Cold fusion: A case study for scientific behavior

Most people—including scientists and politicians—now recognize that a serious energy crisis looms in our future. Human populations use an enormous amount of energy, and as the population grows and standards of living increase, we will require even more. Unfortunately, the energy sources currently available to us all have major drawbacks in the long term. Oil is efficient, but contributes to climate change and will run out eventually. Coal is plentiful but polluting. Solar energy is appealing but only as dependable as a sunny day—and it's currently expensive to boot! A clean, reliable energy source that won't run out any time soon would solve our energy problems and revolutionize the world. You might think such an energy source is a pipe dream, but in fact, it has already been discovered—in seawater! Seawater contains an element called deuterium—hydrogen with an extra neutron (Fig. 1). When two deuterium atoms are pushed close enough together, they will fuse into a single atom, releasing a lot of energy in the process. Unfortunately, figuring out exactly how to get deuterium atoms close enough together—in a way that doesn't take even more energy than their union generates—has been a challenge.

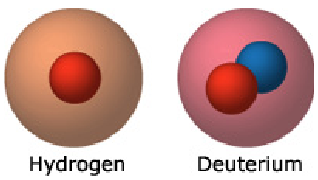

Figure 1. A hydrogen atom has only a single proton in its nucleus, whereas deuterium, a rarer isotope of hydrogen, has a proton and a neutron.

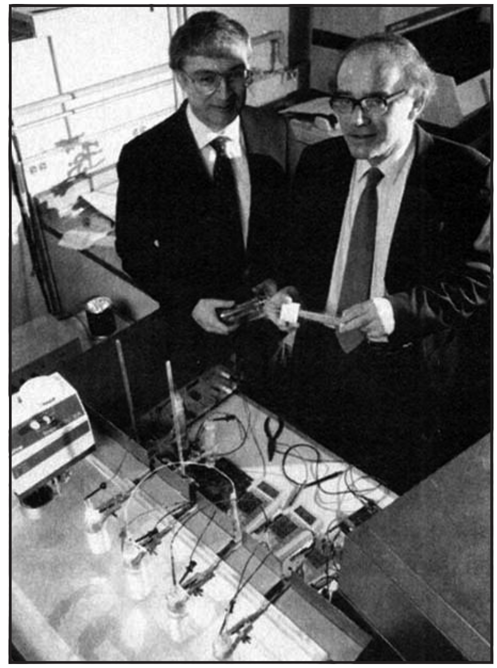

Figure 2. University of Utah chemists Stanley Pons (left) and Martin Fleischmann.

The process by which two atoms join together, or fuse, into a single heavier atom is called fusion. Fusion is the energy source of stars, like our sun—where it takes place at about 27,000,000° F. In 1989, chemists Stanley Pons and Martin Fleischmann (Fig. 2) made headlines with claims that they had produced fusion at room temperature—"cold" fusion compared to the high temperatures the process was thought to require. It was the kind of discovery that scientists dream of: a simple experiment with results that could reshape our understanding of physics and change lives the world over. However, this "discovery" was missing one key ingredient: good scientific behavior.

This case study highlights these aspects of the nature of science:

- The scientific community is responsible for checking the work of community members. Through the scrutiny of this community, science corrects itself.
- Scientists actively seek evidence to test their ideas—even if the test is difficult. They strive to describe and perform the tests that would prove their ideas wrong and/or allow others to do so.
- Scientists take into account all the available evidence when deciding whether to accept an idea or not—even if that means giving up a favorite hypothesis.
- Science relies on a balance between skepticism and openness to new ideas.
- Scientists often verify surprising results by trying to replicate the test.
- In science, discoveries and ideas must be verified with multiple lines of evidence.
- Data require analysis and interpretation. Different scientists can interpret the same data in different ways.

The ingenious idea

The chemists claiming to have solved the world's energy problems with cold fusion, Stanley Pons and Martin

Pons and Fleischmann photo courtesy of the University of Utah

Fleischmann, made a somewhat unlikely pair. Pons was a quiet and modest man from a small town in North Carolina. Fleischmann was an outgoing European who exuded confidence and was almost old enough to be Pons' father. The two had met while Pons was completing his Ph.D. at the University of Southampton in England, where Fleischmann was a professor. Pons admired Fleischmann's intelligence and ingenuity, and Fleischmann soon became his mentor and friend. The two remained close over the years, as Pons moved from a graduate student position into a professorship at the University of Utah. Shortly after Pons took up his post as professor, the two began to collaborate on research projects.

The idea behind their cold fusion experiment was sparked by another one of Fleischmann's studies. In the late 1960s, Fleischmann had been using palladium, a rare metal, as a key ingredient to separate hydrogen from deuterium. In those experiments, he saw firsthand how palladium can absorb unusually large amounts of hydrogen—about 900 times its own volume. That's a bit like using a single kitchen sponge to mop up 30 gallons of spilled milk! This amazing absorption power is due to a chemical reaction on the surface of the palladium that draws hydrogen inside the metal. Because hydrogen and deuterium are so similar (differing by just one neutron), the same reaction occurs with deuterium—it can also be sucked up by palladium in surprisingly large amounts (Fig. 3). Fleischmann reasoned that since the deuterium absorbed by palladium undergoes a dramatic reduction in volume (by a factor of about 900), the deuterium atoms must be squished together inside the palladium. He began to wonder if a similar process could be used to force deuterium atoms close enough to fuse and release energy …

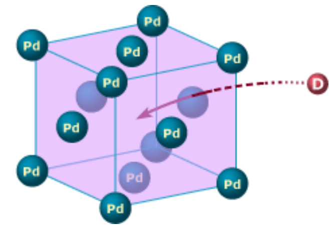

Figure 3.

