KAZAN FEDERAL UNIVERSITY
INSTITUTE OF PHYSICS

GAMMA SPECTROSCOPY

ATTENUATION OF γ-RADIATION WHEN PASSING THROUGH MATTER

Kazan
2013

UDK 539.164
BBK 22.38

Approved by
the Editorial Board of Kazan Federal University
the methodical commission of the Institute of Physics
Protocol № 9 from 18 December 2013

the Solid State Physics Department meeting
Protocol № 5 from 19 November 2013

Authors:
Voronina E.V., Dulov E.N., Bikchantaev M.M., Tagirov L.R.

Reviewer:
***Manapov R.A.**, PhD, Senior researcher of the Kazan Institute for Biochemistry and Biophysics of Russian Academy of Science*

Voronina E.V., *Gamma spectroscopy. Attenuation of gamma radiation when passing through matter.* An educational guide to a general laboratory practicum on nuclear physics / Voronina E.V., Dulov E.N., Bikchantaev M.M., Tagirov L.R. – Kazan: Kazan Federal University publishing house, 2013. – 12 p.: 7 ill.

Destination:

The methodical guide is intended for students of the Institute of Physics, Institute of Geology Petroleum Technologies, as a support to the general physical practicum to the courses «Physics of particles and atomic nuclei», «Nuclear physics» and «Physics».

Introduction

Gamma rays (γ-rays) are a type of electromagnetic radiation appearing in spontaneous decay of excited nuclear states. The range of energies of gamma ray is wide, 10 keV-10 MeV, and partially overlaps with the range of energies of X-rays, 100 eV-100 keV. The X-rays have atomic origin and are emitted in decay of electronic excited states. Indicated energy ranges and their classification are not precise. For example, a hard radiation caused by accelerated motion of electrically charged beta particles because of curved trajectories in accelerators often referred to as gamma rays.

Gamma rays are not the only way for excited states to decay. Energy of the excitation may be released in other decays, such as the nucleon or group of nucleons emission. For this reason, decays with gamma ray emission are called *electromagnetic decays.*

Decay of excited nuclear states

Nuclei usually have many excited states. Most of the lowest-lying states are understood theoretically as excitations of single nucleon states and different collective states of nucleons.

Figure 1 schematically shows the energy levels of an even-even nucleus with total number of nucleons $A \approx 100$. The number A is also referred to as the mass number. Even-even nucleus means a nucleus which has an even number of neutrons and an even number of protons. Above the ground state, individual discrete levels with specific J^P quantum numbers can be seen. Here J – nucleus spin, P – *parity* of the nuclear wave function. The excitation of even-even nuclei generally corresponds to break up of nucleon pairs, which requires about 1–2 MeV of energy. Even-even nuclei with A≥40, therefore, rarely possess single nucleon excitations below 2 MeV. In odd-even and odd-odd nuclei, the number of low-energy states (with excitation energies of a few 100 keV) is considerably larger.

Low lying excited nuclear states usually decay by emitting electromagnetic radiation. This can be described in a series expansion as a superposition of different multipolarities, each with its characteristic angular distribution. Electric dipole, quadrupole, octupole radiation, *etc*. are denoted by *E1*, *E2*, *E3*, *etc*. Similarly, the corresponding magnetic multipoles are denoted by *M1*, *M2*, *M3 etc*. Conservation of the angular momentum and parity determine which multipolarities are possible in a transition. A photon of multipolarity *El* has angular momentum l and parity $(-1)^l$, an *Ml* photon has angular momentum l and parity $(-1)^{(l+1)}$. In a transition $J_i \rightarrow J_f$, conservation of the angular momentum means that the triangle inequality $|J_i - J_f| \leq l \leq J_i + J_f$ must be satisfied.

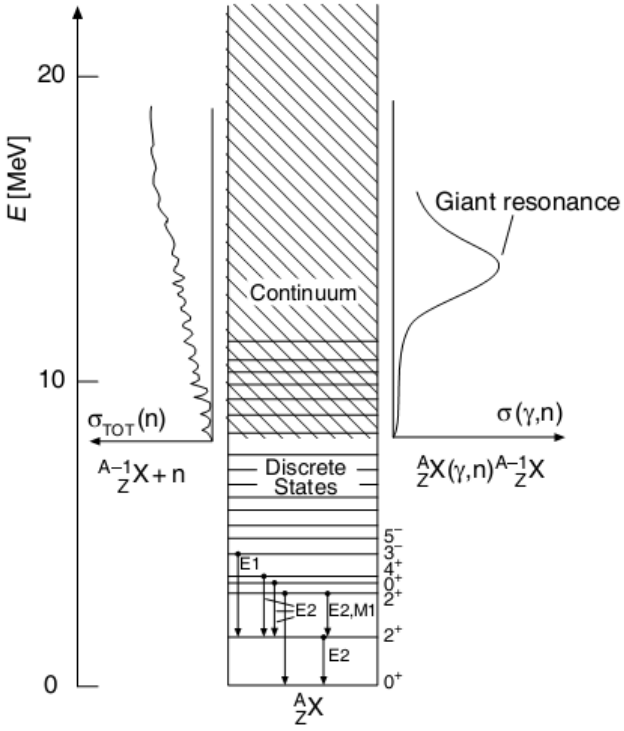

Figure 1. Sketch of typical nuclear energy levels. The example shows an even-even nucleus whose ground state has the quantum numbers 0^+. In the left, the total cross-section for the reaction of the nucleus ${}^{A-1}_{Z}\mathrm{X}$ with neutrons (elastic scattering, inelastic scattering, capture) is shown; in the right the total cross-section for γ-induced neutron emission ${}^{A}_{Z}\mathrm{X} + \gamma \rightarrow {}^{A-1}_{Z}\mathrm{X} + \mathrm{n}$ is displayed.

