Calculation the Effective atomic number , electron density, Half value layer and mean free path of Iron, Copper and Silver.

***Dr. Sabah Mahmoud Aman Allah *Dr. Rafa Abdala A. **Asmaa Ahmad Aziz**
***Ahmad Mohmad Aboead.**
*Physics Department –College of Sciences –Tikrit University P.Box.O:42 -salahdin Iraq.
**Physics Department –College of Education –Tikrit University P.Box.O:42 -salahdin Iraq.

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Abstract

Effective atomic number (Z_{eff}) ,electron densities (N_{el}) , half value layer(HVL) and mean free path (*mfp*) has been determined with the help of semi-empirical relations for Iron, Copper and Silver at energy range 0.36 to 1.33MeV .The study proved the coincidence of the experimental and theoretical values of effective atomic number while the electron densities and mean free path are found nearly remain constant as a function of energy.

Keywords : Effective atomic number ,electron density, half value layer ,mean free path ,iron, copper, silver ,cross section, mass attenuation coefficient, WinXCom.

حساب العدد الذري الموثر والكثافة الالكترونية وسمك النصف ومعدل المسار الحر للنحاس و الحديد والفضة

***د. صباح محمود أمان الله *د. رافع عبدالله عباد ** اسماء احمد عزيز * احمد محمد عبيد**
*قسم الفيزياء –كلية العلوم –جامعة تكريت –ص.ب: 42 - صلاح الدين-العراق
**قسم الفيزياء –كلية التربية–جامعة تكريت –ص.ب: 42 - صلاح الدين-العراق

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الخلاصة

في هذا البحث تم حساب العدد الذري الموثر (Z_{eff}) ,الكثافة الالكترونية (N_{el}), سمك النصفHVL , ومعدل المسار الحر (*mfp*) للنحاس و الحديد والفضة باستخدام عدد من المعادلات شبه التجريبية ولمدى الطاقات 0.36MeV- 1.33 MeV –لقد بينت الدراسة تطابق القيم العملية والنظرية للعدد الذري الموثر وان الكثافة الالكترونية وسمك النصف ومعدل المسار الحر تقريبيا تبقى ثابتة كدالة لطاقة الساقطة .

الكلمات الدالة :العدد الذري الموثر, الحديد – النحاس- الفضة ,الكثافة الالكترونية ,سمك النصف ,معدل المسار الحر ,مساحة المقطع ,معامل التوهين الكتلي ,ويندوز اكس كوم.

Introduction

The photon interactions through matter is of wide interest in industrial ,medicine ,agriculture ,medical radiation dosimetry and radiation shielding [1]. The parameters determining the constitutive structure of material and the support the areas are the mass attenuation coefficient, effective atomic number, effective electron density, and photon mean free path are fundamental parameters to study the interaction of photon with matter. These parameters are important for solving various problems in radiation physics [2]. The most relevant parameter determining the photon interaction in the material is the mass attenuation coefficient (μ/ρ) [3]. It follows from the above that (μ/ρ) is a basic quantity used in calculations of the penetration of photons in biological, shielding and other materials [4]. While the extensive and accurate data sets are available for elements [5–8], studies in composite materials such as different alloys are meager due to difficulty in procuring targets in suitable form for experiments [9]. In composite materials like alloys, it is quite reasonable to define an effective atomic number, Z_{eff} to describe the properties of an alloy in terms of an equivalent element. Effective atomic number of an alloy, which is a very useful parameter for many fields of scientific applications, is similar to that atomic number of elements. However, on the basis of Hine's expression [10] that the effective atomic number of a material composed of several elements cannot be expressed by a single number, it can be concluded that it is an energy-dependent parameter due to different partial photon interaction processes with matter for which the various atomic numbers in the material have to be weighted

differently. Several investigators have contributed to find the effective atomic numbers in different alloys [11–14]. However, these studies seem to be restricted to a limited energy range and also most of them have focused on interpolation procedures and semi empirical relations. Thus, there needs to be some confirmation of the results in a continuous energy range by using a direct method.Also, while determining the effective atomic number of an alloy it should be reasonable to take into account the absorption edges of elements constituting the alloys where there exists more than a single effective atomic number. From this point of view, we found it interesting to study the photon interaction in terms of effective atomic number for various alloys in an extended energy range including the K-absorption edges of elements present in the alloys. In the present study, the effective atomic numbers electron density ,mean free path and half value layer of various stainless steel have been calculated for total photon interaction at photon energies from 0.36 MeV to 1.330 MeV using mass attenuation coefficients from WinXCom computer program [7,8].

