QED processes in a field of an intense laser wave

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- **Motivation:** experiments with intense laser beams and heavy ions.

Approach:

- Scattering theory within the Furry picture. Rates are obtained using dressed solutions to the Dirac equation (Volkov solutions).

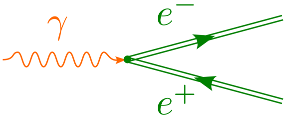
$$\psi = \left[1 + \frac{e}{2(kp)}(\gamma k)(\gamma A)\right] \frac{u}{\sqrt{2p_0}} e^{iS}, \qquad S = -px - \int_0^{kx} \frac{e}{(kp)} \left[(pA) - \frac{e}{2}A^2\right] d\eta$$

- Atomic processes: numerical solution of time-dependent Dirac equation:

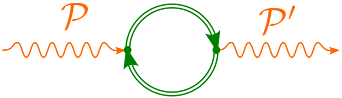
$$i\frac{\partial \Psi}{\partial t} = \hat{\mathcal{H}}\Psi, \qquad \hat{\mathcal{H}} = \vec{\alpha}\left(\vec{p} - e\vec{A}\right) + \beta m + e\varphi$$

The wave function is constructed from a (quasi-) stationary basis:

$$\Psi = \sum_n a_n(t)\Phi_n, \qquad \hat{\mathcal{H}}_0\Phi_n = \mathcal{E}_n\Phi_n.$$



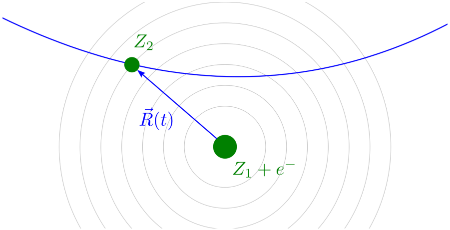
One-photon photoproduction of an $e^- e^+$ pair

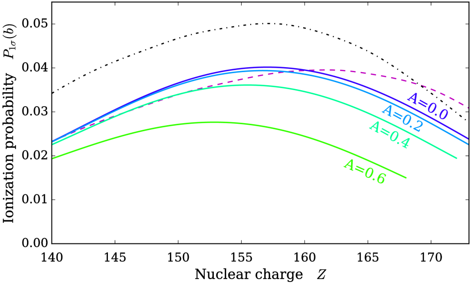


Vacuum birefringence.

- Polarization-dependent rate of one-photon pair production in strong field.
- Vacuum birefringence in weak and supercritical fields.
- A cascade of single-photon $e^- e^+$ pair production and annihilation in a strong magnetic field.

[M. M. Diachenko, O. P. Novak and R. I. Kholodov. Laser Phys. 26, 066001 (2016)]
[O. Novak, M. Diachenko, E. Padusenko, R. Kholodov. Ukr. J. Phys. 63, 979 (2018)]





Heavy ion collision and total ionization probability, $A = (Z_1 - Z_2)/(Z_1 + Z_2)$; $Z = Z_1 + Z_2$.

- Numerical solution to quasi-stationary problem for fixed nuclei positons.
- TDDE solution within perturbation theory and parametrization of the probability amplitude.
- Analytical probability with matrix element parametrization.

[O.Novak, R.Kholodov, A.Surzhykov, A.N.Artemyev, Th.Stöhlker. Phys. Rev. A 97, 032518 (2018)]

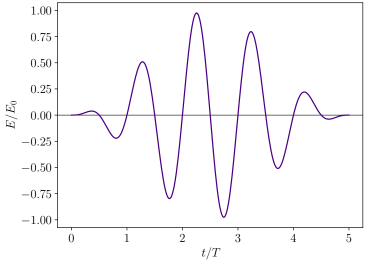
- The problem considered both numerically and within the perturbation theory.
- Laser wave is taken into account in the dipole approximation.
- Laser pulse:

Pulse shape: $A(t) = \frac{E_0}{\omega} \sin^2\left(\frac{\pi t}{\tau}\right) \sin(\omega t + \phi),$

