Science as a Way of Knowing
Best practices for proposing new courses

Introduction and history
In response to the 2010-2011 Academic Program Review of the Liberal Studies Program, the Scientific, Analytical and Computational Thinking Working Group recommended the development of a new designation within Scientific Inquiry: Science as a Way of Knowing. This recommendation was approved by the Provost through a Memorandum of Understanding. The Liberal Studies Council then formed an ad-hoc working group to craft new learning outcomes for SWK, and subsequently these were approved by LSC. As a final step, the new learning outcomes were presented to Faculty Council at their Oct 2014 meeting and approved the following month.

The Scientific Inquiry Domain will work to solicit and review new course proposals for SWK and integrate SWK into our normal syllabi review and assessment cycle. We emphasize that all new SWK classes will go through the proposal process, and no current SI classes will be grandfathered in. Current SI elective courses can be modified to meet the new learning outcomes of SWK by adding activities and assignments that focus on the process and nature of science. To aid faculty in developing new courses or adapt current ones, this best practices document provides example syllabi and exercises. Our goal is to offer students SWK courses that stress the nature and process of science, instead of focusing on delivering scientific content.

The SWK designation is effective starting with students matriculating during the fall of 2015. From the student perspective, the SWK requirement will replace one of two required SI electives, if the student's degree program originally required three SI courses. For other situations, the SWK requirement typically becomes an and/or option with the lab requirement. Students can also take an SWK course to fulfil the SI elective designation. That allows students enrolled before the fall of 2015 to get SI domain credit for taking an SWK course.

We are excited to implement this new designation that will improve the learning outcomes of our students. We also understand this is a significant change, and we are happy to respond to any feedback you have. While the overall direction of SWK is overseen by the Liberal Studies Council, as chair of the Scientific Inquiry Domain, I look forward to hearing your suggestions for implementing this important initiative.

Mark Potosnak, chair of the Scientific Inquiry Domain (mpotosna@depaul.edu)

Table of Contents

Learning outcomes for “Science as a Way of Knowing (SWK)” courses

In the context of natural science content:

1. **Students will understand the scientific worldview.** As a result of their learning in this course, students will be able to:
   a. Identify the types of questions that can and cannot be answered by science, and recognize the strengths and limitations of science in answering questions about the natural world.
   b. Critically evaluate the assumptions that underlie scientific investigations.
   c. Substantiate the claim that scientific knowledge is durable but can evolve with new evidence and perspectives.

2. **Students will understand the nature and process of science.** As a result of their learning in this course, students will be able to:
   a. Connect evidence to the predictions made by theories and hypotheses, and then assess the extent to which the presented evidence supports or refutes a scientific claim.
   b. Evaluate the role of creativity, curiosity, skepticism, open-mindedness and diligence of individuals in scientific discovery and innovation.
   c. Recognize the uncertainty inherent in the scientific approach and evaluate scientists’ efforts to minimize and understand its effect through experimental design, data collection, data analysis and interpretation.
   d. Evaluate the role of communication, collaboration, diversity and peer review in promoting scientific progress and the quality of scientific evidence and ideas, and ensuring compliance with ethical standards.
   e. Determine the extent to which science both influences and is influenced by the societies and cultures in which it operates.
   f. Apply scientific approaches to problem solving and decision-making in their own lives, and evaluate how scientific knowledge informs policies, regulations, and personal decisions.

Note: The Scientific Inquiry Domain Committee will consider proposals grounded in natural science content from any instructor.

FAQS: The New "Science as a Way of Knowing" (SWK) course

What is an SWK course, and how does it differ from the standard Scientific Inquiry course?

- *Drawing from the learning outcomes, SWK courses focus on the scientific worldview and the nature and process of science. A typical SI course captures aspects of these points, but many focus on scientific content before process. A second change is the emphasis on natural science. While SI classes came from a range of scientific disciplines, SWK classes rely on the perspective of natural science to clearly elucidate the process of science.*

Where did the idea for this come from? Who came up with it?