Methodology

2-1The mean free path (*mfp)*

The average distance between two successive interactions, called the photon mean free path (*mfp*) is given by [2].

$$mfp = \frac{\int_0^\infty x e^{-\mu x} dx}{\int_0^\infty e^{-\mu x} dx} = \frac{1}{\mu} \quad \text{.....(1)}$$

Where the mass absorption coefficient μ_m is defined as

$$\mu_m = \frac{\mu}{\rho} \quad \text{.....(2)}$$

Where □ is the mass density of the absorber.

2-2The Half Value Layer (*HVL*)

The following relation relates half value layer to linear attenuation coefficient[15]:

HVL = $0.693 / \mu$ ……(3)

The units of HVL is g/cm^2.

2-3The mass attenuation coefficient(μ/ρ):

The mass attenuation coefficient (μ/ρ) is a measure of the average number of interactions between incident photons and matter that occur in a given mass-per-unit area thickness of the material encountered. In other words, the mass attenuation coefficient (μ/ρ) for any chemical compound represent a measure of the probability of interactions of incident photons with the thickness (g/cm^2)of the target material is of importance in dosimetry ,radiography ,radiation shielding ,computerized tomography ,etc.[3,4] .The quantity (μ/ρ) given by [16,17]:

$$(\mu/\rho) = w(\frac{\mu}{\rho}) \quad \text{.....(4)}$$

Where w is the weight of the element. Due to the contribution of different effects in the attenuation process. Hence, the total attenuation coefficients may be expanded as[18]:

$$\mu = \omega + \tau + \sigma + \kappa \quad \text{.....(5)}$$

Where, ω: the probability of coherent scattering τ: the probability of photoelectric absorption, σ: the probability of Compton scattering, κ: the probability of pair production.

2-4The total atomic cross-sections (σ_a)

The total atomic cross-sections (σ_a) for materials can be obtained from the calculated values of (μ/ρ) using the following relation[2]:

$$\sigma_a = \frac{N}{N_A}(\mu/\rho) \quad \text{.....(6)}$$

Where N is the atomic mass of materials and N_A is the Avogadro's number.

2-5The total electronic cross-section (σ_e)

The total electronic cross-section (σ_e) is given by the following formula[19]:

$$\sigma_{el} = \frac{\sigma_a}{Z_{eff}} \text{.....(7)}$$

The units of σ_{el} is cm^2/g.

2-6The effective atomic number (Z_{eff})

The common method of obtaining the effective atomic number(Z_{eff}) of the material consisting of different elements based on determination of the total attenuation cross section of atomic σ_a and electronic σ_{el} respectively ,which they are related through the following relation[19]

$$Z_{eff} = \frac{\sigma_a}{\sigma_{el}} \text{.....(8)}$$

The effective electron number or electron density ,N_{el}, (number of electrons per unit mass) can be given by[19]:

$$N_{el} = \frac{(\mu/\rho)}{\sigma_{el}} \text{.....(9)}$$

The quantity N_{el} is a dimensionless factor.

Results and Discussion

Cross sections, effective atomic numbers , electron densities at half value layer in additional to mean free path ; have been calculated with respect to the mass attenuation coefficients. The experimental data of mass attenuation coefficient has been taken from [1]. Table(1) contains the experimental and calculated values of μ/ρ by using computer code of XCOM at photon energies of 0.36Mev-1.33Me .The XCOM databases run on a personal computer and prepared by combining previously existing data bases for coherent and incoherent scattering ,photoelectric absorption ,

