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Journal of Physics: Conference Series **194** (2009) 022079 doi:10.1088/1742-6596/194/2/022079

Interference effects in Compton scattering from positronium and from H_2 and H_2^+ molecules

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Synopsis We study the interference effects in Compton scattering of a photon from positronium and from the simplest molecules H_2 and H_2^+ in their ground states. We will discuss the adequacy of impulse approximation in describing these interference effects.

There has been considerable interest recently in Young-type interference effects in the processes of photoeffect [1] and charged particle scattering [2] from diatomic molecules. Often, the simplest molecule, H_2, or its ion is studied.

We will discuss Young-type interference effects in Compton scattering from positronium and from the simplest molecules H_2 and H_2^+ in their ground states. In our study we are using nonrelativistic descriptions of states and of the photon–electron (positron) interaction, which we find adequate for the description of the doubly differential cross section (DDCS), averaged over spins and polarizations, in the energy region considered (up to a few tens of keV). In the case of positronium and the H_2^+ molecule (in a model of fixed centers of Coulomb potentials) the initial states, the final states and the matrix element can be obtained exactly. This allows us to test the adequacy of impulse approximation (IA) in describing DDCS in these and in more general cases. The impulse approximation is very often used in describing Compton scattering from complex systems and serves as a tool for analyzing the electronic structure of these systems [3].

In the positronium case, the Young-type interference effects in Compton scattering (interference of amplitudes of scattering from electron and from positron) appear due to electron–positron interaction. Without the electron–positron interaction there is no interference. We observe the importance of the interference effects and the adequacy of IA for scattering from positronium by comparing the results with the results obtained for the hydrogen atom. In the case of the hydrogen atom, the IA is known to be adequate at photon momentum transfers k which are comparable to or larger than the average electron momentum $a = mZ\alpha$, i.e for $a/k < 1$. In this region the Compton peak of the DDCS is visible and the A^2 term of the photon electron interaction suffices to describe the peak region of the DDCS (the $\vec{p}\cdot\vec{A}$ term can be neglected). In the positronium case we find that, while A^2 is adequate for the description of the peak region for $a/k \simeq 1$, the IA is not [4], due to interference effects. At much higher energies and momentum transfers k, the interference effects vanish and IA is becomes adequate for $a/k << 1$. We will discuss the importance of the $\vec{p}\cdot\vec{A}$ term at lower energies and compare it with the hydrogen case.

In the case of molecules and other complex electronic systems the criterion of validity of IA is often assumed to be the same as in the case of the hydrogen atom. However, in the case of molecules Young type interference effects appear and the adequacy of the IA for their description is not clear. These effects can already be studied for the H_2^+ molecule (a single electron moving in the field of two nuclei). We study this case in an approximation of fixed–in–space centers (which allows for exact treatment), using A^2 and IA, and we discuss the adequacy of IA. We also discuss the IA result for the H_2 molecule and discuss the possibility of observing interference effects.

References

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