An Educational Experience with Linear Absorption Coefficient

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***Abstract*—In this paper is presented a simple procedure for evaluating the absorption coefficient of aluminum (Z = 13) using a gamma-emitting nuclide, highlighting the characteristics and limits that characterize the measurement. Using the educational kit caen, is possible to investigate the full potential of the adopted method. The results obtained give great confidence in the instruments and the aim of this work is to provide the first tools for conducting a good spectroscopic analysis.**

***Keywords*—gamma ray spectrometry, absorption coefficient,**

I. Introduction

Gamma rays are a form of electromagnetic radiation produced by the decay of unstable gamma-emitting nuclei or by atomic / subatomic processes consisting of issuing of photons. When a photon passes through matter can give rise to ionizations or excitations of the atom as it may release all or part of its energy: therefore, from its interaction it's possible to deduce energy and number of incident photons.

Using this information, one can construct an histograms of the pulse frequency as a function of the photon energy: the interaction with a detector gives rise to a distribution of counts characterized by one or more monoenergetic groups (photopeak, escape peaks, backscatter, etc ...) and by a continuous distribution (continuous Compton).

In function of the emitted gamma energy and of the material atomic number with which they interact, three different types of interactions may take place:

- PHOTOELECTRIC EFFECT: in ionization processes, the incident photon is completely absorbed by an electron, which is re-emitted with energy equal to $(h\nu - E_b)$ (photo-electron);
- COMPTON SCATTERING: in scattering processes, the incident photon transfers part of its energy, function of scattering angle, to a free electron;
- PAIR PRODUCTION: at high energies ($> 1022keV$), the incident photon is converted into an electron-positron pair that, following the annihilation phenomenon, emit a pair of photons back-to-back.

Depending on the cross sections that characterize each of these phenomena, the dominant interactions mechanisms are the photoelectric effect and Compton scattering.

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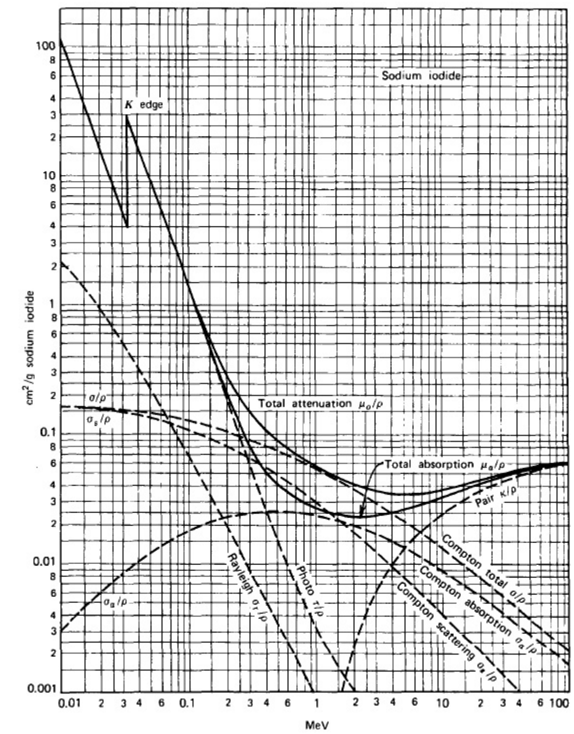

Fig. 1: Cross section vs energy of incident radiation.

II. Methods

When a quantum of energy E passes through matter has a probability P of interacting against an atom:

$$P = \Sigma N_a x \rightarrow dP = \Sigma N_a dx \tag{1}$$

- Σ rappresents the total cross section, sum of the cross sections that characterize all the processes of interaction:

$$\Sigma = \Sigma_{ph} + \Sigma_{com} + \Sigma_{pp}; \tag{2}$$

- N_a is Avogadro's number;
- x is the thickness.

Let I be the number of incident photons per time and surface unit on a target with thickness dx then, crossing it, we have:

$$dI = -IdP = -I\Sigma N_a dx \tag{3}$$

solving the first degree differential equation, we get:

$$\int \frac{dI}{I} = -\int \Sigma N_a dx \rightarrow \log(\frac{dI}{I}) = -\Sigma N_a x \rightarrow \frac{dI}{I} = e^{-\Sigma N_a x} \tag{4}$$

Defining $\mu = \Sigma N_a$, the solution of the differential equation takes the familiar form:

$$dI = Ie^{-\mu x} \tag{5}$$

from which can derive the expression for μ.
Gamma spectrometry applications are vast: measures of environmental contamination, control of radioactive pollution, monitoring of radioactive tracers for various scientific purposes, etc ...
In this experiment, this technique will be used for the acquisition and evaluation of the characteristic peaks of choosen source and were used:

- gamma source: Mn^{54} , $E_\gamma = 835keV$
- alumium shims: $0.5 \pm 0.01cm$ and $1 \pm 0.1cm$
- scintillator: CsI
- Hamamatsu SiPM and elettronic [2]
- SP5600: Power Supply and Amplification Unit [1]
- DT5720A: Desktop Digitizer 250MS/s, 12 bit, with DPP.CI [1]

Instruments are used in experimental configuration shown in figure 2.

