# International School on Magnetic Resonance (Novosibirsk, 20–26 September 1987)

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On 20–26 September 1987, the Academy of Sciences of the USSR and the Siberian Branch of the Academy held the Tenth School on Magnetic Resonance in Novosibirsk, based at the Institute of Chemical Kinetics and Combustion of the Siberian Branch of the Academy.

The School was an activity of AMPERE, the European association of scientists involved in research in the field of magnetic resonance and related problems. It constituted the Ninth International AMPERE Summer School. The School covered 14 scientific directions and gives a picture of the present status of, and directions for further progress in, the theory, the methodological tools, and the applications of magnetic resonance.

The subject of the dynamics and kinetics of spin systems is a traditional one for the All-Union Schools on Magnetic Resonance. At this School, B. N. Provotorov and co-author G. E. Karnaukh read a lecture on "Spin dynamics and a kinetic equation of the Boltzmann type." This lecture attracted much interest and a lively discussion, which was joined by, in particular, A. Abragam (France). In his time, Abragam was one of the first to embrace the methodology of the theory of the saturation of spin systems proposed by B. N. Provotorov. Characteristically, the 25-plus years which have elapsed since Provotorov's first publications have seen an evolution of this author from ingenious solutions of what might seem to be particular problems to the formulation of the general problem of deriving a kinetic equation for a system of interacting spins. In the course of this solution, use was made of the memory-function method, which has won popularity among our own theoreticians because, in particular, of the recent publication of a Russian translation of Abragam and Goldman's book *Nuclear Magnetism: Order and Disorder*, in which this method receives considerable attention. In his lecture, Provotorov also showed how the equations for a three-component polarization density vector $\sigma(h,t)$ for spins which have a resonance field $h$ at time $t$ can be reduced to the magnetic-resonance equations which were introduced a long time ago and which have now become classical equations in limiting cases: the Bloch equation, the Redfield equation, and Provotorov's own equation.

Among the reports presented by Provotorov's school and related researchers we might note in particular the reports read at a satellite symposium on the theory of NMR lineshape in solids (A. A. Lundin) and research on the correlation functions of molecular motions (A. K. Khitrin).

Multipulse NMR methods in solids have again been reflected in some recent reports by Soviet and foreign participants (L. N. Erofeev). V. A. Atsarkin (with co-authors G. A. Vasneva and V. V. Demidov) read a lecture on "Spin dynamics in magnetically dilute objects." This lecture was a generalization of some significant experimental material which had been obtained through the use of some original methodological approaches developed at the Institute of Radio Engineering and Electronics: matrices and a method of intensified longitudinal susceptibility. This choice of topics of study made it possible to reveal, in various examples, a slowing and a nonuniformity of thermalization processes in the spin-spin reservoir of electron spins.

These results had something in common with a lecture by A. M. Raĭtsimring (USSR) entitled "Study of the dipole-dipole interaction in magnetically dilute solids by an electron-spin-echo method." A common feature of these two lectures was an effect of a variation in the spatial distribution of spins on the dynamics of spin-spin interactions. Also falling in the category of research on magnetically dilute sytems were reports by other participants of the School, including one by J. H. Freed (US) on two-dimensional and pulsed ESR. The development of this direction over the past two decades can be judged exceedingly successful.

Of considerable interest to all the participants were reports on experimental methods and apparatus for magnetic resonance and also an exhibition of scientific instruments for magnetic resonance which was held at the same time as the School. Among the Soviet reports, one which attracted much interest was that by A. G. Semenov (Novosibirsk) on "Experience in the use of NMR to search for underground water." A miniature ESR spectrometer, the AÉ-4700, which was displayed at the exhibition by Belorussian State University, attracted interest. Unfortunately, as has often been the case in recent years, the advances in terms of apparatus and thus the methodological and applied advances of certain laboratories have far outstripped the achievements of our institutions. This comment applies in particular to the methods of magnetic-resonance tomography (subsurface imaging) and *in vivo* spectroscopy. The number of instruments which are used directly in the practice of medicine in the US, West Germany, and Great Britain runs to several hundred.

The head of the AMPERE association, and one of the oldest scientists working in the field of NMR, E. R. Andrew (now in the US), delivered an introductory lecture on the principles and practice of NMR tomography in medicine. W. Eichoff, vice president of the Bruker company (West Germany), reported on the "Acquisition of fast images, selective images, and images of flows by the NMR method." In this lecture he reported some new instruments developed by the Bruker company. A specific plan of collaboration between the Siberian Branch of the Academy of Sciences of the USSR and this company in the field of medical NMR tomography has been launched and is working successfully. From the practice of medical tomography, L. A. Sibel'dina

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read a report on oncology, and there was, for example, a poster report on cardiology by I. D. Fedina. These institutions are also using Bruker apparatus. Ya. S. Lebedev read a report on ESR tomography; W. Ebert (West Germany) gave a report on this topic.

