Giant magnetization jumps in high fields: a new macroscopic quantum effect

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Contents

Model Hamiltonian – Heisenberg-Model

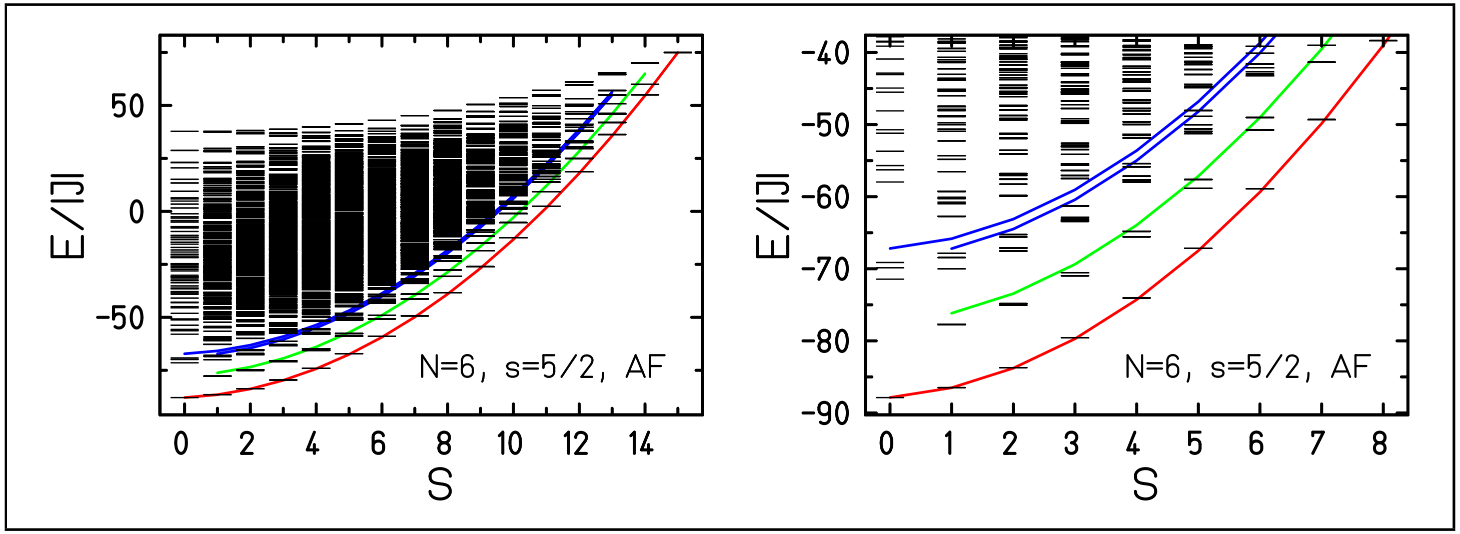
$$\underset{\sim}{H} = -\sum_{i,j} J_{ij}\,\underset{\sim}{\vec{s}}(i)\cdot\underset{\sim}{\vec{s}}(j) \quad + \quad g\,\mu_B\,B\sum_{i}^{N}\underset{\sim}{s}_z(i)$$

Heisenberg Zeeman

The Heisenberg Hamilton operator together with a Zeeman term are used for the following considerations.

$J < 0$: antiferromagnetic coupling.

