Spin dynamics of the concentrated spin glass $Y(Mn_{0.9}Al_{0.1})_2$

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Inelastic-neutron-scattering measurements employing polarization analysis have been performed on a pseudobinary intermetallic compound $Y(Mn_{0.9}Al_{0.1})_2$, which transforms to spin-glass state below $T_{SG}=42$ K. The temperature variation of the energy width of the scattered neutron spectrum follows an Arrhenius law over a wide temperature range, and the width above T_{SG} is much larger when compared with other concentrated spin glasses. The collapse of helical magnetic order caused by a slight dilution of the magnetic Mn atoms with nonmagnetic Al atoms and the very large excitation spectrum above T_{SG} show that the itinerant character of magnetic electrons as well as the strong frustrations of magnetic interactions play an important role in this material. The importance of proper treatment of magnetic moments, taking into account the itinerent character of the magnetic electrons in metallic spin glasses, is discussed.

I. INTRODUCTION

In a series of previous papers,[1-4] we have reported on the magnetic properties of Laves-phase intermetallic compounds $Y(Mn_{1-x}Al_x)_2$ probed by elastic- and inelastic-scattering experiments. These compounds have been shown to form an interesting group of materials *vis-à-vis* the spin fluctuations present in metallic magnetism. In these studies, we also noticed that the spin-glass property of these pseudobinary compounds shows a peculiar character. In this paper, we report on the dynamical aspect of spin-glass property of $Y(Mn_{0.9}Al_{0.1})_2$ as a completion of our neutron-scattering study of $Y(Mn_{1-x}Al_x)_2$ system.

We first summarize the results of previous neutron-scattering experiments of $Y(Mn_{1-x}Al_x)_2$ system. Ballou *et al.*[5] showed by high-resolution neutron-diffraction experiment that the magnetic moments associated with manganese atoms in YMn_2 order helically with a period of ≈ 400 Å below $T_N \approx 100$ K. Temperature variations of local amplitude of spin fluctuations (amplitude of local moment) and their spatial correlations were examined by means of inelastic-neutron-scattering experiment utilizing polarization analysis technique.[2-4,6,7] The amplitude of magnetic moment per manganese atom in the low temperature helical magnetic phase is $2.7\mu_B$. However, it drops suddenly by more than 30% at $T=T_N$ and then increases gradually with increasing temperature. The long range magnetic order developed in YMn_2 easily collapses by substitution of not more than 5% of manganese atoms by aluminum atoms.[1] In these pseudobinary compounds, spin-glass freezing has clearly been indicated by static susceptibility measurements. The magnetic structure of $Y(Mn_{1-x}Al_x)_2$ with the composition range at least $0.05 \leq x \leq 0.20$ is classified as *a short-range-correlated spin glass* at low temperatures.[1] The spin correlations in this *spin-glass* phase originates in the long-period helical structure of YMn_2. Moreover, in these pseudobinary compounds, the amplitude of magnetic moments is nearly the same as the one for helical magnetic phase of YMn_2 and does not change appreciably with temperature.[4] These observations indicate that a transition from local moment magnetism in the low temperature phase to weakly itinerant electron magnetism in the high temperature phase takes place at $T=T_N$ in YMn_2, and that the transition to the weakly itinerant electron magnetism is suppressed as aluminum concentration x is increased. However, the persistence of spatial correlations of spin fluctuations up to very high temperatures observed in the region of *local moment magnetism* suggests that the definition of *itinerant or localized* should not be simply applied to the present system.[4]

During the course of these neutron-scattering studies which were mainly concerned with spin fluctuations, we unexpectedly found that the spin-glass freezing dynamics and the spin dynamics at high temperatures of these pseudobinary compounds are quite interesting in the sense that the energy scale is by far larger than any other dilute or concentrated spin glasses ever reported and that the spin dynamics can be studied over a wide temperature range by conventional triple-axis neutron spectrometers.[4]

