Ultra-high pressures leading to new materials

Breakthroughs such as room-temperature superconductors thought possible

By PAMELA WEINTRAUB

NEW YORK — Scientists are saying that a brief pulse of fantastically high pressure could transform some ordinary substances into a new breed of materials with astonishing properties.

The most challenging goal — compressing hydrogen gas to the point where it becomes a metal — requires more than a million atmospheres of pressure. This still-hypothetical type of hydrogen, an exotic solid, may be impossible to create.

But even if scientists can't generate the incredible pressure needed to make this elusive form of hydrogen, the attempt will help them apply somewhat lower pressures to other materials that might give rise to computers and electric power grids beyond the state of current technology.

If scientists can transform hydrogen into a metal, its usefulness would be extraordinary. It would have an energy content 300 times greater than aircraft fuel and might find applications in controlled nuclear fusion as well as hydrogen bombs — facts that have both encouraged and discouraged the work.

But more important, the material would be a superconductor usable in ultra-fast, ultra-powerful and relatively inexpensive electric generators and computers.

Recent optimism about the chance of making metallic hydrogen has spurred research in at least half a dozen labs around the country. Beyond that, high pressure technology is being used on some other substances that might improve semiconductors and a broad range of electromagnetic devices in the near term.

For example, 40,000 atmospheres briefly applied to a piston cylinder holding the mineral greenockite, a form of cadmium sulfide, yields a unique hybrid — half metal and half non-metal — that seems to function as a superconductor at room temperature.

Superconductors — which have absolutely no resistance to the flow of electricity and lose practically no energy through heat or other types of radiation — could result in computers that work 100 times faster and handle vastly more data than is now possible. They could be used to build power grids that carry electricity cross-country at nearly 100 percent efficiency.

Of course, superconducting materials through which electrons pass at incredible speed have been around for decades. Traditionally, they've been alloys that normally conduct electricity poorly, but which can be made into superconductors by chilling with liquid helium to four degrees above absolute zero.

The technological problem has always been clearcut: how to get around the high cost of cooling with helium. But if scientists can make suprconducting substances that function at room temperature the problem will disappear.

Metallic hydrogen and other superconducting substances that might work at room temperature are created when high pressure alters the molecular structure and corresponding magnetic properties of the material.

Dr. Neil Ashcroft of Cornell University explained the process with hydrogen. That element, he said, exists naturally in its molecular state — essentially two atoms bound together in a free floating gas with millions of similar particles. If 1000 atmospheres are applied, the molecules will condense to liquid. At 57,000 atmospheres they become still more compact, forming a non-metallic solid with a tight crystal structure — a continuous, cube-shaped lattice with one molecule at each corner and all electrons held securely in place.

But at a million atmospheres — apparently produced in the laboratory by squeezing the solid between two tiny diamond faces — the molecules themselves would break down. The crystal still exists, but now the hydrogen is in its simplest form, with one atom at each cube corner. The entire structure would become a super-dense bed of protons and neutrons surrounded by a swirling electron sea.

Called "metallic" because it could release its electrons easily, the hydrogen would go one step further to become a superconductor — where electrons move so freely that no energy is lost as electric current passes through.

Whether or not a million atmospheres have been reached and metallic hydrogen momentarily produced in the lab remains a matter of debate among scientists. But lower pressure can, on the other hand, condense other materials to the point where basic characteristics undergo profound change.

Scientist David Kendall, now pressurizing cadmium sulfide at the Benet Weapons Laboratory of the Watervliet

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Arsenal, Watervliet, N.Y., said that the materi-l will become a superconductor i much the same way as hydrogen. Only 40,000 atmospheres of pressure are needed, however, and that's clearly achievable.

Instead of forming a crystalline structure, part of the ultra-dense greenockite turns into a glassy metal with a random atomic pattern much like that found in glass. A conglomerate of cadmium and sulfur atoms is surrounded by an electron sea — again, the momentary application of pressure has made it so easy for electrons to move at room temperature that superconducting properties result.

Like most superconductors, metallic hydrogen and pressurized cadmium sulfide operate in accordance with electromagnetic principles that could lead to the development of ultra-fast solid state switches.

The idea, first disucussed by Nobel Prize winner Brian Josephson in 1962, used quantum mechanics to predict that if superconductors were sandwiched between two electrodes and chilled with liquid helium, the entire sandwich would be superconducting. If a magnetic field were applied the superconductivity of the sandwich would instantly disappear, but removal of the magnetic field would instantly restore it.

Since the basic element in all computers is the on-off switch, the faster the switch can operate the better the computer will be.

According to Kendall, cadmium sulfide or a similar substance could function like superconductors in the "Josephson-effect" computer with a few differences. First of all, scientists might switch superconductivity on or off with electric current or heat instead of magnetism. But most important, materials that follow Josephson's laws at room temperature could function in the computer without the complex cooling apparatus that must accommodate liquid helium.

So far, pressurized cadmium sulfide is the only element known to exhibit this behavior without first showing strong magnetic properties in its natural form. The behavior can't be explained by present theory, Kendall said, and it appears that an entirely new phenomenon has been discovered.

But, he added, other substances will probably act the same way once scientists get them into the high pressure lab. The Russians, for example, say they've gotten similar results with copper chloride.

The Benet laboratory has thus far produced 50 samples of what it believes is superconducting cadmium sulfide. Each was about one millimeter thick by three in diameter.

If the process is commercialized, Kendall said, researchers will have to develop a large piston cylinder made of something slightly less expensive than diamond — tungsten carbide, for example. Real applications could be five years away. By then, pressurized superconducting materials that are superior to cadmium sulfide will probably be in the works.