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Review Article

Judging the Validity of the Fleischmann–Pons Effect

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Abstract

The Fleischmann–Pons Effect (FPE, aka cold fusion) was rejected as legitimate science within a year after its announcement in 1989. The growing need for a source of clean energy makes a re-examination of the initial rejection increasingly important. An effective way of assessing the status of the effect as legitimate science is to apply criteria that have been established by scientific skeptics. When 27 criteria set forth by Langmuir, Sagan and Shermer are applied, the requirements for scientific legitimacy appear to be met. In addition, a large and growing number of independent experiments are consistent with a nuclear mechanism being the cause of FPE.

Keywords: CMNS, Cold fusion, Critique, Nuclear energy, Review

1. Introduction

The phenomenon called cold fusion (CF), low-energy nuclear reaction (LENR), chemically assisted nuclear reaction (CANR), or condensed matter nuclear science (CMNS) was first demonstrated by Profs. Martin Fleischmann (former head of electrochemistry at the University of Southhampton) and Stanley Pons (then chairman of the Chemistry Department at the University of Utah) in papers starting in 1989 [1–26]. They claimed that a fusion reaction between deuterons could be initiated in palladium after it had acquired a high concentration of deuterium. Their claim was based mainly on production of too much heat energy to be explained any other way. This anomalous result is called "excess energy" or "excess power" in this paper and the general phenomenon is referred to as the Fleischmann–Pons Effect (FPE). Later, work showed that they had discovered a universal phenomenon that could be initiated several different

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ways with similar results. Like most discoveries, theirs only revealed the tip of the iceberg. Eventually, the effect was found to result in helium-4, tritium, and various transmutation reactions, in addition to energy production. However, this paper is not a complete scientific review but rather an evaluation of criteria used by various skeptics to reject the claims. The reader is directed to the citations for more detail about what is known.

A combination of issues created a growing skepticism about the validity of the claims and experimental results. These issues included a significant difficulty in reproducing the claimed excess energy, conflicts with conventional theory, and the challenge that such a simple and low-cost source of energy could pose for the hot fusion program as well as for conventional sources of energy. Especially troubling was the absence of neutrons or other energetic radiation, all of which were expected based upon the nuclear products found using the plasma fusion method or when high-energy deuterium ions bombard a solid. Consequently, many influential scientists [27–34] became outspoken critics of the claim, only a small sample of which is cited here. The US Department of Energy (DOE) established the official policy of the US government in 1989 with a written report provided by the Energy Research Advisory Board (ERAB) [35]. A second review [36] was undertaken in 2004 and arrived at a similar, but less extreme negative opinion.

During the 20 years since the original claim, hundreds of successful replications have been published, and important understanding of the process has been achieved. Apparent reaction rates have been achieved starting at a few events per second to rates that exceed 10^{14} events per second, most well in excess of expected error. Nevertheless, a strong skeptical bias exists in the scientific profession even though many papers, reviews, and books have been published arguing that the phenomenon is real and important. Part of this bias is based on ignorance of what has been discovered. A vicious cycle has apparently developed: because of this bias many respected scientific journals will not publish information on the subject. As a result, information does not reach the professional public and potential reviewers of submitted papers then reject the work as being poor science.

Physical science has adopted criteria that can be used to evaluate the reality of claims. Variations on these criteria have been proposed by several respected scientists including Irving Langmuir, Carl Sagan, and Michael Shermer. These criteria can be stated as questions that this paper will use to answer the basic question: "Is cold fusion science or pseudoscience?" This question has become increasingly important because the skeptical bias continues even though the need for the kind of energy promised by this effect becomes more critical and as evidence supporting the claims mounts.

Using the information provided here, the reader can decide in an objective way whether the claims meet the criteria required of good science and whether further study of the evidence is warranted. For brevity, only a fraction of the available papers and published observations are cited or discussed. A complete list of citations to the evidence exceeding 1000 publications can be found in books [37–44] and on websites [45–47].

2. Summary of evidence for the Fleischmann–Pons effect

FPE research has continued vigorously during the 19 years following its rejection early in 1990 by many people. The FPE effect has been achieved by four different methods – electrolysis, exposure to ambient gas, gas discharge, and sonic implantation. Sufficient evidence is now available to evaluate the effect with respect to experimental results, theory development, methods employed, and the number of people doing the research. Before addressing the criteria required of good science, a brief general summary of the evidence is provided based mainly on the electrolytic method for which the greatest number of replications exist.

2.1. Results of investigations

The five claimed experimental indicators (signatures) of FPE reactions are energy production in excess of any known chemical reaction, production of helium and tritium, radiation characteristic of nuclear reactions, and transmutation of one element into another. Of these, helium and energy production have been shown to have a quantitative relationship to each other. In addition, a few experimental variables, including current applied to an electrolytic cell, deuterium concentration in a palladium cathode, and the nature of the materials, have been shown to clearly influence production of excess energy. Additional variables are actively being explored and are frequently found to influence the process. The important variables are still not well enough understood to make the process occur with a frequency sufficient to allow efficient exploration of the mechanism. Although many attempts have been made to explain the observations, none has been fully successful and is generally accepted. Clearly, much more effort has to be invested before these problems can be solved. This paper explores some reasons why this effort is not being applied and why it should be.

2.1.1. *Experimental indications*

Storms [37] has listed over 380 reports of successful experiments for the four FPE signatures as shown in Table 1. This list contains only those reports that could be described in a quantitative way. Hence, many more successful observations that are non-quantitative were actually made. Furthermore, more than one successful test was frequently reported in the cited publication but not counted in this list. Consequently, this is a minimum number of known successful results as of 2007. Many more have been reported since then. Of course, many more failures, both reported and unreported, exist. The number of failures is not important in evaluating the claims because many conditions, both known and unknown, can prevent the effect from occurring. Some of these are addressed.

Table 1. Reported successful FPE experiments (Table number and page numbers are those in the book by Storms [37]).

	Table No., pages	Number of successes
Excess heat	2, 53–61	184
Tritium production	6, 79-81	61
Helium	Not in table form	6
Transmutation	8, 93–95	80
Radiation	11, 101–104	55
	Total	386

Most of the effects are large and easily detected when they occur at all. Heat, helium, tritium, and energetic particle radiation have been detected at levels well above the expected uncertainty of each measurement. However, neutron emission is detected only at low levels near the detection limit even though many attempts have been made to find this anticipated emission. Four of the signatures are described below.

(A) *Excess Energy* has been measured by four different types of calorimeters – single wall isoperibolic, double-wall isoperibolic, flow-type, and Seebeck. Excess heat has been detected over a wide range as shown as a histogram in Figs. 1 and 2 of reported success vs reported power. The compared measurements are selected from the complete list on the basis of an acceptable expected uncertainty. The range of excess energy is from 0.005 to 183 W, depending on sample size, applied current, and amount of nuclear-active material present on the cathode, which has been shown to be the source of the extra energy. Clearly, the effect is not always small and is usually well in excess of expected error for the method used.

If excess energy results from a nuclear reaction, nuclear products and radiation should be detected. This necessary requirement has been satisfied. Tritium has been created several different ways, but not enough to explain the excess energy. On the other hand, the amount of helium detected is consistent with the amount of excess energy. When suitable detectors are applied, energetic radiation is also detected, but not the type and energy expected based on the behavior during hot fusion. Failure to find the same products as produced by hot fusion has been a major reason for rejection.

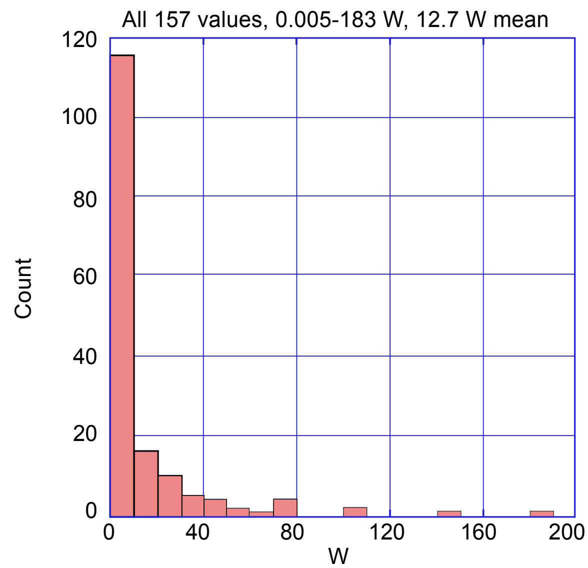

Figure 1. Histograms of reported excess energy [37]. All 157 values, with a range of 0.005–183 W.

