Journal of Physics: Conference Series

SUMMARY • **OPEN ACCESS**

26th International Conference on Low Temperature Physics (LT26)

To cite this article: W M Liu *et al* 2012 *J. Phys.: Conf. Ser.* **400** 001001

Journal of Physics: Conference Series **400** (2012) 001001 doi:10.1088/1742-6596/400/0/001001

Summary of Physics and Issues from the LT26 International Conference, Beijing, China, August 2011

The field of Low Temperature Physics, represented by C-5, has had a remarkable period of discovery in recent years. We have also encountered some issues that have given us difficulty. Here we begin with comments on two areas of difficulty that have been encountered and then move on to discuss some of the remarkable progress that was in evidence at the highly-successful LT26 meeting, which was hosted in Beijing in a very convenient and pleasant location at the Olympic Park.

Members of the C-5 community have had considerable difficulty in obtaining ^{3}He recently. This is due to the dramatic increase in the demand of ^{3}He to construct gas proportional counters for neutron detection for radiation portal monitors deployed for homeland security and the non-proliferation use such detectors. Some areas of experimental low temperature physics, for example, those areas that need dilution refrigerators, have suffered a dramatic increase in the price of ^{3}He, or even no access to ^{3}He at all. There is some progress at resolving this in some countries, but the cost is still very high and access to ^{3}He is still a serious issue for the community. A reasonable discussion of this issue can be found in the November 2010 issue of CryoGas International (published by J.R. Campbell and Associates)and a much more lengthy discussion can be found in the report of the National Research Council (of the United States), with the title *Selling the Nation's Helium Reserve*, which is available from www.nap.edu, the site of the US National Academies Press.

A second area of growing concern is access to adequate research support to allow serious progress to be made in the areas of fundamental discovery and technical development. In particular, access to research support is generally difficult and is non-uniform across the areas of the world where there has been strong traditional support for the field. Similarly, while there have been some remarkable examples of progress that points to technological impact, there is a concern that access to the levels of support needed to allow good progress is growing harder rather than easier.

But, that said, progress is our field has been remarkable and we offer a few highlights that show evidence of this progress.

The dramatic emergence of topological insulators in the previous LT conference held in Amsterdam in 2008 is still a rapidly emerging area. The concept has turned out to be very general. A bulk energy gap which is associated with specific topological properties has to close at the interface to another gap state with different topological properties. Accordingly, the excitation at the interface becomes gapless or metallic. The dispersion relation becomes linear, and the excitation is described as a “Dirac fermion”, which has become popular after the discovery of graphene. In the family of topological insulators, insulators (but often semi-metals) or semiconductors with strong spin-orbit interactions, p-wave superfluids or superconductors, two-dimensional electrons under strong magnetic fields, etc. are involved. The concept is quite interdisciplinary. It is not restricted to one of the traditional LT program areas. In such fields, the importance of LT, with a wide scope, to unify whole areas of low temperature physics is evident. There has been a remarkable expansion of research in this field, including, for example, topology and Berry phase. This trend is expected to continue for a number of years.

The predicted Majorana particle is a strange particle, for which the antiparticle is identical with the particle itself. Some of the excitations at the interfaces of topological insulators possess a similar property to the predicted properties of the Majorana particle. Surface bound states of superfluid ^{3}He-B, which have been known as Andreev bound states, are theoretically predicted to have a Majorana character. Such Majorana states are predicted in many other places including the superconductor vortex core, semiconductor-superconductor SNS junctions, and so on. There is a sudden surge in the hunt for clearly identified Majorana states in low temperature physics.

