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Wigner time delay in quadrupole photoionization channels of atomic Hg

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Synopsis Time delay in quadrupole (E2) channels is studied in atomic Hg using the Relativistic Random Phase Approximation. Interchannel coupling is found to be extremely important and large time delays are found in the region of quadrupole (E2) Cooper minima.

Recent development of ultrafast sciences has enabled the access of quantum dynamics on the atomic time scale. Time delay in nonresonant photoionization has been measured to be a few tens of attoseconds [1]. It is thus important to study the process theoretically to understand time delay at a fundamental level.

Earlier studies have revealed the importance of non-dipole contributions to the photoionization parameters [2]. Though the cross-section for E2 transitions is usually four orders of magnitude less than that of dipole (E1) transitions, it has been found that we do have some energy regimes where E2 cross-sections dominate over E1, particularly near dipole Cooper minima [3] where it is necessary to incorporate E2 transition channels in the theory. Here we study the time delay in E2 channels. Since time delay in E1 channels is strongly affected by relativistic and correlation effects [4], it is important to include these effects in E2 channels too.

Hg has been chosen because some E1 and E2 studies already exist [5]. We have used the Eisenbud-Wigner formalism [6, 7] to calculate the time delay in which the time delay in a transition is given as $\tau = \hbar d\eta / dE$, where η is the phase of the transition matrix element. The Relativistic Random Phase Approximation (RRPA) [8] is employed in the calculations.

Time delay for the $6s \rightarrow \varepsilon d_{5/2}$, $\varepsilon d_{3/2}$ E2 channels are calculated, at various levels of truncation of the RRPA to gain some understanding of the importance of interchannel coupling.

The time delay for the $6s \rightarrow \varepsilon d_{5/2}$ E2 transition is shown in Fig. 1, along with the absolute value of transition matrix elements, for two levels of truncation of the RRPA calculation; 11 channels (all 6s and 5d transitions coupled) and 2 channels (only the 6s transitions coupled). Away from the Cooper minima, the time delay in this quadrupole channel is seen to be comparable to the dipole channels. As in the case of E1 photoionization (not shown), correlations due to interchannel coupling strongly affect the time delay in the E2 channels; interchannel coupling of the 6s with 5d subshell strongly influences the E2 time delay in the Cooper minimum region—the delay drops by about an order of magnitude owing to coupling with 5d. However, even at the 11-channel level, the time delay maximizes at about 50 as.

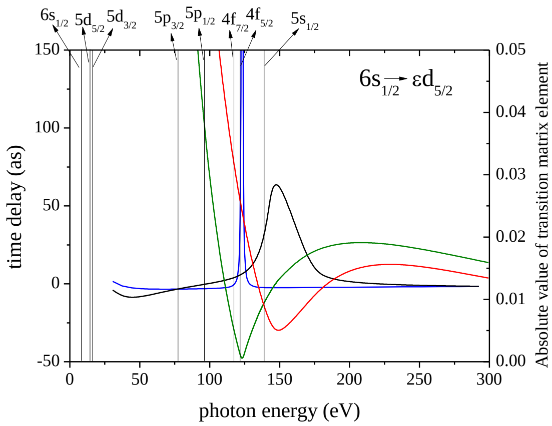

Figure 1. Time delay in the $6s \rightarrow \varepsilon d_{5/2}$ photoionization transition in Hg (left scale); 11 channel (black), 2 channel (blue). Also shown are the absolute values of the transition matrix elements (right scale); 11 channel (red), 2 channel (green). Vertical lines denote thresholds.

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