(B) *Tritium* is easy to measure because it is radioactive. However, because D_2O always contains a small amount of tritium, the amount made by a claimed fusion process is the amount found in the cell above this background value. Sixty-one [37] independent reports have been identified using electrolyte cells containing D_2O as well as during

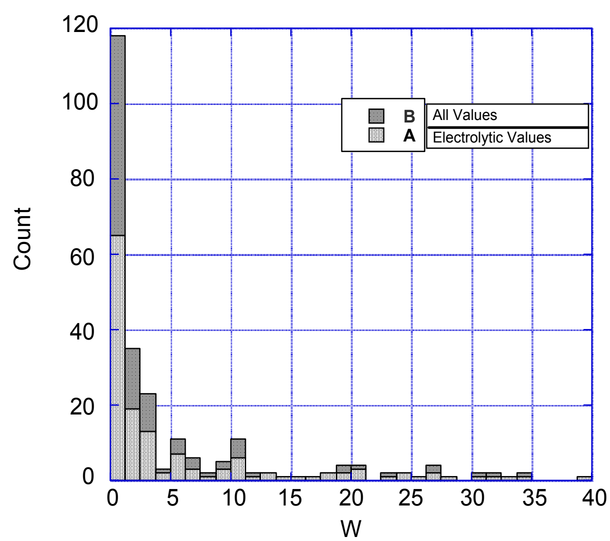

Figure 2. Histograms of reported excess energy [37]. Experiments producing power up to 40 W. Values are shown for all experiments and experiments using electrolytic cells.

low-voltage gas discharge using deuterium gas. Because most researchers do not have access to equipment required to measure tritium, the number of successes might be greater. The amount has been reported as high as 2×10^5times background [48] and as many as 2×10^{16} atoms have been produced in one study [49]. The neutron/tritium ratio is always small with a value between 10^{-4} and 10^9 based on 14 studies. This small neutron/tritium ratio is in sharp contrast to a value of unity found under hot fusion (plasma) conditions.

(C) *Helium* is the main nuclear product of FPE, but it is a challenge to measure accurately because the natural concentration of helium in ambient air is about 5.2 ppm. Helium from the air can enter a cell through a leak or by diffusion through the walls, thereby adding uncertainty to the small signal. In addition, the mass of helium and deuterium are sufficiently similar that great care is required to distinguish between the two species in a mass spectrometer. Nevertheless, studies have shown a relationship between the amount of heat produced and the amount of helium detected [50–59].

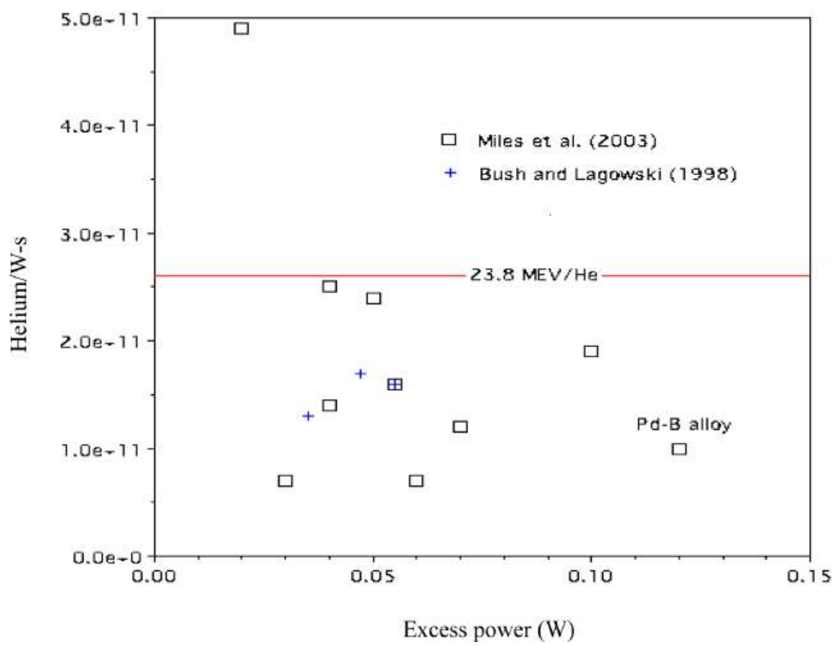

Figure 3. Comparison between several measurements of amount of helium released by the cathode divided by the energy measured as a function of excess power [37] The expected ratio is shown by the horizontal line at 23.8 MeV/He. The cathode is palladium except in the one case when a Pd + B alloy is used, as indicated on the figure.

Figure 3 compares the results from two independent studies using different palladium samples as the cathode and different calorimeter types. All but one of the points fall below the expected ratio (horizontal line) because at least half of the generated helium is usually retained in the cathode, which prevents it from being detected in the generated gas. The data reported by Bush and Lagowski [56] has less scatter than the study reported by Miles et al. because a Seebeck calorimeter was used instead of a double-walled isoperibolic type [58,60]. A similar relationship between heat and helium generation is indicated in both studies. Excess energy along with helium, apparently from FPE, has also been produced [61–65] and replicated [66] simply by exposing special materials to deuterium gas.

(D) *Radiation* of various kinds is expected when a nuclear reaction occurs. For example, helium production from fusion is expected to be accompanied by gamma radiation. Other fusion reactions are expected to emit energetic charged particles, X-rays can be produced by Bremsstrahlung, and neutrons might be produced by energetic alpha particles interacting with various light elements. If the process is similar to hot fusion, emission of energetic tritons, protons, and neutrons will occur.

One of the unexpected behaviors of the FPE is the absence of significant energetic radiation. Occasionally, energetic electromagnetic radiation is found using X-ray film [67–74], and gamma ray detectors. Energetic particle emission is detected using CR-39 [75–81], silicon barrier detectors and Geiger–Mueller detectors. However, the intensity of the radiation does not appear to be consistent with the amount of excess energy. Once again, anomalous behavior associated with nuclear activity is clearly observed during FPE, but it is not consistent with conventional expectations.

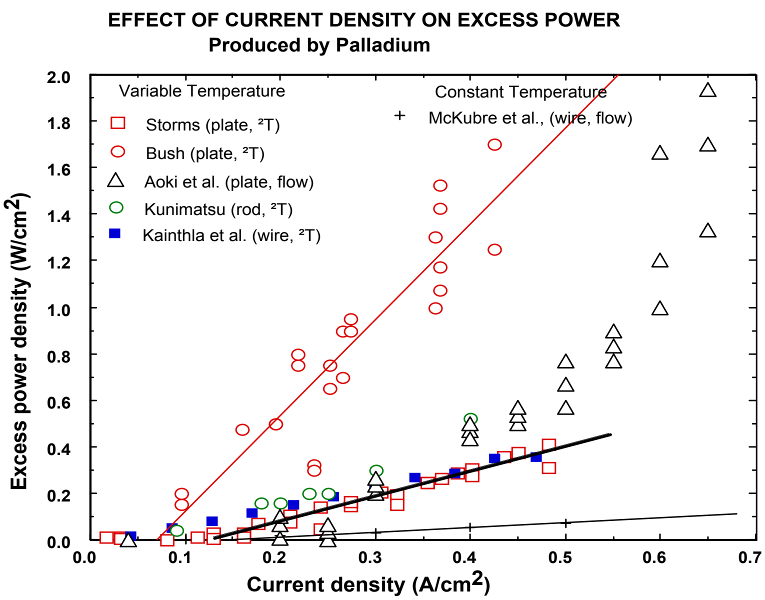

Figure 4. Examples of the effect of applied current on excess power using bulk palladium as the cathode in electrolytic cells [37]. This relationship has been found in all studies of bulk palladium when the values are measured.

2.1.2. *Correlation of cause and effect*

The amount of excess power has been related to applied current (Fig. 4), D/Pd ratio (Fig. 5), and the source of cathode materials. Some batches of palladium are more successful than others regardless of the method used to initiate the anomalous effects. Recently, laser stimulation has been found to enhance the effect [82–94]. More is said about the effect of variables in Section 2.4

2.1.3. *Possible prosaic explanations of heat and tritium observations*

Experimental observations of FPE have been questioned as being the result of error, contamination, or other common sources. The most significant are questions about heat and tritium production. FPE can be accepted only after such processes are ruled out. The questions are discussed in detail because different types of evidence may have several different simple explanations. As expected, many prosaic explanations have been proposed. Only the most plausible are discussed here.

(A) *Heat:* Several different types of calorimeters and cell design, each with its own source of error, have been used and allow the influence of some processes to be evaluated.

Calorimeter: The popular isoperibolic type of calorimeter uses a temperature difference between the electrolyte fluid and the outside of the cell to determine the rate at which heat flows through the wall of the cell. Any temperature gradient within the liquid, caused by convection currents, can introduce an error. The original work of F–P was criticized for having this error [103,104].

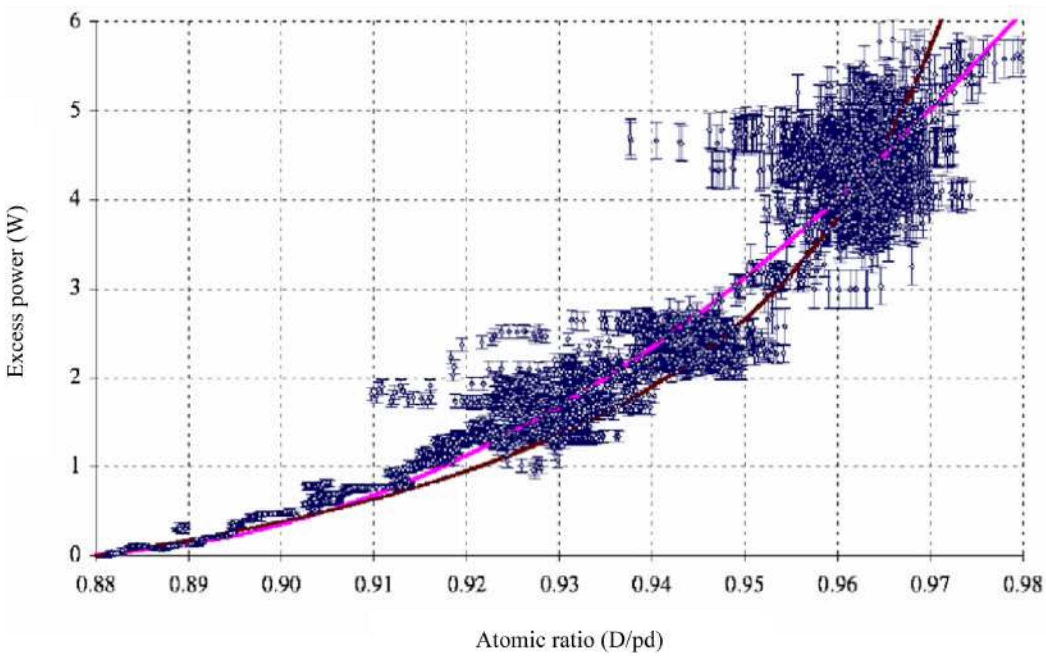

Figure 5. Examples of the effect of average D/Pd ratio of a Pd cathode during electrolysis [51,95]. Only samples of bulk palladium with a D/Pd above a critical value are found to produce excess energy.

