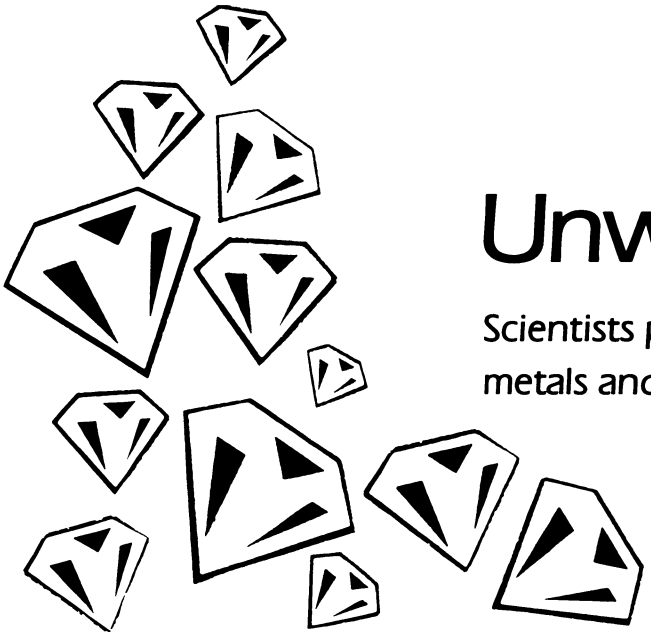


Unworldly Pressures

Scientists put the supersqueeze on gases, metals and minerals

By IVAN AMATO

By squishing materials in the clenched jaws of a diamond vise, scientists are striving to achieve the ultimate tight squeeze. In so doing, at least one team may have pinched a new record for the largest pressures ever sustained in a laboratory — supersqueezes so intense that they apparently exceed even the colossal pressures exerted at the center of the Earth.

Attaining these exotically high pressures in the lab enables geophysicists to mimic conditions deep within the Earth and other planets, and provides physicists with valuable experimental checks on theories about atomic and molecular behavior.

In the December 1990 Review of Scientific Instruments, researchers at Cornell University report squeezing a microscopic sample of molybdenum powder to a pressure of 4.16 million bars (megabars). Earth's atmosphere exerts approximately 1 bar; the planet's center exerts an estimated 3.61 megabars. The Cornell team, led by materials scientist Arthur L. Ruoff, also reports squeezing tungsten and other samples to somewhat lower pressures.

The 4.16-megabar squeeze probably represents a world record, Ruoff told Science News. Then again, it may only approach record status. The answer depends on which big-squeeze researchers you talk to and how they choose to calibrate such huge pressures.

In 1986, a research team headed by Ho-kwang Mao at the Carnegie Institution of Washington (D.C.) and a separate group led by William C. Moss at Lawrence Livermore (Calif.) National Laboratory reported measuring 5.5- and 4.6-megabar pressures in their diamond vises, also known as diamond anvil cells. Those values depend on a calibration method involving the laser-induced fluorescence emitted by tiny ruby crystals squeezed within the anvil, a method Ruoff considers suspect at pressures above 1.8 megabars.

Mao readily acknowledges that the ruby fluorescence technique harbors uncertainties, but he points out that Ruoff's calibration method has limitations of its own. "To claim that their pressures are definitely higher than anybody else's, or that the ruby fluorescence technique is inadequate, is premature," Mao says.

To be sure, no simple barometer exists for ultrahigh pressures. Researchers instead must rely on physical inferences and mathematical extrapolations that are based on more readily measurable properties of the materials under pressure. Debates about the merits and pitfalls of different calibration methods are endemic to high-pressure research.

Technical uncertainties notwithstanding, high-pressure scientists are observing gases, metals and minerals under conditions never before produced in laboratories, or perhaps anywhere else on the planet. For instance, Mao and his coworkers have been squeezing hydrogen gas so tightly that it reorganizes into a solid and displays hints that it might even become a metal — maybe even a superconducting metal, according to calculations by others. At last December's meeting of the American Geophysical Union in San Francisco, Mao reported data from several studies on iron hydride, which he says may be the most abundant material in Earth's core. He also described experiments in which his team pressed graphite into a new molecular arrangement — one apparently strong enough to break the anvil. Each diamond jaw can cost as much as $1,500, Ruoff notes.

