Determination of Atomic Number Exponent for Elemental Absorber at Am– 241 Energy in X–Ray Attenuation Experiments

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Abstract

In X-ray absorption experiment, the dependence of the photoelectric absorption cross-section varied with atomic number *Z*. In this paper, the dependence on *Z* of the cross – section or coefficient of photoelectric absorption is first evaluated from published data for (20) elements ranging from *Al–Sn*, and then the cross–section for *Fe* is obtained experimentally by measuring the X-ray intensity with and without the *Fe* absorber and compared with the theoretical value, the variation of the photoelectric absorption coefficient (μ/ρ_m) showed less dependence on *Z* for the two tested of *Z* regions. This is because of the inclusion of mass density (ρ_m) of the absorber in the coefficient. The values of m obtained in the present work increases linearly with energy for both ranges of elements.

Keywords: Photoelectric effect, Cross section, Mass absorption coefficient, Arial density.

Introduction

The characteristic of X-ray absorption have an important role in radiography. Nearly every one has benefited from the properties of the X-ray absorption cross-section [1,2]. Most people have had the experience of holding a photographic film inside their mouth to record a shadow picture of a suspicious tooth. The ability to take a radiograph, relies on two basic aspects of the absorption process. The first is that X-ray absorption depends on the penetrating power of the X-ray beam, which for a given element varies approximately as ($1/E^3$). The second is that X-ray absorption depends on the atomic number Z to the fourth power [3].

However, Van Dyck and Van Grieken noticed that the absorption coefficient varies roughly with *Z* to the third power for $Z \leq 26$ [4] Further, Greening [5] stated that photoelectric cross-section per atom varies very roughly as *Z* to the fourth power, but the photoelectric component of the mass attenuation coefficient varies approximately as *Z* to the third power.
It seems desirable here to find out explicitly that cross- section or coefficient of photoelectric absorption varies with (*Z*) for photon energies ranging from 30 to 150 keV.

Theoretical Calculation

Photoelectric absorption is sometimes referred to as true absorption. This process is the dominant contribution to the absorption cross-section whenever the photon energy is much less than the rest mass of the electron, mc^2 =511 keV [3]. Am –241 source is suitable since the main gamma ray energy emitted from it is 59.5 keV where the photoelectric effect is dominant.

Photoelectric effect is most likely to occur when the photon energy is slightly greater than the binding energy of the electrons in, say K-shell. Clearly, this condition cannot be achieved simultaneously for a number of different *Z* absorbers. However, for the purpose of evaluating the dependence of photoelectric absorption cross-section σ_a or coefficient on *Z*, photons of 30, 60, 80, 100 and 150 keV are assumed to strike sequentially twenty absorbers ranging from *Al* to *W*.

In transmission experiment, the X-ray intensity (*I*) transmitted through an absorber of thickness *t* in *cm* is given by Beer-Lambert's Law [6]:

$$\mathrm{I} = \mathrm{I}_0 \exp(-\mu t) = \mathrm{I}_0 \exp\left[-(\mu/\rho_m)\rho_m t\right]$$

or $$\ln\frac{\mathrm{I}_0}{\mathrm{I}} = (\mu/\rho_m)\rho_m t = \mu t \quad ....(1)$$

Where I_0 is the incident X-ray intensity, μ is the linear absorption coefficient in cm^{-1} and μ/ρ_m is the photoelectric mass absorption coefficient in cm^2/g. The photoelectric absorption cross-section σ_a in barns/ atom is related to μ through [3].

$$\mu = \left(\frac{\rho_m N_A}{A}\right)\sigma_a \quad \text{.......................................(2)}$$

Where ρ_m, N_A and A are mass density, Avogadro's Number and the mass number respectively.
Eliminating μ between equations (1) and (2) and solving for σ_a, one obtains:

$$\sigma_a = \frac{\ln\frac{I_0}{I}}{\left(\frac{\rho_m N}{A}\right) t} \quad \text{..(3)}$$

Values of σ_a for the absorbers Al–W were taken from Storm and Israel [7]. Table (1) shows some of these values as an example:

Table (1)
Photoelectric absorption cross- section and coefficient (Al–Fe) at 60 keV [7].