This error is eliminated by using calorimeters that do not require measurement of temperature within the cell, such as the flow-type, Seebeck-type, and the double wall isoperibolic-type calorimeter. Production of excess heat energy has been observed numerous times using these types of calorimeter as has been tabulated by Storms [37]. Consequently, calorimeter error based on temperature gradients is no longer a rational explanation of excess energy in many studies.

Cell Design: Electrolysis releases D_2 and O_2 from the D_2O in the electrolyte. If these gases are allowed to leave the cell, as occurs when the so-called open cell is used, energy is lost and a correction needs to be made. This correction can be in error if an unknown amount of this gas recombines to form D_2O within the cell. Again, the original work of F–P was criticized for having this error even though they were fully aware of and took pains to eliminate the error [105].

This error can be eliminated by measuring the amount of electrolyte missing from the cell, as Fleischmann and Pons did. Such a measurement provides the exact amount of gas that exited the cell for which a correction can be made. Alternatively, a catalyst can be placed in the cell that recombines all the D_2 and O_2 back to D_2O, thereby eliminating any gas that might leave the cell and allowing the cell to be closed to any entry or loss of gas. Excess heat energy has been observed when such closed cells have been used as well as when the amount of missing D_2O is measured. Consequently, an error based on unknown recombination within the cell is no longer a rational explanation for excess energy in many studies.

Energy Storage: Energy might be stored in the cell if electrolysis lasts for a long time before excess heat is detected, which could be released later and misidentified as excess energy. This potential source of extra heat has been addressed in two ways. First, all chemical reactions that might take place in such a cell have been examined [106] and found to be too small to account for most of the observed excess power. Second, the excess power is found on many occasions to start soon after electrolytic power is applied, especially after the material has been activated by previous electrolysis or after application of an active layer. Consequently, very little energy has been added to the cell before excess energy is detected. In addition, excess power produced by direct reaction between special materials and deuterium gas provides no opportunity for energy storage. Therefore, many observations attributed to FPE exist that cannot be explained by energy storage.

If such a chemically simple system having such a small mass could store the amount of energy occasionally produced, the process would be thousands of times more potent than the best batteries and could produce the most powerful explosive or chemical fuel known. If energy is actually being stored and then released, this ability should demand intense examination, rather than being cited as a reason to reject or ignore the claims.

(B) *Tritium:* The claimed extra tritium has been proposed to result from contamination of the palladium metal, from ambient tritium in the environment leaking into the cell, or by enrichment of the tritium initially present in the D_2O. Each of these potential sources of tritium has been evaluated. Cedzynska et al. [107–109] analyzed ninety samples of palladium obtained from various commercial sources and found no tritium contamination. In fact, the process of refining commercial palladium would remove all trace of hydrogen. In addition, many studies used palladium that had been purposely subjected to a treatment that is known to remove all dissolved tritium. On the other hand, Storms and Talcott-Storms [110] showed that when any tritium dissolved in palladium is removed during electrolysis, it always is found in the gas, not in the electrolyte where anomalous tritium is always found. Consequently, tritium contamination of palladium as an explanation is not supported by observation.

Tritium entering from the environment would accumulate in the cell immediately, in contrast to the delay that is frequently observed. Besides, the concentration of tritium in the environment is much smaller than the concentration of tritium created in many cells. Extra tritium caused by enrichment within an electrolytic cell has been eliminated in numerous cases by using a sealed cell or by applying corrections. When these factors are taken into account, the amount of tritium detected in many studies is far in excess of any rational explanation based on contamination.

In addition to tritium being occasionally observed in electrolytic cells, it has also been produced in sealed cells subjected to gas discharge of deuterium at voltages too low to produce conventional fusion [111–113]. This tritium has been shown not to result from contamination and it has been measured using two different methods that give consistent result. Success is related to the metal alloy used as the cathode.

2.1.4. *Conditions for experimental success*

Certain conditions are now known to be required for results consistent with FPE to be produced [96,97]. When these conditions are not met, the required behavior will not be observed and the experiment cannot be used to evaluate the reality of the basic claim. Failure to achieve these conditions is the major reason replication has been difficult. Six necessary conditions for the electrolytic method are described below. The other methods have their own set of conditions that would not be discussed here.

No. 1. The D/Pd ratio in the bulk palladium cathode should be in excess of a critical value.

Compositions in excess of a critical value are required in order to support the critical higher composition on the surface. This critical minimum is difficult to achieve and it is variable because it depends on the nature of the active surface. The surface composition can be determined using the open-circuit-voltage [98,99] when the electrolytic method is used.

No. 2. The palladium must be free of cracks

Stress produced during loading of deuterium into the palladium lattice, combined with impurities in the palladium, can produce cracks. These allow deuterium to leave the metal and prevent the critical D/Pd ratio from being achieved at the surface. Initial reaction with deuterium needs to be done slowly at low current density to reduce the formation of these stress fractures [100]. The crack density can be determined by comparing the measured volume to the expected volume based on the D/Pd ratio [101].

No. 3. Except for thin coatings of palladium on platinum, the applied current density has to be above a critical value near 100 mA/cm^2 before detectable heat will be produced

The current must be sufficient to compensate for the loss of deuterium from the cathode in order to achieve the critical surface composition (see Fig. 4) The value depends on the shape of the cathode [102]. A thin coating of palladium plated on platinum does not show a need for a critical current because the loss is much less than from a bulk sample.

No. 4. The D_2O used in the electrolyte must be as free of H_2O as possible.

The presence of H_2O even at the one atomic percent level in D_2O will add enough H^+ to the palladium to stop the heat producing process. Many early studies did not take care to keep the D_2O free of H_2O. The H_2O content can be determined using NMR. However, under certain conditions, cells containing only H_2O have been found to produce excess energy, occasionally by what is proposed to be a nuclear process. Therefore, this electrolyte does not necessarily constitute a blank that can be used to test a calorimeter, as was required of Fleischmann and Pons by various skeptics.

No. 5. Certain impurities in the D_2O electrolyte are known to help and others are known to hinder the process. Therefore, care must be used to insure that the D_2O remains pure

Successful cathodes are frequently found to have silicon dioxide and other stable oxides on their surface. Addition of aluminum or arsenic to the electrolyte has also been found to help achieve the required high deuterium content. However, exposure of copper, such as from unprotected connecting wires, to the electrolyte can result in copper being deposited on the cathode and a failed experiment. A complex assortment of elements is normally found on cathodes after a long study, the role of which is gradually being understood. Some can be beneficial and other might be harmful, which can account for the unpredictable success or failure.

No. 6. Application of additional energy may help initiate the effect

Other conditions are now known to help the process such as application of non-equilibrium conditions and extra energy such as by using a laser, applying RF, or heating the cell to a higher temperature.

Many experiments undertaken early in FPE history did not meet the conditions listed above and could not have succeeded, but were nevertheless cited as evidence that Fleischmann and Pons were wrong. Because all required conditions are still not known, an experiment can nevertheless fail even when the above conditions have been satisfied.

2.2. Theory development

An adequate theoretical underpinning of FPE experimental observations has not yet been achieved. Nevertheless, a number of novel theories have been proposed. The challenge is to account for the very different environments in which hot (plasma) fusion and cold fusion operate. The high concentration of electrons combined with a regular arrangement of atoms in a crystal lattice may allow mechanisms to surmount the Coulomb barrier that do not exist in gaseous plasma, thus providing a way to solve the apparent conflict between observation and expectation.

Theoreticians have taken several different paths. One group proposes that the nuclear reactions result when neutrons are added to various nuclei. These neutrons are proposed to be in the material as a stable cluster that is occasionally made reactive. Or the neutrons are created in the material by a process unique to each theory. Because neutrons have no charge, the Coulomb barrier is not a factor. However, the proposed source of the neutrons requires several novel processes to operate and most of the nuclear products are not consistent with neutrons being involved because many such reactions produce radioactive isotopes that are not found.

Another general approach is based on overcoming the Coulomb barrier in various ways. Various processes are proposed to force the deuterons close enough to cause a detectable reaction or to partially neutralize the positive charge so that the distance is more easily reduced. Some of these mechanisms involve resonance to concentrate energy in certain locations where a high concentration of deuterium is located. Ideas based on particle–wave conversion also have been explored. Even the involvement of unique particles, either from outer space or created in the sample have been suggested. All theories have serious difficulty in being reconciled with accepted nuclear theory or with the known behavior of the process. Nevertheless, many creative ideas are being explored and tested in the laboratory.