The lifetime of a state strongly depends on the multipolarity of the γ-transitions by which it can decay. The lower the multipolarity, the larger the transition probability. A magnetic transition *Ml* has approximately the same probability as an

electric *E(l+1)* transition. A transition $3^+ \rightarrow 1^+$, for example, is in principle a mixture of *E2*, *M3*, and *E4*, but will be easily dominated by the *E2* contribution. A $3^+ \rightarrow 2^+$ transition will usually consist of an *M1/E2* mixture, even though *M3*, *E4*, and *M5* transitions are also possible. In a series of excited states 0^+, 2^+, 4^+, the most probable decay is by a cascade of E2-transitions $4^+ \rightarrow 2^+ \rightarrow 0^+$, and not by a single $4^+ \rightarrow 0^+$ *E4*-transition. The lifetime of a state and the angular distribution of the electromagnetic radiation, which it emits, are signatures for the multipolarity of the transitions. The latter, in turn, betrays the spin and parity of the nuclear levels. The decay probability strongly depends on energy. For radiation of the multipolarity *l* it is proportional to E_γ^{2l+1}.

Table 1. Selection rules for the electromagnetic transitions.

Multi-polarity	Electric			Magnetic		
	Eℓ	$\lvert\Delta \boldsymbol{J}\rvert$	ΔP	Mℓ	$\lvert\Delta \boldsymbol{J}\rvert$	ΔP
Dipole	E1	1	−	M1	1	+
Quadrupole	E2	2	+	M2	2	−
Octupole	E3	3	−	M3	3	+

The excitation energy of a nucleus may also be transferred to an electron in the atomic shell. This process is called internal conversion. It is most important in transitions for which γ-emission is suppressed (high multipolarity, low energy) and the nucleus is heavy (high probability of the electron to be inside the nucleus). $0^+ \rightarrow 0^+$ transitions cannot proceed through a photon emission. If a nucleus is in an excited 0^+-state, and all its lower lying levels also have 0^+ quantum numbers (e.g. in ^{16}O or ^{40}Ca), then, this state can only decay in ~~a~~ different ways: by internal conversion; by emission of 2 photons, or by emission of an e^+e^--pair, if the latter is energetically possible. The parity conservation does not permit internal conversion transitions between two levels with J=0 and the opposite parity. The lifetime of excited nuclear states typically varies between 10^{-9} s and 10^{-15} s, which corresponds to a state width of less than 1 eV. States which can only decay by low energy and high multipolarity transitions have considerably longer lifetimes. They are called isomers and are designated by an "m" superscript on the symbol of the element. An extreme example is the second excited state of ^{110}Ag, the quantum number of which is $J^P=6^+$ and the excitation energy is 117.7 keV. It relaxes via an *M4*-transition into the first excited state (1.3 keV; 2^-) since a decay directly into the ground state (1^+) is even more improbable. The half-life time of ^{110}Ag^m is extremely long ($T_{1/2}$= 235d).

Most nuclei have a binding energy per nucleon of about 8 MeV. This is approximately the average energy required to separate a single nucleon from the nucleus (separation energy). States with excitation energies above this value can therefore emit single nucleons. The emitted nucleons are primarily neutrons since they are not hindered by the Coulomb threshold. Such a strong interaction process is clearly preferred to γ -emission.

The excitation spectrum above the threshold for particle emission is called the continuum, just as in atomic physics. Within this continuum there are also discrete, quasi-bound states. States below this threshold decay only by (relatively slow) γ-emission and are, therefore, very narrow. But for the excitation energies above the particle threshold, the lifetimes of the states decrease dramatically, and their widths increase. The density of states increases approximately exponentially with the excitation energy. At higher excitation energies, the states therefore start to overlap, and states with the same quantum numbers can begin to mix. The continuum can be especially effectively investigated by measuring the cross-sections of neutron capture and neutron scattering. Even at high excitation energies, some narrow states can be identified. These are states with exotic quantum numbers (high spin) which therefore cannot mix with neighboring states.

Figure 1 shows schematically the cross-sections for the neutron capture and γ-induced neutron emission (nuclear photoelectric effect). A broad giant dipole resonance is observed, which is interpreted as a collective excitation.

Principles

Registration of gamma radiation

By means of a scintillation counter, the energy of γ-radiation can be determined. The radiation interacts with the scintillator crystal thus giving rise to light pulses, which are transformed into voltage pulses by a photomultiplier. The number of emitted photons and the pulse height are proportional to the γ-energy E_γ. The pulse-height analysis is performed with a multichannel analyzer (MCA) which is connected to a computer (PC). The analog-digital converter measures the pulse height U_S and converts the measuring value into a proportional digital value k. For a quantitative evaluation an energy calibration is necessary, for which usually a linear relation

$$E_\gamma = a \cdot k + b \qquad (1)$$

is assumed.

