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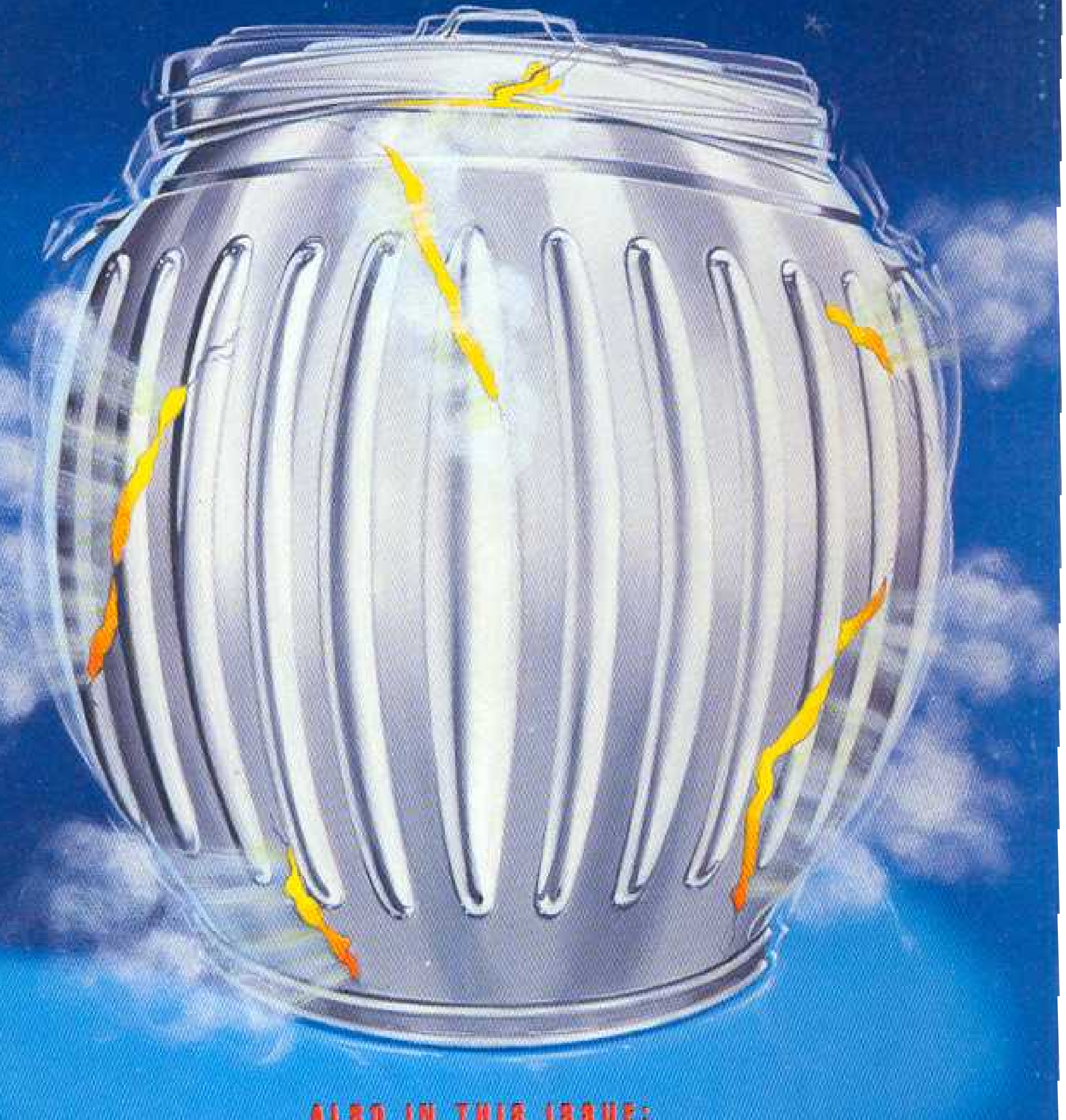
COLD FUSION HEATS UP



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GENZO

FIVE years have passed since two chemists working at the University of Utah announced a startling result: they had built a simple, room-temperature laboratory device that generated more energy in the form of heat than was fed into it as electricity. The researchers—Stanley Pons of the University of Utah and Martin Fleischmann of the University of Southampton in England—attributed this heat to a nuclear fusion reaction.

The claim ignited a scientific controversy not seen for a hundred years. Fusion had been known to occur only in stars and thermonuclear bombs; attempts to harness it for energy had been limited to systems that heat hydrogen fuel to extremely high temperatures using complex and expensive equipment.

