Kowalski, L. *Recent cold fusion claims: are they valid?* in *Eleventh International Conference on Condensed Matter Nuclear Science*. 2004. Marseille, France.

Recent cold fusion claims: are they valid?

Ludwik Kowalski
Department of Mathematical Sciences
Montclair State University, Upper Montclair, NJ, 07043

What is Cold Fusion?

Cold fusion (CF) is a mixture of several claims that may or may not be related. Some of them belong to the realm of basic science while others belong to the area of patents. And some seem to be science fiction. From the point of view of history the CF episode, described in several books (1-7) and articles (8,9), is highly unusual. It is a situation in which the validity of research in one particular field has been officially questioned, at least in the US. According to many scientists, the cold fusion claims are in conflict with basic principles of physics and chemistry. That is why most researchers are no longer interested in cold fusion. Surprisingly, however, the field still attracts a large number of investigators with excellent credentials. Once a year they meet at international conferences and publish papers, most often in conference proceedings and over the Internet (10). As a nuclear physicist, and a physics teacher, I examined some of these publications and attended one cold fusion conference (11).

My goal here is to describe the main CF claims: (a) unexpected neutrons and protons, (b) unexplained excess heat, and, the most extraordinary, (c) transmutation of chemical elements. The first claim resulted from the work of a physicist, Steven Jones, who wrote about his CF work in the early 1980's. The second resulted from the work of a world class electrochemist, Martin Fleischmann; he kept the CF investigations secret up to the 1989 press release. And the third claim can be traced to the 1990's observations of another chemist, John Bockris. For the sake of brevity each claim will be described in terms of its origin and in terms of recent reports with which I am familiar. The task of writing a systematic review of hundreds of investigations conducted by top scientists in the last ten years is beyond my capabilities; I am not a CF researcher.

The Claim of Unexpected Neutrons and Protons.

Steven Jones, working at the Los Alamos National Laboratory, was exploring muonic atoms of hydrogen and the unstable molecules they form (12). Such molecules are about 200 times smaller than their stable electronic counterparts. According to a well verified theory of the so-called "tunneling effect," the proximity of hydrogen atoms in muonic molecules increases the probability of nuclear fusion by many orders of magnitude. This is associated with the release of energy, as in stellar interiors and hydrogen bombs. For nearly a decade the work on muonic atoms was supported by the US government as a possible path toward a new source of energy. The grant, however, was not renewed after it became clear that practical applications, if any, would not materialize in the immediate future.

These investigations led to the idea that cold fusion might be occurring at very high pressures inside planets, as described in (13,14). The notion that guides Jones, of a large electron screening effect in the D-D fusion reaction for deuterons embedded in metals, has been independently confirmed by other experimental physicists (15). Can screening be responsible for lowering of the D-D coulomb barrier in a metal? Recent observations of rare neutrons and charged particles, reported by Jones (16), give credence to such speculations. The rates of observed emission are usually very low but significantly higher than the background; in one experiment the rate of proton emission was 400 times higher than the background.

The particles, identified as 3 MeV protons, were emitted from spots inside thin titanium foils loaded with deuterium. To load hydrogen ions into the foils Jones placed them (for several hours) into a cylinder filled with the deuterium gas at elevated temperature (500^{o} C) and pressure (40 psi). Emission of nuclear particles was subsequently recorded with scintillation and silicon detectors in the low-noise environment. An aluminum foil of 19 microns helped to identify charged particles as protons. Coincidences between protons and other charged particles (tentatively assumed to be ^{3}H) were observed with a set of two silicon detectors. Let me add that protons and alpha particles have also been reported by A. Lipson (17), R. Oriani (18) and A. Karabut (19). These researchers worked independently of each other; their methods of loading metals with ions, and their methods of particle detection, were very different from those used by Jones.

