Soviet Physics—JETP

a review of some recent papers

SOME five years ago, the American Institute of Physics began the translation of the Soviet *Journal of Experimental and Theoretical Physics* under the title *Soviet Physics—JETP*. In the five years since then the circulation of this translation journal has increased to more than 1000, making it about the most successful subscription translation journal to date.

However, most of these subscriptions are library ones, so that it is quite possible that a large fraction of members in the various societies in the AIP are still unaware of the type or quality of research appearing in the Soviet journal. In an effort to bring to the readers of *Physics Today* some idea of the material appearing in *Soviet Physics—JETP*, the AIP Advisory Board on Russian Translations requested several of the translators to review briefly some of the recent Russian articles. This paper is the result. All references in the line of the text are to the translation journal. References to other journals appear as footnotes.

1. Field Theory

(W. H. Furry, Harvard University)

DEVELOPMENTS that have come from the discovery of parity nonconservation have caused strong interest in problems of polarization, angular distribution, and correlation. Soviet theorists have been active both in developing basic formalisms for such problems and in working out specific cases, and have published a great many papers, only a few of which can be mentioned. A basic paper by Yu. M. Shirokov [**8**, 703 (1959)] develops a relation between products of single-particle relativistic wave functions and wave functions for the system as a whole; this relation is the analogue of the Clebsch-Gordan relation for combining angular momenta. A recent paper by Chou Kuang-Chao [**9**, 909 (1959)] on "Reactions Involving Polarized Particles of Zero Rest Mass" is one of a number of papers from a strong group at the Joint Institute of Nuclear Studies; another is "Azimuthal Symmetry in Cascade Reactions and Parity Conservation" by M. I. Shirokov [**9**, 1081 (1959)]. Dolginov and Popov [**9**, 368 (1959)] give explicit formulas for polarization and beta-gamma correlation for first-forbidden transitions of oriented nuclei, in a general formalism including all five types of beta interaction. An excellent review paper on beta decay has been written by Smorodinskii.[1]

Among papers on more general questions of elementary particle interactions we may mention "On the Weak-Interaction Types Possible in the Scheme of Feynman and Gell-Mann" by Shekhter [**9**, 403 (1959)]. In two short papers [**8**, 118, 504 (1959)], Gol'fand has given an example of an entirely different approach to the formulation of weak interactions. In his formalism the CPT theorem does not hold, but there is invariance under each of the combinations CP, CT, and PT. His weak-interaction Hamiltonian is non-Hermitian, but forms part of a Hermitian total Hamiltonian in a "doubled" Hilbert space. Blokhintsev [**8**, 174 (1959)] considers possible limitations on the validity of quantum electrodynamics that may arise from competing processes at high energies. He finds that certain processes caused by four-fermion interactions can come into question here.

Examples of Soviet work on purely theoretical or "academic" problems are found in papers by Popov [**8**, 687 (1959)] and Ansel'm [**9**, 608 (1959)]. Popov solves a problem with an already known solution—the behavior of a particle of arbitrary spin in a magnetic field—by an application of Feynman's calculus for "disentangling" operators. Ansel'm presents "A Model of a Field Theory with a Nonvanishing Renormalized Charge". For two one-dimensional spinor fields with four-fermion interactions there is an infinite charge renormalization, and the renormalized charge can be finite.

Among the occasional speculative communications we have "On the Question of Antigravitation" by Aleksandrov, Andreev, and Bondarenko [**8**, 911 (1959)] and "The Universal Fermi Interaction and Astrophysics" by Pontecorvo [**9**, 1148 (1959)]. Pontecorvo points out that in any electromagnetic process there is not only the possibility of photon (γ) emission, but also that of neutrino-antineutrino ($\nu\bar{\nu}$) emission (*via* a virtual electron-positron pair). The extremely small probability for $\nu\bar{\nu}$ emission may be compensated by the fact that the ν and $\bar{\nu}$ are not reabsorbed. The effect is negligible for the sun, but may be important at some stages of stellar evolution.

2. Nuclear Reactions

(Morton Hamermesh, Argonne National Laboratory)

A GROUP under the direction of D. G. Alkhazov has carried on an excellent program of research on coulomb excitation. In particular, they have used heavy ions accelerated in a cyclotron to excite levels at excitations of 1–2 Mev. For such levels the energies of protons or α particles needed for coulomb excitation are so high that there is a large background from nuclear reactions. By bombardment with nitrogen and oxygen ions, they excited levels at 0.84 and 1.01 Mev

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[1] Ya. Smorodinskii, Soviet Phys. Uspekhi **2**, 1 (1959).

in Al^{27} and determined their lifetimes. They also measured the lifetime of the first excited state in Mg^{24}, at 1.37 Mev: $\tau = (1.7 \pm 0.4) \times 10^{-12}$ sec. Previously there had been only a very rough measurement of this lifetime, using inelastic scattering of 187 Mev electrons [**8**, 736, 737 (1959)]. In the region of heavier nuclei, this group has used α particles for coulomb excitation of states at high excitation in the tungsten isotopes and has established the existence of excited states at 1.22 Mev in W^{182}, 0.90 Mev in W^{184}, and 0.73 Mev in W^{186} [**8**, 926 (1959)].