Fusion requires the joining together of two atomic nuclei, both of which have a positive electric charge and so repel each other strongly. Scientists had thought that only by making the nuclei extremely energetic could they overcome this electrostatic repulsion, sometimes called the "coulombic barrier" (a coulomb is a unit of electrical charge). "Hot fusion" does this by ripping the electrons off atoms of the two heavy forms of hydrogen—deuterium and tritium—at very high temperature, thereby creating a cloud of ions, or plasma. Huge magnets generate fields that hold the plasma together long enough for some of the nuclei to crash into each other and fuse. This fusion reaction creates tritium and helium nuclei, as well as a shower of neutrons and gamma radiation.

But despite decades of work and great expense, hot fusion has yet to produce more energy than needed to heat the fuel and power the magnets. So the notion that a tabletop apparatus at room temperature could produce significant amounts of fusion energy raised hopes among many people for a more easily realizable energy source.

Pons and Fleischmann's experiment—the basic model for much of what has been done since—is based on electrolysis. An electrode pair consisting of a strip of palladium surrounded by a coil of platinum wire is immersed in a container of "heavy water"—that is, water in which deuterium takes the place of ordinary hydrogen. (Deuterium is a commonly occurring form of hydrogen that has one neutron in its nucleus in addition to the one proton that all forms of hydrogen have. Deuterium atoms undergo fusion reactions; ordinary hydrogen atoms do not.) A salt, typically lithium deuterhydroxide, is dissolved in the heavy water to make it more conductive. When a voltage is applied to the electrodes, an electrical current flows through the liquid and causes the heavy water to decompose into its constituent atoms: deuterium migrates to and dissolves in the palladium electrode and oxygen is released as a gas at the platinum electrode. As deuterium builds up in the palladium, it supposedly undergoes the fusion reaction. The palladium's atomic lattice captures the energy released by the reaction and the metal heats up.

Heat is not the only evidence for cold fusion. Many experiments have also produced tritium (the radioactive isotope of hydrogen, with two neutrons along with the lone proton that all hydrogen has) and helium; both tritium and helium are known to be produced only by nuclear reactions. Researchers have also detected neutrons with the 2.54-megaelectron-volt (MeV) energy level characteristic of the neutrons produced by the fusion of two deuterium nuclei, as well as neutrons with other unexpected energies.

In the wake of Pons and Fleischmann's report, dozens of laboratories around the world eagerly tried to duplicate the results. Most failed, and scientists and the general public grew skeptical. But the significance of these negative results, especially by certain well-known institutions such as Caltech and MIT in the United States and Harwell in Britain, has been exaggerated.

In some cases, the conditions those studies used are now known to prevent the cold fusion effect. MIT researchers, for example, used an experimental apparatus that was open to the humid Massachusetts air and therefore subject to contamination by ordinary water, which has since been found to inhibit the cold fusion effect. Also, early experimenters used commercially available palladium without regard for its condition; it is now known that most off-the-shelf palladium samples do not meet the special conditions required for cold fusion. Some labs also used inappropriate equipment to look for heat. Experimenters at both Caltech and Harwell, for example, used heat-measuring techniques that have since been shown to be insensitive to small amounts of excess energy. Moreover, on the few occasions that the MIT and Harwell labs did observe a small amount of excess heat, the researchers attributed the readings to experimental error and ignored them.

If the validity of the effect rested only on results reported during the first year after the initial claims by Pons and Fleischmann, this strange diversion from routine science would have joined "n-rays," polywater, and other excesses of the imagination. But enough reputable researchers have now published findings, produced from a broad enough range of experimental approaches, that it has become difficult to doubt that something is going on outside the explanations offered by conventional physics.

What is happening might be fusion; it might not

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be. But to dismiss the claims as the result of experimental error or fraud is no longer appropriate. Regardless of admitted conflict with accepted theory, these results strongly support the conclusion that a new class of phenomena, which I call chemically assisted nuclear reactions, has been discovered. Given the enormous scientific and economic importance of this work if it turns out to be valid, it is prudent to examine the data with an open mind.