Z	σ_a ***(barns / atom)***	μ/ρ_m ***(cm²/g)***
13	4.23	0.0944
14	5.95	0.1275
15	8.16	0.1586
16	10.9	0.2047
17	14.2	0.2412
18	18.4	0.2775
19	23.3	0.3588
20	29	0.4358
23	53.3	0.6300
26	89.8	0.9680

A graph of σ_a versus Z is shown in Figure1 for Z = 13 to 26 and for $Z \geq 29$ for photon energy 30, 60, 80, 100 and 150 keV respectively. For the range of cross–section values used, an equation of the following form was found suitable to fit the data in Fig.(1).

$$y = C(X)^m \quad \text{.. (4)}$$

Where y represents σ_a, C is constant, X is the atomic number Z and m is the order of Z. Value of m is shown in Fig.(1).

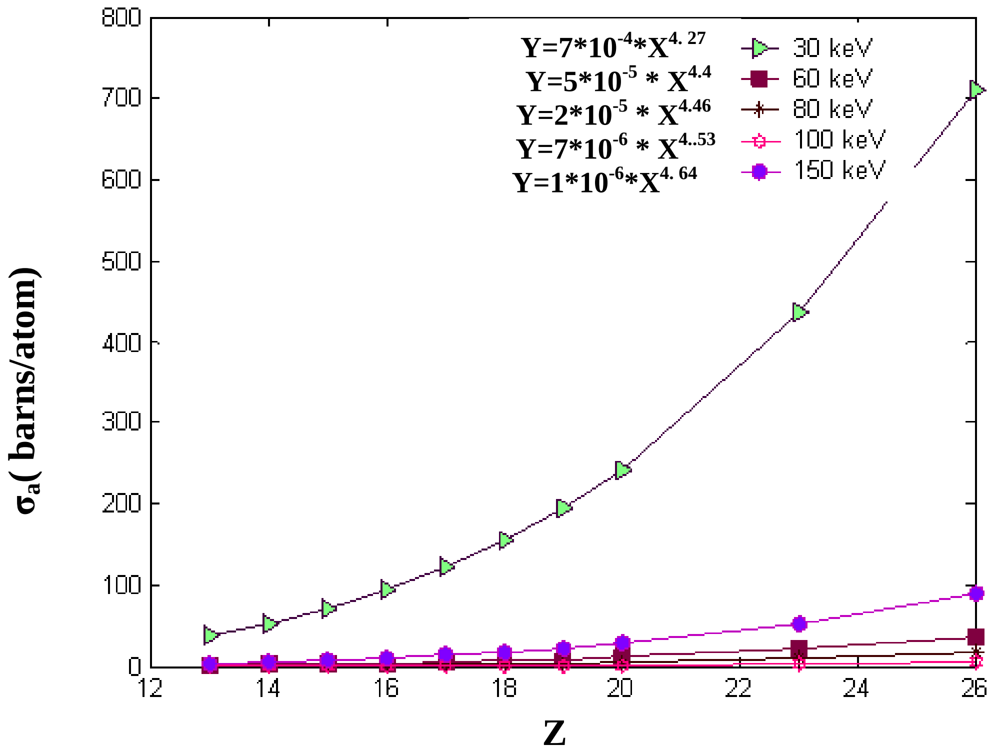

Fig.(1-a) (σ_a) versus atomic number (Z) for 30 , 60, 80 ,100 , and 150 keV energy at Z=13-26.

