other processors also perform an addition operation (which might be a dummy). Although this 'lock-step' characteristic appears very restrictive, most user experience has shown that such lock-step processor arrays are highly flexible. Processor arrays and vector processors are often called single instruction multiple datastream (SIMD) processors, as a single instruction produces many results.

It is generally accepted that a collection of processors that did not have to work in lock-step fashion would be more flexible than a SIMD system. Therefore, there are many attempts to develop multiple instruction datastream (MIMD) systems, mainly as part of programmes such as fifth generation ALVEY and ESPRIT. One of the dreams of computer scientists is the ideal MIMD computer with the following properties: it supports a programming methodology that does not need to know how many computers are in the system; it can double in performance if the number

of computers is doubled; and it automatically rejects any failing computer yet continues to work.

The production of computers with these desirable properties is a major research target. Nearly every day there is a new proposal for a computer architecture system which its designers claim will meet the aims. Many one-off experimental systems exist in universities, but none seem to have gained external acceptance. There is, perhaps, an analogy between the programmes to build an ideal MIMD system and that to build an operational fusion power generation plant. Everyone agrees that it would be a good thing to do, lots of money is being thrown at the problem, but nobody has yet shown that it can be done. However, interesting things are happening — watch this space! □

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Quantum fluid dynamics

Instabilities at absolute zero

from K. W. Schwarz

ILLUSTRATIONS of flow around a sphere are a seemingly essential part of every textbook on fluid dynamics. At low velocities, the fluid is seen to make its way smoothly past the sphere. The nonlinear nature of flow phenomena, however, becomes spectacularly evident at higher velocities, with the appearance of a vortex ring (similar to a smoke ring) in the wake of the sphere. At still higher velocities, the ring is intermittently shed into the fluid, leading eventually to completely turbulent flow behind the sphere. McClintock, Bowley and colleagues, on page 797 of this issue¹, examine the quantum mechanical analogue of this venerable problem. In the latest in a series of remarkably elegant experiments, using electrons injected into liquid helium to form bubbles, they find, unexpectedly, that when a bubble is pulled very quickly through the fluid a stream of microscopic quantized vortex rings is generated. The similarity to classical flow around a sphere is both striking and aesthetically satisfying, and it should help us understand better the appearance of instabilities in quantum fluids, such as ⁴He.

Helium-4 remains liquid down to absolute zero. In this limit, it obeys the laws of quantum mechanics, which operate on a macroscopic scale under such conditions. The rules governing the motion of this 'superfluid' are therefore very different from those of classical fluid dynamics, and are still only imperfectly understood. Two kinds of excitations are known to be possible in superfluid ⁴He: vibrational excitations, somewhat analogous to sound waves, and flow excitations in the form of quantized vortex lines. The latter are

essentially localized microscopic whirlpools, the fluid circulating rapidly around a central line about 0.1 nm thick, with the velocity dropping off away from the core. Such quantized vortex lines can exist as arbitrarily configured continuous curves in the fluid, either as segments which terminate on boundaries, or as free-floating loops and rings. Once there, they obey the laws of classical fluid dynamics. What is not understood is how they arise in the first place as an instability of quantum flow. Thus it is of the utmost interest to study how 'superflow' past a simple object such as a sphere becomes unstable.

To carry out their experiments the authors make use of the well-established fact that an excess electron injected into liquid helium forms a well-defined spherical bubble with a radius of about 1.5 nm. Such electron bubbles can be accelerated through the superfluid by applying an electric field, and their motion can be detected as a current. Since the movement of such a structure displaces thousands of helium atoms, the flow around it can be thought of as macroscopic. Yet, the dimensions of the bubbles are so small that any quantum instability that occurs can be expected to involve individual excitations of the kind described above. Earlier investigations^{2,3} had in fact established that, depending on the pressure, a rapidly moving electron bubble will either create a single vortex ring to which it remains attached, or it will emit a continuous stream of vibrational excitations. Thus, depending on circumstances, instability with respect to either type of possible excitation was known to occur.

Although they have also made major contributions to our knowledge of the vibrational-excitation instability⁴, McClintock, Bowley and coworkers have more recently concentrated on the situation where the flow around the bubble becomes unstable leading to the creation of quantized vortex rings, a situation that appears to more closely resemble the classical problem. By doing experiments in isotopically pure ⁴He at sufficiently low temperatures, the scattering of thermal vibrations by the moving bubble becomes rare, so they have been able to study the problem in its purest form. That is, they can look at what happens as the bubble is pulled more and more forcefully through the zero-temperature superfluid. They find that initially the bubble accelerates exactly as would a sphere moving through an ideally frictionless classical fluid⁵. When a critical velocity is reached, a quantized vortex ring attached to the sphere is created. The unexpected result of their latest experiment¹ is that, when a very large field is applied to pull the bubble through the fluid very quickly, a continuous stream of vortex rings is emitted by the moving bubble.

These latest results promise to lead to new insights into the nature of quantized-vortex creation. At present, not much is understood theoretically about this process. An early calculation by Schwarz and Jang⁶ demonstrated that the critical velocity is determined by the instantaneous application of energy and momentum conservation, implying that the vortex appears as the result of a sudden quantum transition. This point of view appears to be generally accepted today and much more ambitious models have recently been proposed^{8,9}. The subject, however, is controversial, and in particular the very basic issue of defining the configuration in which the quantized vortex first appears remains under debate. By comparing experimental results of the kind reported here against hydrodynamic calculations using various starting geometries for the vortices, it may now be possible to determine this initial configuration. Prospects for attaining this milestone seem encouraging, although a great deal more theoretical and experimental effort will be required. □

1. Nancolas, G.C., Ellis, T., McClintock, P.V.E. & Bowley, R.M. *Nature* **316**, 797 (1985).
2. Reif, F. & Meyer, L. *Phys. Rev.* **123**, 1164 (1960).
3. Rayfield, G.W. & Reif, F. *Phys. Rev.* **136**, 1194 (1984).
4. Ellis, T., McClintock, P.V.E., Bowley, R.M. & Allum, D.R. *Phil. Trans. R. Soc. A* **296**, 581 (1980).
5. Ellis, T., McClintock, P.V.E. & Bowley, R.M. *J. Phys. C* **16**, L485 (1983).
6. Bowley, R.M., McClintock, P.V.E., Moss, F.E., Nancolas, G.G. & Stamp, P.C.E. *Phil. Trans. R. Soc. A* **307**, 201 (1982).
7. Schwarz, K.W. & Jang, P.S. *Phys. Rev. A* **8**, 3199 (1973).
8. Bowley, R.M. *J. Phys. C* **17**, 595 (1984).
9. Muirhead, C.M., Vinen, W.F. & Donnelly, R.J. *Phil. Trans. R. Soc. A* **311**, 433 (1984).

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