Spin dynamics of spin-glass materials, especially the dynamical aspect of spin-freezing process, has extensively been studied by several experimental techniques such as neutron scattering, muon spin relaxation, and frequency dependence of ac susceptibility.[8] These techniques pro-

vide information on the spin dynamics within various characteristic time scales associated with the characters of the experimental methods. Among these experimental techniques, only inelastic neutron scattering has the unique capability to probe spatial correlations of magnetic moments as well as their dynamical properties. However, conventional neutron-scattering spectrometers (triple-axis spectrometers) have hardly been utilized in dynamical studies of spin glasses because the instrumental energy resolution is usually insufficient to probe the dynamics of spin-freezing process of spin-glass materials. High-energy resolution instruments, such as neutron-spin-echo (NSE) spectrometers, have been utilized for the study of spin glasses and provide us with valuable information about dynamical aspects of the spin-glass transition.[9] Finding a very wide range of spin relaxation times is the most important result obtained by NSE spectrometers.[10] However, the experiments with NSE spectrometers cannot provide us with detailed information of spatial spin correlations, which can easily be obtained by experiments with conventional neutron-scattering spectrometers. Furthermore, the accessible energy window of NSE spectrometers is not sufficient to cover the entire spectral range of spin dynamics of a wide variety of spin-glass materials. In the present study with a conventional triple-axis polarized neutron spectrometer, we have extended the energy range of spin-glass dynamics.

In this paper, we present the result of a neutron-scattering study of spin dynamics of $Y(Mn_{0.9}Al_{0.1})_2$ over wide temperature range (from $0.2T_{SG}$ to $16T_{SG}$). Static aspects of spin-glass behavior of $Y(Mn_{1-x}Al_x)_2$ probed by low field dc-susceptibility and elastic-neutron-scattering measurements have already been reported by one of the present authors[1] and the preliminary result of spin dynamics study has been included in the previous paper.[4]

Sample characteristics and the experimental details are described in Sec. II. Results and analysis are reported in Sec. III. In Sec. IV a discussion of the results is presented.

II. EXPERIMENTAL DETAILS

A. Sample

Pseudobinary intermetallic compound $Y(Mn_{0.9}Al_{0.1})_2$ crystallizes in the cubic Cu_2Mg structure [space group ($Fd\bar{3}m$)], same as the case for YMn_2. The polycrystalline sample was prepared by argon arc melting followed by homogenizing anneal at 800 °C for 1 week. Details of the procedure have been reported in the previous papers. Powder x-ray diffraction pattern showed a trace of Y metal, but the existence of any other impurity phase was not detected. Several small pieces (about 100 mg) from different parts of the ingot were reserved for susceptibility measurement. Magnetic susceptibility measurements were made using a SQUID (superconducting quantum interference device) magnetometer (Quantum Design Model MPMS). The rest of the ingot was crushed into powder for the neutron-scattering experiment.

B. Neutron scattering

Inelastic-neutron-scattering measurements were performed on a polarized beam triple-axis spectrometer at the High Flux Beam Reactor of Brookhaven National Laboratory. To eliminate various kinds of background scattering, the technique of polarization analysis combined with horizontal and vertical guide fields was utilized. In this methods, the difference of neutron counts for a pair of measurements with configurations of horizontal and vertical guide fields at sample position gives net magnetic scattering cross section and the background cancels out in the subtraction process.[11,12] In order to optimize the instrumental condition, i.e., energy resolution, accessible energy range, and counting rate, for wide temperature variation of excitation energy spectrum, various combinations of fixed final neutron energy and horizontal beam collimation were utilized. The instrumental energy resolution $2\Gamma_{res}$ (full width at half maximum, FWHM) used in the measurements varies from 0.33 to 10.0 meV. Measurements were made with fixed momentum transfer by scanning neutron energy transfer (constant-Q mode). The sample was mounted in a closed cycle refrigerator or in a conventional evacuated furnace. Details of the apparatus and the performance were described in the previous papers.[3,4]

III. RESULTS AND ANALYSIS

A. Magnetic susceptibility

Temperature variation of magnetic susceptibility of $Y(Mn_{0.9}Al_{0.1})_2$ is shown in Fig. 1. Data were taken in the heating process under the field of 50 Oe, after cooling the sample from room temperature to the lowest temperature in zero field (ZFC) or in the field of 50 Oe (FC). Open and solid circles correspond to the points for ZFC and FC, respectively. Results obtained from other pieces of the sample taken from the same ingot show basically the

