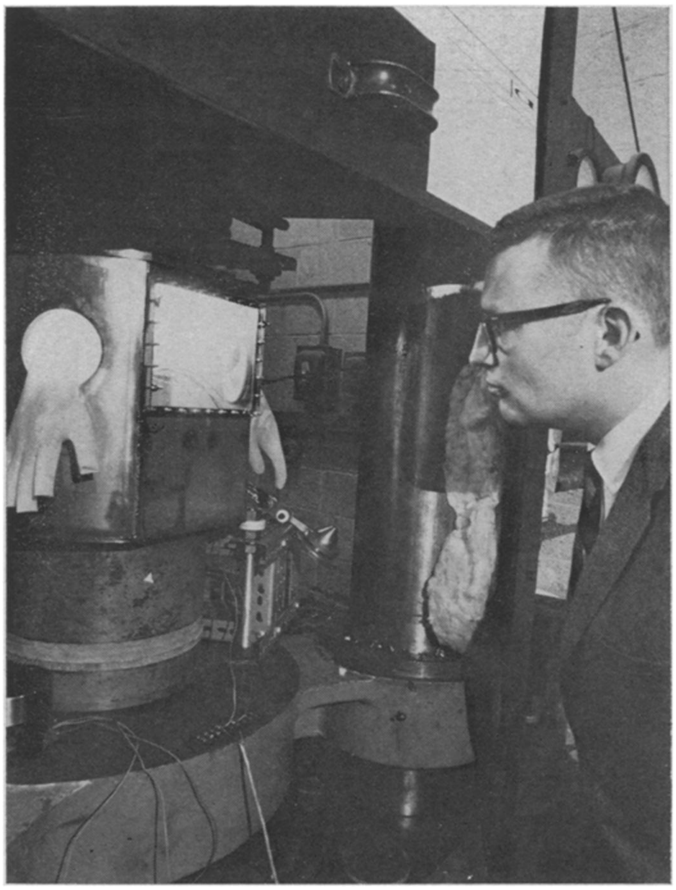


Cornell Univ.

Ruoff: Pressures near those at the earth's center.

The making of metallic hydrogen

Researchers are closing in on a theoretical form of hydrogen at pressures approaching those at the earth's center

by Edward Gross

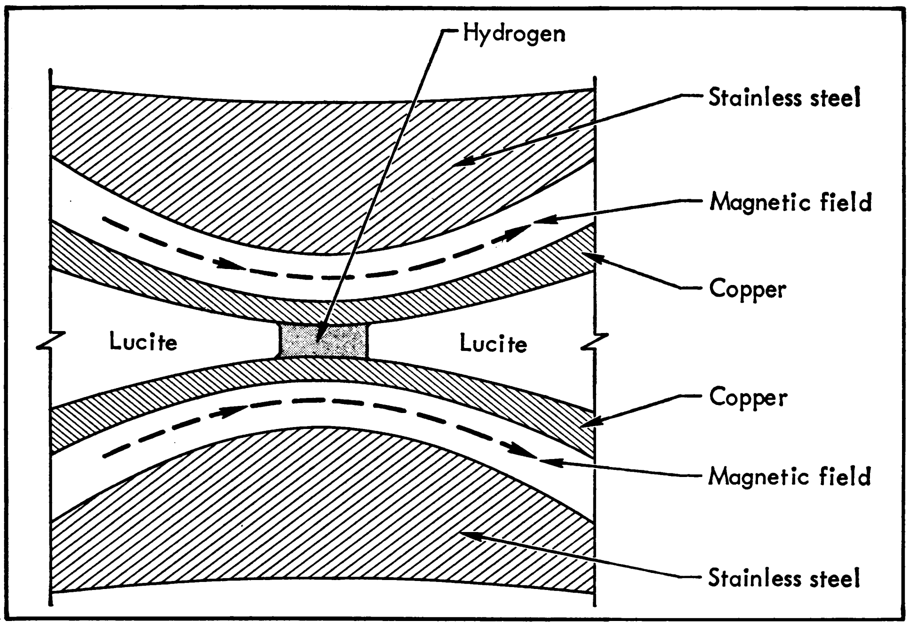
Perched at the top of the Periodic Table of the Elements is element number 1: hydrogen—one proton, one electron, atomic weight 1.008. As might be expected from this simplest and lightest of all elements, its most common state is that of a gas; it has been made both liquid and solid at low temperatures.

