Effect of Domain Wall on Thermal Conductivity of Solid ^{3}He in U2D2 Phase

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Abstract

We calculate the thermal conductivity of solid ^{3}He in U2D2 phase. In our previous work, we could explain the temperature dependence of the thermal conductivity of the magnetic single domain crystal at low temperatures qualitatively. Now, we are interested in the effect of the domain wall to the thermal conductivity. In U2D2 phase, it is well known that there are three domains characterized by the anisotropic axes. Tsubota *et al.* investigated the static structure of the domain wall. We apply the same method as our previous work to this system, and calculate the thermal conductivity caused by the domain wall.

Key words: helium3, U2D2 phase, thermal conductivity, domain wall

1. Introduction

In solid ^{3}He, the nuclear spins of the ^{3}He atoms order below T_N (about 1 mK) with the sequence up-up-down-down (U2D2) along one of the cubic axes, which is denoted by vector $\hat{l}$. Supposing that, in our previous work[1], there are some magnetic plane defects(MPDs) in the magnetic single domain crystal and these have a significant influence on the thermal conductivity at low temperatures, we could explain the temperature dependence of the thermal conductivity measured in the experiment, qualitatively.

Now, we are interested in the effect of the domain wall(DW) on the thermal conductivity. In U2D2 phase, it is well known that there are three magnetic domains characterized by the anisotropic axes. The static structure of the DW was investigated by Tsubota *et al.* [2] theoretically and it is reported that this structure is consistent with the recent experimental data [3]. Therefore, we calculate the thermal conductivity caused by the DW using the same method in our previous work.

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2. Formulation

We start with the Hamiltonian given by

$$H = \sum_{n=1}^{3}\left[-\frac{J_n}{2}\sum_{(i,j)}{}^{n}(\sigma_i\cdot\sigma_j)\right] - \frac{K_p}{4}\sum_{(i,j,k,l)}\delta_{ijkl}, \quad (1)$$

$$\delta_{ijkl} = (\sigma_i\cdot\sigma_j)(\sigma_k\cdot\sigma_l) + (\sigma_i\cdot\sigma_l)(\sigma_j\cdot\sigma_k) - (\sigma_i\cdot\sigma_k)(\sigma_j\cdot\sigma_l),$$

where $n = 1, 2$ and 3 represent the nearest-neighbor, next-nearest-neighbor and third nearest-neighbor, respectively. In the above, we have retained only a four-spin exchange K_p, called “planar” type, since it is most important to stabilize U2D2 phase.

Tsubota *et al.* investigated the some possible types of the configuration of the DW and calculated the magnetic energy of the DW with the multiple-exchange model. They showed that the most stable DW is [110] type (See Fig. 1).

In order to calculate the thermal conductivity, we adopt the same method as used in the calculation of Kapitza resistance [4]. The thermal conductivity is given by

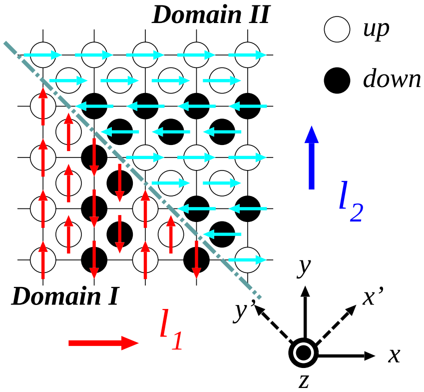

Fig. 1. The schematic figure of the spin configuration investigated by Tsubota *et al.* The broken line represents [110] domain wall.

$$h = \sum_{k,\gamma=\alpha,\beta}{}' \left(\frac{\partial n_k}{\partial T}\right) \hbar\omega_k (\nabla_k \omega_k)_\perp |t_k^\gamma|^2, \tag{2}$$

where n_k is the distribution function of magnon, $\hbar\omega_k$ is the energy of magnon, $(\nabla_k\omega_k)_\perp$ is the normal component of group velocity to the DW, $|t_k^\gamma|^2$ is the transmission coefficient through the DW and $\gamma = \alpha, \beta$ specifies the polarization of magnons.

In order to determine $|t_k^\gamma|^2$, we solve the equations of motion of the spins, which is given by

$$i\hbar\dot{\sigma}_j = [\sigma_j, H]. \tag{3}$$

We use Ceperley's parameters [5] for numerical calculation.

3. Transmittion coefficient and Thermal Conductivity

We show the calculated result for $k_z a = 0$ of α-magnon in Fig. 2. The transmittion coefficients of the other cases, i.e. $k_z a \neq 0$ and β-magnon, are similar to the one given by Fig.2.

First, we find that the low energy magnons pass through the DW. This result implies that, for the magnons, the DW does not work as a conventional potential barrier, in which the transmition probability increases with the energy of the magnon. This characteristic property is similar to that of the MPD and we can say that it may be common to the magnetic ordered system. Second, we find that the magnon whose wave vector is about perpendicular to the DW, namely $k_x \simeq k_y$, hardly pass through the DW. This is caused by the anisotropy of the magnon energy.

Substituting the calculated $|t_k^\gamma|^2$ into eq.(2), we obtain the thermal conductivity and show it in Fig. 3. As expected from calculated $|t_k^\gamma|^2$, this result is similar to the thermal conductivity caused by one MPD.

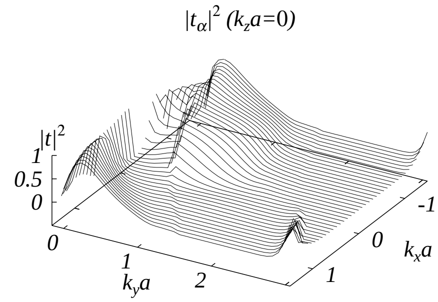

Fig. 2. Transmittion coefficient of the α-magnon of $k_z a = 0$.

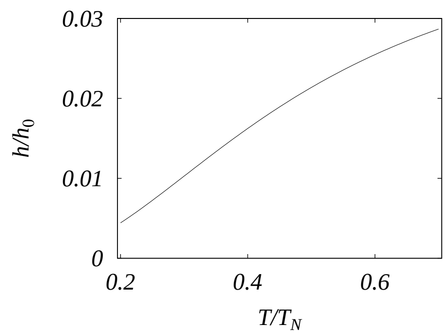

Fig. 3. The temperature dependence of the thermal conductivity. Here, $h_0 = k_B T_N / \hbar a^2$.

4. Conclusions

From our theoretical investigation, we conclude that the DW works as the same of a MPD to the thermal conductivity. This means that the DW does not have a much influence on the thermal conductivity.

Acknowledgments

The authors would like to thank Prof. T. Mizusaki for many useful comments and fruitful discussions.

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