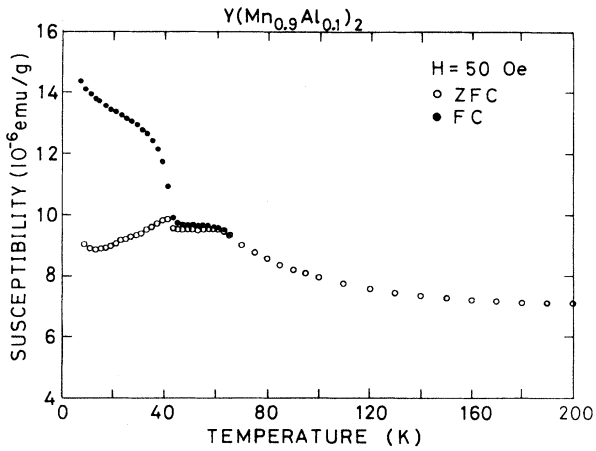

FIG. 1. Temperature variation of magnetic susceptibility of $Y(Mn_{0.9}Al_{0.1})_2$. Open and solid circles correspond to points taken after zero field cooled and field cooled to the lowest temperature, respectively.

identical behavior. The curve corresponding to the measurement after ZFC shows a peak at $T=42$ K, whereas the susceptibility of the FC sample increases rapidly below this temperature. This behavior indicates that the spin-glass freezing takes place at $T_{SG}=42$ K. However, the field hysteresis effect, i.e., the difference of ZFC and FC curves, persists up to $T\approx 60$ K, which has not been explained.

B. Neutron scattering

Figure 2 shows neutron energy spectra scattered from $Y(Mn_{0.9}Al_{0.1})_2$ at representative temperatures. The intensity I(HF-VF) corresponds to the difference between two spin-flip-scattered neutron intensities measured with horizontal and vertical guide field. The former corresponds to the intensity for $\mathbf{P}\|\mathbf{Q}$, the latter to the one for $\mathbf{P}\perp\mathbf{Q}$, where $\mathbf{P}$ and $\mathbf{Q}$ are the polarization direction of incident neutrons and the scattering vector, respectively. Various kinds of scattering cross sections besides magnetic scattering such as thermal diffuse, isotope incoherent and nuclear spin incoherent scatterings do not depend upon the angle between $\mathbf{P}$ and $\mathbf{Q}$; therefore, only the magnetic scattering cross section contributes to I(HF-VF). The data shown in Fig. 2 were taken with momentum transfer $Q=1.80$ Å^{-1}; other experimental parameters for each

