FLUID DYNAMICS

Lord Kelvin's vortex rings

Linking two smoke rings or tying a single ring into a knot is no easy feat. Such topological vortices are now created in water with the aid of specially printed hydrofoils.

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Turbulence and vortices are everyday occurrences we have all experienced — from gusty winds on a street corner to distinctive sudden shaking during air travel. Vortex rings are a related phenomenon that are also familiar: visible in the clouds under a meteorological microburst and in a smoker's exhale (although such smoke rings are more healthily created using a simple cannon comprising only a drum with a circular hole in its end). Such vortical structures also play a fundamental role in fluid dynamics and have been subjects of intense study since the days of Lord Kelvin. However, laboratory studies so far have been limited to studying isolated or colliding rings. Dustin Kleckner and William Irvine have now gone beyond such simple systems by creating knotted and linked vortices, as they describe in *Nature Physics*[1].

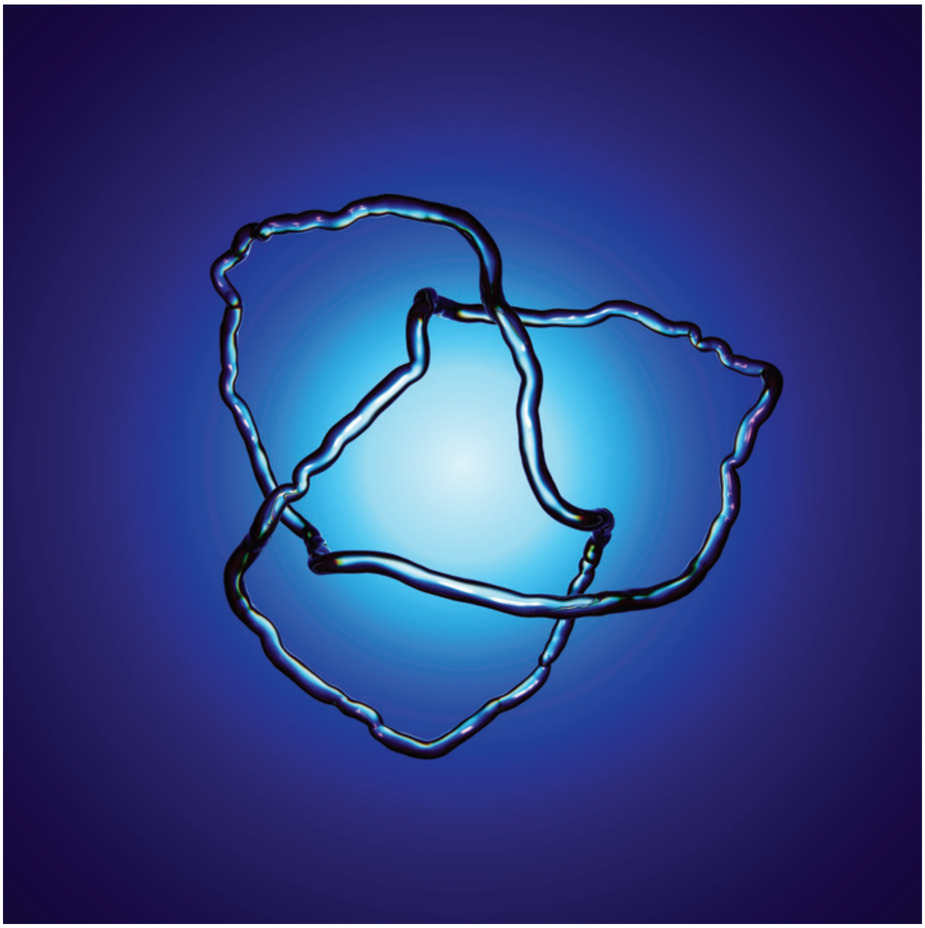
A vortex ring is simply described as a tornado that has been bent into a closed loop. Whereas this example occurs in air, vortex rings also exist in water, plasmas and quantum fluids (superfluids)[2]. Ideal vortices, for which vorticity occurs only in the core, are a convenient tool for analysing flows with limited viscous effects. Notably, they dominate the dynamics of superfluid helium flows and quantum-fluid Bose–Einstein condensates. For line-like vortex cores, topology describes the key properties of connectedness and continuity under deformations like stretching or twisting. As such, research into topological fluid dynamics[3,4] aims to better understand turbulence in fluids and plasmas.

Kleckner and Irvine have now reached beyond simple smoke rings and ideal vortices to produce more topologically complicated linked and knotted rings. The physics of linked vortices is much richer that that of single vortices: they will, for example, influence each other, generally making particle paths helical. The results also address some outstanding issues about topology change in vortex systems. Can vortices unknot, and if so how? Does unknotting, which is a change of topology, cause significant stress on the system? The initial answers here are: yes, they do unknot, and yes, this does cause a stressful wrinkling of the vortices.

But how did the team create these complex structures, a feat that has evaded us for a century? They realized that a three-dimensional printer could form airfoils capable of launching knotted vortices; a brilliant linking of newly available technology with outstanding research issues. As this is an early use of 3D technology in fluid mechanics, we might expect other applications and science to emerge from this marriage. Imagine 3D printed and automated fish or dragonflies for future studies!

These vortex observations are also relevant to other research communities: topology and topological change are critical in a broad range of physical systems. Line-like topological foci appear in a surprisingly large range of phenomena: type-II superconductors, superfluid vortices, dislocations in crystal plasticity, and magnetic helicity[5] and reconnection in plasmas[6] — as occurs in the solar corona and the Earth's magnetosphere. Examining the excellent imagery of solar coronal dynamics, one can easily imagine that the topology of the magnetized plasma plays an important role. Many current quantum-field-theory candidates also have topological solutions; cosmic strings are one example.