The Russian literature has in the past contained important contributions concerning stripping and pickup reactions and diffraction effects in nuclear reactions. There are several articles in this field in recent issues of *JETP*.

In reactions like (n, t) or (n, He^3) there is a competition between the two-stage process $(n\text{-}d\text{-}t)$ and the direct transition with simultaneous capture of two nucleons. There are some cases in which the angular distribution for the two processes should be distinguishable [**8**, 679 (1959)].

Detailed calculations have been made of the effect of exchange in (d, p) stripping reactions [**8**, 815 (1957)].

Diffraction phenomena in deuteron interactions with nuclei have been studied extensively. Similar effects can occur for energetic beams of light nuclei whose binding energies against two-particle breakup are small. Partial cross sections for various diffraction processes have been calculated for arbitrary ratio of particle radius to nuclear radius [**8**, 899 (1959)].

Veksler has published [**8**, 781 (1959)] an interesting note on the use of a high-frequency electromagnetic field as the guide field in a cyclic accelerator.

3. Ferromagnetism

(W. F. Brown, Jr., University of Minnesota)

IN two recent papers by Kaganov and Tsukernik [**7**, 1107 (1958); **9**, 151 (1959)], a theory of the type of Herring and Kittel[2] is used to calculate the relaxation times corresponding to establishment of equilibrium (1) within the spin system and (2) between the spin system and the lattice of a ferromagnetic material. The latter relaxation time is assumed to be much larger than the former, and the final estimates are consistent with this assumption. The steps in the calculation are as follows. First the energy is expressed classically in terms of the variables assumed to be relevant, namely the components of magnetization and elastic displacement and their spatial derivatives. This energy is the volume integral of an energy-density function; the specific form of the function is determined partly by physical considerations and partly by considerations of symmetry, but its general form is that of a series judiciously truncated. The next steps are to reinterpret the classical variables as quantum-mechanical operators subject to certain commutation rules, and the energy as the Hamiltonian operator; then to apply the quantum-mechanical methods already mentioned. This program can be carried out only on the assumption that the deviations from a uniform-magnetization ground state are small; then the equilibrium equations of the theory become linear, so that Fourier transformations and the like are applicable. Even then, it is necessary to introduce a number of further simplifications, such as specialization to various limiting cases and approximation of sums by integrals.

In the first paper, interaction between spins and the lattice is neglected. To determine the stationary states, the Hamiltonian is expressed to the second order in the creation and destruction operators; the solutions determine the spin-wave occupancy numbers. To calculate the interactions of spin waves with spin waves, third- and fourth-order terms are included; they may be interpreted as perturbations that cause transitions between stationary states of the spin-wave system. The third-order terms are attributed to anisotropy and magnetic forces, the fourth-order to exchange forces. It turns out that at sufficiently high temperatures (high in comparison with 10 to 30 °K), the spin waves first reach a quasi-equilibrium state, with a definite magnetic moment, in a time determined by exchange interaction; this nonequilibrium magnetization then relaxes more slowly. At lower temperatures, no definite magnetic moment can be associated with the nonequilibrium state.

In the second paper, spin-lattice interaction is studied by supposing that each subsystem, the spin-wave system and the elastic-wave (phonon) system, is in quasi-equilibrium, but at a slightly different temperature; the relaxation process is then one of temperature equalization. The calculation method is as before; each subsystem has its own Hamiltonian, creation-destruction operators, and stationary states, and the complete Hamiltonian includes interaction terms, mainly of magnetostrictive nature. The various terms in the resulting equations correspond to such processes as creation of a phonon by a spin wave and annihilation of two spin waves with formation of a phonon. The transition probabilities are estimated, and an attempt is made to determine the relative importance of the various processes at various temperatures; but because of the simplifications that have to be introduced, some of the conclusions are very tentative.

A somewhat different approach is used by Beshidze [**9**, 654 (1959)]. His treatment uses no quantum-mechanical concepts but only thermodynamic ones. The basic assumption is that the nonequilibrium state can be described by use of nonequilibrium thermodynamic functions, with different temperatures for the spin and lattice systems. General phenomenological equations are simplified by supposing that a small alternating field is superposed on a large constant field, the usual situation in ferromagnetic resonance experiments. The final relaxation equations are of familiar form, but the relaxation times that appear in them are now expressed in terms of parameters that appeared in the basic thermodynamic functions of the theory.

