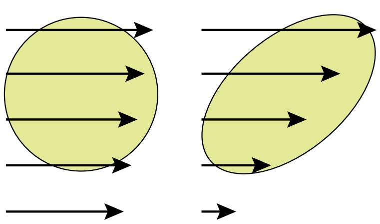
Stirring Up an Elastic Fluid

Critical Viscosity of Xenon–2 (CVX–2)

Whipped cream stays in place even when turned upside down. Yet it readily flows through the nozzle of a spray can to reach the dessert plate. This demonstrates the phenomenon of shear thinning that is important to many industrial and physical processes. Paints, film emulsions, and other complex solutions that are highly viscous under normal conditions but become thin and flow easily under shear forces.

Whipped cream and the filling for pumpkin pie are two familiar materials that exhibit the shear-thinning effect seen in a range of industrial applications. It is thick enough to stand on its own atop a piece of pie, yet flows readily when pushed through a tube. Shear thinning will cause a normally viscous fluid (below) to deform and flow more readily under high shear conditions.

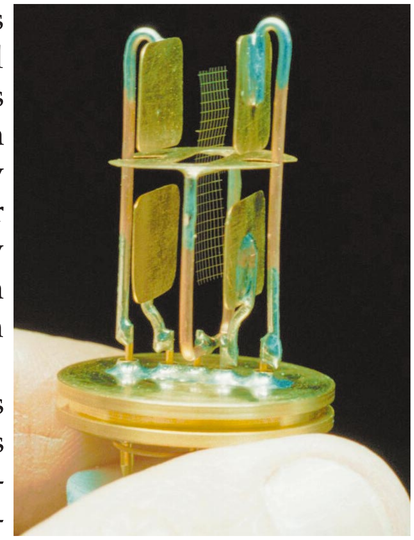


A simple fluid, such as water, does not exhibit shear thinning under normal conditions. Very close to the liquid-vapor critical point, where the distinction between liquid and vapor disappears, the fluid becomes more complex and is predicted to display shear thinning. At the critical point, xenon atoms interact over long distances in a classical model of cooperative phenomena. Physicists rely on this system to learn how long-range order arises.

The Critical Viscosity of Xenon Experiment (CVX–2) will measure the viscous behavior of xenon, a heavy inert gas used in flash lamps and ion rocket engines, at its critical point. Although it does not easily combine with other chemicals, its viscosity at the critical point can be used as a model for a range of fluids.

Viscosity originates from the interactions of individual molecules. It is so complicated that, except for the simplest gas, it cannot be calculated accurately from theory. Tests with critical fluids can provide key data, but are limited on Earth because critical fluids are highly compressed by gravity. CVX–2 employs a tiny metal screen vibrating between two electrodes in a bath of critical xenon. The vibrations and how they dampen are used to measure viscosity.

CVX flew on STS–85 (1997), where it revealed that, close to the critical point, the xenon is partly elastic: it can "stretch" as well as flow. For STS–107, the hardware has been enhanced to determine if critical xenon is a shear-thinning fluid.



Resembling a bit of window screen, the oscillator at the heart of CVX–2 will vibrate between paddle-like

Applications

Understanding shear thinning in a simple fluid such as xenon may help scientists understand more complex, industrially important fluids, such as:

- Paints, emulsions, and foams
- Polymer melts
- Pharmaceutical, food, and cosmetic products.

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Affected Fields

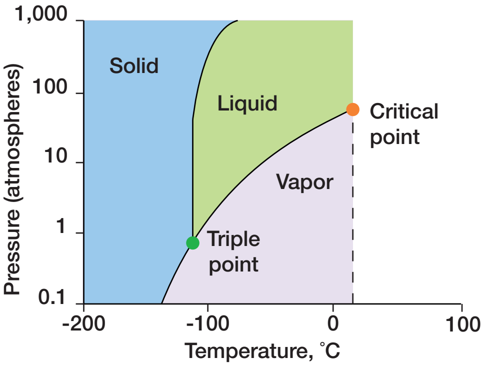
Hydrodynamics: Nonlinear response to oscillatory flows of moderate amplitude.

Physics: Universal behavior of pure fluids at the liquid-vapor critical point.

Background Information

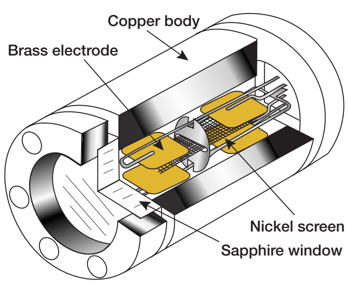
Science

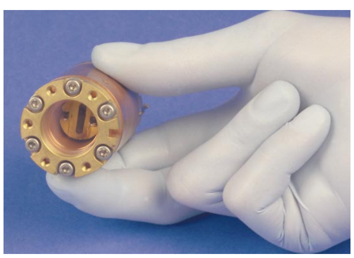
Viscosity — the "thickness" of fluids — is determined by complex interactions between molecules. Except for low density helium, fluid viscosity cannot be predicted accurately by current theory. Progress is being made with experiments using simple fluids near their critical points, a combination of pressure and temperature at which a fluid is balanced between the liquid and gaseous states. This causes the fluid to fluctuate spontaneously between liquid and gas at a microscopic scale. It is somewhat like a soft drink with carbonation bubbling in and out.