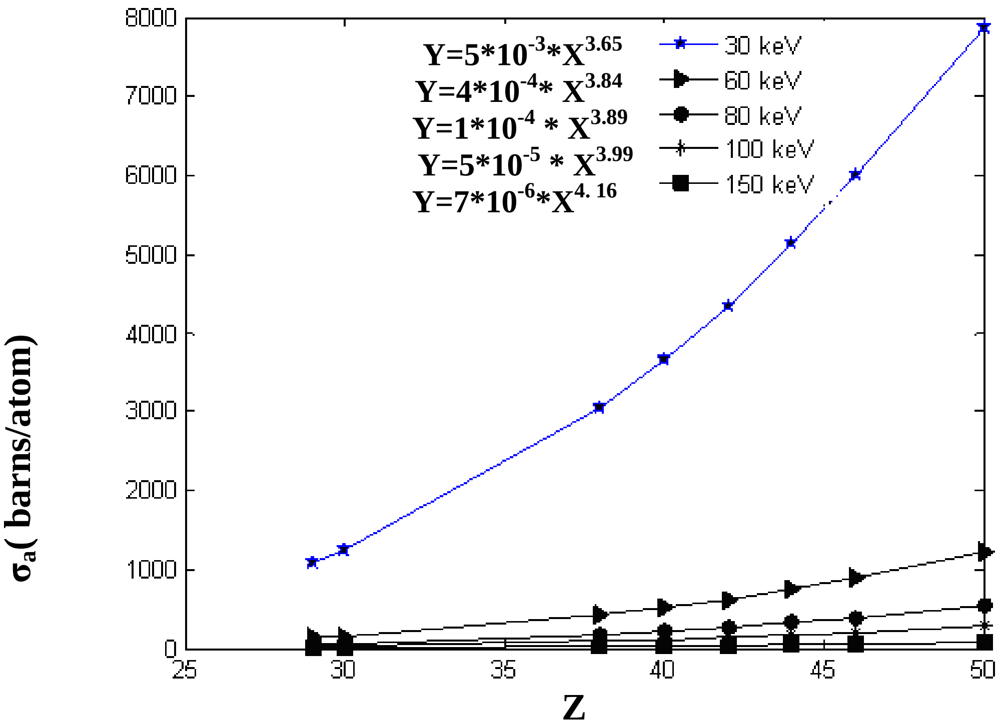

Fig. (1-b) (σ_a) versus atomic number (Z) for 30, 60 , 80 ,100 , and 150 keV energy at $Z \geq 29$.

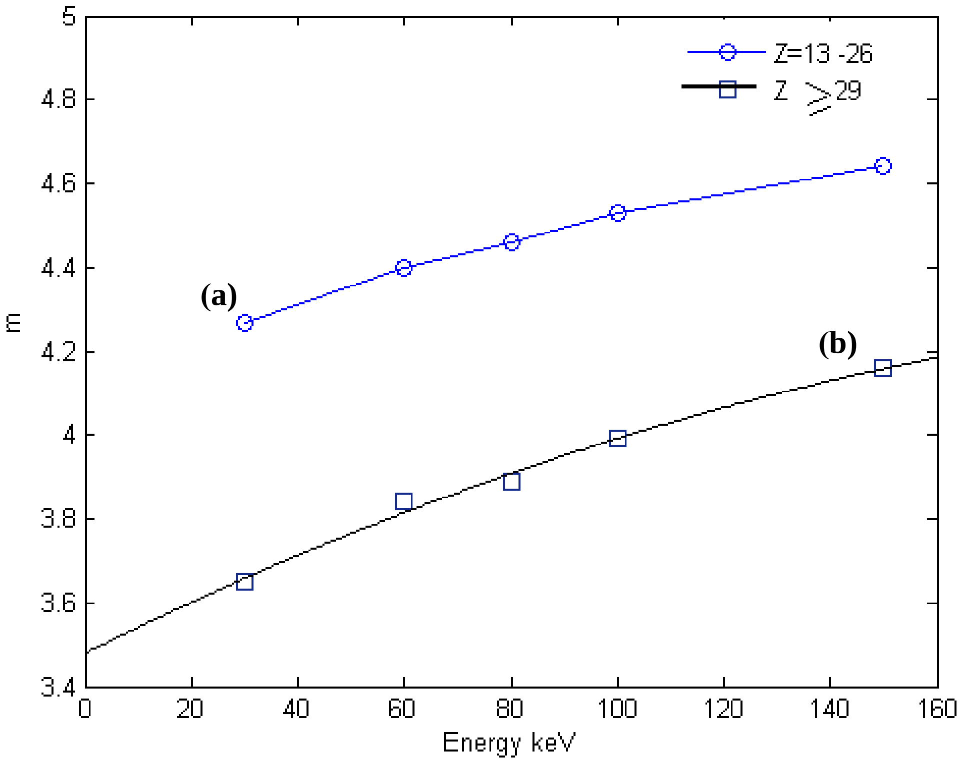

Fig.(2) (m) versus energy at (a) Z=13- 26 (b) Z ≥ 29 .

