Magnon decays

The elementary excitations of magnetically ordered insulators are spin waves, which can be thought of as coherent rotations of the spins around their equilibrium directions. The key characteristic of spin waves is their *dispersion relation*, hw(**q**). The dispersion relation can be seen in momentum and energy scans as sharp peaks (Not infinitely sharp, due to the instrumental resolution). From the variation of the peak positions with **q**, it is possible by inelastic neutron scattering to determine hw(**q**).

A theoretical prediction made (originally) for 2-dimensional antiferromagnets (up-down-up-down arrangement of spins sitting on the vertices of a square lattice) is illustrated in the figures below. The first figure ("Figure 2") shows the calculated classical spin wave spectrum and compares it to the results of two more accurate calculations (The details are not important), which take into account the possibility that spin waves can decay. Two things to notice from this is that (1) When a magnetic field is applied, the spin wave dispersion changes. For H=0, the spin wave dispersion spans the energy range from 0 to 2*Z*J, where Z=1.18 and J is the coupling between nearest neighbor spins. At $Hc=8JS/gmu_B$, which is the field at which all spins have been forced to point along the field. (2) For magnetic fields close to but below Hc, there a qualitative differences between the classical and more accurate, non-classical calculations.

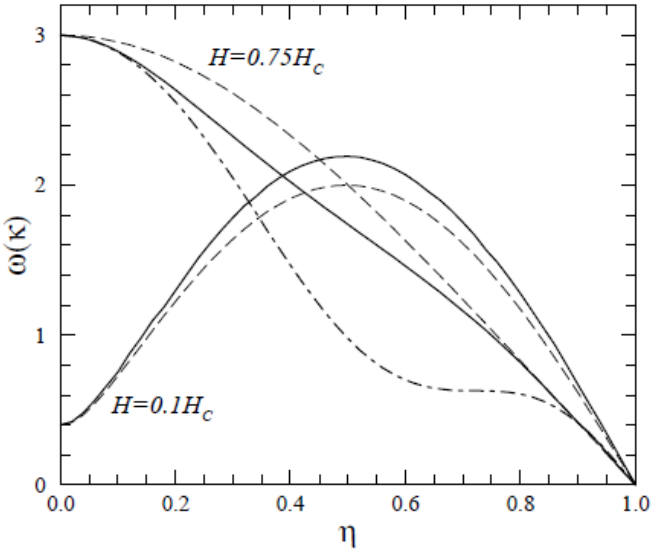


FIG. 2. Magnon dispersion for $\mathbf{k} = \pi(\eta, \eta)$: (i) Thin dashed lines represent the classical spectrum $\omega_{\mathbf{k}}$; (ii) dot-dashed lines are $\omega_{\mathbf{k}}^{\text{pert}}$; (iii) solid lines are solution of the Dyson equation. For $H = 0.1H_c$, curves (ii) and (iii) are indistinguishable.

The next figure ("Figure 3". Focus on the "SCBA" solid lines) shows the prediction, which is that for magnetic fields above about 0.75*Hc, the spin waves will start to decay, i.e. instead of having infinite lifetime (and therefore, through the properties of the time-Fourier transform, is described by a delta-function, convoluted with the resolution), they decay in a finite time, giving rise to broad spectra in energy scans at certain momentum transfers Q. For fields smaller than 0.75*Hc, this does not happen,

and the excitations are sharp in energy everywhere. The spin wave decay is not a quantum mechanical effect, so we would expect to see if for quantum spins, S=1/2 (For example Cu^{2+} or Mn^{2+}), but also for much larger moments like those of the rare earth elements, e.g. Gd (a particularly nasty choice for neutrons due to absorption, but for this exercise, I've teleported us to the perfect world of non-absorbing Gd).

