Spin liquids in frustrated magnets

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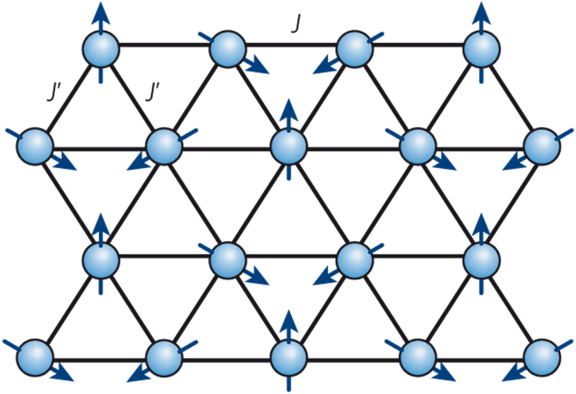
Contents

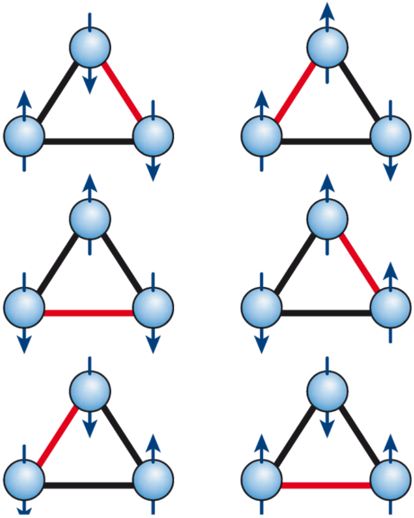
Frustration

The presence of competing forces that cannot be simultaneously satisfied.

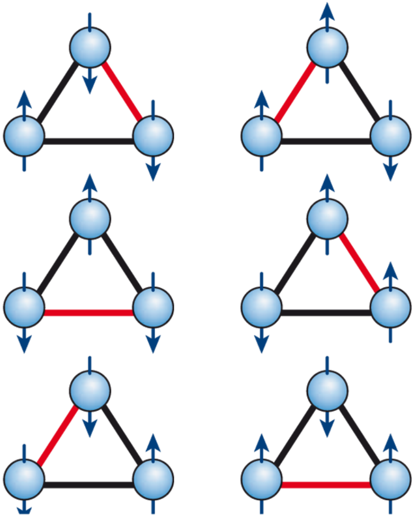
Heisenberg-Hamiltonian

$$H = -\frac{1}{2} \sum_{\langle ij \rangle} J_{ij} \mathbf{S_i} \cdot \mathbf{S_j}$$

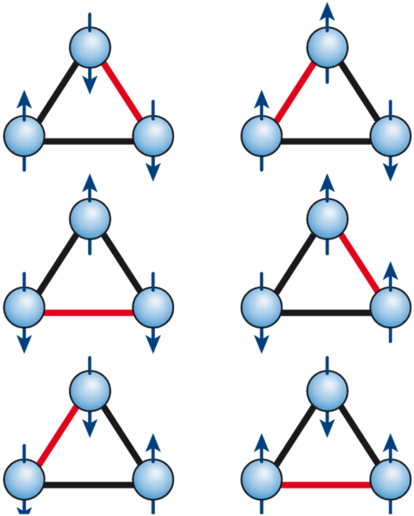




- The ground state of this triangle is sixfold degenerate



- The ground state of this triangle is sixfold degenerate
- Such degeneracies enhance fluctuations and suppress order



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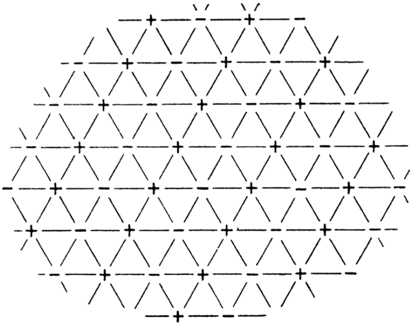
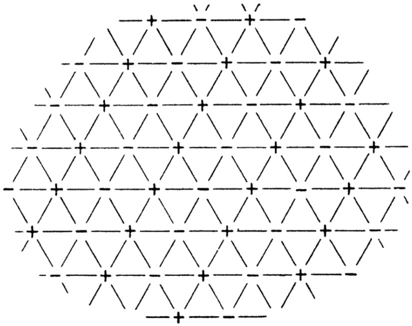
Spin liquid

The spins in a spin liquid form a highly correlated state that has no static order.



