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What is the current scientific thinking on cold fusion? Is there any possible validity to this phenomenon?

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Peter N. Saeta, an assistant professor of physics at Harvey Mudd College, responds:

Eight years ago researchers Martin Fleischmann and Stanley Pons, then both at the University of Utah, made headlines around the world with their claim to have achieved fusion in a simple tabletop apparatus working at room temperature. Other experimenters failed to replicate their work, however, and most of the scientific community no longer considers cold fusion a real phenomenon. Nevertheless, research continues, and a small but very vocal minority still believes in cold fusion.

Michael J. Schaffer, a senior scientist at one of the major U.S. fusion research laboratories (his employer has requested not to be identified), has provided this historical overview, along with a rather moderate assessment current status of cold fusion:

"Because cold fusion is still an unresolved and controversial subject that generates strong opinions and passionate debate among scientists, I begin by stating up front that I am a mainstream plasma physicist researching fusion energy. I also read many of the papers published on cold fusion, however. I attended the last three International Conferences on Cold Fusion, and I myself ran two sets of cold fusion experiments, both with no clear evidence of excess power release. Overall, I consider myself to be a fairly neutral observer.

"To understand the controversy, it helps to know some basic facts about fusion. Fusion is a nuclear reaction wherein two smaller nuclei join (fuse) to form a new, larger nucleus. When that large nucleus is unstable, it quickly breaks apart and releases energy. The big difficulty is that because the initial nuclei are all positively charged, they are strongly repelled as they approach one another. Therefore, only nuclei having a high kinetic energy approach closely enough to fuse. High-speed nuclei can be made on the earth either by particle accelerators or by extremely high temperatures--on the order of 50 million degrees Celsius or more. In controlled 'magnetic' fusion energy experiments, such as tokamaks and others, a magnetically confined plasma is heated by electromagnetic waves or neutral particle beams. In 'inertial' fusion energy experiments, tiny pellets are compressed and heated by powerful pulsed laser or ion beams.

"Cold fusion claims to release measurable energy from fusion reactions at or near room temperature when deuterium is dissolved in a solid, usually palladium metal. The idea, which has its roots in research going back to the 1920s, is that hydrogen and its isotopes can dissolve to such high concentrations in certain solids that the hydrogen nuclei approach closer to one another than even in solid hydrogen. Furthermore, negative electrical charges from the electrons of the solid host partly cancel the repulsion between the nuclei. Early experiments did not detect any signs of fusion, however. Furthermore, modern theoretical calculations show that the proposed effects, while real, are much too small to produce detectable rates of fusion.

"Electrochemists Martin Fleischmann and Stanley Pons decided to revisit room-temperature fusion. Their technique is to pass current

through an electrolytic cell consisting of a palladium (Pd) cathode, platinum (Pt) anode and LiOD (a compound of lithium, oxygen and deuterium, or heavy hydrogen) electrolyte in heavy water (water containing deuterium in place of the ordinary hydrogen). The cathodic reaction liberates unbound atoms of deuterium (D), which enter palladium much more rapidly than do deuterium molecules. Under proper conditions, the concentration can build up to 0.9 or more deuterium atoms per palladium atom, at which point the loss of deuterium balances its rate of implantation. Pons and Fleischmann's cells were part of a calorimeter (heat-measuring device), whose temperature rise on a few occasions indicated on the order of 10 percent excess power, that is, about 10 percent more power leaving the cell than electrical power used to run it. Pons and Fleischmann announced their results at a now famous news conference on March 23, 1989. They also thought they had detected gamma radiation characteristic of neutrons passing through water, but these results later had to be retracted.

"There was an immediate rush to reproduce the Pons and Fleischmann experiments. A few experimenters reported success, many others failure. Even those who reported success had difficulty reproducing their results. Furthermore, no one was seeing the expected fusion products. The three known D + D reactions are:

D + D --> H + T (two deuterium nuclei yield a hydrogen nucleus and tritium, a heavy hydrogen isotope containing two neutrons) or

D + D ---> n + 3He (yielding a neutron and helium 3, a light isotope of helium), or

D + D ---> 4He + gamma (yielding normal helium 4 and a gamma ray).

"The first two reactions are equally probable, and if one watt of nuclear power were produced, the neutron and tritium production would be easy to measure. But they could not be detected; if they were present at all, it was only at an extremely low level. The third D + D reaction normally proceeds much more slowly than the first two. Some experiments eventually did report helium 4 production, although great care must be used to avoid contamination by trace amounts of helium normally present in the air. This led many cold fusion researchers to postulate that somehow the third fusion reaction was catalyzed in the palladium. Moreover, it was necessary to postulate the suppression of the gamma radiation, which was never observed. There is no widely accepted theory that might explain such effects, however. Therefore, most of the scientific community concluded that the 'Pons and Fleischmann effect' was experimental error.

