# Quantum Melting of a Spin-Ice as a New Route to Supersolidity

Predicted forty years ago, supersolids have received renewed interest recently after a possible observation in $^4$He. While the existence of supersolids is still controversial on the experimental side, numerous examples of such phases have been identified theoretically. To investigate a new route to such exotic quantum phases, we have made a theoretical study of the strong quantum fluctuation effects in a special kind of polarized antiferromagnet that has spin-ice properties at the classical limit.

A supersolid phase is characterized by the coexistence of two contradictory order parameters, a solid crystalline order and a superfluid density (or an in-plane spin order in the case of spin systems). This reflects the spontaneous breaking of two independent symmetries, translation and U(1) rotational gauge symmetry. This simultaneous breaking of two unrelated symmetries is a striking feature and does not have a classical counterpart. In some sense, one could think of the supersolid as a quantum phase which is both solid and liquid. It is thus important to obtain a deep understanding of the conditions and mechanisms for supersolidity and to propose new routes to obtain it.

Certain half-polarized antiferromagnetic spinels can be described as anisotropic magnets on a pyrochlore lattice. In the simplified model case of a spin 1/2 antiferromagnet on a checkerboard lattice (the two-dimensional analogue of a pyrochlore), with only an Ising coupling on the bonds and at moderate external magnetic field, the classical ground state is highly degenerate and follows a so-called "ice-rule" constraint: the lowest Ising energy corresponds precisely to one up-spin and three down-spins on every (flattened) tetrahedron (the light blue tetrahedra in Fig. a). Such a classical state is usually referred to as a "spin-ice".

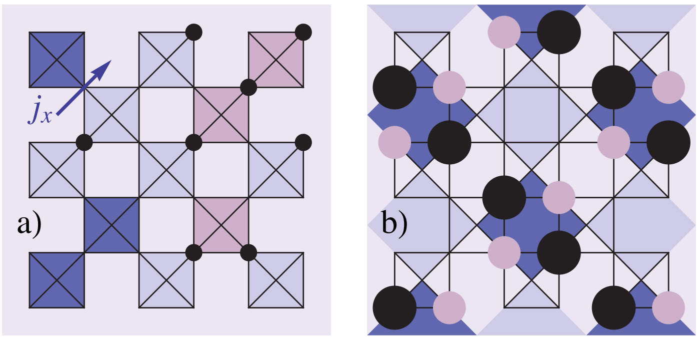


Figure : a) Spin 1/2 antiferromagnet on the 2D checkerboard lattice. Up-spins are shown as black dots. Under quantum fluctuations, the spin-ice configurations (made up of light blue flattened tetrahedra with one up-spin and three down-spins) are partially destroyed. Some defects appear: tetrahedra with fully polarized spins (dark blue) and with two up-spins and two down-spins (red), and stabilize the commensurate supersolid. b) Artist's view of the Valence Bond Crystal supersolid phase at commensurate magnetization, showing the resonating plaquettes (dark blue) with inhomogeneous spin density (dots) as well as the in-plane spin order (light blue).

Once in-plane interactions are included, i.e. away from the classical Ising limit, small quantum fluctuations select certain of the ice-rule configurations and a Valence-Bond Crystal (VBC) insulator is stabilized. In our case, this VBC has been shown to be an exotic phase with paired spins resonating on each tetrahedron. Now, at zero temperature, as quantum fluctuations increase more and more, a quantum melting of this insulating phase occurs. Usually, at fixed magnetization, a transition from a Mott-Insulator to a spin liquid is achieved. However, the residual spin-ice nature of the VBC leads to a double quantum transition point with a novel, commensurate supersolid phase (see Fig b).

The finite entropy of the spin-ice at zero temperature, the magnetic frustration and the strong quantum fluctuations are responsible for the presence of this exotic phase. Thus, spin 1/2 systems with ice-rule constraints constitute a natural and uncharted terrain for searching for supersolidity, both theoretically and experimentally.

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FURTHER READING

A. Ralko, F. Trousselet and D. Poilblanc, Phys. Rev. Lett. 104, 127203 (2010).