- Wannier showed that for a triangular Ising antiferromagnet the ground state entropy equals $0.323 k_B N$



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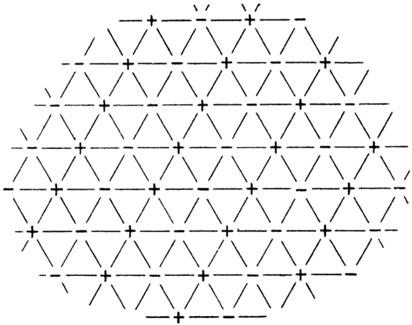
- This provides a counterexample to the third law of thermodynamics



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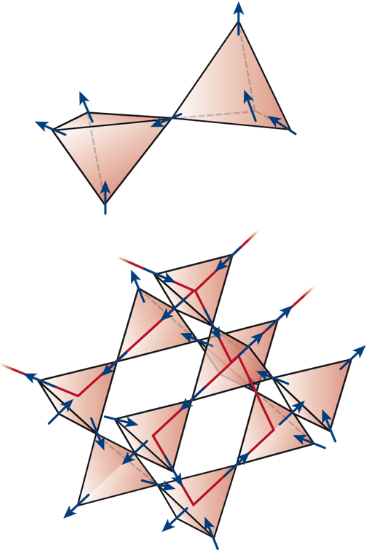
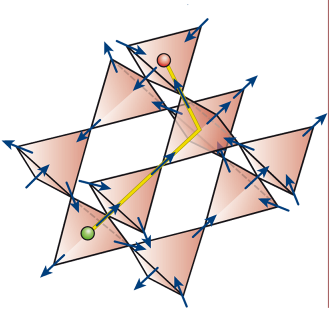
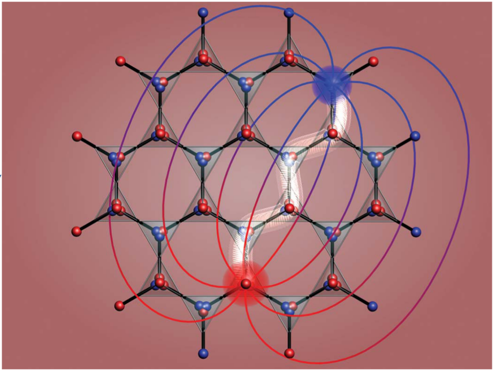


- In spin ice the spins obey the 'ice rules': if two spins on a tetrahedron point out, the other two point in

- Violations of the 'ice rules' create magnetic monopoles as emergent particles

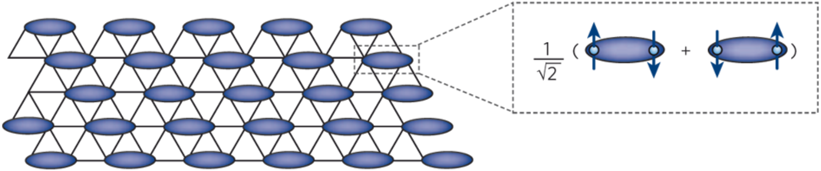




Quantum spin liquids

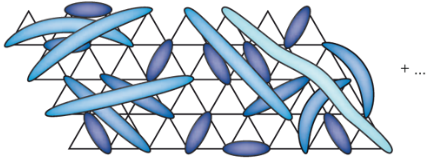
- A quantum spin liquid has a non-magnetic ground state, in which spins continue to fluctuate and evade order even at $T = 0\text{K}$

- A natural building block for non-magnetic states is the valence bond
- Valence bond states provide a way of studying Bose-Einstein condensation of magnons



- A valence bond state is not a true QSL because it breaks lattice symmetry and lacks long-range entanglement

