ЕНИСЕЙСКАЯ ТЕПЛОФИЗИКА

Тезисы докладов
I Всероссийской научной конференции
с международным участием

Красноярск, 28–31 марта 2023 г.

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THERMALLY ACTIVATED SKYRMION GAS DRIFT IN AN INHOMOGENEOUS STRIPE

V. A. Orlov[1,2,*], A. A. Ivanov[1],
I. N. Orlova[3], G. S. Patrin[1,2] [*]

[1]*Siberian Federal University*
660041, Russia, Krasnoyarsk, Svobodny pr., 79
[2]*Kirensky Institute of Physics, Federal Research Center KSC SB RAS*
660036, Russia, Krasnoyarsk, Akademgorodok, 50/38
[3]*Krasnoyarsk State Pedagogical University after V. P. Astafev*
660049, Russia, Krasnoyarsk, Ady Lebedevoi street, 89
* *vaorlov@sfu-kras.ru*

This article theoretically solves the problem of the thermally activated motion of gas of non-interacting magnetic vortices/skyrmions in the field of defects located randomly, i.e., anchoring centers. The process of vortices motion is described as a sequence of thermally activated separation of vortices from the attracting centers. The cases of some model distribution functions of the energy barriers are considered: 1) the barriers are of the same height; 2) the heights of the barriers are distributed evenly; and 3) the heights are distributed according to the normal law. Within these models, analytical expressions for the drift velocity and the diffusion gas coefficient of quasiparticles are obtained.

In thin low-dimensional magnets (nanowires, nanostripes), as a rule, there are defects that create a random or modulated force field, where the vortex moves as a particle. Here, we present a statistical description of the time evolution of a conglomerate of magnetic vortices/skyrmions as a gas of non-interacting quasiparticles involved in one-dimensional motion in the field of magnetic structure defects under the influence of a constant external force. To describe the nature of the vortices displacement under the influence of a driving force in a random field of defects, we calculate the average number of trajectories of the $\rho(x,t)$ cores, resulting in a favorable outcome, i. e., the core is in the x coordinate at the t time. The elementary event: the core is in the x coordinate at the t time. The probability of such an elementary event can be written as:

$$d\rho_n^{(el)}(x,t)=\prod_{k=1}^{n}\rho(\Delta x_k)\rho(\Delta t_k)\rho(W_k)dx_k dt_k dW_k \delta\left(x-\sum_{k=1}^{b}\Delta x_k\right)\delta\left(t-\sum_{k=1}^{n}\Delta t_k\right). \qquad (1)$$

$\rho(W_k)$ is the density of the distribution of the barriers heights; $\rho(\Delta x_k)=\mu\exp(-\mu\Delta x_k)$, $\rho(\Delta t_k)=\nu_k\exp(-\nu_k\Delta t_k)$ are the distribution densities of the jump lengths and their durations, respectively (Poisson's law); μ is the linear coordinate density of the distribution of the anchoring centers; ν_k is the frequency of attempts of the core disruption from the defect, which is determined by the Arrhenius law.

Based on calculations (1), analytical expressions were obtained for the average drift velocity, diffusion coefficients depending on temperature, and the degree of chaos in barrier heights. Calculations were carried out for three models: 1) Identical defects (model 1), 2) Smooth distribution of activation energy (model 2), 3) Normal activation energy distribution (Model 3). After integration (1) expression for models, it is obtained. Characteristic surface $\rho(x,t)$ is shown in Figure 1.

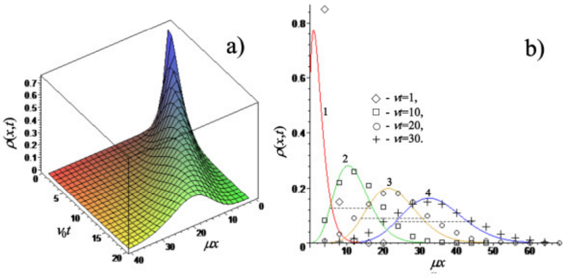

Fig. 1. The distribution of the vortex gas depending on the coordinate and time (Fig. a). To demonstrate the evolution of the coordinate distribution, Fig. b) shows sections of the ρ(x, t) surface at some moments of time. Points - simulation result.