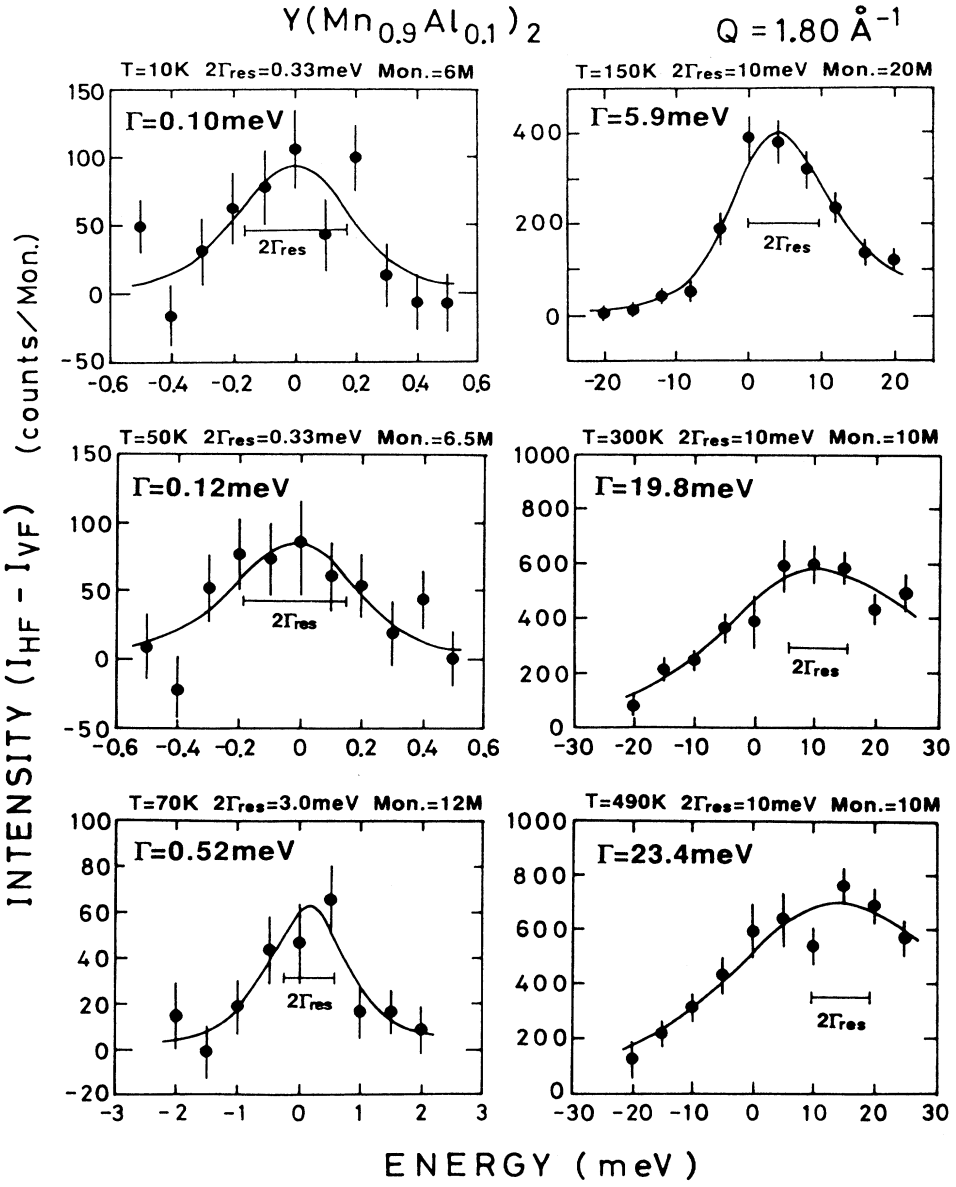

FIG. 2. Neutron-scattering spectra obtained using the parallel-perpendicular method (I_{HF}-I_{VF}) of $Y(Mn_{0.9}Al_{0.1})_2$ at various temperatures. Measurements were made with a momentum transfer $Q=1.80$ Å^{-1}. Curves are the fit of Lorentzian line shape to the data including various corrections described in the text. Measurements were performed with various instrument conditions. The neutron monitor counts (Mon.) are given in each figure (M= millions of counts).

measurement are listed above each frame. The energy width of the spectrum increases with increasing temperature above $T=50$ K, and at higher temperatures the complete energy spectrum could not be covered with the present experimental condition.

The magnetic scattering cross section for a single crystal sample is expressed by[13]

$$\frac{d^2\sigma}{d\omega\, d\Omega}=\gamma_0^2 f^2(\mathbf{Q})e^{-2W}S(\mathbf{q},\omega)\ , \tag{1}$$

where γ_0^2, $f(\mathbf{Q})$, and e^{-2w} are 0.291 b, the magnetic form factor as a function of scattering vector $\mathbf{Q}$ measured with respect to direct beam, and the Debye-Waller factor, respectively. The symbol $\mathbf{q}$ means the wave vector relative to the nearest magnetic reciprocal-lattice point. Above the magnetic transition temperature, the magnetic scattering function $S(\mathbf{q},\omega)$, for relatively small $\mathbf{q}$ and ω, can be expressed by a double Lorentzian form as

$$S(\mathbf{q},\omega)=M^2(\mathbf{q})\frac{1}{\pi}\frac{\Gamma_q}{(\Gamma_q)^2+\omega^2}\frac{\hbar\omega/k_BT}{1-e^{-\hbar\omega/k_BT}}\ , \tag{2}$$

in which

$$M^2(\mathbf{q})=M^2(0)\frac{\kappa_1^2}{\kappa_1^2+q^2}\ , \tag{3}$$

where Γ_q and κ_1 are the q-dependent energy width and the inverse correlation length, respectively. For small values of q and ω, the energy width Γ_q can be expressed unambiguously only for two limiting cases, i.e., local moment limit and weak limit of itinerant electron ferromagnet (or antiferromagnets) as[13,14]