and pair production cross sections. It uses chemical structure and atomic number of material as input for materials ,the values of μ/ρ for the samples varied by reducing with the increasing photon energies for the same materials, because the mass of the material itself provides the attenuation, attenuation coefficients are often characterized by ρ represent is the material density. The values of μ/ρ are believed to be affected by the chemical , molecular and thermal environments .These phenomena lead to the deviation of the experimental μ/ρ values by application equation $Error\% = \left|\frac{Theoretical - Experimental}{Theoretical}\right| 100\%$ .For selected values from that of the present calculated values in the range of minimum 44.5% for iron and maximum for copper 49% respectively , the evaluation of the theoretical value has been done by considering the cross section of an isolated atom .The results given in the table 2 are the experimental and theoretical values of the calculated mean free path (cm)and half value layer(g/cm^2) of Ag, Cu and Fe evaluated by using equations 1 and 3 respectively. The values proportional to the incident photon energy . The mean free path is the average distance between two collisions and therefore it considered as a measure of the probability of a particular interaction. The quantity (*mfp*) inversely proportional to the cross section and the density of the material, that definition of the *mfp* depends on the type of cross section used in the calculation. The HVL physically represent the equivalence of the material thickness that is reduces the intensity of radiation to half such a quantity reflect the fact that energetic photons has an ability to penetrates the steel as energy increases .

The results given in the table 3 are the experimental and theoretical values of the atomic cross-sections of Ag, Cu and Fe ,calculated by using equation 6 .The experimental values of present work are smaller than the theoretical values especially at low energies. This difference might be from experimental setup, counting and efficiency errors in comparison to the calculated results. The Ag atom Copper and Iron respectively ,had a great contribution in various interaction with x-ray due to the size of their atoms(Ag ,Cu and then Fe) are sufficiently large, so the electrons in the last shell are fewer bands to the nucleus; this point increases the interaction probabilities for such these atoms .The table 4and 5 represent the results of experimental and theoretical values of the electronic cross-sections and electron densities for Ag, Cu and Fe ,calculated by using equations 7 and 9 . Values of electronic

cross-sections and electron densities of experimental work are smaller than the theoretical values. The difference might be from experimental setup, counting and efficiency errors in comparison to the calculated results of present work. Table (6) contains the effective atomic number Z_{eff} by employing the equation 8. After finding the cross-section of the samples, the calculation of effective atomic number Z_{eff} and electron density becomes possible, the results ,shows the effective atomic numbers to be constant as a function of energy. This may be due to the dominance of photoelectric effect and Compton effect in their respective energy regions[20].

Conclusions

1-The effective atomic numbers of Ag, Cu and Fe have been calculated for total photon interaction in an extended energy range of gamma-ray (360keV–1.330 MeV) by using mass attenuation coefficients from WinXCom .

2-Although both mass attenuation coefficient and effective atomic number depends upon the photon energies ,the electron density does not significantly depend upon photon energy

4-Both the half value layer and mean free path are increasing with increasing the incident photon energy and decreases with increasing the density of matter.

5- All the evaluated parameters has a physical meaning and allows many characteristics of a material to be visualized with an abstracted numbers.

6- The linear attenuation coefficient μ of a material depends on the photon energy , the atomic numbers Z of the elements that compose the material, and the material density.

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Table1:The calculated (cal-Xcom code)and experimental[1] mass attenuation coefficients of Ag, Cu and Fe.

Energy (MeV)	μ/ρ(Cal.) Ag (cm^2/g)	μ/ρ (Exp.[1]) Ag (cm^2/g)	μ/ρ(cal.) Cu (cm^2/g)	μ/ρ(Exp.) Cu (cm^2/g)	μ/ρ(cal.) Fe (cm^2/g)	μ/ρ(Exp.[1]) Fe (cm^2/g)
0.360	0.125	0.0672	0.09994	0.0601	0.0993	0.058
0.511	0.09165	0.0517	0.0827	0.0489	0.08326	0.0468
0.662	0.07628	0.0462	0.07259	0.0428	0.07346	0.04111
1.17	0.05407	0.0357	0.0544	0.0342	0.05533	0.0334
1.28	0.0515	0.0320	0.05198	0.0316	0.05286	0.0312
1.33	0.05048	0.05048	0.05099	0.0298	0.05185	0.0286

Table2:The calculated(cal.) mean free path (cm)and half value layer(g/cm^2) of Ag, Cu and Fe .

