Elliptic Dichroism in One-, Two-, and Three-Photon Detachment of H^-

M.V. Frolov, N.L. Manakov, S.I. Marmo and A.F. Starace [1]

Physics Department, Voronezh State University
Voronezh, 394693, Russia
E-mail: manakov@thp.vsu.ru
[1] *Department of Physics and Astronomy, The University of Nebraska*
Lincoln, NE 68588-0111, USA
E-mail: astarace1@unl.edu

The angular distribution of electrons in multiphoton detachment of H^- by an elliptically-polarized laser field, $\mathbf{F}(t) = F\mathrm{Re}\{\mathbf{e}\exp[-i(\omega t - \mathbf{k}\cdot\mathbf{r})]\}$, is analyzed analytically using the δ-model potential for H^-. Starting from the general solution [1] of the corresponding complex quasienergy problem, the properly-normalized wavefunction of the quasistationary, quasienergy state (QQES), $\Phi_\epsilon(\mathbf{r},t)$, is presented in terms of a free-electron Green's function in a laser field and the Fourier-coefficients, f_n, of $\Phi_\epsilon(\mathbf{r},t)$ at the origin ($r \to 0$). The complex quasienergy ϵ is the eigenvalue of an infinite system of linear algebraic equations for f_n. The (complex) normalization parameter is calculated as a sum of one-dimensional integrals of the Bessel function. The angular distribution of photoelectrons in n-photon detachment, $d\sigma^{(n)}/d\Omega_{\hat{\mathbf{p}}}$, is determined using the asymptotic form (at $r \to \infty$) of the n-th Fourier coefficient of $\Phi_\epsilon(\mathbf{r},t)$, where $\hat{\mathbf{p}}$ is the electron momentum direction.

The perturbative expansions (in the amplitude of the laser field, F) of ϵ, f_n, Φ_ϵ, and the normalization factor are obtained and used for the calculation of $d\sigma^{(n)}$, which has a simple analytic form for each n. For $n = 2$ and 3 the results are obtained in the lowest-order of perturbation theory (PT). For one-photon detachment, the linear in laser intensity correction to the angular distribution is calculated. This latter correction involves contributions originating both from expansions of ϵ and the normalization factor as well as from the interference between first-order and third-order amplitudes. All these contributions have comparable magnitudes. The third-order amplitude describes the stimulated re-emission (re-scattering) of a photon by the detached electron. The final results for the differential cross sections are:

$$\begin{aligned}
\frac{d\sigma^{(1)}}{d\Omega_{\hat{\mathbf{p}}}} &= \frac{8\alpha}{\omega^3}(\omega-1)^{3/2}|\hat{\mathbf{p}}\cdot\mathbf{e}|^2 + F^2\frac{8\alpha}{3\omega^7}\sqrt{\omega-1}\Big\{-3|\hat{\mathbf{p}}\cdot\mathbf{e}|^4(\omega-1)^2 \\
&+ |\hat{\mathbf{p}}\cdot\mathbf{e}|^2\left[\sqrt{\omega+1}(\omega^2-7)+14-8\omega\right] \\
&+ l\mathrm{Re}\left\{(\hat{\mathbf{p}}\cdot\mathbf{e}^*)^2\right\}\frac{(\omega-1)}{2\omega}[(2\omega-1)^2+1-2(\omega-1)^{3/2}\sqrt{2\omega-1}] \\
&- l\mathrm{Im}\left\{(\hat{\mathbf{p}}\cdot\mathbf{e}^*)^2\right\}\frac{(\omega-1)}{2\omega}[(2\omega-1)^{3/2}-2(\omega-1)^{3/2}-\sqrt{2\omega-1}]\Big\},
\end{aligned} \tag{1}$$

$$\frac{d\sigma^{(2)}}{d\Omega_{\hat{\mathbf{p}}}} = F^2 \frac{2\alpha}{9\omega^7}\sqrt{2\omega-1}\left|\frac{i(2\omega-1)^{3/2}-2i(\omega-1)^{3/2}+1}{1+i\sqrt{2\omega-1}}l - 3(2\omega-1)(\hat{\mathbf{p}}\cdot\mathbf{e})^2\right|^2, \qquad (2)$$

