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SPIN DYNAMICS AND THE PHASE TRANSITION IN TWO-DIMENSIONAL PLANAR FERROMAGNET K_2CuF_4

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Evolution of the spin dynamics with changing the wave number and temperature has been studied in detail by neutron scattering technique. For higher q values than q = 0.04, well defined magnon peaks are observed up to certain temperature higher than T_C, the frequency change being continuous on passing through the T_C. For lower values of q, a sudden decrease of the frequency and increase of the width are observed suggesting that the transition is motivated by the Kosterlitz-Thouless type.

Recent magnetic[1)] as well as neutron scattering[2)] measurements suggest that the phase transition in K_2CuF_4 is essentially a Kosterlitz-Thouless(KT) type transition[3)] slightly modified by the 3D interaction. The observed physical quantities such as susceptibility χ , magnetization M under the symmetry breaking field, correlation length ξ and the critical exponents δ and η in the 2D XY-like cross over regime are consistent with the Kosterlitz theory[4)] with T_{KT} = 5.5 K, whereas the observed Curie point is T_C = 6.25 K. The difference is explained by the 3D interaction[5)]. Above features demonstrate that the static spin correlation changes from the power law decay below T_{KT} to the exponential decay above T_{KT}. This is the most characteristic feature of the KT transition in 2D XY system.

Another important profile of the KT transition is the universal jump in the stiffness constant at T_{KT}. The universal jump which corresponds in superfluid system to the jump in superfluid density has been observed in He II film by Bishop and Reppy[6)], but no observation has been made on the magnetic system because of lacking of suitable magnetic system. In principle, the stiffness constant may be measured by twisting the system on macroscopic scale. But, as we can not expect a spontaneous magnetization, we cannot make experiments by applying static twisting field on this 2D system and see its response on passing through the T_{KT}. Moreover, for such a long wave(Macroscopic scale), the realistic system which is not an ideal 2D system will never show responses as in a 2D system. Probably, the best way is to see the stiffness for the transverse twisting, i.e. the spin wave frequency for properly small q values. If the system is ideally a 2D XY ferromagnet, the exchange constant J at small q thus measured will stay a constant value up to very vicinity of T_{KT} where it will decrease just a little and at T_{KT} it suddenly decreases to zero. This jump in J is a universal value of[3,7)]

$$J/kT_{KT} \cong 1/\pi .$$

This is equivalent to the jump of Fisher's exponent $\eta = kT/4\pi J$ by an amount of 1/4 at T_{KT}.

In a non-ideal system, such as in K_2CuF_4, the transition point is modified by a small amount to higher temperature by the inter-layer coupling J'. At the same time, the amount of the jump will be reduced somewhat, but a feature of steep drop of the spin wave frequency which can not be seen in the conventional phase transition would be seen in K_2CuF_4 if the q is chosen to be small enough in the 2D XY regime but not too small as to enter the 3D XY regime. The adequate q value can roughly estimated from the Hamiltonian and in fact also anticipated through the previous experimental study.

K_2CuF_4 is a good realization of the easy plane type 2D ferromagnet J'/J being 6×10^{-4}. But, the anisotropy giving rise to the easy plane type is only one percent of the main Heisenberg interaction. Thus for greater value of q than ~ 0.02, the system would behave like a 2D Heisenberg system. On the other hand, for smaller values of q than ~ 0.01, the system would behave like a 3D XY system. The 2D XY regime appears in between them.