In 2004 it was announced that in torsional oscillator experiments with solid helium, part of the helium appeared to detach from the sample cell and be left behind when the cell moved. This was interpreted as the likely discovery of a supersolid state. Measurements of the shear modulus suggested that the behavior seen in the torsional oscillators might instead be related to the stiffness of the solid. The field is very active, and filled with polite controversy. Recent work has shown that the behavior of the shear modulus and the torsional oscillators is distinctly different when the sample cell undergoes macroscopic rotation, thus suggesting that the supersolid state may exist. In addition experiments which seek to cause flow through solid helium via the fountain effect have been successful, but the failure of macroscopic squeezing experiments to cause flow raises questions. In addition, it has been shown that shear effects can have a significant effect on some torsional oscillator results. There are several theoretical ideas that seek to explain the various behaviors seen, but none has been firmly confirmed by experiment. The field is extremely active, and there is as yet no clear consensus on what is the true picture of solid ^{4}He.

Vortices and quantum turbulence, superfluid ^{3}He in aerogel, low dimensional confined He system, and surfaces and interfaces continue to attract interest. New visualization techniques of turbulent flow of superfluid He have been pursued and been successful. Small particles of solid hydrogen, electron bubbles, and excimer He molecules are used for such purposes. In particular, the excimer approach seems to hold great potential in this are because the presence of excited states of helium (rather that a larger impurity) does not introduce a disturbance. New phases of superfluid ^{3}He in aerogel and proximity effects are under active study. Adsorbate He systems provide rich ground for fundamental research on strong correlation, phase transitions, friction, and so on, especially due to the high controllability of parameters and extremely clean experimental conditions.

The year of 2011 is a centennial anniversary of the discovery of superconductivity by H. Kammerlingh Onnes. The debut of iron based superconductors took place in the vicinity of LT26 (three years ago). A remarkable amount of work and synthesis of new materials in this family has emerged since then. Consequently, the understanding of multiband superconductivity is strongly enhanced. Traditional high T_c superconducting oxide and superconductivity of heavy electron systems continue to stimulate active research. Quantum criticality seems to be a key to provide a unified understanding of these superconductors in the strongly correlated electron system. Quantum criticality is discussed not only in the context of superconductivity in strongly correlated systems but also in other systems, in particular, strongly frustrated spin systems. As a new direction, superconductivity can now be realized by electric field-induced carrier doping.

The Kondo effect has an as long history in superconductivity and it is still attracting interest. Starting from the resistivity of metals with dilute magnetic impurities, it prevails in heavy electron systems, and eventually in the quantum transport of quantum dots. Here, a nonequilibrium aspect of the problem has been introduced. It is an important area of low temperature physics with constant progress.

Dramatic developments in the area of circuit QED experiments have been remarkable. The technique has been applied to different systems, for example, superconducting Josephson junctions, nano-mechanical oscillators, and so forth. Amazing quantum properties which have been recognized in the cavity QED of atomic or molecular systems have been demonstrated in macroscopic quantum systems as well. These experimental developments make us foresee real quantum information processing in the near future. It is worth noting that evidence for the presence of a quantum limit has been realized in nano-mechanical oscillators. Quantum information process driven research has been extensively developed

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in the spin qubit context in semiconductor quantum dots, where spin-orbit interactions and hyperfine interactions are important.

The study of cold atomic gases continues to develop and quantitative measurements of thermodynamic functions have been realized. The research front is approaching the stage where it is possible to design practical quantum simulators. In addition, a possible improvement in atomic clock precision is likely to have impact on many other fields of science.

The above-mentioned recent developments in low temperature physics provide a very optimistic prospect for a unified understanding of strongly correlated systems. To achieve this, it is obvious that more systematic, quantitative, and high precision low temperature experiments are inevitable. In this context, the recent cryogenic technical development of low temperature scanning probe microscopy and spectroscopy, and the maturing technology of dry cryostat design are important to note.

This year is the 25th anniversary of the discovery of high T_c oxide superconductors. In addition to the fundamental interest in the mechanism of superconductivity, the prospect for the industrial application of such materials is bright. For example, electrical power cables, magnetically levitated high speed trains, electricity generator, etc., may well lead to what might be termed a new type of industrial revolution.

Respectfully submitted by Kimitoshi Kono, Secretary, C5 Robert Hallock, Chair, C5