Influence Of The Experiment-Geometry On The Attenuation Of Beta-Particles

Sarbast S. Ameen, Ari K. Ahmed, Rawand H. Abdullah

Department of Physics, School of Science Education, Faculty of Science and Science Education, University of Sulaimani, Iraq

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Abstract:

The influence of the geometry has been investigated; experiments have been performed for qualitative determination of the effect of Experiment Geometry On beta-ray absorption coefficient. It has been demonstrated that the reduction in the number of beta-particles transmitted through absorbers is due mainly to the process of deflection from initial direction. The investigations have been performed using the beta radioactive source $^{90}_{38}Sr(^{90}_{39}Y)$, and scintillation detector with stilbene crystal. An emperical relation for the number of beta-particles transmitted through an absorber, which accounts for the geometry and the contribution of scattered electron has been tested.

Key words: beta-radiation, absorption coefficient, beta-scattering, attenuation coefficient, beta-spectrum

Introduction

The terms "attenuation coefficient" and "absorption coefficient" are generally used interchangeably. However, in certain situations they are distinguished from the fact that when a narrow beam of radiation passes through a substance, the beam will lose intensity due to two processes: The radiation can be absorbed by the substance, or the radiation can be scattered (i.e., the radiation can change direction) by the substance. Just looking at the narrow beam itself, the two processes cannot be distinguished. However, if a detector is set up to measure radiation leaving in different directions, or conversely using a non-narrow beam, one can measure how much of the lost intensity was scattered, and how much was absorbed [1] .

In this context, the "absorption coefficient" measures how quickly the beam would lose intensity due to the absorption *alone*, while "attenuation coefficient" measures the *total* loss of narrow-beam intensity, including scattering as well. "Narrow-beam attenuation coefficient" always unambiguously refers to the latter. The attenuation coefficient is always larger than the absorption coefficient, although they are equal in the idealized case of no scattering.

In the process of transmission the beta particles are reduced in number due to deflection from the incident direction (scattering) and energy shift below threshold energy (absorption). The probability for a deflected beta particle that is recorded from the detector depends on the relative position of source, absorber, and detector (geometry of the experiment). The undefined geometry conditions in experiments, performed by different authors is a reason for reported deviations of the measured absorption coefficients, see Table (1)[1], of the exponential dependence[2] as well as for the deviation of experimental data and empirical relations[3].

Table 1: Comparison of measured elemental mass attenuation coefficient (cm^2/gm) of various beta particle energies with some calculated and measured values. Percentage deviation are shown with Thummel only [1].

Mass attenuation coefficient in cm^2/gm and Beta particle energy in MeV								
Element	**0.318 MeV**		**0.546 MeV**		**0.77 MeV**		**2.28 MeV**	
	Calculated	**Measured**	**Calculated**	**Measured**	**Calculated**	**Measured**	**Calculated**	**Measured**
Carbon	75.6302	72.2369	33.8897	30.5059	20.3405	20.7939	4.0576	3.9174
	76.4721		33.3983		19.7208		3.7363	
% Deviation		4.4867		9.9866		-2.2293		3.4546
Oxygen	83.3233	82.36	37.3370	37.1946	22.4095	23.5624	4.4703	4.1579
	81.7083		35.9271		21.3054		4.0916	
% Deviation		1.15358		0.3814		-5.1447		6.9885
Aluminum	94.3894	92.1838	42.2957	46.8412	25.3857	25.4176	5.0640	5.4062
	90.3141	86.9000	40.3876	41.1000	24.2092	24.8200	4.8097	5.0000
	82.5000	60.7000	35.9000		22.6000	18.5000	5.8000	5.5700
			37.1500		21.9200		4.2300	3.5000
% Deviation		2.3366		-10.7469		-0.1258		-6.7574

The purpose of the present investigation is:

1. The differentiation of the two main effects-scattering and absorption – to which the loss of electrons is attributed;
2. To find a general relation which describes experimental observations on absorption of beta particles at different positions (source, absorber, and detector).

1. EXPERIMENT

1.1 Contribution of beta-particle in the transmission process

The experiment for measurement of the two effects for transmission is shown in Fig.(2) . The detector is stilbene crystal ($C_{14}H_{12}$), 15mm radius ,10 mm thick, and Al window with 1mg/cm^2,the energy resolution for the 624 KeV of $^{137}_{55}Cs$ is 10%.