Idea into action

Fleischmann filed away his ideas about fusion until the fall of 1983, when he and Pons started talking about the possibility of using chemical processes (reactions among atoms and molecules) to trigger a nuclear process (changes within the nuclei of atoms). They decided to set up a full-blown experiment to test Fleischmann's idea. Working in Pons' laboratory, the two put together what they called a "fusion cell" (Fig. 4). This cell consisted of two pieces of metal, one palladium and the other platinum, submerged in a container of heavy water (water in which the hydrogen of each H_2O molecule is replaced by deuterium). They knew that if they zapped the cell with electricity it would trigger a chemical process called electrolysis, in which the heavy water molecules would split, producing deuterium gas and oxygen. The deuterium could then be absorbed into the palladium via a chemical reaction. Pons and Fleischmann hypothesized that, once inside the palladium, the deuterium atoms would be forced so close together that they would fuse and release large amounts of energy as heat.

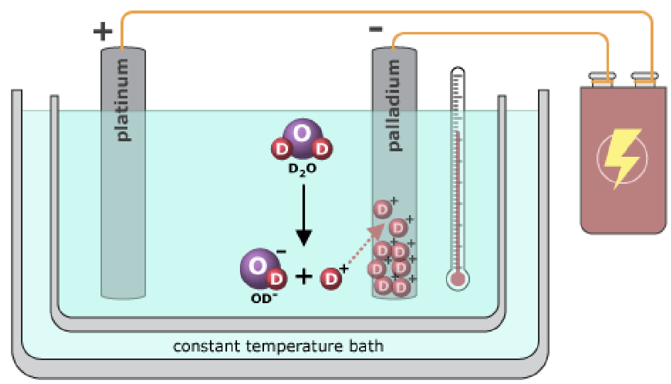

Figure 4. Pons and Fleischmann's fusion cell.

Pons and Fleischmann measured the temperature of the cell continuously throughout its operation. After some analysis of the data, they found that the cell was producing about 100 times more heat than could be accounted for by chemistry alone (Fig. 5)! They interpreted this excess heat as evidence for fusion. Excited by the possibility that they had found an inexpensive way to harness fusion for energy production, Pons and Fleischmann were eager to test their idea further. However, more experiments required more money …

Teammate or rival?

With promising preliminary results to back their cold fusion hypothesis, Pons and Fleischmann applied for a

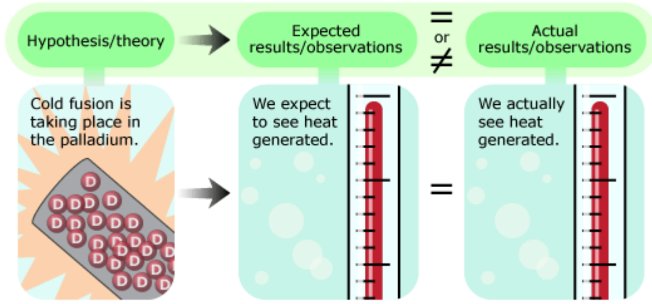

Figure 5.

government grant to get funds for further experiments. As part of the grant process, Pons and Fleischmann's proposal had to go through peer review. One of the reviewers was Steven Jones (Fig. 6), a nuclear physicist at Brigham Young University, just 50 miles away. As it happened, Jones and a group of collaborators were working on a similar experiment but were studying a different line of evidence. While Pons and Fleishmann were concentrating on detecting the heat that would be produced by fusion, Jones' group was looking for another sign of fusion—neutrons.

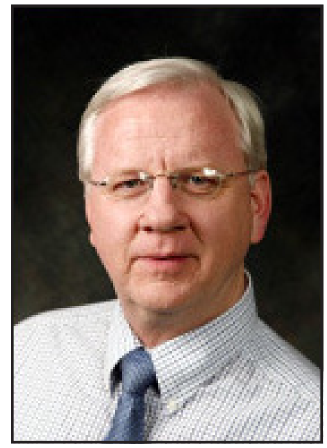

Figure 6. Retired Professor Steven E. Jones, Brigham Young University.

Nuclear theory—the theory of how protons and neutrons interact—explains how fusion works and generates many expectations about what we should observe when fusion actually happens. According to nuclear theory, deuterium atoms fuse and release energy in a two-step process:

1) The two deuterium atoms unite to form a single atom of helium-4 (helium with two protons and two neutrons).
2) This helium-4 atom has a lot of energy—so much energy that it is unstable. The unstable atom quickly discharges some of this energy in one of three ways: releasing a neutron, proton, or gamma ray (a type of electromagnetic radiation) (Fig. 7).

The fusion process—the formation of helium-4 and the subsequent energy release—is expected to generate a great deal of heat. Furthermore, nuclear theory tells us how much of each fusion product we should expect to observe: for a given amount of deuterium undergoing fusion, we should see the production of about equal numbers of protons and neutrons and a much smaller number of gamma rays. The heat, neutrons, and

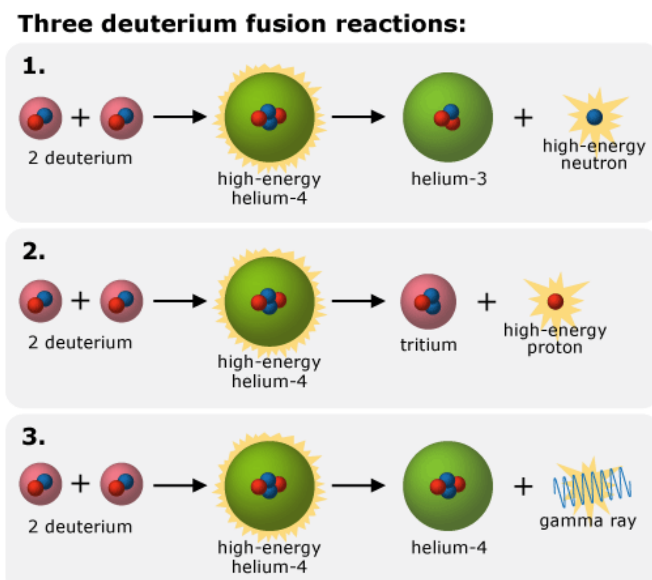

Figure 7.