The figure below shows the main results of the comparative blooms of the three models. In the low temperature range, when the energy of thermal motion is much less than the average value of the energy barriers height, the features of the dependence of the diffusion coefficient on the dispersion of the activation energy of the anchoring centers have been found, i. e., nonmonotonicity associated with the determining role of the magnet defects with the maximum value of the barrier height.

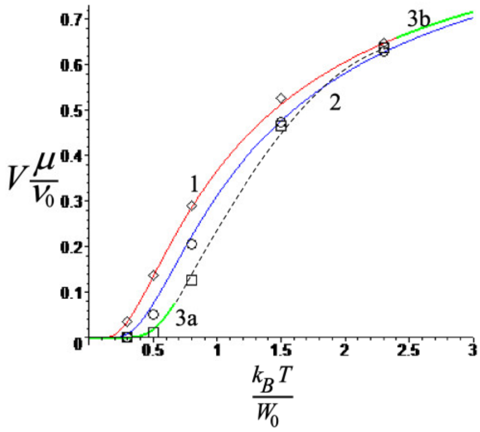

Fig. 2. Temperature dependences of the velocity displacement of the maximum coordinate of the ρ(x, t) function for the models under study.

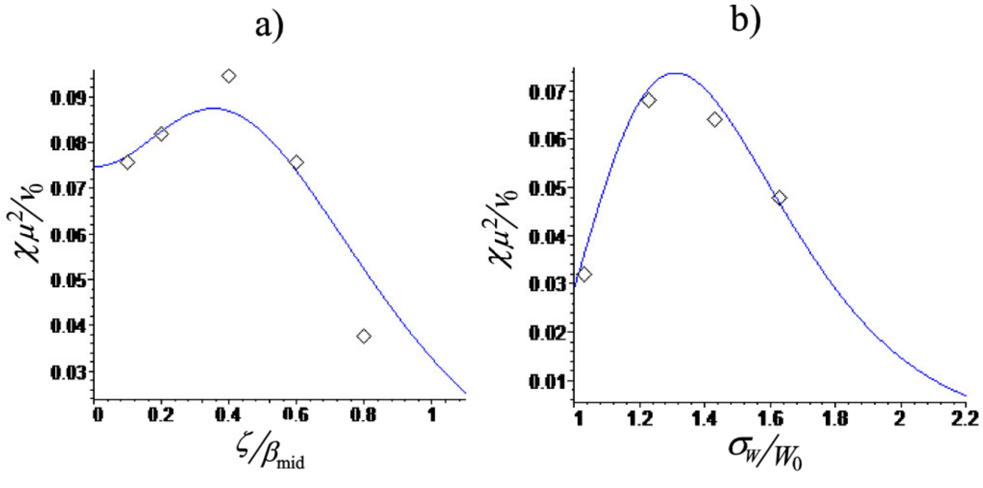

Fig. 3. The dependence of the dimensionless diffusion coefficients of the vortex gas on the value of the activation energy spread for the model of smooth distribution of barrier heights (Fig. a) and for the normal distribution (Fig. b).

An interesting fact is that the graphs in Fig. 3 are nonmonotonic. With a small value of the ($\zeta \ll \beta_{\mathrm{mid}}$ or $\sigma_W \ll W_0$) activation energy spread, when almost all defects are the same in their effect on vortices, a slight increase in accompanied by a natural increase in σ^2, as a response of the system to a more chaotic ”input signal”. But with the growth of chaos in the barriers heights of the anchoring centers at low temperatures, a significant role is played by rare but more rigid defects, where the quasiparticles gas can fix itself and slows down the expansion of its localization area. It results in the diffusion coefficients decrease. The motion of the vortices gas in this case looks as if most of the quasiparticles are delayed at one (several) high barrier with the growth of ζ (or σ), that limits the spread of coordinates and the drift velocity.

The study has been carried out within the framework of the state task of the Ministry of Science and Higher Education of the Russian Federation (topic No.FSRZ-2020-0011).