ISSN : 0974 - 7435 Volume 10 Issue 17

2014

BioTechnology

An Indian Journal

FULL PAPER

BTAIJ, 10(17), 2014 [9767-9771]

Research on heat transport in low-dimensional magnetic materials

Yaheng Zhang, Jincheng Huang
Department of Materials Engineering, Yancheng Institute of Technology, Yancheng, Jiangsu Province, 224051, (P.R.CHINA)
E-mail: zyh@ycit.edu.cn, huangjincheng@jsnu.edu.cn

ABSTRACT

Low-dimensional magnetic materials have attracted much attention due to their exotic ground states, rich physical properties, and their close relationship to high superconductor materials. Studies on the physical properties of the low-dimensional magnetic materials are useful to probe the mechanism of the fantastic phenomena and develop new function materials. This dissertation focuses on the quantum phase transition induced by magnetic field and role of magnetic excitations in the heat transport of low-dimensional magnetic materials. The low-temperature heat transport properties of the spin-dimer material with BEC transition, the one-dimensional magnetic material and the organic spin chain material with staggered magnetization are studied. Low-dimensional magnetic materials provides research related to the quantum ground state and the excited state model, the new phase and the unique possibility of competition between quantum fluctuations and thermal fluctuations, so for quasi-one-dimensional magnetic materials research has developed into an independent research. From a theoretical point of view, this research provides a broad platform for a variety of theoretical and computational methods.

KEYWORDS

Low-dimensional magnetic material; Heat transport; Magnetic excitation.

THEORETICAL INTRODUCTION OF LOW-DIMENSIONAL MAGNETIC MATERIALS

In condensed matter physics, a variety of multi-body systems are extensive and in-depth research. In the many-body system, a large number of entities interacting quantum effects usually occur in which play an important role. If the magnetic exchange interaction is one dimension along the direction or the main direction of the two dimensions, much greater than the other dimensions of the direction of the magnetic exchange interaction, these systems can be as a low-dimensional magnetic system. Figure 1 shows the recent antiferromagnetic exchange interaction of isotropic one-dimensional and two-dimensional spin structure diagram.

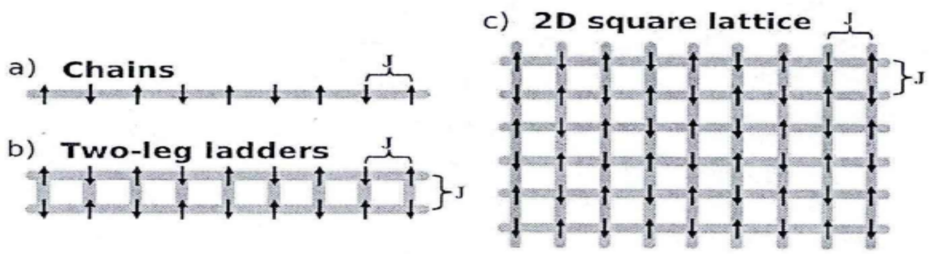


Figure 1 : The one-dimensional and two-dimensional spin structure diagram

One-dimensional anisotropic Heisenberg model and some consider a more general one-dimensional spin excitation energy chain, the correlation function and thermal properties have also been calculated. An important feature of low-dimensional quantum magnetic model is a continuous symmetry of this model there is no long program at finite temperature. The new phenomenon of recent research on low-dimensional quantum magnetic material and has not been finally found a reasonable explanation, and therefore for future research in this area has left more expectations[1].

Because quasi-one-dimensional magnetic materials provides research related to the quantum ground state model and the unique possibility to stimulate competitive state, a new phase as well as quantum fluctuations and thermal fluctuations between, so for quasi-one-dimensional magnetic materials research has developed as an independent field of study. From a theoretical point of view, this research is quite extensive and therefore provide a broad platform for a variety of theoretical and computational methods, these methods include accurate method for solving quantum field theory approximation methods (conformal invariance, Bose, semi-classical the non-linear model), multi-body theory (using Schwinger boson and hard-core bosons), perturbation method (especially senior expand), numerical methods density matrix renormalization group method, Monte Carlo simulation.

