Compton scattering of 662-keV γ rays by various atoms

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Differential cross sections for Compton scattering on Cu, Zn, Cd, Sn, W, Pt, Pb, and U were measured for scattering angles between 5° to 60°. The measurements are in agreement with values of the incoherent-scattering-factor theory, and for small scattering angles deviations from the free-electron Klein-Nishina value occur.

Compton or elastic scattering of γ rays from free electrons is described by the well known formula of Klein and Nishina.[1] However, scattering of radiation from atoms is different because the electrons are bound.[2] The experimental effort on Compton scattering has been concentrated mainly in the following directions. (i) Due to the electronic momentum distribution, the Compton line has a complicated profile with inner-shell contributions at lower and higher energies from the line center. The energy distribution of the scattered photons, which yields the doubly differential cross section $d^2\sigma/d\Omega\, dE$, has been studied extensively especially for angles near 180°, yielding information about the momentum distribution of the atomic electrons $J(q)$.[3] (ii) The other main experimental direction studies the contribution of the Compton cross section $d\sigma/d\Omega$ from individual atomic shells, especially the K shell. Several coincidence experiments between the scattered photons and the produced x rays were performed at 279, 320, 662, and 1120 keV, which are compared in Ref. 2. Generally, the agreement between experiment and theory is poor. (iii) Some coincidence experiments were performed measuring the energy spectra of Compton scattering from the K shell, yielding the doubly differential cross section $d^2\sigma/d\Omega\, dE$.[2] (iv) Only few experiments were made on the singly differential cross section of total atoms.[2,4] In a review paper Hubbell[4] concluded that some disagreement between experiment and the incoherent scattering factor theory exist in the 100-keV region of Pb. However, in the experiments NaI detectors were used and it was difficult to seperate the elastic and inelastic lines. In this paper experiments with GeLi detectors are described at a photon energy of 661.65 keV and compared with theory.

A radioactive ^{137}Cs source of about 40 mCi was used. The radiation scattered at the different targets was investigated with a GeLi detector (about 40 cm^3, 1.3-keV resolution at 662 keV) and a conventional electronic system. In front of the detector was a vertical slit of lead with a width of about 1 cm. The distance of source, target, and detector was about 60 to 120 cm depending on the scattering angle. For an angle of 5° Compton scattering on air yields a background and better collimation was needed for reducing the air volume irradiated and seen by the detector.

The separation of the elastic and inelastic line for the smallest scattering angle (5°) is about 12 keV, which is much larger than the energy resolution of the detector. Results for the cross section of elastic scattering are given in Ref. 5. From the area of the inelastic line the cross sections of Compton scattering were calculated. Absolute cross sections were obtained by measuring the product of intensity of the source and the efficiency of the detector setting the

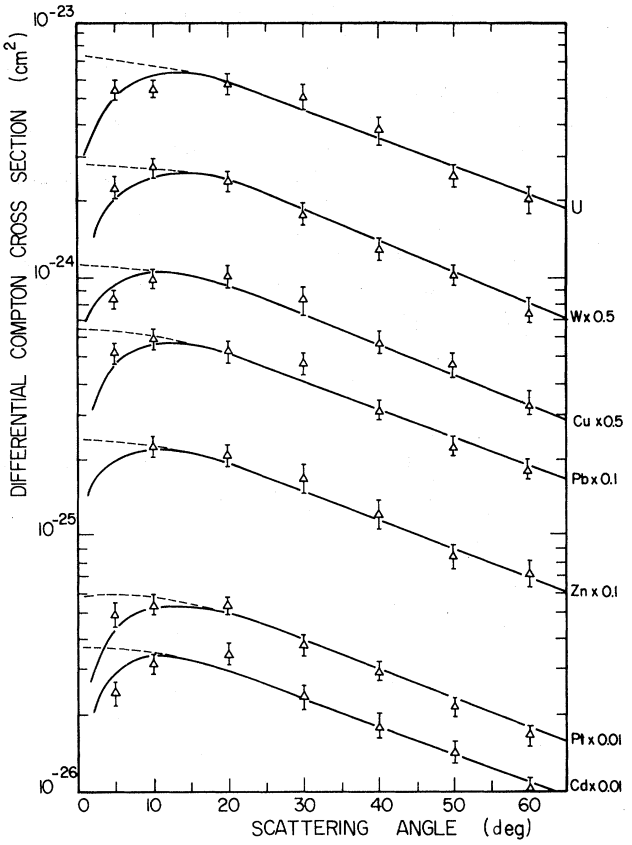

FIG. 1. Experimental results for the differential cross section for Compton scattering as a function of scattering angle for $_{29}$Cu, $_{30}$Zn, $_{48}$Cd, $_{50}$Sn, $_{74}$W, $_{78}$Pt, $_{82}$Pb, and $_{92}$U. The solid curves are theoretical results of the incoherent factor theory using nonrelativistic Hartree-Fock wave functions (Ref. 4). The broken curve is the Klein-Nishina free-electron cross section.

TABLE I. Experimental results for the differential cross section of Compton scattering $d\sigma/d\Omega$ (in units of 10^{-24} cm^2) for γ rays of 662 keV. The experimental error is about $\pm 10\%$.

θ (deg) \ $_{Z}X$	$_{92}$U	$_{82}$Pb	$_{78}$Pt	$_{74}$W	$_{50}$Sn	$_{48}$Cd	$_{30}$Zn	$_{29}$Cu
5	5.61	5.29	4.89	4.54		2.45		1.70
10	5.12	5.59	5.40	5.38		3.09	2.27	1.90
20	5.98	5.31	5.46	4.99	...	3.54	2.07	2.10
30	5.19	4.86	3.74	3.62	2.78	2.36	1.70	1.69
40	3.75	3.12	2.99	2.63	1.90	1.83	1.23	1.16
50	2.50	2.28	2.09	2.03		1.48	0.83	0.97
60	2.03	1.87	1.67	1.51	...	1.04	0.73	0.67

source to 0° scattering angle. The high counting rate was reduced by several sheets of lead and an extrapolation was performed for zero thickness. The variation of the detector efficiency with energy, yielding a correction up to 30%, was taken into account in the determination of the cross section. Corrections for bremsstrahlung were not applied owing to the lack of experimental data for this process. However, for small angles the Compton lines are relatively sharp and contributions of bremsstrahlung are small. For larger angles the experimental values approach the free-electron value, indicating that bremsstrahlung is also not important in this region.

The experimental results for the Compton cross sections are shown in Fig. 1 and Table I. The experimental error is of the order 10%, which is mainly due to systematic uncertainties in the determination of the area of the Compton line. Theoretical differential cross sections of photons scattered inelastically from atoms are available, based upon the incoherent scattering function.[4] The differential cross section is given by the free-electron Klein-Nishina value multiplied by the incoherent scattering function. Various types of wave functions have been used for computing the incoherent scattering function. Within a few per cent these calculations yield equal results. In Fig. 1 theoretical curves from the incoherent scattering factor theory based on nonrelativistic Hartree-Fock wave functions[4] are added as solid curves. The broken curve is the free-electron Klein-Hishina cross section. At large angles the incoherent scattering function is equal to one and both theories yield the same result. Deviations from the free-electron behavior occur especially for heavy elements and scattering angles smaller than 15°. The measured differential cross sections are in agreement within experimental error with the incoherent scattering factor theory.

The only experiment of Compton scattering at 662 keV known was performed on Pb at angles 20° using a NaI detector.[6] As explained before, in this region the cross section is given within experimental error by the free-electron value.

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