subject of a special symposium in which the latest results in Na (W. Ketterle, Cambridge, USA) and Rb (C. Wiemann, Boulder, USA) were presented [see *EN* 27 (1996) 173]. The symposium illustrated the rapid progress which is being made in the areas of excited states of condensates, non-destructive imaging and the interaction between two condensates. Proposals for an atom laser were also discussed.

In the field of cold atoms and optical lattices, the invited paper of C. Salomon (Paris) on the important observation of Bloch oscillations in a caesium lattice attracted considerable attention, as did reports concerning advances in atom interferometry. The applications of cold atoms to the nanofabrication of microstructures form a rapidly growing field of interest and was the subject of a joint CLEO - EQEC session. Nanostructures can be directly etched in silicon by laser writing, as described by M. Mullenborn *et al.* (Lyngby). By comparison, J.J. McClelland et al. (Gaithersburg, USA) and J. Mlynek *et al.* (Constance), by focusing beams of cold chromium atoms, have been able to form various patterns on substrates to achieve minimum dimensions of below only 50 nm. The latter group also reported on etching with metastable helium atoms.

Benefiting from Laser Advances

Research in the field of optical interactions with condensed matter now ranges from single-molecule spectroscopy to clusters and nanostructure dynamics up to bulk semiconductor materials. The area has benefited greatly from recent progress in ultrafast laser technology and the development of new materials. Novel sources covering the electromagnetic spectrum from THz range up to the far-UV make it possible to study and manipulate elementary excitations - work that will have an enormous impact on the design of optical and optoelectronic devices.

The field was well represented at CLEO/Europe - EQEC '96, which included reports of the development of novel far-infrared sub-picosecond laser sources for studying ultrafast carrier relaxation; and of the laser-controlled picosecond creation and annihilation of carriers in semiconductors (A.P. Heberle *et al.*, UK and Germany) that can possibly be used in ultra-fast all-optical communication systems.

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Rotons in Superfluid ^{4}He

The 1996 Nobel Prize in Physics has been awarded to D.M. Lee and R.C. Richardson of Cornell University, NY, USA, and to D.D. Osheroff, Stanford University, CA, USA, for discovering superfluidity in ^{3}He. K.H. Andersen, J. Bossy, J.C. Cook, and O.G. Randl from the Institut Laue-Langevin, Grenoble, report on recent measurements of elementary excitations in superfluid ^{4}He showing that low-temperature research still provides intriguing and challenging results.

With the liquifaction of ^{4}He in the 1930s and the discovery of superfluidity in ^{4}He, it was thought that fermions such as ^{3}He followed Fermi-Dirac statistics and could not condense in the lowest energy state, so superfluidity in ^{3}He would be impossible. However, J. Bardeen, L. Cooper and R. Schrieffer proposed in their BCS theory for superconductivity that electrons in strongly cooled metals combine to form Cooper pairs, and then behave as bosons and are able to undergo Bose-Einstein condensation.

With the fermions in liquid ^{3}He able to form boson pairs, it was expected that superfluidity would be obtainable at very low temperatures. After much work many felt that superfluidity in ^{3}He was impossible to achieve, until its discovery in 1971 by this year's Nobel laureates at temperatures around 2 mK. Studying this exotic quantum liquid and its rich set of physical properties has since led to concepts of general importance which could, for example, help in understanding high-temperature superconductors.

Despite its apparent simplicity, pure liquid ^{4}He constitutes a fascinatingly complex many-body system and still provides intriguing and challenging work for theorists and experimentalists alike. Neutron scattering measurements which probe the density fluctuations of a system show that the elementary excitations in superfluid ^{4}He follow a dispersion curve known as the phonon - roton curve (Fig. 1). Superfluidity can be inferred from the kinematical restraints on creating an elementary excitation, and it can be shown [1] that for low flow velocities, the only contributions to the viscosity arise from the thermally excited elementary excitations; the actual