A particular theory is not advocated here, although several general characteristics are thought to be required. A theory must describe a process that does not violate the conservation of energy or momentum. In addition, it must be clearly related to the chemical and physical properties of real materials. Unlike the need to apply extra energy as required by hot fusion, the FPE nuclear reactions occur spontaneously only after the required chemical environment has formed, largely by chance at the present time. This behavior forces an explanation to consider materials science rather than just the type of nuclear physics applied to hot fusion. This situation is not unlike the materials problems that plagued early transistors and required investment of billions of dollars to discover that a few parts per billion of certain impurity atoms were important to achieve reliable behavior in spite of the physical process being understood.

In spite of these present limitations, a good understanding is required before acceptance of the effect can be complete and it is essential before practical application is possible. However, such understanding is not required to justify further study.

2.3. Research methods and investigators

Conventional methods are universally employed in FPE research, in many cases at major laboratories using commercially available equipment. FPE research is conducted at the present time by well-respected scientists in many countries, including the US, Italy, Japan, Russia, China, Israel, and France.

The FPE community consists of at least 200 active researchers as well as many other experts and interested parties. Table 2 lists a sample of 57 people who have made recent contributions to the subject by being the main author on recent published papers. Many researchers who are listed under the experimental category are also contributing to development of theory. This rather small effect is largely dictated by the widespread skeptical attitude toward the subject, not by failure to achieve successful replication of the claims.

FPE investigators have developed a research setting that is outside of, but in many ways parallel to mainstream science. For example, a professional organization has emerged as the International Society of Condensed Matter Nuclear Science (ISCMNS). Conferences are held about every 16–18 months with the most recent being the 15th ICCF Conference, held in Rome, Italy with over 150 attendees. Publications of the proceedings for the last three conferences are available at www.WorldScientific.com.

Papers are regularly given at periodic American Chemical Society (ACS) and American Physical Society (APS) meetings. Local conferences on the subject are regularly held in Japan[a] and Russia[b].

An open source journal for cold fusion papers (*J. Condensed Matter Nucl. Sci.*) has been initiated. At least two websites have been developed that include most of the papers published in CF research since the beginning; one of the sites (www.LENR.org) includes more than 500 papers and a bibliography of over 3,000 journal articles and books. Newsworthy CF events are covered on The New Energy Times website. Technical and sociological dialogue takes place on a Google Group private mailing list, named Condensed Matter Nuclear Science (CMNS), which can be joined by invitation from a current participant. The site has been active for about 4 years and has experienced over 10,000 postings, with an average of about 180 postings per month[c] Currently there are about 210 participants.

Interest remains at a significant level after a rapid drop during the first few years following the initial strong rejection[d]. Downloads of full text papers from LENR-CANR.org has remained steady over the last few years at 40,000/month, as shown in Fig. 6. The average monthly downloads of full-text papers is now slowly increasing with spikes in interest when the media focuses attention on the subject. Clearly, significant interest in the subject continues, although it remains relatively low.

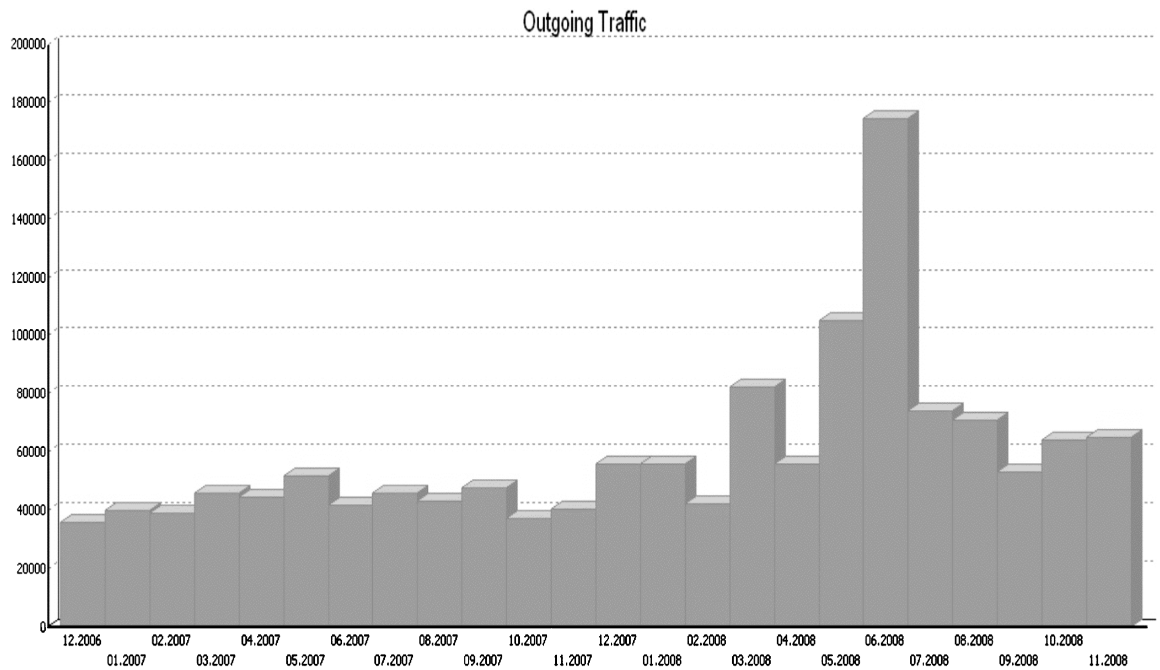

Figure 6. Monthly downloads of full text papers for 2007 and 2008 from LENR-CANR.org.

[a]Nineth annual meeting of Japan CF-Research Society, 28–29 March 2009, Shizuoka, Japan.

[b]Sixteenth Russian Conference on Cold Nuclear Transmutation & Ball Lightning (RCCNT&DL-16).

[c]Personal communication, Heiko Leitz, Group Sponsor, January 2009.

[d]See http://www.google.com/insights/search/#cat=174&q=cold%20fusion&cmpt=q for detailed information.

3. Application of skeptics' criteria

Langmuir, Sagan and Shermer have proposed three somewhat overlapping sets of criteria for distinguishing science from pseudoscience. Some of these criteria have been used in the past to discredit the Fleischmann–Pons claims. Now that additional information is available, these criteria may be more objectively applied. The criteria are stated here as 27 questions that must be answered in order for FPE to qualify as legitimate science. The responses provided here are based on the observations briefly described in Section 2 and on the cited literature.

3.1. Irving Langmuir's symptoms of pathological science

Irving Langmuir conducted research over a forty-year career until he retired in 1950. He won the Nobel Price in Chemistry in 1932. Langmuir was also interested in scientific boundary work – in defining what he called "pathological science." Although he did not formally publish his work in this area, he held a colloquium in 1953 that was subsequently transcribed. The highlights were subsequently published [114] and are shown in Fig. 7. Many papers and books have used the Langmuir criteria to conclude that FPE is a pathological science. Consequently, test of the claims using these criteria is important. Table 2. Sample of 57 recent contributors to FPE Research

(IL1) Is the maximum effect that is observed produced by a causative agent of more than barely detectable intensity?

The causative agent for the nuclear reactions is unknown, but it can be created on occasion. When it is created, most of the effects are large and easily detected. Heat, helium, tritium, and energetic particle radiation have been detected well above the expected uncertainties of each measurement. Only the expected neutron emission is detected at low levels near the detection limit (see Section 3.1.1.)

(IL2) Is the magnitude of the effect substantially dependent on (not independent of) the intensity of the cause?

The magnitude is increased by various changes in experimental conditions. For example, applied current (Fig. 4), D/Pd ratio (Fig. 5), and source of materials all affect the magnitude of the FPE signatures. Some batches of palladium

Symptoms of Pathological Science

- ▷The maximum effect that is observed is produced by a causative agent of barely detectable intensity, and the magnitude of the effect is substantially independent of the intensity of the cause.
- ▷The effect is of a magnitude that remains close to the limit of detectability or, many measurements are necessary because of the very low statistical significance of the results.
- ▷There are claims of great accuracy.
- ▷Fantastic theories contrary to experience are suggested.
- ▷Criticisms are met by *ad hoc* excuses thought up on the spur of the moment.
- ▷The ratio of supporters to critics rises up to somewhere near 50% and then falls gradually to oblivion.

Figure 7. Irving Langmuir's Symptoms.