"Even so, several laboratories continued cold fusion experiments. Excess power remained small and sporadic. If some of the recent reports of new work can be verified, however, the years of effort might be paying off. Pons and Fleischmann now report excess powers of 100 watt (150 percent of the input power) sustained over a 30-day run. The Pons and Fleischmann technique calls for about 20 days of electrolytic conditioning, after which the cell is allowed to heat to boiling for the power run. This technique was reportedly reproduced by a separate group under G. Lonchampt, with support by the French Atomic Energy Commission and in consultation with Pons. Other groups in Japan and Italy are beginning to report excess powers in the 30 to 100 percent range. Experimental results of this magnitude are far beyond ordinary chemistry and point toward the possible existence of some new effect. It might not be 'cold fusion' at all. Whether the effect is a new kind of chemical reaction, a new pathway for nuclear reactions, or something either more surprising or more mundane will only be known after more research.

"Different techniques have been tried to produce cold fusion, including electrical discharges, ultrasound and hydrogen in ceramic electrolytes. Here I will highlight only electrolysis using nickel cathodes in alkali salt solutions in ordinary, light water. These cells are much cheaper than ones using heavy water and palladium. The most impressive excess power to date from this class is reported by James Patterson and his company, Clean Energy Technologies (CETI), in the U.S.

"There are tantalizing new hints about possible products from nuclear reactions. Tadahiko Mizuno's group at the University of Hokkaido in Japan analyzed the components of a Pd-heavy water cell before and after an extended run at high temperature. They reported low concentrations of a range of heavy elements, including calcium, titanium, chromium, manganese, iron, cobalt, copper and zinc. George Miley of the University of Illinois, working with Patterson cells and either nickel or layered nickel-palladium cathodes, also reported a wide range of medium and heavy elements. Similar, but less detailed, results have been related by a few other groups. Production of such heavy nuclei is so unexpected from our present understanding of low-energy nuclear reactions, that extraordinary experimental proof will be needed to convince the scientific community. All available analytical techniques will have to be applied and the results reproduced. CETI recently started lending Patterson cells to independent laboratories to speed up research.

"So, what is the current scientific thinking on cold fusion? Frankly, most scientists have not followed the field since the disenchantment of 1989 and 1990. They typically still dismiss cold fusion as experimental error, but most of them are unaware of the newly reported results. Even so, given the extraordinary nature of the claimed cold fusion results, it will take extraordinarily high quality, conclusive data to convince most scientists, unless a compelling theoretical explanation is found first.

"Most cold fusion research today is done in Japan. The New Energy and Industrial Technology Development Organization, a government organization, sponsors the New Hydrogen Energy Laboratory in Sapporo. IMRA, a foundation of the Toyota family, sponsors another well-equipped lab in Sapporo, as well as Pons and Fleischmann's facility in France. Several Japanese universities and industries also do cold fusion research."

Douglas R.O. Morrison, who was a physicist at CERN for 38 years, is a longtime observer of cold fusion research; he has also attended the International Cold Fusion Conferences. Here is his assessment:

" 'You mean it's not dead?' is the incredulous reaction when I say I have been to a cold fusion conference. Almost all scientists and most of the public no longer believe the 1989 claim of Fleischmann and Pons of having solved the world's energy problems by using electrochemistry to fuse deuterium nuclei together at low energy. But true believers soldier on.

"The Sixth International Cold Fusion Conference, ICCF-6, was held in October 1996 near Sapporo in northern Japan. It was sponsored by a branch of MITI, which has given some $30 million over four years for cold fusion research; this support was matched by funds and personnel from some 20 major Japanese companies and in cooperation with a dozen Japanese universities. MITI started the New Hydrogen Energy (NHE) laboratory near Sapporo, which visitors have estimated contains some $10-million worth of equipment. "The conference was remarkable for three reports of high-quality Japanese experiments, which contrasted sharply with other reports. The NHE lab of MITI described a large series of experiments devised to check the original claims of Fleischmann and Pons. No excess heat was found.

"Toyota established a new organization, called IMRA, that has two laboratories, one near Sapporo and the other near Nice in the south of France; the latter has employed Pons. The second major experimental report came from the IMRA-Japan lab, where researchers built an improved calorimeter, which had no interaction with the surroundings. Twenty-six experiments were tried employing the various systems and tricks that had been suggested to cause excess heat, but no excess heat was observed. Further, the upper limits were very low, +/- 0.23 watts, or 2.3 percent of the input power--far from the cry of 'one watt in, four watts out' and the hundreds of percent increases claimed back in 1989.