Different combinations of temperature and pressure will change the xenon's phase, or allow two or three phases to exist simultaneously.

Experiments on Earth are highly limited. At 0.001 ˚C above its critical temperature (T_c), xenon (a heavy, inert gas) is 6,000 times more compressible than air. Even a fluid layer as thin as a dime (1mm) compresses under its own weight. Experiments in the microgravity of orbit eliminate density differences and allow extended experiments to achieve the precision that scientists need.



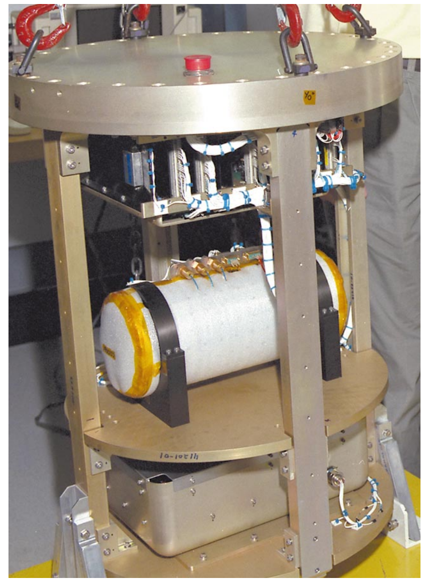


The sample cell (top) at the heart of CVX comprises a copper body (above) that conducts heat efficiently and smooths out thermal variations that would destroy the xenon's uniformity. The cell sits inside a thermostat (bottom) providing three layers of insulation.

Flight Research Equipment

The heart of CVX–2 is a nickel screen that vibrates between two pairs of brass electrodes in a xenon bath. The grid is 7 × 19 mm (0.28 × 0.74 in) and weighs less than 1 mg. An electrode is positioned 4 mm (0.16 in) to each side of the screen. An electrical charge applied by the electrodes will oscillate the screen. The electrodes measure the screen's displacement and period, like a pendulum swinging in a liquid. The cell holds a small quantity of xenon near its critical temperature (T_c=16.6 °C, or 62 °F) and critical density (1.1 times that of water) at 58 atmospheres, equivalent to a depth under water of almost 0.6 kilometer (1,914 ft).

The experiment plan involves four "sweeps" as the temperature gently moves up and down through T_c while the screen oscillates and data are continuously recorded. CVX–2 will determine T_c to within 0.001 °C. These first results will be compared to those from CVX.



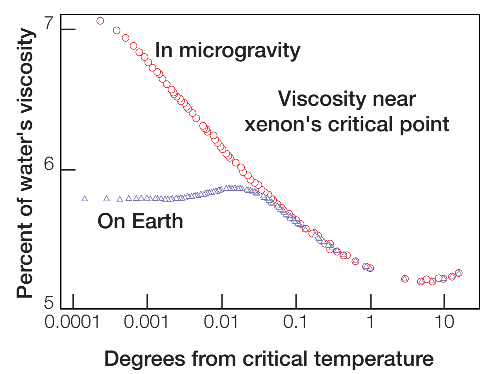
The thermostat for CVX sits inside the white cylinder on a support structure that is placed inside a pressure canister. A similar canister holds the electronics and control systems. The CVX–2 arrangement is identical.

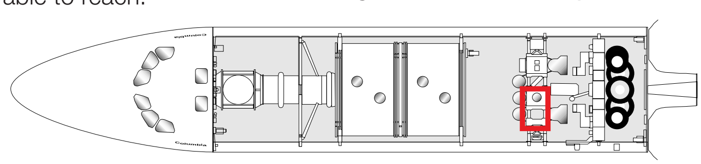
On CVX, the screen oscillated at less than 13 cycles per second (13 Hz) through a distance of less than 0.01 mm, less than the thickness of a hair, to avoid disrupting the density fluctuations in the xenon. On CVX–2, the screen vibrates at up to 25 Hz and amplitudes of 0.3 mm in a deliberate attempt to disrupt the density fluctuations and cause shear thinning.

Previous Results

CVX operated well on its first flight on STS–85 in 1997. It accurately measured the viscosity of xenon to within 0.0001 °C of T_c and showed a viscosity increase of 37 percent, double the best measurements on Earth. CVX also showed that xenon's viscoelastic response (a partly elastic response to shear stress) was twice as great as predicted by theory. The results were published in two journals, *Physical Review Letters* [**82**, 920 (1999)] and *Physical Review E* [**60**, 4079 (1999)].

Because xenon near the critical point will compress under its own weight, experiments on Earth (blue line) are limited as they near the critical point (to the left). In the microgravity (red line), CVX moved into new territory that scientists had not been able to reach.





Approximate location of this payload aboard STS–107.

Photos. NASA, National Institute of Standards and Technology.

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