Scientific session of the Division of General Physics and Astronomy, USSR Academy of Sciences (26 March, 1975)

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A scientific session of the Division of General Physics and Astronomy was held on March 26, 1975 at the Conference Hall of the P. N. Lebedev Physics Institute. The following papers were delivered:

1. G. A. Delone, N. B. Delone, B. A. Zon, N. L. Manakov, and L. P. Rapoport. Nonresonant Excitation of the Atomic Spectrum in a Light Field.

2. G. V. Gadiak, D. A. Kirzhnits, and Yu. E. Lozovik. Collective Excited States in Atoms.

We publish below brief contents of the papers.

G. A. Delone, N. B. Delone, B. A. Zon, N. L. Manakov, and L. P. Rapoport. Nonresonant Excitation of the Atomic Spectrum in a Light Field. Excitation of the atomic spectrum in an alternating field is much more complicated in nature than excitation in a constant field. This is because the alternating field is characterized not only by intensity, but also by frequency and ellipticity (we are considering only fully polarized monochromatic fields). Our studies were concerned with nonresonant excitation. We class as resonant excitations those cases in which the energy of the transition between the states ij in the field $\Delta E_{ij}(\mathscr{E}) = k\hbar\omega$ (where k = 1, 2, ..., $\mathscr{E}$ is the electric field strength, and ω is the frequency of the field), the ij transition is allowed by the selection rules, and resonant mixing of the states ij (which is sometimes called the saturation effect)[1] arises.

For all practical purposes, only one effect had been studied previously: nonresonant excitation of an isolated bound electron state in a linearly polarized field[2]. It is known that in this case, the change in the energy of level i is described in the first nonvanishing order of perturbation theory by the relation $\Delta E_i(\mathscr{E}) = -(1/2) = -(1/2)(\eta - i\gamma)\mathscr{E}^2$, where η and γ are the real and imaginary parts of the dynamic polarizability of the i-th level. The advance that we made in the experiment consisted in the use of a resonant process of multiphoton ionization of the atoms[3] to observe the change in the transition energy, $\Delta E_{ij}(\mathscr{E})$. Compared to the classical methods of observing spontaneous relaxation of a state i or absorption of light from an auxiliary source[2], this method makes it possible to move into a range of higher field strengths and higher atomic levels, i.e., into conditions under which ionization from the resonant state dominates. The resonant multiphoton ionization method made it possible to obtain data up to a field strength $\sim 10^6$ V·cm^{-1} and for levels with principal quantum numbers up to n = 15[4]. Progress in the development of the theory consisted in the creation of methods that permit calculation of the dynamic polarizability for various states in various atoms[5]. In addition, the limit of applicability of perturbation theory was found for a number of typical examples. Thus, $\delta E_i(\mathscr{E}^2) \sim \delta E_i(\mathscr{E}^4)$ at $\mathscr{E} \sim 10^7$ V·cm^{-1} for the ground states of alkali-metal atoms. Thus, the foundations were laid for systematic experimental measurements and calculations for a broad range of variation of the principal parameters characterizing the linearly polarized field and various atoms.

Qualitatively new phenomena appear in an elliptic field. Because there is no preferred direction, the degeneracy in the projection of the orbital angular momentum is lifted completely, the magnetic quantum number ceases to be good, and the quasistationary states formed under the action of the fields constitute a superposition of states with different projections of the momentum. The experiment of[6] made it possible to observe state splitting in the elliptical field and a change in the energy of the new states compared to the energy of the original unsplit state. Theoretical description of the disturbance of the bound electron state in the elliptical field explains both the number of components observed and their energies in the field[7]. We should note that the quasistationary states that arise under the action of the elliptical field are found to be nonorthogonal at $\hbar\omega > I_i$ (where I_i is the ionization potential of state i) because of the possibility of their decay into the same channel (ionization), so that interference effects can arise.