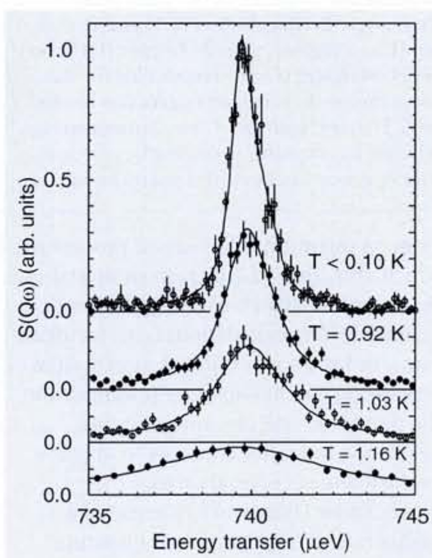

Fig. 2. Roton peaks measured on the ILL's IN10B spectrometer at four different temperatures. The solid line is the best-fit line shape. The shoulder on the high-energy side, which is most clearly seen at low temperature, is caused by the width of the instrumental Q-resolution.

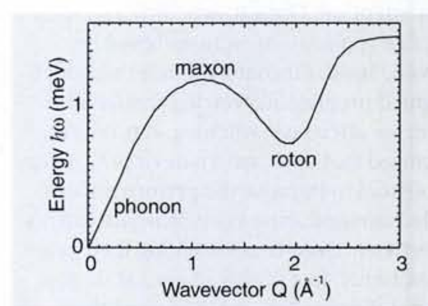

Fig. 1. Phonon-roton dispersion curve of superfluid ^{4}He.

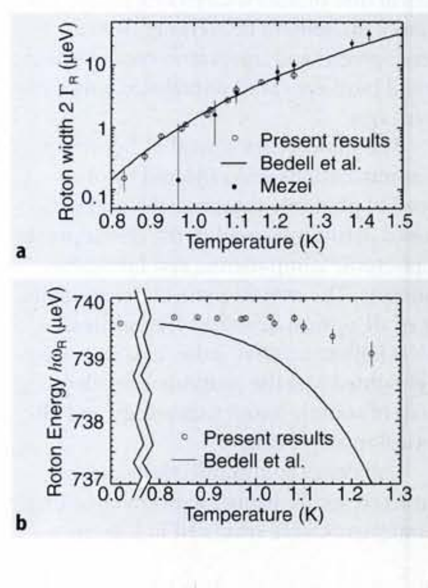

Fig. 3. Measured roton parameters. **a:** The best-fit half-width compared with the 1984 neutron spin echo data of Mezei and the values predicted by Bedell *et al.* The agreement between experiment and theory is excellent. **b:** Best-fit roton energy: the observed temperature dependence is clearly less than that expected from the theory of Bedell *et al.*

fluid acts as if it has zero viscosity. At low temperature, the only elementary excitations that have a non-negligible probability of being thermally excited are those in the linear (phonon) region and around the parabolic (roton) minimum. It should be noted that, despite their different names, it is difficult to picture phonons and rotons as qualitatively different. It is more appropriate to regard them as labels given to excitations in different wavevector Q regions of the same dispersion curve.

The lifetime of a roton can be understood in terms of the four-quasiparticle decay process first introduced by Landau and Khalatnikov [2] and refined by Bedell *et al.* [3]. A roton excited by a neutron decays by combining with a thermally excited roton and then decaying into two other quasiparticles. As the temperature is lowered, the number of thermally excited rotons rapidly decreases, giving rise to a very strong temperature dependence of the roton lifetime and hence the linewidth of the density fluctuation spectrum $S(Q,\omega)$ measured for wavevectors Q and energy transfers ω by neutron scattering.

Until recently, only the neutron spin-echo (NSE) technique has been capable of resolving the anticipated linewidths at temperatures T below about 1.2 K. In a pioneering NSE experiment, Mezei obtained high-resolution measurements of roton widths down to 0.96 K [4]. Recent developments on the neutron backscattering spectrometer IN10 [5] at the Institut Laue-Langevin, Grenoble, have allowed access to the Q,ω range of the roton minimum with very high (<1 meV) energy resolution, thereby extending the range of measured roton parameters to lower temperatures.

Examples of the measured raw spectra from neutron scattering are shown in Fig. 2 [6]. It may be noted that when the intrinsic peak width is small compared to the energy resolution, the peaks are asymmetric with a shoulder on the larger neutron energy loss side. This peak shape was modelled on the premise that it resulted from the finite-Q resolution sampling $S(Q,\omega)$ around the parabolic roton minimum. The intrinsic lineshape was described by a Lorentzian and the extracted roton width and energies are plotted in Fig. 3 as a function of the temperature.