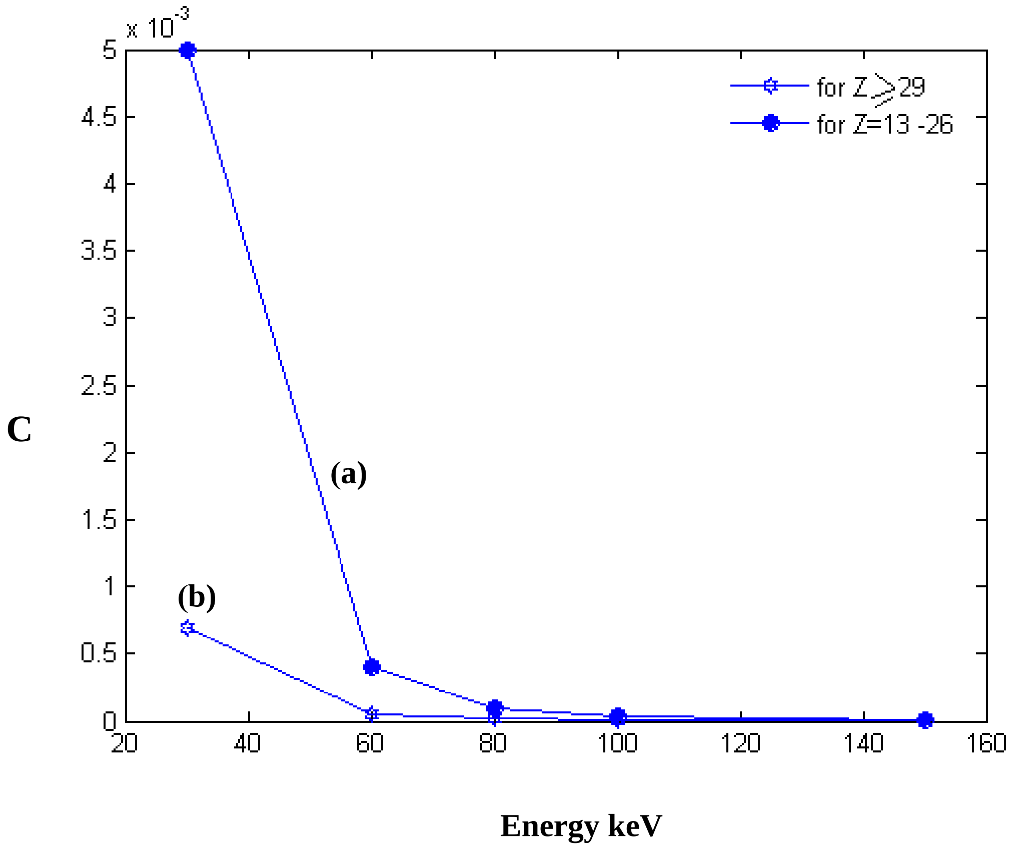

Fig.(3) (C) versus energy at (a) Z=13- 26 (b) Z ≥ 29.

Table (2) shows these values of m order of Z with their averages.

Table (2)
Values of m, the order of Z obtained from Figure (1).

Z	***Values of m***					
	30 keV	***60 keV***	***80 keV***	***100 keV***	***150 keV***	***Average m***
13 to 26	4.27	4.4	4.46	4.53	4.64	4.46
≥ 29	3.65	3.84	3.89	3.99	4.16	3.90

Analyzes of the data tabulated in Table (2) ,indicate that the order of atomic number m varies with the energy follows a linear dimension for each range of elements as shown in Fig.(2), the values of the constant C obtained by the fitting processes showed that its value decreases exponentially with energy for both ranges of elements as shown in Fig.(3). Errors associated with the theoretical evaluation of *m* are attributed mainly to the photoelectric cross–section data, where 10% is quoted for the region where photoelectric interaction dominates, [7]. The uncertainty in the order of atomic number *m*
Was found to be about 0.7%. So, σ_a varies as $Z^{4.46 \pm .03}$ for *Z* =13 to 26, and σ_a varies as $Z^{3.9 \pm .03}$ for $Z \geq 29$.