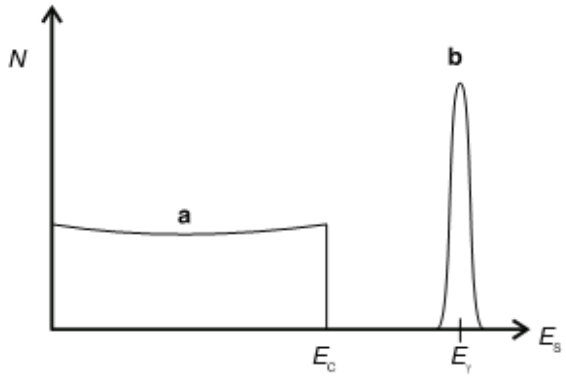

Figure 2. A histogram of a simplified pulse-height distribution of a scintillation counter, when monoenergetic γ-radiation is absorbed; a – Compton distribution, b – peak of complete absorption.

In the γ-energy range between 50 and 2000 keV, two interaction processes of the γ-radiation with the scintillator crystal have to be taken into account: In the photoeffect, the γ-quantum transfers its energy completely to the crystal. The γ-quantum is recorded in the complete absorption peak labeled "b" in Fig. 2. In the case of the *Compton scattering*, only a part of the γ-energy is transferred to the crystal in many cases since the scattered γ-quantum leaves the crystal with a certain probability. The primary γ-quantum is recorded in a continuous distribution labeled by "a" in Fig. 2. The upper and the lower limits of this distribution are determined by the maximum and the minimum energy that can be transferred to the electron in the Compton scattering (see more details in Ref. [1]).

As a rule, for the identification of γ-radiation only the complete absorption peaks are used. The calibration is done with two complete absorption peaks with known γ-energy. At least two peaks must be used for precise calibration because of shifting of the apparatus zero of measured pulses amplitudes. As a rule, this kind of signal distortion appears in practical analog signal processing (discrimination, detection the time of maximum of pulse amplitude, sample-and-hold circuits) before analog to digital conversion of the pulse height. Zero-shifting causes non-zero b in (1) and, therefore, two unknown calibration coefficients *a, b*. Radioactive isotope mixture or single radioactive isotope with two and more gamma-transitions may be used for the calibration. One of the convenient isotopes is ^{60}Co, which has two gamma-transitions and corresponding complete absorption peaks at the energies of 1.17 MeV and 1.33 MeV.

Interaction with matter

Absorption – more precisely attenuation – of γ-radiation means decrease of the intensity when the radiation passes through a matter. The transmission T characterizes the permeability of the absorber for the radiation:

$$T = \frac{R}{R_0}, \qquad (2)$$

where R_0 – initial counting rate, R – counting rate behind the absorber.

The greater the transmission, the smaller the attenuating effect is. The transmission depends on thickness x of the absorber. If the thickness x is enhanced by a small amount dx, the transmission T is decreased by a small amount dT.

The relative decrease of the transmission is proportional to the absolute increase of the thickness:

$$-\frac{dT}{T} = \mu \mathrm{d}x \,. \qquad (3)$$

The proportionality factor μ is called the linear attenuation coefficient. Integration of this equation leads to the Lambert's law:

$$T = e^{-\mu x} \,. \qquad (4)$$

From the attenuation coefficient the absorption half-value thickness $d_{1/2}$ can be calculated:

$$d_{1/2} = \frac{\ln 2}{\mu} \,. \qquad (5)$$

After passing this thickness in the absorber, the intensity of γ-radiation has fallen to half of its initial value.

Several interaction processes of γ-radiation with matter contribute to the attenuation: in the photoeffect, a γ-quantum is absorbed. It transfers its energy completely to an atom of the absorber. The probability of the photoeffect to take place strongly decreases with increasing the γ-energy. Then, the influence of the Compton scattering becomes dominant. In the Compton scattering, γ-quantum transfers a part of its energy to an orbital electron. The scattered γ-quantum therefore has a smaller energy and moves into another direction than the primary γ-quantum. This leads to decrease of the intensity at the original energy and in the original direction. The third kind of interaction, electron-positron pair production, plays a role only at γ-energies above 2 MeV.

In the experiment, the attenuation of γ-radiation in aluminium and lead is measured. The aim of the experiment is to confirm the Lambert's law. Moreover, it is demonstrated that the attenuation depends on the absorber material and on the energy of the γ-radiation.

Detection of weak radioactivity

For determining the activity of a weakly radioactive sample, the sample is often put into a Marinelli beaker (see Fig. 3).

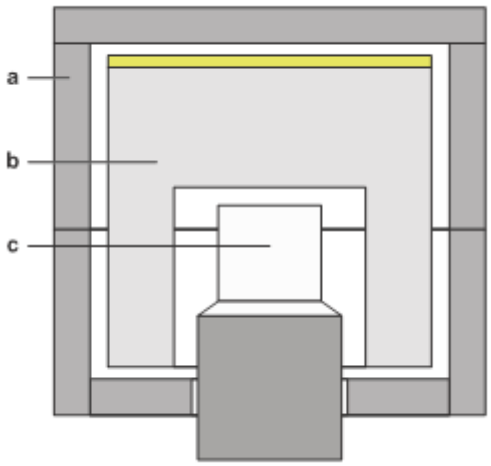

Figure 3. Measuring setup with a scintillation counter for determining the activities of weakly radioactive samples: a - lead shield; b - Marinelli beaker with a sample; c - scintillation detector.