Some lectures which were extremely polished, and useful in content, in the field of experimental methodology were read by R. Ernst (Switzerland) on "Recent advances in multidimensional magnetic resonance" and E. Hahn (US) on the weak-signal effect in NMR with SQUIDs. Ernst's lecture dealt with the problem of detecting multiquantum transitions in high-resolution spectra of complex molecular systems (in liquids). A study of these transitions makes possible an unambiguous recognition of extremely complex structural fragments. The lecture by Hahn, who is the original discoverer of pulsed spin-echo methods in NMR, was evidence that the sensitivity of NMR apparatus today is approaching the theoretical limit. A SQUID amplifier has detected a spontaneous emission from $I = 3/2$ nuclear spins of $^{35}Cl$ nuclei at the quadrupole-splitting frequency in a $NaClO_3$ single crystal at 4 K.

Scientists in the Siberian Branch of the Academy of Sciences of the USSR have made an important contribution to the development of research on spin effects in chemical reactions. The spin states of intermediate, and extremely short-lived, particles in chemical reactions influence the yield of the final products of these reactions. It was research in Novosibirsk, at the Institute of Chemical Kinetics and Combustion of the Siberian Branch of the Academy of Sciences of the USSR, that first revealed that the influence of spin on a chemical process has a significant number of effects or that these effects lead directly to changes in the spin state of molecules formed in a reaction and also in the total yield of reaction products in a magnetic field.

Not surprisingly, the School in Novosibirsk attracted a particularly large number of people who lectured and reported on problems concerning research on chemical reactions in magnetic fields (the chemical polarization of nuclear and electron spins, etc.). A new and effective method for indirectly observing an ESR of intermediate short-lived free radicals is the method of a nuclear polarization stimulated by a resonance irradiation of the reaction medium in a magnetic field. The polarization of nuclei is observed by measuring the NMR signal of a reaction product in a strong magnetic field; the reaction itself, like the excitation (or saturation) of ESR, is carried out in the weak field of an auxiliary magnet with a variable field strength. This method has turned out to be not merely sensitive (it can detect particles whose instantaneous concentration is considerably lower than $10^{10}$ $cm^{-3}$) but also selective, making it possible to distinguish one type of radical from another on the basis of the hyperfine structure of the lines. A team of authors (the lecturer was K. M. Salikhov, from Novosibirsk) gave a lecture on the theory of this method and the results of its use.

The incursion of magnetic-resonance methods into the field of photochemistry has made it possible to trace the details of many processes which occur during the photoexcitation of reactions in a magnetic field. A lecture by K. Möbius (West Berlin) and coauthors reported data on "The role of multifrequency electron-nuclear resonance methods in understanding structural-functional relations in primary photosynthesis processes."

Among the reports and lectures on the use of magnetic-resonance methods to study chemical reactions were some by A. D. Trifunac (US), on research on the magnetic resonance of paramagnetic transitions in pulsed radiolysis; H. G. O. Becker (East Germany), on "CPN in electron-transfer reactions"; G. Kloss (US), on a manifestation of a spin-spin interaction in CPE in micelles; O. A. Anisimov (Novosibirsk); and M. Okazaki (Japan).

The use of magnetic resonance to study optically excited systems was the subject of several extremely serious lectures, which attracted considerable interest among the participants of the School: a lecture by P. G. Baranov on the "Optical magnetic double resonance in ionic crystals and semiconductors," a lecture by D. Stelik (West Berlin) on the "Use of optical polarization of nuclear spins to study the spin dynamics and kinetics of reactions of excited triplet states and in solving problems of the NMR of solids," a report by J. Schmidt (The Netherlands) on the "Electron-spin-echo spectroscopy of photoexcited triplet molecules," and a report by V. G. Fleĭsher on "Optical and galvanic effects in optically induced NMR in semiconductors." The very titles of these reports indicate the broad scope of the problems and the fundamental nature of the reports. At the same time, the authors discussed a fairly large number of experimental results which they had obtained in their own laboratories.

A lecture of high pedagogical level and at the same time a high scientific level, judging from the responses of primarily the foreign participants of the School, was a lecture by B. I. Kochelaev, a professor at Kazan' University, on "Spin kinetics and ESR in superconductors."

Professor A. Abragam (France), well known as the author of fundamental monographs and the discoverer of several magnetic-resonance effects, spoke at the first session of the School. Abragam discussed several cycles of research on such effects as nuclear magnetic order, spin-dependent scattering of polarized neutrons, and the spin resonance of muons. The content of this lecture went far beyond the scope of its original title and to some extent conveyed the range of ideas in the recent monograph *Nuclear Magnetism:Order and Disorder* by Abragam, which we have already mentioned. Abragam's report was undoubtedly one of the most interesting at the School.