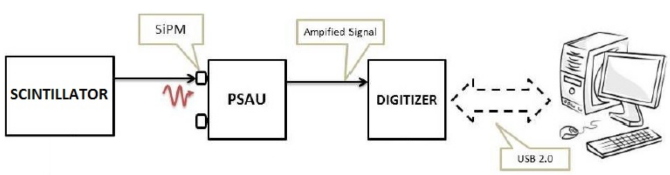

Fig. 2: set-up.

To evaluate the area under the photopeak was used the usual formula:

$$area = a \cdot c \cdot \sqrt{\pi} \tag{6}$$

where:

- a is the peak height;
- c is the peak widht, to be corrected by $\sqrt{2}$ factor

Also, to evaluate the energy resolution was used:

$$ResolutionPower = \frac{FWHM}{PeakPosition} \tag{7}$$

Three important tests were made:

- Acceptance check: defined as the ratio between the area of the scintillator and the incident area of the sphere of radius r, characteristic of the isotropic emission;
- Normalization of the measure: TIME (1h): this normalization parameter was chosen because of the stochastic nature of the events in question;
- Poisson statistics: this verification has been made to justify in the data analysis the use of Poissonian errors: 10 spectra were acquired under the same conditions to verify that error of individual area is equal to the standard deviation of all of the points.

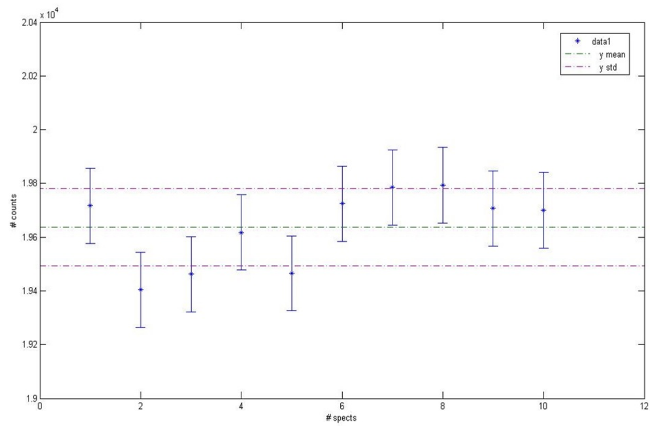

Fig. 3: plot to check Poisson Statistics

Using different shims between source and scintillator, spectra at different distances with and without thickness were acquired to evaluate the ratio between the areas of these, obtaining the relative value of μ: the procedure was performed for all thicknesses available (7 in this case, with 14 spectra acquired). At first glance were noted two different effects:

- Strong temperature dependence: at small temperature variations corresponds significant variations in the gain, effect who affect the energy resolution;

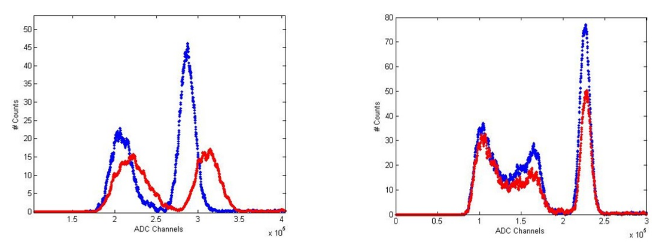

Fig. 4: shift in temperatura e valutazione della risoluzione energetica.

- Background Compton: Compton tail lead events that overestimate the photopeak; to remedy, was used an algorithm of background subtraction (SNIP [3]) which, in our case, is equivalent to about 6 percent of the total area of the photopeak. ;

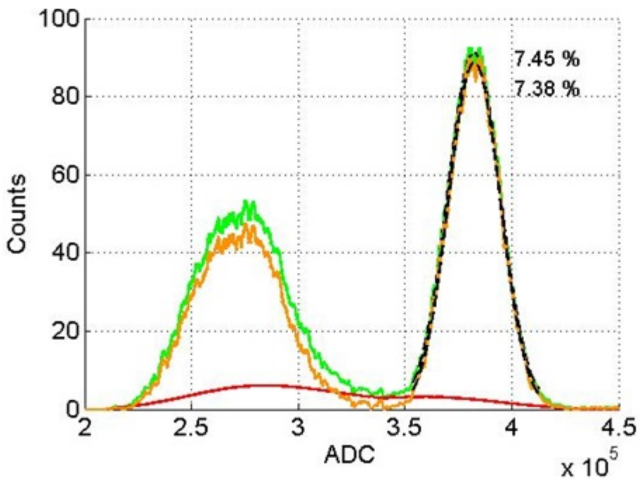

Fig. 5: esempio di SNIPPING

III. Results

The reference value of μ was calculated by evaluating the mass absorption coefficient for aluminum corresponding to the energy of the incident radiation:

$$\frac{\mu}{\rho} = 0.06841 \rightarrow \mu = \frac{\mu}{\rho} \cdot \rho_A l = 0.06841 \cdot 2.7 = 0.1847 cm^{-1} \quad (8)$$

