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Editorial

Special Issue Editorial “Atomic Processes in Plasmas and Gases: Symmetries and Beyond”

Eugene Oks

Physics Department, Auburn University, 380 Duncan Drive, Auburn, AL 36849, USA; goks@physics.auburn.edu

Atomic processes in plasmas and gases encompass broad areas in theoretical and experimental atomic and molecular physics. One example is atomic processes that are involved in the study of various plasmas over a wide range of electron densities (from 10^{11} cm^{-3} to 10^{23} cm^{-3}) and temperatures (from eV to a few keVs). The topics in this field include (but are not limited to) magnetic fusion plasmas, laser-produced plasmas, relativistic laser–plasma interactions, powerful radiation sources (Z-pinches, plasma focus, XFEL, etc.), low-temperature and industrial plasmas, astrophysical plasmas, as well as plasma spectroscopy for all of the abovementioned applications. Another example is atomic and molecular processes in neutral gases. The topics in this field include (but are not limited to) the molecular spectroscopy of gases, from low-resolution to ultra-high-resolution, from the microwave to the ultraviolet, and from fundamental science to applications such as astronomy and atmospheric science.

Considerations of symmetry often play an important role in theoretical advances, especially in plasma spectroscopy and molecular spectroscopy. For example, the employment of additional conserved quantities, originating from algebraic symmetries of underlying quantum systems, frequently allows important analytical results to be obtained and/or leads to more robust codes.

N.L. Popov and A.V. Vinogradov, in the paper “Space-Time Coupling: Current Concept and Two Examples from Ultrafast Optics Studied Using Exact Solution of EM Equations” [1], discussed the manifestation of space–time coupling (STC) phenomena in the framework of the simplest exact localized solution of Maxwell’s equations, exhibiting a “collapsing shell”. They considered the excitation of a two-level system located in the center of the collapsing EM (electromagnetic) pulse. This study showed that as it propagates, a unipolar pulse can turn into a bipolar one, and in the case of measuring the excitation efficiency, we can judge which of these two pulses we are dealing with. The obtained results have no limitation on the number of cycles in a pulse. The work confirmed the productivity of using exact solutions of EM wave equations for describing the phenomena associated with STC effects.

M. Goto and N. Ramaiya, in the paper “Polarization of Lyman-α Line Due to the Anisotropy of Electron Collisions in a Plasma” [2], developed an atomic model for the calculation of the polarization state of the Lyman-α line in plasma caused by anisotropic electron collision excitations. The calculation results gave the polarization degree of several percent under typical conditions in the edge region of a magnetically confined fusion plasma. They also found that the relaxation of polarization due to collisional averaging among the magnetic sublevels was effective in the electron density region considered. Their analysis of the experimental data measured in the Large Helical Device yielded $T\perp/T\|$ = 7.6 at the expected Lyman-α emission location outside the confined region. The result was derived with the absolute polarization degree of 0.033, and $T\perp$ = 32 eV and ne = 9.6 × 1018 m^{-3}, measured using the Thomson scattering diagnostic system.

P.A. Sdvizhenskii et al., in the paper “Data for Beryllium–Hydrogen Charge Exchange in One and Two Centres Models, Relevant for Tokamak Plasmas” [3], presented the analysis of data on the cross section and kinetic rate of charge exchange (CX) between the bare beryllium nucleus, the ion Be(+4), and the neutral hydrogen atom. These data are of

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great interest for visible-range high-resolution spectroscopy in the ITER tokamak because beryllium is intended as the material for the first wall in the main chamber. Data in the range of a few eV/amu to ~100 eV/amu (amu stands for the atomic mass unit) needed for simulations of level populations for principal and orbital quantum numbers in the emitting beryllium ions Be(+3) can be obtained with the help of two-dimensional kinetic codes. The lack of literature data, especially for data resolved in orbital quantum numbers, has prompted us to make numerical calculations with the ARSENY code. The authors presented the comparison of the results obtained for the one-center Coulomb problem using an analytic approach with the two-center problem using numerical simulations.

C.G. Parigger et al., in the paper "Hypersonic Imaging and Emission Spectroscopy of Hydrogen and Cyanide Following Laser-Induced Optical Breakdown" [4], communicated the connection of measured shadowgraphs from optically induced air breakdown with emission spectroscopy in selected gas mixtures. Laser-induced optical breakdown was generated using 850 and 170 mJ and 6 ns pulses at a wavelength of 1064 nm, the shadowgraphs were recorded using time-delayed 5 ns pulses at a wavelength of 532 nm and a digital camera, and emission spectra were recorded for typically a dozen discrete time-delays from optical breakdown by employing an intensified charge-coupled device. The symmetry of the breakdown event could be viewed as close-to spherical symmetry for time-delays of several 100 ns. The analysis of the air breakdown and selected gas breakdown events permitted the use of Abel inversion for the inference of the expanding species distribution. Overall, the recorded air breakdown shadowgraphs were indicative of laser–plasma expansion in selected gas mixtures, and optical spectroscopy delivered analytical insight into plasma expansion phenomena.

V.A. Astapenko and E.V. Sakhno, in the paper "Chirped Laser Pulse Effect on a Quantum Linear Oscillator" [5], presented a theoretical study of the excitation of a charged quantum linear oscillator via a chirped laser pulse by using the probability of the process throughout the pulse action. They focused on the case of the excitation of the oscillator from the ground state without relaxation. Calculations were made for an arbitrary value of the electric field strength by utilizing the exact expression for the excitation probability. The dependence of the excitation probability on the pulse parameters was analyzed both numerically and by using analytical formulas.

