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Technical Note

Determination of beta attenuation coefficients by means of timing method

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ABSTRACT

Using a counting system with plastic scintillation detector, beta linear and mass attenuation coefficients were determined for bakelite, Al, Fe and plexiglass absorbers by means of timing method. To show the accuracy and reliability of the obtained results through this method, the coefficients were also found via conventional energy method. Obtained beta attenuation coefficients from both methods were compared with each other and the literature values. Beta attenuation coefficients obtained through timing method were found to be compatible with the values obtained from conventional energy method and the literature.

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1. Introduction

While passing through matter, electrons lose energy to atomic electrons via the electric interaction in the same way as heavy charged particles. However, they are much lighter and their speeds are greater (Lilley, 2001). The energy loss by electrons fluctuates much more than for heavy particles. This is due to the much greater energy transfer per collision allowed for electrons and to the emission of bremsstrahlung. In both cases, it is possible for a few single collisions (or photons) to absorb the major part of the electron's energy. This, of course, results in greater range straggling (Leo, 1987).

The transmission curve for beta particles emitted by a radioisotope source, because of the continuous distribution in their energy, differs significantly. The "soft" or low-energy beta particles are rapidly absorbed even in small thicknesses of the absorber. For the majority of beta spectra, the attenuation curve is nearly linear on the semi-logarithmic plot (Knoll, 2000).

Exponential variation of β-ray intensity with depth for monoenergetic incident beam is given by

$$I = I_0 \exp(-\mu x) \quad (1)$$

where I_0 represents the incident intensity, x the depth in units of length and the linear attenuation coefficient (μ), which has dimension of (length)$^{-1}$. The mass attenuation coefficient μ_m is defined as the linear attenuated coefficient divided by the density of the medium (Lilley, 2001).

$$\mu_m = \mu/\rho \quad (2)$$

La Rocca and Riggi (2009) obtained the experimental beta mass attenuation coefficients of brass, cardboard and aluminum by using ^{90}Sr radioactive source. Beta mass attenuation coefficients of Al, Cu and Au absorber materials were obtained by Gurler and Yalcin (2005) as a result of their theoretical calculations. Yi et al. (1999) calculated the ratio of beta linear attenuation coefficients to positron linear attenuation coefficients of Sn, Pb, Cu and Al absorber materials by theoretical study. Kawada et al. (2008) obtained the pulse height spectrum of passing beta particles of the absorber materials of ^{137}Cs, ^{60}Co, ^{90}Sr–^{90}Y and ^{147}Pm radioisotopes by using plastic scintillation detector.

A particle energy spectrum is a function giving the distribution of particles in terms of their energy. To determine the energy spectrum of particles emitted by a source, one measures, with the help of a detector and appropriate electronics, the pulse height distribution produced by these particles.

Timing experiments are used in measurement of the time development of an event (Tsoulfanidis, 1995). Timing in nuclear physics refers to the measurements of very small time intervals. Accurate measurements of very small time intervals require special techniques (Leo, 1987). Timing measurement focuses on the determination of the time when a particular event has happened (i.e. a charged particle has crossed the detector), with a certain accuracy. The information on the energy associated with the event has a lesser priority or may even be disregarded. This fact fundamentally changes the way timing radiation systems are designed and optimized (Martoiu and Rivetti, 2011).

Timing methods are characterized as 'slow' and 'fast' depending on the way the signal is derived (Tsoulfanidis, 1995). It is important to distinguish between fast and slow pulses in an electronics system. Fast signals are very important for timing applications (Leo, 1987). Fast timing signals are based on the unshaped pulse at the output of the detector or on a signal shaped specifically for

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timing (Tsoulfanidis, 1995). Conventional energy method uses the slow pulses from the detector output whereas the timing method utilizes the fast signals.

In this study, beta-ray linear and mass attenuation coefficients of bakelite, plexiglass, Al and Fe absorber materials were obtained by means of timing method. Obtained beta attenuation coefficients were compared with the values from the conventional energy method and from the literature, and they were consistent with each other.

