Report on 27th International Conference on Low Temperature Physics (LT27), Buenos Aires, Argentina, August 2014

Abstract. The following is an extract from the Activity Report to the IUPAP General Assembly, November 2014 by Commission C5 (Low Temperature Physics). It provides an overview of LT27, reflecting the most important and recent developments.

The LT series is the flagship international conference in low temperature physics, held triennially. LT27 was a landmark meeting: the first LT held in the southern hemisphere and the first in South America. Also notable was the fact that for the first time the Conference Chair was a woman, as was the Co-Chair.

Low temperature physics, the field which C5 represents, is a research area of extraordinary range, reach and impact. This was reflected in the topics covered at the meeting and the progress made, with research which cross-cut the traditional session topics of: Quantum Gases, Fluids and Solids; Superconductivity, Cryogenic Techniques and Applications; Magnetism and Quantum Phases; Electronic Quantum Transport in Condensed Matter. This breadth of activity was also reflected by the range of research reported by the IUPAP Young Scientist Prize winners, covering superconducting quantum devices, x-ray spectroscopy of high T_c superconductors, and the discovery of Hofstadter's butterfly in graphene systems.

The field of quantum mechanics in artificial, engineered systems (designed, nanofabricated and tuneable) is making dramatic progress. The remarkable developments in superconducting quantum circuits, operating quantum mechanically, formed the subject of the London Prize Lectures. The London Prize is an IUPAP sponsored award as well. The achievement of sufficiently long qubit lifetimes now seems enable the implementation of quantum error correction, and realization of large scale fault- tolerant quantum computers. At the same time advances in quantum sensors are expected to deliver new capabilities in sensing technologies.

Furthermore, and not least, this research area contributes to advances in fundamental understanding. For example, it has been demonstrated that a man-made macroscopic objects (realised by nanofabrication techniques) can behave as Schrödinger's cat, existing in a superposition of quantum states! And new quantum systems are emerging, with fresh opportunities for quantum control. In particular non-linear nano-electromechanical resonators, engineered in a variety of ways, in some cases with very high quality factors, can be cooled into the quantum regime. The area of engineered quantum mechanical-resonators is expected to develop strongly in future.

The Superconducting Quantum Interference Device (SQUID) constitutes a more mature technology and the LT27 meeting celebrated the SQUID's 50th anniversary. The conference heard a review of the widespread applications, realised and potential, of SQUIDs: geophysics and the discovery of mineral deposits; magnetoencephalography; dark matter (axion) detectors; photon detectors for cosmic microwave backround; high resolution x-ray spectroscopy; noise thermometry; MRI systems operating at magnetic fields four orders of magnitude lower than conventional MRI systems with several potential clinical applications, and many more. An important developing direction is SQUIDs for micro- and nanoscale detection. And in this context it was also interesting to hear a review of work over the past on the realisation of a SQUID in liquid 4He, the SHeQUID, of both fundamental interest and application as a sensitive detectors of rotation.

Nanophysics at low temperatures continues to be exploited to create novel devices with new functionalities (and acronyms), for example those based on hybrid metallic nanostructures such as the SQUIPT and HyQUID. In semiconductor-superconductor hybrid structures the focus is on the unambiguous detection, and potential manipulation of Majoranas. These particles, which are their own antiparticle, are yet to be discovered. Their quantum entanglement offers a route to topologically protected quantum computing. Developments in scanning tunnelling microscopy with superconducting tips have led to new insights into amorphous and homogeneous superconducting films, while scanning SQUID microscopy now provides a powerful technique to image complex oxide heterostructures, an important new class of materials.

These new systems and regimes of investigation challenge our fundamental understanding. A fascinating example concerns how thermodynamics applies on the nanoscale. Here it was reported that the investigation of work and dissipation in driven processes manipulating single electrons has led to an experimental realization of Maxwell's Demon!