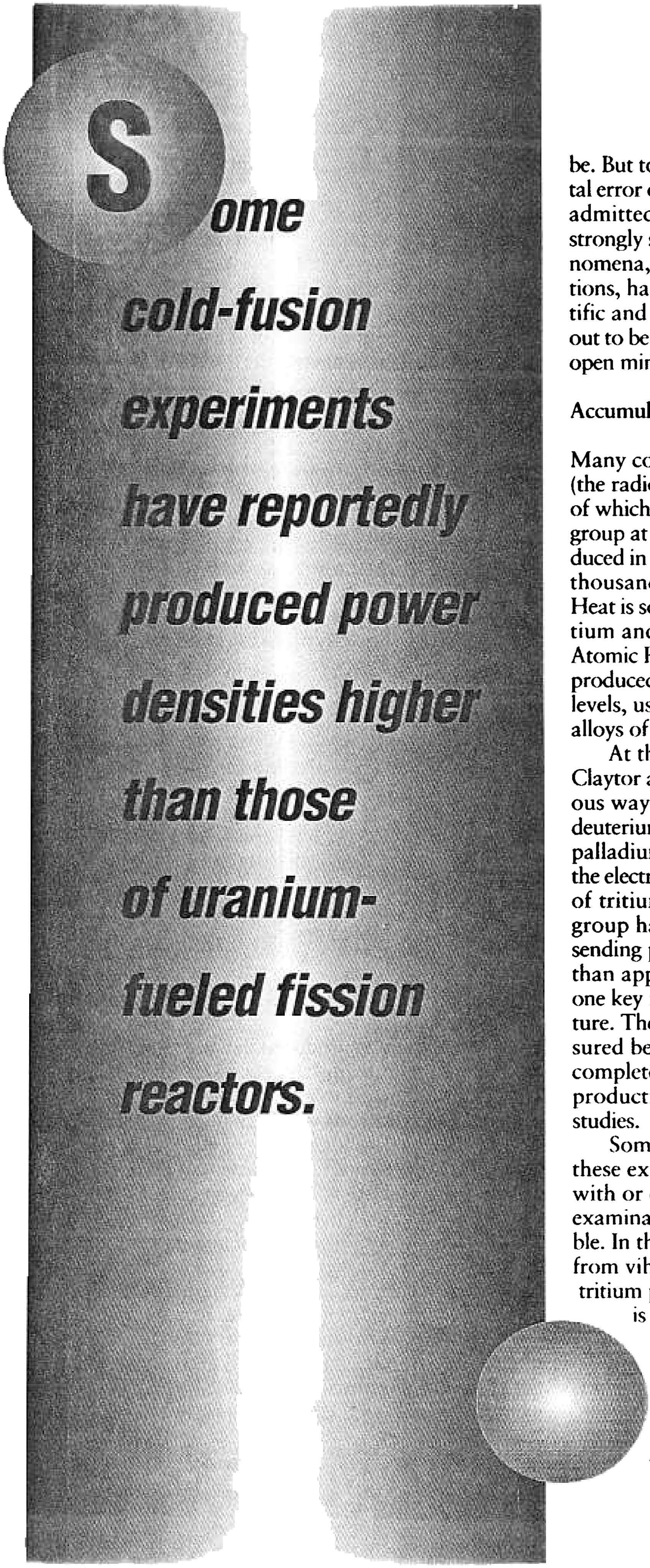
Accumulating Evidence: Tritium

Many cold fusion experiments have produced tritium (the radioactive isotope of hydrogen) and helium, both of which can be produced only by nuclear reactions. A group at Texas A&M University, for example, has produced in electrolytic cells quantities of tritium about one thousand times those found in normal heavy water. Heat is sometimes detected during the production of tritium and neutrons; sometimes it is not. The Bhabha Atomic Research Centre (BARC) in Bombay, India, has produced tritium at several thousand times background levels, using a variety of electrode materials, including alloys of palladium and titanium.

At the Los Alamos National Laboratory, Thomas Claytor and Dale Tuggle have produced tritium in various ways. In one method, they applied a voltage to a deuterium-filled cell containing alternating electrodes of palladium and silicon. The electric discharge between the electrodes has repeatedly generated 20 billion atoms of tritium per hour. More recently, the Los Alamos group has obtained even higher production rates by sending pulses of current through the palladium rather than applying a voltage through the gas. Apparently, one key may be to induce a sudden change in temperature. The amount of tritium in the materials was measured before each study was begun, each system was completely sealed from the environment, and tritium production was monitored continuously during the studies.

Some skeptics contend that the tritium found in these experiments either is in the palladium to begin with or enters the cell from the environment. Closer examination of the results shows that this is improbable. In the Texas A&M work, for example, turbulence from vibration or the addition of heavy water caused tritium production to stop temporarily—an effect that is inconsistent with contamination.

My own studies of the behavior of dissolved tritium in palladium cast further doubt on the likelihood that tritium is present in the metal to begin with. I have found that during normal electrolysis, almost all the dissolved tritium (more than 99 percent) leaves the metal as



Some cold-fusion experiments have reportedly produced power densities higher than those of uranium-fueled fission reactors.

a gas; very little tritium initially present in the palladium appears in the electrolyte solution, which is where the "anomalous" tritium is being found in the cold fusion experiments. Furthermore, the tritium begins to leave the platinum electrode immediately after electrolysis begins, and one-half is gone between 12 and 24 hours later. Anomalous tritium, on the other hand, takes many days to appear and the appearance is sudden.

Experiments that use crack-free palladium and follow the proper procedures now routinely produce heat, nuclear products, or both.