A look at the elements grouped with hydrogen in the Periodic Table turns up an interesting fact. Hydrogen bears a familial relationship with elements such as lithium, sodium, potassium, rubidium—all alkali metals.

This seems to make a metallic hydrogen likely—at least theoretically—although it has not been found in nature. Because of the theoretical likelihood, however, scientists and engineers in the United States and, it is speculated, in the Soviet Union, are trying to make metallic hydrogen: a substance whose atoms are arranged so that its electrons are free to move.

The electrons in a metal are communal property; they are not bound to any specific atom and are often thought of as existing as an electron gas. Their freedom to move provides the basis for the electrical conductivity of a metal.

To make hydrogen a metal, then, the task becomes one of freeing its electron from the grasp of its proton. And the way that is presently being tried is through pressure, enormous pressures—800,000 to 2.6 million atmospheres—taxing the ingenuity and skill of high-pressure engineers.



LRL

Magnetic implosion should put over a million-atmosphere squeeze on hydrogen.

"The higher range of pressures approach those at the center of the earth, which is slightly above three million atmospheres," notes Prof. Arthur L. Ruoff of Cornell University. "These extraordinary pressures must be attained with present-day materials which have uniaxial (one-directional) compressive strengths of only 70,000 atmospheres." The best of such presses can produce pressures in the 600,000 to 700,000 atmosphere range.

The effort is motivated largely by scientific curiosity although tremendous practical payoffs may result. The primary one could be the long-sought goal of a superconductor at room

LRL

Hawke (right) with LRL team: Adjusting the electronic equipment will tell whether metallic state has been attained.

temperature (SN: 6/20, p. 602). Present superconductors can operate only at temperatures close to absolute zero, but if metallic hydrogen could be made and recovered in enough quantities, then it could be used for superconducting generators and even magnets for the effort to achieve a controlled thermonuclear reaction (SN: 4/11, p. 373).

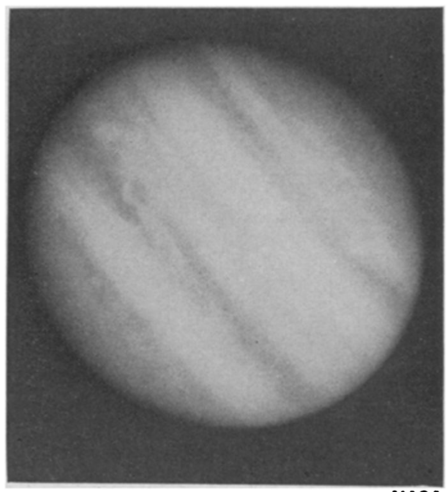
As a fuel, it could be burned both in rockets and future supersonic transports. Because it would be a solid, it would take up about a seventh of the space of liquid hydrogen. Being compact and powerful, it qualifies as a candidate for fuel cells to power an electric car.

It is also of interest to astronomers and astrophysicists because there is reason to believe that the interiors of Jupiter and Saturn contain large amounts of it. This notion comes from the observed perturbation of their planetary orbits. Calculations based on those planets' size and mass lead scientists to conclude that the only material with a density able to produce such perturbations would be hydrogen. But even ordinary hydrogen would not be dense enough; scientists suspect that it might be metallic hydrogen.

"It's all very speculative, of course," says Dr. David C. Welch, assistant professor of solid state sciences at Princeton University. "Jupiter, which is mainly hydrogen and helium, appears to have the best chance of containing metallic hydrogen because of its size. There's a good chance that the pressure is high enough in Jupiter so the hydrogen is metallic in the core."

The idea of metallic hydrogen's possible existence is not new. It goes back to 1925, when the British physicist J. D. Bernal postulated that if any substance were compressed enough, it would become metallic. In 1936, mathematical physicist E. P. Wigner, now at Princeton University, and Dr. H. B. Huntington, now at Rensselaer Polytechnic Institute, laid the theoretical groundwork for metallic hydrogen by showing mathematically that it was possible to apply Bernal's hypothesis to it. They came up with a figure of about 1 million atmospheres of pressure to do the job.