2. Experimental

A ^{90}Sr beta emitter with the activity of 0.1 μCi and a Bicron BC-400 (equivalent to NE10A) plastic scintillation detector (3 mm ×3 in.) were used in this work.

Beta linear and mass attenuation coefficients were obtained experimentally by using two different methods.

First method was the conventional energy method which was consisted of slow signals. Slow signals have rise times (this is the time it takes for the pulse to rise from 10% to 90% of its full amplitude) on the order of hundreds of nanosecond or greater (Leo, 1987). In this method, beta particles emitted from the radioactive source produced analog signals in the detector. The detector output signals were forwarded to a preamplifier (PA, Ortec 113) and a main amplifier (MA, Ortec 440A), respectively. Pulse height spectrum of the radioisotope was recorded in a multichannel analyzer (MCA-Ortec trump 8 K). This spectrum was shown in Fig. 1.

To count the output of the main amplifier, a counter (C, Ortec 775) was used instead of the MCA. The block diagram of the circuit for this method was given in Fig. 2.

Bakelite, plexiglass, Al and Fe absorber materials in different thicknesses were placed between the detector and the beta emitter. Dimensions of bakelite, plexiglass, Al, and Fe absorber materials were 10 cm × 10 cm and thicknesses were 0.1 cm, 0.2 cm and 0.05 cm, respectively. The distance between the absorber materials and source was 2 cm. Counts per different absorber thicknesses were recorded in the counter in the interval of 240 s via timer (T, Ortec 719). Background correction was performed to obtain net beta counts for bakelite, plexiglass and Al. Attenuation graphs were plotted according to the different absorber thicknesses vs. the obtained counts in semi-logarithmic scale. From the slope of these attenuation graphs, linear attenuation coefficients of the absorbers were evaluated. After that, mass attenuation coefficients were calculated by dividing the obtained linear attenuation coefficients by the densities of the absorber materials.

In the second step of the study, timing method was used. In this method, digital fast timing signals were utilized unlike the conventional method. Fast signals generally refer to pulses with rise times of a few nanoseconds (Leo, 1987). The circuit diagram used for this method was illustrated in Fig 3.

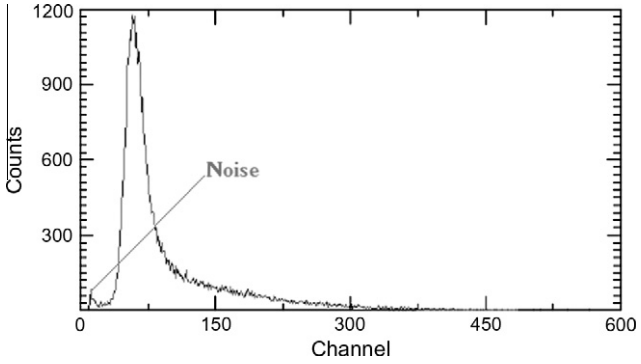


Fig. 1. Pulse height spectrum of ^{90}Sr.

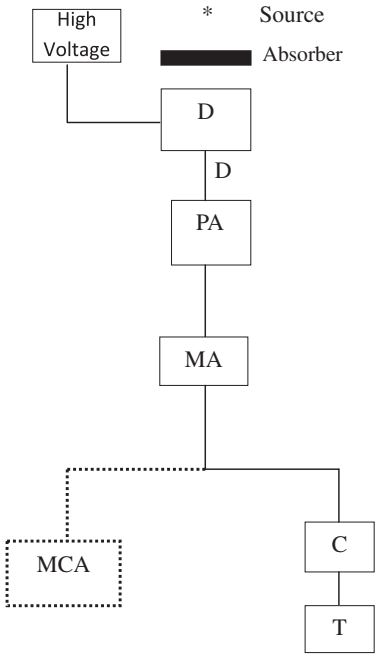


Fig. 2. Block diagram of conventional energy measurement circuit.