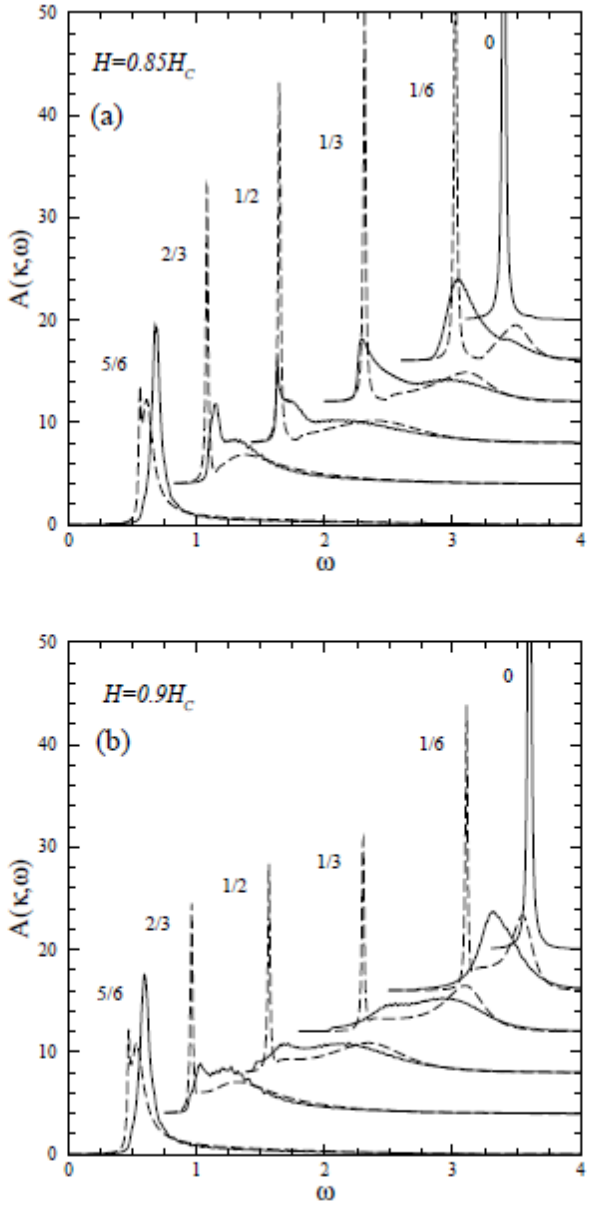


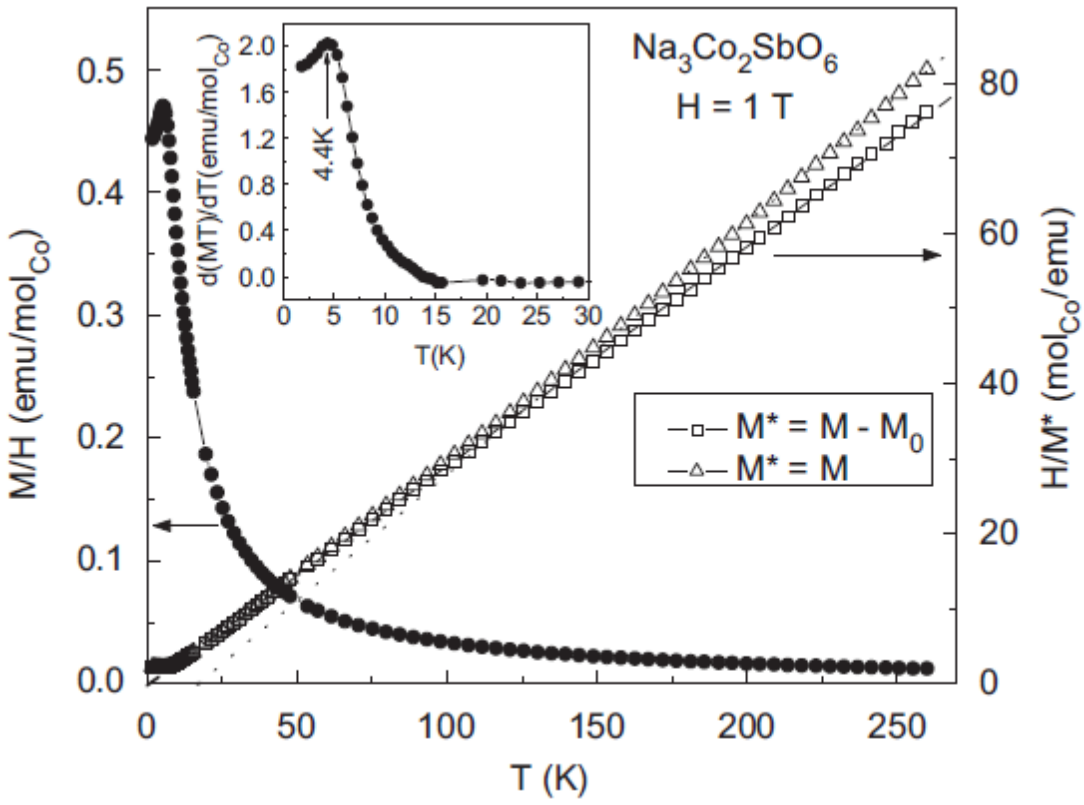
FIG. 3. Magnon spectral function for several points $\mathbf{k} = \pi(\eta, \eta)$ (a) $H = 0.85H_c$, (b) $H = 0.9H_c$. Thin dashed lines represent the non-SCBA. Solid lines are the results of the SCBA. Corresponding values of η are shown near each curve.

