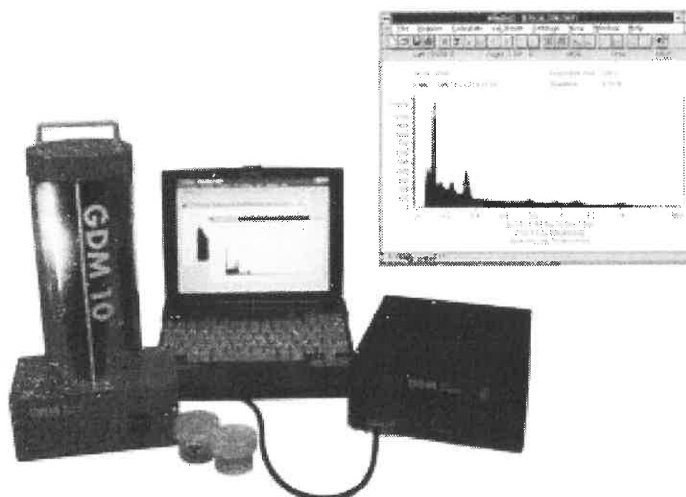
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1 Introduction

GDM 10 is a new detector system adapted for schools to study the gamma radiation from radioactive sources. GDM 10 presents completely new possibilities to experimentally visualise important sections of the high-school and college courses in physics. Because of the much higher sensitivity of the detector, as compared to the GM tube, it can be used in conjunction with much weaker sources than was earlier common. For example, it is possible to measure the radioactivity of samples collected from our environment.

Together with the GDM 10 User's Guide the Teacher's Handbook is meant to clarify the technical and methodical difficulties, which may be encountered in using this new measuring technique in the school.

The Teacher's Handbook is primarily written for high-school and college teachers in physics, but it also gives suggestions for experiments related to biology. The Teacher's Handbook contains suggestions for experiments, demonstrations and more advanced studies. Each suggestion for an experiment is accompanied by suggestions for the planning, the preparation and the performance of the experiment. Corresponding student's instructions can be found further back in the binder, which together with the figure and text material in the Teacher's Handbook and the GDM 10 User's Guide may be used for taking copies.

Since the previous knowledge of the students may vary very much, it is important how the experiments or the demonstrations are presented. The student instructions are primarily written for the physics course, which e.g. in the case of biology means that the preparations must be adapted to the level of knowledge of the students. The section 'Methodical and Practical Advice' gives, among other things, suggestions and ideas on how this adoption can be done.

The description of the experiments in the Teacher's Handbook should be read in parallel with the student instructions. For each experiment the time and purpose of the experiment is given. Then follows a short description of the theoretical background necessary to perform the experiment and in the next section practical advices for the performance of the detector are given. Finally a key to the additional exercises is given.

The suggestions for the experiments and the student instructions can also be useful when planning demonstration experiments.

1.1 Methodical and practical advice

It is important to prepare the class for the experiments or the demonstrations. The WinDAS and GDM 10 User's Guides for the detector system contains much material to help in the preparation of the lectures concerning the functioning of the detector, the data collection, the form of a gamma spectrum, the analysis of the spectrum etc. It is advised to give the students the necessary theoretical background for a particular experiment before the performance of the experiment. The level of knowledge of the students is decisive for how comprehensive the theoretical introduction ought to be. In many cases it is more a question of how to visualise the principle of the measuring system, rather than to give a detailed description.

Before the first experiment all students should be taught how to handle radioactive sources and samples. The handling must be based on knowledge and insight and follow official regulations. General recommendations are given in the GDM 10 User's Guide.

If enough computers are available it is possible to perform experiments with the whole class. For classes where the students have little computer experience it is advisable to work with smaller groups, since the instruction otherwise may become too time-consuming.

One of the computers is selected for the data collection, while the remaining computers are used for the analysis. It is important that the teacher is well acquainted with how the detector is connected to the data-collecting computer, and how the collected spectra are stored and transferred to the other computers. If there are difficulties with the connection between the detector and the computer, the technician of the school or other technical personnel can probably help. Also the systems operator or the computer expert of the school can probably be of help.

The laboratory instructions are written as if the students were to perform each step themselves. This is to give a chronological feeling of the events in the experiment. If one teaches a group of students it is necessary to clarify that the students should copy the measured spectra into their own computer and then only work with these spectra.

At the start of the experiment a copy of all necessary commands as presented by the WinDAS User's Guide should be handed out to the students.