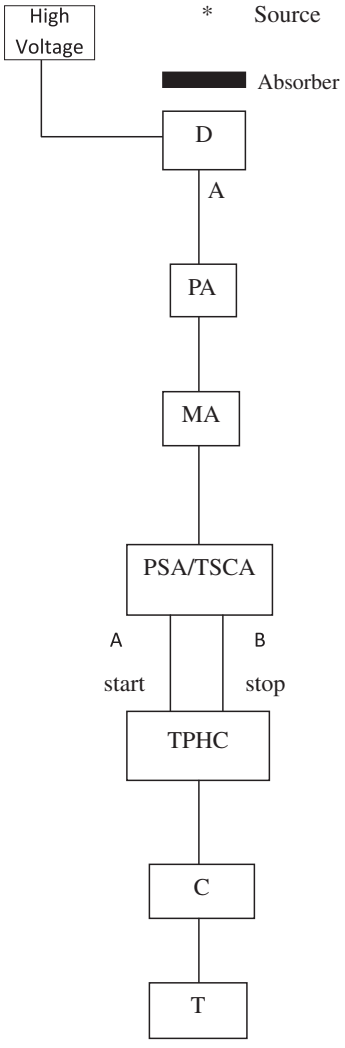


Fig. 3. Block diagram of timing measurement circuit.

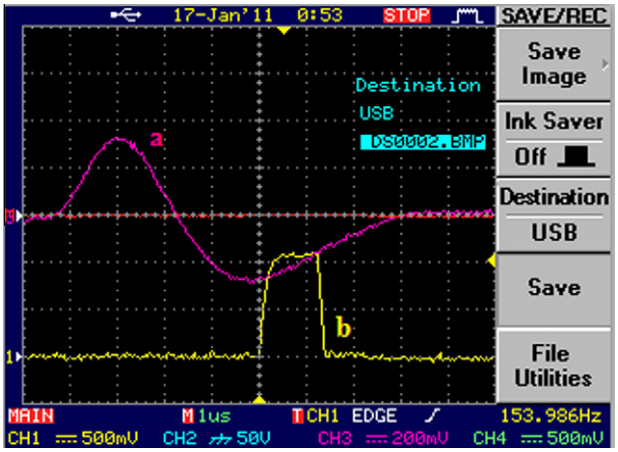


Fig. 4. Signal shapes for both methods (a) conventional energy method and (b) timing method.

As can be seen in Fig. 3, a pulse shape analyzer/timing single channel analyzer (PSA/TSCA, Ortec 552) and a time to pulse height converter (TPHC, Ortec 437A) were used in this circuit additionally. After passing through the preamplifier and the amplifier, the signals were directed to PSA/TSCA electronic module. This module gives two logic outputs at the 10% of leading edge (output A) and at the 90% of leading edge of its input signal (output B). A and B outputs of this module were connected to start and stop inputs of TPHC. TPHC is an electronic device which converts the time difference to a digital signal between its start and stop input signals. Thus, a time signal is generated on its output. These time signals were recorded in the counter in the designed second method. The experimental procedure was the same as the former method.

The signal shapes in both methods (energy and timing) were shown in Fig. 4.

Laboratory conditions such as ambient light intensity and increase in the room temperature results in the detector noise (dark noise), leading to additional counts (Leo, 1987). Therefore, whole experiment processes were acquired at constant room temperature (20 °C) and in the dark medium.

3. Results

The experimental attenuation graphs of the absorbers via conventional energy method and timing method were illustrated in Figs. 5–8.

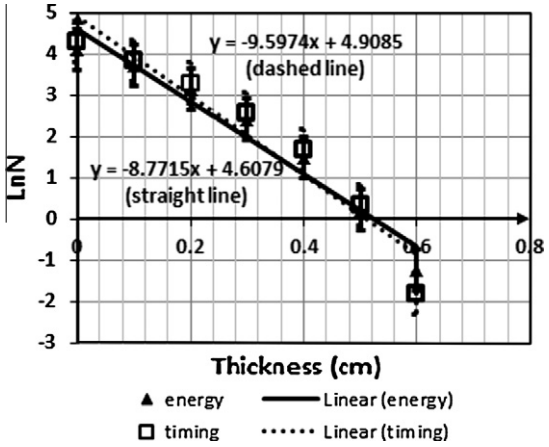


Fig. 5. Experimental attenuation graphs through energy and timing methods for bakelite.