The resolving power of the detector was measured with the line of Conversion electrons k-shell of $^{137}_{55}Cs$, (624 KeV), and using the beta-spectrum of $^{90}_{38}Sr(^{90}_{39}Y)$ [4] ,the decay scheme and energies are tabulated in Fig.(1) and Table (2 and 3) [5] :

Table 2: The energy of beta-decays of $^{90}_{38}$**Sr**, and $^{90}_{39}$**Y** [5].

Type of Radiation, $^{90}_{38}Sr$	***E (KeV)***	$E_{max}(KeV$	***(I) %***
β^-	195.80	546.20	100
Type of Radiation, $^{90}_{39}Y$			
β^-	933.70	2281.4	99.99
β-total	933.60		100.00

Table 3 : Table of the all-probable energy decays of $^{137}_{55}$Cs [5].

Type of Radiation	*E (KeV)*	$E_{max}(KeV)$	*(I) %*
β^-	174.32	513.97	94.4
β^-	416.26	1175.62	5.60
β-total	187.87		100
Auger electron L-shell	3.67		7.20
Conversion electron k-shell	624.22		7.70
Conversion electron L-shell	655.67		1.39
Characteristic X-ray L-shell	4.47		1.00
Characteristic X-ray k_2-shell	31.82		1.96
Characteristic X-ray k_1-shell	32.19		3.60

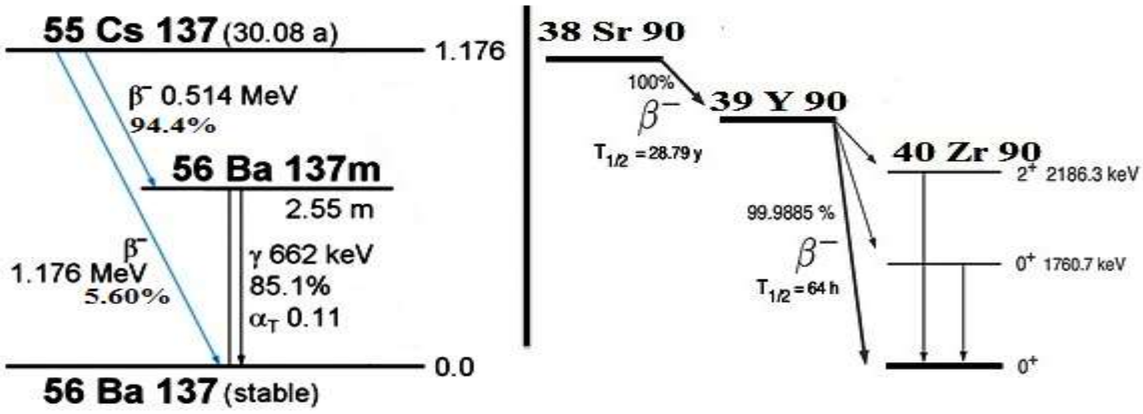

Fig. 1 : The decay diagram of ${}^{137}_{55}Cs$ and ${}^{90}_{38}Sr({}^{90}_{39}Y)$

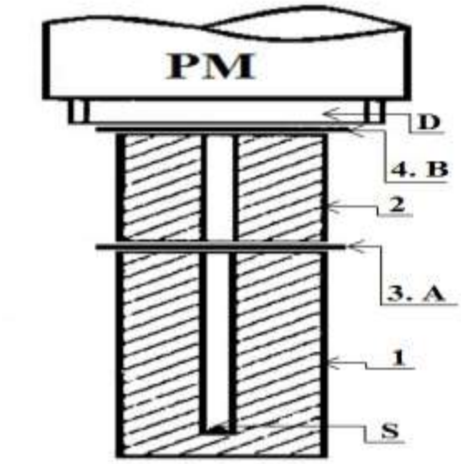

Fig.2: Experimental setup for measurement of contribution of beta-absorption and scattering. D-scintillation detector (stilbene) S-source ${}^{90}_{38}Sr({}^{90}_{39}Y)$, 1- , 2-Plastic collimator, 3-absorbers at position A and 4-absorbers at position B.The source (S) is ${}^{90}_{38}Sr({}^{90}_{39}Y)$ 2.5×10^5 Bq. and is fixed in a plastic collimator(1) with 4mm radius and collimation angle $\approx 2.5^{\circ}$. A second plastic collimator(2) with ($4mm$ radius, collimation angle $\approx 5^{\circ}$) at a distance $5mm$ from the first colimator and $5mm$ from the detector window.