- *It came out of the extensive science self-study and response from reviewers in the last comprehensive Academic Program Review of the Liberal Studies Program in 2010. It demonstrated that students were not learning very basic scientific ideas even though they were taking lab courses.*
- *The notion of making SWKs an SI requirement was taken up and passed by the Liberal Studies Council, a standing committee of Faculty Council, and was part of the Memorandum of Understanding signed by the Provost and reviewed by Faculty Council.*
- *A working group of faculty from all colleges produced learning outcomes for SWK classes approved by the Scientific Inquiry Domain Committee and then passed by the LSC and FC.*
- *In short, hundreds of people—and dozens of faculty—from across all colleges and units were involved in the process to create this designation.*

Will this be a new LSP requirement? How does this change the current Scientific Inquiry (SI) domain requirements?

- *Yes, this is a new requirement. Beginning in autumn, 2015, SWK courses are required for all incoming first-year students.*
- *Each college and program has slightly different SI requirements. Most outside of the sciences have three—a Lab, and two Electives. Now, most students will have SI requirements comprised of: a Lab, an Elective, and an SWK course.*

How can teachers apply to teach SWK courses? What is the proposal process?

- *An online proposal system is up and running at:* https://lascollege.depaul.edu/lspcourseproposal *Like other LSP proposals, a faculty member submits a course proposal online, it gets routed to their chair and to the LSP, and eventually reaches the Scientific Inquiry Domain for vetting.*
- *The LSP can advise and assist at any stage of the process and there will be materials to aid faculty in writing their proposals. We invite submissions of either existing courses—many SI courses can become SWK courses—or brand new courses.*

What information should be included in the course proposal form?

- *In addition to attaching the syllabus and filling out the parts of the online form, please list each individual sub-point from the two SWK learning outcomes and give at least one example of a course assignment, rubric or other activity that explicitly demonstrates how the course would meet the sub-point. See an example provided on the following page of this best practices document. Most likely you will need additional space over 4000 characters, so use the option to attach a file.*

Example point-by-point response by Margaret Workman, Environmental Science and Studies

1. Students will understand the scientific worldview. As a result of their learning in this course, students will:
    a. Identify the types of questions that can and cannot be answered by science, and recognize the strengths and limitations of science in answering questions about the natural world.

As a homework assignment, students will read the website "Understanding Science: Science has limits" and answer questions about the strengths and limitations of science. Students will be given statements reflecting common misconceptions about science and asked to reflect on the statements.

http://undsci.berkeley.edu/article/0_0_0/whatisscience_12

Sample question from assignment: Reflect on the following misconception about science: Science contradicts the existence of God.

    b. Critically evaluate the assumptions that underlie scientific investigations.

As a homework assignment, students will read the website "Understanding Science: Basic Assumptions of Science" and answer questions that highlight how science operates on the assumption that natural causes explain natural phenomena, that evidence from the natural world can inform us about those causes, and that these causes are consistent.

http://undsci.berkeley.edu/article/basic_assumptions

Sample question from assignment: Detail the 3 basic assumptions of science discussed in the reading using a ball dropping to the ground as an example.

    c. Substantiate the claim that scientific knowledge is durable but can evolve with new evidence and perspectives.

Students will be given an article to read as homework with questions to be answered. The article is "Continents: Jigsaw Puzzle with No Mechanism." It describes Alfred Wegener's development of the Theory of Continental Drift. The questions will focus on the thought and effort that went into developing and substantiating ideas that account for the available evidence at the time; and how these thoughts and ideas change as more evidence becomes available. In addition, homework questions will highlight how often much time passes as scientific ideas emerge, develop and are eventually accepted or discarded.

http://www.storybehindthescience.org/pdf/jigsaw.pdf

Sample question from assignment: Discuss how our scientific knowledge of Earth's landforms and shapes evolved from global catastrophes to the Theory of Continental Drift to our current understanding of Plate Tectonics as new evidence and perspectives became available.

