Dynamic hyperpolarizability and two-photon detachment of H^- in the presence of a strong static electric field

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The interaction of the H^- negative ion with two fields, a static electric field, $\vec{\mathcal{F}}$, and a monochromatic laser field having an arbitrary elliptic polarization, $\mathbf{F}(t) = F\mathrm{Re}\{\mathbf{e}\exp[-i(\omega t - \mathbf{k}\cdot\mathbf{r})]\}$, is analyzed using for H^- the zero-range δ-potential model with binding energy $E_0 = -\hbar^2\kappa^2/2m$. Our analysis is based on the complex quasienergy, $\epsilon = \mathrm{Re}\,\epsilon - i\,\Gamma/2$, approach for this model system [1]. Γ gives the total decay rate of a bound level in both laser and static fields. A perturbative treatment of the laser field up to terms $\propto F^4$ together with an exact account of static electric field effects (SEFE) gives (for $\Delta\epsilon = \epsilon - E_0$):

$$\Delta\epsilon = -\frac{1}{4}\alpha(\mathcal{F},\omega)F^2 - \frac{1}{24}\gamma(\mathcal{F},\omega)F^4. \tag{1}$$

A detailed analysis of the dynamic polarizability $\alpha(\mathcal{F},\omega)$ and of one-photon detachment in a weak laser field was performed in Ref. [2]. Starting from the exact equation for ϵ (cf. [1, 2]), we obtained an analytical result for the dynamic hyperpolarizability, $\gamma(\mathcal{F},\omega)$, in terms of Airy functions, $Ai(\xi_n)$, and their derivatives, $Ai'(\xi_n)$, where $\xi_n = (1-n\omega)\mathcal{F}^{-3/2}$ with $n = 0, \pm1$ and ±2. We measure the frequency ω and field strengths, $\mathcal{F}$ and F, in scaled units, $|E_0|/\hbar$ and $\sqrt{2m|E_0|^3}/e\hbar$, respectively. Our result for γ is valid for an arbitrary geometry and an arbitrary polarization of the laser field.

For not too strong $\mathcal{F}$, and for $1/2 \le \omega \le 1$, the dominant contribution to Γ comes from the two-photon detachment channel. The corresponding cross section [in units $1/4(E_a/|E_0|)^3 a_0^4\hbar/E_a$, where $E_a = e^2/a_0$, and a_0 is the Bohr radius] is given by the imaginary part of γ:

$$\hat{\sigma}^{(2)} = \frac{16}{3}(\pi\alpha\omega)^2\mathrm{Im}\,\gamma(\mathcal{F},\omega). \tag{2}$$

The exact result for $\hat{\sigma}^{(2)}$ simplifies upon neglecting SEFE in the initial state and final state interactions of the detached electron with the core (i. e., rescattering effects). This approximation (I) is similar to the approximate results for one-photon detachment in Refs. [3]. For the case of a linearly-polarized laser field collinear to $\vec{\mathcal{F}}$,

$$\begin{aligned}\hat{\sigma}_I^{(2)} &= \frac{64\pi^3\alpha^2\mathcal{F}^{1/3}}{\omega^4}B\left[(Ai'^2 - \xi Ai^2)\left(\frac{1}{16} + \xi\frac{\mathcal{F}^{2/3}}{6\omega} + \xi\frac{\mathcal{F}^{4/3}}{5\omega^2}\right)\right. \\ &\left. -AiAi'\frac{\mathcal{F}^{2/3}}{\omega}\left(\frac{1}{6} + \frac{2\mathcal{F}^{2/3}}{5\omega}\right) - \frac{\mathcal{F}^{4/3}}{20\omega^2}Ai^2\right],\end{aligned}$$

where $\xi \equiv \xi_2$, $Ai \equiv Ai(\xi_2)$, $Ai' \equiv Ai'(\xi_2)$, and $B = 2.6551$ is a ground state normalization factor. Approximation II is similar to I, but with an exact account of SEFE in the initial state:

$$\begin{aligned}\hat{\sigma}^{(2)}_{II} &= \frac{64\pi^3\mathcal{F}^{1/3}\alpha^2}{\omega^4}B\left[Ai'^2\left(\frac{1}{16}+\frac{\mathcal{F}^4}{\omega^6}-\frac{3\mathcal{F}^2}{2\omega^3}\right)-\xi Ai^2\left(\frac{1}{4}+\frac{\mathcal{F}^2}{\omega^3}\right)^2\right.\\ &- \xi^2(Ai^2-Ai'^2)\left(\frac{\mathcal{F}^{2/3}}{6\omega}-\frac{2\mathcal{F}^{8/3}}{3\omega^4}\right)-Ai'Ai\left(\frac{\mathcal{F}^{2/3}}{6\omega}+\frac{10\mathcal{F}^{8/3}}{3\omega^4}\right)\\ &- \left. Ai^2\left(\frac{2\mathcal{F}^{10/3}}{\omega^5}+\frac{3\mathcal{F}^{4/3}}{10\omega^2}\right)-\frac{\mathcal{F}^{4/3}}{5\omega}\left(\xi^3Ai^2-\xi^2Ai'^2+2\xi AiAi'\right)\right].\end{aligned}$$

This result coincides exactly with that obtained in Ref. [4] (see Eq. (51) for $N = 2$). A third approximation (III) consists in combining the amplitude II with the rescattering correction for an unperturbed initial state [5]. A comparison of these approximate results with our exact calculations is presented in Fig. 1.

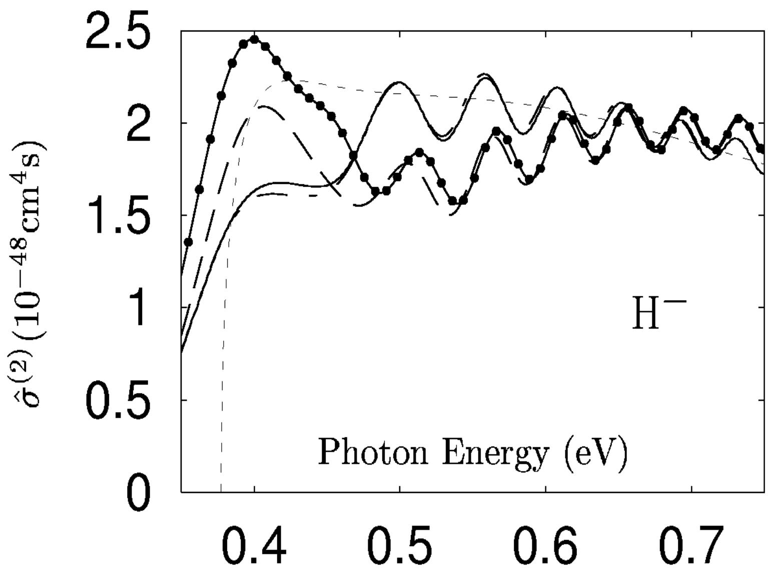

Figure 1: Frequency dependence of $\hat{\sigma}^{(2)}$ for $\mathcal{F} = 1$MV/cm. *Solid line:* present exact result; *solid circles:* approximation I; *long dashed line:* approximation II [4]; *dot-dashed line:* approximation III [5]; *short dashed line:* result for $\mathcal{F} = 0$.

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