Steven Jones photo courtesy of Steven Jones

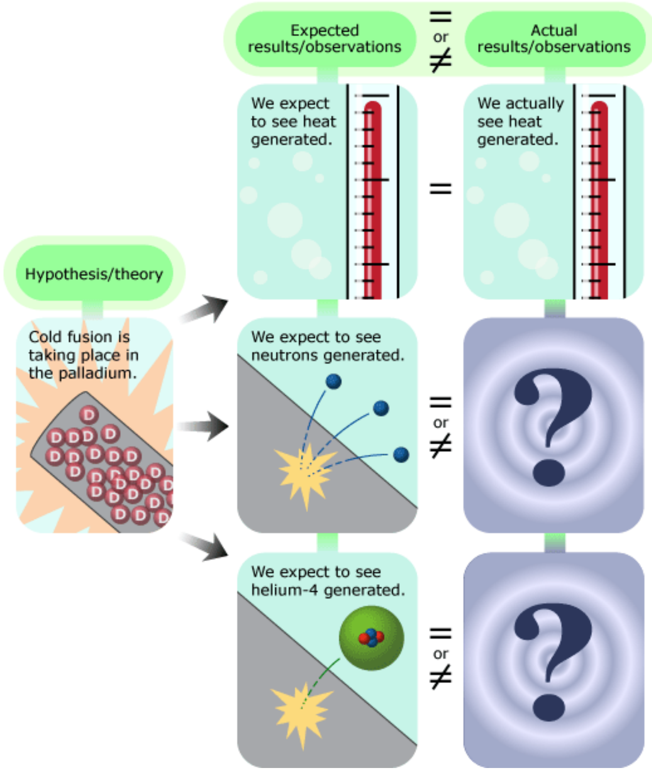

Figure 8.

helium-4 could all have been detected by equipment available at the time. That made at least three lines of evidence available to shed light on whether or not fusion was occurring (Fig. 8). Detecting these three products in the appropriate amounts would have been strong evidence in favor of cold fusion.

Using a brand new, state-of-the-art neutron detector, Jones' team (Fig. 9) had found evidence of a small number of neutrons coming from their fusion cell. Jones interpreted this as evidence for fusion. Despite this conceptual agreement that cold fusion is possible, the details of Jones' results did not mesh with Pons and

Figure 9. Professor Steven Jones and fellow BYU physicists with their neutron detection equipment. From left are Jones, J. Bart Czirr, Gary L. Jensen, Daniel L. Decker, and E. Paul Palmer.

Fleischmann's findings. The amount of fusion Jones thought he was detecting was so minute that it had no practical application—whereas Pons and Fleischmann's results indicated that fusion cells could be used as an energy source, one day fueling entire power plants.

Jones' team photo courtesy of Steven Jones

Since they were seeking different lines of evidence for the same phenomenon, Jones asked the funding agency, the United States Department of Energy, to inform Pons and Fleischmann about his research—and suggest a collaboration. Scientifically speaking, collaborating was a good idea. Scientists are expected to understand the current research and theory in their fields in order to ensure that their work is up-to-date and takes recent advances into account. Though Pons and Fleischmann had extensive training in chemistry, neither of them had studied nuclear physics, which was Jones' area of expertise. Additional physics knowledge would have been especially helpful in this case because the hypothesis about fusion occurring in palladium was so unconventional. It went against the grain of well-supported physical theories—which suggested that the deuterium atoms inside palladium wouldn't get close enough to one another to fuse. Both groups had relevant knowledge that the other lacked. By collaborating, they would broaden their understandings of the problem, techniques, and evidence—and would be better able to judge whether or not fusion was occurring.

Unfortunately, the benefits of collaboration were not enough to persuade Pons and Fleischmann to work with Jones' group. Pons and Fleischmann were convinced that Jones had used details gathered from their grant application to get his experiment running. They refused to collaborate—and in so doing, missed an opportunity to expand the expertise of their team (Fig. 10).

Figure 10.

Anomalous neutrons

Worried that Jones would scoop them, Pons rushed to perform neutron experiments of his own, but his search for neutrons did not start off well. He was initially unable to detect any sign of neutrons being released from his cold fusion cell, although the large number of neutrons produced by fusion should have been relatively easy to detect. Pons then tried a second technique for neutron detection. This time he found neutrons—but a hundred million times *fewer* than the number he had expected to detect! However, this was still many times *more* neutrons than the number that Jones had found (Fig. 11). Nothing seemed to be matching up—Pons' neutron results didn't agree with his heat measurements, with Jones' neutron results, or with established nuclear theory, which suggested no fusion should be occurring at all!

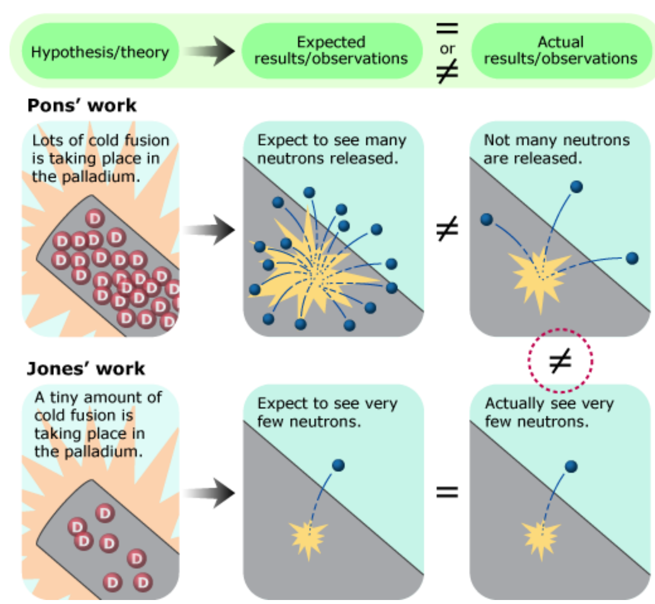

Figure 11.

