We publish below brief contents of two of the papers.

V. V. Ovsyankin and P. P. Feofilov. Cooperative Optical Phenomena in Condensed Media.

A number of phenomena associated with transformation of electron-excitation energy (cooperative phenomena) are observed in systems of optically excited interacting particles in condensed media. Some of these phenomena are not only of considerable interest from the standpoint of the physics of the interaction of radiation and matter, but also open new avenues to the understanding of a number of extremely important processes many of whose aspects remain unclear today.

The greatest interest attaches to phenomena in which energy accumulates on one particle in the system of excited particles, with formation of high excited states. These phenomena, which are observed with greatest clarity in activated crystals, can be regarded as model phenomena with respect to more complex and more important phenomena in artificially created and natural heterogeneous systems (optical sensitization, photosynthesis). To demarcate the intrinsically cooperative processes of formation of high excited states from the phenomenologically similar processes of stepwise (sequential) excitation, we have a number of experimental criteria based on study of the characteristics of anti-Stokes luminescence from high excited states (the dependence on the intensity of the exciting radiation, interacting-particle concentrations, kinetics, excitation spectra).

The following cooperative energy-transformation processes have been observed in crystals with rare-earth activators: a) Summing of the energies of identical excited states. b) Summing of the energies of unlike excited states of identical ions. c) Summing of the energies of the excited states of unlike ions. d) Decay of an excited state of one particle with formation of a lower excited state of the same particle and excitation of a neighboring particle (relaxation of ion pairs). e) Summing of the excitation energies of two ions with simultaneous transfer of energy to a third ion (cooperative sensitization of luminescence). f) Decay of an excited state of a particle with excitation of two (or more) lower energy states of other particles.

In a number of cases, the accumulation of energy takes place with high probability; this makes it possible to treat the corresponding systems as efficient "step-up" frequency transformers for the incident radiation.

Processes in which virtual rather than real excited states are intermediate are also possible in activated crystals: a) Cooperative excitation of two interacting particles by one photon. b) Emission of one "cooperative" photon by two interacting particles. c) Cooperative amplification of light at the doubled (sum) frequency on its distribution in a medium with population inversion of the energy states of the interacting particles.

Cooperative processes of recombination of real electron levels of different particles are possible in interacting-particle systems: a) Raman excitation (absorption). b) Raman luminescence.

Cooperative accumulation of excitation energy manifested in anti-Stokes luminescence has been observed in a number of semiconductive crystals (silver halides, iodides of mercury and lead, thallium chloride and others) with a layer of energy-donor dye adsorbed onto their surfaces, and in photosynthetic systems (green leaves, Chlorella). The high efficiency of the accumulation process down to extremely low (subnanowatt) exciting-radiation densities, which can be observed in sensitized photographic emulsions, makes it possible to construct noncontradictory models of the primary acts of optical sensitization of photolytic (and photosynthetic) processes.

In a system of two interacting particles, one with discrete and one with continuous excited states (e.g., rare-earth ions and color centers), interference of these states, manifested in various peculiarities in the absorption spectra ("antiresonance"), is possible.

The data on which the presentation was based have been published in the following papers: V. V. Ovsyankin and P. P. Feofilov, ZhETF Pis. Red. 3, 494 (1966); 4, 471 (1967), 14, 548 (1971) [JETP Lett. 3, 322 (1966); 4, 317 (1967), 14, 377 (1971)]; Opt. Spektrosk. 20, 526 (1966); 31, 944 (1971); Dokl. Akad. Nauk SSSR 174, 787 (1967) [Sov. Phys.-Dokl. 12, 573 (1967)]; Zh. Prikl. Spektrosk. 7, 498 (1967); Appl. Opt. 6, 1828 (1967); the collection "Nelineĭnaya optika" (Nonlinear Optics), Nauka, 1968, p. 293; Trudy 9-ĭ Mezhdunarodnoĭ konferentsii po fizike poluprovodnikov-(Trans. Ninth International Conference on Semiconductor Physics), Vol. 1, Nauka, 1969, p. 251; the collection "Spektroskopiya kristallov" (Spectroscopy of Crystals), Nauka, 1970, p. 135; the collection "Molekulyarnaya fotonika" (Molecular Photonics), Nauka, 1970, p. 86; Biofizika 15, 589 (1970); P. P. Feofilov and A. K. Trofimov, Opt. Spektrosk. 27, 538 (1969); P. P. Feofilov, ibid. 31, 849 (1971); V. V. Ovsyankin, ibid. 28, 206 (1970); V. A. Arkhangel'skaya and P. P. Feofilov, ibid., p. 1215.

A. A. Abrikosov. Certain Properties of Metals with Magnetic Impurities (Kondo Effect).

It was observed back in the 1930's that the resistances of a whole series of metals begin at low temperatures to increase with decreasing temperature. This could be interpreted only as indicating the existence of a new electron-scattering mechanism whose effectiveness increases with decreasing temperature or energy of the electron. Subsequent experiments showed that this effect is related to the presence of magnetic impurities in the metal, i.e., impurities whose atoms have unfilled inner shells and retain their spin when situated in the host nonmagnetic metal. The effect was observed only at very low impurity concentrations ($<0.1\%$).

