Palacký University Olomouc
Faculty of Science
Joint Laboratory of Optics

MASTER THESIS

Development of a spectrometric chain for the detection of low-energy gamma radiation using semiconductors.

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DECLARATION

I hereby declare that I elaborated this bachelor thesis independently under the supervision of Mgr. Leo Schlattauer Ph.D., using only information sources referred in the Literature chapter.

In Olomouc November 4, 2023

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Contents

Introduction

Chapter 1

Gamma rays properties and matter interaction

1.1 Gamma emission

1.2 Passage of radiation and particles through matter

Interaction of a particle (radiation) with another particle (atom, nuclei, free electron) or with continuous matter can result into many types of reactions and effects - scattering of a particle from incident direction, creation of new particles and nuclei, annihilation of incident particle etc. It mainly depends on particle's energy, electric charge, spin and mass, but also on the properties of target particle or matter. The physical quantity describing the probability of a specific interaction of particle with single point target is known as the cross section. Normalized to the unit solid angle - differential cross section:

$$\frac{d\sigma}{d\Omega} = \frac{1}{F}\frac{dN_{\mathrm{s}}}{d\Omega} \tag{1.1}$$

Where F is a particle flux, Ω is a solid angle and N_{s} is the average number of scattered particles per unit time. And the total cross section is given by integration:

$$\sigma = \int \frac{d\sigma}{d\Omega} d\Omega \tag{1.2}$$

However, to characterize the interaction probability of particle with continuous matter, which contains many interaction centres (defined by their density), other assumptions have to be made. The average number of scattered particles is given by:

$$N(\Omega) = FAN\delta x \frac{d\sigma}{d\Omega} \tag{1.3}$$

and integrated:

$$N_{tot} = FAN\sigma\delta x \tag{1.4}$$

The A is a total area perpendicular to the flux, δx is the material thickness and N is the density of interaction centres.

Depending on the type of particle

Heavy charged particles (such as alpha particles, protons, muons, pions) lose their energy mainly due to the atomic electrons collisions. Due to their mass which is much higher than the mass of electrons ($M >> m_e$) they collide with, the direction of their path is left unchanged. The loses of energy per unit path is defined as stopping power $\frac{dE}{dx}$. The stopping power for the heavy charged particles is given by Bethe-Bloch formula which relates stopping power and particle's energy. However the Bethe-Bloch formula doesn't apply on low energies (Lindhard-Sharf nuclear loses) and on higher energies (bremsstrahlung radiation). The change of their path direction is possible by the second process with lesser probability - by the elastic scattering from nuclei.

Electrons and positrons have much smaller mass than the heavy charged particles, and thus the direction of their path is changed due to the movement in an electric field of nucleus. The bremsstrahlung radiation loses are mayor yet at low energies. However, the energy lost due to the collisions also comes to play - it is guided by special Bethe-Bloch formula, which takes the path direction change into account.

Other interaction effects are also possible (Cherenkov radiation emission, nuclear reactions), but they are rare or does not affect the particle's energy as those previously mentioned.

The interaction of neutrons is totally different due to the lack of charge.

This thesis, which is described more detail in following chapter.

1.2.1 Gamma matter interaction

1.3 Photoelectric effect

1.4 Compton scattering

1.5 Pair production

Chapter 2

Gamma rays detection

2.1 Properties and parameters of detectors

2.1.1 Gaseous detectors

2.1.2 Scintillation Detectors

2.1.3 Detectors based on semiconductors

Chapter 3

Semiconductor Detectors

3.1 Principle and parameters

3.2 Construction scheme of Instruments for gamma detection based on semiconductors

3.2.1 XR-100CdTe X-Ray and Gamma Ray Detector

3.2.2 MIMOS 2

3.3 Available semiconductor sensors

3.4 Hamamatsu detectors

3.5 OPF420 PIN diode

Chapter 4

Detector pulse analysis

Chapter 5

Mössbauer effect

Mössbauer effect is a physical effect, which can under certain circumstances occur on atomic nuclei. It consists of recoilless resonance emission/absorption of gamma photons by nuclei of source/absorber with discrete nuclear energy levels.

5.1 Physical concept

It is well-known fact, that the atomic nuclei are quantum systems with discrete energy levels (analogous to the energy levels of electron shell), thus upon deexcitation or excitation they absorb/emit gamma photon with energy equal to the difference between the levels. However, this energy may be altered - due to the momentum conservation law, some part of the gamma photon energy is transferred to the kinetic energy of nucleus, crystal as whole body or is possibly transformed into lattice vibrations (phonons). Due to this fact, the emission and absorption energy spectra may be different and without any overlaps, which prevents the resonance effects from happening.

5.2 Mössbauer Fe^{57} spectroscopy

This thesis is mainly devoted to the application of semiconductor detectors for detection of the 14.4 keV gamma photons.

It is also necessary to consider, that the Fe^{57} isotope have relative abundance only 2.21% [**compounds**]. Although this fact, the spectra are still be measured with very respectable precision and efficiency, which makes the Mössbauer spectroscopy very sensitive measurement method.

Conclusion

The work on thesis was both very hard and experiencing, and thus it can be compared to have to chug a bottle of 50% vodka - get sick, get experienced.