$$\begin{aligned}\frac{d\sigma^{(3)}}{d\Omega_{\hat{\mathbf{p}}}} &= F^4 \frac{2\alpha}{9\omega^{11}}|\hat{\mathbf{p}}\cdot\mathbf{e}|^2(3\omega-1)^{3/2} \\ &\times \left|(\hat{\mathbf{p}}\cdot\mathbf{e})^2(3\omega-1) - l\frac{i(2\omega-1)^{3/2}-2i(\omega-1)^{3/2}+1}{1+i\sqrt{2\omega-1}}\right|^2, \qquad (3)\end{aligned}$$

where $\sigma^{(n)}$, ω, and F are in scaled units: κ^{-2}, $|E_0|/\hbar$ and $\sqrt{2m|E_0|^3}/e\hbar$, respectively. Here $E_0 = -\hbar^2\kappa^2/2m$ is the initial bound state energy, $l = \mathbf{e}\cdot\mathbf{e}$ is the linear polarization degree of a laser field $\mathbf{F}(t)$, and $\alpha = e^2/\hbar c$.

The most interesting polarization effect in multiphoton processes with an elliptically-polarized laser field is elliptic dichroism (ED), which consists in the dependence of cross sections on the sign of the circular polarization degree (i. e., on the helicity) of a photon. This effect vanishes both for linear and circular polarizations of $\mathbf{F}(t)$ and occurs only for the case of an elliptic polarization [2]. Eqs. (1) - (3) demonstrate that in n-photon detachment ED originates formally from the term

$$(\mathbf{e}^*\cdot\mathbf{e}^*)\mathrm{Im}\left\{(\hat{\mathbf{p}}\cdot\mathbf{e})^2\right\} = l\,\mathrm{Im}\left\{(\hat{\mathbf{p}}\cdot\mathbf{e})^2\right\} = l\,\xi\,\cos\alpha\,\cos\beta \qquad (4)$$

in expressions for $d\sigma^{(n)}$. The parameter ξ $(-1 \leq \xi \leq +1)$ is the circular polarization degree: $\xi = i\hat{\mathbf{k}}\cdot[\mathbf{e}\times\mathbf{e}^*]$. The angles α and β are those between the directions of the photoelectron momentum, $\mathbf{p}$, and the major and minor axes of the laser polarization ellipse. Physically, in all cases ED is caused by the interference between real and imaginary parts of detachment amplitudes. For the case $n=1$ it arises from the interference between first-order and third-order ("rescattering") amplitudes. Obviously the ED effect in this case is small in the perturbative regime and for its measurement the case of a strong laser field is most appropriate. For $n=2$ and 3 the magnitude of the ED term is comparable to those of other contributions to $d\sigma^{(n)}/d\Omega_{\hat{\mathbf{p}}}$.

Our result for $d\sigma^{(2)}$ coincides with that obtained by standard PT calculations [3]. ED vanishes after integrating over the directions of $\hat{\mathbf{p}}$. For this case, total rates of photodetachment, $\sigma^{(n)}$, coincide with those obtained from the imaginary part of the complex quasienergy ϵ, i. e., without using the QQES wavefunction. For the case of linear polarization of $\mathbf{F}(t)$, the 3 independent parameters of the angular distribution $d\sigma^{(2)}$ are in good agreement with those measured for H^- in a recent experiment [4]. Four independent atomic parameters describe the angular distributions of two- and three-photon detachment from an initial S-state for an elliptically-polarized laser field, and one of them is the ED-parameter.

[1] N. L. Manakov and A. G. Fainshtein, Sov. Phys.—JETP **52**, 382 (1980).

[2] N. L. Manakov, in *Super-Intense Laser-Atom Processes* (Kluwer, Dordrecht, 1996) p. 152.

[3] N. L. Manakov, S. I.Marmo, A. Maquet *et al.* J. Phys. B **32**, 3747 (1999).

[4] M. S. Gulley, X. M. Zhao, H. C. Bryant *et al.* Phys. Rev. A **60**, 4753 (1999).