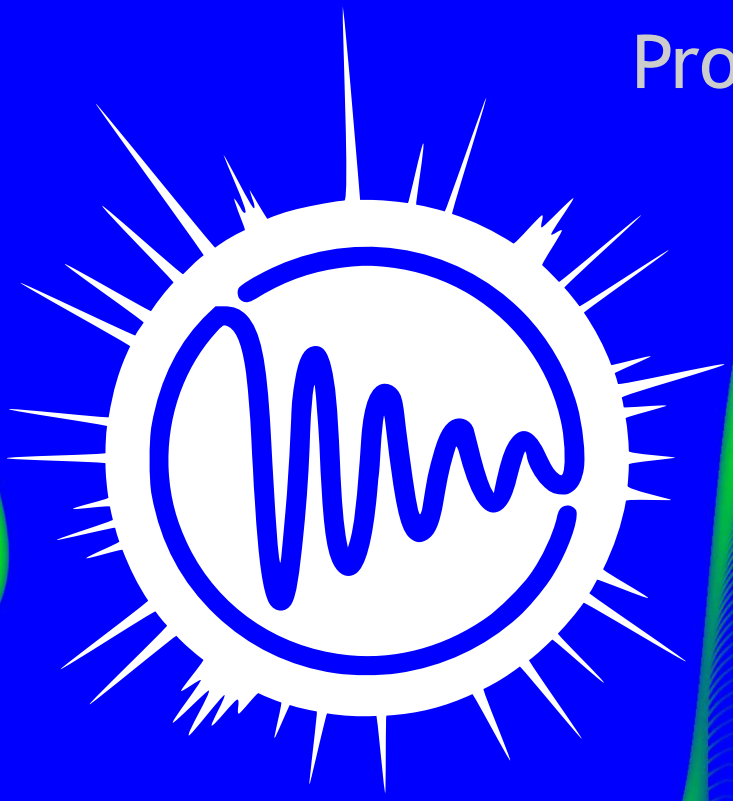
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The School-Conference "Spinus" of Saint Petersburg State University

The St. Petersburg State University (SPbSU) holds International School-Conference "Magnetic resonance and its application" (Spinus) since 2004. "Spinus" is organized in according to the subjects of researches and educational programs, which have been developed and implemented in the SPbSU. During the 22 years of the conference, more than one thousand scientists, including young ones, took part in it, and many of them participated repeatedly. In modern physics, the term "magnetic resonance" refers to a set of phenomena accompanied with the emission or absorption of electromagnetic waves of the radiofrequency diapason by quantum systems (nuclei, electrons, atoms, molecules, etc.). These phenomena, the physical nature of which is of independent interest, provided the basis of radiospectroscopic methods for studying the structure of matter and physical-chemical processes in it. They are also used for the creation of quantum generators, amplifiers, and magnetometers. For the development of ideas and applications of magnetic resonance six Nobel Prizes were awarded in the areas of physics, chemistry, biology, physiology and medicine (the latter was in 2003).

Primarily, magnetic resonance methods are:

- Nuclear Magnetic Resonance (NMR)
- Electron Paramagnetic Resonance (EPR)
- Nuclear Quadrupole Resonance (NQR)

These methods, being contactless, do not destroy an object under a study, that makes them unique and in demand not only in physics and chemistry, but also in medicine, geology, biology, and archeology. Now, any medical center with high reputation has a magnetic resonance imaging (MRI). In Russia, NMR is used in oil well logging, laboratory analysis of the productivity of oil-bearing reservoirs, analysis of oil content and moisture of seeds; EPR technique is used for geological research, non-destructive control of precious stones, as well as for the dating of paleontological artifacts; there are NQR applications for remote detection of solid explosives and narcotics. Magnetometry methods based on magnetic resonance are indispensable for carrying out archaeological researches.

Earlier the school organizers worked at the Department of quantum magnetic phenomena (QMPh) of the St. Petersburg State University, which was founded in 1993 on the initiative of Professor V. I. Chizhik on the basis of the laboratory, created in the 50s of the last century by F. I. Skripov at the Department of Radio Physics (the branch "Quantum Radiophysics"). On January 1, 2014, the Department of QMPh joined the united Department of nuclear-physics research methods (Head of the Department is Corresponding Member of the Russian Academy of Sciences, Professor Mikhail Kovalchuk). The QMPh collective has a number of priority works in the field of nuclear magnetic resonance. One of the most significant achievements was the first in the world implementation (in 1958) of the Fourier transform of a free induction signal in order to obtain a NMR spectrum (see the details in [1]). Concurrently with the research activity, the staffs of the department are involved in the development of practical applications of magnetic resonance. The department graduates work not only in Russia and the CIS, but also in Sweden, China, Australia, New Zealand, England, Cuba, Germany, France, USA, Italy, Turkey, occupying positions from a highly advanced operator of radiospectrometers to a professor.

