MEETINGS AND CONFERENCES

Scientific session of the Division of General Physics and Astronomy, USSR Academy of Sciences (23 April 1975)

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An excursion scientific session of the Division of General Physics and Astronomy of the USSR Academy of Sciences was held on April 23 at the USSR Academy of Sciences Institute of Spectroscopy (Krasnaya Pakhra, Akademgorodok). The following papers were delivered:

1. Ya. B. Zel'dovich, N. L. Manakov and L. P. Rapoport, Quasienergy of a System Subjected to a Periodic External Disturbance.

2. S. L. Mandel'shtam and É. Ya. Kononov, Spectroscopy of Highly Ionized Atoms.

3. R. V. Ambartsumyan and V. S. Letokhov, Collisionless Dissociation of Polyatomic Molecules in a Strong Infrared Laser Field, and Its Use for Separation of Isotopes.

4. V. M. Agranovich, Yu. E. Lozovik and A. G. Mal'shukov, Electronic Restructuring at the Dielectric-Metal Boundary and the Search for High-Temperature Superconductivity.

5. G. N. Zhizhin, O. I. Kapusta, M. A. Moskaleva, V. G. Nazin and V. A. Yakovlev, Spectroscopy of Surface Waves and the Properties of the Surface.

6. E. N. Antonov, V. G. Koloshnikov and V. R. Mironenko, In-Cavity Absorption Spectroscopy with a Continuous Dye Laser.

We publish below brief contents of the papers.

Ya. B. Zel'dovich, N. L. Manakov and L. P. Rapoport. Quasienergy of a System Subjected to a Periodic External Disturbance. The first part of the paper describes the general properties of solutions of the Schrödinger equation with a Hamiltonian that depends periodically on the time. An analogy is drawn between the quasienergy states (QES) of the system in a periodic field and stationary states in a time-independent potential. The problems of emission and absorption on transitions of the system between different QES are discussed[1].

The second part of the report discusses the problems of determining the exact spectrum of the quasienergy ϵ and the corresponding QES wave functions $\psi_\epsilon(\mathbf{r}, t)$ in specific cases. Since the problem then requires exact solution of the nonstationary Schrödinger equation, states with definite quasienergy are now known only for the simplest quantum systems: the free electron in a field and the harmonic oscillator with variable parameters[2]. The theory of perturbations in the system-field interaction is used in one form or another in more complex cases.

For the interaction of the system with the field of a strong circularly polarized electromagnetic wave, an explicit expression can be obtained for the quasienergy operator, and ϵ and ψ_ϵ can be calculated without using perturbation theory. This is because the operator of the interaction with the field (in the dipole approximation)

$$V(\mathbf{r}, t) = eFr \sin\theta \cdot \cos(\varphi - \omega t)$$

possesses obvious symmetry with respect to the variables φ and ωt, and the Schrödinger equation

$$i\hbar \frac{\partial\psi(\mathbf{r}, t)}{\partial t} = [\mathcal{H}_0(\mathbf{r}) + V(\mathbf{r}, t)]\,\psi(\mathbf{r}, t) \tag{1}$$

has a stationary Hamiltonian on conversion to a coordinate system that rotates at the field frequency:[1)]

$$Q(\mathbf{r}) = \mathcal{H}_0(\mathbf{r}) - \omega L_z + eFx.$$

The operator Q is the quasienergy operator because solutions of the eigenvalue equation

$$Q(\mathbf{r})\,\varphi_E(\mathbf{r}) = E\varphi_E(\mathbf{r}) \tag{2}$$

have corresponding functions $\psi_E(\mathbf{r}, t) = e^{-iEt/\hbar} \times e^{-(i\omega t/\hbar)L_z}\varphi_E(\mathbf{r})$, which are solutions of (1) with quasienergy E.

The simplest case of application is a rotator that has a constant dipole moment p_0 and rotates in the plane perpendicular to the direction of wave propagation. Equation (2) then reduces to an equation of the Mathieu type, and ψ_ϵ can be represented in the form of a combination of Mathieu functions. What is interesting here is the fact that the quasienergy spectrum, which is identical in the absence of field to the rotational spectrum of the rotator, depends on F, and becomes equidistant, i.e., has an oscillatory structure, in the strong-field limit (when the interaction with the field is considerably greater than the rotational constant of the rotator). This is because the strong field "untwists" the rotator, and the dipole moment p_0 may describe small oscillations about the field vector $\mathbf{F}$ in the rotating system. This example shows that the quasienergy spectrum is determined by the field and may have nothing in common with the spectrum of the unperturbed problem.