Write a proposal to verify or dismiss the theoretically predicted effect. Consider the following questions

1) If J is not known, how would you determine it?
2) The maximum available field at neutron sources is 15T. If the experiment can be done at all, what are the maximum values of J for S=1/2 and for S=5/2?
3) Which instrument type should you use, if J=0.2 meV,S=5/2 and which instrument would you use if J=0.1 meV, S=1/2. The answer is not necessarily unambiguous, so you need to argue.
4) For all spins, the integral of the magnetic scattering is S(S+1) for all S. All other things equal, would you study systems with large or small S?
5) What would you measure (minimum requirements) to verify the effect and also determine J, if it is not known
6) How many days would you estimate you need for this?
7) Could the experiment be done with powders?

A new magnetic material

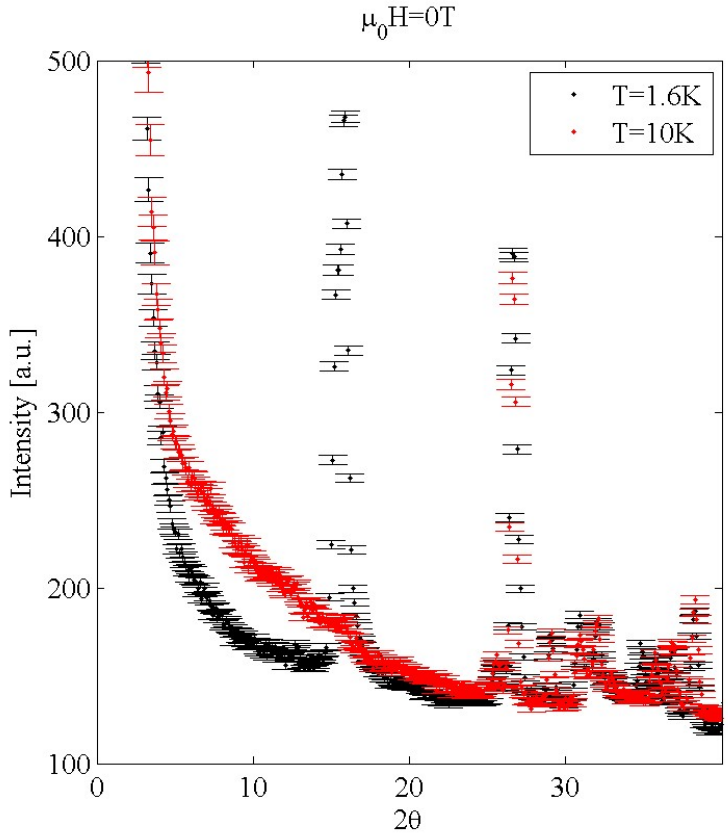
A clever chemist has developed a new magnetic material, with magnetic ions residing on a honeycomb lattice. When measuring the magnetic susceptibility, she finds the Curie Weiss temperature T_{CW}=0K (See figure below) which is proportional to the weighted average of magnetic couplings T_{CW}=z1*J1+j2*J2, where J1 and J2 are nearest and next nearest neighbors, and z1/z2 are the numbers of these couplings.



1) What is z1 and z2 for the Honeycomb lattice?

Without further information, TCW=0 implies that antiferromagnetic and ferromagnetic interactions are roughly balanced in our new magnet.

Neutron powder diffraction measurements tells us that magnetic order sets in at roughly 8K. This is shown by the next figure.



2) Why and what is the nature of the magnetic order? What causes the diffuse low-Q scattering at 10K?

From T_{CW}=0, we can deduce the ratio J1/J2, but not the absolute values of J1 and J2.

White a proposal to determine J1 and J2 using an appropriate instrument of your choice. Consider the following questions

3) How would you measure J1 and J2 in a single-crystal?
4) Which instrument do you need? Hint: Consider lattice vibrations as an analogy. The harder the material, the steeper the dispersion of the phonons, and the larger the upper limit of the dispersion.
5) What if you only had powder samples available? What would you observe? Hint: Consider the analogy to the difference between single-crystal and powder diffraction.
6) Which experiment (powder, single-crystal) gives the most useful information?
7) How long time would you estimate for single-crystal and powder experiments, respectively?