The disturbance of degenerate levels in the hydrogen atom may be either linear or quadratic in the field, depending on the frequency of the alternating field. The parameter that determines the transition from linear to quadratic disturbances is the ratio $\lambda = (2\pi\mathscr{E}/\omega)^2 = E_{vib}/I_n$, where E_{vib} is the vibrational energy of the free electron in the alternating field and I_n is the ionization potential of state n. At $\lambda \gg 1$, we have $\delta E(\mathscr{E}) \sim \mathscr{E}$. At $\lambda \ll 1$, $\delta E(\mathscr{E}) \sim \mathscr{E}^2$, and $\delta E(\mathscr{E}) \to E_{vib}$ as n increases. Convergence with the asymptote takes place at the frequencies at which the channel of single-photon ionization of the atom is opened[8]. When the atom-field interaction energy is comparable to the distance between levels, $V_{ij} \sim \Delta E_{ij}$, their mixing results in the appearance of new quasistationary states. Analysis of intramultiplet mixing without consideration of intermultiplet mixing yielded an estimate of the role of the effect[9]. Thus, for example, at the typical distance ~ 0.1 cm^{-1} between doublet levels, mixing can take place in fields $\sim 10^6$ V/cm if the disturbance lasts long enough, $\tau \sim 10^{-9}$ sec.

We should note in conclusion that the further development of studies of atomic-spectrum disturbance in the light field is of interest both from the standpoint of development of the quantum mechanics of the atom and from the standpoint of practical multiquantum spectroscopy.

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G. V. Gadiyak, D. A. Kirzhnits and Yu. E. Lozovik. Collective Excited States in Atoms. The paper argues in favor of the existence of special, collective excited states (CES) of the electron shells of heavy atoms (atomic numbers $Z \gg 1$). CES resemble vibrations of a charged liquid drop or plasma oscillations of the electron fluid in a metal. They have specific quantum numbers that do not reduce to the electron-hole numbers that correspond to ordinary single-frequency excitations in the atom.

Two difficulties stood in the way of solution of the problem of the existence of CES in the atom, which was posed more than 40 years ago. First, the CES had to lie within the continuous single-frequency spectrum corresponding to excitations of outer electrons of the atom, and separation of the CES from the corresponding background is an independent problem. The authors proposed that the CES proper are localized at the center of the atom and make the transition to background excitations only as a result of decay. This was confirmed by the appearance of distinct plateaus on the curves of CES frequency and damping as functions of the localization radius; it is to these plateaus that realistic values of the above quantities correspond. The second difficulty was that the damping of CES in the atom does not have literal smallness with respect to the frequency, in contrast to the case of a homogeneous medium. Therefore only a numerical calculation based on the theory of inhomogeneous systems could lead to smallness of the corresponding ratio and hence to the conclusion that the CES actually exist.

A calculation of this kind made on the BÉSM-6 computer of the USSR Academy of Sciences Siberian Division Computer Center was used as a basis for the theory of dielectric response for inhomogeneous systems proposed earlier by the authors, which was based on a combination of the random-phase approximation and the quasiclassical description of the single-frequency states. The accuracy of this theory as applied to the heavy atom is determined by the parameter $Z^{-2/3}$. A search for weakly damped CES of the dipolar optically active type (which correspond in first approximation to vibrations of the shell as a whole with respect to the nucleus) resulted in detection of two such excitations with the respective frequencies 13.7Z eV and 36.0Z eV and damping ratios of $3 \times 10^{-3}Z$ eV and $10^{-4}Z$ eV. The oscillator strength for the lower level is of the order of 0.1Z, while that for the upper level is three orders smaller. The observed CES lie in the soft x-ray range (vacuum ultraviolet). They could have been manifested in experiments as narrow peaks in the photoabsorption cross section or as the cause of the appearance of atomic-reaction features typical for the Bohr picture.

The results reported in the paper were published in:

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The two-level system in a strong light field

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The section on Atomic Collisions (Chairman V. V. Afrosimov) of the USSR Academy of Sciences Council on Plasma Physics has recently shown excellent initiative in organizing conferences on specific problems that are of immediate importance for practice and new from the standpoint of basic research. Two excursion sessions were held in 1974. A conference on the topic "Coherence of Laser Radiation and Multiquantum Processes" (Chairman of Program Committee S. I. Anisimov) was held in February at the USSR Academy of Sciences Institutes of Theoretical Physics and Solid-State Physics (Chernogolovka, Moscow Oblast'). Another on the subject "The Two-Level System in a Strong Light Field" (Program Committee Chairman V. A. Kovarskiĭ) was held at the Moldavian Academy of Sciences Institute of Applied Physics (Kishinev) in December. The narrow specialization of the conferees who are working actively in this area, the use of invited papers in the basic format of the conferences, the original scientific communications presented by most of those in attendance, and the planned free discussions all combine to make such conferences highly productive.

The conference at Kishinev is a good example. At first glance, the two-level system is one of the most thoroughly studied models that have come into extensive use in quantum radiophysics. However, various new