PhD Open Days

Geometric Frustration and Liquid Phases

PHD in Physics

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Ordered vs Liquid Phases

At low temperatures, materials typically transition into an ordered phase that spontaneously breaks some symmetry of the underlying microscopic system. Examples are ferromagnetic, superfluid and superconducting phases.

Frustrated interactions can lead to systems that evade this paradigm, the so-called **liquid phases**. They fail to order even at very low temperatures and are characterized by non-trivial low energy excitations that can be quite exotic.

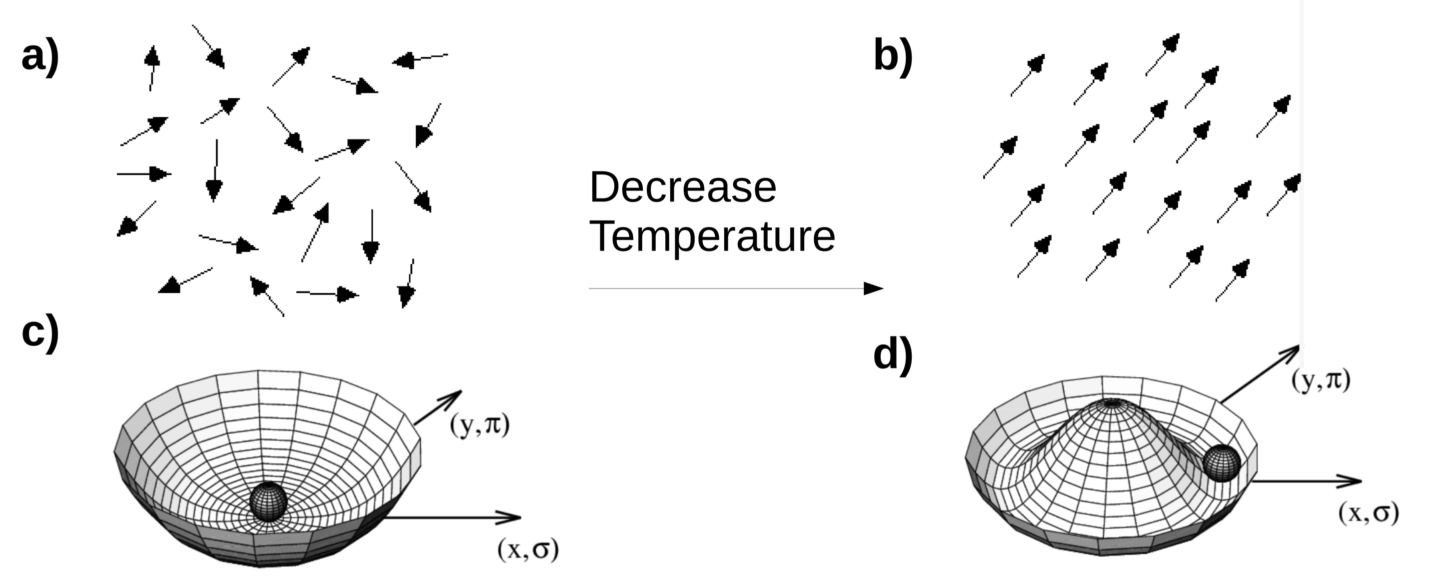

Figure 1: **a)** disordered, **b)** ordered spin configuration. Free energy for **c)** symmetric phase and d) symmetry-broken phase **[1]**.

Classical Liquids

Frustration occurs when there are competing interactions that cannot be mutually satisfied. This leads to a massive degeneracy of the ground state.

Examples of classical liquids:

- Anti-ferromagnetic Ising model on the triangular lattice, which possesses an extensive entropy at zero temperature;

- Spin Ice, whose ground state is also highly degenerate and obeys the local constraint of the ice rule. It contains “magnetic” monopole excitations.

