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Spin-lattice NMR relaxation by anomalous translational diffusion

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Abstract

A model-free theoretical framework for a phenomenological description of spin-lattice relaxation by anomalous translational diffusion in inhomogeneous systems based on the fractional diffusion equation is developed. The dependence of the spin-lattice relaxation time on the size of the pores in porous glass Vycor is experimentally obtained and found to agree well with our theoretical predictions. We obtain nonmonotonic behavior of the translational spin-lattice relaxation rate constant (it passes through a maximum) with the variation of the parameter referring to the extent of inhomogeneity of the system.

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1. Introduction

Anomalous diffusion processes in randomly disordered media are of considerable interest at present (see [1] and references therein). The list of examples includes, glasses and supercooled liquids [2], porous [3–5], percolative [6–8], polymeric [9], and diffusive [10] systems, etc. One of the powerful methods for investigation of such processes is that of nuclear magnetic resonance (NMR) diffusometry [3]. The latter was successfully applied to the systems listed above [3–9]. The theory of NMR diffusometry in disordered media [4,8] is developed within the framework of a modern approach to anomalous diffusion [1] invoking the so-called fractional calculus [11].

The aim of the present paper is to report the experimental results on spin-lattice relaxation time in porous glass Vycor with molecules of hexane as a diffusion tracer and to compare them with phenomenological generalization of the theory of spin-lattice relaxation in homogeneous media for the case of inhomogeneous one.

A modern description of anomalous diffusion processes in disordered (e.g., porous) media makes use of the so-called fractional diffusion equation (FDE). The idea of this approach goes back to many pioneers whose achievements are honored in the review article [1]. The reason for introducing this equation is as follows. As is well known the mean squared displacement of a free particle in a homogeneous media increases linearly with time $\langle x^2(t)\rangle \sim C_1 t$, where C_1 is the diffusion coefficient with the dimension cm^2/s. This conventional Einstein relationship of the classical theory results from the ordinary diffusion equation for the probability density function to find the particle at position x at time t and is a direct consequence of the Fick's second law. In the case of an inhomogeneous media a disorder (like e.g., obstacles caused by walls of pores in a porous materials) leads to a slower increase of the mean squared displacement with time

$$\langle x^2(t)\rangle \sim C_\alpha t^\alpha, \qquad (1)$$

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