Table 2. Sample of 57 recent contributors to FPE Research

Author	Institution/Location
Theory	
Bass, R.	USA
Bazhutov, Y.	Inst. Terrestrial Magnet, Russia
Chubb, S.	Research Systems Inc., USA
Chubb, T.	NRL (ret.) USA
Collis, W.	ISCMNS, Italy
Fisher, J.	USA
Hagelstein, P.	MIT, USA
Kim, Y.	Purdue University, USA
Kozima, H.	Cold Fusion Research Lab., Japan
Nagel, D.	The George Washington Univ. USA
Srivastava, Y.	Univ. Studi di Perugia, Italy
Takahashi, A.	Osaka Univ., Japan
Widom, A.	Norhteastern Univ., USA
Experimental	
Arata, Y.	Osaka Univ. Japan
Biberian, J-P.	Univ. Marseilles Luminy, France
Bockris, J.	Texas A&M, (ret.)USA
Campari, E.	Univ. di Bologna, Italy
Cantwell, R.	Coolesence LLC, USA
Celani, F.	INFN, Italy
Claytor, T.	LANL, USA
Cravens, D.	Private Lab., USA
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Fleischmann, M.	Univ. Southampton (ret.), UK
Iwamura, Y.	Mitsubishi Heavy Industries, Japan
Jones, S.	BYU (ret.) USA
Karabut, A. B.	FSUE "LUCH", Russia
Kasagi, J.	Tohoku Univ, Japan
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Koldamasov, A.	Sci Ctr of Syst Res & Technol, Russia
Kowalski, L.	Montclair State Univ. (ret.), USA
Letts, D.	Private Lab., USA
Li, X. Z.	Tsinghau Univ., China
Lipson, A.	The Russian Acad. Sci., Russia
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Vysotskii, V.	Kiev Na'l Shevchenko Univ., Ukraine
Wei, Q. M.	Tsinghua Univ., China
Yamada, H.	Iwate Univ., Japan
Yamaguchi, T.	Kobe Univ., Japan
Zhong, X.	Tsinghua Univ., China

or other active material are more successful than others. Recently, laser stimulation has been found to enhance the effect [82–94]. How these conditions relate to the cause is unknown.

(IL3) Is the effect well above (not close to) the limit of detectability?

The signatures of FPE are detected well above the expected uncertainty for each. Note Figs. 1 and 2 as an example of the magnitude of heat production typically reported.

(IL4) Is the statistical significance of the results high, so that an excessive number of measurements are unnecessary?

The effect is robust and unambiguous when it occurs (see Section 2.1). For example, tritium measurements in successful experiments have been reported as high as 2×10^5 times background and excess power production is frequently over 100 times the expected uncertainty.

(IL5) Is there an absence of claims of great accuracy?

The claims for accuracy are typical of what is normally experienced and reported using the conventional experimental methods applied to FPE studies. For example, calorimeters that are used to measure excess heat in electrolytic cell investigations are well understood and have an uncertainty less than 0.1 W.

(IL6) Is there an absence of fantastic theories contrary to experience? Many theories have been advanced to explain FPE phenomena mostly in the context of what is already known about nuclear physics. The theories have a wide range of acceptability, but each attempts to explain some part of the observations. The theories that remain in serious contention in the FPE research community are generally grounded in currently accepted understanding. However, fantastic theories are occasionally suggested and may actually be required before the effect is understood (see Section 2.2).

(IL7) Are ad hoc excuses thought up on the spur of the moment when criticism is received?

The explanations have been well thought out and published. Several Google discussion groups are active in the critique of proposed theories (see Section 2.3).

(IL8) Has there been a rise of the ratio of supporters up to somewhere near 50% and then a gradual fall to oblivion?

The number of supporters has fallen after the initial rejection, but remains relative constant since then as can be seen in Fig. 6 (see Section 2.4). With a present research community of well over 200 scientists, a fall to oblivion has not occurred.

3.1.1. *Carl Sagan's baloney detection kit*

Carl Sagan was a scientist and science popularizer of considerable note. One of his most influential works was "The Demon-Haunted World"[e], an exposition of the role of science in promoting human welfare. Sagan also advocated the role of healthy skepticism in protecting the public welfare, particularly in Chapter 13, "The Fine Art of Baloney Detection." The scientific method and skeptical thinking are described as follows (pp. 209–210).

'In science we may start with experimental results, data, observations, measurements, "facts." We invent, if we can, a rich array of possible explanations and systematically confront each explanation with the facts. In the course of their training, scientists are equipped with a baloney detection kit. The kit is brought out as a matter of course whenever new ideas are offered for consideration. If the new idea survives examination by the tools in our kit, we grant it warm, although tentative, acceptance. If you're so inclined, if you don't want to buy baloney even when it's reassuring to do so, there are precautions that can be taken; there's a tried-and-true, consumer-tested method. What's in the kit? Tools for skeptical thinking. What skeptical thinking boils down to is the means to construct, and to understand, a reasoned argument and—especially important— to recognize a fallacious or fraudulent argument. The question is not whether we like the conclusion that emerges out of a train of reasoning, but whether the conclusion follows from the premise or starting point and whether that premise is true." (pp. 210–212)

The criteria in Sagan's baloney detection kit can be posed as questions shown below.

(CS1) Has there been independent confirmation of the "facts"?

The "facts" are obtained from measurement of the four principal FPE signatures. Table 1 provides a summary of 386 confirmations of these signatures. The measurements of the signatures have been replicated numerous times (see Section 2.1).

(CS2) Has there been substantive debate on the evidence by knowledgeable proponents of all points of view?

Extensive debate has taken place among the more than 200 scientists engaged in FPE research, using published papers, conference presentations, internet chat rooms, and personal contact (see Section 2.3).

(CS3) Have assertions been free from "argument from authority?

Because no recognized authority yet exists for FPE, assertions are based on experimental observations. Many of the more than 200 authors are experts in the methods they use to study the effect, such as calorimeters and mass spectrometers. Credible authority is therefore applied to the interpretation of the FPE observations in a manner similar to other fields of study.

On the other side of the coin, there appears to be evidence of argument from authority against public support for FPE research in the early days after its announcement. In April 1989 Glenn Seaborg advised President Bush against support based primarily on his own opinion and authority, when little experimental evidence had yet been developed[f]. Even today, this approach is occasionally used to reject the observations.

(CS4) Has more than one hypothesis been considered (e.g., "multiple working hypotheses"?)

Many theories have been advanced with varying degrees of merit that are frequently subjected to examination, debate, and refinement. A consensus has not yet emerged (see Sections 2.2 and 2.3).

(CS5) Have the hypotheses been free of personal attachment or bias?

While the ideal scientist is expected to be free of personal bias, this is seldom achieved. The only realistic criteria involve the degree of bias and whether the scientist is able to achieve a suitable objective consideration of evidence that runs counter to personal bias. This statement applies to a bias both for and against a claim. The real issue is whether skeptics can be sufficiently free from personal bias to examine the case with an open mind.

[e] Sagan, Carl. *The Demon-Haunted World – Science as a Candle in the Dark*. New York, Random House, 1995.

[f] Seaborg, Glenn. "FDR to Bush – Fifty Years of Advising the Presidents". Presentation made at Lawrence Berkeley National Laboratory, October 28, 1995. Online. Available: http://video.google.com/videoplay?docid=-6144236233611516224&hl=en.

(CS6) Has a rigorous attempt been made to quantify the assertion or experiment?

Work on FPE has continued for 20 years in at least 12 countries involving hundreds of scientists, which produced over 380 clear indications that the assertion is real. The assertions have been debated both with skeptics and among supporters in print and in private. All of this information is easily available to interested scholars in books and on websites (see Section 2.3). Various methods and equipment are used in the different approaches for achieving FPE. The different signatures – excess heat, helium, tritium and radiation – are measured by different instruments or techniques, which frequently yield consistent results.

(CS7) If there is a chain of argument and is every link in the chain valid?

The theory is still being developed. Consequently, the chain of argument is constantly changing. Nevertheless, the links are constantly being examined for validity. The experimental support is described in Sections 2.1–2.3.

(**CS8)** If more than one hypothesis is applicable, has the simplest one been selected (Occam's razor)?

Evaluation of the explanations is still underway. Simplicity is one of several criteria that are actively applied as theories are compared. Selection of the most straightforward hypothesis can only take place after complete explanations have been developed. At the present time, no theory can explain all observations.

(CS9) Can the hypothesis, at least in principle, be falsified?

The basic hypothesis that nuclear reactions can be initiated in special solids at ambient temperatures has been supported by the observation of concurrent nuclear products, radiation, and excess energy. This conclusion can only be falsified by finding prosaic explanations for each of the hundreds of observations. Use of trivial processes to account for FPE has not been successful so far (see Section 2.1.3). On the other hand, experimental failures were used to reject the effect. Most failures are caused by not using conditions required to achieve success, hence are not a true falsification.

3.1.2. *Michael Shermer's boundary detection kit*

Michael Shermer is a science historian who also specializes in the boundary work of skepticism. He has written a number of books on pseudoscience, superstition, skepticism and the border between what is rational and what is not. He founded the Skeptics Society, which has over 50,000 members, and he also writes a monthly column, "Skeptic", for the popular science magazine, "Scientific American". In addition, he has been an outspoken skeptic of FPE. In one of his main works, "Borderlands" [115], Shermer sets forth a "Boundary Detection Kit", which he describes (pp. 17,18) as follows:

"The Boundary Detection Kit"

Like any kit to be properly built and used, one must read the instructions carefully to receive the full benefit of the product. The Boundary Detection Kit requires the user to examine each claim in great detail, and to get to know the subject deeply enough to have a good feel for how to answer these questions. in so doing there is an implicit commitment to be honest and fair, and to not go into the investigation with a prearranged verdict in mind. This is difficult to do, of course, since none of us comes to the data with unvarnished thoughts free of theory. Science is theory laden. We all bring to the table a set of preconceptions born from the paradigms in which we were trained or raised. Nevertheless, we can rise above our biases, if not to an Archimedean point of unsullied objectivity, at least to a level at which the claimant under investigation might feel he or she got a fair shake. In fact, a principle of fairness in our Boundary Detection Kit might be to ask this question—what I call the fairness question — before all others: *If I were to ask the holders of the claim if they felt that they and their beliefs were fairly treated, how would they respond?* Where possible, in fact, why not ask them? I have done so on a number of occasions and to my considerable surprise I discovered that I had not been fair in my analysis, particularly in truncating someone's beliefs to a handful of simplified tenets that could be more easily analyzed (and, usually, debunked). This is sometimes called the "straw man" fallacy in logic, where one sets up a straw man that can be easily toppled but does not represent anyone's actual position. I find that I learn a lot more in the process when I bear in mind the fairness question. In many cases questioning the belief holder is not practical, but the fairness question still works as a hypothetical standard toward which to aim." Shermer lists "ten useful questions to ask in determining validity of a claim. These ten questions were also published by Shermer in a series of two articles in his "Skeptic" column in Scientific American in 2001. The version in the Skeptic column was renamed "baloney detection" and had a set of annotations accompanying the questions that differed from those in the boundary detection kit. The ten questions are provided below with responses for the FPE case.

