

The spin kinetics of ^3He in contact with nanosized crystalline powders LaF_3

This content has been downloaded from IOPscience. Please scroll down to see the full text.

2014 J. Phys.: Conf. Ser. 568 012001

(<http://iopscience.iop.org/1742-6596/568/1/012001>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 178.213.241.4

This content was downloaded on 13/09/2016 at 12:44

Please note that [terms and conditions apply](#).

You may also be interested in:

[The spin valve device based on asymmetrical ferromagnet-superconductor trilayer in an external magnetic field](#)

Yu Proshin and M Avdeev

[High-frequency ESR measurements and ESR/NMR double resonance experiments of lightly phosphorous-doped silicon](#)

Y Fujii, S Mitsudo, K Morimoto et al.

[Cryogen free cryostat for neutron scattering experiments](#)

O Kirichek, R B E Down, P Manuel et al.

[High field paramagnetic effect in YBCO single crystals with different oxygen contents](#)

J P Peña, O J Freitas and P Pureur

[Weak localization in ZnO:Ga and ZnO:Al thin films](#)

O V Reukova, V G Kytin, V A Kulbachinskii et al.

The spin kinetics of ^3He in contact with nanosized crystalline powders LaF_3

**E M Alakshin, A M Gazizulina, R R Gazizulin, A V Klochkov, T R Safin,
K R Safiullin, M S Tagirov and M Yu Zakharov**

Kazan Federal University, Institute of Physics, 420008, Kremlevskaya, 18, Kazan,
Russia

E-mail: alakshin@gmail.com

Abstract. The spin kinetics of ^3He in contact with nanosized crystalline powders LaF_3 has been studied by NMR methods at the temperature 1.5 K. The ^3He longitudinal relaxation time increases proportionally to the magnitude of the external magnetic field and the transverse relaxation time does not depend on the magnetic field. Relaxation of the gaseous and liquid ^3He in contact with nanosized crystalline powder LaF_3 takes place by the ^3He adsorbed layer. The nuclear magnetic relaxation of adsorbed ^3He layer on the surface of LaF_3 nanoparticles is due to the two-dimensional spin-diffusion motion.

Introduction

Hyperpolarized ^3He gas is widely used in neutron accelerators for the polarization of neutron beams [1–4], nuclear magnetic resonance tomography, and diverse fundamental scientific researches [5–10]. Therefore, obtaining the hyperpolarized spin state of ^3He nuclei using new methods remains a topical problem to date.

In 1995 the possibility of dynamic ^3He nuclear polarization using dielectric Van Vleck paramagnetic was discussed [11]. The channel of energy transfer from the PrF_3 to liquid ^3He via magnetic coupling between the nuclear spins was proposed. The " $^{141}\text{Pr} - ^3\text{He}$ " system has been studied in detail [12–16].

The process previously interpreted [13] as a relaxation mechanism of ^3He on the surface of nanosized crystalline powders PrF_3 through the adsorbed layer may be a cross-relaxation effect between ^{141}Pr and ^3He nuclei. To confirm this idea the additional experiments with nanosized crystalline powders LaF_3 (diamagnetic analogue of PrF_3) have been required.

We report here the experimental investigation of ^3He spin kinetics in the system " LaF_3 nanoparticles - ^3He ". The home built NMR spectrometer has been used and low temperature was achieved by ^4He vapor pumping. The complete details of the experimental setup were published earlier [17]. The typical thermalization time of ^3He adsorbed layer on a diamagnetic solid state substrate is less than 2 hours for our setup and temperature range [18]. The covering of sample surface by ^3He was carried out in the following sequence: gaseous ^3He was condensed in the experimental cell at temperature 1.5 K in small amounts (about $0.5 \text{ cm}^3 \text{ STP}$). The pressure in the system has been monitored, and when it reached a value less than 10^{-2} mbar the next dose of ^3He was added. When the equilibrium pressure in the system rose above 10^{-1} mbar, the entire surface was assumed to be covered by ^3He layer. Further condensation of ^3He led to an increase of the pressure with most of the ^3He remaining in the gas phase. When the pressure approached the vapor saturation value (67 mbar at



1.5 K), the liquid phase appeared in the cell and further dosing of ^3He was controlled by the ^3He NMR signal amplitude until whole sample has been filled completely. Before all NMR measurements the sample was thermalized during 2 hours.