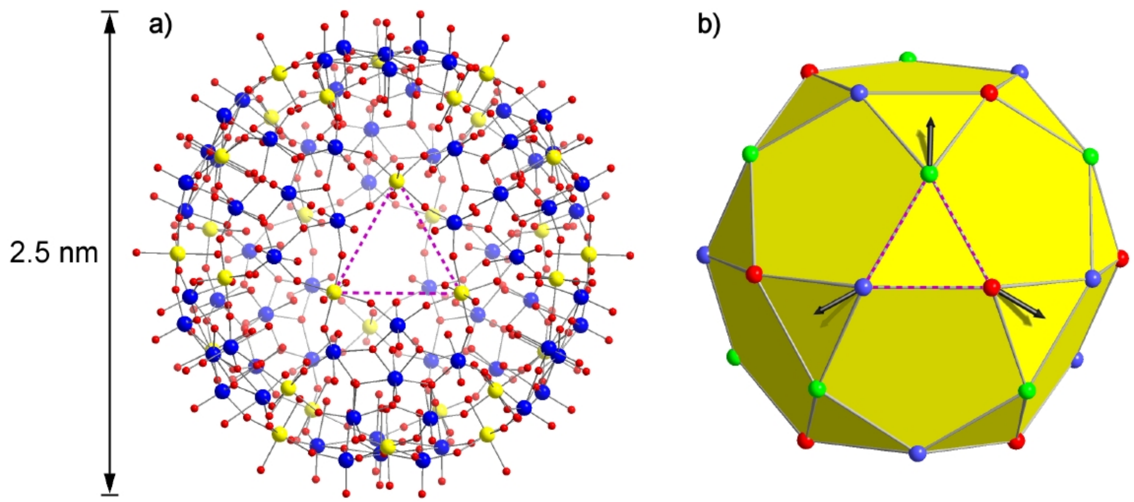
MM point of view: Rotational bands



- For magnetic molecules the minimal energies $E_{min}(S)$ often form a rotational band, i. e. depend quadratically on S: Landé interval rule (1);
- Most pronounced for bipartite systems (2), good approximation for more general systems;
- Sometimes low-lying spectrum is a sequence of rotational bands (3).

(1) A. Caneschi *et al.*, Chem. Eur. J. **2**, 1379 (1996), G. L. Abbati *et al.*, Inorg. Chim. Acta **297**, 291 (2000)
(2) J. Schnack and M. Luban, Phys. Rev. B **63**, 014418 (2001)
(3) O. Waldmann, Phys. Rev. B **65**, 024424 (2002)

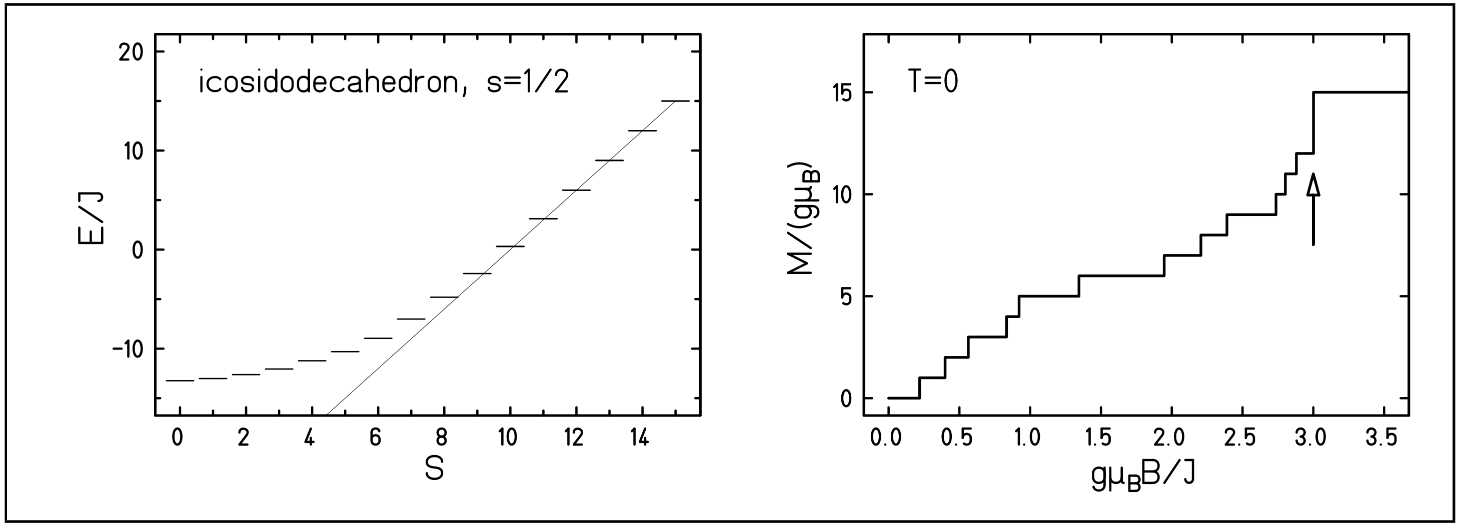
Strange magnetic molecule $\{Mo_{72}Fe_{30}\}$



- Structure of $\{Mo_{72}Fe_{30}\}$: Fe - yellow, Mo - blue, O - red,
- Antiferromagnetic interaction mediated by O-Mo-O bridges (1).
- Classical ground state of $\{Mo_{72}Fe_{30}\}$: three sublattice structure, coplanar spins (2);
- Quantum mechanical ground state $S = 0$ can only be approximated (3,4), dimension of Hilbert space $(2s+1)^N \approx 10^{23}$.