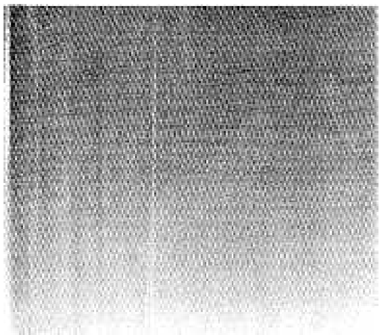
What about environmental contamination? Tritium is rare but not absent in the normal environment. Studies at Los Alamos show that if tritium does enter a cell from the environment, it begins to accumulate immediately and at a roughly constant rate. But anomalous production of tritium starts only after many hours of electrolysis and frequently occurs in bursts. In some cases, the amounts produced are so large that if the tritium had originated in the environment, the required concentrations would pose a health hazard and be easily detected by laboratory monitoring systems. High tritium concentrations do occur occasionally in some areas of laboratories. But such "hot spots" typically occur in places—unlike the sealed cell of a typical cold fusion experiment—where environmental tritium can easily concentrate.

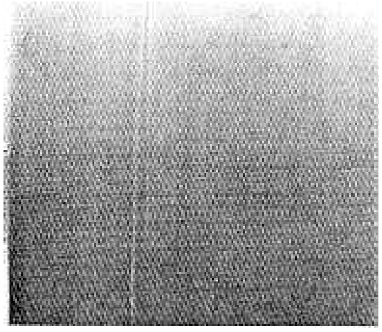
A third possibility, raised most prominently by journalist Gary Taubes, is that proponents of cold fusion have deliberately added tritium to the cells, actions that would of course constitute scientific fraud. But numerous positive results reported at many laboratories worldwide make this assertion an unlikely explanation of all results.

While the presence of tritium provides evidence that a nuclear reaction is occurring, it also raises questions. According to conventional understanding, the fusion of two deuterium nuclei should produce significant amounts of gamma radiation as well as neutrons and tritium. But in cold fusion work, gamma radiation, if detected at all, occurs at very low levels. And tritium and neutrons are found in the wrong amounts and with the wrong energies.

When tritium is produced in conventional fusion, for example, it normally has enough energy to fuse with any deuterium nuclei that might be present. This reaction produces neutrons with a characteristic energy of 14 MeV, as well as high-energy helium-3 nuclei. (In helium-3, two protons in the nucleus are accompanied by one neutron instead of the two neutrons found in the more common helium-4.) The absence of 14-MeV neutrons and helium-3 when tritium is produced by the cold fusion effect shows that the tritium is born without enough energy to fuse with deuterium. Where does the energy released from the nuclear reaction go, then, if not into neutrons or tritium? Energy apparently transfers directly from the nuclear reaction to the atomic lattice of the metal where it is manifest as heat. This effect, which is at odds with current theory, has never before been observed.

Tritium detection also provides evidence that nuclear reactions other than fusion can occur in the environment of a cold fusion cell. Researchers at Bhaba, for example, recently reported producing tritium in a cell containing not heavy water but rather normal water, in which was dissolved either lithium carbonate or potassium carbonate. The ordinary hydrogen nuclei (that is, naked protons) that make up normal water do not fuse with one another, even under "hot fusion" conditions. The tritium in these experiments is therefore most likely to originate in nuclear reactions between protons and the dissolved lithium or potassium nuclei.





Accumulating Evidence: Excess Heat

A variety of experimental designs continue to produce heat output exceeding the electrical input. Several studies have produced excess energy thousands of times larger than any known chemical (that is, non-nuclear) reaction could produce. In some experiments, the power "density," in watts per cubic centimeter of palladium, exceeds those found in uranium-fueled nuclear fission reactors.

Excess heat in the experiments by Pons and Fleischmann, who have continued their work in France with support from the Japanese company Technova, has reached levels that cause water in the electrolytic cells to boil. These scientists claim that when they applied 37.5 watts to a cell as electric power, it produced 144 watts of excess power as heat—enough to raise the temperature of the palladium electrode to several hundred degrees. And the cells have produced excess energy at a comparable level for many hours after the applied power is turned off. No oxygen is allowed into the cells during this time, ruling out the possibility that the energy results from the reaction of deuterium with oxygen—that is, ordinary chemical combustion.

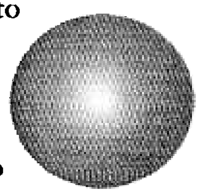
Dozens of examples reporting such excess energy have now been published. Francesco Celani at Italy's Frascati National Laboratory has reported producing heat levels that exceed electrical energy input by as much as 7.5 percent for many weeks, with bursts to 25 percent. Akito Takahashi of Osaka University measured up to 130 watts of excess power (an average of 70 percent) using special palladium produced by Tanaka Metals. The excess heat increased over several months, and the cells also produced a small amount of tritium and neutrons. In my own attempts to replicate the Osaka experiments, using the same palladium source, I produced 7.5 watts—20 percent more power than I put into the cell.