The process of emission of such particles remains to be interpreted. For the time being Jones favors the model according to which the 2.45 MeV neutrons and the 3.02 MeV protons are accompanied by 0.82 MeV ^{3}He and by 1.01 MeV ^{3}H, respectively, as in well known thermonuclear reactions. The probability of emission of these particles in a metallic environment, however, is much higher than expected. A recent paper, published by a large team of German scientists (15), does show that the cross section of the D(d,p)t reaction, at very low energies (down to 5 keV), is about one order of magnitude larger in the deuterated Ta than in a gas target. Similar observations were made earlier in Japan (20). Very recently, a team of researchers from Russian Academy of Science (21), found a unique way of observing protons (presumably from the same reaction) down to the energy of 0.8 keV. The observed rate of emission, at the lowest energy, turned out to be nine orders of magnitude higher than predicted by an accepted theory. This seems to indicate that the theory which agrees with experimental data above the energy of 10 keV fails to account for what happens to the embedded ions in titanium at much lower energies. But arguments about a model (screening versus other possible explanations) should not be confused with arguments about the validity of experimental data (observing unexpected neutrons and protons).

The Claim of Excess Heat

The claim of excess heat was first made in a famous press conference, on March 23, 1989. That event, and its consequences, are described in several books about cold fusion (1-5). Two scientists, M. Fleischmann and S. Pons, announced that they had been conducting research on highly unusual electrochemical cells for several years. These cells were said to be outputting more thermal energy than received in the form of electric energy. The authors wrote that chemical contributions to excess heat were found to be insignificant. On that basis they tentatively concluded that the origin of excess heat was nuclear. Rejecting this hypothesis the critics pointed out that rates of nuclear reactions accompanying excess heat, if the origin of that heat were nuclear, would be many orders of magnitude higher than what was observed.

The path of M. Fleischmann toward CF research was prompted by a theoretical consideration. In an article published in 2000 (22), he wrote: "Realization that models of electrolyte solutions had to be based on the Q.E.D. paradigm inevitably focused my attention again on the Pd/H and Pd/D systems. I had realized since the end of 1947 that these were the most extraordinary examples of electrolytes. . . . The question of whether one could induce nuclear reactions became more clearly-defined at the end of that decade [1960s]. Work on the isotopic separation of H and D showed that it was necessary to assume that the H and D present had to be modeled as many-body systems in order to explain the macroscopic behavior . . . In the early 1980's Stan Pons and I started a number of collaborative projects. . . . We decided that the project not only had to have a 'hidden agenda', it had to be totally hidden. This was all the more necessary because the military applications of any positive outcome of the research were not at all clear. . . . The overall structure of the problem had become reasonably clear by the summer of 1988. We were observing the generation of heat in excess of the enthalpy input to the cells, and far above that commensurate with the generation of tritium and neutrons predicted by measurements on 'hot fusion.' Moreover, the excess enthalpy was far beyond that which could be attributed to any parasitic chemical reactions. "

Subsequent work in the area is described in two books (6,7) and in many papers, such as (23,24). The authors of these references describe experiments in which excess heat was presumably generated. But they do not always provide enough data to rule out the possibility that a large fraction of excess heat can be due to parasitic chemical reactions, or other non-nuclear processes. Furthermore, according to Shanahan (25), the excess heat claims are due to calibration errors. It is difficult for me to accept this accusation because similar results have been reported by a large number of highly qualified scientists in several countries. On the other hand, I do not ignore the possibility of experimental bias, mutual self-deception, or even fraud. The best evidence that the excess heat is nuclear would be to show the commensurate accumulation of byproducts of nuclear reactions, such as ^{4}He. This will be discussed in the next section.

The most recent contribution, in the area of excess heat, belongs to a group of Chinese scientists (26). X. Li, a veteran of cold fusion research, did not use electrochemistry to load palladium with deuterium. The excess heat was generated when compressed gas was allowed to diffuse through a thin palladium wall. According to the authors, that heat could not be explained by the well known Joule-Thomson effect or by chemical reactions. They write: "this experiment has been repeated 6 times already in various configurations. The 'excess power' density in the Pd disk is more than 100 W per cubic centimeter, which is about the power density in a fuel rod of a thermal neutron fission reactor." Reproducible results on generation of excess heat, in a glow discharge chamber (another non-electrolytic method of loading metals with D+ ions), were also reported by Russian scientists (19).