DePaul University
STEM Studies Department

Autumn 2014

Course Number:	STEM 231
Course Title:	Introduction to Earth and Space Science
Location:	McGowan South, Room 200
Class Times:	Tuesdays and Thursdays, 9:40-11:10 AM September 11-November 18, 2014

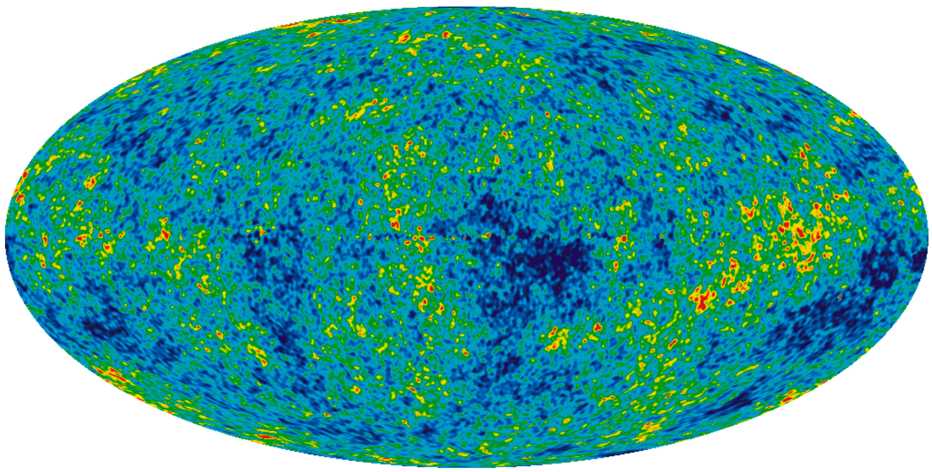
This course fulfills the *Scientific Inquiry Domain Elective* requirement of the Liberal Studies Program.

Instructor:
Prof. Bernhard Beck-Winchatz
Office: 990 W Fullerton Ave, Suite 4400
Phone: 773-325-4545
Email: bbeckwin@depaul.edu
Office Hours: Tuesdays and Thursdays, 1:00-2:00 PM and by appointment

Instructor bio: Bernhard Beck-Winchatz is an associate professor in the STEM Studies Department. (STEM is an acronym for Science, Technology, Engineering and Math.) He received his Ph.D. in astronomy from the University of Washington in Seattle and his masters in physics from the Ludwig Maximilian's University in Munich, Germany. He joined DePaul University in 1998 to serve as the associate director of the NASA-funded DePaul Space Science Center for Education and Outreach where his main job was to work with space scientists, teachers, and museum professionals on NASA-related educational projects. In 2002 he also became a member of the DePaul faculty. His research focuses on both science education and astronomy. He is the author or co-author of over 50 journal articles. He grew up in a small town near Heidelberg, Germany with nine sisters and three brothers and now lives in Rogers Park with his wife Michaela Winchatz, who is a faculty member in the College of Communication.

Course description: STEM 231 is a science course designed specifically for students majoring in non-science disciplines. Maybe you are wondering why DePaul requires you to take science courses in the first place. Wouldn't it make more sense to save your time and energy and focus on courses more directly related to your future career? I think the main reason why it does make sense for *all* students to study science in college is that we live in a global civilization that profoundly depends on science and technology. Like it or not, science affects your daily life. There are big questions that have to be addressed by society, such as what to do about climate change, and personal questions about your own life, such as what to eat in order to stay healthy and what medical treatment to seek when you are sick. So a major goal of this course is to learn about the process scientists use to answer questions and generate new knowledge. How is science as a way of knowing different from other ways of knowing the world, for example those used by religious scholars, historians and artists? How do you distinguish between science and pseudo science?

