[QMS2020 invited talk]

# Spin ice and quantum spin ice physics: the neutron scattering perspective

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Magnetic frustration, the inability of a system to simultaneously satisfy all of its interactions, is the subject of much research in condensed matter physics. This phenomenon, which can be related to the topology of the crystalline network or to the competition between interactions, constitutes the source of new exotic states of matter, the description of which goes beyond the classical models. Spin ice and its quantum analogues are an emblematic example of this physics. The crystallographic structure of these materials is based on a pyrochlore-type network, formed by a set of tetrahedra connected by their vertices, each node being occupied by a magnetic rare earth ion (Tb, Dy, Ho, Pr, etc.). In these compounds, the relevant electronic orbitals have the shape of a very thin needle, elongated towards the centres of each tetrahedra. The magnetic moment of each ion can then only point inward or outward, much like the ±1 states of an Ising variable. The classical fundamental state of such a system is very peculiar in that it is infinitely degenerate. Indeed, the only prescription for constructing it is to follow a local organizing principle, which states that each tetrahedron must have two spins “in" and two "out". In recent years, theoretical physicists have proposed a new vision of the problem, noting that the "two in-two out" rule is actually analogous to the conservation law of a fictitious magnetic flux (div B=0) in electromagnetism [1]. The analogy is complete when quantum fluctuations are incorporated. Indeed, the fluctuations of the fictitious magnetic field B, create by virtue of the Lenz law curl E=- dB/dt an "emergent" electric field E. According to theoretical predictions, a quantum spin ice should have a particular excitation spectrum characterized by a photon-like mode. Using examples from the literature and from our own research, we will show in this presentation that, despite much work, the experiments carried out so far in this family of compounds have not yet made it possible to demonstrate this particular dynamic, with the possible exception of $Pr_2Hf_2O_7$. However, the influence of quantum effects has been very clearly observed, highlighting a very rich array of behaviors. We will especially discuss the case of $Tb_2Ti_2O_7$, $Pr_2Zr_2O_7$, as well as the possible “magnetic fragmentation” in $Nd_2Zr_2O_7$ [2,3,4].

[1] Quantum spin ice: a search for gapless quantum spin liquids in pyrochlore magnets, M.J.P. Gingras and P.A. McClarty, Rep Prog Phys 77 (2017) 056501.
[2] E. Lhotel et al, Physical Review Letters 115, 197202 (2015).
[3] S. Petit et al, Nature Physics 12, 746 (2016).
[4] E. Lhotel et al, Nature communications, Vol 9, article number 3786 (2018).