A central theme of the conference was the discussion of a wide range of systems coming under the umbrella of quantum matter: topological insulators; graphene; unconventional superconductors, including their paradigm-superfluid ^{3}He; quantum spin liquids. The pervasive importance of the topological classification of quantum matter has been widely recognised recently, and its experimental ramifications are an active area of study. This conceptual unification provides a strong feature of low temperature physics and this conference. Another key concept in strongly correlated quantum systems is that of quantum phase transitions and quantum criticality, where a control parameter such as pressure or magnetic field is used to tune a system between ground states. The breakdown of the standard model of interacting Fermi systems at a quantum critical point remains a major unresolved issue, being actively pursued experimentally and theoretically, with significantly divergent views being presented. Here heavy fermion metals are important prototypes. There is evidence that quantum critical fluctuations enhance superconductivity in the iron-pnictides, which feeds into the debate on high T_c cuprates, where Fermi surface reconstruction is also believed to play a key role. In related work there has also been significant progress in establishing the rich behaviour of organic charge transfer salts. These systems are highly tuneable by composition and pressure, and are models for the Mott metal-insulator transition and candidate quantum spin liquids.

Superfluid ^{3}He currently provides our only established example of a topological superfluid or superconductor. The ability to fingerprint the order parameter by NMR has led to striking discoveries on how superfluidity can be manipulated by disorder with controlled anisotropy, through the introduction of aerogel. Recently this has led to the stabilization and identification of a new phase, the polar phase, not found in usual bulk liquid. Of relevance to the upsurge of interest in topological quantum matter, the surface of ^{3}He-B is predicted to host Majorana fermions. Surface acoustic studies already provide indirect evidence of a Majorana cone of dispersing surface excitations.

Both superfluid ^{3}He and ^{4}He continue to be the focus of investigations of turbulence, one of the major unsolved problems in physics. In a superfluid, the quantization of vorticity simplifies the problem and permits the confrontation of experiment with detailed theoretical simulation. For the past ten years the experimental claims for a form of superfluidity in solid ^{4}He has attracted the attention of a significant segment of the quantum fluids and solids community. The pendulum has swung towards impressive detailed studies of the elastic properties of this quantum solid and its dislocations, and this is now probably the best understood material from this point of view. However the enigma of supersolidity, as it is sometimes referred to, remains just that. The community only now is beginning to fully understand how to eliminate elastic artifacts from attempts to detect superfluidity with torsional pendular. There are a number of new results using this technique, and the problem remains open. However intriguing new work was presented which seemed to provide possible evidence for quasi-one dimensional superfluidity (probably along dislocations or grain boundaries) in the bulk solid, and evidence for a new class of quasi-condensate in two-dimensional helium. The interplay of solid order and superfluidity in bose-solids remains a subject of active interest for both the cold-atom and condensed matter communities.

Finally we address the strategic issues that have been discussed in previous reports, and recently in the literature. There have been shifts in the demand for ^{3}He gas, a key ingredient in dilution refrigerator technology, which have results in a significant lowering in price relative to the recently experienced high. On the other hand, the price of liquid ^{4}He has continued to increase, as a result of a combination of global supply and US government policy. While it is anticipated that new sources will come on stream, from newly developed natural gas reserves, further price increases are inevitable. Wastage of this non-renewable resource by sectors where helium recovery is not practiced cannot be justified. However this is beyond the control of our community. The trend is for our community to mitigate the impact of these price increases by installing efficient helium liquifier/recovery plant or by single-cryostat based recycling schemes. The alternative is to adopt cryogen-free technology. Indeed, the development of cryogen-free dilution refrigerator technology by a number of suppliers, has led to a relative explosion of demand. The number of dilution refrigerators (the 50th anniversary of which is approaching) is increasing rapidly: an important driver is research on quantum technologies, which rely on millikelvin temperatures for their operation. The push-button operation of these dilution refrigerator systems is attractive to users, and also facilitates practical applications. Perhaps the advent of the desk-top dilution refrigerator is not far away. More recently even the feasibility of achieving microkelvin temperatures, by a booster nuclear demagnetisation stage attached to a cryogen-free dilution refrigerator, has been demonstrated. Thus the ever-widening accessibility of ever-lower temperatures seems to be an inevitable trend, opening up to new fields.

In that context we note that the European Microkelvin community is working, with the support of the European Commission, to establish a European Microkelvin Platform as a "virtual laboratory", to promote accessibility, engage with interdisciplinary research directions, and promote discovery. The pooling of complementary expertise and collective approach to scientific challenges has been effective. Engagement and exchange of best practice with the wider international community is likely to contribute to the global development of low temperature physics, a field of established strategic importance.

LT27 conference summary respectfully submitted by
John Saunders, Secretary, C5
Kimitoshi Kono, Chair, C5