To attain the necessary pressures, two approaches are being tried: an unconventional one at the Lawrence Radiation Laboratory at Livermore, Calif., and a direct mechanical method at Cornell University. Soviet scientists have proposed the mechanical method and will have access to a huge multistory press designed to hit very high pressures, perhaps 2 million atmospheres.

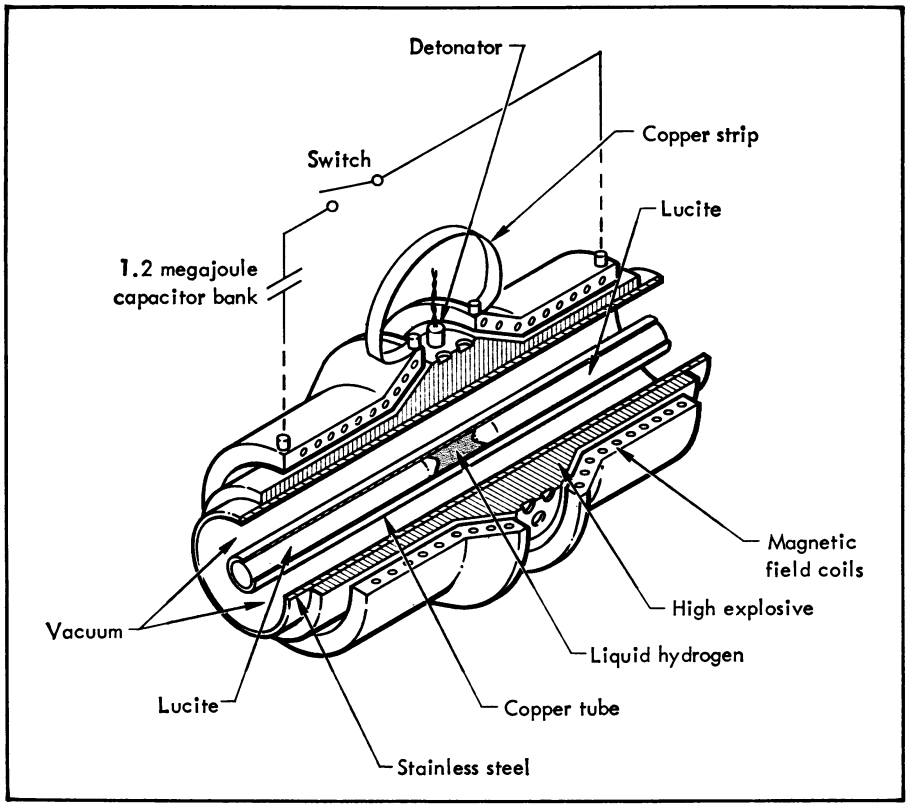


NASA

Jupiter: Metallic hydrogen candidate.

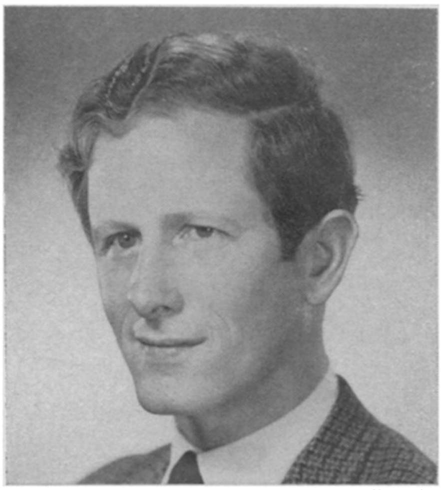
The LRL team, led by Ronald S. Hawke, is using a method developed by Max Fowler of the Los Alamos Scientific Laboratory in the early 1960's called magnetic implosion. In this technique, high fields are attained by setting off a cylinder of explosives that compresses a metal tube and the magnetic field inside. The resulting squeeze on the field can achieve intensities of more than 10 million gauss. Five to 10 million gauss will produce maximum pressures of 1 to 4 million atmospheres.