(1) A. Müller *et al.*, Chem. Phys. Chem. **2**, 517 (2001) , (2) M. Axenovich and M. Luban, Phys. Rev. B **63**, 100407 (2001) , (3) J. Schnack, M. Luban, R. Modler, Europhys. Lett. **56** 863 (2001) 863 , (4) M. Exler, J. Schnack, Phys. Rev. B **67** (2003) 094440

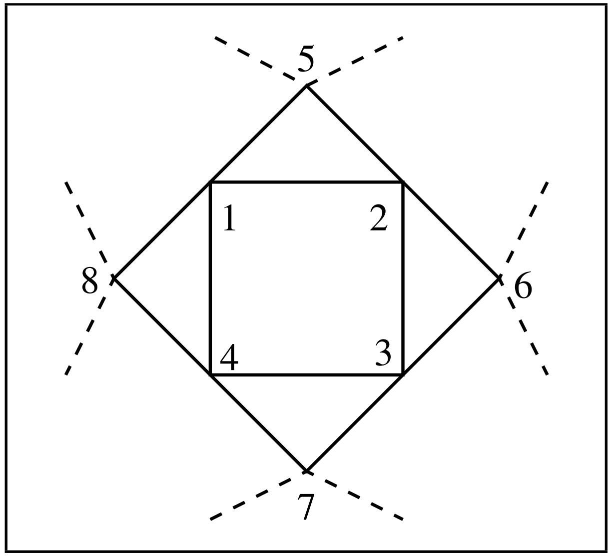
$\{Mo_{72}Fe_{30}\}$ - magnetization jump



- $E_{\text{min}}(S)$ linear in S for high S instead of being quadratic (1);
- Heisenberg model: property depends only on the structure but not on s (2);
- Alternative formulation: independent localized magnons (3);

(1) J. Schnack, H.-J. Schmidt, J. Richter, J. Schulenburg, Eur. Phys. J. B **24**, 475 (2001)
(2) H.-J. Schmidt, J. Phys. A: Math. Gen. **35**, 6545 (2002)
(3) J. Schulenburg, A. Honecker, J. Schnack, J. Richter, H.-J. Schmidt, Phys. Rev. Lett. **88** (2002) 167207

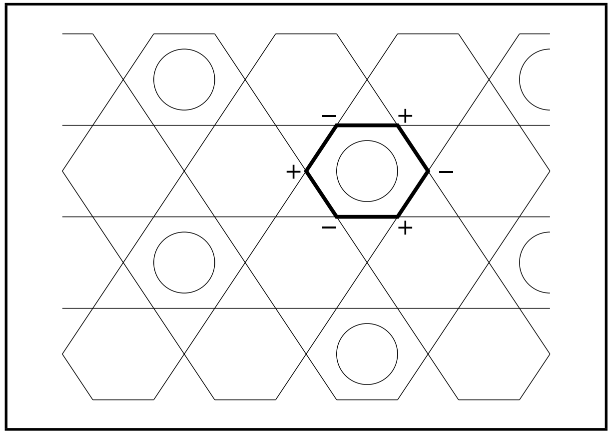
Localized Magnons



- $|\,\text{localized magnon}\,\rangle = \frac{1}{2}(\,|\,1\,\rangle - \,|\,2\,\rangle + \,|\,3\,\rangle - \,|\,4\,\rangle)$
- $|\,u\,\rangle = \underset{\sim}{s}^{-}(u)\,|\,\Omega\,\rangle$; $|\,\Omega\,\rangle$ – magnon vacuum; $u = 1, 2, 3, 4$
- $\underset{\sim}{H}\,|\,1\,\rangle = J\{\,|\,1\,\rangle + 1/2(\,|\,2\,\rangle + \,|\,4\,\rangle + \,|\,5\,\rangle + \,|\,8\,\rangle)\}$
- $\underset{\sim}{H}\,|\,\text{localized magnon}\,\rangle \propto \,|\,\text{localized magnon}\,\rangle$

- Triangles trap the localized magnon, amplitudes cancel at outer vertices.