An inability to replicate results continues to frustrate many cold fusion researchers (and bolster skeptics' disbelief that the phenomenon is real). Bor Liaw and colleagues at the University of Hawaii, for example, produced up to 1,500 percent excess energy using a molten salt electrolyte. Because the lithium-potassium-chloride electrolyte is at 400 degrees C, this energy could be more useful than that generated in a heavy-water cell. However, Liaw has been unable to duplicate this one tantalizing experiment.

Critics of cold fusion work have questioned the validity of such measurements. Some maintain that because the water in the cells is not stirred, temperature gradients could account for the unusual readings. In fact, active stirring is not necessary: as long as enough current is applied to the cell, the gas that bubbles out of the water does the mixing. Nevertheless, recent studies have corrected for this possible source of error by actively stirring the cells or by using a type of heat-measuring system—that is, a calorimeter—that temperature gradients do not affect.

Another charge concerns a lack of control studies. Such studies would, for example, replace the cell's heavy water with normal water or replace the palladium with platinum. Because it is extremely unlikely that the hydrogen in ordinary water would undergo fusion, any anomalous heat from a normal-water cell would suggest that the effect has some other, less spectacular source—such as experimental error or a chemical (that is, non-nuclear) process.

But many such control studies have now been carried out, and no one so far has claimed excess heat in a palladium/normal-water or a platinum/heavy-water cell. Skeptics have complained, however, that these control studies run for too brief a time, since the active cold fusion cells run for months. To rule out the possibility that the anomalous results arise from random error, these critics say, the controls should run for the same duration. This presents a problem: to address such concerns, researchers would have to devote a significant fraction of time and funding to waiting for possible errors to show up rather than to understanding the nature of the effect. As a compromise, experimenters run control cells for a shorter time and take great pains to make the calorimeters stable.



The demand for long-term control cells reflects results from the early cold fusion experiments, which produced heat or nuclear products in occasional bursts. More recent work has achieved steady output. Once a cell turns on, it typically stays on for many days.

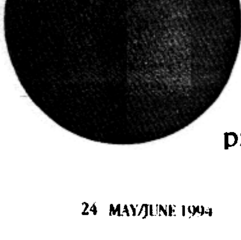
Skeptics who accept the data on excess heat nevertheless assert that it originates not from any nuclear process but from some hitherto unknown chemical reaction. But no evidence from any study has been reported to support various speculated chemical sources. If a novel chemical reaction is the source of this power, significant quantities of some chemical product must be present in the cell, yet no such products have been observed. Moreover, many distinct and novel chemical reactions would be required to explain the excess-heat observations in a the variety of chemical environments that have now been studied.

One reason that cold fusion has been so difficult to accept is that the experiments are so hard to replicate. Many experienced researchers, attempting to follow exactly the methods described in published studies, have, until recently, produced little or no evidence for a nuclear reaction. But scientists are starting to solve the puzzle of why some cells work and some do not.

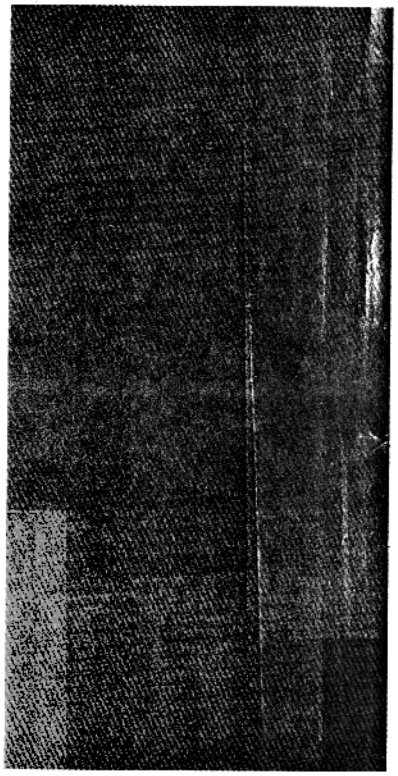
An important requirement for producing heat, for example, now appears to be palladium largely free of microscopic cracks. Deuterium apparently escapes from any cracks too fast for a critical concentration to build up. Michael McKubre and co-workers at SRI International, as well as researchers at several other laboratories, have shown that the larger the ratio of deuterium to palladium in the electrode, the greater the heat.

The presence of surface impurities is also important to produce the required deuterium content. McKubre's first experiments, which were successful, used pyrex containers for the cell. When he changed to Teflon, the cell did not work. Further investigation revealed the apparent reason: aluminum and silicon atoms from the pyrex migrated to the palladium surface and allowed the deuterium to build up to higher concentrations.

McKubre's studies also identified another criterion for producing excess heat. His work, which have now been supported by at least four other laboratories, indicates that the electrical current entering the cell must exceed a threshold of at least 150 milliamperes per square centimeter of palladium. For experiments using large pieces of palladium, this can mean a very large overall current. Many experimenters have failed to produce anomalous effects because they have not applied enough current to their cells.