"Another set of results came from IMRA-Europe, which was presented by Pons. He said that seven experiments were performed; they yielded excess heats of 250 percent, 150 percent, 'variable' and four that gave no excess heat at all. This result might be considered rather meager after five years of work conducted before the 1989 announcement and seven years after, when Pons and Fleischmann were well funded. A high-temperature (near boiling) cell was used at IMRA-Europe, although such a device had been shown to produce greater uncertainties.

"Extremely high temperatures are normally needed to obtain practical fusion rates by overcoming the repulsion of the nuclei that are both positively charged. At low energies--that is, at room temperatures--this potential barrier makes fusion reactions have an incredibly low probability of occurring. True believers claim that in the lattice of a metal such as palladium, the rate of deuterium-deuterium fusion is much higher, so all that is needed is to fill the lattice with deuterium.

"The third careful Japanese experiment by Jirohta Kasagi and his colleagues at Tohoku University was designed to test this hypothesis. Deuterium ions of a variety of low energies were fired into metals that had been saturated with deuterium; the measured rates of fusion were then compared with expectations. The rates decreased steeply at low energies because of the Coulomb barrier (electrical repulsion), and no unexpected enhancement was observed of the kind that would be needed to justify Fleischmann and Pons's claims.

"It might be thought that the three Japanese results would be decisive, but the two summary speakers, Tullio Bressani of Turin and Mike McKubre of SRI International, were optimistic and belittled or ignored them and instead talked of other experiments that were not performed with the same careful controls. Some remarkable new claims were mentioned. James Patterson of Clean Energy Technologies (CETI) was scheduled to speak about his claims that tiny balls coated with metal, generally nickel, could generate energy, but he did not talk. Instead his collaborator, George Miley of the University of Illinois and editor of the journal *Fusion Technology*,

reported that experiments using these balls produced transmutations of the nickel to many other elements even as heavy as lead; he did not worry about the origin of the extra neutrons needed to create lead.

"What was *not* said at ICCF-6 was also interesting. Many people who had reported a sensational first result now no longer speak of it or try to extend it. For instance, on the first day of the ICCF-3 conference in Nagoya, Nippon Telephone and Telegraph (NTT) had issued a press release saying that one of their researchers had solved cold fusion and had reproducible results. NTT promptly saw its shares rise in value by $8 billion--but within a few days, they fell back to their previous level. The experiment was widely criticized but since has neither been mentioned again nor formally withdrawn.

"There is one point on which all true believers in cold fusion agree: their results are not reproducible. To most scientists, this implies that cold fusion results are not believable, but true believers suggest that this unpredictability makes them more interesting!

"From 1992 onward, many claims were made for cold fusion using normal water instead of heavy water. It is well known that D-D (deuterium-deuterium) fusion has a much higher rate, by many orders of magnitude, than H-H (hydrogen-hydrogen) fusion. In fact, early claims of cold fusion stated that the results must be attributed to fusion because they happened only with deuterium and never with hydrogen, which indeed was used as a control. Also, from 1992 onward, claims of transmutations have been made. One of these was the old alchemists' claim of turning mercury to gold; others claimed small changes in the isotopes. Miley's claim was doubly astonishing, as his claimed transmutations used hydrogen instead of deuterium.

"If there are so many claims over so many years, some people inevitably wonder if perhaps there just might be something in them. But the cold fusion claims are mutually contradictory; if H-H fusion were to work, then D-D fusion should cause the apparatus to explode. Also, there are more experiments that find no effect than those claiming one, and these negative experiments tend to be more carefully carried out. Some claims can be rejected by other subsequent experiments: Steve Jones of Brigham Young University--originally a rival of Fleischmann and Pons who made somewhat different claims for neutron production--is now a strong opponent of cold fusion and indeed has done experiments showing that in Fleischmann and Pons's open cells, the hydrogen and oxygen gases can mingle and recombine giving out apparent excess heat. If this potential for recombination is blocked, there is no excess heat.

"With all this negative evidence, how can Fleischmann, Pons and others continue? The short answer is that true believers can always find something to encourage them, and they can ignore the rest. Cold fusion is much more persistent than previous examples of pathological science, such as polywater, which ended soon after the principal supporters gave up. Here there have been well-organized public relations campaigns.

"Initially, in 1989, Pons provided a series of escalating claims, including showing what he claimed was a working cell 'giving off 15 to 20 times the amount of energy that is put into the cell.' It was claimed that it 'could provide boiling water for a cup of tea.' Now there are several people publishing magazines, spreading claims and trying to influence media people who sometimes present their hand-outs without checking. This technique keeps the flame alive. Also some editors publish cold fusion claims in sympathetic journals such as *Fusion Technology*. They claim that at the next American Nuclear Society meeting in Orlando, to be held June 1 to 5, there will be a cold fusion session featuring a panel discussion with Miley and Patterson.