Despite their confusing results, Pons, Fleischmann, and Jones were in an exciting place. Their results conflicted with established theory (Fig. 12)—and such anomalous results sometimes lead to major scientific advances. Nuclear theory itself came about in this way, when Ernst Rutherford and his colleagues discovered that their experimental findings didn't fit with established views of the atom. Could the surprising cold fusion results indicate that nuclear theory also needed to be reconsidered? Perhaps, but Pons, Fleischmann, and Jones would

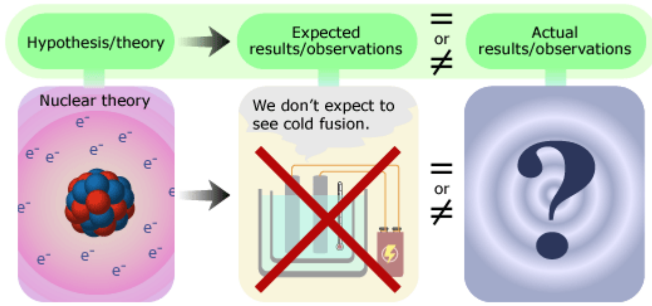

Figure 12.

need strong evidence to support this conclusion. Such theoretical revolutions are the exceptions, not the rule. Fifty years' worth of scientific labor and all the evidence supporting nuclear theory was telling them that they'd made a mistake; fusion couldn't be occurring.

As scientists, the correct course of action was clear. Scientific conduct involves balancing skepticism and open-mindedness. The cold fusion scientists were expected to keep both the new results and the old theory in mind, while doing their best to gather more evidence. With such surprising results, they had an even greater responsibility to complete thorough and careful testing to support their results and eliminate the possibility of experimental error.

Though Jones, Pons, and Fleischmann knew their scientific responsibilities, there was new pressure to publish quickly since the two groups would be competing. In science, it's not uncommon for two or more groups to investigate the same problem at the same time, and so science has a rule for assigning credit. The first group to publish gets the credit for a new discovery. Thus, if either Jones or the Pons/Fleischmann team spent too much time doing additional tests before publishing, they ran the risk of missing out on the scientific credit. Additionally, Pons and Fleischmann's results suggested the possibility of lucrative applications for power generation—and so they were also concerned about patent rights. The standards for scientific conduct (and the time required for thorough testing) were in conflict with the time crunch compelled by other concerns.

Only two months after Pons and Fleischmann had learned that they had competition, Jones informed them that he was prepared to publish. Jones generously proposed that both groups submit their papers to the same journal at the same time so that the credit could be shared. The proposed date of submission was just 18 days away, but Pons and Fleischmann had been hoping for another 18 *months* to complete their testing. Despite the fact that this severely cut down on their time to gather data, Pons and Fleischmann felt they had no choice and agreed to the joint paper submission. They returned to the lab (Fig. 13), determined to collect as much evidence as possible in the remaining days.

Figure 13. Pons (left) and Fleischmann in their lab.

Pons and Fleischmann photo by Paul Barker, courtesy of *Deseret News*

The rush to publish

Though they'd just agreed to a joint submission in 18 days and despite the fact that they'd originally wanted 18 months to complete their experiments, Pons and Fleischmann jumped ahead of Jones and submitted a journal article on their own just five days later. This action broke with standards for scientific behavior on two levels (Fig. 14). First, they failed to uphold the ethical standards set by the scientific community by breaking the intent (if not the letter) of their agreement with Jones. Second, they didn't sufficiently expose their ideas to testing. In their rush to publish, they failed to perform some simple and obvious experiments, the results of which would have provided key evidence about whether or not their cold fusion hypothesis was correct. For example, they could have:

How did Pons, Fleischmann and their colleagues violate each of the guidelines for good scientific behavior?

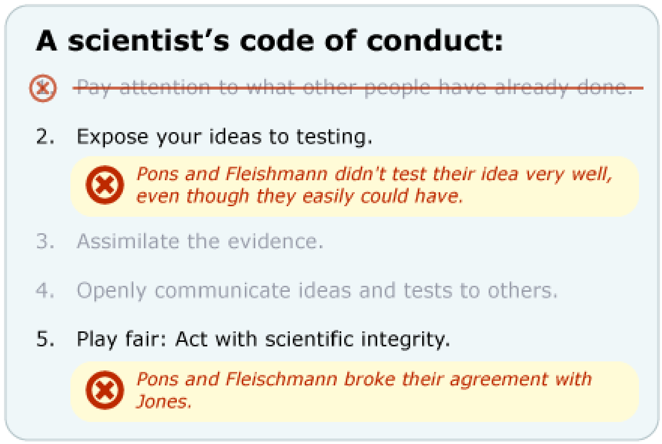

Figure 14.