The Marinelli beaker encloses the scintillation crystal almost completely and ensures a well defined geometry of the measurement.

By comparison with the γ-spectrum of a calibration preparation, which has the same geometry, the activity of the sample can be calculated immediately. One should keep in mind that the detection probability of the scintillation counter depends on the γ-energy. Therefore, depending on the γ-energy, a suitable calibration preparation has to be chosen. When the γ-spectra are recorded, a background radiation interferes. The admixture of the background radiation to the measurements is minimized by a lead shielding around the measuring arrangement.

Investigations with the scintillation counter can be made, *e.g.*, on rock stones containing uranium or thorium, and on numerous organic substances which store radionuclides:

- The radionuclide ^{40}K is contained in almost all natural materials and food stuffs. One gram of the natural potassium (metallic) contains an admixture of 120 µg of ^{40}K leading to an activity of approx. 30 Bq.
- A residual pollution has been caused by the radionuclide ^{137}Cs which was released

into the atmosphere in surface nuclear tests or, e.g., in the reactor accident in Chernobyl, Ukraine. After being washed out by rain, cesium contaminated the soil and is still taken up by plants and mushrooms. The Cep (Boletus edulis) takes its nutrients from the uppermost layers of the soil and is, therefore, particularly exposed to the supply with ^{137}Cs stored near the ground surface.

- The Brazil nut (bertholletia excelsa), which grows in the Amazon region, absorbs a large amount of barium in a particular process via a widely extended root system. As radium hardly differs from barium chemically, the tree takes up the radionuclide ^{226}Ra, which belongs to the decay series of ^{238}U, at the same time. The radium is also stored in the nuts.

Setup

Two similar setups are used in this work (Fig. 4 and Fig. 5).
The Universal CassyLab2 data acquisition unit **1** with module **2** of the multichannel analyzer MCA and appropriate software are used. A sample is set around the scintillation detector inside lead shield **4** (Fig. 5) or placed in source holder **6** (Fig. 4). Scintillation detector is connected to the input of CassyLab2 data acquisition unit **1** (Figs. 4 and 5). Detector voltage is adjusted by high voltage power supply **5** in Fig. 4 or **3** in Fig. 5. A notebook with specified software installed is used to display and process the data.
Marinelli beaker **5** in Fig. 5 is used to measure spectra of weak radioactive sample.
Take care while working with the scintillation counter and radiation source.

Carrying out the experiment

Before operations make sure that all units of setups are available according to the scheme above.
The preparation stage is identical for each of the two setups.

Preparation

- Switch on the notebook, the power supply of the CassyLab2 unit, the high-voltage power supply.
- Run the CassyLab2 by clicking the icon on the desktop.
- In the window "Cassy" select "measurements channel" by the upper square selection of the left column (multichannel analyser). Measurements scale will appear and the window Voltage U_a.
- In the window "Cassy" click on Show Measuring Parameters. In the tab Settings on the right, the "Measuring Parameters" window will pop-up. Set measurements time - 200 (400) c with measurement increments - 1sec.
- Adjust voltage on the high-voltage power supply - 650 V.
- Click button "Close" in the Cassy window.
- Measure spectrum. Tune high voltage and repeat measurements until spectrum covers most of channels, like on Fig. 6 and Fig. 7. The more voltage the higher the gain. Typical high voltage value in these works is 700-900 V.
- When tune is completed, delete all intermediate data.

Energy calibration

- A mixed radioactive source of the first setup contains ^{137}Cs. The most intensive spectral line corresponds to this isotope (Fig. 6). Perform calibration of the abscissa using this spectral line as described below.
- Click by the right button to get "Menu of Actions" with the spectrum. Select "Fit Function" → "Gaussian of equal Width". Then, hold the left button to mark the line of the spectrum.
- Read results of the processing in the line at the bottom of the window CassyLab2 (line center - μ, line width – σ).
- In the tab "Settings" perform the energy calibration of the abscissa. Select in the Settings tree the item "Cassys" → "Input A_1" → "Channel n_A".