The LRL experiment will involve placing liquid hydrogen in a copper tube about a half-inch in diameter. This tube will be centered inside a four-inch diameter steel tube. A magnetic field will be between the two, and a cylinder of explosives will be around the outside of the steel tube.



LRL

Implosion experiment: Creating metallic state, but no attempt at recovery.



Cornell Univ.

Ashcroft: A metastability question.

When the explosives are detonated, the force implodes the steel tube, which compresses the magnetic field into a smaller area. The increased force from the field will squeeze the hydrogen to 20 percent of its volume, hopefully forcing the protons into a dense metal and freeing the electrons.

The magnetic implosion is being used to slow up the rate at which the hydrogen is compressed to prevent heat generation. Explosives alone would generate a shock wave, the result of which would be the instantaneous heat buildup in the hydrogen. Heat is the nemesis of compression; it would raise the solid to metal transition pressure of the hydrogen.

The magnetic field prevents the shock wave from entering the hydrogen by isolating it from the explosives. Instead of taking about a nanosecond to raise the pressure, it takes about 10 microseconds. Hence, the total pressure does not hit the hydrogen all at once like a hammer blow but arrives gradually. The lower the temperature, the more a given pressure will compress a material; hence, the metallic transition can be attained at a lower pressure if the temperature is kept low.

An important milestone has been reached by the Livermore group. Before trying to make metallic hydrogen, they used a magnetic implosion experiment on a plastic Lucite (polymethyl metha-crylate) sample. Since they knew Lucite's properties and what could be expected from it, the data from the test told them what pressures will be obtainable in the liquid hydrogen. Preliminary results indicate a pressure of over 1 million atmospheres was reached.

According to Hawke, they will make an attempt on hydrogen before the end of the year. "I'm fairly confident that we can compress liquid hydrogen to a high enough pressure to obtain the metallic state," he says. He points out that the purpose of the experiment is to learn if metallic hydrogen exists. No attempt will be made to collect any of it. Electronic measurements will determine whether or not it was made.

Even if recovery were attempted, it might not be stable enough to exist once the conditions that produced it were removed. If the small amounts are not metastable (persistent), they would become normal hydrogen again. "If it is metastable, it would have half the density of water at room pressure," says Hawke. "However, recovery would be very difficult in the presence of 20 pounds of explosives."

But if the Livermore experiment is not designed to recover metallic hydrogen, the Cornell work is, because a mechanical press is being used. Using solid hydrogen at cryogenic temperatures, Prof. Ruoff and Prof. Neil W. Ashcroft are striving for a pressure of at least a million atmospheres, but the big problem is one of materials: the pressure vessel cannot withstand pressure above 600,000 atmospheres and so its tungsten carbide anvils fail.

There is a possible solution, however, and that is to reduce the shear stress, or slippage, in a material. This could be handled through a redesign of the piston in the press so that its geometry transmits pressure nearly equally in all directions; the researchers are presently engaged in this work.

They too have their worries over metastability. "The question of how long the metallic hydrogen will stay around is an open one at the moment," says Prof. Ashcroft. But he adds: "There are physical reasons why it may stay."

Those reasons boil down to probability. In order for the metallic hydrogen to be formed, electrons must be freed. In order for it to revert to its original molecular state, when the pressure is released, the electrons must band together in groups. But this cannot happen unless the protons come together in just the right way, a statistically highly unlikely event, as Prof. Ashcroft sees it, even in that higher energy state.

Both men see their chances of success depending on finances. "It depends on the magnitude of support," says Prof. Ruoff. "Assuming we get everything we ask for"—an amount he prefers not to divulge—"in a year and a half we will have pinned down the transition pressure for sure. If it's higher than we believe now, that puts us on the low percentage side for success. Otherwise in two or three years, we would have a very small quantity."

If and when metallic hydrogen is made, it will not be the first time a metal has been made from a nonmetal. Dr. Willard F. Libby, 1960 Nobelist in chemistry, has been converting semiconductors for several years now (SN: 7/5/65, p. 5). □