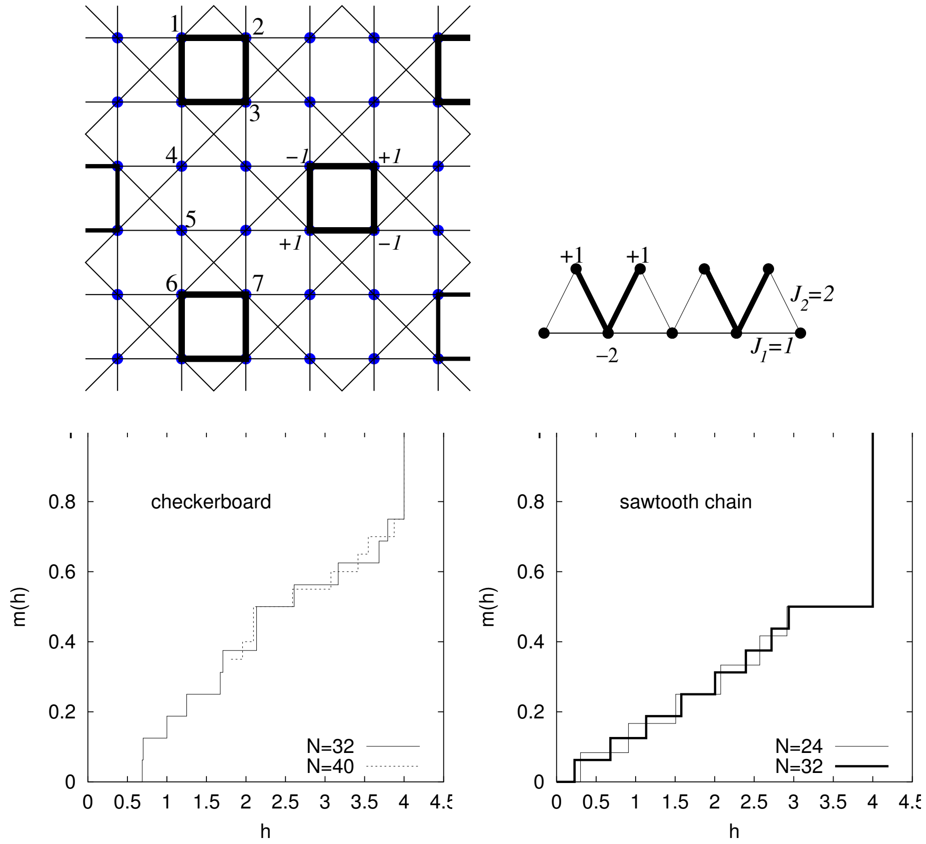
Kagome Lattice



- Localized one-magnon state indicated by bold lines;
- Non-interacting one-magnon states can be placed on the grid; each state of n independent magnons is the ground state in the Hilbert subspace with $M = Ns - n$;
- $\Rightarrow$ Linear dependence of E_{min} on M; magnetization jump;
- Maximal number of independent magnons: N/9;
- Magnetization jump is a macroscopic quantum effect!