Generation of excess heat without producing radioactive material would certainly be desirable. But how can nuclear energy be released without commensurate amounts of radioactivity? According to some theoretical considerations (27), deuterium ions embedded in crystals might be influenced by a large number of atoms able to supply and to remove energy "in unison". Theoretical modeling of natural phenomena, however, and attempts to validate these phenomena experimentally, are two different things. Arguments for or against models do not resolve disputes about validity of experimental data.

The Alchemy Claim

Attempts to change one chemical element into another are usually referred to as alchemy. Such transformations are believed to be impossible unless nuclear reactions are involved. A nuclear fusion of two deuterons (^2H + ^2H), for example, nearly always results in production of either ^3He or ^3H (associated with the emission of neutrons and protons, respectively). Turning atoms of one element into atoms of another element, such as ^2H into ^3He, by means of nuclear reactions, is usually called transmutation. Atomic nuclei repel each other and for that reason they are not expected to fuse spontaneously at temperatures below tens of millions of degrees. That is why the claim of nuclear origin of excess heat was not taken seriously when it was first made in 1989. But several years later J. Bockris reported (28) accumulation of ^4He, and other atoms, in the electrodes of cold fusion cells. Some of his early claims were later withdrawn (29) due to irreproducibilities.

Progressive accumulation of ^4He, however, was later observed by other investigators (30,31). They reported that helium generated via cold fusion is mainly ^4He; the ^3H and ^3He atoms are produced much less frequently. The situation is dramatically different from what happens in thermonuclear reactions taking place in ionized gasses. In these reactions the probability of the ^2D+^2D--> ^4He (releasing about 24 MeV of energy) is 10^{-6} while the probabilities of reactions producing ^3H and ^3He (releasing about 3 MeV of energy) are roughly 0.5 each. How can this difference be explained? That is one of the many unanswered theoretical questions. At present, however, the main issue is experimental rather than theoretical.

Is the accumulation of ^4He, at the rate of about one atom per 24 MeV of excess heat, real or apparent? It is natural to suspect that helium comes from the surrounding air and not from a totally unexpected nuclear reaction. The authors of the above mentioned reports, however, addressed this issue and ruled out the possibility of atmospheric contamination. If confirmed, such findings could become very significant. They would indicate that ^4He is the main "ash" of the mysterious CF burning, at least in some cases. A connection between the excess heat and alchemy would be established. Observation of alpha particles emitted from metallic foils loaded with deuterium, reported by two Russian teams (16,19), might also be linked with the accumulation of helium. It is significant, however, that the reported rates of alpha particle emission are not commensurate with the rate of generation of excess heat.

Production of elements heavier that helium, first reported and then withdrawn by Bockris, was later heralded by some investigators (6,19,32). Results from a very extensive study are summarized in (33). The most recent report in this disputed area was presented by Iwamura, from Advanced Technology Research Center, Mitsubishi Heavy Industries, Ltd., in Japan. Addressing the 10th international CF conference (August 2003) Iwamura described a fascinating setup (34) in which cesium was turned into praseodymium and strontium was turned into molybdenum. The paper describing these experiments (35) had already been published in the prestigious Japanese Journal of Applied Physics (JJAP). Was I the only one whose first reaction, during Iwamura's conference presentation, was to think about pseudo-scientists?

Imagine a 0.1 mm membrane, mostly Pd, forming a window of a container filled with deuterium. The gas diffuses slowly through the membrane and enters a vacuum chamber (from which it is constantly removed by a pump). On the deuterium side the membrane is covered, either electrolytically or by the ion injection method, with a material to be transformed. Using highly sophisticated analytical tools the researchers were able to show that the amount of deposited material, such as purified Cs or Sr, decreases, while the amount of new material, such as Pr and Mo, increases at the same rate. Comparing this situation with a typical nuclear reaction setup (a target and a beam from an accelerator) the authors write: "Analysis of the depth profile of Pr indicated that a very thin surface region up to 100 angstroms was the active transmutation zone. Many experimental results showed that the quantity of Pr was proportional to the deuterium flux through the Pd complex. The cross section of transmutation of Cs into Pr can be roughly estimated at 1 barn if we consider the deuterium flux as an ultra-low-energy deuteron beam."