$$\Gamma_q=\Gamma_0 q^2(\kappa^2+q^2)\ \text{(local moment)} \tag{4}$$

and

$$\Gamma_q=\Gamma_0 q(\kappa^2+q^2)\ \text{(itinerant)}\ , \tag{5}$$

where the parameter κ varies with temperature. For the present material, the characteristics of spin fluctuations cannot be classified either by the local moment limit or weak itinerant electron antiferromagnet. Moreover, the present measurement was made using a powdered polycrystalline sample where the observed intensity is composed of scattering from many numbers of randomly oriented crystallites. Although the total momentum transfer $\mathbf{Q}$ is kept constant against the energy scan, the momentum transfer $\mathbf{q}$ measured from a magnetic Bragg point varies for each crystallite depending upon the orientation of its crystal axis. Therefore, there is no theoretical justification that the energy spectrum follows the simple Lorentzian form that appears in Eq. (2). However, at every temperature between 10 and 760 K, the observed pattern is fairly well represented by a Lorentzian curve, probably due to the combined effect of the powder average and the limited instrumental energy resolution. The curves in Fig. 2 show the results of least-squares fits to a Lorentzian scattering function including instrumental energy resolution and the thermal factor. The obtained energy width Γ of the Lorentzian scattering function is also shown in each frame.

Figure 3 shows the energy width Γ of scattered neutrons from $Y(Mn_{0.9}Al_{0.1})_2$ as a function of momentum transfer Q measured at $T=150$ K. Arrows in the figure indicate the positions corresponding to the magnetic Bragg peaks observed in the antiferromagnetic phase of YMn_2, around which magnetic diffuse scattering intensity of the present sample increases at low temperatures. The energy width Γ does not change appreciably with Q except for the point $Q=2.10$ Å^{-1}. Therefore, for each temperature, most of the available experimental time was dedicated to the measurements at $Q=1.80$ Å^{-1} where the magnetic intensity shows its maximum.

In Fig. 4, we show temperature variation of energy width Γ measured at momentum transfer $Q=1.80$ Å^{-1}. The low temperature part is also shown with enlarged scale in the inset. Below $T=50$ K, the width and its temperature variation are very small. Around $T=70$ K the width starts to increase and it keeps increasing with temperature up to $T=680$ K, which is the highest temperature reached in the present experiment. The observed temperature dependence of Γ can reasonably be approximated by an Arrhenius law, which has widely been used as the simplest form to characterize the spin-freezing dynamics. This expression is based on a simple phenomenological model in which the spin freezing is caused by temperature independent energy barriers. Parameters Γ_0 and E_a in the Arrhenius law

$$\Gamma(T)=\Gamma_0\exp\left[\frac{-E_a}{k_BT}\right] \tag{6}$$

determined from the least-squares fitting procedure are $\Gamma_0=42$ meV and $E_a=24$ meV, respectively. The curve in Fig. 4 represents the calculation with these parameters.

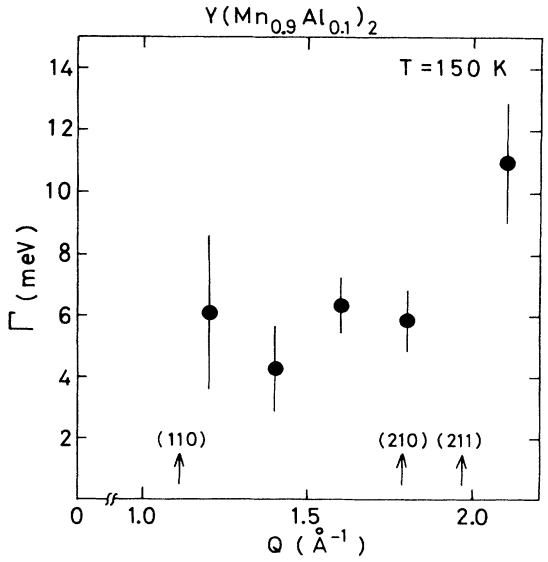

FIG. 3. Energy width of scattered neutrons from $Y(Mn_{0.9}Al_{0.1})_2$ as a function of momentum transfer. Measurements were made at $T=150$ K. The curve is drawn to guide the eye.