- Run their fusion cell with regular water in place of the deuterium-rich heavy water. In science, this is known as a control. If the experiment generated excess heat—even when it lacked the key ingredient, deuterium—it would be strong evidence *against* the idea that fusion was the cause of the heat.
- Used another metal in place of palladium. Their hypothesis relied on the large amount of deuterium that palladium could absorb. If another metal with less absorption capacity could produce similar results, then this would also be strong evidence against fusion. This is another example of a control.
- Used a more advanced heat measurement technique. Pons and Fleischmann used a technique in which gasses were allowed to escape the fusion cell and then the amount of heat carried away by these gasses was estimated. If they had used a different technique in which no gasses escaped, they would have obtained more accurate results.
- Sought expert advice on their search for neutrons and other nuclear products. Detecting these particles is not easy, and Pons had no previous experience in this area. On top of that, the equipment Pons used was not very sensitive. More sensitive equipment and more experience operating it would have added credibility to their claims.

Pons and Fleischmann submitted their paper to the *Journal of Electroanalytical Chemistry* (Fig. 15), whose editor felt that the weight of Pons and Fleischmann's potential discovery merited special treatment. The editor put the article through an abbreviated form of peer review—the system science has in place to make sure journal articles meet good scientific standards. Peer review can catch a variety of shortcomings in articles before they get published. For instance, peer reviewers normally notice when the evidence is insufficient to support the authors' claims (as was the case for Pons and Fleischmann's) and suggest that additional evidence be collected before publication. Reviewers also look for potential flaws in reason-

Figure 15.

ing and experimental design. Adequate peer review might have caught a serious flaw in Pons and Fleischmann's logic—they had incorrectly calculated the magnitudes of the forces acting on deuterium while inside palladium. The correct calculation revealed forces much, much smaller—too small to push deuterium atoms close enough together to fuse. However, this and other shortcomings in Pons and Fleischmann's article slipped through the rushed review. The reviewers had just one week to scrutinize the paper (when several weeks are usually allowed) and didn't get to review the changes the authors made in the second draft.1 This short review period bypassed some of the checks set up in the process of science, and would eventually contribute to unnecessary confusion, as well as wasted time, energy and money.

It's not entirely clear why Pons and Fleischmann chose to publish so much earlier than they had initially intended, but the impact on their study is apparent. Many scientists later criticized their lack of thoroughness as well as the quality of their work. Pons and Fleischmann had not performed the experiments or the analysis very carefully, and a month after the paper appeared, they had to publish a list of corrections two pages long that included important modifications to their data. However, before the scientific community got their chance to evaluate Pons and Fleischmann's ideas about cold fusion, the two brought their claims to the public at large.

Publication by press conference

Instead of waiting for the scientific community to have its say on Pons and Fleischmann's radical claims—or even for the paper to be published—the University of Utah held a press conference (Fig. 16) to announce the success of cold fusion to the world. Very little concrete information was given, but the two scientists and university officials repeatedly emphasized the amount of energy that Pons and Fleischmann thought their fusion cells could produce in the future if the cells were made bigger and better. This gave the public a highly optimistic view of cold fusion and aroused much excitement about the possibilities, all before the scientific community had even had a chance to determine if cold fusion was real.

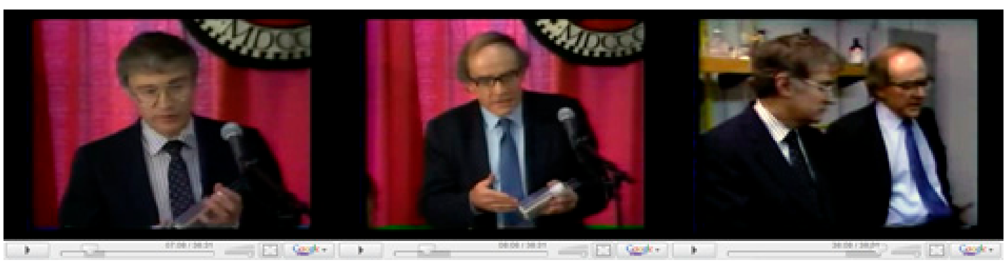

Figure 16. Pons (left) and Fleischmann at the March 23, 1989, University of Utah press conference. These clips are taken from a video of the press conference, viewable on YouTube.

Roadblock to replication

While publicizing exciting discoveries is normal, early publicity, combined with curtailed peer review, caused some problems in this case. The scientific community was in an uproar after the press conference. Pons and Fleischmann had made extraordinary claims, but because the paper was not yet available, the scientific community had no way to evaluate the work presented in the paper—let alone try to replicate it.

While the process of science doesn't require that every experiment be replicated, with results as surprising as Pons and Fleischmann's—results that contradict a well-supported theory—it is mandatory. After all, science aims to uncover the unchanging rules by which the universe operates. This means that a phenomenon should operate the same way regardless of who's testing it where. Nuclear theory had passed this test, but it still remained to be seen if cold fusion could.

Pons and Fleischmann's paper was still several weeks away from publication, but scientists didn't let that stop them. Unauthorized copies of the article began to circulate within the scientific community by fax—but when

Press conference video copyright holder could not be determined; diagram of cold fusion cell adapted from Figure 1 in Fleischmann, M., S. Pons, et al. 1990. Calorimetry of the palladium-deuterium-heavy water system. *Journal of Electroanalytical Chemistry* 287:293-348

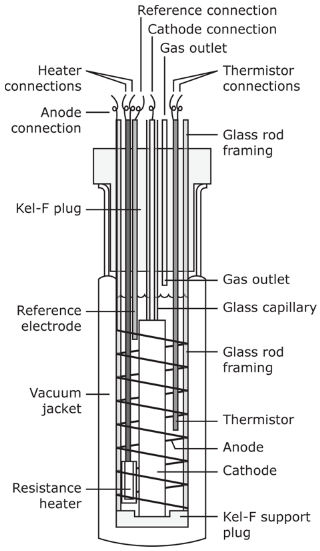

Figure 17. A diagram of Pons and Fleischmann's cold fusion cell from one of their published papers.

other scientists tried to set up the same experiment (Fig. 17), they found that the paper did not describe all the relevant details. This is not that unusual in science today. Many procedures are complex, and fully describing them would take too many pages. In these cases, the authors are expected to furnish the relevant details upon request. However, Pons and Fleischmann refused to provide these details when asked (Fig. 18). University of Utah officials later revealed that they had instructed Pons and Fleischmann not to give away too many details before a patent was filed. Withholding information like this obstructs the scientific process by shielding ideas from testing. But the scientific community wouldn't let this roadblock stop them either …

How did Pons, Fleischmann and their colleagues violate each of the guidelines for good scientific behavior?