The Cornell researchers, too, have uncovered strange material effects in their supersqueeze experiments. They find, for example, that extreme pressures dramatically distort the normal cubic arrangement of carbon atoms in the anvil's diamond, squashing the atoms into a highly strained structure. This "surprising" distortion, says Ruoff, shows up as a colorful effect called birefringence, in which light bends at different angles as it passes through the stressed material.

The Cornell team has also pulled off an offbeat sort of alchemy. Under megabar pressures, samples of zirconium and hafnium — so-called rare earth or transition metal elements — show substantial changes in shape and chemical character. Their crystal structures and the arrangement of their valence electrons (the ones that participate in chemical bonds) reshuffle, Ruoff says, to match those of the unstressed elements in the column to the right on the periodic table — namely, niobium and tantalum.

"When you press things really hard, you change the distances between their atoms," he explains. Since the Cornell researchers can maintain multimegabar pressures for weeks in their diamond anvil cells, they can precisely determine these interatomic distances with X-ray crystallography. But since their samples are small — about the size of a mist particle — they need an especially bright source of X-rays. The Cornell High-Energy Synchrotron Source fills the bill, shining an intense X-ray beam through the anvil's diamond jaws, which conveniently double as observation windows.

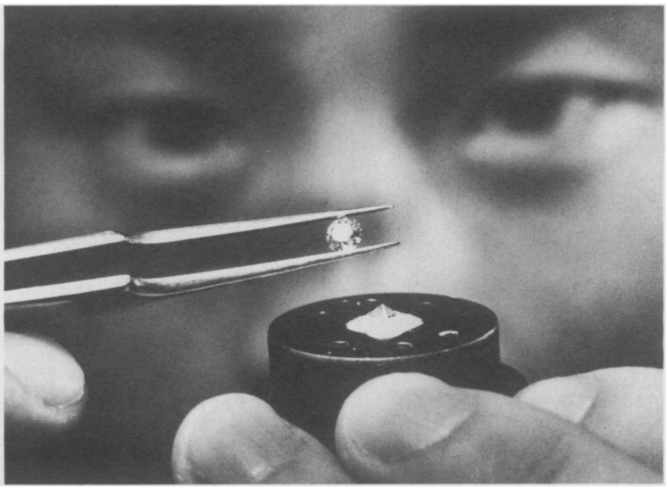
Crystallography alone cannot furnish a quantitative measure of pressure. Researchers must also apply some physical chemistry and mathematics in the form of "equations of state" — formulas expressing the relationship among a material's temperature, pressure and volume. Only the volume data come directly from crystallography studies.

The Cornell crew uses a specific equation derived by other investigators who performed "shock experiments," in which explosions or high-speed impacts squeeze targets such as tungsten pellets to enormous pressures (up to tens of megabars or more), but only for a few millionths of a second. The velocity of sound waves emerging from these shocks provides information about the target's properties, such as stiffness. This, in turn, serves as an indicator of the pressure on the shocked target material.

Mao warns that minute geometric irregularities in these targets might easily yield complex acoustic signals that could introduce an error of as much as 0.5 megabar into subsequent pressure calculations based on the shock experiments.

Ruoff acknowledges this possibility, but he claims that at higher pressures, the ruby fluorescence calibration used by the Carnegie and Livermore groups suffers from more troublesome uncertainties. Above 1.8 megabars, he says, the ruby fluorescence signal fades and disappears, and a second fluorescence signal then appears. Mao and others interpret that signal as coming from the ruby at higher pressures, but Ruoff remains unconvinced.

"A lot of things could have happened" during the ruby fluorescence "blackout," he says. Thus, the assumption that the same fluorescence-pressure relation holds both before the ruby fluorescence dims and after the second fluorescence appears is shaky at best, Ruoff contends. The tiny ruby crystals may have undergone a change in crystal structures, or the increased pressure may have induced unanticipated fluorescence from the diamond, he suggests.


Ruoff, Xia, et al.

Between these $1,500 diamond jaws, Cornell scientists produced what they consider the highest sustained pressures ever achieved in a lab.