In the case considered above, the system had only a discrete spectrum in the absence of the field, and the quasienergy spectrum remained discrete. If, in addition to the discrete spectrum, $\mathcal{H}_0(\mathbf{r})$ has a continuous component (for example, an atom or ion), it follows from the form of $Q(\mathbf{r})$ that the quasienergy spectrum is continuous and fills the entire real axis. Decay of the system (ionization) is possible in this case, and interest therefore attaches to calculation of the parameters of the quasistationary states that arise out of the unperturbed spectrum E_n when the field is switched on.

In rigorous formulation, the problem consists in calculating the coefficients C_E of the expansion of the unperturbed state $\psi_0(\mathbf{r})$ in the complete system of functions $\varphi_E(\mathbf{r})$. However, the problem can be simplified considerably if Eq. (2) for the system with the continuous quasienergy spectrum is regarded as a quasistationary-state equation, i.e., if the parameter E is regarded as complex and solutions $\varphi_E(\mathbf{r})$ that have asymptotic behavior of the diverging-wave type are sought.

[1)]Here it is assumed that $\mathcal{H}_0$ commutes with L_z.

As an example of calculation of the parameters of the quasistationary state, the paper considers the problem of decay of a level bound by short-range forces, one case of which is the ionization of a negative ion. In the zero-radius-potential approximation, Eq. (2) assumes the form

$$\left(\frac{\mathbf{p}^2}{2m}-\omega L_z+eFx-E\right)\varphi_E(\mathbf{r})=\frac{\hbar^2}{2m}\delta(\mathbf{r}).$$

The solution $\varphi_E(\mathbf{r})$ that satisfies the condition for emission as $r \to \infty$ agrees with the Fourier transform of the retarded Green function of a free particle in a constant electric field in a rotating coordinate system. Using the boundary condition that defines the behavior of $\varphi_E(\mathbf{r})$ as $r \to \infty$ (in the effective region of the potential), we can obtain an equation that relates the parameter E to the ionization potential I of the level in the absence of the field and to the characteristics of the field F and ω:

$$\sqrt{\varepsilon}=1-\frac{1}{\sqrt{4\pi i}}\int_0^\infty \frac{e^{-i\varepsilon t}}{t^{3/2}}\left[1-\exp\left(i\frac{\gamma^2\sin^3\delta t}{\delta^2 t}\right)\right]dt, \qquad (3)$$

where $\epsilon = \gamma^2 - (E/I)$, $\gamma^2 = e^2F^2/2m\omega^2 I$, $1/2\delta = I/\hbar\omega$. What is essential here is that both the shift and the width of the level are determined uniquely as the real and imaginary parts of the root of a transcendental equation. For values of $\gamma \gg 1$ and $\gamma \ll 1$, Eq. (3) yields an analytic expression for the probabilities of both tunnel and multiphoton ionization.

A detailed analysis of solutions of (3) with various values of the parameters γ and δ is given in [3].

A comparison is made between the ionization probabilities obtained and approximate calculations made previously and pertaining in large part to plane-polarized waves. The difference between the results is partly due to the fact that by acquiring an energy $n\hbar\omega$ in a circularly polarized wave, the system also acquires a momentum $n\hbar$.

[1]Ya. B. Zel'dovich, Usp. Fiz. Nauk 110, 139 (1973) [Sov. Phys.-Usp. 16, 427 (1973)].
[2]A. I. Baz', Ya. B. Zel'dovich, and A. M. Perelomov, Rasseyanie, reaktsii i raspady v nerelyativistskoĭ kvantovoĭ mekhanike [Scattering, Reactions, and Decays in Nonrelativistic Quantum Mechanics], Nauka, Moscow. 1971.
[3]N. L. Manakov and L. P. Rapoport, Zh. Eksp. Teor. Fiz. 69, 842 (1975) [Sov. Phys.-JETP 42, No. 3].