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2009 J. Phys.: Condens. Matter 21 160402

(http://iopscience.iop.org/0953-8984/21/16/160402)

IOP Publishing | Journal of Physics: Condensed Matter
J. Phys.: Condens. Matter **21** (2009) 160402 (2pp) | doi:10.1088/0953-8984/21/16/160402

DEVELOPMENTS

New developments in low temperature physics

Bob Hallock
University of Massachusetts, USA

Mikko Paalanenn
Helsinki University of Technology, Finland

Below you will find part of the activity report to the IUPAP General Assembly, October 2008, by the present and previous Chairmen of C5. It provides an overview of the most important and recent developments in low temperature physics, much in line with the program of LT25.

For the field of experimental low temperature physics, the ability to conduct research has been damaged by the dramatic increase in the price of liquid helium. In the USA, for example, the price of liquid helium has approximately doubled over the past two years. This has led to a reduction in activity in many laboratories as the funding agencies have not quickly increased support in proportion.

The increase in price of liquid helium has accelerated interest in the development and use of alternative cooling systems. In particular, pulse-tube coolers are now available that will allow cryostats with modest cooling needs to operate dilution refrigerators without the need for repeated refills of liquid helium from external supply sources.

Solid helium research has seen a dramatic resurgence. Torsional oscillator experiments have been interpreted to show that solid helium may undergo a transition to a state in which some of the atoms in the container do not follow the motion of the container, e.g. may be 'supersolid'. The observation is robust, but the interpretation is controversial. The shear modulus of solid helium undergoes a similar signature with respect to temperature. Experiments that should be expected to cause helium to flow give conflicting results. Theory predicts that a perfect solid cannot show supersolid behavior, but novel superfluid-like behavior should be seen in various defects that can exist in the solid, and vorticity may play a significant role. And, recently there have been reports of unusual mass decoupling in films of pure ^{4}He on graphite surfaces as well as ^{3}He-^{4}He mixture films on solid hydrogen surfaces. These may be other examples of unusual superfluid-like behavior.

There is continued interest in superfluid turbulence, where there has been progress in the use of very sensitive ultra-cold detectors as well as the use of injected ions. Interesting progress is being made in understanding how quantum turbulence resembles classical turbulence. New evidence shows that turbulence can develop by the entanglement of vortex rings. It now appears possible to control the transition to quantum turbulence in ^{4}He.

High temperature and unconventional superconductivity continues to show progress. Over the past few years we have seen new work on the coexistence of superconductivity and ferromagnetism in the uranium compounds. Discovery of superconductivity in layered iron-arsenic compounds may lead to a new generation of high temperature superconductors and holds great promise. There has also been strong progress in the possible use of layered transition metal oxide materials as the basis for the discovery of new superconductors. The visualization via STM of the electronic states of high transition temperature materials continue to provide new insights into the pairing that takes place in such materials. There is also emerging new work that shows that in a two dimensional superconducting system with patterned holes, pairing may exist in the insulating state.

Graphene has been a very hot topic due to the ability to readily create atomically thin sheets of carbon, which has given rise to investigation in a number of settings via many techniques. These thin sheets, unknown until a few years ago, reveal remarkable electronic and optical properties, which are only beginning to be understood and explored. There has also been continuing progress in the area of carbon nanotubes where there have been developments in the study of the spin and orbital motion of electrons, which have implications for spintronics applications.

There has been progress in the area of qubits, where it now seems possible to communicate quantum information between qubits using photons. Thus emerges the possibility of using superconducting integrated circuits to carry out experimental studies in quantum optics. In addition, small Josephson junctions are being used to study quantum coherence in ways not possible previously.

Device-driven research continues to show remarkable new results. The use of SQUID detection has allowed the possibility of very low magnetic field magnetic imaging (MRI) with the ability to resolve structures to a higher degree than previously possible. There has also been work in the area of nano-mechanical resonators, which may allow the future study of squeezed states in a mechanical system. In addition, there continues to be work on nanomagnets, which show self-assembly properties and unusual temperature dependence to the magnetization.

Ultra-cold gases continue to see dramatic progress due to the unprecedented ability of the realm of cold-atom physics to manipulate atoms and their environment. Optical superlattices have allowed studies of superexchange interactions and open the possibility of further investigation of the dynamical behavior of quantum spin systems. Such cold gas experiments have allowed unprecedented opportunity to study quantum degenerate Fermi gases and the realization of superfluidity with unusual interactions. Also in this area it has been possible to create controlled disorder and subsequently directly observe localization phenomena in one dimension, with the expectation that this can be extended to higher dimensions.