THERMAL CONDUCTIVITY OF LOW-DIMENSIONAL MAGNETIC MATERIALS

The thermal conductivity of solid materials even for very weak disorder is often very sensitive, very vulnerable to the impact of the phase transition. Therefore, the thermal conductivity measurements are carried out a study of solid state physics a valid experimental section. Before the introduction of low-dimensional magnetic thermal conductivity we briefly introduce solid theoretical background in energy transport. The most common method of measuring the thermal conductivity of the heat flux is obtained by the ratio and temperature gradients obtained, i.e. the Fourier's law. And thermal conductivity similar to the ideal gas, if it is assumed that all the energy of carriers have the same speed and through the same mean free path[2].

Thermal conductivity measurement method most commonly used by the steady-state heat flow through the sample set up a fixed temperature gradient, thus achieving a simple low-dimensional spin system is impossible to measure the energy transport in the experiments. The actual experimental measurements are carried out in a three-dimensional material that contains particles with a non-zero spin and spin-lattice system formed by the exchange interaction of the magnetic system. In steady-state method to measure the thermal conductivity of the experiment, the contribution of the phonon thermal conductivity is certainly exist, they may even have the contribution of other quasi-particles. Therefore, the thermal conductivity of the spin to the contribution from the other portions such as the phonon thermal conductivity of the separation is very difficult. Generally, the separation of the thermal conductivity of the spin is performed by deducting the contribution of the relative values of the other parameters or a portion of the theoretical model and the actual experimentally obtained to accurately calculate the contribution of the other portions.

For the quasi-one-dimensional spin-chain material, due to the energy dispersion relation vertical spin chains parallel to the spin chain, compared with more flat, which has a smaller group velocity, so the spin-spin excitations in the chain perpendicular to the parade heat transport chain is generally higher than the contribution of the spin direction of the spin chain is much smaller. Therefore contrast perpendicular and parallel to the direction of a one-dimensional system space expansion thermal conductivity usually helps to extract the contribution of the background section. In a typical experiment, the thermal conductivity, the heat flow through the sample is generated by the heater, and only the lattice excitation, so to transfer the energy to the spin system from the lattice, spin-lattice and there must be a degree of said together. Spin - lattice, said co-existence, mutual scattering due to the different types of quasi-particles, naturally, will make the phonons and spin excitations of the thermal conductivity of different degrees of inhibition. However, if the spin - phonon interaction is missing or very weak, through experiments on the thermal conductivity of the thermal conductivity of less than observed spin-dependent[3].

MEASUREMENT METHOD OF THERMAL CONDUCTIVITY OF MAGNETIC MATERIAL

Non-uniform temperature distribution in the solid, heat will flow from the low temperature portion the high temperature part, a phenomenon known as thermal conduction. The definition of the heat flux vector represents a unit of time and the heat flow through unit cross section perpendicular to the direction of the transmission of heat. The most common method is to measure the energy transport in the steady-state method, the measurement is carried out by controlling the temperature gradient, and the temperature gradient by applying a constant heat flow to the sample to achieve. Of course, it is impossible to achieve energy transport measurements in isolated and purely one-dimensional spin system. In reality, three-dimensional measurements are performed in the system, which material comprises an ion having a three-dimensional non-zero spin and spin-exchange interactions along one direction is much larger than in the other direction[4].

In general, by reducing the relative contribution to the amplitude of other portions, or the use of reliable parameters of the theoretical model or inserted experimentally obtained easily, thermal conductivity can be separated magnetically. In a typical experiment, the thermal conductivity, the heat flow through the sample is provided by a heater, the heater can generate phonon excitation, so to transfer the energy to the spin system from the lattice, spin gave moderate said co-promoter is necessary. Obviously, since two kinds of scattering of the quasi-particles involved in the spin - lattice interaction while reducing the phonon thermal conductivity of the thermal and magnetic conductivity, but if this does not exist or is very weak interaction, the thermal conductivity is not a magnetic may be observed by heat conduction.

Two types of spin-phonon interaction can be resolved. The first is a single-particle interaction paramagnetic ion-induced resonance scattering of phonons. The second is the spin-phonon interaction may be caused, which is the change of the exchange interaction caused by the lattice distortion caused. Energy transport spin system can also be detected by other methods. Magnetic excitation can reduce phonon scattering phonon thermal conductivity. Magnetic material in the magnetic excitation or participate in the heat transport in heat transfer, or other quasi-particle scattering, or scattering effect and heat transfer occur simultaneously, the overall effect is dependent on the relative strength of the two mechanisms, but also in its different temperature zones effect is different. Furthermore, applying an external magnetic field can change both the size of the change in thermal conductivity can also be spin-phonon scattering intensity.