A scientist's code of conduct:

~~Pay attention to what other people have already done.~~

~~Expose your ideas to testing.~~

3. Assimilate the evidence.

4. Openly communicate ideas and tests to others.

Pons and Fleischmann refused to reveal the details of their test design to other scientists.

~~Play fair: Act with scientific integrity.~~

Figure 18.

Serious scrutiny

In addition to trying to replicate Pons and Fleischmann's experiment—attempts which had been thwarted by lack of information—scientists also tried to verify the work in other ways, scrutinizing the cold fusion paper for potential sources of error. Many of the problems they noticed would likely have been caught in a thorough peer review, and some mistakes were surprisingly simple. For example, scientists noted that Pons and Fleischmann hadn't stirred the heavy water inside their fusion cells. Just as not stirring a pot of soup on the stove is likely to leave some parts cold and others burnt, not stirring the water in a fusion cell leads to uneven heat distribution and inaccurate temperature measurements.

Others continued to try to replicate the findings by trying out many different experimental combinations, hoping to hit on the one used by Pons and Fleischmann (Fig. 19). Initial results were mixed. While most research groups reported seeing no evidence for fusion, a few groups did claim to observe excess heat and/or neutrons coming from their fusion cells. However these groups conflicted with each other on the conditions needed for fusion. For example, some found that months were needed for the nuclear reactions to begin, others noted results in just a few hours. And often, these groups couldn't even replicate their own results.

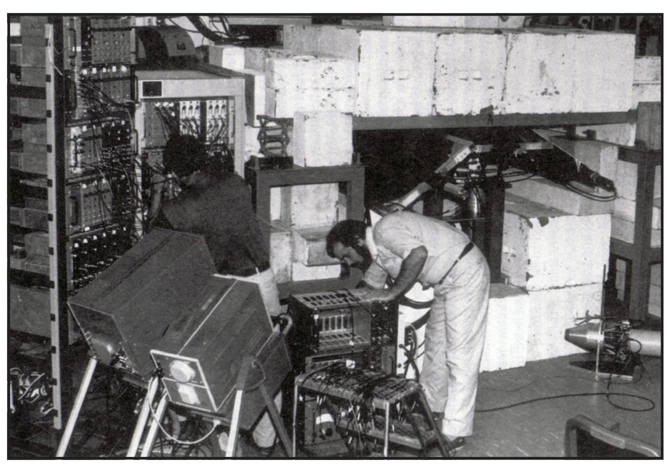

Figure 19. A team of scientists from Yale University, Brookhaven National Laboratory, and Brigham Young University was one of the groups attempting to replicate the results of Pons and Fleischmann. Here, crew members tune the electronics for their experimental setup.

Yale-BNL-BYU team photo courtesy of Moshe Gai

How was it possible for very similar experiments to produce such varied results? Some of the results were simply mistakes. Several of the confirmations of Pons and Fleischmann's results had to be retracted due to errors—for example, forgetting to connect a key wire in the experimental set up. Other discrepancies were due to differences in data analysis. Scientists collect "raw" data—which must be analyzed and interpreted before it can say anything meaningful about the test. For example, many of the cold fusion scientists, including Pons and Fleischmann, tried to gauge whether fusion was happening by measuring the heat produced by the cell. This sounds like it would be simple—just measure the temperature of the cell—but, in fact, it's not. The cell exchanges heat with its surroundings, and some heat is carried away by escaping gasses (Fig. 20). The impact of these factors must be carefully estimated and taken into account in the data analysis. If two groups handle these adjustments differently in their analyses, they might come to different conclusions about the experimental results.

Scientists can also make different interpretations of the same analyzed data. One group was able to show that Pons and Fleischmann had misinterpreted the data from their neutron search. At first glance, the data seemed to show clear evidence of neutrons—but neutrons, if they are really there, would lead to a series of reactions with the water surrounding the cell—and Pons and Fleischmann's data was missing any evidence of the last link in that chain of reactions. Further investigation revealed problems with the equipment used to gather the neutron data. Thus, it seems that Pons and Fleischmann's data would have been more reasonably interpreted as evidence of equipment error, not as evidence in favor of the cold fusion hypothesis.

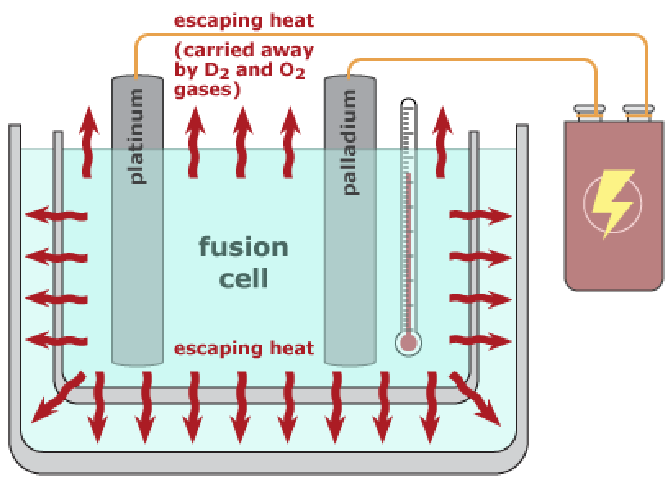

Figure 20. To really know how much heat is being produced by the fusion cell it is necessary to estimate how much heat is escaping from it.