For this first linear fit the formula used is:

$$-log(\frac{dI}{I}) = \mu \cdot x \quad (9)$$

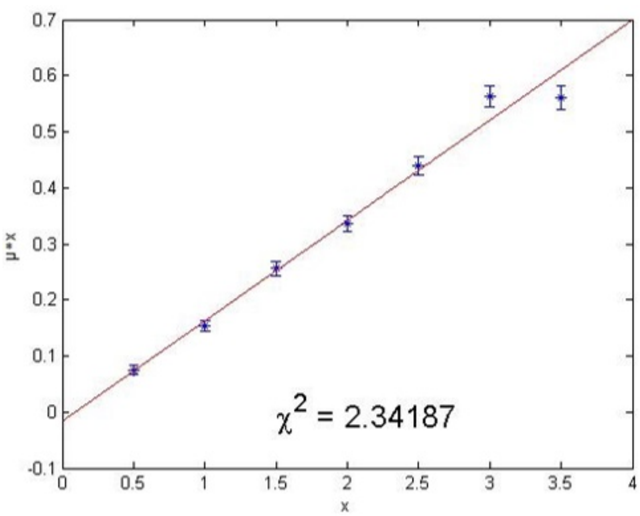

Fig. 6: linear fit with equation (9)

instead, for this following fit the formula used is:

$$(\frac{dI}{I}) = e^{-\mu \cdot x} \quad (10)$$

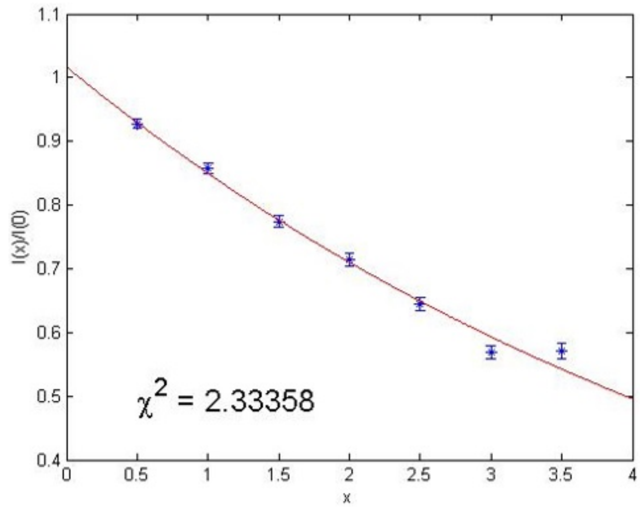

Fig. 7: exponential fit with equation (12)

and from data:

$$\mu = 0.1789 \pm 0.0087 \quad (11)$$

that deviates 0.66σ from the expected value.

The following fit, with the equation

$$-log(\frac{dI}{I})\frac{1}{x} = \mu \quad (12)$$

follows the weighted average of the datas, and this appears to be a check on the good quality of data.

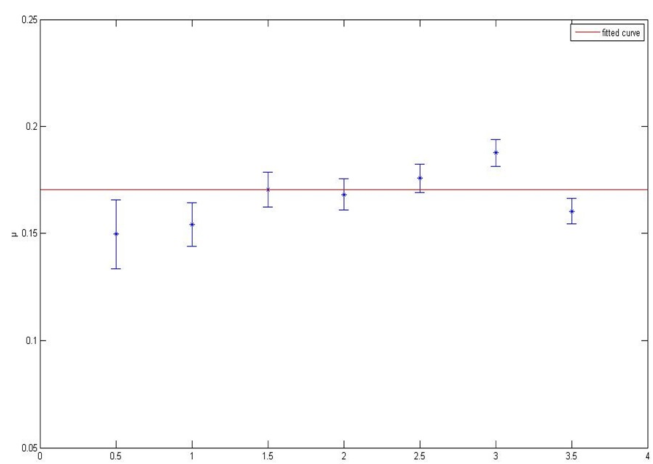

Fig. 8: secondo fit lineare.

The procedure examinated is simple to perform but is sensitive to different aspects, such as changes in temperature (without an adequate electronic) and good acquisition geometry results an essential condition for the success of the measures: this is why we are working to finding a contrivance engineering to mitigate this strong addiction.

REFERENCES

[1] www.caen.it
[2] www.hamamatsu.com
[3] riferimento allo snip