# Laser-Assisted (e,2e) Process on Hydrogen in the Parabolic Quasi Sturmians Approach

**A. S. Zaytsev$^{\circ}$, K. A. Kouzakov$^{\star}$, L. U. Ancarani$^{\dagger}$ and S. A. Zaytsev$^{\circ}$** [1]

$^{\circ}$ Pacific National University, Khabarovsk 680035, Russia
$^{\star}$ Lomonosov Moscow State University, Moscow 119991, Russia
$^{\dagger}$ Equipe TMS, SRSMC, UMR CNRS 7565, Université de Lorraine, 57078 Metz, France

**Synopsis** We study electron-impact ionization of atomic hydrogen in the presence of a laser field employing the Floquet theory to solve the time-dependent Schrödinger equation (TDSE). Both the initial and the final states are obtained in the Kramers-Henneberger (KH) frame. Specifically, the final-state problem is recast as a driven equation, which is solved numerically using expansions on the parabolic Quasi Sturmian (QS) functions.

We investigate a laser-assisted (e,2e) process on atomic hydrogen using a parabolic QS approach. The interaction of the fast projectile electron with the atomic target is treated in the first Born approximation.

Within a Floquet approach, we solve the TDSE using the KH representation for both initial and final states. For a laser frequency $\omega$, we present the solution in the form

$$\Psi(\mathbf{r},t) = e^{-iE_f t}\left[\psi_C^{(-)}(\mathbf{r}) + \sum_{n=-\infty}^{\infty} e^{-in\omega t} F_n(E_f,\mathbf{r})\right], \quad (1)$$

where the Coulomb wave $\psi_C^{(-)}$, corresponding to the ejected electron with the energy $E_f$, ensures the correct asymptotic behavior of the final state. In the acceleration frame [1], the TDSE is then recast into

$$\begin{aligned}&\left(-\tfrac{1}{2\mu}\Delta + V_0(\mathbf{a}_0,\mathbf{r}) - E_f - n\omega\right) F_n(E_f,\mathbf{r})\\ &\quad + \sum_{\substack{\nu=-\infty\\ \nu\neq n}}^{\infty} V_{n-\nu}(\mathbf{a}_0,\mathbf{r}) F_\nu(E_f,\mathbf{r})\\ &= -\left[V_n(\mathbf{a}_0,\mathbf{r}) - \delta_{n,0}\tfrac{Z}{r}\right]\psi^{(-)}(\mathbf{r}),\end{aligned} \quad (2)$$

where $V_n(\mathbf{a}_0,\mathbf{r})$ are the Fourier components of the potential.

We propose to solve equation (2) by expanding the components $F_n$ in terms of QS functions:

$$\begin{aligned}F_n(E_f,\mathbf{r}) &= \sum_{m,\,n_1,\,n_2} C^n_{m,n_1,n_2}\,|k_n;\; m,\, n_1,\, n_2\rangle_Q\,,\\ k_n &= \begin{cases}\sqrt{2\mu(E_f+n\omega)}, & E_f+n\omega \geq 0,\\ -i\sqrt{-2\mu(E_f+n\omega)}, & E_f+n\omega < 0.\end{cases}\end{aligned} \quad (3)$$

Specifically, we use parabolic coordinates $(\xi,\eta,\phi)$, with the $z$ axis being parallel to the momentum $\mathbf{k}_f$ of the ejected electron. Each QS function satisfies the inhomogeneous equation (with the incoming boundary condition)

$$\begin{aligned}&\left(-\tfrac{1}{2\mu}\Delta + \tfrac{Z}{r} - \tfrac{k^2}{2\mu}\right)|k;\; m,\, n_1,\, n_2\rangle_Q\\ &\quad = \tfrac{|m,n_1,n_2\rangle_L}{(\xi+\eta)},\end{aligned} \quad (4)$$

where the right-hand side

$$|m,n_1,n_2\rangle_L \equiv \frac{e^{im\phi}}{\sqrt{2\pi}}\varphi_{n_1}^{|m|}(\xi)\varphi_{n_2}^{|m|}(\eta), \quad (5)$$

is expressed in terms of products of Laguerre basis functions $\varphi_n^{\kappa}(x)$. For the parabolic QS we succeeded to derive an integral representation as well as its expansion in terms of the Laguerre basis functions.

The initial state of the system is also obtained in the KH frame (by analogy with the KH state [2]) by diagonalizing the Hamiltonian in the basis (5). For a geometry in which the polarization vector is perpendicular to the scattering plane, the potential $V_n$ matrix in the Laguerre basis is independent of $\mathbf{k}_f$.

Since the inhomogeneity in (2) decreases, at least, as $1/r^2$, we have verified numerically that expansion (3) converges quite rapidly with increasing the number of basis functions. The subject of our current investigation is the convergence of the $(e,2e)$ cross section as the number of involved photons increases.

## References

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[1] E-mail: zaytsevsa@pnu.edu.ru