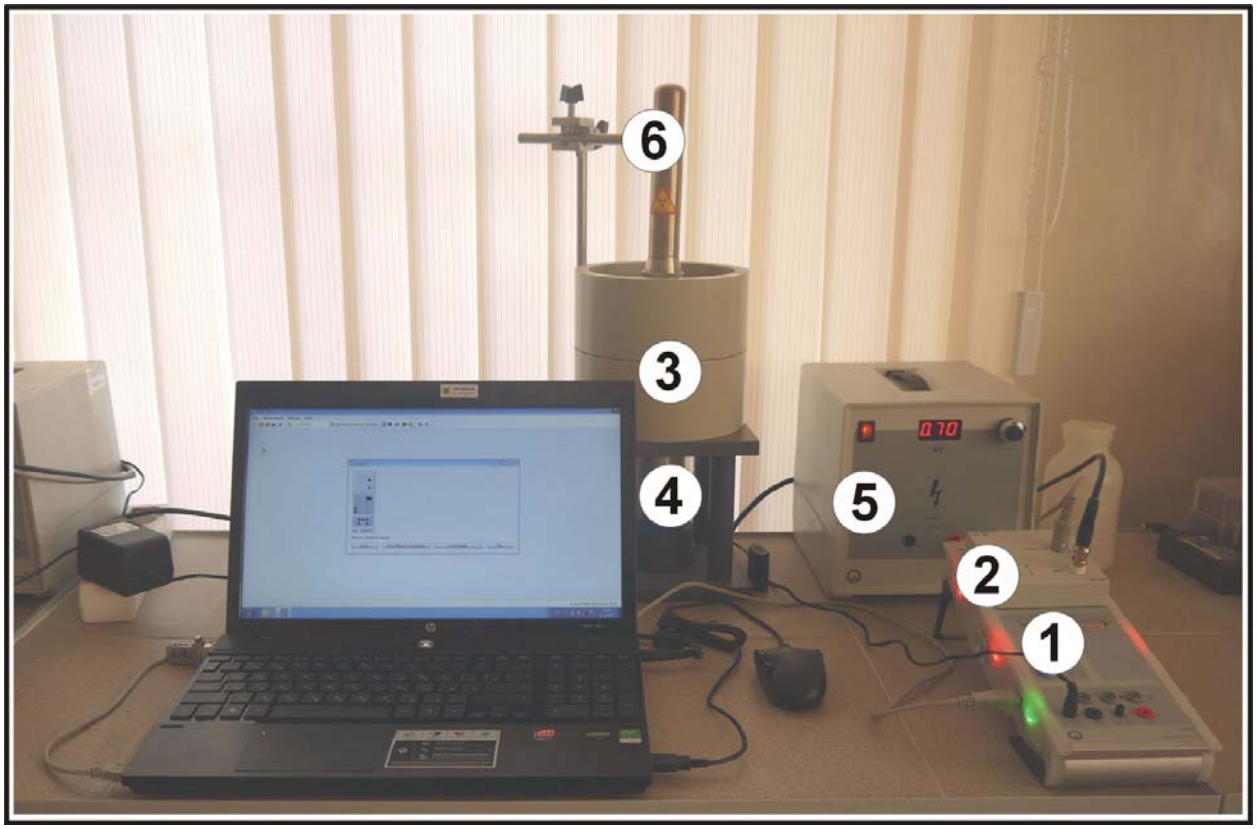

Figure 4. The first experimental setup intended to gamma spectroscopy of radioactive samples having mixture of radioactive nuclei. 1 – CassyLab2 data acquisition unit; 2 – multichannel analyzer module; 3 - scintillator shielding (Pb, ~1 cm); 4 – scintillation detector; 5 – high-voltage scintillator power supply; 6 – holder for the gamma radioactive source.

