Scientific session of the Division of General Physics and Astronomy and the Divsision of Nuclear Physics of the Academy of Sciences of the USSR (27–28 May 1987)

Usp. Fiz. Nauk **153**, 525–530 (November 1987)

A joint scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics of the USSR Academy of Sciences was held on May 27 and 28, 1987 at the S. I. Vavilov Institute of Physical Problems of the USSR Academy of Sciences. The following reports were presented at the session:

May 27

1. *V. V. Zheleznyakov, V. V. Kocharovskiĭ, and Vl. V. Kocharovskiĭ.* Cyclotron superradiance in a plasma as a classical analog of Dicke superradiance.

2. *V. Yu. Trakhtengerts.* Ion cyclotron maser and the dynamics of the magnetospheric ring current.

3. *V. V. Zaĭtsev, E. Ya. Zlotnik, and V. E. Shaposhnikov.* Cyclotron mechanism of decameter radio emission of Jupiter.

May 28

4. *A. A. Boyarchuk and Yu. N. Gnedin.* Observations of the supernova 1987-a (in the Great Magellanic cloud) by Soviet observatories.

5. *G. T. Zatsepin and O. G. Ryazhskaya.* Events recorded on February 23 by underground detectors.

6. *E. N. Alekseev, L. N. Alekseeva, V. I. Volchenko, and I. V. Krivosheina.* Possible detection of a neutron burst on February 23 at 7 h 36 min by underground water-Cherenkov equipment and the Baksan scintillation telescope.

Summaries of three of the reports are presented below.

V. V. Zheleznyakov, V. V. Kocharovskiĭ, and Vl. V. Kocharovskiĭ. *Cyclotron superradiance in a plasma as a classical analog of Dicke superradiance.* In the report cyclotron superradiance (SR) in classical plasma physics and electronics[1] is explained and an analogy is established between it and Dicke SR in quantum electronics.[2,3] The latter effect, as is well known,[4] is associated with the dissipative instability of polarization waves (polariton modes) in a sample with preinverted atoms. The development of this instability leads to spontaneous appearance of phased dipole oscillations of atoms, whose simultaneous coherent emission forms a short SR pulse. The power of this pulse is proportional to the square of the number of active atoms: $Q \propto N^2$.

The study of the analogous SR effect in classical electronics and plasma physics is motivated by the search for methods for generating powerful pulses of coherent electromagnetic radiation that do not depend on the use of high-Q resonators. Existing methods of generation in more or less open samples are most often based on the so-called superluminescence effect, i.e., induced amplification of spontaneous emission of unphased excited particles. On the scale of the lifetime T_2 (incoherent relaxation) of the dipole oscillations of separate particles—atoms or electrons, however, the process of superluminescence develops slowly and therefore the polarization arising in an active sample is comparatively weak, and the collective behavior of the particles is also comparatively weak.

It is therefore important to analyze the mechanisms of generation in which the spontaneous appearance of oscillations of emitting particles is accompanied by effective mutual phasing of the particles, occurring as a result of the interaction of the particles with one another through the radiation field. The case when there is no constant pump and the emission process developing spontaneously in an open nonequilibrium system of initially nonoscillating active particles is a nonstationary coherent process of short duration $\Delta t \ll T_2$ is of special interest. Such a fast transient process has a number of advantages and differs fundamentally from the process of superluminescence; it is called *collective spontaneous emission*.

In classical plasma physics and electronics, where the active particles are moving electronic oscillators with a slightly nonequidistant spectrum of energy levels, such processes have been little studied. To establish a concrete analogy between processes of this type and Dicke superradiance, a symmetric one-dimensional model of a magnetic trap, in which there are two oppositely moving single-velocity streams of electrons (with density N_e and energy $\mathscr{E}_0$), moving along a uniform magnetic field $\mathbf{B}_0$ under conditions of the anomalous Doppler effect, when the velocity of the electrons $v_\parallel$ is greater than the phase velocity of electromagnetic waves in the medium $c_0 = c/\varepsilon_0^{1/2}$, is studied in detail in the report. A retarding electrodynamic system or a dielectric material with permittivity $\varepsilon_0 > 1$ (Fig. 1) can play the role of the medium. It is shown that in this situation the *cyclotron superradiance* effect can occur—the stream of classical electron oscillators in a magnetic field can spontaneously emit short coherent pulses in modes with a discrete spectrum; in addition, the maxium power of the pulses is proportional to the square of the electron density: $Q_{\max} \propto N^2$. It has been established that the mechanism of cyclotron superradiance is dissipative instability of a slow cyclotron wave with negative energy, developing as a result of loss of energy of the electromagnetic wave—ohmic or diffraction, owing to the emission of radiation through the lateral surface of the trap.