After starting the data collection for an experiment there may be time that can be used to go through the home work or to penetrate further into the theory. As soon as a spectrum is stored it can be made available to all computers by copying via the computer net or via floppy discs, so that the following analysis can be done individually at each computer. At the end of the experiment it is now possible to compare the results obtained, which are based on the same data. The variation in the results may give rise to interesting discussions about the sources of errors in the experiment.

If the time assigned for the experiment is not sufficient for the data collection one had in mind, it is possible to save time by for example measuring a background spectrum in advance. This can also be done with the other spectra if one requires a better statistical accuracy than it is possible to achieve within the time of the experiment.

Since there is normally no time to perform all experiments described in the Teacher's Handbook, it is as a rule necessary to make a selection. The experiment 'Measurement of a gamma-ray spectrum' is basic for the other experiments. If one must save time, this experiment can be done in the form of a demonstration lecture by the teacher, showing the students how to collect, store and energy calibrate a gamma-ray spectrum.

It is also possible to shorten the time needed for experiments in which radioactivity is measured by giving the students the efficiency curve of the detector, which may be determined at another occasion. However, it is important that the students understand how this curve has been obtained. For measuring the activity of samples containing both the isotopes ^{134}Cs and ^{137}Cs there is a simple version, based on the comparison with a calibration sample containing the same type of activity.

As mentioned earlier it is recommended that the instruction material is adapted to the level of knowledge of the students. As regards the explanation of the shape of the gamma spectrum it may be sufficient to briefly treat the processes involved (for example the photo peak and the Compton distribution). It may be advantageous not to use the word Compton but rather talk about collisions between the gamma quanta and the electrons. It is sufficient that the students understand the meaning of the photo peak in the determination of the intensity of the radiation and in the identification of the radioactive isotope that gave rise to the photo peak.

2 Measurement of a Gamma-Ray Spectrum

2.1 The purpose of the experiment

The purpose of the experiment is to show how one detects and determines the energy of the gamma radiation from a radioactive decay. First a spectrum with known gamma-ray energies is measured. The calibration curve obtained is then used to determine the energy of gamma radiation from an unknown decay. With the help of these radiation energies one can then identify the radioactive isotope which has been measured. The experiment also includes the measurement of the background radiation in the room, which may be subtracted from all obtained spectra. With the measured background radiation as a basis, one can discuss the natural radiation in our environment.

Time required: Approximately 2 periods.

2.2 Required theoretical background

2.2.1 Nuclear physics

The students should be accustomed to the concepts of radioactive decay, mother nucleus, daughter nucleus and the type of radiation that can be emitted. One can explain the unit of energy, MeV, depending on the previous knowledge of the students. To students without any deeper background in physics it suffices to explain the equivalent of 1 MeV in Joule ($1 \text{ MeV} = 1.6 \cdot 10^{-13} \text{ Joule}$). It can be valuable to illustrate the energy unit Joule by reminding the students of the potential energy gained by lifting the mass of 1 kg one meter. In this way the students will get a feeling for the order of magnitude of the atomic units.

For the physics students one should discuss in a simplified way the different processes in which gamma radiation interacts with matter. For other students one can limit the discussion to the explanation of the characteristic form of the gamma spectrum, by qualitatively describing the collision between the gamma quanta and electrons.

Figures for visualisation and other material can be taken from the 'Nuclear physics vocabulary' in the WinDAS User's Guide.

2.2.2 The detector

The manual contains a description of how the detector works. In most cases it is sufficient to schematically explain how the analogue information is converted to digital information, which can be processed by the computer. It is important that the students understand that the spectrum is a frequency diagram of the energies of the detected gamma quanta, i.e. that each channel corresponds to a certain energy.

One here has the possibility to explain the statistical distribution and the standard deviation by reading the content of a small number of channels (about 10) at different measuring times.

The characteristic shape of a gamma spectrum should be explained so that the students understand the concepts in the laboratory instruction, like the photo peak, the Compton distribution and the discriminator threshold (= lower level). Material for visualising this can be found in the GDM 10 User's Guide.

The necessary commands for the analysis are presented to the students, who also should be given a copy of all commands given in the WinDAS User's Guide. This includes for example how to load spectra from the secondary memory (floppy disc or hard disc), determination of the channel position and the area of the photo peak and the energy calibration of a spectrum. All these steps are explained in more detail in the manual.