J. Schulenburg, A. Honecker, J. Schnack, J. Richter, H.-J. Schmidt, Phys. Rev. Lett. **88** (2002) 167207

Example spin systems



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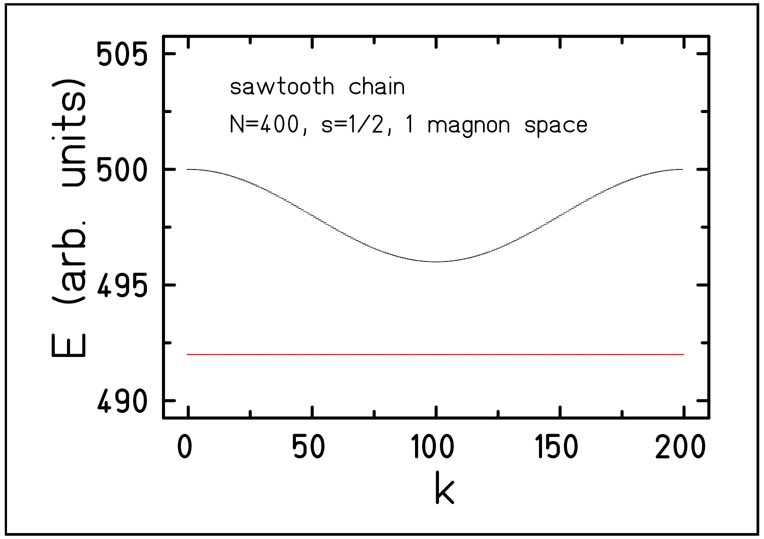
Solid state point of view: Flat band

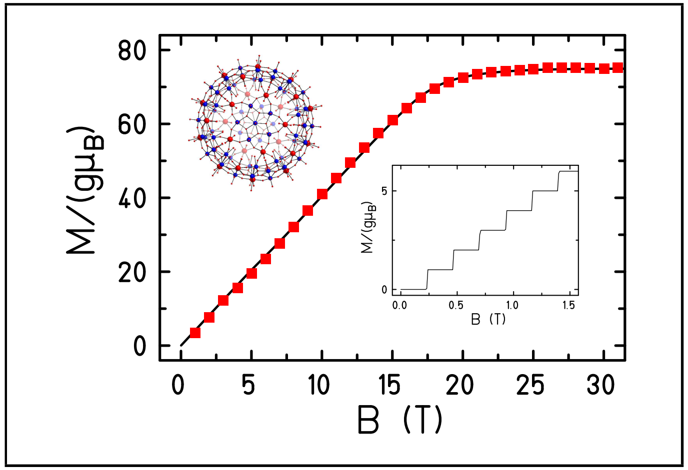


- Flat band of minimal energy in one-magnon space, i. e. high degeneracy of ground state energy in $\mathcal{H}(M = Ns - 1)$;
- Localized magnons can be built from eigen-states of the shift (translation) operator;
- Sawtooth chain exceptional since degeneracy is $N/2$ (very high).

Yet another point of view

- Localized magnons are special solitons;
- They are well localized and have dispersionless time-evolution;
- But they are also stationary, i. e. do not move.

Outlook



- Magnetization jump in $\{Mo_{72}Fe_{30}\}$ not detectable: too small, temperature too high;
- A material like Kagome, checkerboard or saw-tooth chain would be preferable since there the effect is of macroscopic nature;

- Our hope is that dipolar interactions smear out the magnetization jump only weakly.
- Magnetocaloric effect presumably especially strong close to the jump (compare symposium on MC and (1-3)).

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(2) M. Zhitomirsky, A. Honecker, J. Stat. Mech.: Theor. Exp. (2004) P07012;
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Thank you very much for your attention.

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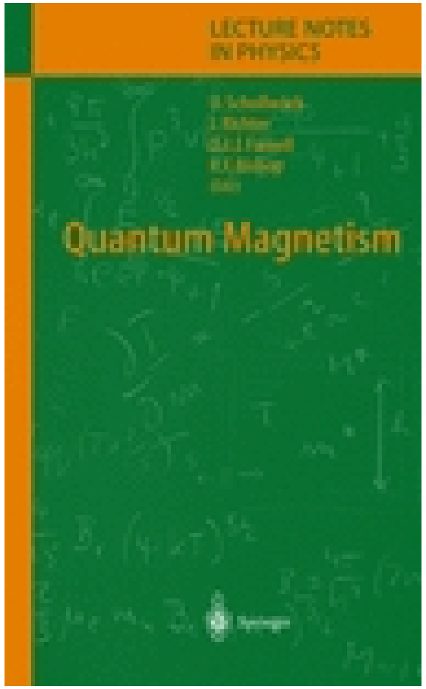
Buy now!



Quantum Magnetism

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