The main research areas developing by the collective:

- Nuclear magnetic resonance in liquids (spectra, relaxation, diffusometry, …);
- Nuclear magnetic resonance in solids;
- NMR in liquid crystals;

- NMR in heterogeneous systems;
- Nuclear magnetic resonance in the magnetic field of the Earth;
- The quantum magnetometry in archeology and industry;
- Computing modeling in magnetic resonance.

It is evident from the above that the scope of our research interests is quite wide. We are always open for the collaboration with researchers from various fields of science.

Our team has published a series of monographs, textbooks and training manuals on Magnetic Resonance. For example:

1. Vladimir I. Chizhik, Yuri S. Chernyshev, Alexey V. Donets, Viatcheslav Frolov, Andrei Komolkin, Marina G. Shelyapina. Magnetic Resonance and Its Applications. 2014, Springer-Verlag. 782 pp. *(Now more than 45000 chapters download).*
2. Квантовая радиофизика: магнитный резонанс и его приложения. Учеб. пособие. 2-е изд., перераб. Под ред. В. И. Чижика. – СПб.: Изд-во С.-Петерб. ун-та, 2009. 700 с.
3. В. И. Чижик. Ядерная магнитная релаксация. Учеб. пособие. 3-е изд. – СПб.: Изд-во С.-Петерб. ун-та, 2004. 388 с.
4. Практикум по магнитному резонансу. Учебное пособие. Под ред. В. И. Чижика. – СПб.: Изд-во С.-Петерб. ун-та, 2003. 184 с.

The goal of “Spinus” is to provide a forum for young scientists to discuss the use of all aspects of magnetic resonance methods and techniques, as well as computational and theoretical approaches, for the solving of fundamental and applied problems in physics, chemistry, archeology, medicine and biology.
Annually, selected papers of participants are published in a special issue of the journal “Applied Magnetic Resonance”

Welcome to the annual “Spinus”!



M. Sci., researcher, SPbSU, Alexandr V. Ievlev
Vice-chairman of Organizing committee of the 23rd School-conference
“Magnetic resonance and its applications” Spinus-2026

[1] V.I. Chizhik. On the history of the Fourier transform in NMR spectroscopy. 2018, BULLETIN DU GROUPEMENT AMPERE, 67, № 4 (273), p 5-6.

Nature of ^{75}As spin-lattice relaxation in a GaAs semi-insulator single crystal

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Introduction

Spin-lattice relaxation of quadrupole nuclei in ideal pure nonconducting solids is known to be realized due to modulation of crystalline electric field gradients by thermal phonons [1]. This "lattice" quadrupole relaxation has a specific temperature dependence of its velocity [2]. Another contribution to spin-lattice relaxation can occur in real solids owing to paramagnetic impurities. However, even in pure materials, which do not comprise paramagnetic impurities, there can be an additional relaxation channel associated with intrinsic structural point defects, such as electron centers. Nuclear spin relaxation in semi-insulator undopped gallium arsenide crystals is an example of such a case [3]. Electron centers, which are strongly coupled to the phonon system, are also linked to neighbor nuclei via hyperfine magnetic and electric quadrupole interactions [4]. It leads to fast nuclear spin relaxation near the electron centers, which extends over the whole crystal volume due to spin diffusion. The contribution of electron centers to nuclear spin-lattice relaxation can be found using a method of measuring the spin-lattice relaxation rate under continuous magnetic saturation of the nuclear spin system [5]. The magnitude of the contribution caused by electron centers and its variation with temperature is mainly driven by the nature of the interaction between nuclei and electron centers. Recently, it was shown [3] for the ^{71}Ga and ^{69}Ga isotopes in a semi-insulator GaAs crystal that the contribution to spin relaxation due to electron centers is dominated by quadrupole interaction while the impact of the hyperfine magnetic interaction is not noticeable. Another scenario can be expected for the ^{75}As nuclear spin system since the magnetic hyperfine interaction of electron centers with arsenic nuclei is more effective than with gallium isotopes as was demonstrated for most numerous EL2 centers [6]. Here we present NMR studies of different contributions to ^{75}As spin-lattice relaxation in the same semi-insulator GaAs crystal, which was used in [3]. The results for gallium and arsenic nuclei will be compared.