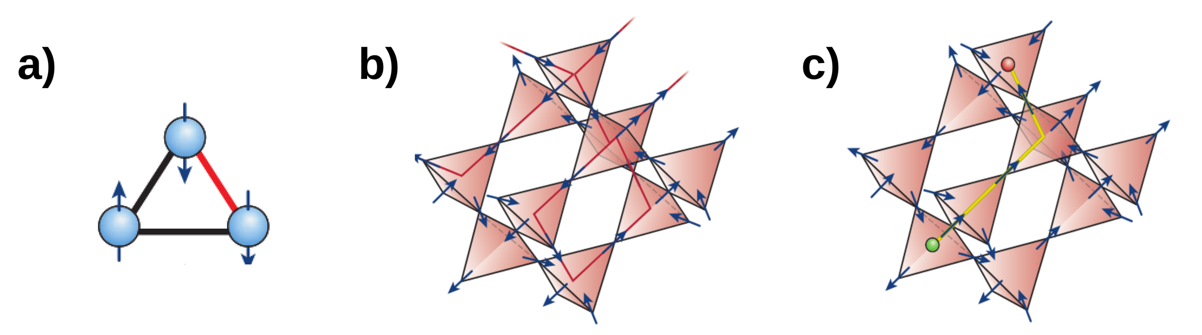

Figure 2: **a)** example of anti-ferromagnetic interaction on triangle. Spin ice **b)** displaying ice rule and **c)** with magnetic monopoles **[4]**.

Future Work Directions

There are three main anticipated work directions:

- Verify if the liquid regions in the FK model are robust towards turning on the f-electron hopping;

- Improve Monte-Carlo sampling of frustrated systems using Boltzmann machines that serve as surrogate models for proposing new configurations that are more likely to be accepted;

- Use tensor networks and neural networks as variational states for liquid phases.

Quantum Liquids

Quantum fluctuations lift the degeneracy of the classical case and lead to a highly entangled ground-state, which constitutes the defining feature of quantum liquids.

Examples of quantum liquids:

- Resonating valence bond (RVB), which supports spinon excitations and was proposed as a possible parent state of high temperature superconductors **[2]** ;

- Toric code, which can be cast as an emergent Z_2 gauge theory with anyon excitations.