A second reason why I believe it is important for all students to study science in college is that knowing how the natural world works can enrich your life and contribute to your understanding of who you are and where you came from. Take a look at the picture below. It was taken by NASA's WMAP satellite and shows what the universe looked like shortly after it was born 13.7 billion years ago.



Back then the universe was basically nothing but a dense and almost uniform cloud of hydrogen and helium gas. Not even the basic building blocks of our world, such as carbon, nitrogen, oxygen, phosphorus and iron existed. But every atom in your body, Earth, the sun and every other object and living being came from the same kind of material you see in this image. How did we get from this dull cloud of gas to the richness we observe around us today? Science provides us with the tools to figure it out.

Our basic strategy in this course is to start right here on Earth by asking some fundamental questions about our planet. How do we know its size? How did it form? How is it affected by its celestial neighbors? And then make our way out to the edge of our universe seen in the picture. On the way we will ask questions about gravity and orbits, light and spectra, the possibility of extraterrestrial life, and the origin and age of the universe. At every step of the way we will not only learn scientific facts, but also investigate the process by which these facts were discovered.

What I expect from you:

- Come prepared to each class. Complete all homework assignments and readings.
- Contribute to classroom discussions by offering your own insights, questions and perspectives.
- Complete all in-class assignments. Approach each assignment critically and imaginatively. Ask questions.
- Constantly evaluate your learning and reflect on what you are learning and what you would like to learn. Talk to me about this.

What you can expect from me:

- I will read your assignments and exams, and provide feedback to help you achieve the learning outcomes of this course.
- I will strive to create a classroom environment in which you enjoy learning science and feel comfortable participating in discussions.
- I will respond (almost) immediately to any phone calls, e-mails, or other communications that take place outside of the class.
- I will be respectful of the views students express in class.

Learning Outcomes:

Science Content
Students will be able to

1. Apply different methods, such as those developed by Eratosthenes and Johannes Kepler, to measure basic properties of Earth and other celestial objects.
2. Create and use models to predict the positions, motions and appearances of celestial objects.
3. Analyze celestial observations to measure times and positions (celestial navigation).
4. Evaluate the relationship between diameter, angular size, parallax and distance to determine astronomical distances.
5. Analyze the light spectrum emitted by stars to determine their basic properties.
6. Evaluate the evidence for the scale and expansion of the universe, and generate estimates of the age of the universe from the motions of distant galaxies.

Scientific Inquiry
This course is a pilot course for the new Science as a Way of Knowing (SWK) designation of the Scientific Inquiry Domain. In addition to the SWK learning outcomes listed below, students will also be able to achieve the Scientific Inquiry Domain Learning Outcomes listed on the Liberal Studies Program web site.
(http://las.depaul.edu/academics/liberal-studies)

1. Students will understand the scientific worldview. As a result of their learning in this course, students will be able to:
    a. Identify the types of questions that can and cannot be answered by science, and recognize the strengths and limitations of science in answering questions about the natural world.
    b. Critically evaluate the assumptions that underlie scientific investigations.
    c. Substantiate the claim that scientific knowledge is durable but can evolve with new evidence and perspectives.
2. Students will understand the nature and process of science. As a result of their learning in this course, students will be able to:
    a. Connect evidence to the predictions made by theories and hypotheses, and then assess the extent to which the presented evidence supports or refutes a scientific claim.
    b. Evaluate the role of creativity, curiosity, skepticism, open-mindedness and diligence of individuals in scientific discovery and innovation.

c. Recognize the uncertainty inherent in the scientific approach and evaluate scientists' efforts to minimize and understand its effect through experimental design, data collection, data analysis and interpretation.
d. Evaluate the role of communication, collaboration, diversity and peer review in promoting scientific progress and the quality of scientific evidence and ideas, and ensuring compliance with ethical standards.
e. Determine the extent to which science both influences and is influenced by the societies and cultures in which it operates.
f. Apply scientific approaches to problem solving and decision-making in their own lives, and evaluate how scientific knowledge informs policies, regulations, and personal decisions.