2.3 Equipment

A source of ^{137}Cs and pure KCl powder are used for the manual energy calibration. It is also possible to use a mineral salt, but because of its lower concentration of potassium the measuring time will be longer. The sealed ^{137}Cs sources, which normally are available in schools, are often so strong that one should place them at least 10 cm away from the detector in order to avoid disturbing effects because of high counting rates.

For the energy calibration routine of the detector system a source of ^{152}Eu is used. As 'unknown isotopes' one can use other isotopes than the ones suggested in this experiment. It is often more instructive to use the activities naturally occurring in everyday life, like for instance old wrist watches, radioactive rock samples, collected radon daughters (as described in the experiment 'The half life of ^{214}Pb ') or soil or plant samples from areas exposed to the fallout from the Chernobyl accident.

2.4 Performance

The computer that collects the data should be placed well visible to the whole group. The ^{137}Cs source is placed on the detector and the measurement can start. During the measurement one can quickly repeat the commands necessary for the analysis. The students must be able to copy the spectra to their computers and must be informed of all steps of the analysis.

As soon as the spectrum of ^{40}K has been measured and the collection of the background spectrum has been started, the students can start their own analysis according to the laboratory instruction. The students must now show that they have understood how to transfer the spectra to their own computers, which in the simplest way can be done by copying the spectra to their own floppy discs. By comparing the background spectra with the spectrum of ^{40}K , one can explain the ^{40}K photo peak in the background spectrum.

2.5 Questions and answers

Question 1. From which decay does the measured radiation originate?

*The answer depends on the nuclide that has been chosen for the examination.
A selection of decay schemes with associated spectra is given in the manual.
Relevant decay schemes can be copied to the students.*

Question 2. Which are the daughter nuclei of the decay you have studied in this laboratory exercise?

*The answer depends on the nuclide that has been chosen for the examination.
A selection of decay schemes with associated spectra is given in the manual.
Relevant decay schemes can be copied to the students.*

Question 3. From the decaying nuclei gamma radiation as well as beta radiation is emitted. Why cannot the beta radiation be detected in the NaI detector?

*The aluminium case of the detector is not transparent to β -radiation.
In addition the detection efficiency of a NaI crystal would be too low.*

Question 4) From where does the background radiation originate? Is there any radioactive isotope that can easily be identified?

The background radiation mainly originates from cosmic radiation, ^{40}K and radon daughters. The 1.46 MeV peak from ^{40}K is easily identified.

Additional experiment:

Comparison of the detection efficiency of a GM tube and the NaI detector.
Put the source of ^{137}Cs at about the same distance from the GM tube as from the NaI detector earlier. Count the number of pulses with the counter of the GM tube. Use the same measuring time as with the recording of the spectrum of ^{137}Cs .

The ratio between the efficiencies of the GM tube and the NaI detector (calculated at the photo peak) is of the order of a few percent.

3 The Absorption of Gamma Radiation in Different Materials

3.1 The purpose of the experiment

By measuring the reduction of the intensity of the gamma radiation as a function of the thickness of a material it is possible to determine the half thickness and the absorption coefficient for the material. As an extra experiment one can study the dependence of the absorption on the gamma energy.

Time required: Approximately 2 periods.

3.2 Required theoretical background

It is recommended that the students have a qualitative knowledge of the different absorption processes. The theory section of the student instructions recapitulates the exponential law of absorption. It may be necessary also to explain the lin-log paper if this is to be used to determine the half thickness. The students may have to practice in advance to make suitable divisions of the axes and to interpret the lin-log diagram. It is also suggested to let the students solve simple problems in connection with the theory lecture.

3.3 Performance

Depending on the availability of different types of mechanical stands, one can choose a vertical or a horizontal experimental set-up. The detector can be used in either position. The thickness of the absorber metal sheets depends on the material. The total absorber thickness should be at least about three times larger than the half thickness of the absorber.

It is not necessary to make an energy calibration. If a sufficiently strong source is chosen, it is not necessary to correct for the background radiation, i.e. it is not necessary to collect a background spectrum.

If several absorber materials are chosen one can after the experiment discuss the choice of absorber and thickness with regard to radiation safety. One may also ask the students to see if they can find a relation between the half thickness and the electron density of the material.