"In another, nonscientific episode, Fleischmann, Pons and Italian researchers Tullio Bressani, Guiliano Preparata and Emilio Del Giudice sued the Italian newspaper *La Repubblica*, its editor and the science editor, Giovanni Maria Pace, who had written in 1991 that cold fusion was 'scientific fraud.' The decision of the three judges was that this was justified comment, and further they awarded costs to the newspaper. They also expressed the opinion that some of the plaintiffs had lost touch with reality.

"What is the future of cold fusion? True believers never give up, and the funding keeps coming in. At first, American and some Russian work was largely funded by the Electric Power Research Industry (EPRI), which spent many millions of dollars, but that support has essentially stopped. Japanese funding seems to be on the decline after ICCF-6. But private investors remain hopeful--they tend to reason that it is worth the odd-million investment if the return on investment is worth billions. They do not appreciate, however, that the likely return is about 10^{-40}--which means that even investing one penny to earn possible billions would be a bad bet. The next cold fusion conference, ICCF-7, with private sponsors, will be held in Vancouver in April 1998. We all hope to be served a cup of cold fusion tea."

Robert F. Heeter of the Princeton Plasma Physics Laboratory is the author of the "Conventional Fusion FAQ"

(internet newsgroup sci.physics.fusion) and webmaster of the Fusion Energy Educational Web Site. He responds:

"The 'cold fusion' phenomenon, in which the law of conservation of energy is apparently violated when electricity and heat are applied to special systems involving hydrogen isotopes (in water or gaseous form) and particular metals (notably palladium and nickel), defies conventional scientific explanation. All new theories explaining 'cold fusion' effects require large revisions in existing physical theories (one might call them 'miracles'). Scientific skepticism requires that unless the experimental evidence justifies belief in these miracles, we must conclude that experimental errors are being misinterpreted as positive results.

"One would normally expect that about half of all careful energy-balance measurements would indicate excess energy, and about half would show an energy deficit, because experimental error spreads the results around the expected outcome. A preponderance of results showing excess energy might indicate something new. But if one is deliberately searching for excess energy, then one may be able to 'optimize' a complicated system to yield large amounts of apparent excess energy by fooling the measurement apparatus somehow. Whether a given excess-heat result represents a physical 'miracle' or an experimental error is very difficult to determine if the amount of excess heat is small or if the fraction of excess power to total input power is low--as is the case in reports of cold fusion.

"If indeed miracles are occurring in 'cold fusion,' they are not fusion reactions involving hydrogen isotopes. The inevitable signatures of fusion reactions--in which atomic nuclei combine, thereby releasing a large amount of energy--are combinations of energetic particles (neutrons, positrons and ions) and gamma rays. The direct conversion of fusion energy into heat is not possible because of energy and momentum conservation and the laws of special relativity. Energetic particles and their secondary effects should be easily detectable if the claimed levels of excess power were the result of fusion reactions. But measurements of these fusion signatures have been either nonexistent, inaccurate or orders of magnitude too low. Attempts to explain 'cold fusion' as something other than nuclear fusion require similar miracles supported by similarly weak evidence.

"The case for experimental error is supported by the unreliability and lack of independent replication of key results. Furthermore, the nature of the complex systems and measurement equipment involved in 'cold fusion' research is beyond the range of expertise of most researchers involved.

"'Cold fusion' resembles the alchemy of the middle ages. The search for truth suffers now, in the quest to convert hydrogen into energy, just as it did 1,000 years ago in the quest to convert lead into gold. The allure of fame and wealth and the natural desire to believe in good news have been corrupting influences on scientific skepticism. So researchers working outside their main areas of professional expertise are even more likely to misinterpret experimental errors as positive results. And it is hard not to be skeptical about a revolutionary new discovery that would so conveniently have such tremendous and immediate economic value.

"I entered graduate school wishing to help solve our impending energy crisis, so I studied 'cold fusion' carefully and with an open mind in order to make a wise career choice. I learned that the critical positive results have not been reliably and independently reproduced, and many careful and thorough studies have yielded negative conclusions, although often these unexciting results went unpublished. It is probably impossible to prove that 'cold fusion' is nothing more than the result of misinterpreted experimental errors, but the probability of it being otherwise is low.

"Efforts to disprove 'cold fusion' remind me of the O. J. Simpson case--the evidence is clear enough that most people have firm beliefs, yet truly conclusive proof is elusive. But science is not law: when one puts a scientific theory on trial in an experiment, the existing theory is presumed guilty of explaining your observations until it is proven innocent by showing that only a new theory will fit the evidence properly. Large changes in well-established theories require a stronger body of evidence. 'Cold fusion,' if true, requires radical changes in our understanding of energy and matter, but even after eight years of intense effort costing tens of millions of dollars, the evidence remains weak--although apparently the cold fusion conferences in Hawaii, Monte Carlo and elsewhere have been quite lavish. I now doubt 'cold fusion' is really an easy alchemical solution to the world's energy needs.