E. Oks, in the paper "Oscillatory-Precessional Motion of a Rydberg Electron Around a Polar Molecule" [6], provided a detailed classical description of the oscillatory–precessional motion of an electron in the field of an electric dipole. Specifically, he demonstrated that in the general case of the oscillatory–precessional motion of an electron (with the oscillations being in the meridional direction (θ-direction) and the precession being along parallels of latitude (φ-direction)), both the θ-oscillations and the φ-precessions can actually occur on the same time scale—contrary to the statement from the work by another author. He obtained the dependence of φ on θ, the time evolution of the dynamical variable θ, the period T_θ of the θ-oscillations, and the change in the angular variable φ during one half-period of the θ-motion—all in the forms of one-fold integrals in the general case—and illustrated it pictorially. The author also produced the corresponding explicit analytical expressions for relatively small values of the projection p_φ of the angular momentum on the axis of the electric dipole. He also derived a general condition for this conditionally periodic motion to become periodic (the trajectory of the electron would become a closed curve) and then provide examples of the values of p_φ for this to happen. In addition, for the particular case of $p_\varphi = 0$, he produced an explicit analytical result for the dependence of the time t on θ. For the opposite particular case, where p_φ is equal to its maximum possible value (consistent with the bound motion), he derived an explicit analytical result for the period of the revolution of the electron along the parallel of latitude.

E. Oks, in the paper "Application of the Generalized Hamiltonian Dynamics to Spherical Harmonic Oscillators" [7], extended the applications of the Dirac's Generalized Hamiltonian Dynamics (GHD) to a charged Spherical Harmonic Oscillator (SHO). Dirac's Generalized Hamiltonian Dynamics (GHD) is a purely classical formalism for systems having constraints: it incorporates the constraints into the Hamiltonian. Dirac designed the GHD specifically for applications to quantum field theory. In one of Oks' previous papers (coauthored with T. Uzer) [8], he redesigned Dirac's GHD for its applications to atomic and molecular physics by choosing integrals of the motion as the constraints. In that paper, after a general description of the formalism, they considered hydrogenic atoms as an example. They showed that this formalism leads to the existence of classical non-radiating (stationary) states and that there is an infinite number of such states—just as in the corresponding quantum solution. In the present paper, while extending the applications of the GHD to the SHO, Oks demonstrated that, by using the higher-than-geometrical symmetry (i.e., the algebraic symmetry) of the SHO and the corresponding additional conserved quantities, it is possible to obtain the classical non-radiating (stationary) states of the SHO and that, generally speaking, there is an infinite number of such states of the SHO. Both the existence of the classical stationary states of the SHO and the infinite number of such states are consistent with the corresponding quantum results. He obtained these new results from first principles. Physically, the existence of the classical stationary states is the manifestation of a non-Einsteinian time dilation. Time dilates more and more as the energy of the system becomes closer and closer to the energy of the classical non-radiating state. He emphasized that the SHO and hydrogenic atoms are not the only microscopic systems that can be successfully treated by the GHD. All classical systems of N degrees of freedom have the algebraic symmetries O_{N+1} and SU_N, and this does not depend on the functional form of the Hamiltonian. In particular, all classical spherically symmetric potentials have algebraic symmetries, namely O_4 and SU_3; they possess an additional vector integral of the motion, while the quantal counterpart-operator does not exist. This offers possibilities that are absent in quantum mechanics.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Popov, N.L.; Vinogradov, A.V. Space-Time Coupling: Current Concept and Two Examples from Ultrafast Optics Studied Using Exact Solution of EM Equations. *Symmetry* **2021**, *13*, 529. [CrossRef]
2. Goto, M.; Ramaiya, N. Polarization of Lyman-α Line Due to the Anisotropy of Electron Collisions in a Plasma. *Symmetry* **2021**, *13*, 297. [CrossRef]
3. Sdvizhenskii, P.A.; Tolstikhina, I.Y.; Lisitsa, V.S.; Kukushkin, A.B.; Tugarinov, S.N. Data for Beryllium–Hydrogen Charge Exchange in One and Two Centres Models, Relevant for Tokamak Plasmas. *Symmetry* **2021**, *13*, 16. [CrossRef]
4. Parigger, C.G.; Helstern, C.M.; Gautam, G. Hypersonic Imaging and Emission Spectroscopy of Hydrogen and Cyanide Following Laser-Induced Optical Breakdown. *Symmetry* **2021**, *12*, 2116. [CrossRef]
5. Astapenko, V.A.; Sakhno, E.V. Chirped Laser Pulse Effect on a Quantum Linear Oscillator. *Symmetry* **2021**, *12*, 1293. [CrossRef]
6. Oks, E. Oscillatory-Precessional Motion of a Rydberg Electron Around a Polar Molecule. *Symmetry* **2021**, *12*, 1275. [CrossRef]
7. Oks, E. Application of the Generalized Hamiltonian Dynamics to Spherical Harmonic Oscillators. *Symmetry* **2021**, *12*, 1130. [CrossRef]
8. Oks, E.; Uzer, T. Application of Dirac's Generalized Hamiltonian Dynamics to Atomic and Molecular Systems. *J. Phys. B At. Mol. Opt. Phys.* **2002**, *35*, 165–173. [CrossRef]