Results and discussion

The series of LaF_3 nanosamples were synthesized using different microwave irradiation time (sample 1 – 0 min, sample 2 – 20 min, sample 3 – 40 min, sample 4 – 60 min, sample 5 – 420 min), the procedure described in [13]. The X-ray analysis of synthesized samples is shown in figure 1, which identifies samples as crystalline powders LaF_3 . Further on, the data on ^3He spin kinetics in the system " LaF_3 nanoparticles - ^3He " are presented for sample 2.

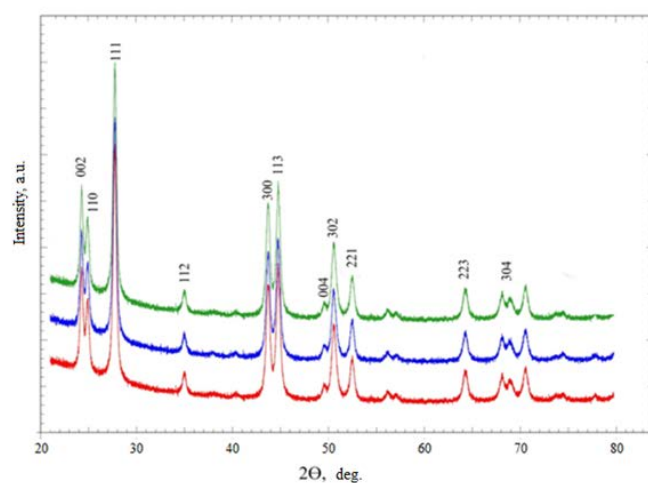


Figure 1. X-ray analysis of LaF_3 nanoparticles.

The typical image of PrF_3 (diamagnetic analog of LaF_3) nanoparticle obtained by high resolution transmission electron microscopy presented in figure 2. The size of nanoparticles is 20-40 nm.

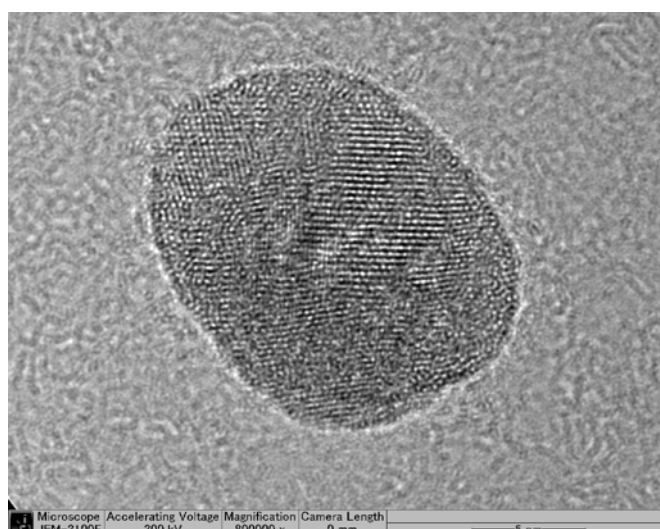


Figure 2. High-resolution transmission electron microscopy image of PrF_3 nanoparticle.

The magnetic field dependence of the ^3He nuclear magnetic relaxation times in contact with LaF_3 nanoparticles in different aggregate states of ^3He have been investigated. Dependences of the ^3He relaxation times T_1 and T_2 on the magnetic field for the three aggregate states are shown in figures 3 and 4.

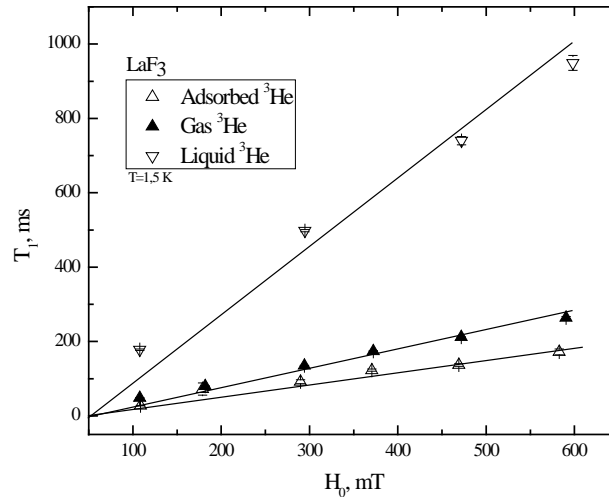


Figure 3. Longitudinal relaxation time of ^3He in contact with LaF_3 nanoparticles in different aggregate states of ^3He versus magnetic field.