3.4 Questions and answers

Question 1. Try to derive equation (5) from equation (4).

$$\ln(I_0/2) = \ln I_0 - \mu X_{1/2} \quad (4)$$

$$\mu = (\ln 2) X_{1/2} \quad (5)$$

Question 2a. Calculate the thickness of the lead shield needed to reduce the intensity to one thousandth of its initial value.

$$\mu_{Pb} = 1.22 \text{ cm}^{-1} \text{ for the gamma energy of 0.66 MeV.}$$

$$X_{Pb} = 5.66 \text{ cm}$$

Question 2b. Repeat the calculation for aluminium.

$$\mu_{Al} = 0.208 \text{ cm}^{-1} \text{ for the gamma energy of 0.66 MeV.}$$

$$X_{Al} = 33 \text{ cm}$$

Question 2c. Repeat the calculation for air.

$$\mu_{air} = 0.000112 \text{ cm}^{-1} \text{ for the gamma energy of 0.66 MeV.}$$

$$X_{air} = 617 \text{ m}$$

Question 3a. Calculate the reduction of the intensity of the gamma radiation after the passage of 20 cm of air.

$$I/I_0 = 0.9978$$

Question 3b. Calculate the reduction of the intensity of the gamma radiation after the passage of 20 cm of lead.

$$I/I_0 = 2.5 \cdot 10^{-11}$$

Question 4. In the experiment the intensity of the gamma radiation is measured by summing the number of pulses in the photo peak. Why is not a window set over the whole spectrum to count all pulses in the spectrum?

By only studying the photo peak one avoids counting pulses at lower energies, which may originate from scattered radiation.

Additional experiment:

The absorption decreases with the gamma energy. This means that μ and $X_{1/2}$ also depend on the energy of the gamma radiation!

Extra experiment:

To study how the absorption varies with the energy. First collect a spectrum of the solution of ^{152}Eu . Then compare the relative intensities of the photo peaks with the relative intensities of the gamma transitions, which have been derived in connection with the determination of the efficiency curve of the detector. The intensities are preferably calculated relative to the 0.122 MeV transition. Compare with the intensities given in the WinDAS User's Guide.

4 The Efficiency of the NaI Detector

(Measurement of the activity of a ^{40}K solution)

4.1 The purpose of the experiment

The experiment shows how to determine the efficiency of a NaI detector. The student learns how to measure the activity of a sample containing ^{40}K . The student is also given the opportunity to calculate theoretically the value of the activity of ^{40}K in natural potassium. The experiment can be used as an introduction to the more advanced experiments to determine the activity of food samples or similar (see chapter 6).

Time required: Approximately 2 periods.

4.2 Required theoretical background

The calculation of the activity of ^{40}K is rather difficult and is only recommended for more advanced students. It is important to make clear to the students the difference between the isotope activity and the gamma activity for a certain transition. If one has for instance a ^{40}K sample with a 1000 Bq activity, only 11 % will decay to ^{40}Ar through electron capture (see figure 3 in the instruction to the experiment). For each such decay one gets a 1.46 MeV gamma quantum, i.e. the gamma activity from the sample is 110 Bq.

4.3 Performance

It is important to avoid any change of the geometry of the experimental set-up between the collection of an efficiency calibration spectrum and the spectrum of a sample to be measured. A changed geometry means that the detector might see the activities at different solid angles, i.e. the efficiency of the detector is changed. Also a change of shape of the samples affects the result of the measurement. Differences in the density and structure of the samples are of less importance for the accuracy, but one should keep in mind that the self absorption of the gamma radiation varies with the density of the sample.

The measuring time can be shorter if pure KCl salt rather than mineral salt is used. A spectrum of the mineral salt may still be taken to show the presence of ^{40}K . The solution of ^{152}Eu contains an activity of about 2 kBq.

To save time, the measurement of the background spectrum can be started in advance. The measuring time should be about 20 minutes. The spectrum of ^{152}Eu is measured for about 10 minutes. Finally a spectrum from a solution of ^{40}K is measured. Because of its low activity a measuring time of more than

30 minutes may be required. It is also possible to measure a spectrum of ^{40}K over a longer period of time, if the measurement is done in advance.

While the background spectrum is being collected, the students can produce the efficiency calibration curve. Eventual waiting times can also be used to repeat the theoretical calculation, which should have been discussed prior to the actual experiment.

5 The Half Life of ^{214}Pb

5.1 The purpose of the experiment

The exercise gives the students an opportunity to experimentally study the decay of a source of natural radioactivity. Concepts like half life and decay constants are naturally explained in the analysis of the experimental data.

Time required: If the collection of the activity is started well in advance of the experiment, the experiment takes about 2 periods.