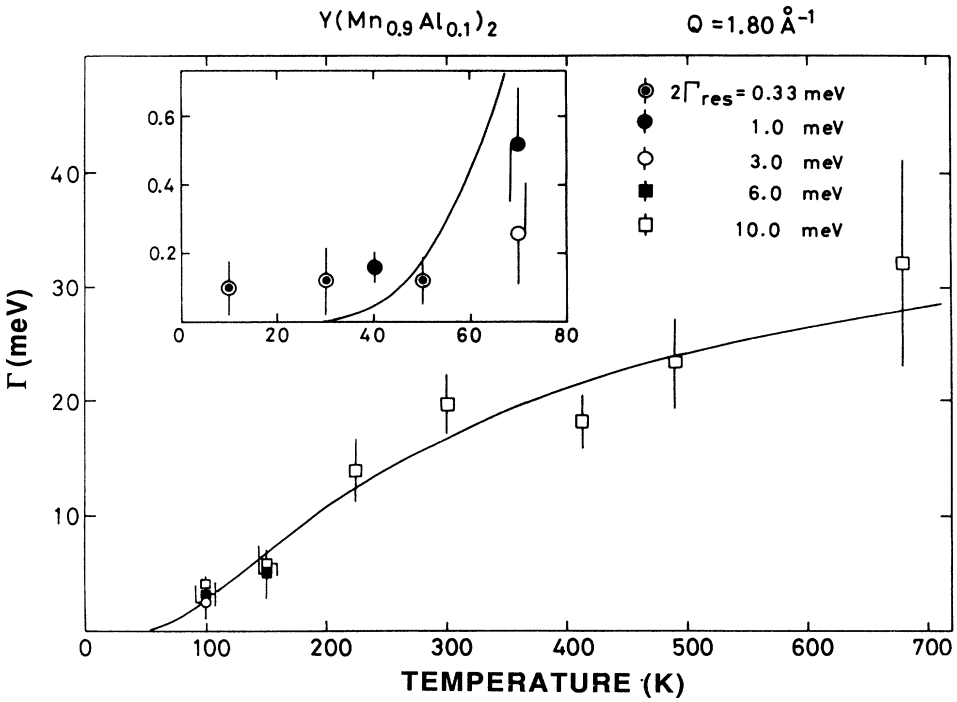

FIG. 4. Temperature variation of the energy width of scattered neutrons from $Y(Mn_{0.9}Al_{0.1})_2$ at $Q=1.80$ Å^{-1}. Low temperature part is also shown with a enlarged scale as the inset. The meaning of the curves is described in the text.

IV. DISCUSSION

The most remarkable observation in the present experiment is an unusually large energy width of the excitation spectrum above the spin-glass transition temperature ($T_{SG}=42$ K) compared with any other spin glass ever examined and its successive increase with temperature up to $T\approx 16T_{SG}$. In this section, we discuss these features in connection with characteristics of electronic and magnetic states of the present material. Comparison of dynamical behavior with other spin-glass materials is also presented.

As we have already shown in the previous paper,[4] magnetic electrons in the $Y(Mn_{1-x}Al_x)_2$ system transform between itinerant and localized characters when temperature or composition x is varied. Magnetic ordering behavior of the $Y(Mn_{1-x}Al_x)_2$ system is also very peculiar and sensitive to the composition x. Development of a long-period helical magnetic ordering in YMn_2 indicates that there exist competing magnetic interactions (magnetic frustration) between different kinds of neighboring atoms. In such a frustrated system, it can easily be recognized that the substitution of a very small amount of nonmagnetic atoms causes the collapse of magnetic order because of the delicate balance of competing interactions.

The pseudobinary compounds $Y(Mn_{1-x}Al_x)_2$, therefore, may be classified as a quite interesting group of materials in which the magnetic state is determined by frustration among magnetic interactions as well as by the unstable character of atomic magnetic moments.