It is seen in figure 3 that the longitudinal relaxation time T_1 increases proportionally to the magnitude of the external magnetic field. The transverse relaxation time T_2 is independent on the applied magnetic field (figure 4).

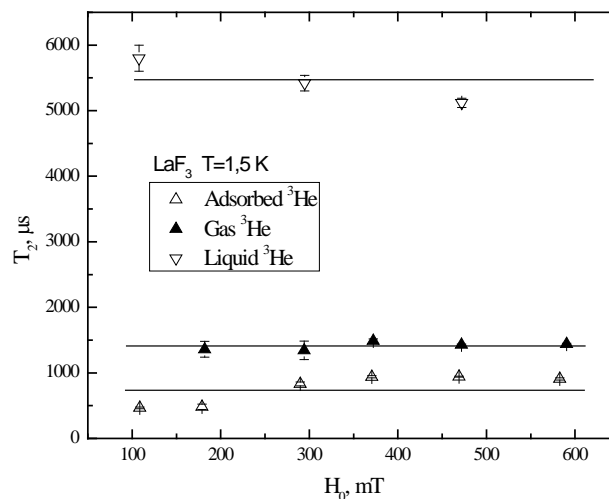


Figure 4. Transverse relaxation time of ^3He in contact with LaF_3 nanoparticles in different aggregate states of ^3He versus magnetic field.

The presence of "free" ^3He (gaseous or liquid) above adsorbed layer in the experimental cell significantly increase the relaxation times values, therefore the relaxation occurs through the ^3He adsorbed layer [19].

The ^3He T_1 and T_2 dependences in the gaseous and liquid phases in the cell on the total number of ^3He atoms (figures 3 and 4) clearly shows that the magnetic relaxation times are directly proportional to the corresponding relaxation times in the adsorbed layer and to the ratio of the number of ^3He spins of whole nuclear spin system to the number of ^3He spins in the layer, i.e.

$$T_1 = T_{1S} \cdot N_0 / N_S, \quad (1)$$

where T_1 , T_{1S} – longitudinal magnetization recovery times, N_0 , N_S -number of spins in the whole system and the adsorbed layer, respectively;

$$T_2 = T_{2S} \cdot N_0 / N_S, \quad (2)$$

where T_2 , T_{2S} - times of the transverse magnetization decay, N_0 , N_S -number of spins in the entire system and in the adsorbed layer, respectively.

This fact as well as the character of dependence of the relaxation times on the magnetic field plays in favor of relaxation mechanism of adsorbed ^3He in the two-dimensional film by the two-dimensional spin-diffusion motion, as proposed by Cowan [20, 21].

The model of 2D relaxation, proposed by Cowan, only qualitatively describes obtained data. Comparison of ^3He T_1 values of adsorbed layer on various diamagnetic surfaces [21-24] shows quite good similarity with presented here experimental data, which additionally supports proposed relaxation mechanism. However, there are several additional mechanisms of ^3He surface relaxation due to dipole-dipole interaction between ^3He spins and solid substrate [25-31]. The direct transfer of magnetization from ^3He to ^{19}F will not speed up ^3He nuclear transverse relaxation sufficiently to observed values, because at helium temperatures the intrinsic spin-lattice relaxation of ^{19}F in pure diamagnetic fluoride crystals is in the order of 100s of seconds [see for example 32]. The ^3He nuclear magnetic relaxation of adsorbed layer due to the modulation of the dipole-dipole interaction between ^{19}F and ^3He by the quantum zero point motion [31] is not sufficient, as well.

Conclusion

Nuclear magnetic relaxation of the gaseous and liquid ^3He in contact with nanosized crystalline powder LaF_3 takes place by the adsorbed layer. The nuclear magnetic relaxation of adsorbed ^3He layer on the surface of LaF_3 nanoparticles is due to the two-dimensional spin-diffusion motion.