Mao counters that the ruby's fluorescence never completely disappears, but instead becomes very faint as a stronger fluorescence from the diamond temporarily competes with it.

That's still not enough for Ruoff. In August 1988, he and colleagues reported observing diamond fluorescence at about 2.5 megabars, which he thinks could have misled Mao's group to calculate a 5.5-megabar pressure. Similar subtleties may have led Moss' team at Livermore to measure 4.6 megabars in their vise, he adds. If Ruoff is right, then the recent 4.16-megabar reading at Cornell might indeed mark a record high.

The potential pitfalls of both calibration methods place pressure investigators between a rock and a hard place. "The high-pressure business is very tough," Ruoff says, and he gets no argument from Mao on that. But with much to learn about how materials cope in the big squeeze, the researchers intend to press on. ☐

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sants and microbial oil scavengers — to assist the Saudis, who will manage containment operations.

Kuwaiti oil also left its mark in the air last month, as fires on parts of the spill, coupled with oil fires in Kuwait, sent black smoke billowing into the atmosphere. While those blazes remained relatively small, scientists are debating the possible environmental effects of the huge conflagrations that could erupt if Iraq decided to burn hundreds of Kuwaiti oil wells in an act of desperation.

As a worst-case scenario, some researchers suggest that smoke from such fires could reduce rainfall over southeast Asia and could even cause unseasonal frosts as far away as the United States. Others deny the possibility of far-flung impacts, saying the fires could only affect regions close to Kuwait.

At a meeting in London last month, Richard P. Turco of the University of California, Los Angeles, assessed the potential for large-scale hemispheric effects. He and astronomer Carl Sagan of Cornell University have calculated that major fires in the Kuwaiti fields could burn several million barrels of oil daily, sending 50,000 tons of soot into the atmosphere each day for months. While the smoke would initially rise no higher than 1 or 2 kilometers, the black soot particles would absorb sunlight and could eventually move up to the middle troposphere, from which they would travel east with the prevailing winds. If the soot reached such altitudes, the region's dry climate could keep it in the atmosphere for several weeks.

To gauge the possible impact of such a cloud, Turco turns to the 1815 volcanic eruption of Tambora in Indonesia. Although volcanoes produce a very different type of cloud, the oil fires could lead to a comparable reduction in solar radiation over a vast portion of the Northern Hemisphere, Turco told SCIENCE NEWS. In the year following Tambora's eruption, parts of the United States and Europe suffered unseasonal crop-killing frosts, and Turco suggests a similar effect might accompany fires in Kuwait.

John Cox, an engineer who consults on safety at Persian Gulf oil installations, suggests another chilling scenario: The smoke cloud from more than 300 burning oil wells could cool India enough to prevent the summer monsoonal rainfall. The resulting crop failure would place hundreds of millions of people in jeopardy of starvation, he told scientists at the January meeting.

A particularly inconclusive report from the British Meteorological Office in Bracknell, based on computer simulations of oil-fire smoke, plays down these potential effects while not discounting them entirely. The report, issued Jan. 17, states: "Downwind of Kuwait, the obscuration of sunlight might significantly reduce the surface temperature locally. This in turn could locally reduce the rainfall over parts of southeast Asia during the period of the summer monsoon."

A relatively optimistic analysis comes from U.S. researchers who have run computer simulations of their own. Michael C. MacCracken of Lawrence Livermore (Calif.) National Laboratory found that the soot would have limited climate effects because it should fall out of the atmosphere much sooner than Turco and Sagan have suggested. MacCracken estimates the plume would rise less than 5 kilometers; from this value, the computer calculates that soot would stay in the atmosphere at most nine days.

Richard Small, a fire-effects expert at the Pacific-Sierra Research Corp. in Los Angeles, projects even shorter smoke plumes. In his computer simulations, the clouds from well fires rise only 1 kilometer, says Small, who reported these results to the Defense Department in early January. "While there's a very large amount of smoke, it's not large enough to have climate effects," he told SCIENCE NEWS. By the time the smoke reached India, it would reduce solar radiation by only 5 percent — not enough to significantly affect rainfall there, he says.

— J. Raloff and R. Monastersky