Before discussing the features observed in the present experiment, we briefly summarize the relation between the inelastic-neutron-scattering spectra above the magnetic transition temperature and the different types of magnetic interactions for simple magnetic materials, i.e., ferromagnets and antiferromagnets. Neutron energy spectrum for magnetic scattering above magnetic transition temperature was calculated by de Gennes.[15] For large scattering angle (large Q), a spectrum from a polycrystalline sample is very close in shape to a Gaussian, of which second moment is given by

$$\langle\omega^2\rangle=\tfrac{2}{3}S(S+1)\sum_j\left[\frac{2J_{ij}}{\hbar}\right]^2, \tag{7}$$

where S is the spin per atom and J_{ij} the exchange interaction between ith and jth spins. In molecular-field approximation, the exchange interaction J is related with the Weiss temperature Θ as

$$\Theta=\frac{2S(S+1)}{3k_B}\sum_k Z_kJ_k, \tag{8}$$

where Z_k and J_k are the number of kth nearest neighbors of a given atom and the exchange interaction between a pair of kth nearest-neighbor atoms, respectively. Therefore within the approximation of nearest-neighbor interaction, the second moment is expressed as

$$\langle\omega^2\rangle=\left[\frac{k_B\Theta}{\hbar}\right]^2\frac{6}{ZS(S+1)}. \tag{9}$$

Therefore Γ, the half-width at half height of the Gaussian energy distribution curve, is proportional to Θ as[16]

$$\Gamma=\sqrt{2\ln 2}\sqrt{\langle\omega^2\rangle}=\frac{2.9}{\sqrt{ZS(S+1)}}\frac{k_B\Theta}{\hbar} . \quad (10)$$

As shown in Eq. (8), in the framework of molecular-field theory, the Weiss temperature is given by the simple algebraic sum of the exchange interactions. On the other hand, the magnetic transition temperature (T_C or T_N) is related to the sum of exchange energies properly calculated based on the ground state structure. Therefore for simple ferromagnets, in which all magnetic interactions are positive and the difference between T_C and Θ is small, the energy width Γ is simply related with Curie temperature T_C. However in antiferromagnetics $|\Theta|$ is usually much higher than T_N. The ratio $|\Theta|/T_N$ is especially large in antiferromagnets in which magnetic atoms form fcc lattice, where competing (or frustrated) interactions exist because every magnetic atom has nearest-neighbor magnetic atoms which belong to the same sublattice.[17] For example in MnO the ratio $|\Theta|/T_N\approx 5$. Therefore, in these antiferromagnets with frustrated interactions, we should not expect a simple relation between Γ and T_N. On the other hand, the relation between Γ and Θ still remains without any essential modifications.

For spin glasses, especially for concentrated spin glasses, we can conjecture that the relation between T_{SG} and the amplitude of exchange interactions exerted on one magnetic moment from neighboring atoms is much more complicated than the cases for antiferromagnets with frustrated interactions in which effect of randomness does not exist. Thus information obtained from inelastic-neutron-scattering experiments above the spin-freezing temperature is quite valuable for the study of magnetic interactions in the spin-glass system.

In Table I, we compare the spin-glass transition temperature (spin-freezing temperature), T_{SG}, and some characteristic parameters obtained by neutron-scattering experiments representing spin dynamics of various concentrated spin-glass materials. In this table, the parameter $\Gamma(2T_{SG})$ is the half-width of Lorentzian energy spectrum at $T=2T_{SG}$, which represents a characteristic energy scale of spin fluctuations (spin relaxation rate) in the paramagnetic state. Symbols Γ_0 and E_a are the energy scale parameter and activation energy of Arrhenius law described in Sec. III, respectively.

Magnetic properties of an amorphous intermetallic compound MnSi is quite different from those of crystalline MnSi, which has been extensively studied from the point of view of spin fluctuation properties in metallic magnetism.[23] Crystalline MnSi orders in a helical arrangement below $T_N=29.5$ K. Above T_N, spin fluctuation properties typically manifest those characters of weakly itinerant electron ferromagnets. On the other hand, amorphous MnSi transforms to a spin-glass state below $T_{SG}=22\pm2$ K,[18] and has been regarded as a material in which the energy scale for spin fluctuations relative to the spin-glass transition temperature is much larger than in any other concentrated spin glasses.[19] A disordered crystalline alloy $Ni_{0.784}Mn_{0.216}$ orders ferromagnetically below $T_C=330$ K and below $T_{SG}=40$ K, it transforms to a spin-glass state.[20] An amorphous insulator $Mn_3Al_2Si_3O_{12}$ transforms to a spin-glass state below $T_{SG}=3.2$ K whereas the crystalline phase counterpart, Mn-garnet spessartite, orders antiferromagnetically below $T_N=7.5$ K. A neutron-scattering experiment[21] shows that the spin-glass state of this material is not static but completely dynamic in the whole temperature range under investigation (down to $T\approx1.5$ K). Inelastic-neutron-scattering measurements of the disordered single crystal alloy $Cu_{78.7}Mn_{21.3}$ indicate the existence of strong space and time correlations of the spins over the temperature range of the measurements ($0.22T_{SG}\le T\le 3.2T_{SG}$).[22] The variation of energy width of scattered neutrons is very small and the Arrhenius law cannot be applied for this material.