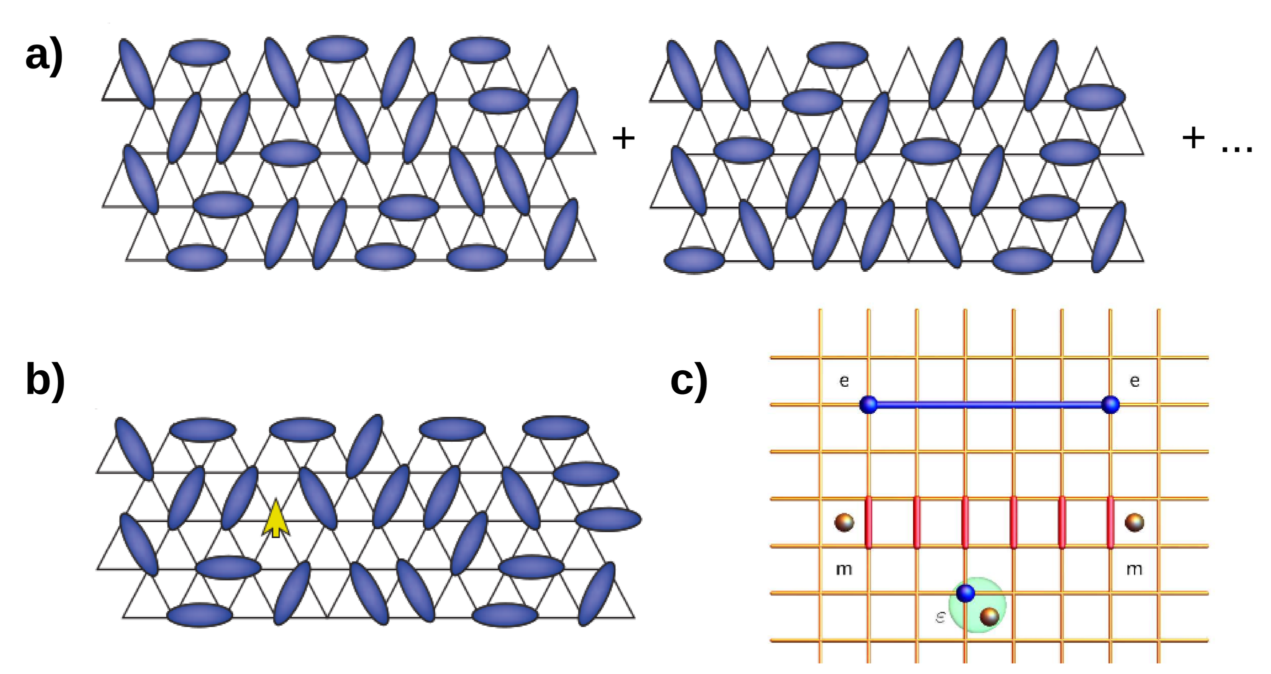

Figure 3: **a)** Representation of RVB state and **b)** spinon excitation. **c)** Anyon excitations in 2D toric code **[3]**.

Preliminary results

We studied the Falicov-Kimball model on the triangular lattice

$$H=-t\sum_{\langle ij\rangle} c_i^\dagger c_j + U\sum_i n_{f,i} c_i^\dagger c_i - \mu_f N_f - \mu_c N_c$$

It’s a hybrid model of both classical and quantum degrees of freedom. On the triangular lattice it can lead to frustrated interactions and liquid-like regimes at low temperature.

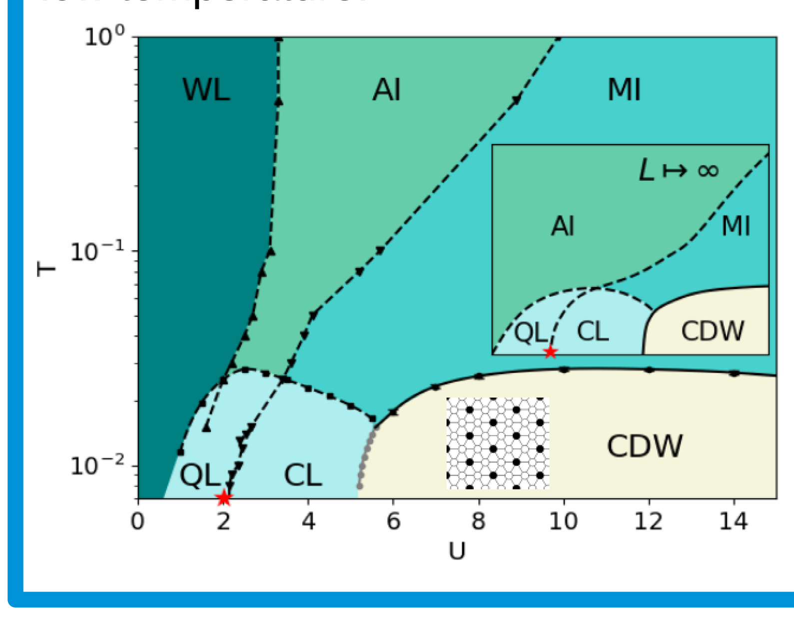

Figure 4: T-U phase diagram of the FK model on the triangular lattice for 1/3 filling **[5]**.

References

[1] V. Koch, International Journal of Modern Physics E, 06(02):203–249 (1997)
[2] P. W. Anderson, Science, 235(4793):1196–1198 (1987)
[3] L. Savary, L. Balents, Reports on Progress in Physics, 80(1):016502 (2016)
[4] L. Balents, Nature, 464:199 EP (2010)
[5] M. M. Oliveira, P. Ribeiro, S. Kirchner, arXiv:1810.10582 (2018)