HEAT CONDUCTION RESEARCH OF $BA_3MN_2O_3$ SINGLE CRYSTAL

$Ba_3Mn_2O_3$ polycrystalline powder was first prepared by M. Uchida, who use traditional methods Gao temperature solid-phase reactions, but until 2008 only after preclude the use of slow cool method for preparing a chunk of the EC Samulon, who use NaOH as a co-solvent, single crystal. We learn EC Samulon crystal growth Ba3Mn2O3 others approach and by adjusting the solution temperature and cooling rate of ways to get chunks of crystal. $Ba_3Mn_2O_3$ crystal growth is the use of co-solvent to dissolve the traditional slow down by nuclear methods. Single crystal growth, due to $Ba_3Mn_2O_3$ has a valence, so when using a co-solvent method $Ba_3Mn_2O_3$ crystal growth, preclude the use of strong oxidizing and has a lower melting point of anhydrous NaOH as a co-solvent[5]. Figure 2 shows the photograph of $Ba_3Mn_2O_3$.

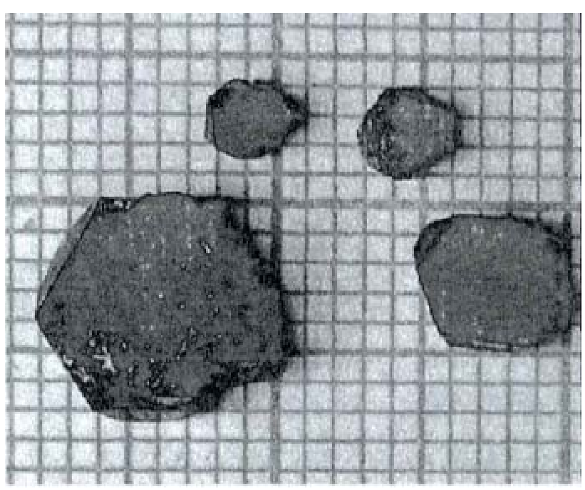


Figure 2 : The photograph of $Ba_3Mn_2O_3$

Measurement of thermal conductivity using the traditional steady-state method, the measuring process in two steps: First, the 4He pulse tube refrigerator and use constantan - nickel-chromium thermocouple measurement method for measuring the temperature difference has been at zero field 4 K to 300 K thermal conductivity data; are utilized in a lower temperature range of 8 K to 0.3 K thermal conductivity data 3He chillers and 14 T superconducting magnet to "one heater, two thermometers," the method for measuring. Before the applied magnetic field measurements carried out, on the resistance thermometer resistance can be at different magnetic fields for accurate calibration. The growth process can be divided into two steps: First, the use of high-temperature solid-state reaction method for preparing single-phase high-purity polycrystalline powder: 99.99 % purity BaCCb MnO_2 powder and powder of 99.99% purity by high-temperature baking 500 ° C according to the stoichiometric ratio $Ba_3Mn_2O_3$ weighed, mixed and sufficiently dried after grinding, then the mixed powder was placed in the A1203 progenitor disaster conditions at 1000 ° C sintered in normal air environment for 100 hours[6].

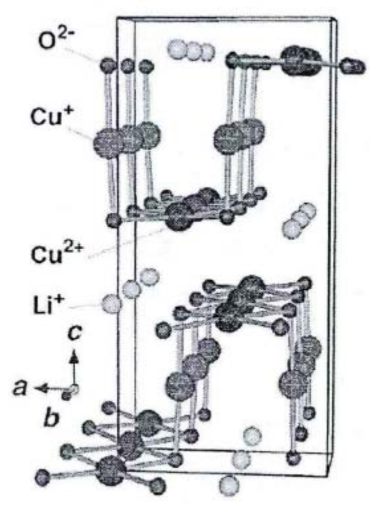
$Ba_3Mn_2O_3$ thermal transport properties of single crystals in strong magnetic fields at extremely low mild conditions, and by thermal transport measurements to detect the magnetic field induced magnetic phase transition and magnon heat conduction in. Under the zero-field conditions, the low thermal conductivity exhibited pure phonon thermal behavior. Strengthening the external magnetic field, with the gradual disappearance of the spin gap, the magnetic excitation was inspired by a lot, leading to magnetic scattering of phonons by enhanced with increasing magnetic field, and makes the overall thermal conductivity by a strong repression. However, at very low temperatures, resulting in the spin gap closure long-range ordered antiferromagnetic state occurs, the phase change phonon scattering by the strong position. $Ba_3Mn_2O_3$ Bose-Einstein condensate found no evidence has considerable magnetic heat transport.