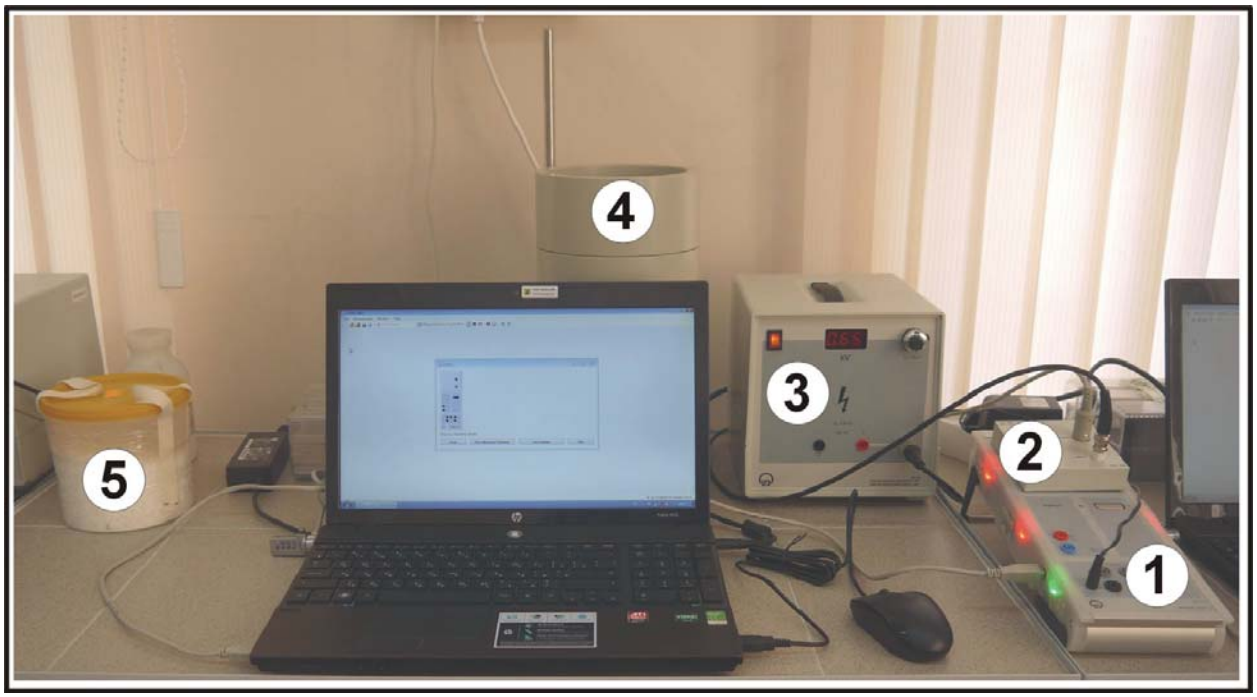

Figure 5. The second experimental setup intended for detection and spectroscopy of weakly radioactive samples. 1 – CassyLab2 data acquisition unit; 2 – multichannel analyzer module; 3 – high-voltage scintillator power supply; 4 – scintillator shielding (Pb, ~1 cm); 5 – Marinelli beaker for weakly radioactive samples.

• In the Group Box named "Energy Calibration" set check mark in the line "Global for all channels" and type two calibration points in the corresponding windows. Enter for the first point: channel – "0", energy – "0". Enter for the second point channel – "μ". Energy should be chosen from the drop-down menu window corresponding to the line of the calibration source.

• Select in Settings tree the item Cassys → Display → Standard → $N_A(n_A)$ after that rename the *Ox* axis: E_A instead of n_A. The spectrum should be redrawn in the energy scale.

• Weak radioactive source in Marinelli beaker with known activity of ^{137}Cs radioactive isotope is used for calibration of the second setup.

• Mount the ^{137}Cs Marinelli beaker around the scintillation detector.

• Do all aforementioned operations to calibrate second experimental setup (Fig. 5). It is recommended to determine the background without a preparation.

Identifying radioactive nuclei

With an energy-calibrated scintillation counter the γ-energies can be measured.

• For the second setup (Fig. 5) mount weak radioactive sample in the Marinelli beaker around the scintillation detector. Measure gamma spectrum in the precalibrated scale.

• Approximate spectral peaks by Gaussians. For the first setup (Fig. 4) treat same as the one used for the calibration spectrum.

• Find energies of the spectral lines and their relative probabilities.

• Identify radioactive nuclei using the data obtained.

Recording gamma spectra with different absorbers thickness

• For the first setup place an absorber of known thickness over the scintillator counter and repeat the spectrum measurements for at least five values of aluminium and lead absorber thicknesses.

• In the measured spectra determine area η of different spectral peaks for the each absorber thickness value d. Collect values in a table.

• Plot η versus the absorber thickness. Select in the tree "Settings" the item Cassys → Display, button "New".

• In the field "Name" type "Area, a.u." and press the button "Add new Curve"

• Specify in the drop-down window the label for *x*-axis: *d.* Specify the label for *y*-axis: η. In the column "Style" set check mark at "Values".

• In the plot select "Fit Function"→ "Best fit Exponential Decay" clicking with right button of the mice.

• Estimate mean free path for the gamma quanta.

Report

Process the spectra by the CassyLab2 software. Analyze the spectra obtained.

Save the results as graphs making screenshots or by exporting windows as images by means of the CassyLab2 software. Save the graphs in an external storage and use in the documentation of your work.

Use CassyLab2 software to determine linear attenuation coefficient for the different spectral lines and different absorber materials as described above.

Make qualitative decision about mean free path dependence on energy and the absorber material.

Compare the area of the ^{137}Cs peak of the calibration source and the area of the gamma peak of measured and identified sample in the Marinelli beaker. The calibration source has the same geometry and known activity printed on the top of the Marinelli beaker. Taking into account relative probabilities of the different decay channels, estimate the activity of the measured weak radioactive sample.

Represent the results in print including all estimations and graphs.

