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Final report
on the results obtained by the
Project "Excitations of nuclei by ultra-intense laser fields. Quasiclassical methods", 2016-2019, ELI-RO, IFA, 5.1 June 2020

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The activity within the framework of this Project produced 5 published papers:

1. Scattering of non-relativistic charged particles by electromagnetic radiation M. Apostol Z. Naturforschung **A72** 1173-1177 (2017) 2. Fast atom ionization in strong electromagnetic radiation M. Apostol Z. Naturforschung **A73** 461-466 (2018) 3. Electromagnetic-radiation effect on alpha decay M. Apostol J. Math. Theor. Phys. **1** 155-159 (2018) 4. Analysis of the cross-section of charge scattering by electromagnetic radiation M. Apostol and L. C. Cune Roum. J. Phys. **63** 110 (2018) 5. Resonant coupling of the electron cloud with the nucleus in heavy atoms M. Apostol Roum. Reps. Phys. **71** 210 (2019)

Three new, original, basic and very important results have been obtained in these papers:

a) charges (like electrons) can be diffracted by laser pulses in vacuum b) fast ionziation rate was computed for high-intensity radiation fields c) high-intensity radiation fields have practically no effect upon alpha decay, nor upon proton ejection from the nuclei. All these results can be tested experimentaly.

Paper 1 The starting point is the charge-nucleus collision in laser field. A collision fully immersed in laser radiation was taken up in a classical work by Kroll and Watson in 1973, with the well-known result of a Born cross-section modulated by Bessel functions which account for multiple absorption and emission of photons. Paper 1 relates to the charge collision by laser radiation confined to a limited spatial region, in the laser beam focus. This problem is of absolute novelty; it predicts a new phenomenon which can be tested in experiments at ELI facility. The result exhibits a cross-section due to the charge-laser focus scattering. The resulting modulation of the cross-section is due to multiple photons distributed over the whole region of the laser-beams focus. The diffraction maxima are given by the energy and momentum conservation laws. The cross-section is large, due to the large spatial extension of the focus. The method employed in this paper is the dipole approximation, standard canonical transformations, the identification of the scattering potential and the computation of the S-matrix in the lowest-order approximation.

Paper 4 We have been concerned with the experimental test of the cross-section derived in Paper 1. Consequently, we have extended the analysis of the cross-section of charge scattering by laser pulses, in order to be more adapted for experimental analysis. The extenson consists in estimating specific experimental situations and providing numerical results for possible experimental measurements. In particular, scattering angles, separation angles and momentum transfer have been computed in this paper, and the multiple-photon emission and absorption regions have been identified. The cross-section has been estimated in terms directly amenable to experimental use. In addition, particular cases of transverse scattering and longitudinal "scattering" are presented in this paper.

Paper 2 The ionization of heavy atoms in low-intensity radiation field is known since long (L. V. Keldysh, "Ionization in the field of a strong electromagnetic wave", Sov. Phys.-JETP **20** 1307-1314 (1965) (ZhETF **47** 1945-1957 (1965)). It has the well-known exponential dependence on the electric field, which saturates at high field. It is obtained by estimating the quasiclassical tunneling rate of adiabatic transitons, a well-known technique in Quantum Mechanics. The rate of ionisation is used for estimating the laser intensity in the focal region. With the advent of high-intensity lasers this formula became inapplicable. We have analyzed the motion of a bound charge in electromagnetic radiation by means of the quantum-mechanical Goeppert-Henneberger canonical transformations. By this analysis we have discovered that high-intensity electromagnetic radition decreases appreciably the binding potential and may liberate the charge (electron) from the atom. We have computed the rate of ionization in this case, for heavy atoms, which has an algebraic dependence on the field intensity (in contrast to the exponential dependemce). This is a completely new and original result, and a basic addition to the theory of high-power lasers. The same theory may be applied to proton emission from atomic nuclei, providing a high-intensity feld may act upon the nucleus in heavy atoms. Experimentalists who endeavour with measuring the laser intensity in the focal region (calibration of the laser power) may use the formula given by us in this publication. The theory has also been extended to constant (uniform) high electric fields.

Paper 3 In the community of high-power laser physicists a great interest exists for a possible use of these lasers to reduce the lifetime of nuclear waste, especially by accelerating the rate of alpha decay. The nuclear physicists are divided: a large part of them claims that the laser radiation would not have an effect on the rate of the alpha decay, as high the intensity would be, while other large part claims that this rate would be greatly enhanced by high intensity. Both parties do calculations in support of their claim without a sufficient analysis of the problem. The difficulty resides in the very small effect the laser radiation may have upon the alpha decay. A large effect is easy to be estimated, while a small effect requires subtle investigation methods, which are not immediate for everybody. This paper made a rigorous and thorough analysis of the tunneling rate of the alpha particle from the atomic nucleus, within the correspondingly appropriate quasiclassical approximation, and found an extremely low effect, indeed. Because the community is so sharply, and deeply, divided, the paper couldnt be published but in a rather obscure journal. However, this is a basic paper for a current problem in the application of the high-power lasers to the nuclear physics.

Paper 5 With the advent of the high-power lasers the quest appeared of probing the atomic nucleus with high-intensity electromagnetic radiation. Apart from alpha decay, it was thought that protons may be ejected from the nucleus under the action of a high-intensity electromagnetic field. Of course, heavy nuclei would be prone to such an effect. We showed in this paper that this is a pretty illusory problem. The electromagnetic field produces a giant oscillation of the electron cloud surrounding the nucleus in a heavy atom. This was shown in a previous paper (M. Apostol, Roum. Reps. Phys. **67** 837 (2015)). This is a new phenomenon, which can be probed by X-ray scattering. The screening brought about by this electronic oscillation leaves a very low-intensity electromagnetic field to act upon the nucleus, so we do not expect a significant effect upon the nucleus. However, a resonance exists, for a high frequency, which may be attained by free electron lasers. It may appear that high field could be obtained on the nucleus. We have shown in this paper that this high field produces a fast ionization of the atom, eliminating an electron, or more, from the atom, such that the resonance condition is fastly lost; in the newly formed ion, the screening acts again, and the field acting upon the nucleus becomes low. The rate of proton ejection was estimated in this paper, and found very small. This is an important paper in the research area of lasers interacting with the atomic nuclei, because it destroys a myth.