Although T_{SG} of these materials fall in the same order of magnitude except for amorphous $Mn_3Al_2Si_3O_{12}$, the parameter $\Gamma(2T_{SG})$ varies by more than two orders of magnitude among these materials. Similarly, although the energy scale parameter of Arrhenius law Γ_0 varies more than two orders of magnitude among these materials, the activation energy E_a varies more moderately with T_{SG}. Therefore, as we conjectured from the case for antiferromagnets with frustrated interactions, we can conclude that the spin-glass freezing temperature does not directly relate with the amplitude of magnetic interactions. In other words, the essential factor to determine spin-freezing temperature is the detail of frustrations among magnetic interactions.

In this table, we can clearly see that the energy scale of spin fluctuations in $Y(Mn_{0.9}Al_{0.1})_2$ is much larger than

TABLE I. Comparison of spin-glass transition temperature T_{SG} and some characteristic parameters representing spin dynamics of various concentrated spin-glass materials. The parameter $\Gamma(2T_{SG})$ is the half-width of Lorentzian energy spectrum at $T=2T_{SG}$. Γ_0 and E_a are the energy scale parameter and the activation energy of Arrhenius law described in the text.

Material	T_{SG} (K)	$\Gamma(2T_{SG})$ (meV)	Γ_0 (meV)	E_a (meV)	Reference
$Y(Mn_{0.9}Al_{0.1})_2$	42	2.6 ($T=2.4T_{SG}$)	42	24	Present work
Amorphous MnSi	24	0.14	0.95	6.3	19
$Ni_{0.784}Mn_{0.216}$	40	0.015	0.33	21.5	20
a-$Mn_3Al_2Si_3O_{12}$	3.2	0.021	5.62	3.09	21
$Cu_{0.787}Mn_{0.213}$	90	3.5 ($T=0.22T_{SG}$ and $1.6T_{SG}$) 4.5 ($T=3.2T_{SG}$)			22

even amorphous MnSi, which has been regarded as a material in which the energy scale for spin fluctuations *relative to the spin-glass transition temperature* is the highest in concentrated spin glasses. As we have argued, it is not appropriate to compare the energy scale of spin fluctuations with the spin-glass transition temperature. However, it might be interesting to compare the present material with amorphous MnSi. Both of these spin glasses have related phases which have been extensively studied from the point of view of itinerant electron magnetism. Moreover, both of these related materials order helically with a long period, which indicates the existence of competing magnetic interactions.

We have pointed out two kinds of similarities between the present material and amorphous MnSi. One is the presence of competing magnetic interactions even in the nondiluted or nondisordered related materials. The other is the itinerant character of magnetic electrons, although the extent of itinerant character for each material has not been clarified at present. The large energy width of excitation spectrum observed in the present material as well as in amorphous MnSi might be attributed to both of these two common characteristics.

For more than two decades, the importance of proper understanding of spin fluctuation properties has widely been recognized in the field of metallic magnetism and many theoretical and experimental works have focused on this problem.[14] However, in the field of spin-glasses, the aspect of spin statistics or phase transition property is the most important and almost the unique interest for most researchers. Therefore, even in concentrated metallic spin glasses, magnetic moments have been regarded as *stable and localized* such as is the case for insulators, although some considerations have been given to the environment effect. Differences between metallic and insulating spin glasses, aside from the range of exchange interactions, have been neglected so far. We stress that the present study demonstrates that the proper treatment of magnetic moments taking into account the itinerant character of magnetic electrons is essentially important in the study of concentrated metallic spin glasses in which the magnetic property is determined by the interplay of magnetic frustrations and spin fluctuations.

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