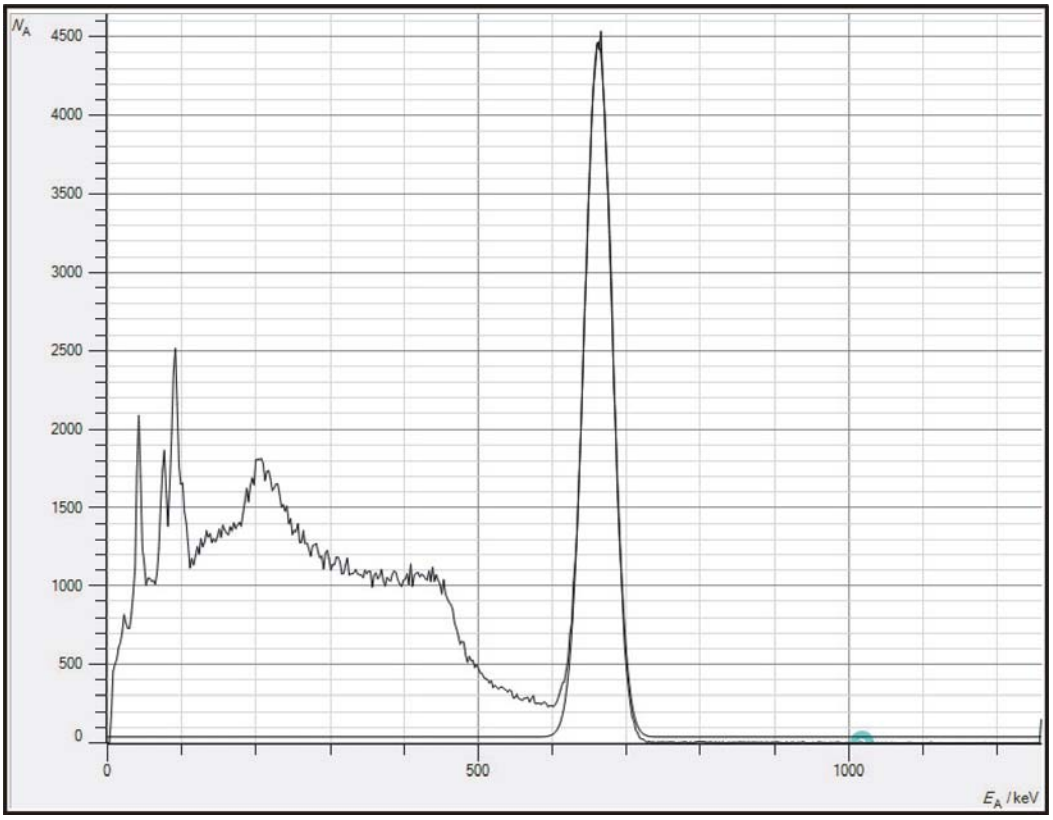

Figure 6. Gamma spectrum of the sample with radioactive nuclei mixture. Most intensive line corresponds to ^{137}Cs and is used as reference.

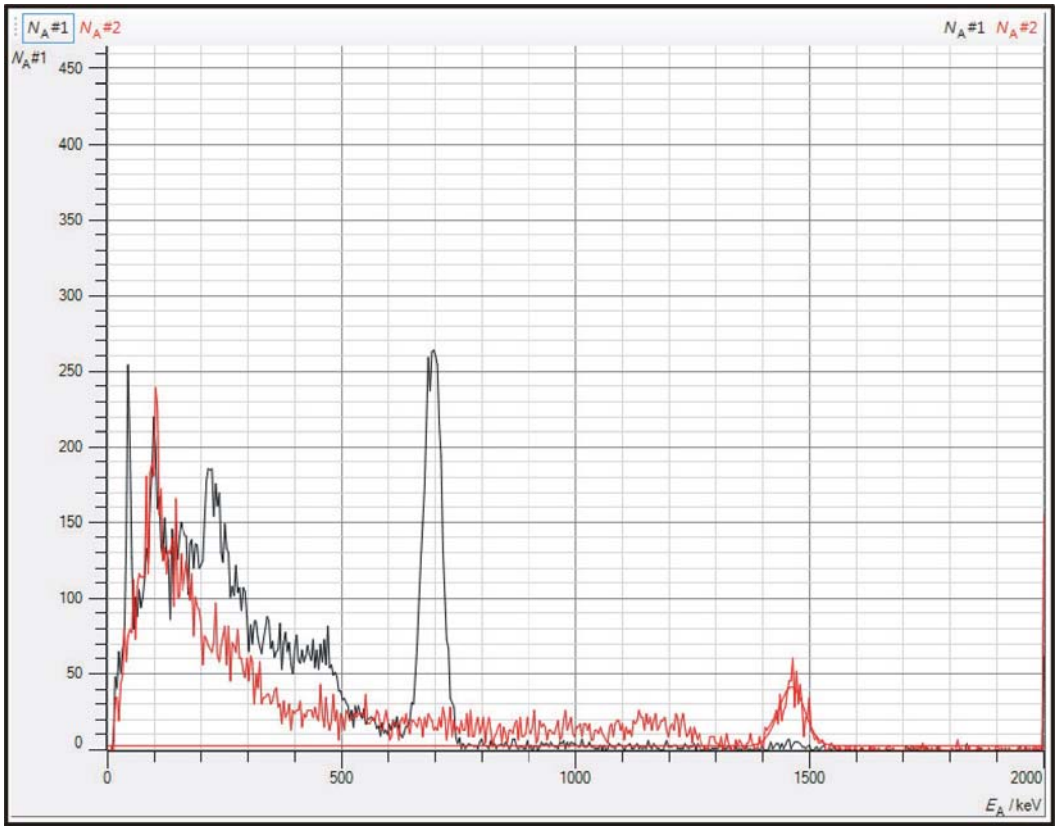

Figure 7. Gamma spectra of weakly radioactive samples. One of the samples is known, ^{137}Cs, and used as a reference.

Safety notes

The following safety rules must nevertheless be kept to:

- **Prevent access to the preparations by unauthorized persons.**
- **Before using the preparations make sure that they are intact.**
- **For the purpose of shielding, keep the preparations in their safety vessel.**
- **To ensure minimum exposure time and minimum activity, take the preparations out of the safety vessel only as long as is necessary for carrying out the experiment.**
- **To ensure maximum distance, hold the preparations only at the upper end of the metal holder and keep them away from your body as far as possible.**

Self-test problems

1. What is the range of energies of gamma rays?
2. How long are gamma rays wavelengths in comparison with atom/nuclei radii?
3. What is the origin of gamma rays?
4. What is the difference between giant dipole resonance and single-nucleon excitation?
5. Compare sketches of nuclear and atomic energy levels. Demonstrate qualitative difference and compare orders of energies.
6. How long are lifetimes of excited nuclear states?
7. Does a gamma quantum change their energy when passing through matter?
8. What is a function of the lead shield in gamma spectroscopy?
9. Describe the principle of operation of scintillation detector and their advantages in gamma-spectroscopy.