It is significant that cyclotron superradiance is a nonsteady-state transient process that differs fundamentally both from the quasi-steady-state processes, usually em-

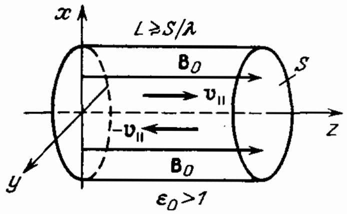

FIG. 1. One-dimensional model of a magnetic trap with a small Fresnel number $F = S/L\lambda$ (λ is the wavelength of the radiation, L is the length of the trap, S is the area of its endfaces, reflecting electrons and the electromagnetic field).

ployed in electronics, in resonators (for example, in the case of cyclotron masers based on the anomalous Doppler effect) and from the quasiperiodic oscillations associated with nonlinear Landau damping in plasma physics. Unlike the nonlinear Landau damping, which exists in the absence of real energy dissipation and is determined by the dephasing of particles with different velocities and energies, in the system of single-velocity particles under study the process loses its oscillatory character and becomes aperiodic owing to strong dissipation of the energy in the field, associated with its escape from the trap.

In the report, the conditions for the appearance of cyclotron superradiance, its linear and nonlinear stages, as well as the temporal and energy parameters of the pulses generated in the single-and multimode regimes of superradiance are described.[1,5] The characteristic form of the pulse in the case of instability of one cyclotron mode of the oscillations of the trap is shown in Fig. 2. In the case of simultaneous instability of several cyclotron modes it is shown that there exists a "mode succession" regime, corresponding to the uniformly retarded motion of the electron stream and propagation of the radiation power upwards in the frequency spectrum of the modes of the trap.

Together with the general properties of cyclotron superradiance and Dicke superradiance, a number of differences between these two properties were clarified. The most significant difference is associated with the type of nonlinearity determining the form of the superradiance pulse. For two-level atoms the nonlinearity is of the saturation type, owing to the change in the difference of the populations of the levels of the atoms, which affects the increments of the polariton modes with different wave numbers to the same extent, whereas for electrons moving in a magnetic field the nonlinearity is of the resonance type, caused by the Doppler shift of the frequency of the oscillations of the electrons as they are retarded by the field, which has a selective effect on

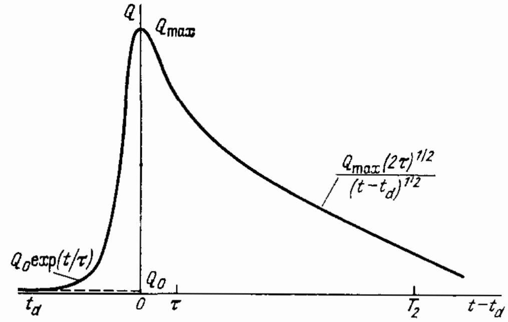

FIG. 2. Shape of the cyclotron superradiance pulse in the one-mode regime. The pulse duration is of the order of several $\tau = 2\pi\sigma_0 c_0/\omega_L^2 (v_\parallel - c_0)$, the delay time is $t_d = \tau \ln (Q_{max}/Q_0)$, the maximum power per unit volume is $Q_{max} = \mathscr{E}_0 N_e \omega_L^2 (v_\parallel - c_0)/\omega_0(\varepsilon_0 - 1)\varepsilon_0 c_0$, where $\omega_0 = \omega_B c_0/(v_\parallel - c_0)$ is the frequency of the radiation, $\omega_B = eB_0/mc$ is the relativistic gyrofrequency, $\omega_L = (4\pi e^2 N_e/m)^{1/2}$ is the plasma frequency of the electron beam, σ_0 is the effective conductivity, characterizing the distribution of the diffraction or ohmic radiation losses in the trap, and Q_0 is the initial spontaneous power of noncoherent cyclotron emission from the trap.

the increments of the cyclotron modes with different wave numbers.

It should be emphasized that the concrete analogy established between Dicke superradiance in the system of quantum (two-level) atomic oscillators and cyclotron superradiance in a system of classical electron oscillators, moving in a magnetic field under the conditions of the anomalous Doppler effect, has not been exhausted, and actually merely raises the problem of SR (collective spontaneous emission) in classical plasma physics and electronics. In particular, according to Ref. 6, the possibilities for realizing collective spontaneous emission of a moving cluster of electrons also exist in free-electron lasers. In addition, the emission by an electron cluster of both discrete modes and waves of the continuous spectrum, including those in the regime of unidirectional emission of a superradiance pulse, is also of interest.

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[5]V. V. Zheleznyakov, V. V. Kocharovsky, and Vl. V. Kocharovsky, Proceedings of Contributed Papers of the International Conference on Plasma Physics, Kiev (1987), Vol. 4, p. 111.
[6]R. Bonifacio and F. Casagrande, Nucl. Instr. Methods Phys. Res. Ser. A **239**, 36 (1985).