The view of the membrane in Figure 1 (of their paper), shows that it is essentially a 0.1 mm Pd foil coated with several alternating thin layers of CaO and Pd. The first layer encoutered by deuterium, as it enters the membrane, consists of Pd; it is 400 A thin. Pure Cs or Sr were deposited on that layer. As indicated in another figure, it took nearly 100 hours to turn all atoms of Cs (about $1.3*10^{15}$) into atoms of Pr; transformation of an equal amount of Sr into Mo took about 300 hours. The Cs --> Pr experiment was performed two times while the Sr --> Mo experiment was performed three times; the results were shown to be reasonably reproducible. I find it highly significant that the isotopic composition of Mo, produced from Sr, is drastically different from that found in nature. This seems to rule out the possibility of contamination (redistribution of impurities). On the other hand, I recognize the exotic nature of the suggested mechanism (see below) and the small amount of products (fractions of microgram).

Low energy transmutations in condensed matter, reported by Iwamura, have recently been repeated by scientists from Osaka University (36). Here is a quote from their brief description: "As a result, we confirmed that the nuclear transmutation reaction, from

^{133}Cs to ^{141}Pr, occurred. This transmutation suggests that the mass number and the atomic number increase by 8 and 4, respectively. . . The model of multi-body resonance fusion of deuterons, proposed by A. Takahashi, can explain this mass-8-and-charge-4-increased transmutation, as follows:

(Primary reaction) : 8D --> $^{16}O^*$ --> $^{8}Be^*$ + $^{8}Be^*$ + 95.2 (MeV)

(Secondary reaction) : ^{133}Cs + ^{8}Be (47.6 MeV) --> $^{141}Pr^*$ (50.47 MeV)

or $^{8}Be^*$ --> ^{4}He + ^{4}He

If the phenomena occur according to this model then ^{4}He should also be produced. So we are trying to detect ^{4}He."

I am puzzled by some aspects of the suggested model. For example, I do not understand the nature of the "multibody resonance" process by which eight deuterons fuse to form a highly excited (109.8 MeV) oxygen nucleus. If the $^{141}Pr^*$ nuclei are excited, as indicated by the asterisk, then characteristic gamma rays would be emitted. But why should this influence my attitude toward experimental data? It is interesting that radioactive byproducts (of presumed nuclear reactions) are not mentioned in (33) or in (34). Most radioactive byproducts would be much easier to identify, in small quantities, than their stable counterparts. Confirmed absence of radioactive byproducts would indicate that nuclear reactions in condensed matter (presumably responsible for exotic transmutations), are totally different from common nuclear reactions. This has already been suggested by those who investigated generation of helium.

Final Comments

Cold fusion is not taken seriously by most scientists. But, according to my own informal survey, the opinion of many is still based on what was known in 1989 and not on recent publications. I think that the often repeated labels, such as "pseudoscience" and "fiasco of the century" were justifiable in 1989, when the ERAB report was published. The ERAB, Energy Research Advisory Board (37), was a team of American experts appointed to evaluate the CF claims. But are such labels justifiable today? Most of us are not equipped to answer this question through laboratory investigations. That is why another official evaluation, for example, by teams of experts appointed by the US National Academy of Sciences, is desirable. Each of the three claims should be investigated independently; finding that something is wrong with one does not necessairely mean the other two claims are not valid.

Are the credentials of CF scientists doubtful or not? Are their ways of validation consistent with scientific methodologies? Is there any evidence of deliberate deception? Answers to such questions should help us decide what to think about the controversial field, and what to tell students when they ask questions about it. For the time being I tell them that cold fusion is nothing more, and nothing less, than an area of investigation that has to be explored because a large number of competent scientists are working in it. The degree of support, as in any other area of basic research, should depend on results at hand, on available means, and on the rate of progress. I also tell students that claims conflicting with what is known about natural phenomena should not be accepted without extraordinary evidence. Let me end this essay by quoting from an e-mail message received from a recognized authority in the area of nuclear chemistry.

