Seminar and Workshop

Topological Order:
From quantum Hall systems to magnetic materials

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The international seminar and workshop "Topological Order: From quantum Hall systems to magnetic materials" was devoted to a broad variety of physical systems that exhibit unconventionally ordered phases including frustrated magnets, quantum Hall systems, time-reversal symmetry breaking superconductors, ultracold atom systems, and topological insulators. It brought together theorists working on fundamental concepts of topological order, quantum phase transitions in constrained systems, spin liquid phases, and quantum information theory as well as experimentalists working on two-dimensional electron gases, quantum wells, and transitional metal compounds including Iridium oxides, spinels, and chiral magnets.

The **three-week seminar** program was structured around one or two daily talks, including two lectures devoted to pedagogical introductions in each week. The three weeks were not organized to have special focus topics, since one of the central objectives of the workshop was to bring together scientists from two seemingly disjoint communities, but with overlapping interests – on the one hand scientists working on frustrated magnetism motivated primarily from a materials-science perspective and on the other hand scientists with a focus on topological phases and their harnessing for topological quantum computing with a particular emphasis on fractional quantum Hall based systems. Judging from the lively activity, vigorous discussions and overwhelmingly positive feedback throughout the program we believe that this concept has worked very well.

Nevertheless, some themes shaped the discussions of the individual seminar weeks more than others, mostly due to the varying roster of participants in each week. The first week greatly benefited from an introductory lecture of Alexei Kitaev (Caltech), one of the pioneers in the field of topological order and topological quantum computation. He reviewed fundamental aspects of topological order in microscopic models and then proceeded to an advanced mathematical description of the interplay of topological order and quantum critical behavior. Impressive progress in the theoretical description of quantum phase transitions in highly constrained systems was also reported by various speakers throughout the program including John Chalker (Oxford), Kai Schmidt (Dortmund), Claudio Castelnovo (Oxford), and Eun-Ah Kim (Cornell).
Other topics of the seminar weeks included the exotic physics of highly frustrated magnets put forward in talks by Ribhu Kaul (Santa Barbara), Chris Henley (Cornell), Wolfram Brenig (Braunschweig), and Oleg Tchernyshyov

(Johns Hopkins) as well as conceptual approaches to exotic spin liquid behavior discussed by T. Senthil (MIT). Quantum information approaches to topological order were highlighted in various talks including those by Frank Verstraete (Vienna) and Vincent Pasquier (CEA/IPhT).

A recurring theme of the seminar weeks was the conjectured non-Abelian statistics of anyonic excitations in certain fractional quantum Hall states, especially the v=5/2 state. Several discussions evolved around possible experimental schemes to probe such a peculiar state of matter including quantum interferometers put forward in talks by Ady Stern (Weizmann), Kirill Shtengel (UC Riverside), and Bernd Rosenow (MPI Stuttgart). Other aspects of non-Abelian quantum Hall states, including interaction effects, hierarchy constructions, and quasiparticle descriptions, were discussed in talks by Eddy Ardonne (Nordita), Andrei Bernevig (Princeton), Hans Hansson (Nordita), Gil Refael (Caltech), and Nicola Regnault (ENS Paris).

The culmination of the workshop was an international **workshop** held in the third week, which Xiao-Gang Wen (MIT) later described as the "grand unification of topological order". The dense conference program not only covered the most recent theoretical developments, but also gained significant momentum from outstanding experimental talks. Alois Loidl (Augsburg) overviewed spinel compounds, Merav Dolev (Weizmann) reported on charge fractionalization in the v=5/2 FQH state, Christian Pfleiderer (TU Munich) discussed skyrmion lattices in chiral metals and semi-conductors, Hidenori Takagi (University of Tokyo/RIKEN) reported on Ir oxides including the experimental observation of quantum spin liquid behavior in $Na_4Ir_3O_8$ and experimental indications for a topological insulator in Na_2IrO_3. Satoru Nakatsuji discussed unconventional, spin nematic phases in $NiGa_2S_4$, and Laurens Molenkamp reported on the experimental observation of the quantum spin Hall effect in HgTe quantum well structures. These experimental talks were put into broader context by some impressive theoretical talks given by many of the world leaders in the field. A particular highlight was the colloquium of Michael Freedman (Microsoft, Station Q) on "Topology, Physics, and Complexity: The birthing of the quantum computer", which gave an intriguing perspective on topological quantum computation.

The seminar and workshop was attended by more than 125 scientists including a large group of junior scientists who actively contributed in the discussions. The two poster sessions were largely shaped by the contributions of these junior attendees and were attended well past the originally scheduled discussion time.

This event was billed as a joint MPIPKS-APCTP workshop, and it benefitted from the collaboration, as the APCTP was able to identify the most promising young scientists in its catchment area, thereby effectively enhancing the geographic reach to the benefit of all sides involved. As a result, the event assembled some of the most promising young researchers from Asia, Europe and North America, the three global hubs of condensed matter physics.

In summary, the event managed to attract an outstanding international roster of scientists at very different stages in their careers, ranging from doctoral students to a Fields medalist. The concept for a workshop on this budding field has been conceived in the summer of 2007, its topicality further increased over time, and it benefitted greatly from developments in the intervening two years: the program ended up providing a platform for a number of new and important developments in the rapidly evolving field of topological phases of matter.