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Incoherent scattering of gamma rays

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The total atomic cross-sections are determined in Carbon, Aluminium Copper, Silver, Samarium, Tungsten and Lead at selected photon energies in the energy range 45–1115 keV by the transmission method in a good-geometry set-up employing a 35 cc Co-axial Ge(Li) spectrometer The values of the bound-electron incoherent scattering cross-sections σ_b are extracted. The bound electron incoherent scattering cross-sections calculated using the $S(q, Z)$ values based on the Thomas-Fermi (TF) and Hatree-Fock-Slater (HFS) models, are interpolated and the theoretical values of σ_b are obtained. The free-electron incoherent scattering cross-sections σ_f are computed from the Klein-Nishina Formula The bound to free electron cross-section ratios are formed and a comparison is made between the values of $(\sigma_b/\sigma_f)_{exptl}$ and $(\sigma_b/\sigma_f)_{theor}$.

1. Introduction

The incoherent scattering of gamma rays by free electrons is accurately described by the Klein-Nishina theory (1929) But in all practical situations where the scattering electrons are bound, the applicability of the Klein-Nishina theory is restricted to cases where the momentum q transferred to the electron is large compared with the square root of the binding energy of the electron If this condition is not fulfilled, the incoherent scattering cross-section is reduced and is obtained by multiplying the Klein-Nishina cross-section by a factor $S(q, Z)$, called the incoherent scattering function. This function approaches unity in situations where the free-electron hypothesis is justified and vanishes in the other extreme case of small momentum transfer Theoretical calculations of $S(q, Z)$ have usually been carried out using various models for the atomic charge distribution. Of the various models used to describe the atomic charge distribution, only two namely the Thomas-Fermi (1926, 1928) and Hartree-Fock-Slater (1928, 1930, 1951) models are important from the stand point of applicability and accuracy.

Experimental investigations on the incoherent scattering of gamma rays are relatively few. Generally two experimental methods are employed to study the incoherent scattering process : the coincidence method and the subtraction

method. In view of the low coincidence counting rates involved, the experimental accuracy attainable with the first method is, however, not adequate, the associated errors ranging from 5 to 20%. The second method consists of determining the total atomic cross-sections by transmission experiments and subtracting from it the theoretically computed contributions due to photoelectric, coherent scattering and pair production processes. The extracted incoherent scattering cross sections (σ_b) can be divided by the respective free electron scattering cross-sections (σ_f) computed from the Klein-Nishina formula to obtain the incoherent scattering function (σ_b/σ_f). By suitably selecting the energy region for each element, reasonably good experimental accuracy can be attained with this method. The previous investigations (Ramana Rao *et al* 1965) are confined to limited energy and Z regions only. Moreover, in these investigations the subtracted theoretical cross-sections are less accurate. Recently, improved and more accurate theoretical cross sections (Scofield, 1973; Storm & Israel, 1970) have been reported. Hence, in the present investigations, the bound electron incoherent scattering cross-sections are extracted by using the subtraction technique over a wide energy and Z regions.

2 Experiment

The total atomic cross sections are determined in seven elements C, Al, Cu, Ag, Sm, W and Pb at selected photon energies in the energy region of 45 to 1115 keV by conducting transmission experiments in a good geometry set-up (Lakshminarayana, 1961; Subrahmanya Reddi, 1973; Premchand, 1973; Aruna Prasad, 1975). A 35 cc co-axial Ge(Li) spectrometer equipped with a ND 512 channel analyser is employed as the photon detector. The errors associated with the total cross-sections are about 1%, except in five cases using the element samarium. In the case of samarium which is used in the form of Sm_2O_3 powder, the total cross sections are, however, associated with an error of about 2%. The bound electron incoherent scattering cross sections are extracted, by subtracting the theoretical cross sections from the measured total cross-sections. The bound to free electron cross sections ratios (σ_b/σ_f) are then formed. Photoelectric cross-sections reported by Sfofiled (1973) and coherent and pair production cross-sections tabulated by Storm & Israel (1970) are utilised for subtraction. No errors are reported in the theoretical values of Coherent scattering cross-sections (Storm & Israel, 1970). Moreover, the contribution due to this effect is very small. The error in the photoelectric cross-sections is of the order of 0.1% as reported by the author (Scofield, 1973). Hence, the effect of errors in the theoretical cross-sections of photoelectric process and coherent scattering is negligibly small. However, this effect is also taken into consideration while estimating the error in the bound-electron incoherent scattering cross-section as well as the integral incoherent scattering function (σ_b/σ_f).

Table 1 Ratios of bound electron to free electron incoherent scattering cross- sections