“The whole atmosphere around CF has been filled with poisonous material, some valid and some emotional. One must be very careful, on entry into such an atmosphere, to be protected by a useful theoretical proposal or at least a plausible explanation that can be subjected to experimental tests. On the basic level there are two obvious questions:(1) How could hydrogen atoms fuse at such a low temperature? (2) If they do fuse, how is the energy released (if not in gamma rays, then how) i.e. what reaction occurred? If one has no proposed answer or proposed experiment to get an answer, then one is in a state of massive weakness. . . . I infer that the major skepticism in the mainstream nuclear science community stems from the silence on the basic two questions above. . . . Such skepticism seems to me to be justified until something reasonable is proposed or, better yet, demonstrated. Until then, essentially all responses will be ‘impurities or errors’.”

Yes, these two theoretical questions are very important. But, as indicated above, arguments about models should not be confused with arguments about the validity of experimental data. No theoretical model existed when excess heat from radium was discovered by Pierre Curie. On the other hand, experimental findings conflicting with confirmed theories, as in the case of cold fusion, should be scutinized very carefully before being accepted. That is why many of us would benefit from another formal investigation of the main CF claims by experts.

References:

1) F.D. Peat, "Cold Fusion", Contemporary Books, Chicago, 1989.
2) F. Close, "Too Hot to Handle: the Race for Cold Fusion," Princeton University Press, Princeton, New Jersey, 1991.
3) E.F. Mallove, "Fire from Ice: Searching for Truth Behind the Cold Fusion Furror," John Wiley & Sons, Inc., New York, 1991.
4) G. Taubes, "Bad Acience: the Short Life and Weird Times of Cold Fusion," Random House, New York, 1993.
5) J.R. Huizenga, "Cold Fusion: The Scientific Fiasco of the Century," Oxford University Press, 2nd editions, Oxford, 1993.
6) T. Mizuno, "Nuclear Transmutations: The Reality of Cold Fusion," Oak Grow Press, Concord, NH, 1998.
7) C. Beaudette, "Excess Heat. Why Cold Fusion Research Prevailed." Concord, NH, 2000.
8) G.H. Miley,”Some personal reflections on Scientific Ethics and the Cold Fusion ‘Episode;’“ Accountability in Research,” 2000. 8: p. 121.
9) D. J. Nagel, “Cold Fusion and Philosophy,” Accountability in Research,” 2000. 8: p. 137.
10) A large number of “cold fusion” papers is downloadable over the Internet, in the form of pdf files, from the library section at