5.2 Required theoretical background

It is important that the students understand the decay chain of ^{238}U , i.e. that they know which activity is to be measured. For some classes it may be sufficient to inform about the decay to be studied and very shortly mention that it is a part of a naturally occurring decay chain. One can also mention here the health problems caused by the radon daughters.

The theory section of the student instructions should be taught in advance. It may be necessary to explain the use of the lin-log paper if one has decided to determine the half life of the decay. With a few examples the students can practise to make suitable divisions of the axes and readings in lin-log graphs. It is also suggested that the students solve some exercises in this connection.

Before the experiment starts one can discuss the various physical aspects of the collection of the activity on the wire.

5.3 Performance

To save time the collection of the activity should be started before the students arrive at the laboratory. The collecting wire should have a diameter of about 0.2 mm. After the collection has been completed the wire is wound around a thin piece of paper or wood and everything is then placed in a small plastic bag. It is important that the collected activity as quickly as possible is moved to the detector and placed close to it. The detection efficiency is then the largest.

While the wire collection still is going on it is suitable to record a calibration spectrum. The energy calibration is necessary for the identification of the 0.351 and 0.295 MeV transitions in ^{214}Bi . To save time one can also collect a calibration spectrum in advance.

As soon as a calibration spectrum has been collected, the recording of the spectra of ^{214}Pb is started. While this is going on the students can perform their energy calibration so that they directly after the completion of the measurement can copy these spectra for the subsequent analysis. Waiting times can be used to do the theory exercises.

The 0.242 MeV transition in ^{214}Bi is not included in the analysis since the corresponding photo peak is a doublet, i.e. it consists of two photo peaks of which one originates from the 0.238 MeV transition in ^{212}Bi , which is a member of the ^{232}Th chain that also is collected.

5.4 Questions and answers

Question 1. Try to derive equation (5) from equation (4).

$$\ln(N_0/2) = \ln N_0 - tT_{1/2} \quad (4)$$

$$t = (\ln 2)T_{1/2} \quad (5)$$

Question 2. What sources of error may influence the result? Try to rank these sources of error. The error in the result (an error calculation is not necessary!) can be estimated by choosing two alternative slopes of the line in the lin-log diagram and determine the corresponding half lives.

The following sources of error can be mentioned:

The determination of the area of the photo peaks (one can get an idea about the size of the error by repeating the determination of the area and see how the different background subtractions affect the value of the area).

The fitting of the straight line in the lin-log graph (one can get an idea about the size of the error by choosing alternative slopes of the line and observe how they affect the value of the half life).

Question 3. The tabulated value of the half life of ^{214}Pb is 26.8 minutes. How long will it take for the original activity to reduce to one per mille?

$$t = 267 \text{ minutes}$$

Question 4. The half life of ^{137}Cs is 30 years. A source contains an activity of 37 kBq. How large is the activity after a hundred years and how many ^{137}Cs nuclei does the source then contain?

$$I = 3.7 \text{ kBq}$$

$$N = 5.0 \cdot 10^9 \text{ nuclei}$$

6 Measurement of Cesium Activity

(with the aid of an efficiency curve)

6.1 The purpose of the experiment

The experiment gives the students an opportunity to study the efficiency of the detector at different gamma energies. The efficiency curve obtained can be used to determine the activity of samples containing cesium from the fallout after the accident in Chernobyl. In the districts that have not been subjected to the radioactive fallout from the Chernobyl accident one can use samples collected from exposed places or make use of the samples that were delivered with the detector system.

Time required: Approximately 2 periods.

6.2 Required theoretical background

The procedure of efficiency calibration should be discussed with the students. For some classes it may be suitable to skip the efficiency calibration, since it may be seen as difficult to understand. One can then use a calibration spectrum taken in advance, and only schematically account for how the detector is calibrated.

Chapter 7 shows an alternative method to determine the cesium activity, which is quicker and simpler and therefore more suitable for students with less background in physics.

The theory section contains the decay schemes of both of the cesium isotopes. It is important that the students understand the difference between the number of decays per second of the isotopes and the corresponding gamma activities.

If one chooses to let the students carry out the efficiency calibration, a solution of ^{152}Eu with known activity is used as a calibration source. In the efficiency calibration one may use the 0.122, 0.245, 0.344, 0.964 and 1.408 MeV transitions. The relative intensities of the transitions are given in 'The Student Instruction'.

