Summary

Just twenty years ago, quantum magnetism was a dead-end track of condensed matter physics. Now it is one of the most promising fields to look for new states of matter. It all started with the unforeseen discovery of high-temperature superconductivity in a family of cuprates in 1986, and the suggestion by Anderson that, although superconductivity is achieved by doping a standard antiferromagnet, what actually happens is that doped holes drive the magnetic background into another state known as a Resonating Valence Bond (RVB) state, a superposition of configurations in which pairs of spins form singlets but change partner from one configuration to the other. This gave a new and strong impetus to the search for new materials with unconventional magnetic properties and to a real understanding of the connection between magnetism and superconductivity. It is now clear that the essential ingredient in the quest for the RVB physics and other novel states in quantum magnets is the presence of competing interactions, a situation referred to as frustration. Typical geometries where antiferromagnetic exchange between nearest neighbors leads to strong frustration are the Kagome and pyrochlore lattices (with corner sharing triangles and tetrahedra, respectively), which are now widely studied both theoretically and experimentally.

From a completely different perspective, recent developments in atomic physics and laser technologies make it possible to trap a large number of atoms in optical lattices at very low temperatures. These systems should be very helpful for the general understanding of fundamental properties that are induced by the strong correlation. In fact, here it seems possible to obtain an experimental realization of simple models of strongly interacting electrons or bosons, making it also possible to switch off “undesirable” effects that naturally appear in complicate crystalline structures (e.g., defects, electron-phonon interaction, etc.). One important result that has been shown is the existence of the superfluid-insulator transition in bosonic models. Besides having access to simple realizations of well-known quantum phases (e.g., superfluid, Mott and Anderson insulators), these systems allow one to simulate various microscopic models and to stabilize new quantum phases that have not been detected so far. One example is for instance the pair-superfluid, where pairs of bosons of different species condense, whereas none of the single specie show a macroscopic condensate fraction.

Very remarkably, there are tight connections between frustrated magnets and cold atoms in optical lattices and very similar quantum phases can be found and studied in both cases. One spectacular consequence of frustration can be seen in the magnetization curve of antiferromagnets. As first reported a few years ago in $SrCu_2(BO_3)_2$, a two-dimensional arrangement of mutually orthogonal weakly coupled dimers, frustration can induce plateaux at rational values 1/8, 1/4, and 1/3 of the saturation magnetization. These plateaux correspond to a gapped phase with broken (translational) symmetry, whereas (uniform) gapless states will naturally lead to a monotonically increasing magnetization with the external field. The mathematical connection between triplet excitations and (had-core) bosons makes it possible to study exotic bosonic phases in magnetic systems. One example is the recent claim that the equivalent of a super-solid phase (with both broken translational symmetry and gapless excitations) can be stabilized in the vicinity of the 1/8 plateau.

Description of the scientific content

The workshop covered different topics on both highly frustrated materials and cold atomic gases trapped in optical lattices. In particular, the main subjects covered were: triangular systems, Kagome materials, spinels and pyrochores, supersolids and bosonic models, quantum magnetism in atomic gases, fundamental mechanisms and modeling, as well as other theoretical and experimental aspects.

The workshop had 17 invited and 14 contributed speakers. The total number of participants were 82.

One important issue was about the recent developments in the synthesis and characterization of Kagome antiferromagnets (Z. Hiroi and P. Mendels). Particular emphasis was given to $ZnCu_3(OH)_6Cl_2$, an almost perfect 2D spin-1/2 Kagome lattice, or $Cu_3V_2O_7(OH)_2 2H_2O$, that generated much excitement in the field. The tremendous experimental effort currently under way to unveil the properties these Kagome systems is typical of a very hot topic.

Thermodynamic, transport, and NMR measurements for organic materials have been reported (K. Kanoda). These compounds can be described by an anisotropic 2D triangular lattice and, by varying the external pressure, it is possible to study a metal-insulator transition (Mott transition). The existence of very low-energy charge excitations even in the insulating phase makes the characterization of these materials very challenging. The nature of the insulating phase is still debated, but it is presumably some kind of spin liquid down to very low temperatures. The nature of the Mott transition in presence of frustration has also been discussed a couple of theoretical talks (F. Mila and C. Gros).

Pyrochlores and spinels are two families of compounds that have been largely investigated in the recent past. These materials show an enormous variety of compositions and physical properties. The highly frustrated structure of the lattice leads to a subtle interplay between magnetism and different disordered states. Different aspects of quantum spin ices have been discussed (M. Gingras, S. Bramwell, and P. Holdsworth).

Some talks were devoted to different aspects of dimer and compass models (D. Poilblanc and W. Brzezicki). These models are usually used to describe the low-energy properties of magnetically disordered systems. The discussion was articulated around their actual relation with real spin models (J. Richter) and their relevance to describe the Kagome lattice or system with orbital ordering.

Very interesting talks on exact spin-half quantum spin liquids with emergent Fermi surfaces (G. Baskaran) and a novel field-theory approach to treat spin ladders (A. Tsvelik) have been presented. These approaches have also a tight connection with high-temperature Cuprate superconductors.

Some talks were devoted to the possibility to have an unconventional magnetic order in spin-one or SU(3) models (K. Penc and T. Toth). In particuler, SU(3) models may be relevant to microscopic models with orbital degrees of freedom coupled to spin variables.

Finally, various experimental and theoretical talks on cold atomic gases have been presented. In particular, atomic Bose-Bose mixtures have been shown to mimic quantum magnetism in atomic systems (F. Minardi) and the possibility to probe both static and dynamical properties of a quantum gas i (D. Stamper-Kurn). From a theoretical point of view, the possibility to mimic non-abelian anyons with ultracold atoms in artificial gauge potentials has been discussed (A. Trombettoni), as well as transport and many-body localization in bosonic insulators and disordered magnets (M. Mueller).

During the workshop, a quite lively discussion time took place every day, from 17 pm on, on different aspects by different speakers.

Impact of the event

Both fields of highly frustrated magnetism and cold atomic gases trapped in optical lattices are at present rapidly developing, relating fundamental conceptual aspects to modeling problems as well as materials related questions. This activity brought together experimentalists and theorists working on different aspects and using different but complementary techniques. The exchange took place at a very high level and provided a good opportunity to clarify the state of the art. Moreover, the school covered a wide range of topics, from the fundamental ones to the more advanced ones, giving an excellent introduction to the field to younger scientists. A substantial part of the ICTP support was given to people coming from the developing countries. The importance of the activity was also highlighted by the large number of steering committee members of HFM (Highly Frustrated Magnetism) present, as well as by a strong participation from outside Europe (North America and Japan).

Final Program

The final program can be found at:

http://cdsagenda5.ictp.trieste.it/full_display.php?smr=0&ida=a09157