Peer pressure

Over the next few months, scientists brought the most sophisticated and sensitive experiments to bear on the questions of cold fusion, but were unable to find any evidence in support of it. The case for cold fusion was not looking good. However, there was still the possibility that the finding couldn't be replicated—not because cold fusion wasn't happening—but because other scientists weren't matching the conditions of the original experiment exactly. Perhaps Pons and Fleischmann were doing something special in their experiment that they were not revealing or were not aware of themselves, and it was this "special something" that led to cold fusion. The best way to test this would be to have independent experts search for fusion products coming from Pons and Fleischmann's fusion cells. Many scientists offered to collaborate, but their offers were declined. Pons and Fleischmann were actively standing in the way of tests that could have shed light on whether or not their hypothesis was correct (Fig. 21).

After months with no resolution as to whether cold fusion was real, the scientific community began insisting that these tests be done. There is no governing body of science that could have forced Pons and Fleischmann to perform the follow-up tests; however, the scientific community *can* apply pressure to uphold the standards of good science by withholding esteem, funding, or jobs, and by being particularly skeptical of research performed with lax standards. Only after significant pressure from the scientific community did Pons and Fleischmann finally agree to perform the tests.

How did Pons, Fleischmann and their colleagues violate each of the guidelines for good scientific behavior?

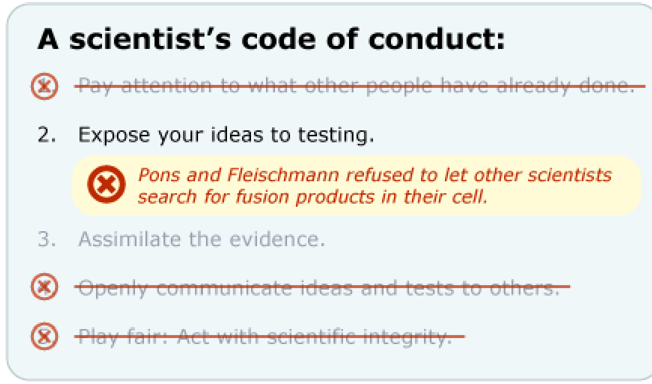

Figure 21.

One follow-up study involved searching for helium-4, one of the products of the fusion reaction. Perhaps, it was reasoned, the searches for neutrons had come up empty because the helium was stuck in the palladium rods and was not releasing its excess energy as neutrons, but in another way. Pons and a group of other scientists decided to test for helium in five palladium rods, only one of which had been used in Pons and Fleischmann's fusion cell. If fusion had indeed occurred, then only the fusion rod should have elevated helium levels. To reduce the possibility of bias influencing results, they decided on a "double-blind" study design. Pons would give the rods to an intermediary, who would distribute segments of all five rods to six different laboratories. Neither the intermediary nor the testing labs would know which rod was which, and Pons wouldn't be able to unintentionally tip off the laboratories about it when he gave them the rods.

The six labs tested each rod segment for helium and gave their results back to the intermediary, who met with Pons to exchange the results and the rod information. Pons had initially agreed to reveal which rod had been used in a fusion cell at this time, but changed his mind and kept those details to himself. He reviewed the helium data and saw that the fusion rod did not have elevated helium levels. The study did not support cold fusion (Fig. 22).

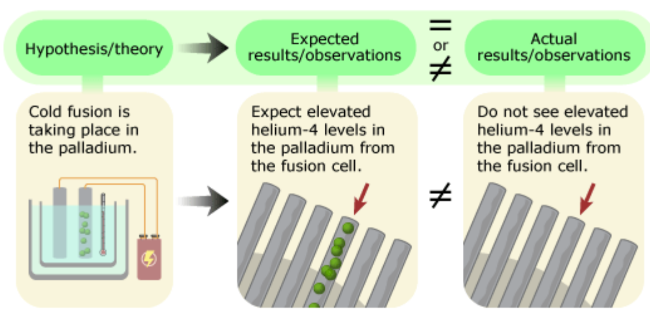

Figure 22.

While these results might seem cut-and-dried, Pons cast doubt on them when they were finally publicized. He explained that the particular fusion rod he'd submitted for helium analysis had not produced as much heat as he'd claimed at recent scientific conferences. This was problematic on several levels. If the rod hadn't had much fusion going on in it, then that would explain why it didn't have elevated helium levels. But then why did Pons sabotage the helium study by providing a bad rod? And why did he report such high levels of heat for his original fusion experiment? Was Pons manipulating the data?

Still no neutrons

In a last ditch effort to validate the cold fusion results, fellow University of Utah professor Michael Salamon (Fig. 23) was allowed into Pons' lab to conduct experiments searching for neutrons coming from Pons and Fleischmann's own fusion cells. If *any* experiment could be sure to replicate the conditions of the original, this would be it. During his five-week long test, Salamon was unable to detect any neutrons (Fig. 24).

Pons tried to cast doubt on these results by claiming that the cells were not producing excess heat (and hence, that fusion was not going on) during those five weeks, except during a two-hour period that happened to coincide with a power outage. However, one of Salamon's instruments was still able to collect data on neutrons during the outage. Not surprisingly, no spike in neutrons was observed. Pons even went so far as to attempt to censure Salamon's data by threatening legal action if Salamon did not voluntarily retract his report. Such attempts to control information are a severe violation of scientific ethics and present an obstacle to scientific progress.

Figure 23. Michael Salamon, now with NASA, in 2009.