Several experiments have shown that the nature and timing of the electrical input to a cell significantly affects the chances of its success. Heat is more likely to be produced when the electrical current is repeatedly "ramped" from a high to lower level or briefly pulsed to high values. Applying certain microwave frequencies is also beneficial. Moreover, for reasons still unknown, electrolysis must continue for several days before the cell "turns on" and begins to generate excess heat. Many of the early efforts to reproduce the effect failed at least partly because the researchers did not stick with them long enough. Experiments that use crack-free palladium and follow the proper procedures now routinely result in excess heat, nuclear products, or both.



Heat might be arising from nuclear reactions other than fusion, as well. At least 10 different laboratories have measured significant excess energy coming from light-water cells using nickel, rather than paladium, as the cathode, and in which is dissolved a carbonate of one of the so-called alkali metals (lithium, sodium, potassium, or rubidium). Experiments by Robert Bush and Robert Eagleton at California Polytechnical University and by Reiko Notoya at Hokkaido University in Japan suggest that this heat arises from a transmutation reaction: a proton enters the nucleus of the dissolved metal to give the next higher element in the periodic table. Potassium, for example, is proposed to take up a proton to produce calcium, and rubidium is similarly transformed into strontium. Researchers have detected calcium and strontium at levels that suggest this transmutation is occurring.

Accumulating Evidence: Helium

One of the products of the fusion of two deuterium atoms is helium, which with its two protons is the next element up on the periodic table. Many experiments have produced measurable helium. Hawaii's Liaw, for example, found significant helium in the palladium in his heat-producing experiments with a molten-salt electrolyte. Workers at Texas A&M also detected normal helium-4 in the palladium after tritium was produced. However, no effort was made to measure heat during this study. Q.F. Zhang and colleagues at the University of Science and Technology in Chengdu, China, have detected helium-4 in titanium rods that produced excess heat in an electrolytic cell. They saw no helium when excess heat was absent, suggesting a link between the two.

For cold fusion to occur, the palladium probably must transform into a special condition of matter, akin to superconductivity.

Skeptics have complained that cold-fusion experiments have produced too little helium; if the heat measured truly has nuclear origin, they contend, far more helium should be detected. The helium found in the palladium after the Hawaii experiments, for example, while significant, could account for only 10 percent of the large amounts of excess energy that this work generated.

Recent work has whittled away at this objection. Melvin Miles and Benjamin Bush of the Naval Air Warfare Center at China Lake, Calif., for example, have measured helium in the gas emitted by electrolytic cells and have measured helium levels 90 percent of those needed to account for the measured heat. Since these scientists found no helium when using normal water in the cell instead of deuterium-bearing heavy water, the heat appears to be nuclear in origin. When critics suggested that the helium entered the glass collection flasks from the atmosphere, Miles and Bush repeated the experiment using steel flasks and obtained similar results while also showing that the diffusion rate of helium through glass was too small to account for the observed amounts. Apparently, most of the generated helium resides in the gas, rather than in the electrodes where researchers have mainly been looking.

When helium forms during fusion, two particles are condensed into one. The laws of physics require that in any interaction between particles, momentum (the product of mass and velocity) must be conserved. In hot fusion, a 24-MeV gamma ray is emitted to satisfy this conservation requirement. No gamma rays with this energy are observed in cold fusion.

The most probable reason, I believe, is that the material has transformed into a special condition that enables the atomic lattice to absorb most of the nuclear energy being generated. If we assume that the material in this condition has a similar ability to absorb nuclear radiation applied from outside, a straightforward experiment could test this hypothesis. One could irradiate the material with gamma radiation, which easily penetrates ordinary palladium. When this special condition exists, the material should block some of the gamma rays; the portion of gamma radiation absorbed should correspond to the amount of the material that has switched to the fusion-enabling condition.

None of the proposed explanations for cold fusion accounts for the full range of experimental observations.

Evidence for this special condition does exist. Experiments by Yan Kucherov and co-workers at Russia's Scientific Industrial Association (LUCH) in Podolsk produced an electrical discharge in low-pressure deuterium, using palladium as one of the electrodes. Heat was accompanied by an unusual form of gamma radiation. Gamma rays ordinarily fan out in all directions from their source. In this case, the radiation emerged from the palladium in tightly focused beams. Such beams suggest the existence within the metal of reflection planes with much closer spacing than normally exist in the atomic lattice. Such planes might be owing to an unusual, tightly bound electron structure.

Much of the evidence for cold fusion has come from techniques alien to nuclear physics, such as electrolysis and the precise measurement of heat. But in the past several years, researchers have been producing cold fusion results using the tools of nuclear physics, such as high-energy ion beams.