The work of Lord Kelvin informs much of our current knowledge on thermodynamics, but he also contributed important early ideas about electrodynamics and the dynamics of vortices. He would have been keenly interested in the current work. In fact, Kelvin waves are now understood to be the main disturbances on a long, straight vortex. These transverse helical waves are clearly seen in tornadoes, or



An example of a trefoil knotted vortex ring. Image provided by Dustin Kleckner and William T. M. Irvine even in your local science museum's tornado vortex demonstrations. Lord Kelvin further proposed that elementary particles were associated with the phenomenon of linked vortex rings, but this idea was dropped after the Michelson–Morley experiments disproved the idea of an electromagnetic ether as a transmission medium for light.

Here is the twist on Lord Kelvin's legacy: the Higgs mechanism, long embraced in the standard model, endows the vacuum with at least one relativistic field — which has properties similar to a superconductor or superfluid. There is an ether; so the discredit of Lord Kelvin's notion was perhaps premature. Ask your favourite high-energy theorist this question: how many Higgs fields are part of the vacuum? Each of those may or may not have topological defects depending on the order (symmetry) of the fields.

And a final puzzle: how much of the stability of the known elementary particles is topological in nature? How much of the turbulence in plasmas and fluids is topological in nature? The scientific community is not settled on these questions. Studying vortex rings and knotted vortex rings may well be important in finding a final answer. ❒

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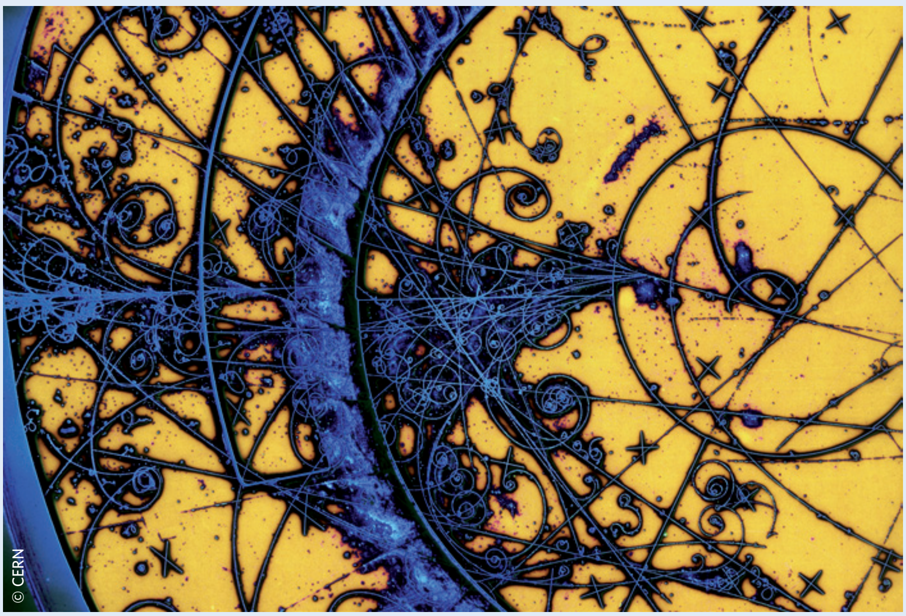
Brilliant bubbles

They are some of the most beautiful, iconic images in particle physics, indeed in all of physics: the curling tracks of subatomic particles photographed as their ionization energy causes a trail of bubbles to nucleate in a body of superheated liquid.

The bubble chamber was invented in 1952 by Donald Glaser, who had studied for his doctorate at the Californian Institute of Technology under Carl Anderson, discoverer of the positron. Particle physicists were then facing the challenge of understanding the 'strange particles' that had been spotted in cloud-chamber tracks of cosmic rays in the late 1940s, and also of improving particle detection capabilities to match the new accelerator technology — synchrotrons that could accelerate protons to energies of a few gigaelectronvolts. Something bigger than a cloud chamber, and with a faster cycling time, was needed.

Glaser calculated that the thermal instability of a superheated liquid could be exploited to make a high-density, large-volume detector, such that energetic particles passing through would cause a trail of vapour bubbles large enough to be captured photographically and from which the particle trajectories could be determined accurately. Some of his early laboratory investigations of bubbling liquids apparently involved bottles of beer and ginger ale, but the first serious experiments were performed using diethyl ether.



Glaser's 15-cm propane-filled prototype became the first bubble chamber to be used for high-energy physics, at the 'Cosmotron', a proton synchrotron at Brookhaven National Laboratory. Soon, laboratories around the world were building bubble chambers, of ever increasing size and often filled with liquid hydrogen for optimum performance. And the data — on types of particle, their masses, spins, lifetimes and so on — flooded in. In 1973, from the freon-filled bubble chamber Gargamelle, at CERN, came the first evidence of the weak neutral current: a crucial step in understanding the relation of the electromagnetic and weak forces, leading later to the discovery of the W and Z bosons.

This famous image was recorded by the Big European Bubble Chamber (BEBC) — one of its 6.3 million photographs recorded between 1973 and 1984, on 3,000 km of film, pored over by 600 scientists from 50 laboratories. BEBC was filled with 35 m^3 of liquid (hydrogen, deuterium or a neon-hydrogen mixture) whose pressure was regulated using a 2-tonne piston. (BEBC, its piston and Gargamelle are all on display at CERN.)

Ultimately, the bubble chamber was superseded by technology capable of electronic, rather than photographic, data read-out — the wire chamber, in particular. Having carried off the 1960 Nobel Prize in physics for his invention of the bubble chamber, Glaser moved on to a research career in molecular biology, and then later in neurobiology. He died on 28 February 2013.

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