Despite all the evidence against them—conflict with established theory, problems with the original experiments, multiple failed replication attempts, and even tests suggesting that the original experiments had produced no fusion—Pons and Fleischmann refused to adjust their hypothesis about fusion occurring in palladium and, in this way, broke with standards for good scientific behavior (Fig. 25). Though scientists are expected to be open-minded about new ideas, when multiple lines of evidence accumulate against them, even the most intriguing hypotheses must be abandoned.

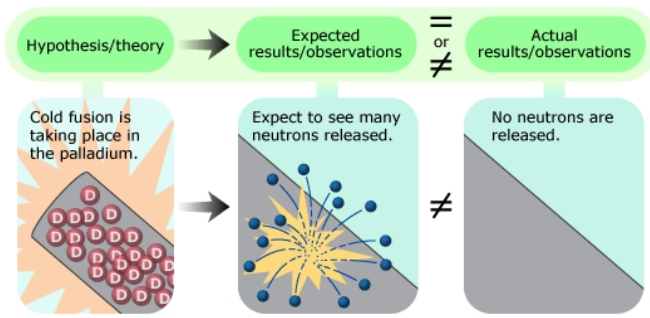

Figure 24.

How did Pons, Fleischmann and their colleagues violate each of the guidelines for good scientific behavior?

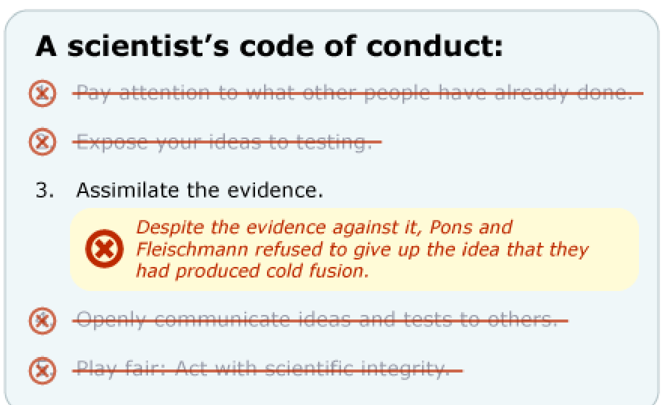

Figure 25.

The smoke clears

One year after the press conference that had garnered Pons and Fleischmann so much attention, the scientific process had finally been able to sort through the evidence regarding cold fusion. Few groups had found support for the hypothesis, and those few had inconsistent results and could not reliably reproduce their findings. This lack of replicable evidence was a major blow for cold fusion. The laws of nature don't play favorites. If cold

Michael Salamon photo courtesy of Michael Salamon, NASA

Figure 26.

fusion works in one laboratory under a certain set of conditions, we'd expect it to work in other laboratories at other times under the same conditions. Hence, lack of reproducibility is a serious problem for any scientific finding, casting doubt on the validity of the original result and suggesting that there's been a misinterpretation of what's going on. In Pons and Fleischmann's case, lack of reproducibility indicated that whatever it was they had originally detected, it probably wasn't cold fusion. This interpretation is also supported by the fact that independent scientists couldn't find any evidence that Pons and Fleischmann's own cells had actually produced fusion. In light of all this evidence, most scientists consider Pons and Fleischmann's results to be an experimental error (Fig. 26).

An error like this would normally be detected before it caused an uproar in the scientific and broader communities. However, in the case of cold fusion, the checks inherent in the process of science were weakened when Pons, Fleischmann, and others caught up in the excitement broke with norms for good scientific conduct (Fig. 27). While the process of science is resilient to a single, or even a few divergences from best practices, the convergence of multiple infractions can hinder the process. The journal editor who allowed the original article to be published with minimal peer review did not adhere to the standards science had set for such publications. Pons and Fleischmann withheld experimental details from the community and tried to shield their ideas from testing. They and the other scientists who "reproduced" cold fusion, only to later retract their results, failed to perform adequate tests to evaluate their ideas. And, of course, Pons' behavior during the helium experiment, as well as the broken publication agreement with Jones, smacked of dishonesty (Fig. 27). It's important to note that even with such unscientific behavior, the process of science still *worked*. Within a year, the scientific community had investigated Pons and Fleischmann's claims and come to the consensus that what had been observed wasn't really cold fusion. However, there was still a price to pay for this misconduct: time, energy, and upwards of 100 million tax dollars were squandered on cold fusion.

A scientist's code of conduct:

- ~~Pay attention to what other people have already done.~~
- ~~Expose your ideas to testing.~~
- ~~Assimilate the evidence.~~
- ~~Openly communicate ideas and tests to others.~~
- ~~Play fair: Act with scientific integrity.~~

Figure 27.

Pons and Fleischmann also did damage that is harder to quantify. Perhaps most worrying is the effect that this debacle had on the public's perception of science. Pons and Fleischmann's unclear statements at the press conference, which emphasized only the future benefits of cold fusion and not the early stage of the investigation, contributed to the media hype and raised society's expectations without warrant. These unmet expectations coupled with accusations of fraud and dishonesty damaged the public's trust in science. Because science is so deeply intertwined with the broader community, scientific misbehavior has implications far beyond the group of physicists and chemists who study cold fusion.

Despite all this, some scientists continue to investigate the possibility of cold fusion. Science doesn't give up on ideas that have merit, even if they experience setbacks. All scientific knowledge is, after all, tentative. So though there is every reason to think that what Pons and Fleischmann observed was not cold fusion, some scientists (though a small minority of the physics community) continue to investigate whether or not cold fusion is possible. But to convince the rest of the physics community, they'll need to find many lines of solid evidence to support their views.

Want to learn more? Check out these references

Popular and historical accounts:

Huizenga, J. 1993. Cold Fusion: The Scientific Fiasco of the Century. New York: University of Rochester Press.

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