Writing Expectations
Writing is integral for communicating ideas and progress in science, mathematics and technology. The form of writing in these disciplines is different from most other fields and includes, for example, mathematical equations, computer code, figures and graphs, lab reports and journals. Courses in the SI domain must include a writing component where that component takes on the form appropriate for that course (e.g., lab reports, technical reports, etc.*)*

Course Readings:

- Astronomy Notes
  http://www.astronomynotes.com/
- Teach Astronomy
  http://www.teachastronomy.com
- Understanding Science – How Science Really Works
  http://undsci.berkeley.edu
- Visionlearning – Your Insight into Science
  http://visionlearning.org
- The Story Behind the Science – Bring Science and Scientists to Life
  http://www.storybehindthescience.org

Course Grading:
Your overall grade will be based on your performance on the exams, homework assignments, and participation. In determining your course grade, each assignment will be weighted as follows:

Midterm exam:	25%
Final exam:	35%
Homework assignments:	30%
Participation:	10%

Final Letter Grades

0%-59%	*F*
60%-66%	*D*
67%-69%	*D+*
70%-72%	*C-*
73%-76%	*C*
77%-79%	*C+*
80%-82%	*B-*
83%-86%	*B*
87%-89%	*B+*
90%-92%	*A-*
93%-100%	*A*

Policies:

Exams: The final exam must be taken in order to receive a grade for this course, and you must receive a grade of 61% or more to pass the course. In the rare event that an emergency arises and you cannot take the final exam, it is your responsibility to contact the Dean of Students Office (Student Center, Suite 307, 773-325-7290) to present the required documentation for officially excused absences. In such situations you will typically receive an incomplete grade for the course, and we will make arrangements for you to take the exam as soon as possible in the next term. Examples of events that do not qualify as emergencies include conflicts with work schedules, important family vacations, etc. The policy for the midterm exam is the same as for the final exam, except that there is no make-up exam. An unexcused midterm exam will count as 0. In case of an officially excused (by the Dean of Students Office) absence the midterm exam will not be used in the calculation of the final grade.

Homework assignments: All assignments are to be submitted via D2L Dropbox by midnight of the due date. Late assignments will result in a 10% grade reduction each day that they are late, weekends included, except in the case of an extreme emergency. If an assignment is over 10 days late, it receives a zero.

Attendance: Attendance will be taken at the beginning of each class period. Two late arrivals of 15 minutes or less count as one absence. If you are more than 15 minutes late the class period will count as an absence. You are allowed two absences without grade penalty (the equivalent of one week of classes). If you have to miss more than two class periods due to family emergencies, illness, etc. it is your responsibility to contact the Dean of Students Office to present the required documentation for officially excused absences. You cannot receive a passing grade for this course if you have more than two unexcused absences.

Disability-related accommodations: Students seeking disability-related accommodations are required to register with DePaul's Center for Students with Disabilities (CSD) enabling you to access accommodations and support services to assist your success. There are two office locations:

- Loop Campus – Lewis Center #1420 – (312) 362-8002
- Lincoln Park Campus – Student Center #370 – (773) 325-1677

Students are also invited to contact me privately to discuss your challenges and how I may assist in facilitating the accommodations you will use in this course. This is best done early in the term and our conversation will remain confidential.