HEAT CONDUCTION RESEARCH OF $LICU_2O_2$ SINGLE CRYSTAL

Cu^{2+} of $LiCu_2O_2$ along the crystal axis b axis showing a one-dimensional chain-like arrangement of features, and is found in the copper oxide when the first zero field to have an intrinsic material, which has been particularly widespread attention. In-depth study $LiCu_2O_2$ for low-dimensional magnetic reluctance setback effect has found opened up a new path. $LiCu_2O_2$ crystal structure and equal amount of Cu2 + Cu + are arranged in lattice positions are not equivalent, only Cu2 + with a S = 1/2; Cu2 + Cu04 side of the center plane of the co-located, are formed along the axial direction of the spin of the edge-chain, bond angles between the Cu-O-Cu is 94 °, so the bond angle generally corresponds to the adjacent ferromagnetic spin exchange interaction between the ultra[7].

Specific heat is one of the important macro parameters condensed matter, especially in low temperature, due to the lattice vibration becomes weak, the contribution of other subsystems such as the specific heat of the spin system, electronic system or more significant, we studied the phenomenon for many microscopic mechanisms helpful. For the insulating low-dimensional magnetic system, when the temperature is low, the contribution of the specific heat of the electronic system is very small, almost negligible; contribution of magnetic excitation of the spin system in contrast to the increasing heat, especially in the vicinity of the magnetic phase transition. Therefore, the low-temperature specific heat is an important means of low dimensional magnetic materials. In $LiCu_2O_2$ spiral antiferromagnetic ordered phase, along the b axis between the spin-spin current model mentioned earlier by neighboring or anti-DM interaction mechanism produces electrodes along the C-axis direction, thus the emergence of anti-ferromagnetic and ferroelectric orderly coexistence interesting phenomenon.

When used Li_2CO_3, CuO and ZnO as a raw material, alumina crucible in full bloom, the raw material using high-temperature furnace temperature was raised to 1090 ° C to make it fully melt reaction to 5 ° C / h at a rate slow cooling to 930 ° C remove rapidly cooled in liquid nitrogen. Slow cooling caused by rapid cooling to avoid the decomposition of $LiCu_2O_2$ impurity phase. This morphology can be obtained large volumes of $LiCu_2O_2$ good single crystal having a plate-like crystal shape rules, typical dimensions for 10x8x0.5nim3, shiny surfaces, such as thin single crystal mirror easily. Figure 3 shows the photograph of $LiCu_2O_2$.



s

Figure 3 : The photograph of $Ba_3Mn_2O_3$

Magnetic measurement system using the various components of the magnetic field are parallel, and perpendicular crystal magnetic susceptibility and magnetization curves, and then use a comprehensive physical property measurement system (Physical Property Measurement System referred PPMS) were measured a specific heat of 0.4 to 300K. Magnetic field applying chromium town thermocouple (using 4He thermostat) is measured using the first method and the measurement - Low thermal conductivity using the "one heater, two thermometers" (using PPMS) method or constantan to 14T. For $LiCu_2O_2$ crystal peak around 48K, mainly from the contribution of phonon thermal conductivity, 14K near the peak of long-range magnetic order in the state is the magnetic excitation participate as a heat carrier quasi-particle heat transport results. The current experimental results show that the magnetic heat transport behavior is similar to the three-dimensional crystal $LiCu_2O_2$ antiferromagnetic material. Complexity and lack of spin frustration and spin structure of low-dimensional quantum spin system features related to the transport behavior[8].

HEAT CONDUCTION RESEARCH OF $CUC1_2$*2($(CH_3)_2$SO) SINGLE CRYSTAL

$CuC1_2$*2($(CH_3)_2$SO) (referred to as the CDC) is a typical effective staggered 5 = ½ spin chain material magnetic field induced by the applied magnetic field. Experiments show that the strong staggered magnetic field contains excitation spectra and spin oscillator bound state, one-dimensional feature makes the spin oscillator potential energy of the bound spin excitation oscillator in the absence of cross-field does not exist. Thermal conductivity measurements is to study low-dimensional magnetic ground state is an important means of elementary excitations in nature and can pass with the change of the magnetic field to detect due to the applied magnetic field-induced quantum phase transition. The low temperature thermal transport properties are still missing, especially the impact of the external magnetic field induced staggered field on the thermal capacity of the one-dimensional spin chain is still lack of research.