Similar curves to those in figures 1 are obtained for the photoelectric absorption coefficient (μ/ρ_m) in cm^2/g versus *Z* but with smaller values of *m*. For example, for 60 keV

(μ/ρ_m)varies as $Z^{3.31 \pm .03}$ for *Z* = 13 to 26 and (μ/ρ_m)Varies as$Z^{2.72 \pm .03}$ for $Z \geq 29$

Experimental and Results

The experimental part is aimed towards measuring the experimental value of $\sigma_{a(\text{exp})}$. For certain element and energy, and comparing it with the theoretical value $\sigma_{a(\text{theor})}$. That yielded an order of *Z* which agrees with the literature value.

The radioactive source used was americium -241 half life (433 year), principle α – energy 5.442 (12.5%), 5.484 (85.2%), and γ - energies 59.5 keV (35.5%), X-ray energies 11.9-22.2 keV, Gamma ray were measured by using "2×2" *NaI* (*Tl*) scintillation detector attached by photomultiplier tube and spectroscopy displayed on CANBERRA Multi–Channel Analyzer MCA Model 8503. The measurements were done with and without *Fe* absorber. After subtracting the background, value of (I_0/I) was found to be 34.2 for *Fe* absorber whose mass per unit area equals to 4563 mg/cm^2.

Substituting (I_0/I) in equation (3), the cross–section $(\sigma_a)_{\text{exp}}$. is obtained. The constants (ρ_m) and (A) for iron were taken from [8].

The error related to I_0 and I was found using $(N \pm \sqrt{N})$, where *N* is the number of count. Therefore, the value of $\sigma_{a(\text{exp})}$ with the associated experimental error will be,

$\sigma_{a(\text{exp})}$ = (71.8 ± 14) × 10^{-24} cm^2 for Am-241 ,γ-ray=59.5keV

By comparison with , $\sigma_{a(\text{theor})}$ = (89.8 ± 8.89) × 10^{-24} cm^2 for 60 keV photons incident on *Fe* absorber, (Table (1)). An agreement between the two values within the error is clear.

Conclusions

The dependence of the photon absorption cross–section on atomic number *Z* was evaluated for two ranges of *Z* and for five photon energies namely 30, 60, 80, 100 and 150 keV. The values of m obtained in the present work insist that m is not fixed for all elements as given by Greening [5], but increases linearly with energy for both ranges of elements, but changed slowly with the photon energy incident on the absorber. (Table (2)) displays *m* values explicitly for photon energy in the range 30 to 150 keV. A slight increase in *m* is clear as the photon energy is increased for absorbers in the range *Z* = 13 to 26. Similar increase in *m* is noticed for *Z* ≥ 29. However, values of *m* for *Z* ≥ 29 are smaller than those corresponding values for Z = 13 to 26 by about 14% for all the energies used.

The variation of the photoelectric absorption coefficient (μ/ρ_m) showed less dependence on Z for the two regions of Z tested. This is because of the inclusion of mass density (ρ_m) of the absorber in the coefficient.

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الخلاصة

يتغير اعتماد المقطع العرضي للامتصاص الكهروضوئي في تجارب امتصاص الأشعة على العدد الذري Z. تم في هذا البحث تضمن اعتماد المقطع العرضي أو معامل الامتصاص الكهروضوئي على العدد الذري من البيانات المنشورة أولا لعشرين عنصر تتراوح $Al - Sn$ حيث تم الحصول على المقطع العرضي للحديد تجريبيا بقياس شدة الأشعة السينية بدون وبوجود الحديد ومقارنة مع القيم النظرية، مقدار التغير في معامل الامتصاص الكهروضوئي (μ/ρ_m) يظهر أقل اعتمادا على Z بالنسبة لمنطقتي Z التي تم اختبارهما. هذا بسبب الأخذ بنظر الاعتبار الكثافة الكتلية (ρ_m) للمادة الماصة في المعامل وتزداد قيم m التي حصلنا عليها خطيا مع الطاقة لكلا مديات العناصر المستخدمة.