The plastic absorbers (3, 4) are placed at position A ,between the collimators and at position B, between the detector and the second collimator.

The idea of the experiment is that, for an absorber at position A, all beta- particles which, are deflected at an angle $\geq 5^{\circ}$ from the initial direction donot reach the detector, which means at positionA, the reduction of the number of beta-particals is due to both effects of scattering and absorption; while for an absorber at position B all scattered beta-particles are recorded by the detector, and the reducation is due to absorption.

The experimental absorption curves for positions A and B are plotted in Fig.(3) in semilogarithmic scale. The effect of position of the absorbers on transmission differs by an order of magnitude.

Definitely the dominate effect in the reducation of the number of beta-particles is the scattering and hence the measured mass attenuation coefficients depend on the relative position of *absorber and detector*.

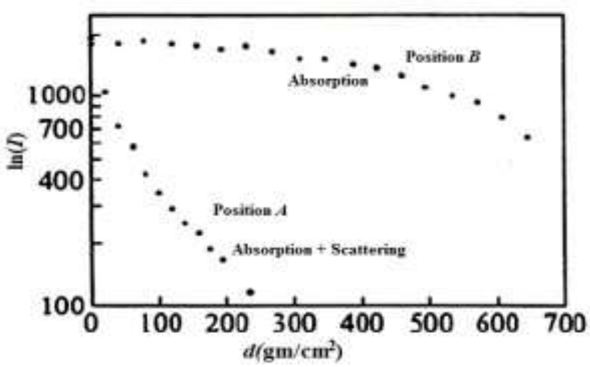

Fig.3: Experimental absorption curves for positions A and B.

The recorded beta-spectra (Fig.4) confirm the conclusion that the reduction of the number of beta-particles is due to scattering in position A and predominatly to absorption in position B for thick absorber .

The beta-source is also thick, and therefore the radiation from ${}^{90}_{38}Sr$ is almost totally absorbed and only the radiation from ${}^{90}_{39}Y$ reaches the detector.

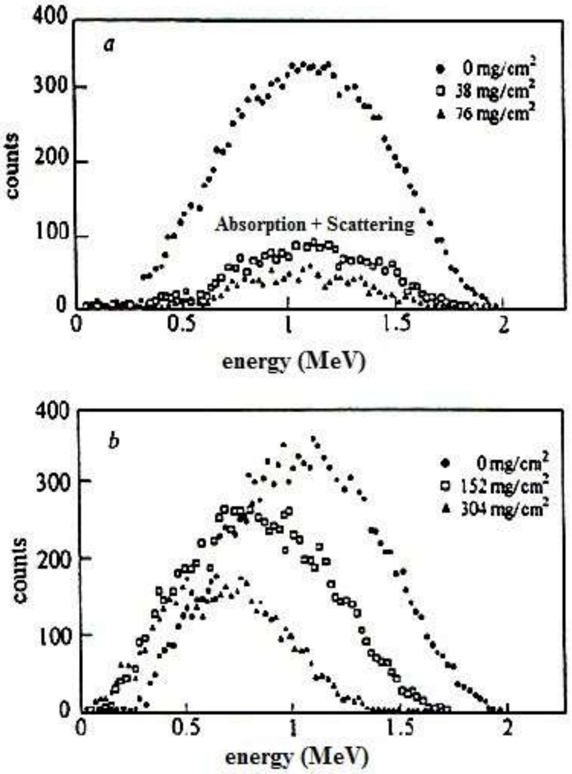

Fig. 4 : Recorded beta- spectra for positions A (a) and B (b) for different absorber thickness. [The Beta- Source is also thick and therefore the radiation from ${}^{90}_{38}Sr$ is almost totally absorbed and only radiation from ${}^{90}_{39}Y$ reaches the detector.]

2.2 Influence of Experiment geometry

The experiment in section 2.1 shows that adequate description of transmission experiments can be achieved if the process of scattering is properly accounted for. The experimental setup which is used in the second set of the experiment is shown in Fig.(5) .