Low thermal conductivity of the experimental data in the Oxford Instruments 3He chillers and 14 T by superconducting magnets "one heater, two thermometers," obtained by the method for measuring the thermal conductivity is measured in the high temperature section of 4He refrigerator by constantan - were nickel-chromium thermocouple method for measuring the temperature difference. CDC is likely to occur due to fragmentation in the cooling process, so all measurements made cryogenic experiments should take relatively slow cooling rate. Thus, even after the end of the magnetic measurement and still be able to measure the specific heat of cracking of the sample was observed, and thus the magnetization curve of magnetic susceptibility data of different directions in the three samples are obtained[9].

CDC extremely low temperature single crystal c-axis is parallel to the direction of the magnetic field at the specific heat flux along the b-axis direction and the heat transport properties. The materials at extremely low temperatures occur antiferromagnetic ordered phase, the thermal conductivity results show that the presence of magnetic excitation in the ordered phase thermal phonon scattering effect, strengthening the external magnetic field caused the disappearance of the ordered phase and can appear along with spin gap reduces the magnetic excitation of phonon scattering makes the thermal conductivity of the material in an external magnetic field significantly increased.

CONCLUSIONS

An important feature of low-dimensional magnets is the lack of long-range order that exists at any temperature continuous symmetry, even in the ground state when they are no long-range magnetic order. In this paper, in low-dimensional magnets are one-dimensional magnet was aroused people's interest and flourish because these materials can be excited states of quantum models, materials and new phase quantum fluctuations and thermal fluctuations of interaction provides a unique study. Copper oxide high-temperature superconductivity and the emergence of low-dimensional magnetic materials in a strong magnetic related fluctuations. In addition, and CuO2 surface copper oxide high-temperature superconducting properties close to a quasi-two-dimensional magnetic structure, in-depth study of low-dimensional quantum magnetic materials for help deepen people's understanding of high-temperature superconductors. At the same time, we provide a greater range of energy spallation neutron source to promote the study of neutron scattering experiments on low-dimensional quantum magnetic materials.

REFERENCES

[1] F.Aimo, S.Kramer, M.Klanjsek, M.Horvatic, C.Berthier, H.Kikuchi; Phys.Rev.Lett., **102**, 127205 **(2009)**.
[2] J.Kang, C.Lee, R.K.Kremer, M-H Whangbo; J.Phys.: Condens.Matter, **21**, 392201 **(2009)**.
[3] K.C.Rule, D.A.Tennant J.S.Caux, M.C.R.Gibson, M.T.F.Telling, S.Gerischer, S Siillow, M.Lang; Phys.Rev.B., **84**, 184419 **(2011)**.
[4] W.P.Ke, X.M.Wang, C.Fan, Z.Y.Zhao, X.G.Liu, L.M.Chen, Q.J.Li, X.Zhao, X.F.Sun; Phys.Rev.B., **84**, 094440 **(2011)**.
[5] X.M.Wang, C.Fan, Z.Y.Zhao, W.Tao, X.G.Liu, W P.Ke, X.Zhao, X.F.Sun; Phys.Rev.B., **82**, 094405 **(2010)**.
[6] H.Jeschke, I.Opahle, H.Kandpal, R.Valenti, H.Das, T.Saha-Dasgupta, O.Janson, H.Rosner, A.Bruhl, B.Wolf, M.Lang, J.Richter, S.Hu, X.Wang, R.Peters, T.Pruschke, A.Honecker; Phys.Rev.Lett., **106**, 217201**(2011)**.
[7] K.C.Rule, M.Reehuis, M.C.R.Gibson, B.Ouladdiaf, M.J.Gutmann, Hoffmann, S.Gerischer, D.A.Tennant, S.Sullow, M.Lang, Phys.Rev.B., **83**, 104401 **(2011)**.
[8] L.M.Chen, X.M.Wang, W.P.Ke, Z.Zhao, X.G.Liu, C.Fan, Q.J.Li, X.Zhao, X.F.Sun; Phys.Rev.B., **8d**, 134429 **(2011)**.
[9] Z.Y.Zhao, X.M.Wang, C.Fan, W.Tao, X.G.Liu, W.P.Ke, F.B.Zhang, X.Zhao, X.F.Sun; Phys.Rev.B., **83**, 014414 **(2011)**.