6.3 Performance

The samples to be measured should be collected before the experiment and placed in the standard jars. It is important that no activity is allowed to contaminate the different parts of the detector. Such contamination can be difficult to remove and can result in a disturbing background in future measurements.

The calibration spectrum is collected for at least 10 minutes. The determination of the efficiency curve of the detector can be started as soon as the unknown sample has been placed on the detector and the data collection has started.

If one wishes to skip the calibration to save time one can use the graph from an earlier efficiency calibration provided that the geometry of the experimental setup is the same. An example of an efficiency curve for activities dissolved in water in a standard jar is given in The WinDAS User's Guide.

The measuring times can vary considerably depending on the activity of the sample. A sample with a specific activity of 1000 Bq per kg requires about 3 minutes to give a result with a statistical accuracy of about 20 %. For a demonstration in class it is often suitable to run the spectrum for a longer time in order to obtain a clear peak structure. If the activity is weak one can start the data collection before the experiment. The same applies also to the collection of the background spectrum.

If one wishes to increase the accuracy in measurements of low-activity samples, one can improve the lead shielding. One can also use a so-called Marinelli geometry to increase the effective volume of the sample. All these extra accessories are described in the manual.

If one wishes to compare the measurements with measurements done with professional accuracy one can order samples which have been measured at the laboratory of Gammadata Mätteknik AB.

7 Measurement of Cesium Activity

(Simpler method)

7.1 The purpose of the experiment

The experiment gives the students an opportunity to determine the cesium activity in samples collected in our own environment. In the districts that have not been subjected to the radioactive fallout from the Chernobyl accident one can use samples collected from exposed places or make use of the samples that were delivered with the detector system.

Time required: 1 - 2 periods, depending on how many samples one wants to measure.
The time of the experiment can be decreased by measuring a background spectrum in advance.

7.2 Required theoretical background

The theory discussion includes the decay schemes for the two isotopes. It is important that the students understand that the method is based on a comparison between the photo peaks from the samples with the known and unknown activities, respectively. The jars delivered with the detector are labelled with the activity of the calibration sample.

7.3 Performance

The environmental samples should be collected before the exercise and placed in the standard jars intended for the detector. When handling high-activity samples one must be cautious with the sealing of the jars and it is also important to wash one's hands afterwards. It is important that no activity is allowed to contaminate the different parts of the detector. Such contamination can be difficult to remove and can result in a disturbing background in future measurements.

The background spectrum should be collected for about 30 minutes. Then a spectrum of the calibration sample is collected. A suitable measuring time is about 15 minutes. Finally a spectrum from each sample is collected. The measuring times can vary considerably depending on the activity of the sample.

A sample with a specific activity of 1000 Bq per kg requires about 3 minutes to give a result with a statistical accuracy of about 20%. For a demonstration in class it is often suitable to run the spectrum for a longer time in order to obtain a clear peak structure. If the activity is weak one can start the data collection before the experiment. The same applies also to the collection of the background spectrum.

If one wishes to compare the measurements with measurements done with professional accuracy one can order samples which had been measured at the laboratory of Gammadata Mätteknik AB.

8 Compton Scattering

8.1 The purpose of the experiment

To investigate Compton scattering inside and outside the detector crystal. The exercise gives the students an opportunity to:

1. Experimentally determine the energy position of the Compton edge in a ^{137}Cs spectrum. The energy is compared with the theoretically calculated value.
2. By scattering the gamma radiation from one scatterer, the energy of the scattered radiation is studied as a function of the scattering angle.

Time required: Approximately 2 periods.

8.2 Required theoretical background

The collision between a gamma quantum and an electron is called Compton scattering. In the theoretical derivation of the scattering law, which gives the energy and angular distribution of the scattered gamma quanta, the scattering can be compared with the collision between two bodies, for example two billiard balls. The scattering law and an explanatory figure is given in 'The Student Instructions'. The derivation of this law is probably too difficult, since it requires a relativistic treatment of the scattering process. Interested students are referred to literature on a university level.

It suffices to present the scattering equation and to discuss with the students at what scattering angle ($= 180^\circ$) a gamma quantum loses its maximum energy in the NaI crystal. The maximum energy deposited corresponds to the Compton edge in the gamma spectrum. The rest of the Compton distribution originates from scattering in angles different from 180° . In the second part of the exercise the scattering equation is used to calculate the energy of the scattered gamma quanta in the detector.