The arrangement in Fig.(5a) has been used for measurement of the absorption coefficient for the case of collimation of incident radiation. The collimator 1 is fixed in the middle of the distance (*source and detector)* and the absorber 2 is placed on the collimator. The middle position was chosen as a typical position in many experiments, although the authors in ref. [2] show that the absorption coefficient depends on the position (*absorber and detector).* Since the major contribution to the attenuation coefficient comes from scattering, the value of absorption coefficient decreases when the absorber is close to the detector and increases with the distance (*absorber, detector).*

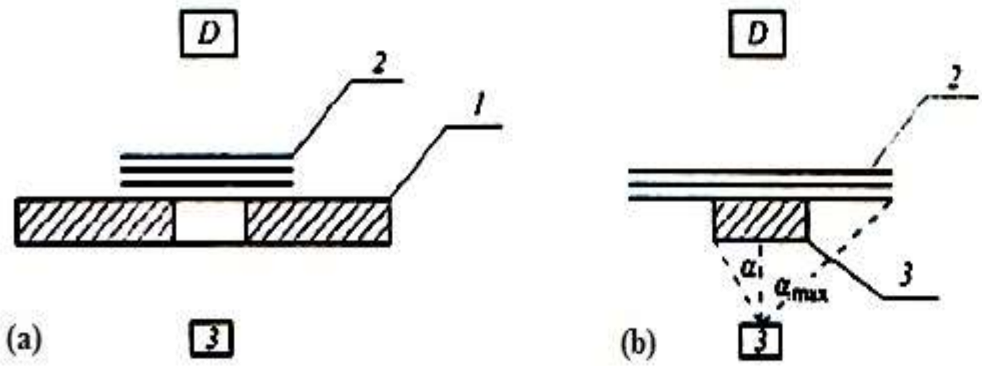

Fig. 5 : Experimental setup for measurement of absorption coefficient (a) for the case of collimation of the incident radiation, (b) measurement of scattered radiation from α to α_{max}.

The arrangement in Fig.(5b) is for measurement of the contribution of scattered in the absorber beta- particles, which hit the detector. The detector is shielded by a circular screen (3), with radius R, from beta- particles, which hit the detector directly **or** are scattered at very small angles in usual transmission experiments. Thus in the second case, only the contribution of the scattered beta- particles is measured from absorbers (2) ,which are mounted on the circular screen. The differential contribution, or the beta- particles which are scattered from the circular strip *(R to R +ΔR)* is calculated by subtracting data for a screen with diameter *R* to *R+ΔR* from data for screen with diameter R.

The experiments are performed in air with a Stilbene ($C_{14}H_{12}$) Scintillation detector with a thin Al window and 10% energy resolution for the 624Kev of $^{137}_{55}$Cs [4][5]. The detector and the source are surrounded with plastic screens. All metal parts are covered with either plastic or thick paper in order to reduce background scattering. The *(source,detector)* is approximately 15 cm, and the scattering from about 18 $mg/\,cm^2$ air is inevitable. The absorbers are made from paper.

The $^{90}_{38}Sr(^{90}_{39}Y)$ source was with very high activity (2.5×10^5 Bq) and therefore the scattering experiments were perfomed within resonable periods,(5 to 30 $minute\,/\,point$). The source was thick and the emitted spectrum is distorted and differs from the theoretical beta-spectra. The experimental spectra measured with stilbene detector and absorbers with different thicknesses and a spectrum of a thin $^{90}_{38}Sr(^{90}_{39}Y)$ [6], with the same detector shown in Fig.6 . The great difference in the end-point beta –energy is not a strong argument for choosing a source, since it has been shown that for an appropriate scaling (e.g. in units of maximum range) beta -ray doses are independent of maximum energy [7]. It is expected that for suitable absorber scaling the number of beta-particles will independent of the maximum energy.