(MS1) How reliable is the source of the claim?

Most researchers in the FPE are competent scientists who have successful or even distinguished careers in other fields. In fact, Profs. Bockris and Fleischmann are pioneers in the field of electrochemistry and acknowledged leaders in their profession. Many other scientists still conduct research in "mainstream" science simultaneously with their FPE investigations. Given the large number and excellent credentials of the FPE research community, reliability of the source appears to be one of the main strengths of the FPE case (see Section 2.3)

(MS2) Does this source often make similar claims?

These sources have not made similar claims beyond their published work on the subject.

(MS3) Have the claims been verified by another source?

Numerous investigators have repeatedly verified the claims by during the past 20 years. Verifications have included more than 380 documented experimental successes (see Section 2.1).

(MS4) How does the claim fit with what we know about how the world works?

The effect is not consistent with how we "know" the world works, which is characteristic of all new discoveries. This is the reason the effect has been largely rejected in the past. Efforts are being made to expand nuclear theory to account for the FPE observations (see Section 2.2).

(MS5) Has anyone gone out of the way to disprove the claim, or has only supportive evidence been sought?

An experiment either produces excess heat, nuclear products and/or radiation, or it does not. Most attempts have failed to produce the anomalous FPE results. The question is whether the failures were caused by non-existence of FPE or because the experiment was not properly performed. This issue has been given a lot of attention as described above because it is the main reason used to reject the observations (see Section 2.1.3).

(MS6) Does the preponderance of evidence point to the claimant's conclusion or to a different one?

Occurrence of nuclear reactions is the only conclusion that is consistent with observed products. However, several different conclusions can be suggested about the process and mechanism. These conclusions are being debated and additional studies are underway to form an exact opinion.

(MS7) Is the claimant employing the accepted rules of reason and tools of research, or have these been abandoned in favor of others that lead to the desired conclusion?

The researchers and theoreticians who are active in the field regularly employ accepted rules of reason and conventional tools of research as described in Section 2. For example, the possible prosaic explanations have been well investigated and found to be insufficient to account for the observations of excess heat and production of helium. As another example, well-developed calorimeters with acceptable levels of uncertainty (<0.1 W) are routinely used to measure excess heat. Radiation is being measured using a variety of well-accepted methods.

(MS8) Is the claimant providing an explanation for the observed phenomena or merely denying the existing explanation?

Efforts are being made at the present time in laboratories located in eight countries to extend conventional theory in order to explain the anomalous FPE observations. The existing explanation, which is applicable to conventional "hot" fusion, clearly is inconsistent with the observations attributed to FPE. One possible explanation, noted in Section 2.2, is based on the high concentration of electrons and the regular arrangement of atoms in the metal lattice in the FPE environment. These conditions are much different from gaseous plasma and may provide mechanisms to surmount the Coulomb barrier that are not yet understood. In addition, evidence is growing that the physical environment can affect many other nuclear processes, in contrast to what conventional theory would predict.

(MS9) If the claimant proffers a new explanation, does it account for as many phenomena as the old explanation did?

The "old" explanation describes a different environment and a different range of applied energy. It does not address the effects that might occur in a solid. On the other hand, any new explanation based on a solid environment cannot be applied to conventional plasma. The conditions within the two environments are just too different. Acceptance of a new theory depends on whether the reader will consider that the environment in a solid might play a role in initiating nuclear reactions at low energy.

(MS10) Do the claimant's personal beliefs and biases drive the conclusions, or vice versa?

The researchers who support the claim of FPE are expected to be influenced by their personal beliefs and biases in the same manner as any other scientist. However, given the size, diversity, and quality of the research community, and the conventional methods they use, it is unlikely that bias is greater for investigators of FPE than it is for researchers in any other field of science.

4. Conclusions

FPE, unlike most other rejected scientific claims, has not faded into oblivion. Continued research in the field has yielded many confirmations of the principal signatures of FPE reactions. Prosaic explanations for most observations no longer apply. Contrary to common belief, evidence of FPE has grown in magnitude and become more consistent as better understanding has been achieved. Many critical variables have been identified that make the effect easier to replicate.

Theory development and experimental methods are consistent with the practices of mainstream science. The community of active FPE researchers consists of conventional scientists who, in most cases, are actively engaged in conventional areas of investigation independent of FPE. Borrowing from the legal field, there appears to be a preponderance of evidence that FPE is a "real" phenomenon based on experimental verification and the credentials of the scientists making the FPE claims.

The phenomenon cannot always be produced on demand, and no satisfactory theory explains the process or describes all of the required conditions. Despite this lack of understanding, anomalous behaviors are clearly evident under conditions that would normally produce no nuclear reactions and no energy at the levels being observed. These limitations demonstrate that more work is required to achieve success rather than, as the antagonists argue, being further evidence for bad science.

The original claims made by Profs. Fleischmann and Pons stand and are now supported by a well documented body of work. When the criteria for science versus pseudoscience are applied to FPE, all of the criteria appear to be met. It is therefore concluded that FPE, and the research into its causes and conditions, are legitimate science rather than pseudoscience.

Regardless of the explanation or the history of the claims, it is important for the reader to decide whether this phenomenon is now worthy of unrestrained investigation. The need for a potential source of energy, such as this phenomenon promises, is too important to reject the claims for trivial reasons.

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References

[1] Fleischmann, M., Pons, S., Hawkins, M., Electrochemically induced nuclear fusion of deuterium, *J. Electroanal. Chem.* 261, 301 and errata in Vol. 263 (1989).

[2] Fleischmann, M., Pons, S., Hawkins, M., Hoffman, R. J., Measurements of gamma-rays from cold fusion, *Nature*, London **339** (1989) 667.

[3] Fleischmann, M., in *The First Annual Conference on Cold Fusion* (ed. Will, F.), p. 344 (National Cold Fusion Institute, University of Utah Research Park, Salt Lake City, Utah, 1990).

[4] Pons, S. , Fleischmann, M., in *The First Annual Conference on Cold Fusion* (ed. Will, F. G.), p. 1 (National Cold Fusion Institute, University of Utah Research Park, Salt Lake City, Utah, 1990).

[5] Pons, S., Fleischmann, M., Walling, C. T., Simons, J. P. (WO 90/10935,1990, 1990).

[6] Fleischmann, M., Pons, S., Anderson, M. W., Li, L. J., Hawkins, M., Calorimetry of the palladium–deuterium–heavy water system, *J. Electroanal. Chem.* **287** (1990) 293.

[7] Pons, S. , Fleischmann, M., Calorimetric measurements of the palladium/deuterium system: fact and fiction, *Fusion Technol.* **17** (1990) 669.

[8] Fleischmann, M., in *Second Annual Conference on Cold Fusion, "The Science of Cold Fusion"* (eds. Bressani, T., Del Giudice, E. , Preparata, G.), p. 475 (Societa Italiana di Fisica, Bologna, Italy, Como, Italy, 1991).

[9] Pons, S. , Fleischmann, M., in *Second Annual Conference on Cold Fusion, "The Science of Cold Fusion"* (eds. Bressani, T., Del Giudice, E. , Preparata, G.), p. 349 (Societa Italiana di Fisica, Bologna, Italy, Como, Italy, 1991).

[10] Fleischmann, M. , Pons, S., Some comments on the paper "Analysis of experiments on the calorimetry of LiOD-D_2O electrochemical cells", R.H. Wilson et al., J. Electroanal. Chem. 332 [1992] 1. *J. Electroanal. Chem.* **332**(1992) 33.

[11] Fleischmann, M. , Pons, S., in *Third International Conference on Cold Fusion, "Frontiers of Cold Fusion"* (ed. Ikegami, H.), p. 47 (Universal Academy Press Inc., Tokyo, Japan, Nagoya Japan, 1992).

[12] Pons, S. , Fleischmann, M., Concerning the detection of neutron and gamma-rays from cells containing palladium cathodes polarized in heavy water, *Nuovo Cimento Soc. Ital. Fis. A* **105A**(1992) 763 .

[13] Fleischmann, M., Pons, S., Le Roux, M. , Roulette, J. in *Fourth International Conference on Cold Fusion* (ed. Passell, T. O.), p. 1 (Electric Power Research Institute 3412 Hillview Ave., Palo Alto, CA 94304, Lahaina, Maui, 1993).

[14] Fleischmann, M. , Pons, S. Calorimetry of the Pd-D_2O system: from simplicity via complications to simplicity, *Phys. Lett. A* **176**(1993) 118 .

