Angular dependence of Wigner-Eisenbud-Smith time delay in photoionization: A case study on $4f$ subshell of atomic mercury

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Synopsis The angular dependence of Wigner-Eisenbud-Smith (WES) time delay in photoionization from the $4f$ subshell of atomic mercury is computed using the relativistic-random-phase approximation [11]. Specifically, the angular dependence of WES time delay is investigated in the near-threshold region of the $4f$ photoionization channels.

Time domain studies of light-matter interactions is now a very hot field. This covers a variety of research with different focii, extending from astrophysical to biological relevance to foundational aspects of quantum theory [1, 2]. The time scale of electronic motion is now experimentally observable with the aid of the recent development of ultrafast laser technologies [3].

The time taken for a process to occur is a measurable quantity. The Wigner-Eisenbud-Smith (WES) time delay [4, 2, 5] is highly sensitive to the potential (local and nonlocal) and correlation effects [6]. It has been realized that WES time delay is angle dependent in general [7]. How exactly it depends on angle of emission with respect to the photon polarization is very much specific to the channels and energies under inspection.

Single photon, dipole photoionization from np and nd subshells have been studied earlier [7, 8]. Hence the next step is to examine the angular dependence for nf.

It has been found that the $4f$ photoionization cross section of atomic mercury undergoes a minimum in the energy region just above the $4f$ threshold because of the energy-dependent behaviors of the $4f \to \varepsilon g$ and $4f \to \varepsilon d$ oscillator strength [9, 10]. This minimum impacts the angle dependent of WES time delay.

Following the formalism of [11] and [7] we compute the WES time delay. For a one-electron transition from an initial state characterized by quantum numbers ljm to a final continuum state $\bar{l}\bar{j}\bar{m}$ with the spin described by a two-component spinor χ_ν the dipole transition matrix element is given by [7],

$$\begin{aligned} T_{JM}^{(\lambda)} &= i\sqrt{\frac{2\pi^2}{Ep}}\sqrt{\frac{(2J+1)(J+1)}{J}}\frac{\omega^J}{(2J+1)!!} \\ &\quad \times \sum_{\bar{\kappa}\bar{m}} (\chi_\nu^\dagger \Omega_{\bar{\kappa}\bar{m}}(\hat{p}))(-1)^{\bar{j}-\bar{m}} \begin{pmatrix} \bar{j} & J & j \\ -\bar{m} & M & m \end{pmatrix} \\ &\quad \times i^{1-\bar{l}} e^{i\delta_{\bar{\kappa}}} \left\langle \bar{a} \| Q_J^{(\lambda)} \| a \right\rangle (-1)^{\bar{j}+j+J}. \end{aligned}$$

All possible dipole channels originating from the $4f$ subshell are studied. The interference between different channels produces an angle dependence of the WES time delay which become particularly interesting in the neighborhood of the minimum in $4f$ cross section mentioned above.

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