8.3 Performance

Depending on the availability of holders and stands one chooses a vertical or horizontal experimental setup. The detector is intended to be used also in a horizontal position. For the introductory experiment, where the energy of the Compton edge is to be determined, the only thing to keep in mind is not to put the source too close to the detector, since the ^{137}Cs sources of the schools often are very active in comparison with the sensitivity of the detector.

In the second half of the exercise the energy distribution of mono-energetic gamma quanta scattered into the detector is studied. These scattered gamma quanta have a broad energy distribution, since the lack of good collimation gives a less well-defined scattering angle.

If there is extra lead available it is possible to improve the suggested collimation, which gives a sharper photo peak in the spectrum of the scattered radiation. At the same time, however, it may be necessary to increase the measurement time to get sufficient statistics. The suggestion in the Student Instructions to use thin lead bricks to build a 2 cm wide slit in front of the detector gives a satisfactory result.

Since the gamma radiation from ^{137}Cs also scatters from objects surrounding the detector opening and since it would be very difficult to avoid this unwanted Compton scattering, one collects a spectrum without a scatterer. By subtracting the unwanted contribution the desired effect is observed more easily.

Aluminium, copper or steel are suggested as scattering material. Generally, the scattering yield increases with the density of the material. The thickness of the scatterer is chosen to be about 5 mm. A thinner scatterer gives fewer scattered gamma quanta and thus longer measurement times.

9 X-Ray Fluorescence

9.1 The purpose of the experiment

To investigate X-ray fluorescence in different materials, and to use X-ray fluorescence to determine the elements in unknown materials. The exercise gives the students an opportunity to use their knowledge in atomic physics, particularly the atomic model of Bohr, to interpret spectra from X-ray radiation. The exercise also gives an opportunity to get familiarised with an analysis method which is commonly used in X-ray spectrometry.

Time required: Approximately 2 periods.

9.2 Required theoretical background

The interpretation of the spectra requires knowledge of the process that gives rise to the X-ray radiation. The exercise gives a good opportunity to use the model of Bohr to calculate the $K\alpha$ -energy of different elements, and to practise Moseley's law. Besides X-ray fluorescence also Compton scattering occurs. To interpret the whole structure of the spectra and to exclude Compton scattering as an explanation to the peaks the students must calculate the energy of the scattered radiation. The scattering law and an explanatory figure is given in the Student Instructions. The derivation of this law is probably too difficult, since it requires a relativistic treatment of the scattering process. Interested students are referred to literature on a university level.

9.3 Performance

Depending on the availability of holders and stands one chooses a vertical or horizontal experimental setup. The detector is intended to be used also in a horizontal position.

Since on delivery the detector has a gain adjusted to be suitable for investigation of gamma radiation with considerably higher energies, the gain, i.e. the high voltage to the photomultiplier of the detector, must be increased. This is done with the knob on the detector box. An ^{241}Am source is held in front of the detector, and the high voltage is increased. It can now be seen how the position of the photo peak is changing. When its position is at about channel 220, the gain is correct.

The energy calibration spectrum can now be collected. This is done by first collecting a spectrum of the ^{241}Am source, for about 1 minute. Use the peak at 0.05954 MeV as the first calibration peak. Then switch to the ^{137}Cs source, and start the data acquisition again. Collect for about 1 minute. Use the peak at 0.03219 MeV as the second calibration peak (it originates from X-ray transitions in the ^{137}Cs daughter nucleus ^{137}Ba). The obtained mixed spectrum is used for energy calibration and it is saved for later use.

Now one collects a number of spectra with different scatterers. To get suitable X-ray energies within the adjusted gain, they ought to be chosen amongst elements with atomic numbers between 35 and 69. Suitable scatter materials are e.g. molybdenum, silver, cadmium and tin. In figure 1 an X-ray fluorescence spectrum from cadmium is shown. To obtain a scatterer with a high atomic number, one can use CeO_2 (powder) wrapped in a thin aluminium foil.

The lower limit of the atomic number is set by the $K\alpha$ -energy, which becomes too low to penetrate the detector shielding. The upper limit is set by the ionising energy of the K-shell, which cannot be higher than the available photon energy. To show that the $K\alpha$ -energy becomes too small when one uses elements of too small atomic number, one can for example use a scatterer of aluminium.