These phenomenological theories are by their nature

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[2] C. Herring and C. Kittel, Phys. Rev. **81**, 869 (1951).

incapable of relating observable quantities to fundamental atomic constants; and because of the drastic simplifications that have to be introduced, even the calculated relations between different observable quantities (such as different relaxation times) are valid only in limiting cases. Therefore, particularly in the case of the long and intricate calculations of Kaganov and Tsukernik, it appears that an enormous amount of labor has produced a discouragingly small amount of useful information. Unfortunately this seems at present to be inherent in the problems treated; they are extremely complex ones, and no really powerful method of handling them has emerged. This is true even in the spin-wave approximation, which corresponds to linearization of the equations of equilibrium and of motion. Such linearization is justifiable in the usual ferromagnetic-resonance situation; but in many practically important states of a ferromagnetic specimen, the nonlinearity of the equations is an essential feature. Here the elegant formalisms of spin-wave theory fail utterly, and theorists resort to the much less elegant methods of domain theory.

Even within the linear range, spin-wave theory is open to criticism when, as here, it purports to take account of magnetic interactions. The dipole-dipole energy depends on the specimen shape and continues to do so as the specimen size becomes infinite; therefore the Fourier series of the theory need to be replaced by series of other orthonormal functions, appropriate to the specimen shape. This problem is usually bypassed by reasoning that the Fourier functions (plane waves) are a good approximation at short wavelengths, by using demagnetizing factors at infinite wavelength, and by pretending that any wavelength not infinite is short. Kaganov and Tsukernik merely write down the Fourier series without explanation, apparently ignoring the (semiconvergent!) magnetic-energy integral with which they started. More careful study of this problem is needed.

These papers do not solve completely the problems treated; but they do take us a few steps further in the laborious endeavor to understand ferromagnetism.

4. Superconductivity

(R. T. Beyer, Brown University)

SOVIET research on superconductors has included a number of applications of the Bardeen, Cooper, Schrieffer (BCS) theory to special problems. Thus, Abrikosov, Gor'kov, and Khalatnikov [**8**, 182 (1959)] use the theory to determine the temperature and frequency dependence of the impedance of a bulk conductor in a high-frequency field. Abrikosov and Gor'kov [**8**, 1090 (1959)] analyzed the electrodynamics of alloys at absolute zero. Working in BCS theory by means by Feynman diagrams, they obtained the electrodynamic equations in an alternating field for superconductors with a mean free path smaller than the correlation length. In a subsequent note [**9**, 220 (1959)], they extended this analysis to higher temperatures.

The same group at Kapitza's Institute for Physical Problems contributed two other interesting papers. Khalatnikov [**9**, 1296 (1959)] computed the thermal conductivity of anisotropic superconductors on the basis of BCS theory. The results indicated a difference in the temperature dependence of the thermal conductivity along the crystallographic axes of uniaxial crystals. Some preliminary measurements of Zavaritskii[3] on gadolinium appear to bear this out. Gor'kov [**9**, 1364 (1959)] derived the equations of Ginzburg and Landau's phenomenological theory of superconductivity[4] from the BCS theory. In Gor'kov's development, the effective charge occurring in the Ginzburg-Landau theory must be taken as twice the electronic charge—a result which corresponds to the charge of the Cooper electron pairs. In a subsequent letter [**9**, 1372 (1959)], Ginzburg pointed out that their original theory set $e_{\text{eff}} = e$. When he made the charge identification noted by Gor'kov, good agreement was found between experimental results and the macroscopic theory.

Writing from the Ukrainian Academy of Sciences, Akhiezer and Pomeranchuk [**9**, 605 (1959)] noted that in the application of the BCS concept of bound electron pairs near the Fermi surface of a metal, an additional effective term will appear in the case of ferromagnets because of spin-wave exchange. They suggested that this attraction might, under suitable conditions, contribute to the appearance of superconductivity in the ferromagnet. Such ferromagnetic superconductivity has recently been reported.[5]

Another group that carries on theoretical studies in superconductivity is that of Bogolyubov and his colleagues at the Steklov Mathematics Institute. Publications of this group are frequently characterized by their failure to mention the BCS theory or the work of physicists at the Institute for Physical Problems. Thus Shirkov [**9**, 421 (1959)] followed up the analysis of the Coulomb interaction between electrons in superconductors given by Bogolyubov et al.[6] and obtained a relation between the matrix elements of the variational derivatives of the scattering matrix and the energy operator. The integral equation for compensation of dangerous diagrams is then expressed in terms of Green's functions.

In another paper, Tsekhmistrenko [**9**, 1096 (1959)] applied the method of summation of the main Feynman diagrams to the construction of a Hamiltonian with a direct electron-electron interaction which describes in the given approximation a Fröhlich system of interacting electrons and phonons.

While these four surveys do not exhaust the range of topics in *Soviet Physics—JETP*, they do give some suggestion of what is available there for Western physicists to read.

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[3] N. V. Zavaritskii, Fifth All-Union Congress on Physics of Low Temperatures, Tiflis, 1958.

[4] V. L. Ginzburg and L. D. Landau. J. Exptl. Theoret. Phys. (USSR) **20**, 1064 (1950).

[5] Matthias, Sahl and Corenzwit, Phys. Rev. Lett. **1**, 449 (1958).

[6] Bogolyubov, Tolmachev and Shirkov, *A New Method in the Theory of Superconductivity* (translated from the Russian, Consultants Bureau, New York, 1959).