- In a quantum spin liquid the ground state is a superposition of different partitionings of spins into valence bonds. Such a state is called a resonating valence bond state

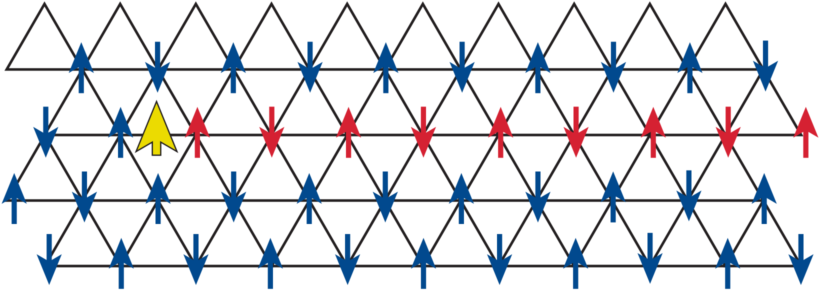


- Such states might underlie the physics of high-temperature superconductivity

Exotic excitations

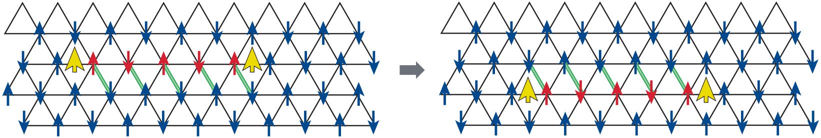
- One of the defining characteristics of QSL are exotic excitations
- Exotic excitations carry fractional quantum numbers
  - The magnetic monopoles are examples of this: the elementary magnetic dipole splits into a monopole pair

- In a quasi-1D system, spinons are formed as a domain wall between the two antiferromagnetic ground states



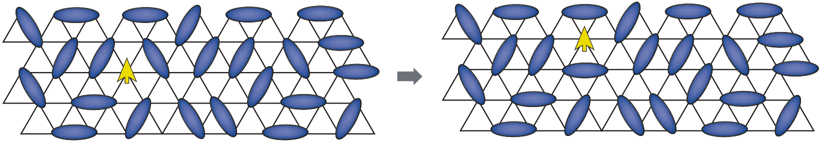
- The spinon cannot hop between chains, because to do so would require the flipping of an infinite number of spins

- A bound pair of 1D spinons forms a triplon



- The triplon can move between chains by flipping the spins along the green bonds

- In a 2D QSL, a spinon is created as an unpaired spin



- It can move by locally adjusting the valence bonds

Connection to superconductivity

- Anderson proposed a connection between resonating valence-bond states and high-temperature superconductivity
- In an RVB state, electrons are paired even though the state is non-superconducting
- If the material can be made conducting and phase coherent, e.g. by doping, it could become superconducting

This is my last slide

Thank you for your attention.

References

Anderson, P. W., Baskaran, G., Zou, Z., and Hsu, T. Resonating–valence-bond theory of phase transitions and superconductivity in *la*2*cuo*4-based compounds. *Phys. Rev. Lett. 58*, 26 (Jun 1987), 2790–2793.

Balents, L. Spin liquids in frustrated magnets. *Nature 464* (Mar 2010), 199–208.

Cabrera, B. First results from a superconductive detector for moving magnetic monopoles. *Phys. Rev. Lett. 48*, 20 (May 1982), 1378–1381.

Castelnovo, C., Moessner, R., and Sondhi, S. Magnetic monopoles in spin ice. *Nature 451* (Jan 2007), 42–45.

Isakov, S. V., Moessner, R., and Sondhi, S. L. Why spin ice obeys the ice rules. *Phys. Rev. Lett. 95*, 21 (Nov 2005), 217201.

Lee, P. A., Nagaosa, N., and Wen, X.-G. Doping a mott insulator: Physics of high-temperature superconductivity. *Rev. Mod. Phys. 78*, 1 (Jan 2006), 17–85.

Wannier, G. H. Antiferromagnetism. The triangular ising net. *Phys. Rev. 79*, 2 (Jul 1950), 357–364.