We now know many combinations of host metals and impurities in which this effect occurs. Temperature curves of resistivity were measured quantitatively in the mid-50's by Croft et al. on copper and by N. E. Alekseevskiĭ and Yu. P. Gaĭdukov on gold with a small iron impurity. It was found that resistivity is described at low temperatures by the formula $\rho = \rho_1 + \rho_2 \ln (1/T)$. A theory of this phenomenon was offered by the Japanese theoretician Kondo in 1964, and the effect has since borne his name. According to Kondo, the interaction of the electron with the impurity contains, in addition to the usual potential part, an exchange term proportional to $\sigma \times s$, where σ and s are the spin operators of the electron and the impurity. Both interactions yield a constant when the scattering amplitude is calculated in the first (Born) approximation of perturbation theory. This also holds for the exact calculation in the case of the ordinary interaction. For the exchange part, however, the second approximation yields a logarithmic term in the scattering amplitude and, accordingly, also in the resistivity. We obtain as a result

$$\rho = \rho_V + \rho_{ex}^{(0)} [1 - (3J/z\mathscr{E}_F) \ln (\mathscr{E}_F/T)], \quad (1)$$

where ρ_V is the potential part of the resistivity in the Born approximation, $\rho_{ex}^{(0)}$ is the exchange part, $\mathscr{E}_F$ is the Fermi energy, J is the energy of the exchange, and z is the number of valence electrons per atom of the host metal.

It is assumed in the derivation of (1) that the spins of the impurity atoms are freely oriented in space. This is the case as long as the temperature is large by comparison with the energy of interaction of the impurity spins with one another. At lower temperatures, the spins become ordered. The characteristic temperature is of the order of $\Theta \sim cJ^2/\mathscr{E}_F$, where c is the atomic concentration of the impurity.

By lowering the impurity concentration, Θ can be lowered below the temperature at which the correction to (1) becomes large compared to unity. In this case, this formula is invalid. In 1956, by summing the most dangerous terms of the perturbation-theory series, the present author obtained

$$\rho_{ex} = \rho_{ex}(0)/[1 + (3JZ/2\mathscr{E}_F) \ln (\mathscr{E}_F/T)]^2. \quad (2)$$

If $J > 0$ (this corresponds to the ferromagnetic sign of the electron-impurity interaction), this formula gives the answer to the problem. But if $J < 0$, the resistivity increases without limit at the "Kondo temperature"

$$T_K \sim \mathscr{E}_F \exp (-2\mathscr{E}_F/3 \,|\, J \,|\, Z)$$

This corresponds to an unbounded increase of the scattering amplitude at a certain electron energy (reckoned from the chemical potential) of the order of T_K, which contradicts the general principles of quantum mechanics. Expression (2) is therefore inadequate in this range.

Numerous investigations of the problem have failed to produce the final resolution of this question. This is explained by the fact that strong binding of the electrons to the impurity occurs in the energy and tempera-range below or of the order of T_K, leading to major mathematical complexities. It is therefore necessary to adopt further assumptions that influence the result.

There are two approaches that appear to be most consistent. One of them (that of A. A. Abrikosov and A. A. Migdal, 1970) proceeds from the methods applied in the theory of elementary particles with strong binding and in the theory of phase transformations. In this approach, we obtain for $T \ll T_K$

$$\rho = \rho_0\{1 - a(s)\,(T/T_K)^{b(s)/s}\},$$

where a(s) and b(s) are unknown positive coefficients of the order of unity that remain finite as $s \to \infty$. As $T \to 0$, the impurity spin is completely screened by electrons, but the susceptibility $\chi \to \infty$ as $T \to 0$.

According to the second idea, the very existence of impurity spin in a metal is possible only with sufficiently weak binding. The problem should therefore be given fully microscopic treatment. Although this program has never been rigorously implemented, various simplified schemes yield approximately the same result:

$$\rho = \rho_0 [1 - q\,(T/T_K)^2]. \quad (3)$$

The impurity spin vanishes at $T = 0$ and $\chi \to$ const as $T \to 0$. The experimental situation is as yet unclear. Most experimentors are inclined to accept formula (3) and $\chi \to$ const, but there are also data that are qualitatively in agreement with the first approach. However, there is no doubt as to the main point: electrons at $T \ll T_K$ fully screen the impurity spin when the exchange interaction is antiferromagnetic in sign $(J < 0)$. This was first conjectured by Schrieffer in 1967.

Apart from the magnetic properties and resistivity, the Kondo effect is manifested in a whole series of other phenomena. For example, the behavior of the thermal emf changes radically at low temperatures owing to the appearance of a dependence of scattering amplitude on electron energy. In the residual-resistivity range, the differential thermal emf reaches a constant negative value on the order of 10^{-5} W/cm (Kondo, 1956). At $T \ll T_K$, it begins to decrease in absolute magnitude, and it vanishes as $T \to 0$.

If the host metal is a superconductor with a critical temperature $T_c \sim 10\, T_K$, there should exist, according to theoretical prediction (Müller and Hartmann, Zittartz, 1970) a range of impurity concentrations in which two transitions are observed as the temperature is lowered: from normal to superconductive and then back to normal. This prediction was recently confirmed in experiment.

There are also many other phenomena in which the Kondo effect is manifested: the characteristic of the tunnel junction, thermal conductivity, magnetic ordering, etc.