Sample and experiment

The sample is an undoped semi-insulator GaAs single crystal with an electrical resistivity of 10^8 Ω cm at room temperature and with a concentration of uncontrolled impurities of no more than 10^{15} cm^{-3}. NMR measurements were performed using a Bruker Avance III 400 pulse spectrometer optimized for solid samples in the range from 30 K to 220 K. Relaxation of the ^{75}As isotope was observed with the inversion recovery protocol under additional continuous resonance magnetic saturation of the spin system following the procedure described in detail in [5]. Briefly, this procedure is based on two competing processes. On the one hand, nuclear spin-lattice relaxation accelerates near the electron centers and averages over the crystal volume via spin diffusion [7]. On the other hand, magnetic saturation of the spin-system at the Larmor frequency is also more effective close to the electron centers and can generally suppress relaxation due to electron centers under high enough saturation level [8]. Note that the recovery time of nuclear longitudinal magnetization to its equilibrium value under saturation is given by

$$\tau = T_1^{\Sigma} Z^{st}, \qquad (1)$$

where T_1^{Σ} is the total relaxation time, the saturation factor is defined here as $Z^{st}=A^{st}/A_0$, where A^{st} and A_0 are the integral intensities of the NMR signals after a single 90^o pulse under additional saturation and without it.

Results and discussion

The dependence of the relative integral intensity of the ^{75}As NMR signal $Z(t)=A(t)/A_0$ on the time interval t between the 180° and 90° pulses was measured under application of additional weak long electromagnetic pulses at the Larmor frequency, which produced saturation of the arsenic nuclear spin system to the value Z^{st} in the range from 1 to 0.2. When the mean spin temperature over the crystal volume is negative that corresponds to $Z(t)<0$ the recovery of nuclear magnetization follows the exponential law

$$Z(t) = Z^{st}\left[1 - b\exp\left(-t/\tau_1\right)\right], \qquad (2)$$

where b is a numerical coefficient (b<2). For the positive average spin temperature ($Z(t)>0$) and in the case of Z^{st} less than some threshold saturation factor Z_{th}^{st}, the magnetization recovery is described by the sum of two exponentials similar to [3]:

$$Z(t) = Z^{st}\left\{1 - \left[\rho\exp\left(-\left(t-t_0\right)/\tau_1\right) + (1-\rho)\exp\left(-\left(t-t_0\right)/\tau_2\right)\right]\right\}, \qquad (3)$$

where ρ is the coefficient characterizing the fraction of nuclei, which relax with relaxation time τ_1. The emergence of the second exponential with a longer time of nuclear magnetization recovery demonstrates a decrease in the efficiency of spin–phonon coupling for the fraction (1-ρ) of nuclei and corresponds to a decrease in the spin-lattice relaxation rate.

The dependences of the recovery time's τ_1, τ_2 and the coefficient (1-ρ) on the saturation factor Z^{st} is shown in Fig. 1.

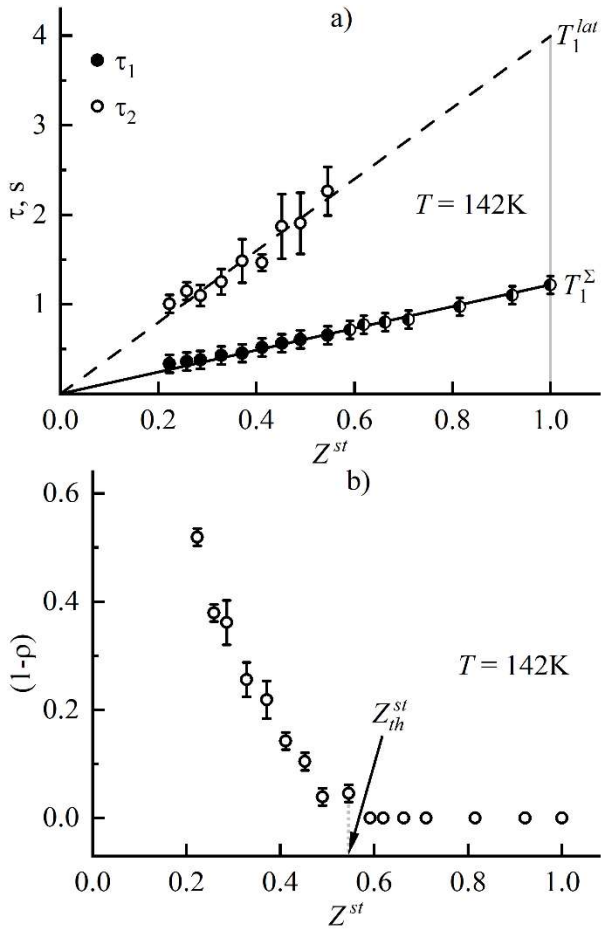


Figure 1. a) The recovery times τ_1 and τ_2 for ^{75}As and b) the fraction of nuclei, which relax with recovery time τ_2 depending on the continuous magnetic saturation factor Z^{st} in an undoped semi-insulator GaAs crystal at 142 K.