[15] Pons, S. , Fleischmann, M. , in *Fourth International Conference on Cold Fusion* (ed. Passell, T. O.), p. 8 (Electric Power Research Institute 3412 Hillview Ave., Palo Alto, CA 94304, Lahaina, Maui, 1993).

[16] Fleischmann, M., Pons, S. , Preparata, G., Possible theories of cold fusion, *IL Nuovo Cimento* **107A**(1994) 143. .

[17] Fleischmann, M. , Pons, S., Reply to the critique by Morrison entitled 'Comments on claims of excess enthalpy by FLeischmann and Pons using simple cells made to boil, *Phys. Lett. A* **187**(1994) 276 .

[18] Fleischmann, M., Pons, S., Le Roux, M. , Roulette, J., Calorimetry of the Pd–D_2O system: The search for simplicity and accuracy, *Trans. Fusion Technol.* **26**(1994) 323 .

[19] Pons, S. , Fleischmann, M., Heat after death, *Trans. Fusion Technol.* **26**(1994) 97 .

[20] Fleischmann, M. , in *5th International Conference on Cold Fusion* (ed. Pons, S.), p. 152 (IMRA Europe, Sophia Antipolis Cedex, France, Monte-Carlo, Monaco, 1995).

[21] Fleischmann, M., in *5th International Conference on Cold Fusion* (ed. Pons, S.), p. 140 (IMRA Europe, Sophia Antipolis Cedex, France, Monte-Carlo, Monaco, 1995).

[22] Pons, S. , Fleischmann, M., Etalonnage du systeme Pd–D_2O: effets de protocole et feed-back positif. ["Calibration of the Pd–D_2O system: protocol and positive feed-back effects"], *J. Chim. Phys.* **93**(1996) 711 (in French) .

[23] Fleischmann, M., in *The Seventh International Conference on Cold Fusion* (ed. Jaeger, F.), p. 119 (ENECO Inc., Salt Lake City, UT., Vancouver, Canada, 1998).

[24] Fleischmann, M., in *8th International Conference on Cold Fusion* (ed. Scaramuzzi, F.), p. XXIII (Italian Physical Society, Bologna, Italy, Lerici (La Spezia), Italy, 2000).

[25] Miles, M. H., Imam, M. A. , Fleischmann, M., in *8th International Conference on Cold Fusion* (ed. Scaramuzzi, F.), p. 105 (Italian Physical Society, Bologna, Italy, Lerici (La Spezia), Italy, 2000).

[26] Fleischmann, M., Reflections on the sociology of science and social responsibility in science, in relationship to cold fusion, *Accountability Res.* **8**(2000) 19 .

[27] Close, F., *Too hot to handle. The race for cold fusion* (Penguin, paperback, New York, 1992).

[28] Close, F., Cold fusion I: The discovery that never was, *New Scientist* **1752**(1991) 46 .

[29] Huizenga, J. R., *Cold fusion: The scientific fiasco of the century* (Oxford University Press, New York, 1993).

[30] Goodstein, D., Pariah science. Whatever happened to cold fusion? ,*The American Scholar* **63**(1994) 527 .

[31] Morrison, D. R. O., Review of progress in cold fusion, *Trans. Fusion Technol.* **26**(1994) 48 .
[32] Jones, S. E., Current issues in cold fusion research: heat, helium, tritium, and energetic particles, *Surf. Coatings Technol.* **51**(1992) 283 .
[33] Park, R. L., The cold fusion story has been an object lesson on why science flourishes only in the open, *The Chronicle of Higher Education*, A44 (1989).
[34] Park, R., *Voodoo science* (Oxford University Press, New York, NY, 2000).
[35] ERAB (Department of Energy, DOE/S-0073, Washington, DC, 1989).
[36] DoE. in, *Review of Low Energy Nuclear Reactions* (Department of Energy, Office of Science, Washington, DC, 2004).
[37] Storms, E. K. , *The science of low energy nuclear reaction* (World Scientific, Singapore, 2007).
[38] Rothwell, J., *Cold fusion and the future* , www.LENR.org, 2007.
[39] Kozima, H., *The science of the cold fusion phenomenon* (Elsevier Science, Amsterdam, 2006).
[40] Krivit, S. B. , Winocur, N., *The rebirth of cold fusion; Real science, real hope, real energy* (Pacific Oaks Press, Los Angeles, CA, 2004).
[41] Simon, B., *Undead science: Science studies and the afterlife of cold fusion* (Rutgers University Press, New Brunswick, NJ, 2002).
[42] Beaudette, C. G., *Excess heat. Why cold fusion research prevailed* (Oak Grove Press (Infinite Energy, Distributor), Concord, NH, 2000).
[43] Mizuno, T. ,*Nuclear transmutation: The reality of cold fusion* (Infinite Energy Press, Concord, NH, 1998).
[44] Mallove, E., *Fire from ice* (John Wiley, NY, 1991).
[45] , www.LENR.org.
[46] Britz, D. , http://www.kemi.aau.dk/∼britz/fusion.
[47] Japan CF Society, http://dragon.elc.iwate-u.ac.jp/jcf/indexe.html.
[48] Romodanov, V. A., in *Tenth International Conference on Cold Fusion* (eds. Hagelstein, P. L. , Chubb, S. R.), p. 325 (World Scientific, Cambridge, MA, 2003).
[49] Kaushik, T. C. et al. , Preliminary report on direct measurement of tritium in liquid nitrogen treated TiDx chips, *Indian J. Technol.* **28**(1990) 667 .
[50] Miles, M., in *Tenth International Conference on Cold Fusion* (eds. Hagelstein, P. L. , Chubb, S. R.), p. 123 (World Scientific, Cambridge, MA, 2003).
[51] McKubre, M. C. H., in *Tenth International Conference on Cold Fusion* (eds. Hagelstein, P. L. , Chubb, S. R.) (World Scientific, Cambridge, MA, 2003).
[52] De Ninno, A., Frattolillo, A., Rizzo, A. , Del Gindice, E., in *Tenth International Conference on Cold Fusion* (eds. Hagelstein, P. L. , Chubb, S. R.), p. 133 (World Scientific, Cambridge, MA, 2003).
[53] Arata, Y. , Zhang, Y.-C. , The basics of nuclear fusion reactor using solid pycnodeuterium as nuclear fuel, *High Temp. Soc, Japan* **29**(2003) 1 .
[54] Miles, M., Imam, M. A. , Fleischmann, M. ,Excess heat and helium production in the palladium-boron system, *Trans. Am. Nucl. Soc.* **83**(2000) 371 .
[55] Gozzi, D. et al., Erratum to "X-ray, heat excess and ^{4}He in the D/Pd system", *J. Electroanal. Chem.* **452**(1998) 251 .
[56] Bush, B. F. , Lagowski, J. J., in *The Seventh International Conference on Cold Fusion* (ed. Jaeger, F.), p. 38 (ENECO Inc., Salt Lake City, UT., Vancouver, Canada, 1998).
[57] Miles, M. H. , Bush, B. F. ,Heat and helium measurements in deuterated palladium, *Trans. Fusion Technol.* **26**(1994) 156 .
[58] Miles, M. H., Hollins, R. A., Bush, B. F., Lagowski, J. J. , Miles, R. E., Correlation of excess power and helium production during D_2O and H_2O electrolysis using palladium cathodes, *J. Electroanal. Chem.* **346**(1993) 99 .
[59] Bush, B. F., Lagowski, J. J., Miles, M. H. , Ostrom, G. S., Helium production during the electrolysis of D_2O in cold fusion experiments, *J. Electroanal. Chem.* **304**(1991) 271.
[60] Miles, M., Bush, B. F. , Lagowski, J. J., Anomalous effects involving excess power, radiation, and helium production during D_2O electrolysis using palladium cathodes, *Fusion Technol.* **25**(1994)478 .
[61] Arata, Y. , Zhang, Y. C. , in *The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science* (ed. Li, X. Z.), p. 5 (Tsinghua Univ. Press, Tsinghua Univ., Beijing, China, 2002).
[62] Arata, Y. , Zhang, Y. C., Definitive difference between [DS-D_2O] and [Bulk-D_2O] cells in 'deuterium-reaction'. *Proc. Jpn.*

Acad., Ser. B 75 Ser. B, 71 (1999).

[63] Arata, Y. , Zhang, Y. C. , Observation of anomalous heat release and helium-4 production from highly deuterated fine particles, *Jpn. J. Appl. Phys. Part 2* **38**(1999) L774 .

[64] Arata, Y. , Zhang, Y. C., in *8th International Conference on Cold Fusion*, (ed. Scaramuzzi, F.),p. 11 (Italian Physical Society, Bologna, Italy, Lerici (La Spezia), Italy, 2000).

[65] Arata, Y. , Zhang, Y. C., Formation of condensed metallic deuterium lattice and nuclear fusion, *Proc. Jpn. Acad., Ser. B* **78**(2002) 57 .

[66] McKubre, M. C. H., Tanzella, F. L., Tripodi, P. , Hagelstein, P. L. ,in *8th International Conference on Cold Fusion* (ed. Scaramuzzi, F.), p. 3 (Italian Physical Society, Bologna, Italy, Lerici (La Spezia), Italy, 2000).

[67] Iyengar, P. K. , Srinivasan, M. , in *The First Annual Conference on Cold Fusion* (ed. Will, F.), p. 62 (National Cold Fusion Institute, University of Utah Research Park, Salt Lake City, Utah, 1990).