Energy (keV)		Elements						
		Carbon	Aluminium	Copper	Silver	Samarium	Tungsten	Lead
5.71	$(\sigma_b/\sigma_f)_{expt}$	0.94±0.01	0.88±0.03	—	—	—	—	—
	$(\sigma_b/\sigma_f)_{TF}$	0 968	0 928					
	$(\sigma_b/\sigma_f)_{HFS}$	0.959	0 912					
86 79	$(\sigma_b/\sigma_f)_{expt}$	0.97±0 01	0.94±0 01	—	—	—	—	—
	$(\sigma_b/\sigma_f)_{TF}$	0.990	0.971					
	$(\sigma_b/\sigma_f)_{HFS}$	0.984	0.959					
121 11	$(\sigma_b/\sigma_f)_{expt}$	0 99±0 01	0 96±0.01	0 91±0 02	—	—	—	—
	$(\sigma_b/\sigma_f)_{TF}$	0.993	0.984	0.959				
	$(\sigma_b/\sigma_f)_{HFS}$	0.993	0.979	0.949				
135.97	$(\sigma_b/\sigma_f)_{expt}$	0 99±0 01	0.96±0.01	0.92±0 02	—	—	—	—
	$(\sigma_b/\sigma_f)_{TF}$	0.993	0.985	0.966				
	$(\sigma_b/\sigma_f)_{HFS}$	0.993	0 980	0 958				
197.02	$(\sigma_b/\sigma_f)_{expt}$	0.99±0 01	0 97±0 01	0.94±0 02	0 93±0 03	—	—	—
	$(\sigma_b/\sigma_f)_{TF}$	0.996	0.992	0.985	0.967			
	$(\sigma_b/\sigma_f)_{HFS}$	0.996	0 989	0.978	0.965			
234.67	$(\sigma_b/\sigma_f)_{expt}$		0.99±0 01	0.96±0 01	0.95±0.02	0.86±0 06		
	$(\sigma_b/\sigma_f)_{TF}$	—	0 994	0.987	0 977	0.969	—	—
	$(\sigma_b/\sigma_f)_{HFS}$		0.992	0 983	0 975	0.967		
279.58	$(\sigma_b/\sigma_f)_{expt}$		0 99±0.01	0 97±0 01	0.95±0 02	0 87±0.05		
	$(\sigma_b/\sigma_f)_{TF}$	—	0.996	0 988	0.979	0 971	—	—
	$(\sigma_b/\sigma)_{HFS}$		0.994	0.984	0.978	0.969		
400.7	$(\sigma_b/\sigma_f)_{expt}$			0.99±0 01	0.97±0 01	0.94±0.04	0.91±0.03	
	$(\sigma_b/\sigma_f)_{TF}$	—	—	0 994	0 986	0.984	0.980	—
	$(\sigma_b/\sigma_f)_{HFS}$			0.991	0.986	0 984	0.982	
604.83	$(\sigma_b/\sigma_f)_{expt}$				0.98±0 01	0 96±0 02	0.95±0 02	0.94±0.02
	$(\sigma_b/\sigma_f)_{TF}$	—	—	—	0 995	0 990	0.990	0 985
	$(\sigma_b/\sigma_f)_{HFS}$				0 994	0 989	0.990	0.986
796.02	$(\sigma_b/\sigma_f)_{expt}$				0.99±0.01	0.98±0 02	0.97±0 01	0 95±0.02
	$(\sigma_b/\sigma_f)_{TF}$	—	—	—	0.998	0.995	0.994	0.990
	$(\sigma_b/\sigma_f)_{HFS}$				0 998	0 994	0.995	0.990
1115.5	$(\sigma_b/\sigma_f)_{expt}$	—	—	—	—	—	0 99±0.01	0 98±0.01
	$(\sigma_b/\sigma_f)_{TF}$	—	—	—	—	—	0.999	0 999
	$(\sigma_b/\sigma_f)_{HFS}$						0.999	0.998

3. Results and Discussion

The experimental ratios and the theoretical ratios based on the Thomas-Fermi (TF) and Hartree-Fock-Slater (HFS) models are furnished in table 1 The ratio (σ_b/σ_f) enables a quantitative estimation of the influence of binding, the deviation of this ratio from unity being a simple measure of it. It can be seen from table 1 that $(\sigma_b/\sigma_f)_{expt}$ and $(\sigma_b/\sigma_f)_{theor}$ show a progressive decrease with increasing atomic number and decreasing energy in conformity with the expected trend of variation

It can also be seen from table 1 that the ratios based on the HFS model, show better agreement, in general, with the experimental ratios in low- and medium-Z elements particularly in C, Al and Cu. This is because of the more sophisticated nature of the HFS model calculations. It can be observed that both the TF and HFS models fail equally in the case of tungsten and lead This is possibly due to the fact that relativistic effects which are considered important for high-Z elements are neglected in both the models.

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References

Aruna Prasad, G 1975 Ph.D. Thesis, Andhra University, India (Unpublished)
Fermi, E 1928 *Z Physik* **48**, 73
Fock, V 1930 *Z Physik* **61**, 126.
Hartree, D. R. 1928 *Proc. Camb. Phil. Soc.* **24**, 89.
Klein, O & Nishina, Y. 1929 *Z. Physik* **52**, 853.
Lakshmanarayana, V & Jnanananda, S. 1961 *Proc. Phy. Soc.* **77**, 593.
Pramchand, K. 1973 Ph.D. Thesis, Andhra University, India (Unpublished).
Ramana Rao P V , Rama Rao J. & Lakshmanarayana, V. 1965 Indian Jour. of Physics Vol **XXXIX** No. 4, 195.
Ramana Rao, P. V , Rama Rao J. & Lakshmanarayana, V. 1965 *Proc. Phy. Soc.* **85**, 1081.
Scofield, J H 1973 Private Communication , UCRL-51326 Jan. 12 University of California, Livermore.
Slater, J C 1951 *Phy Rev.* **81**, 385
Storm, E. & Israel, H. T 1970 *N clear Data Tables* **7A**, 565.
Subrahmanya Reddy, D. K 1973 Ph.D. Thesis Andhra University, India (Unpublished).
Thomas, L. H. 1926 *Proc. Camb. Phil. Soc.* **23**, 542.