Acknowledgments

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University, partly supported by the Russian Foundation for Basic Research and Tatarstan government (project no. 12-02-97048) and by the Ministry of Education and Science of the Russian Federation (project no. 02.G25.31.0029).

References

- [1] Gentile T R, Babcock E, Borchers J A, et al., 2005 *Physica B* **356** 96
- [2] Petoukhov A K, Andersen K H, Jullien D, et al., 2006 *Physica B* **385-386** 1146
- [3] Chang L J, Mueller R, Appelt S, et al., 2004 *Physica B* **350** e707
- [4] Krimmer J, Distler M, Heil W, et al., 2009 *Nucl. Instrum. Methods Phys. Res.* **611** 18
- [5] Van Beek E J, Wild J M, Kauczor H U, et al., 2004 *J. Magn. Reson. Imag.* **20** 540
- [6] Schreiber W G, Morbach A E, Stavngaard T, et al., 2005 *Respir. Physiol. Neurobiol.* **148** 23
- [7] Patz S, Muradian I, Hrovat M I, et al., 2008 *Acad. Radiol.* **15** 713
- [8] Baudin E, Hayden M E, Tastevin G, et al., 2008 *Compt. Rend. Chim.* **11** 560
- [9] Gazizulin R R, Klochkov A V, Kuzmin V V, et al., 2010 *Appl. Magn. Reson.* **38** 271
- [10] Gazizulin R R, Klochkov A V, Kuzmin V V, et al., 2009 *Magn. Reson. Solids* **11** 33
- [11] Tagirov M S, Tayurskii D A, 1995 *JETP Lett.* **61** 672

- [12] Alakshin E M, Gabidullin B M, Gubaidullin A T, et al., 2011 *arXiv:condmat*. **1104** 0208 - <http://arxiv.org/abs/1104.0208>
- [13] Alakshin E M, Gazizulin R R, Egorov A V, et al., 2011 *J. Low Temp. Phys.* **162** 645
- [14] Alakshin E M, Blokhin D S, Sabitova A M, et al., 2012 *JETP Lett.* **96** 181
- [15] Alakshin E M, Aleksandrov A S, Egorov A V, et al., 2011 *JETP Lett.* **94** 240
- [16] Alakshin E M, Gazizulin R R, Klochkov A V, et al., 2013 *JETP Lett.* **97** 579
- [17] Alakshin E M, Gazizulin R R, Klochkov A V, et al., 2013 *Magnetic Resonance in Solids* **15** 1
- [18] Alakshin E M, Gazizulin R R, Klochkov A V, et al., 2011 *JETP Lett.* **93** 223
- [19] Hammel P C and Richardson R C, 1970 *Phys. Rev. Lett.* **51** 1441
- [20] Cowan B P, 1980 *J. Phys. C* **13** (24) 4575
- [21] Cowan B P, 1983 *J. Low Temp. Phys.* **50** (1-2) 135
- [22] Alakshin E M, Gazizulin R R, Klochkov A V, et al., 2011 *J. Phys.: Conf. Ser.* **324** 012028
- [23] Klochkov A V, Kuz'min V V, Safiullin K R, et. al., 2008 *JETP Lett.* **88** 823
- [24] Klochkov A V, Kuzmin V V, Safiullin K R, et. al., 2009 *J. Phys.: Conf. Ser.* **150** 032019
- [25] Friedman L J, Millet P J, and Richardson R C, 1981 *Phys. Rev. Lett.* **47** 1078
- [26] Friedman L J, Gramila T J, and Richardson R C, 1984 *J. Low Temp. Phys.* **55** 83
- [27] Singerman R W, Van Keuls F W, and Richardson R C, 1994 *Phys. Rev. Lett.* **72** 2789
- [28] Van Keuls F W, Singerman R W, and Richardson R C, 1994 *J. Low Temp. Phys.* **96** 103
- [29] Egorov A V, Aukhadeev F L, Tagirov M S, and Teplov M A, 1984 *JETP Lett.* **39** 584
- [30] Schuhl A, Maegawa S, Meisel M W, et al., 1987 *Phys. Rev. B* **36** 6811
- [31] Genio E B, Ihas G G and Sullivan N S, 1998 *J. Low Temp. Phys.* **112** 21
- [32] Klochkov A V, Kurzin S P, Mukhamedshin I R, et. al., 1998 *Appl. Magn. Reson.* **14** 525