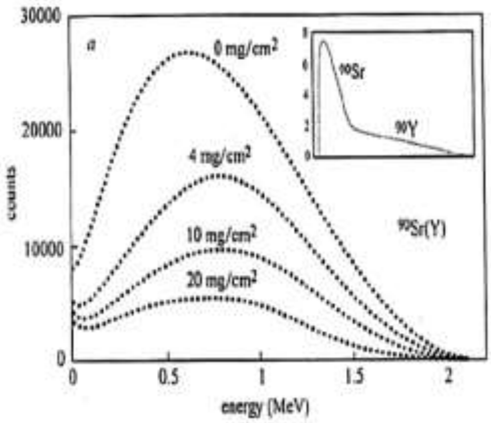

Fig.6 : Experimental spectrum of the used source $^{90}_{38}Sr(^{90}_{39}Y)$ measured with a stilbene detector with different absorbers, and the spectrum of a thin source $^{90}_{38}Sr(^{90}_{39}Y)$ with the same detector.

2.3 Energy transfer for transmission and scattering

When an ionization chamber is used for detection of electrons, the relevant quantity is incident on the detector, energy per unit time. Except number of electrons the spectroscopic detectors provide the option of calculation of the transmitted or scattered energy and also the average energy of the beta-particles.

The transmitted energy $E(d)$ calculated by [8]:

$$E(d) = c\sum_{i=1}^{i_{max}} iN_d(i) \qquad (1)$$

Here c is calibration constant $KeV\,/channel$, i is the channel number, i_{max} is the maximum number of channels and $N_d(i)$ *is* the recorded spectrum of transmitted or scattered electrons for thickness d.

Then the average energy is also calculated by numerical integration:

$$E_{av}(d) = \frac{c\,\sum_{i=1}^{i_{max}} i\,N_d(i)}{\sum_{i=1}^{i_{max}} N_d(i)} \qquad (2)$$

The average energy and the energy absorption coefficient were also measured.

2. Results and Discussion

The measured absorption dependences for the case of collimation are shown in Fig.(7) . The experimental curve shows that the dependence is not necessarily exponential. The observed absorption curve depends on the beta-spectra shape and therefore the assumed exponential (law) is only suitable approximation.

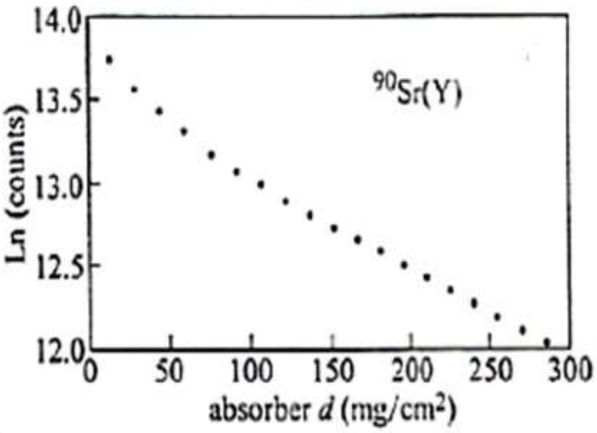

Fig.7 : Experimental absorption curve for $^{90}_{38}Sr(^{90}_{39}Y)$.

Averaged absorption coefficients μ_{col} (a fit over all experimental points) has been used in the further calculations.

The intensity of scattered radiation is shown in Fig.(8) . The experimental data fit very well to the expression of the type $(ln\, I_0 \,/\, I) * (\mu_{col}.\, d)$.

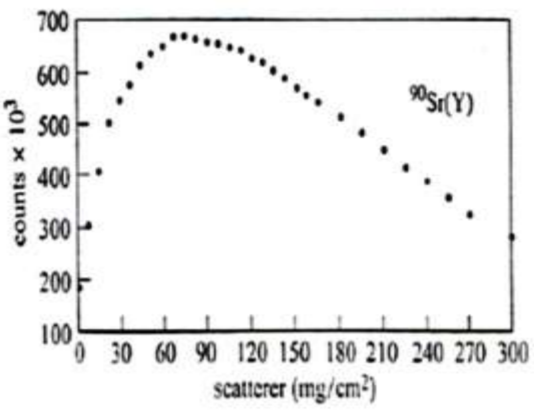

Fig.8 : Experimental curve for intensity of scattered radiation from $^{90}_{38}Sr(^{90}_{39}Y)$.