Toshiyuki Iida and co-workers at Osaka University, for example, bombarded palladium and titanium samples with energetic deuterium nuclei. During this bombardment, the cell emitted a variety of ions with energies consistent with conventional fusion between two deuterium nuclei. This was in itself unremarkable, and could be explained as "hot" fusion, as high-energy deuterons in the beam slammed into those that had already taken up residence in the metal. But defying expectations, emission of energetic ions continued from the palladium target for many hours after the implantation beam was turned off. The Osaka group also detected high-energy helium nuclei. Such observations suggest that fusion—cold fusion—continues in the material even without the presence of a high-energy beam.

A trail of evidence for cold fusion comes from work by Jirohta Kasagi and co-workers at Tohoku University in Japan. Kasagi bombarded titanium deuteride with 150-kiloelectron-volt deuterons. When the deuterium content of the titanium deuteride was high enough, the experiment produced protons with energies up to 17.5 MeV. These energetic protons are thought to result from the fusion of deuterium and helium-3. It is the helium-3 that provides evidence for cold fusion.

In theory, helium-3 could arise in two ways. One is from the "hot" fusion of the energetic deuterium nuclei with the deuterium contained in the metal. But the helium-3 is found in isolated pockets within the titanium, which is inconsistent with this explanation. If the helium were formed in hot fusion, it is unlikely to diffuse through the material, as is required for the build-up in pockets. More likely is that the helium-3 is a product of the radioactive decay of tritium, which was produced within the metal in a cold fusion process. The tritium thus formed could, unlike helium, easily migrate through the material and accumulate in pockets, where it would decay into helium-3. (Hydrogen is well known to accumulate in regions of high stress within a metal.)

Attempting an Explanation

Many aspects of the cold fusion effect are now reproducible if known procedures are used. Palladium, when reacted with enough deuterium, apparently converts to a special condition of matter in which various nuclear reactions—including deuterium-deuterium fusion—can occur despite the repulsive force of the two positively charged nuclei. These reactions can be made to proceed rapidly enough to produce measurable heat.

But any explanation for the cold-fusion phenomenon must answer some fundamental questions. What is the mechanism that allows positively charged atomic nuclei to overcome the coulombic barrier and join together? How is the significant energy unleashed by a nuclear reaction transferred directly to a material, instead of departing the scene in the form of energetic particles and radiation? Finally, why does cold fusion occur when a material is in a special condition of matter, akin to the state of superconductivity that some materials enter at low temperatures? What is this special condition that occurs in palladium and some other materials when they are infused with high concentrations of deuterium?

Scientists have published several dozen models, ranging from highly analytical approaches to pictorial representations, to explain these events. Most theories address only the problem of overcoming the coulombic barrier—how it is possible for nuclei to overcome their natural repulsion for each other without an infusion of massive amounts of energy from the outside. A sampling follows:

○**NEUTRON TRANSFER.** According to this theory, the nuclear reactions that occur are not fusion but rather involve the transfer of a neutron from one nucleus to another. Neutrons have no charge and can therefore enter a nucleus and initiate a reaction without having to acquire enough energy to overcome a barrier. While this approach removes the coulombic barrier problem, it cannot explain all the nuclear reactions that appear to have taken place in various experiments. Furthermore, it raises the question of why so few neutrons are seen leaving the material; if even a small fraction of the neutrons leaving one nucleus are not captured by another nucleus, a great many neutrons should emanate from the material.

○**SCREENING OF THE NUCLEAR CHARGE BY ELECTRONS.** The high concentration of negatively charged electrons in a metal might partially offset the positive nuclear charge. However, electrons in materials ordinarily do not have enough energy to completely mask the nuclear charge. Therefore, unless the electrons can achieve much higher energy states than are presently known, this is unlikely to be the only process.

○**RESONANCE.** Some nuclear processes are known to occur when the reactants have an energy level that matches a characteristic value, known as a resonance. Such resonance levels may be far below the energy ordinarily required to initiate the reaction. Among a large number of deuterium nuclei at room temperature, then, a few might possess such a resonant energy, permitting them to undergo reactions that would seem to be off-limits. While appealing, this theory falters on lack of evidence; physicists have never detected such a low-energy resonance for deuterium-deuterium fusion. Also, if such a resonance does exist, it must operate only in the special environment created by cold fusion cells. Otherwise, fusion would occur all the time.

○**HIDDEN HIGH VOLTAGES.** According to this theory, cracks in the material generate a large voltage that accelerates deuterium ions briefly to energies that can produce normal "hot" fusion. The problem with this explanation is that the radiation detected from cold fusion is different from that known to be generated in hot fusion. Also, while this process might partly account for fusion, it does not explain the other nuclear reactions.