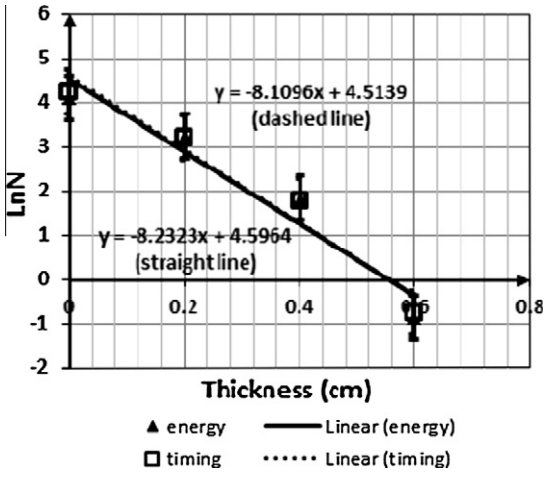


Fig. 6. Experimental attenuation graphs through energy and timing methods for plexiglass.

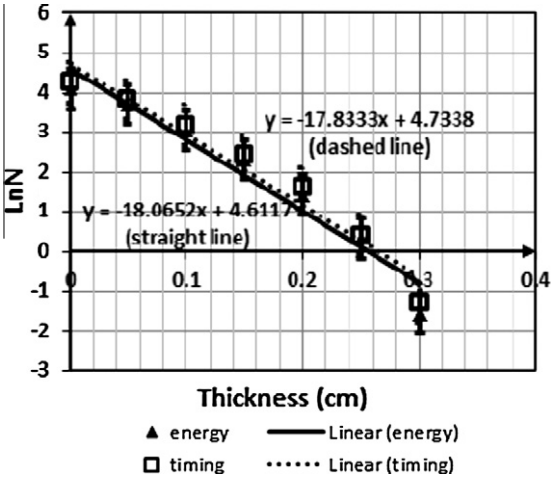


Fig. 7. Experimental attenuation graphs through energy and timing methods for Al.

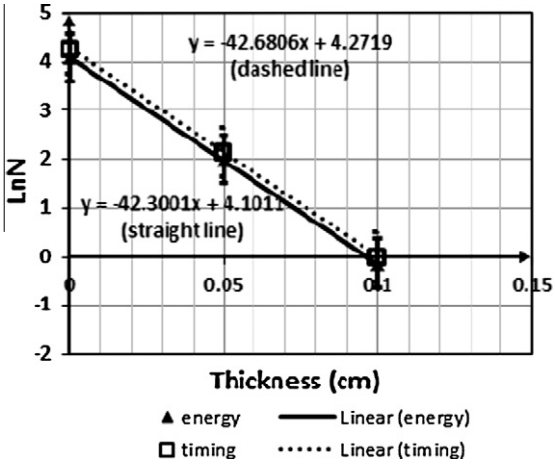


Fig. 8. Experimental attenuation graphs through energy and timing methods for Fe.

An electron colliding with other electrons loses a much greater fraction of its energy in a single collision than does a heavy ion. Its range therefore is much less (Lilley, 2001). Since maximum

Table 1
Obtained beta linear and mass attenuation coefficients with literature values.

Material	Experimental linear attenuation coefficient (cm^{-1}) (energy method)	Experimental linear attenuation coefficient(cm^{-1}) (timing method)	Linear attenuation coefficient (cm^{-1}) (literature)	Experimental mass attenuation coefficient (cm^2/g) (energy method)	Experimental mass attenuation coefficient (cm^2/g) (timing method)	Mass attenuation coefficient (cm^2/g) (literature)
Bakelite	8.771 ± 0.014	9.597 ± 0.013	–	7.017 ± 0.011	7.677 ± 0.010	–
Plexiglass	8.109 ± 0.013	8.232 ± 0.012	–	6.872 ± 0.011	6.976 ± 0.010	–
Al	18.065 ± 0.014	17.833 ± 0.005	13.5–16.2 (La Rocca and Riggi, 2009)	6.690 ± 0.005	6.604 ± 0.001	5.0–6.0(La Rocca and Riggi, 2009)
Fe	42.300 ± 0.013	42.680 ± 0.012	–	5.374 ± 0.001	5.423 ± 0.001	–