The total relaxation rate is a sum of the contributions from quadrupole "lattice" relaxation and from relaxation due to electron centers combined with spin diffusion, denoted as "electron centers" relaxation:

$$\left(T_1^{\Sigma}\right)^{-1} = \left(T_1^{lat}\right)^{-1} + \left(T_1^{ec}\right)^{-1}. \quad (4)$$

Fig. 1,a shows that for saturation factors less than the threshold value $Z_{th}^{st} = 0.54$ the magnetic saturation suppresses the contribution from electron centers. The dependence of the fraction of nuclei with slower relaxation increases with decreasing saturation factor as can be seen in Fig. 1,b.

The linear approximation using Equation (1) of the experimental data $\tau_2(Z^{st})$ in Fig. 1,a gives us the time $T_1^{lat} = (4.0 \pm 0.8)s$ at $Z^{st} = 1$.

Similar experiments at different temperatures combined with calculations by Equation (4) allow us to find three relaxation times T_1^{Σ}, T_1^{lat} and T_1^{ec} within the temperature range from 30 and 220 K. Then the relevant relaxation rates $\left(T_1^{\Sigma}\right)^{-1}$, $\left(T_1^{lat}\right)^{-1}$ and $\left(T_1^{ec}\right)^{-1}$ can be evaluated. The obtained results are shown by symbols in Fig. 2. The solid lines in Fig. 2 are theoretical predictions bound to the data at 220 K for quadrupole spin-lattice relaxation due to two-phonon Raman processes assuming the Debye model of the phonon spectrum.

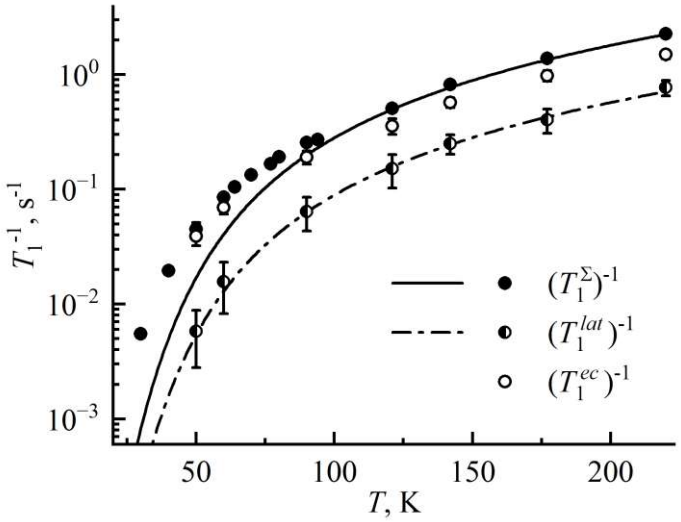


Figure 2. Relaxation rates $\left(T_1^{\Sigma}\right)^{-1}$ *(closed symbols),* $\left(T_1^{lat}\right)^{-1}$ *(semi-closed symbols) and* $\left(T_1^{ec}\right)^{-1}$ *(open symbols) for 75As in an undoped semi-insulator GaAs crystal obtained at different temperatures.*

We can see the perfect agreement between the calculated data for $\left(T_1^{lat}\right)^{-1}$ and the relevant theoretical curve as is expected for "lattice" quadrupole relaxation. In contrast, pronounced divergence is observed between the $\left(T_1^{\Sigma}\right)^{-1}$ and $\left(T_1^{ec}\right)^{-1}$ rates and the theoretical prediction for quadrupole relaxation. The later result differs from studies of total relaxation and relaxation due to electron centers obtained for two gallium isotopes in the same GaAs crystal [3]. The findings for ^{75}As can be explained by stronger magnetic coupling of electron centers to neighbor arsenic nuclei, which affects the temperature dependence of the total relaxation and relaxation due to electron centers. The electron centers, most active in the

relaxation process in the semi-insulator GaAs crystal, are likely the EL2 centers [9], which comprise the antisite arsenic atoms As_{Ga}.

Conclusions

^{75}As NMR studies of spin-lattice relaxation in a semi-insulator GaAs crystal under magnetic saturation allowed separating contributions to relaxation due to the “lattice” mechanism and due to electron centers. The temperature dependences of the “lattice” contribution agreed with predictions for quadrupole relaxation in ideal crystals. The total relaxation rate and the relaxation rate due to electron centers demonstrated deviations from these theoretical predictions in contrast to the results for gallium isotopes in the same GaAs sample. The differences observed are likely caused by stronger magnetic hyperfine coupling of electron centers with arsenic nuclei.

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