References

1. Povh, B. Particles and Nuclei [Text] / B. Povh, K. Rith, C. Scholz, F. Zetsche // Springer. – 2006. – 391 p.
2. Nuclear and particle physics [Text] / B.R. Martin // Wiley. – 2006. – 411 p.
3. Cottingham, W.N. An introduction to nuclear physics (second edition) [Text] / W.N. Cottingham, D.A. Greenwood // Cambridge University Press. – 2001. – 271 p.
4. Das, A. Introduction to nuclear and particle physics [Text] / A. Das, T. Ferbel // World Scientific. – 2003. – 399 p.
5. Basdevant, J.L. Fundamentals in nuclear physics. From nuclear structure to cosmology [Text] / J.L. Basdevant, J. Rich, M. Spiro // Springer. – 2005. – 515 p.
6. Shultz, J.K. Fundamental of nuclear science and engineering [Text] / J.K. Shultz, R.E. Faw // Marcel Decker. – 2002. – 506 p.
7. Kapitonov, I.M. An introduction to nuclear and particle physics (in Russian) [Text] / I.M. Kapitonov // M.: URSS. – 2004. – 383 p.
8. An introduction to nuclear physics (in Russian) [Text] / K.N. Mukhin // M.: Atomizdat. – 1965. – 613 p.
9. Basics of nuclear physics (in Russian) [Text] / P.E. Kolpakov // M.: Prosveschenie. – 1969. – 287 p.
10. Shirokov, Yu.M. Nuclear physics (in Russian) [Text] / Yu.M. Shirokov, N.P. Yudin // M.: Nauka. – 1980. – 783 p.

РЕЦЕНЗИЯ
на учебно-методическое пособие

Ворониной Е.В., Дулова Е.Н., Бикчантаева М.М., Тагирова Л.Р.

«Gamma spectroscopy. Attenuation of γ-radiation when passing through matter»

Рецензируемое учебно-методическое пособие «Gamma spectroscopy. Attenuation of γ-radiation when passing through matter» разработано авторами в рамках общефизического лабораторного практикума к лекционным курсам «Ядерная физика», «Физика ядра и частиц» и «Атомная и ядерная физика», и предназначено для англоязычных студентов, проходящих ядерно-физический практикум на материально-технической базе лаборатории ядерной физики кафедры ФТТ Института физики КФУ.

Пособие начинается с обзорной вводной части, в которой даются основные представления о природе гамма-излучения, схеме уровней энергии ядра, а также необходимые сведения о взаимодействии гамма-излучения с веществом. Затем следует часть с описанием экспериментальной лабораторной установки, в которой показаны основные узлы и их назначение. Далее приводится описание порядка выполнения работы, даются рекомендации по анализу и представлению экспериментальных результатов.

В пособии последовательно изложен материал, необходимый для понимания и применения метода гамма-спектроскопии в решении практических задач. Подробно рассматриваются многие явления и эффекты, необходимые как для работы с оборудованием, так и для анализа результатов.

Практическая часть задания даёт наглядное представление о физических процессах, происходящих в спектрометре гамма-излучения, содержит все необходимые элементы для получения навыков работы на экспериментальных установках, в том числе на современном спектроскопическом оборудовании.

Рецензируемое пособие актуально и представляет несомненный интерес для преподавателей и студентов, сталкивающихся с гамма-спектроскопией в учебной работе.

Считаю, что учебно-методическое пособие Ворониной Е.В., Дулова Е.Н., Бикчантаева М.М., Тагирова Л.Р. «Gamma spectroscopy. Attenuation of γ-radiation when passing through matter» может быть рекомендовано в качестве пособия для англоязычных студентов.

С.н.с. КИББ КазНЦ РАН,
к.ф.-м.н. Манапов Р.А.

ВЫПИСКА ИЗ ПРОТОКОЛА № 9

от 18 декабря 2013

заседания Учебно-методической комиссии Института физики КФУ

ПРИСУТСТВОВАЛИ: проф. Таюрский Д.А. (председатель комиссии), доц. Шерстюков О.Н. (зам. председателя комиссии), Хуснутдинов Н.Р., Ильясов К.А., Воронина Е.В., Тюрин В.А., Корчагин П.А., Дуглав А.В., Мокшин А.В., Гарнаева Г.И., Шиманская Н.Н., Соколова М.Г.

СЛУШАЛИ: рекомендацию в печать методического пособия «Gamma spectroscopy – Attenuation of γ-radiation when passing through matter» (авторы: Воронина Е.В., Дулов Е.Н., Бикчантаев М.М.,Тагиров Л.Р.)

ПОСТАНОВИЛИ: на основании положительной рецензии к.ф.-м.н., старшего научного сотрудника КИББ КНЦ РАН Манапова Р.А. рекомендовать вышеуказанное методическое пособие к опубликованию в электронном виде на сайте Института физики.

Председатель Учебно-методической комиссии
Института физики, профессор Таюрский Д.А.