The fitted roton widths in Fig. 3a are seen to be in excellent agreement with the predictions of Bedell *et al.* and the NSE measurements of Mezei. It is clear from the magnitude of the error bars that the present measurements constitute a significant improvement on those of Mezei, expanding the range of reliable measurement of the roton width by an order of magnitude. However, the temperature dependence of the roton energy clearly disagrees with the predictions of Bedell *et al.* The measured roton energy changes much more slowly with temperature than expected. The rather good agreement between theory and experiment previously shown by the NSE technique [4] is seen to break down at temperatures below 1.2 K, while the theory is expected to work best in the $T \rightarrow 0$ limit.

The origin of this behaviour is not understood at present and will require further study. There may be temperature-dependent mechanisms such as multiphonon effects that play a role in determining the roton energy but do not directly affect the temperature dependence of the roton lifetime [7]. Alternatively, the roton lineshape may not be Lorentzian, but intrinsically asymmetric [P. Nozières, private communication], which would shift the roton energy away from the centre of gravity of the peak.

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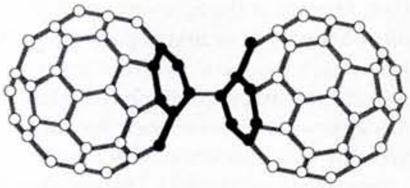
C_{60} Discovery Written in Molecules

The 1996 Nobel Prize in Chemistry has been awarded to R.F. Curl, Jr., and R.E. Smalley of Rice University, Houston, USA, and to H.W. Kroto, University of Sussex, UK, for their discovery of fullerenes. Laszlo Forro from the Ecole Polytechnique Fédérale, Lausanne, who chaired the *Fullerenes and Naonotubes* symposium at the *EPS-10 General Conference* (Sevilla; 9–13 September 1996) reports that the latest developments highlighted at the symposium illustrated perfectly the versatility of these remarkable materials.

Following the discovery of high-temperature superconductivity in doped fullerenes, the latest excitement in fullerene chemistry research is coming from structures based on the intermolecular bonding of the C_{60} spheres to form C_{60} dimers, one-dimensional polymers, two-dimensional networks, high-pressure polymerized phases, *etc.* Many of the bonded C_{60} structures can be produced using a high-temperature, high-pressure treatment. S. Buga (Institute for Superhard Materials, Moscow) showed at the EPS-10 symposium *Fullerenes and Naonotubes* a fascinating pressure-temperature phase diagram of fullerenes, ranging from soft C_{60} to structures "harder" than diamond. Application of these materials is foreseen.

A second major development is chemical modification of the C_{60} cage by, for instance, replacing a carbon atom with nitrogen (synthesized by F. Wudl, Santa Barbara, CA). This leads to a new family of compounds, called azafullerenes, which are charged, very reactive and might lie at the origin of a whole class of new fullerene-derivatives. W. Andreoni (IBM, Zurich), who is one of the leading theorists in this field, gave a talk on the electronic structure and the unconventional bonding in azafullerenes. The most interesting molecule is the $(C_{59}N)_2$ dimer, which seems to have the same structure as the



Local bonding in an azafullerene dimer molecule maps out "96", the year azafullerenes were discovered.

$(RbC_{60})_2$ dimer. The structural refinements of this latter compound, which may present a prototype for a whole class of C_{60} dimers, were illustrated by G. Oszlanyi (Central Research Institute for Physics, Budapest). The local bonding structure in the dimer resembles the number "96" (see figure), prompting Oszlanyi to joke that the date of the discovery of this new type of molecule was inherently written in the molecule itself.

The exceptionally good electron field-emitting characteristics of C_{60} nanotubes make them potentially very attractive for applications in devices such as displays, for example. W.A. de Heer (EPF, Lausanne) demonstrated how his group has developed a method of purifying and aligning carbon nanotubes in a thin-film form. They have also performed a wide variety of different types of physical measurements (transport, magnetotransport, magnetism, electron spectroscopy, *etc.*).