http://www.lenr-canr.org
11) The Tenth International Conference on Cold Fusion was held in Cambridge, Massachusetts 24 - 29 August 2003. Proceedings, in the form of pdf files, can be downloaded from the Internet site at http://www.lenr-canr.org/iccf10/iccf10.htm
12) S.E. Jones et al., Phys. Rev. Lett, 51, 1757 (1983)
13) S.E. Jones et al., Phys. Rev. Lett, 56, 588 (1986)
14) S.E. Jones et al., “Cold Nuclear Fusion,” Scientific American, July 1987, p 7
15) F. Raiola et al., "Enhanced electron screening in d(d,p)t for deuterated Ta" Eur. Phys. J. A 13, 377-382 (2002).
16) S.E. Jones et al.; August 2003. See three papers presented at the 10th International Cold Fusion Conference (ref. #11 above).
17) A. Lipson et al.; August 2003. See his paper presented at the 10th International Conference on Cold Fusion (item 11 above).
18) R. Oriani et al.; August 2003. See his paper presented at the 10th International Cold Fusion Conference (ref. #11 above).
19) A. B. Karabut et al.; “ “Nuclear product ratio for glow discharge in deuterium;” Phys. Let. A, 170, p 265, 1992. (A much more detailed report, based on recent data, was presented at the 9th International Cold Fusion Conference in China (2002). See reference 10 above.)
20) J. Kasagi et al., “Anomalously Enhanced D(d,p)T Reaction in Pd and PdO Observed at Very-Low-Energy Bombardments.” This 1998 paper is available over the Internet (see ref. 10 above).
21) A. Lipson et al., “Enhancement of DD-reaction Accompanied by X-ray Generation in a Pulsed Low Voltage High-Current Deuterium Glow Discharge with a Ti-Cathode.” This 2003 paper is available over the Internet (see reference 11 above).
22) M. Fleischmann, “Reflections on the Sociology of Science and Social Responsibility in Science, in Relationship to Cold Fusion;” Accountability in Research, 2000. 8: p. 19.
23) M. McKubre, This paper, presented at the 10th International Cold Fusion Conference, is available over the Internet (see ref 1 above).
24) E. Storms, 2000. "Excess Power Production from Platinum Cathodes Using the Pons-Fleischmann Effect," in Eighth International Conference on Cold Fusion. 2000 Lerici (La Spezia), Italy. This paper is available over the Internet (see ref. 11 above).
25) K. Shanahan “A systematic error in mass flow calorimetry demonstrated,” Thermochimica Acta 387 (2002) pages 95–100. This article is available over the Internet (see ref. 11 above).
26) X.Z.Li et al., “Correlation between abnormal deuterium flux and heat flow in a D/Pd system, ” J.Phys, D: Appl.Phys.36 (2003) 3095-3097. This article is available over the Internet (see ref. 11 above)
27) T. Chubb, S. Chubb and P. Hagelstein. Each of these authors has an abstract of a paper to be present at the March 2004 meeting of American Physical Society. These abstracts can be seen at the APS web site: http://www.eps.org/aps/meet/MAR03/baps/abs/S9530.html

28) J. Bockris “Early Contributions From Workers at Texas A&M University to (So-Called) Low Energy Nuclear Reactions.” Journal of New Energy, Vol 4, no 2, 1999, p. 40
29) J. Bockris, G. Lin, and N. Packham " A Review of the Investigations of the Fleischmann-Pons Phenomena," in Fusion Technology , 18, 11-31, August (1990)
30) M. Miles, and B.F. Bush, "Heat and Helium Measurements in Deuterated Palladium." Trans. Fusion Technol., Vol. 26(4T), p. 156., 1994.
31). Y. Arata, and Y. Zhang, "Helium (He-4, He-3) within deuterated Pd-black." Proc. Japan Acad. B, Vol. 73, p. 1, 1997.
32) T. Ohmori et al. (1996), “Iron Formation in Gold and Palladium Cathodes,” J. New Energy, vol 1, no 1, pp 15-22.
33) G. Miley, et al., 2000. "Advances in Thin-Film Electrode Experiments;" 8th International Conference on Cold Fusion. Lerici, Italy. This paper is downloadable from the library at http://www.lenr-canr.org
34) Y. Iwamura et al. “Energy Nuclear Transmutation In Condensed Matter Induced By D2 Gas Permeation Through Pd Complexes: Correlation Between Deuterium Flux And Nuclear Products” This paper is available over the Internet (see ref 1 above).
35) Y. Iwamura et al. “Elemental Analysis of Pd Complexes: Effects of D2 gas permeation. Jpn. J. Appl. Phys. 41 (2002), pp. 4642-4648.
36) T. Higashiyama et al. “Low Energy Nuclear Transmutation In Condensed Matter Induced By D2 Gas Permeation Through Pd Complexes: Correlation Between Deuterium Flux And Nuclear Products.” This paper is available over the Internet (see ref 1 above).
37) The executive summary of the Energy Research Advisory Board (ERAB) report can be found in (5). The "Cold Fusion Research. A Report of the Energy Research Advisory Board to the United States Department of Energy," can be downloaded from the Internet site: http://www.ncas.org/erab).