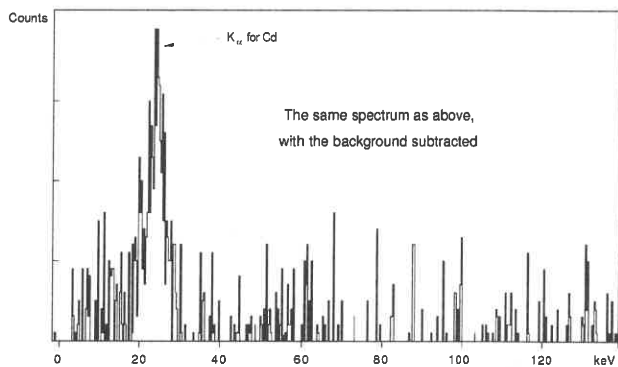
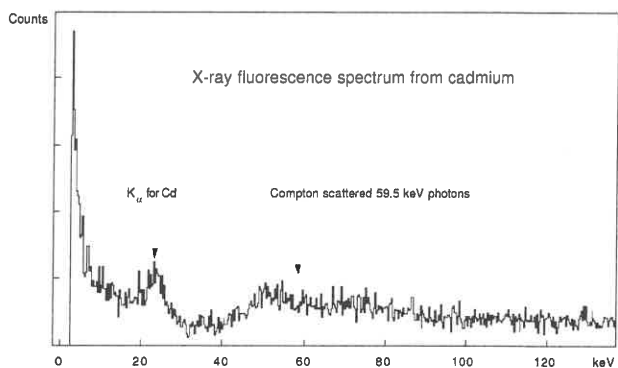


Figure 1.

10 Suggestions for More Advanced Studies

The following projects are expected to take more than 2 periods.

1. Examination of the properties of a NaI detector

- How does the width of the photo peak depend on the gamma energy (compare with the theory for the PM tube)?
- How does the channel position of the photo peak depend on the voltage applied to the PM tube?
- Examination of the linearity of the energy of the detector in the energy region 0.1 - 2.0 MeV.
- Examination of the linearity of the efficiency of the detector in the energy region 0.1 - 2.0 MeV.

2. The absorption of the gamma radiation in different materials and its energy dependence

Determination of the half thickness and the linear absorption coefficient for a selection of different materials. To study the energy dependence of these quantities a number of different gamma energies are selected.

3. The Compton effect

- The theory of Compton scattering, the dependence of the energy and the intensity on the scattering angle.
- Experimental study of the energy as a function of the scattering angle.
- Experimental study of the intensity as a function of the scattering angle.

4. Radioactive chain decay

- Mathematical derivation of a chain decay. At least two steps are included in the derivation. Derived equations are illustrated with graphs.
- Experimental study of the chain decay $^{214}\text{Pb} \Rightarrow ^{214}\text{Bi} \Rightarrow ^{214}\text{Po}$. The activity is collected on a wire connected to a negative voltage and then studied with equally long time intervals. The half life is determined for ^{214}Pb and ^{214}Bi . The experiment also includes the optimisation of the experimental conditions so that the half life of the latter nuclide can be measured with the best yield.

5. Attempt to determine the content of radon in air

- a) Develop a standard method to collect radon daughters with a help of a vacuum cleaner or a conducting wire.
- b) Calibration of the efficiency of the NaI detector and the experimental method by using a commercial radon meter.
- c) The calibrated detector is used to map the content of radon in different rooms. Factors that affect the radon content, such as building materials and soil composition, can be studied.

6. Mapping of the cesium content

By collecting samples from a certain area and measuring the activity of ^{137}Cs in the samples one can attempt to do a mapping.

As sample materials one can use various types of lichen, peat-moss, golden maiden hair, bilberry twigs, lingonberry twigs etc.

7. Variations in the activity of cesium with respect to plants and their habitat

- a) Examination of differences between plants from potassium rich soils and from potassium-poor, acid soils.
- b) Examination of mosses, lichen and mushrooms with respect to different species and habitats.

8. Study of the activity of cesium in different parts of a nutrition chain

Mapping of the activity of cesium in a nutrition chain. Samples are taken from the different parts of the chain like e.g. from a lake.

9. Change of the cesium content in a sample as a result of boiling in salt water

The measurement is performed with plant or meat samples with relatively high cesium contents. By boiling in water with different contents of salt one can study how boiling time and content of salt affect the decrease of the cesium content in the sample.

10. Examination of rocks

A selection of rocks is studied to find out which decay chains are represented in the different rocks. The study is aimed at identifying the occurring radioactive nuclides and determine their relative abundance.