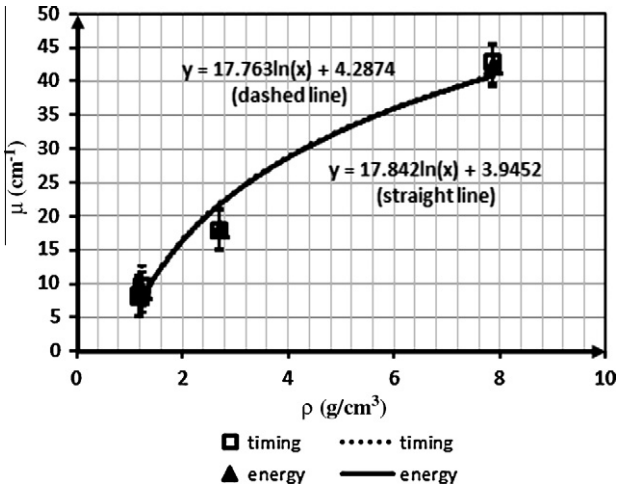


Fig. 9. Beta linear attenuation coefficients vs. absorber densities.

0.546 MeV-energy beta particles cannot penetrate 0.1 cm into Fe (http://trshare.triumf.ca/~safety/EHS/rpt/rpt_2/node23.html#-beta_r) and we did not have thinner absorbers, we could not add the data points in Fig. 8 and could not do the background correction for only this material in order not to decrease the counts.

From these graphs, beta linear and mass absorption coefficients from both methods were calculated, and the obtained results were given in Table 1.

Since the coefficients for only Al could be obtained from the literature, literature values for other absorbers were not given in this table.

As it is known, increasing absorber material density increases the possibility of the absorption of a radiation since the chances of an interaction between the radiation and the atoms of the absorber are increased. In order to test this case with the obtained results, the variation of the obtained beta linear attenuation coefficients vs. absorber densities was examined in Fig. 9. It was seen that the obtained graph was accorded with the literature (Yi et al., 1999).

4. Discussion

As shown in Table 1, the beta attenuation coefficients obtained from both conventional energy and designed timing method were found to be compatible with each other and with the literature values for Al absorber.

Linear attenuation coefficients from timing method were increased linearly with increasing absorber densities as expected. This case is shown in Fig. 9. We have concluded from this figure that timing method could be accepted as an alternative method to the conventional one since the attenuation graphs were consistent with each other.

The beta attenuation coefficients obtained from the presented work were in accordance with the offered attenuation coefficients from the spectrometer with Geiger–Mueller (G–M) detector (La Rocca and Riggi, 2003). In the literature, the offered coefficients were mostly obtained by the spectrometer with G–M counter (La Rocca and Riggi, 2003; http://www-personal.umich.edu/~ianrit/lab4.pdf; http://images.library.wisc.edu/EcoNatRes/EFacs/NAPC/NAPC05/reference/econatres.napc05.mjohnson.pdf). In addition, the range of beta particles was calculated by means of a spectrometer with NaI scintillation detector (http://helios.augustana.edu/~jvh/courses/350/SampleWriteupDRS.pdf), and self-absorption correction for beta radioactivity measurements was inspected with a gas flow proportional counter (Pujol and Suarez-Navarro, 2003). Unlike these experiments, in this study, a plastic scintillation detector which has high sensitivity and efficiency to betas was used. In addition, one of the important differences between inorganic (i.e. NaI(Tl)) and organic scintillators (i.e. plastic) is in the response time, which is less than 10 ns for the latter (response time of inorganic scintillators is ≈1 μs) and makes them suitable for fast timing measurements (Tsoulfanidis, 1987). As a result, it can be concluded that the use of this detector is increased the effectiveness of the obtained results.

In order to determine the beta attenuation coefficients of absorber materials, an alternative experimental method, namely timing method was presented in this work. Results from this method were in accordance with the results from the conventional one and the literature values. Therefore, we can conclude that the beta attenuation coefficients could be determined through the timing method.

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