[68] McKubre, M. C. H. et al., in *The First Annual Conference on Cold Fusion* (ed. Will, F. G.), p. 20 (National Cold Fusion Institute, University of Utah Research Park, Salt Lake City, Utah, 1990).

[69] Rout, R. K., Shyam, A., Srinivasan, M. , Bansal, A., Copious low energy emissions from palladium loaded with hydrogen or deuterium, *Indian J. Technol.* **29**(1991) 571 .

[70] Rout, R. K., Shyam, A., Srinivasan, M., Garg, A. B. , Shrikhande, V. K., Reproducible, anomalous emissions from palladium deuteride/hydride, *Fusion Technol.* **30**(1996) 273 .

[71] Savvatimova, I. B. , Karabut, A. B., Radioactivity of palladium cathodes after irradiation in a glow discharge, *Poverkhnost (Surface)*, 76 (in Russian) (1996).

[72] Violante, V. et al., in *The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science* (ed. Li, X. Z.), p. 376 (Tsinghua Univ. Press, Tsinghua Univ., Beijing, China, 2002).

[73] Szpak, S., Mosier-Boss, P. A. , Smith, J. J., On the behavior of Pd deposited in the presence of evolving deuterium, *J. Electroanal. Chem.* **302**(1991) 255 .

[74] Matsumoto, T. , Observation of new particles emitted during cold fusion, *Fusion Technol.* **18**(1990) 356 .

[75] Fisher, J. C., in *8th International Workshop on Anomalies in Hydrogen/Deuterium Loaded Metals* (eds. Rothwell, J. , Mobberley, P.), p. 62 (The International Society for Condensed Matter Science, Catania, Sicily, Italy, 2007).

[76] Kowalski, L., Jones, S., Letts, D. , Cravens, D., in *11th International Conference on Cold Fusion* (ed. Biberian, J.-P.), p. 269 (World Scientific, Marseille, France, 2004).

[77] Lipson, A. G., Lyakhov, B. F., Rousstesky, A. S. , Asami, N. in, *8th International Conference on Cold Fusion* (ed. Scaramuzzi, F.), p. 231 (Italian Physical Society, Bologna, Italy, Lerici (La Spezia), Italy, 2000).

[78] Mosier-Boss, P. A., Szpak, S., Gordon, F. E. , Forsley, L. P. G., Use of CR-39 in Pd/D co-deposition experiments, *Eur. Phys. J. Appl. Phys.* **40**(2007) 293–303 .

[79] Oriani, R. A. , Fisher, J. C., in *11th International Conference on Cold Fusion* (ed. Biberian, J.-P.), p. 295 (World Scientific, Marseilles, France, 2004).

[80] Qiao, G. S. et al., in *The 7th International Conference on Cold Fusion* (ed. Jaeger, F. G.), p. 314 (Vancouver, Canada, 1998).

[81] Roussetski, A. S., in *11th International Conference on Cold Fusion* (ed. Biberian, J.-P.), p. 274 (World Scientific, Marseilles, France, 2004).

[82] Tian, J., Jin, L. H., Shen, B. J., Weng, Z. K. , Lu, X., in *ICCF-14 International Conference on Condensed Matter Nuclear Science* (ed. Rothwell, J.) www.LENR.org, Washington, DC, 2008).

[83] Letts, D., Cravens, D. , Hagelstein, P. I., in *ACS Symposium Series 998, Low-Energy Nuclear Reactions Sourcebook*, (eds. Marwan, J. , Krivit, S. B.), p. 337 (American Chemical Society, Washington, DC, 2008).

[84] Letts, D. , Hagelstein, P. I., in *14th International Conference on Condensed Matter Nuclear Science*, (ed. Nagel, D.) (Washington, DC, 2008).

[85] Sinha, K. P. , Meulenberg Jr., A., Laser stimulation of low-energy nuclear reactions in deuterated palladium, *Curr. Sci.* **91**(2006) 907 .

[86] Violante, V. et al., in *Condensed Matter Nuclear Science, ICCF-12*, (eds. Takahashi, A., Ken-ichiro, O. , Iwamura, Y.), p. 55 (World Scientific, Yokohama, Japan, 2005).

[87] Apicella, M. et al., in *Condensed Matter Nuclear Science, ICCF-12*, (eds. Takahashi, A., Ken-ichiro, O. , Iwamura, Y.), p. 117 (World Scientific, Yokohama, Japan, 2005).

[88] McKubre, M. C., in *ASTI-5*, www.iscmns.org, Asti, Italy, 2004.
[89] Letts, D. , Cravens, D., in *ASTI-5*, www.iscmns.org, Asti, Italy, 2004.
[90] Bazhutov, Y., Bazhutova, S. Y., Nekrasov, V. V., Dyad'kin, A. P. , Sharkov, V. F., in *11th International Conference on Cold Fusion*, (ed. Biberian, J.-P.), p. 374 (World Scientific, Marseilles, France, 2004).
[91] Swartz, M. R., in *10th International Conference on Cold Fusion*, (eds. Hagelstein, P. L. , Chubb, S. R.), p. 213 (World Scientific, Cambridge, MA, 2003).
[92] Storms, E. K., in *10th International Conference on Cold Fusion*, (eds. Hagelstein, P. L. , Chubb, S. R.), p. 183 (World Scientific, Cambridge, MA, 2003).
[93] Clark, E. L. et al., Energetic heavy-ion and proton generation from ultraintense laser–plasma interactions with solids, *Phys. Rev. Lett.* **85**(2000) 1654.
[94] Castellano et al., in *8th International Conference on Cold Fusion*, (ed. Scaramuzzi, F.), p. 287 (Italian Physical Society, Bologna, Italy, Lerici (La Spezia), Italy, 2000).
[95] McKubre, M. C. H. et al., (EPRI, Palo Alto, 1998).
[96] Cravens, D. , Letts, D., in *ICCF-14, International Conference on Condensed Matter Nuclear Science* (ed. Rothwell, J.), www.LENR.org, Washington, DC, 2008.
[97] Storms, E. How to produce the Pons–Fleischmann effect, *Fusion Technol.* **29**(1996) 261.
[98] Storms, E. K., in *The 7th International Conference on Cold Fusion*, ed. Jaeger, F. G., p. 356 (ENECO Inc., Salt Lake City, UT, Vancouver, Canada, 1998).
[99] Storms, E. K., Formation of b-PdD containing high deuterium concentration using electrolysis of heavy-water, *J. Alloys Comp.* **268**(1998) 89 .
[100] Storms, E. K., A study of those properties of palladium that influence excess energy production by the Pons–Fleischmann effect, *Infinite Energy* **2**(1996) 50 .
[101] Storms, E., in *American Physical Society* (Atlanta, GA, 1999).
[102] Storms, E. K., The nature of the energy-active state in Pd–D. *Infinite Energy*, 77 (1995).
[103] Lewis, N. S. et al., Searches for low-temperature nuclear fusion of deuterium in palladium, *Nature (London)* **340**(1989) 525 .
[104] Shelton, D. S., Hansen, L. D., Thorne, J. M. , Jones, S. E., An assessment of claims of 'excess heat' in 'cold fusion' calorimetry. *Thermochim. Acta* 297, 7 (1997).
[105] Hansen, L. D., Jones, S. E. , Shelton, D. S. A response to hydrogen + oxygen recombination and related heat generation in undivided electrolysis cells, *J. Electroanal. Chem.* **447**(1998) 225.
[106] Kainthla, R. C. et al., Eight chemical explanations of the Fleischmann–Pons effect, *J. Hydrogen Energy* **14**(1989) 771.
[107] Cedzynska, K., Barrowes, S. C., Bergeson, H. E., Knight, L. C. , Will, F. G., in *Anomalous Nuclear Effects in Deuterium/Solid Systems, "AIP Conference Proceedings 228"* (eds. Jones, S., Scaramuzzi, F. , Worledge, D.) 463 (American Institute of Physics, New York, Brigham Young Univ., Provo, UT, 1990).
[108] Cedzynska, K., Barrowes, S. C., Bergeson, H. E., Knight, L. C. , Will, F. G., Tritium analysis in palladium with an open system analytical procedure, *Fusion Technol.* **20**(1991) 108.
[109] Cedzynska, K. , Will, F. G. Closed-system analysis of tritium in palladium. *Fusion Technol.* 22, 156 (1992).
[110] Storms, E. K. , Talcott-Storms, C., The effect of hydriding on the physical structure of palladium and on the release of contained tritium, *Fusion Technol.* **20**(1991) 246.
[111] Claytor, T. N., Schwab, M. J., Thoma, D. J., Teter, D. F. , Tuggle, D. G., in *The 7th International Conference on Cold Fusion* (ed. Jaeger, F.), p. 88 (ENECO Inc., Salt Lake City, UT., Vancouver, Canada, 1998).
[112] Claytor, T. N., Jackson, D. D. , Tuggle, D. G., Tritium production from a low voltage deuterium discharge of palladium and other metalsm, *J. New Energy* **1**(1996) 111.
[113] Tuggle, D. G., Claytor, T. N. , Taylor, S. F., Tritium evolution from various morphologies of palladiumm, *Trans. Fusion Technol.* **26**(1994) 221 .
[114] Langmiur, I. (ed.), *Pathological science* (1989).
[115] Shermer, M., *The Borderlands of Science – Where Sense Meets Nonsense.* (Oxford Univ. Press, Oxford, UK, 2001).