○**FUSION INVOLVING MORE THAN TWO DEUTERONS.** This proposal is consistent with the observed need for a high deuterium concentration in the metal, and with the observed energy of some emitted nuclear products. However, it cannot explain the other nuclear reactions nor all of the observed energies. Also, this theory says nothing about how such multinucleus fusion reactions might be initiated; in particular, the puzzle of how the coulombic barrier is overcome remains.

○**UNUSUAL TUNNELING PROCESSES.** Conventional nuclear theory recognizes processes that allow a small fraction of charged particles to "tunnel" through the coulombic barrier. Tunneling is a logical consequence of the quantum-mechanical principle that it is impossible to know a particle's location and momentum simultaneously. However, according to our understanding of this phenomenon, while low-energy nuclei may tunnel through the barrier at a rate to account for the observed neutrons, the rate would be too slow to account for tritium or heat.

○**A NOVEL CHEMICAL EFFECT.** Randell Mills, of Hydro-Catalysis Power in Lancaster, Pa., has proposed that excess heat results neither from nuclear fusion nor from a conventional chemical reaction but rather when the electrons in hydrogen drop to a lower energy state than has been previously thought as it forms a two-hydrogen "dihydrino" molecule. This theory offers a possible explanation for some of the excess heat that several labs have detected in nickel/light-water cells. But the explanation cannot account for any of the nuclear products (neutrons, tritium, and helium) that often accompany heat in heavy-water cells. Moreover, studies using sealed calorimeters have failed to observe the expected pressure increase that would result from the buildup of the hypothesized dihydrino gas.

○ **A NEW MODEL OF NUCLEAR STRUCTURE.** Maybe our current understanding of the nucleus is wrong, or at least incomplete. An explanation of cold fusion might then invoke new nuclear particles or new types of nuclear interactions.

Cold fusion research is caught in a catch-22: journals will not accept papers in the field until more evidence for the phenomenon is published in journals.

Theoreticians are nowhere near a consensus on which of these explanations are most likely to contribute to our ultimate understanding of the phenomenon. None of the proposed explanations accounts for the full range of experimental observations. Many of the theories do not offer predictions that can be quantitatively checked.

Nevertheless, a workable theory is crucial if we ever hope to apply cold fusion. It will be important to develop an understanding of the special condition of matter in which these nuclear reactions occur. For example, what is the crystal structure of the material when it is in this phase? What other characteristics will it exhibit? How can it be created and then modified to trigger a variety of nuclear reactions? Such questions will need to be answered before the phenomenon can be made to occur reproducibly and at high levels—an essential requirement if the effect is to be used to produce energy on an industrial scale.

Is Science Dropping the Ball?

Early investigations of all new phenomena tend to be incomplete, prone to error, and difficult to reproduce. Further scientific investigations require money; the more complex the phenomenon, the more money is required. But dollars tend to flow toward research with a clear chance of success. Thus many potentially important ideas never receive enough funding to enable scientists to understand them.

To a large extent, this is the case with cold fusion. Skeptics maintain that the effect is not real and that funds should therefore not be wasted on studying it. Rather than invest a little money on the possibility that they might be wrong, skeptics actively try to turn off support. The U.S. Department of Energy is not funding research on cold fusion, nor, for the most part, are other federal agencies. The patent office has stopped issuing patents related to this field. Fortunately, a few imaginative and courageous organizations are backing U.S. cold fusion work—most conspicuously the Electric Power Research Institute and, more recently, ENECO, a company based in Salt Lake City that has begun to fund research at a number of labs. ENECO has also invested heavily in buying up rights to the cold fusion patents that do exist.

The advance of scientific knowledge rests on the idea that before work is judged valid it must be evaluated by, and reproduced by, other scientists. While these procedures have kept science from making too many mistakes, they can also stifle new ideas. It is now virtually impossible to publish positive cold fusion results in certain journals because the editors or their chosen peer reviewers are convinced that the effect is bogus. This creates a catch-22: the journals will not accept papers until more papers published in such journals show evidence for the effect.

The cold fusion effect is one of the most intriguing scientific puzzles of this century. Its ultimate practicality is still open to question, but practical worth does not always follow immediately upon discovery of a scientific phenomenon. Superconductivity, for example, was first observed in 1911 and languished as an unexplained laboratory curiosity for most of this century; today we have magnetic resonance imaging systems that rely on superconducting magnets. Einstein predicted the basic principle of a laser before 1920; decades later, we have supermarket checkout scanners, compact discs, and fiber-optic communications.

The comparison of cold fusion with these technologies is not exact. The theory of lasers was well accepted for decades before anyone figured out how to build one. Superconducting effects were consistently observed in the lab for decades before physicists were able to explain it. So far, cold fusion falls short on both fronts: experimental evidence is difficult to replicate and a theoretical underpinning is absent. It is up to scientists of all disciplines to perform the experiments and devise the theories that will transform cold fusion from laboratory scale phenomenon into something of lasting value.■