In the following, we shall present our recent work on how the spin dynamics on passing through the T_c evolves with q value. The details of the work will be published elsewhere, so that we shall give a brief description of our results. In Fig.1 is shown the temperature dependence of the spin wave frequency as a function of q, where q is a wave vector in the direction of [100] in the 2D plane. The dispersion along the [001] is negligibly small and we actually chose $q_c = 0.4$. Experimentally, for higher q than 0.04, there is no serious change in frequency on passing through T_c and the well defined spin wave peaks are observable up to certain temperature higher than T_c. For lower values of q, however, a steep drop in frequency is observed at the very vicinity of T_c. For even low q values such as $q \sim 0.01$, the frequency softening starts from lower temperatures as often seen in the conventional 3D ferromagnet. The most pronounced change at T_{KT} is seen for q = 0.025 and 0.03. In this region, in accord with the sudden softening, a sudden increase in the damping also occurs. Consequently, we can not follow the frequency change in more detail at higher temperature. This is a fault of such a dynamical study which attempts to measure the stiffness constant through the spin wave measurement. We think, however, that this steep decrease of the frequency at T_c is again powerful evidence for the previous conjecture[8)] that the transition is fundamentally of the Kosterlitz-Thouless type transition. The 2D XY regime which is presently observed appears in a slightly higher q region than we estimated above at 0 K.

Finally, we should note that for higher values of q than 0.04, the dynamical response is in good agreement with the theory proposed by Moussa and Villain[9)].

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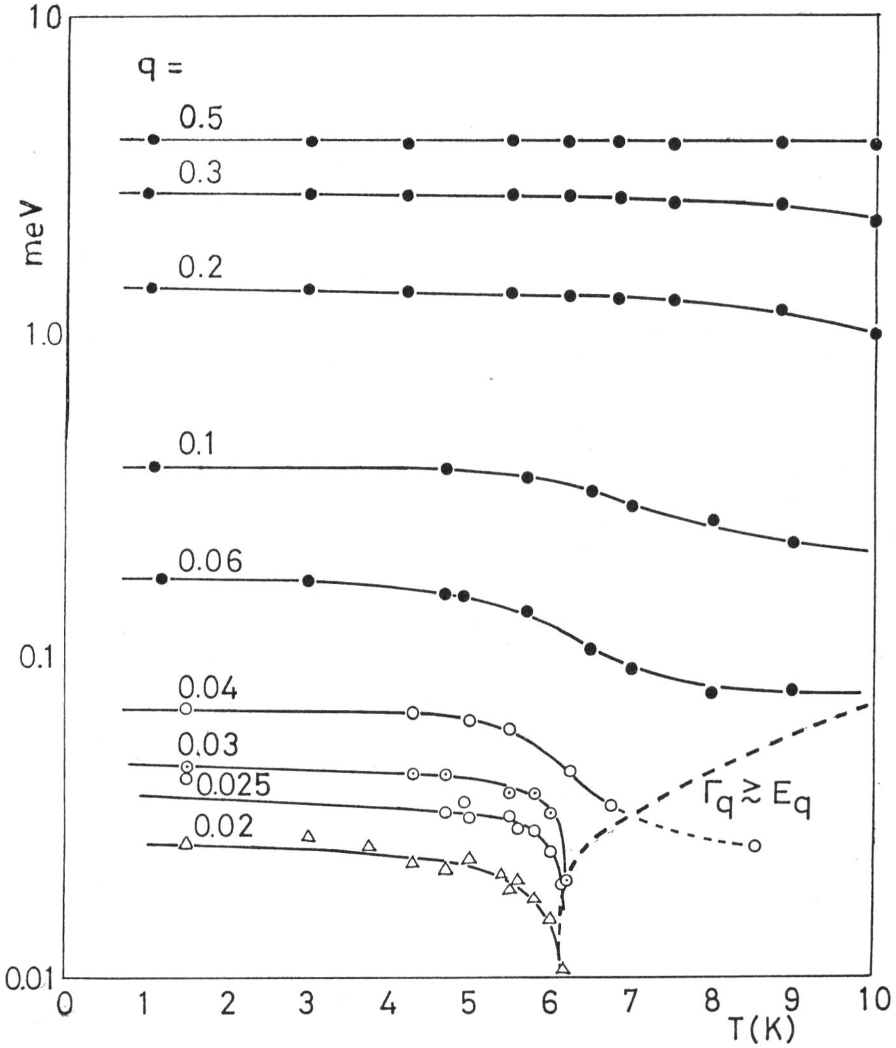

Fig.1 Temperature change of spin wave frequency as a function of q. The boundary between the underdamped and overdamped regions is shown by the broken line.

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