Duration: $\tau = 5 \cdot 2\pi/\omega$

Field strength: $E_0 = 10^{-2} E',$ where

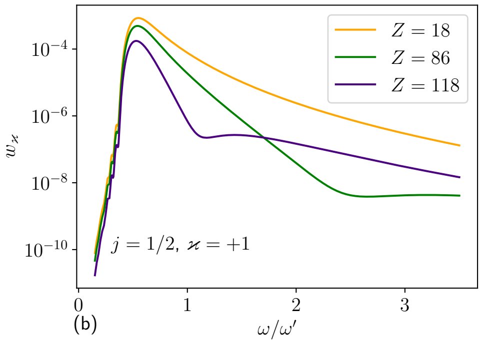
$E' = 3Z/< r^2 >$

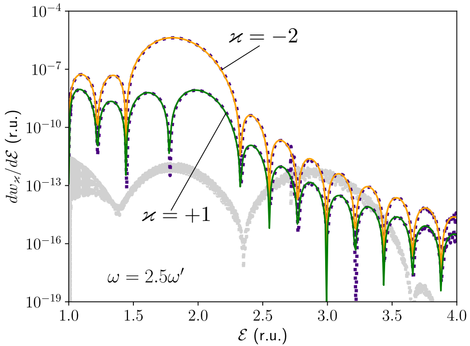


- Main channels for photoionization from the ground state:

$$l = 1, \quad j = 3/2, \quad \varkappa = -2; \tag{1}$$
$$l = 1, \quad j = 1/2, \quad \varkappa = +1. \tag{2}$$

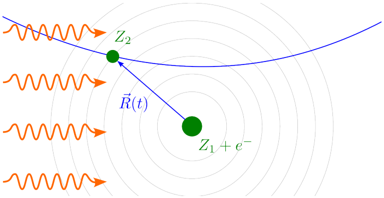
Heavy ion photoionization.

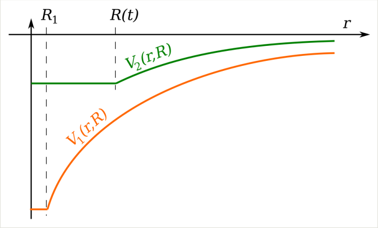




Photoionization probability $w_\varkappa$ as a function of laser frequency, $\varkappa = +1$.
Electronic spectra of Rn photoionization: perturbative and numerical results.
In the case $\varkappa = +1$ the local minimum is present at approximately $\omega = mc^2$.

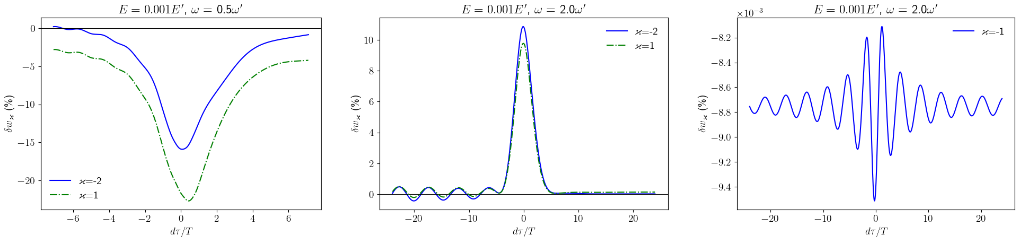
$$\omega' = 2\mathcal{E}_{bind}$$





- Ground-state ionization in a laser-assisted collision of a ${}_{82}\text{Pb}^{81+}$ and an α-particle.
- Laser in the dipole approximation and Coulomb potential in the monopole approximation.
- Perturbative result: ionization channels are independent and the total probability is the sum of the "collision-only" and "laser-only" probabilities. Transitions are allowed to

$$\begin{cases} \kappa' = -2 \\ j' = 3/2 \end{cases} \qquad \begin{cases} \kappa' = -1 \\ j' = 1/2 \end{cases} \qquad \begin{cases} \kappa' = +1; \\ j' = 1/2 \end{cases}$$



(a) (b) (c)

Relative difference of the total probability $\delta w_\varkappa$
and the sum of "collision only" and "laser only" probabilities.
(a,b) are "photoionization channels", $\varkappa = -2, +1$; (c) is the "collision channel", $\varkappa = -1$.

$$E' = \frac{3Ze}{\langle r^2 \rangle}, \qquad \omega' = 2\mathcal{E}_{bind}$$

$$\mathcal{E}_{CM} = 10 \text{ MeV}; \ \rho = 0.$$

Thank you for attention!