For geometries which differ from the case of good collimation, we assumed that the experimental data can be fitted with an expression which accounts for transmitted and scattered radiation (The emission angles are between 12° and 65°):

$$I(d) \;=\; I_0 \,\{\, e^{-\,\mu_{col}.d} \;+\; b(\,\omega).\, \mu_{col}.\, d\;\; e^{-\,\mu_{col}.d} \,\} \qquad (3)$$

Here $I(d)$ is the intensity of the detected radiation versus the absorber thickness d for poor collimation (bad geometry), $b(\,\omega)$ is the coefficient which accounts for the contribution of scattered radiation that depends on the emission and scattering angles **(**for absorber in the middle of the distance (*source, detector)*these angles coincide**)**,(ω)is the emission angle for absorber in the middle of the distance. It assumed that the scattered radiation depends on the thickness d as $\mu_{col}.\, d\;\; e^{-\,\mu_{col}.d}$.

The fitted values of the coefficient $b(\,\omega)$ for experiments with poor collimation are shown in Table 4. The average absorber coefficient (cm^2/gm) for the case of good collimation and poor collimation are presented in Table 5.

Table4:Contribution of scattered radiation,coefficient b(ω), for different emission angles

Angle ,deg	$b(\,\omega)$
0-12	0
12-22	0.23
22-40	0.45
40-65	0.50

Table 5: absorber coefficients for a case of good collimation and without collimation (cm^2/gm)

Collimation angle	Absorber coefficients
12^0	7.85
65^0	4.40

An important consequence of the empirical expression, in eq.(3), is that the measured absorption coefficient increases as the angle of collimation decreases and its highest value is for the case of very good collimation. Actually for all cases which differ from "good geometry" the researchers assume that the relation in eq. (3) is equal to ($I_0\, e^{-\mu_{col}.d}$) and the experimental value of the measured absorption coefficient μ_{col} is less than μ_{col} .The results from the experiments on energy transfer are shown in Fig.9 , for transmission (a) and for scattering (b). The average energies are normalized to the average energy without any absorber,$E_{ave}\ (0)\ =\ 0.820\ MeV$, average energy for ${}^{90}_{38}$Sr(${}^{90}_{39}$Y) for thin source is $196\ KeV\ (Sr)$ and $931\ KeV$ for(Y)[6].

For transmission there is a slight increase of normalized average energy due to absorption and scattering of the low energy electrons in the spectrum for thin absorbers. Further the energy shift and scattering of the rest of the electrons overcome and the normalized average energy decreases.

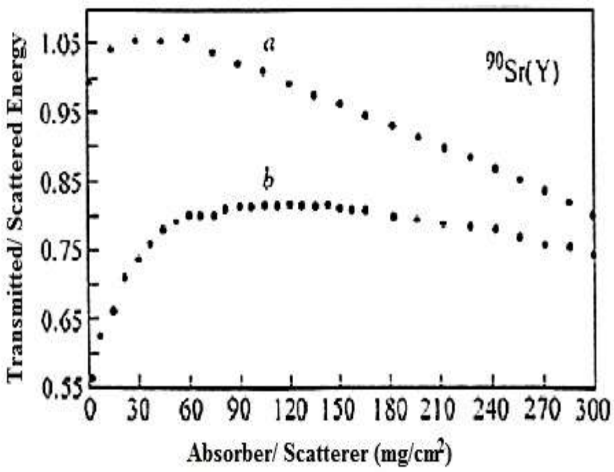

Fig. 9: Experimental results for the normalized average energy for transmission (a) and for scattering (b)

The energy transfer for scattering, in Fig.(9b) does not start from zero, since there is inevitable scattering in the air.

3. Conclusion

The experiments performed is a clear demonstration of different aspect of the values of absorption coefficient, the (source and absorber) and (absorber and detector) positions can vary significantly the values of absorption coefficient and the total attenuation coefficient

The experiments in section 2.1 show that the main contribution to the effect of reduction of number of beta-particles in the process of transmission is scattering or deflection of beta-particles. This observation explains the effect of the influence of "Experiment-geometry" or the collimation on the absorption coefficient.

For the case of experiments without collimation, the contribution of the scattered from the absorber beta-particles are accounted for with a relation of a type (3).

Since the absorption coefficients depend essentially on the "geometry of the experiment" , the measured values in handbooks should be accompanied by information about the conditions of experiments which are degree of collimation and ratio of the distance (source –absorber)and (absorber- detector).

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