Energy (MeV)	mfp(cal.) Ag(cm)	HVL(cal.) Ag(cm)	mfp(cal.) Cu(cm)	HVL(cal.) Cu(cm)	mfp(cal.) Fe(cm)	HVL(cal.) Fe(cm)
0.360	0.7620	0.90956	1.116744	0.62055	1.279	0.88646
0.511	1.03915	0.6669	1.351168	0.51288	1.52536	1.0570
0.662	1.24853	0.5550	1.53751	0.4507	1.72884	1.198
1.17	1.7615	0.39341	2.0517	0.33776	2.29532	1.590
1.28	1.85185	0.37422	2.1473	0.32273	2.4025	1.664988
1.33	1.8868	0.3673	2.18055	0.3178	2.44938	1.69744

Table3.The calculated (cal.) code and experimental[1] atomic Cross section in units(cm^2/atom) , of Ag, Cu and Fe

Energy (MeV)	$\sigma_a \times 10^{-23}$ Cal. Ag	$\sigma_a \times 10^{-23}$ Exp.[1] Ag	$\sigma_a \times 10^{-23}$ Cal. Cu	$\sigma_a \times 10^{-23}$ Exp.[1] Cu	$\sigma_a \times 10^{-23}$ Cal. Fe	$\sigma_a \times 10^{-23}$ Exp.[1] Fe
0.360	2.236	1.2025	1.05436	0.6340	0.920	0.53766
0.511	1.640	0.92517	0.872	0.5159	0.77144	0.43384
0.662	1.3650	0.82647	0.7658	0.45154	0.6810	0.3810
1.17	0.9675	0.63885	0.57392	0.3608	0.5130	0.3096
1.28	0.9216	0.57264	0.5483	0.33338	0.49	0.2892
1.33	0.9033	0.53685	0.537944	0.3144	0.480	0.265122

Table 4: The calculated (cal.) and experimental[1] electronic cross-sections in units of (cm^2/electron) and electron density of Ag, Cu and Fe .

Energy (MeV)	$\sigma_{el} \times 10^{-23}$ Ag(Cal.)	$\sigma_{el} \times 10^{-23}$ Ag-Exp.[1]	$\sigma_{el} \times 10^{-23}$ Cu(cal.)	$\sigma_{el} \times 10^{-23}$ Cu(Exp.)	$\sigma_{el} \times 10^{-23}$ Fe(cal)	$\sigma_{el} \times 10^{-23}$ Fe(Exp.[1]
0.360	0.04757	0.025585	0.03635	0.021862	0.03538	0.020676
0.511	0.03489	0.0196844	0.0300	0.01779	0.02967	0.016686
0.662	0.0290	0.0175844	0.02640	0.01557	0.026188	0.0146538
1.17	0.02058	0.0135925	0.01979	0.012413	0.019726	0.011907
1.28	0.01960	0.0121838	0.01890	0.0114931	0.018846	0.011123
1.33	0.019219	0.0114223	0.01855	0.010841	0.018461	0.010197

Table 5: The calculated(cal.) and experimental[1] of electron density of Ag, Cu and Fe.

Energy (MeV)	$N_{el}\times 10^{23}$ Ag(Cal.)	$N_{el}\times 10^{23}$ Ag(Exp.[1])	$N_{el}\times 10^{23}$ Cu(Cal)	$N_{el}\times 10^{23}$ Cu(Exp.[1])	$N_{el}\times 10^{23}$ Fe(cal)	$N_{el}\times 10^{23}$ Fe(Exp.[1])
0.360	2.6277	2.6049	2.7493	2.749	2.8063	2.80518
0.511	2.6268	2.609	2.7566	2.7487	2.8062	2.8047
0.662	2.63034	2.62732	2.7496	2.7488	2.8051	2.80488
1.17	2.6273	2.62644	2.7488	2.755	2.70	2.80493
1.28	2.6264	2.62643	2.75026	2.74947	2.8048	2.805
1.33	2.62656	2.62644	2.74878	2.7488	2.8086	2.80475

Table 6:The calculated(cal.) and experimental [1]effective charge(dimensionless quantity) of Ag, Cu and Fe

Energy (KeV)	Z_{eff} Ag (cal.)	Z_{eff} Ag (Exp.[1])	Z_{eff} Cu (cal.)	Z_{eff} Cu (Exp.[1])	Z_{eff} Fe (cal.)	Z_{eff} Fe (Exp.[1])
0.360	47	47	29	29	26	26
0.511	47	47	29	28.99943	26	26
0.662	47	47	29	29	25.966	26
1.17	47	47	29	29	26	25.966
1.28	46.996	47	29	29	26	26
1.33	47	47	28.9996	29	26	26

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