In accordance with the traditions of AMPERE and the All-Union Schools on Magnetic Resonance, the activities of this particular School touched on (although to a lesser extent) other directions in magnetic resonance of current interest. The direction of NMR and ESR in liquids, listed in the program of the School, was actually oriented toward the problem of chemical radiospectroscopy. One lecture in this field was that by N. M. Sergeev (Moscow State University) on "Isotope effects for screening constants and spin-spin interaction constants." Also in this field was the report by I. L. Barsukov (IBOKh, Academy of Sciences of the USSR, Moscow), on "Conformation forms of gramicidin A in organic solvents according to two-dimensional NMR spectroscopy."

The field of NMR and ESR in solids spans, in addition to the problems listed above, several specific structural applications of magnetic resonance. É. P. Zeer (Krasnoyarsk) read a report on the NMR of hexafluoride compounds; H. K. Roth (Leipzig, East Germany) read a report on the ESR of

semiconducting tetracyanofulvalenes. In the satellite symposium, this field of research was represented by, for example, reports by Yu. N. Moskvich (Krasnoyarsk), M. D. Glinchuk (Kiev), and R. L. Armstrong (Canada). This group of reports dealt primarily with phase transitions in ferroelectric systems. Yu. V.Yablokov (Kazan', Physicotechnical Institute) and J. Stankowski (Poland) gave reports of a general nature on these problems at the sessions in Novosibirsk.

The specific interests of the Krasnoyarsk physicists were reflected in the program of the satellite symposium. Here there was extremely broad coverage of the problems of an incommensurable structure of crystals, e.g., in reports by W. Windsch (Leipzig), I. P. Aleksandrov (Krasnoyarsk), B. Topič (Ljubljana, Yugoslavia), and V. S. Vikhnin (Leningrad). We might also mention a group of reports on magnetic resonance in superconductors: one by B. I. Kochelaev (Kazan') on "ESR in the high-temperature superconductor $Y_{1-x}Gd_xBa_2Cu_3O_4$" and one by J. Stankowski (Poland) on "Research on high-temperature superconductors and Josephson oscillations by an ESR method." When we add to these reports such reports as that by S. M. Ryabchenko and coauthors (Kiev), on relaxation studies of the nuclear quadrupole resonance of incommensurable phases in crystals, and the report by (again) J. Stankowski on the "Proton spin-glass state in $Rb_{1-x}(NH_4)xH_2AsO_4$," we see that the symposium was hearing the results of the latest research in the directions of most current interest in specific entities. Among the reports on genuinely "new ideas and methods in radiospectroscopy" we might note the interesting report (unfortunately, on a poster) by A. E. Mefed, on "Nuclear magnetic relaxation in a doubly rotating coordinate system; slow molecular motions in solids." After the two activities (the School and the symposium) ended, their mutually complementary nature became particularly obvious.

To some extent, the directions represented at the School were those which have been widely discussed at recent specialized meetings and symposia. Undoubtedly, such reports as that by M. A. Teplov (Kazan' University) on "Magnetic relaxation of liquid $^3He$ in an oriented $LiTmF_4$ powder," that by A. I. Smirnov (IFP, Academy of Sciences of the USSR) on "The geometry of attractors in spin-wave turbulence in antiferromagnets," that by S. P. Gabud (INKh Siberian Branch, Academy of Sciences of the USSR) on "The convergence of structural data obtained by NMR and neutron-diffraction," that by I. V. Ovchinnikov (Kazan' Physicotechnical Institute, Academy of Sciences of the USSR, Kazan') on "Paramagnetic liquid-crystal metal complexes," and many others made it possible for the participants of the School to get a picture of the present status of the development of the most important problems in magnetic resonance. This was essentially the basic purpose of the School and of the satellite symposium.

Furthermore, it can be hoped that interest in the current scientific directions was aroused in the large groups of young scientists, particularly from the Siberian Branch of the Academy of Sciences of the USSR and other scientific institutions in Siberia. Judging from the comments of the foreign participants, they obtained a favorable impression of the level and scope of the scientific activity of the Soviet specialists in the field of magnetic resonance and on our readiness for an all-encompassing scientific collaboration. The activities at the School were marked with the development of an active mutual interest and good will and the mutual respect of the participants. Foreign specialists furnished 26 recent scientific papers for copying; they also requested, with interest, copies of Soviet studies. Perhaps one of the most important practical results of the participation of foreign companies in the exhibition of scientific instruments which ran in parallel with the School was the decision to found a Joint Center for Medical NMR Tomography in Novosibirsk (by the West Germany company Bruker and the Siberian Branch of the Academy of Sciences of the USSR).

Since this School was the tenth for the Soviet specialists and, in a sense, an anniversary (the first had been held 20 years earlier, in 1968), we cannot fail to note the usefulness of these All-Union Schools, which to some extent combine the coordinating activity of Soviet specialists in this field, whose development began with the well-known work by E. K. Zavoĭskiĭ. At the same time, the fact that the Soviet manufacture of magnetic-resonance instruments lags behind caused deep dissatisfaction. Catching up will of course require a more constructive participation and guidance of the Academy of Sciences of the USSR and of the magnetic-resonance specialists themselves.

Translated by Dave Parsons