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Report on the Doctoral Thesis, "Investigation of cryogenic helium flows using mechanical oscillators" by David Schmoranzer.

This thesis concerns various aspects of quantum turbulence which is a currently rapidly expanding field. To put the subject matter into context, in quantum turbulence in the zero temperature limit where there is no normal fluid, the turbulent motion comprises an assembly of singly-quantized vortices. This is a very simple system in contrast to turbulent motion in classical fluids where, although we can attempt to describe the motion in terms of vortices, the vortices have no restrictions on amplitude and the system is really too complex to characterize in this way. In consequence the conceptually simpler quantum turbulence may offer insights into the classical situation, with all its universal applicability. It is thus a subject with potentially wide and general implications.

The thesis itself begins with a very thorough scene-setting introduction to superfluidity

Then follows the main experimental body of the work which is divided into four main themes; first a series of experiments on the behaviour of oscillating objects in classical fluids, including a very nice section on visualization where the effects of a number of parameters, size, roughness etc. on the transition to turbulence are investigated.

Chapter 3 on the transition to turbulence in superfluid ^{4}He addresses the problem of modelling the effects of turbulence on oscillating objects. This is made much more complicated by the existence of the two effective fluids, the superfluid and the normal fluid and how these are coupled together to present an effective kinematic viscosity. A phenomenological model is presented as a yardstick for categorizing the behaviour. The model is compared with a wide series of measurements and is found to follow the observed behaviour rather well.

For many years oscillating systems have been used for probing the behaviour of superfluids, especially superfluid ^{3}He. Such devices are used as thermometers, vorticity generators and detectors and in-liquid heaters, and have become universal tools in the field. The vibrating wire has been for many years been the mainstay device used, but this suffers from three main drawbacks; the geometry is not simple, the size of the moving parts are relatively large (of order millimetres) and the frequency is relatively low. Over the last few years, to overcome at least some of these drawbacks, miniature quartz tuning-fork devices have been employed in the same way. These are readily available commercially as providing frequency standards; they are much smaller and oscillate at much higher frequencies. Unfortunately the geometry is even more complex than that of the systems replaced. However, the advantages are so great that we need these devices and thus we need to know how they work. Chapter 4 provides a major contribution to this knowledge with a very thorough study of the acoustic emission by quartz tuning forks and how this contributes to the mechanical damping of the devices. The data of Figure 4.3 shows the damping of a quartz resonator as a function of changing temperature and pressure. Overlaid on this we see any number of acoustic emission peaks corresponding to acoustic resonances in the surrounding liquid. This means that the simple damping of the oscillator cannot be used as a measurement parameter without attention being paid to the emission properties.

The final work discussed is the combined Prague-Helsinki measurement of the Andreev reflection of a quasiparticle flux from an ordered array of rectilinear vortices in a rotating superfluid. The experiment makes use of the fact that when an excitation is reflected by an Andreev process the return trajectory virtually retraces the incoming path. Thus in a box with a small orifice (in this case the box containing an array of vortices) excitations entering the box are either reflected by normal processes which leads to their being trapped in the box, or by Andreev processes on the flow fields around the vortices which retroreflects them back out through the hole by which they entered. The system thus distinguishes between those excitations reflected by the two different processes and this can be used to "image" the vortex lattice inside the enclosed volume. The measurements are made as a function of rotation velocity in the Helsinki rotating cryostat, and the Andreev reflection fraction gives a convincingly good measure of the vortex density (which of course increases with rotation speed). This is an interesting "textbook" measurement and, bearing in mind that it must be done in a rotating cryostat at temperatures of a hundred microkelvin or more, it also indicates a high level of technical virtuosity.

The thesis covers a wide portmanteau of experiments embracing many aspects of oscillators in superfluids and shows a high level of originality in the devising, implementation and analysis of the various experiments. This is an excellent piece of work and in comparison with international standards well merits the award of a doctorate.

I should also say that the quality of the English in the thesis is of a very high level and that the whole thing was a pleasure to read. If only my native-speaking students could write so well in their own language.

There are two questions I would put to the candidate regarding this work.

First, in chapter 5 where the Andreev measurement is discussed, on page 71 figure 5.2 illustrates the experimental setup (also shown in the figure on page 147). Can the candidate explain how the influence of the vortices in the upper volume can be ignored in making the Andreev reflection measurement?

Secondly, if acoustic emission can be a predominant energy-loss mechanism in tuning forks moving in superfluids as implied by figure 4.3 on page 67, what precautions would the candidate suggest should be taken to allow these devices to be used in the "conventional" way for measuring (non-acoustic) damping?

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