Dean of Students: The Dean of Students Office (DOS) helps students in navigating the university, particularly during difficult situations, such as personal, financial, medical, and/or family crises. Absence Notifications to faculty (see above), Late Withdrawals, and Community Resource Referrals, support students both in and outside of the classroom. Additionally the DOS has resources and programs to support health and wellness, violence prevention, substance abuse and drug prevention, and LGBTQ student services. http://studentaffairs.depaul.edu/dos/

Academic Integrity. DePaul University is a learning community that fosters the pursuit of knowledge and the transmission of ideas within a context that emphasizes a sense of responsibility for oneself, for others and for society at large. Violations of academic integrity, in any of their forms, are, therefore, detrimental to the values of DePaul, to the students' own development as responsible members of society, and to the pursuit of knowledge and the transmission of ideas. Violations include but are not limited to the following categories: cheating; plagiarism; fabrication; falsification or sabotage of research data; destruction or misuse of the university's academic resources; alteration or falsification of academic records; and academic misconduct. Conduct that is punishable under the Academic Integrity Policy could result in additional disciplinary actions by other university officials and possible civil or criminal prosecution. Please refer to your Student Handbook or visit Academic Integrity at DePaul University (http://academicintegrity.depaul.edu) for further details.

Introduction to Earth and Space Science
***Course Calendar: Spring 2014**

Date	*Topics*
Week 1 (9/11,9/16)	Introduction to course and syllabus; Scale of the Universe; Measuring the circumference of Earth using GPS
Week 2 (9/18,9/23)	Earth, Moon and Sun; Predicting phases, ocean tides, seasons
Week 3 (9/25,9/30)	Motions of the Sun and stars; Measuring time, celestial navigation
Week 4 (10/2,10/7)	The solar system; Orbits
Week 5 (10/9,10/14)	Midterm exam Gravity; Weighing the Universe
Week 6 (10/16,10/21)	Extrasolar planets; Radial velocity and transits; habitable zones
Week 7 (10/23,10/28)	Stars; Decoding starlight; stellar evolution
Week 8 (10/30,11/4)	The universe; the cosmic distance ladder
Week 9 (11/6,11/11)	The universe; Measuring the age of the expanding universe.
Week 10 (11/13,11/18)	TBD
Week 11 (11/25)	Final exam (8:45-11:00)

*Topics, and dates are subject to change throughout the quarter.

Examples SWK assignments
(From STEM 231)

1. Answer the following questions after reading *Theories, Hypotheses, and Laws* on the Visionlearning web site
http://visionlearning.org/en/library/Process-of-Science/49

- Is it possible to prove scientific theories? Please explain!
- Discuss the difference between scientific theories, hypotheses and laws. Provide examples for each.
- How do scientists know that a theory is correct? Can widely accepted scientific theories change? Please explain!
- What is the difference between data and evidence?

2. Read one of the articles available on the Understanding Science web site.
(An extraordinary claim with extraordinary evidence, Asteroids and Dinosaurs, …)
http://undsci.berkeley.edu/resourcelibrary.php
Each article shows how the research relates to the How Science Works flowchart. Discuss examples in class.

3. Write a paper about the history of a research topic relevant to a particular course. Use the How Science Works flowchart to track the pathways of different investigations.
http://undsci.berkeley.edu/lessons/pdfs/complex_flow_handout.pdf

4. Evaluate/compare different web sites using the Science Checklist
http://undsci.berkeley.edu/images/science_checklist.pdf
Examples:
- Compare the NASA Astrobiology Institute and the National UFO Reporting Center web sites.
- Compare the IPCC and NIPCC web sites

5. Read about Galileo's research on pendulum motion on the Story Behind the Science web site: http://www.storybehindthescience.org
- Answer the four questions about Galileo's new approach to using idealized mathematical equations in science.

6. Watch these How Science Works videos:
Discovery of a new spider
https://www.youtube.com/watch?v=Jj9iNphbY88
Climate change throughout Earth's history
https://www.youtube.com/watch?v=JH0_xC7q9tU&feature=youtu.be
- In class, use these videos as a context to discuss how the process of science works.

ENV 101
Introduction to Environmental Science w/o lab
Spring 2014

Margaret A. Workman
McGowan South Rm 203
773-325-7445
mworkman@depaul.edu

Texts

The required textbook for the class is called *Environmental Science*, written by Professors Cutler Cleveland and Robert Kaufmann.

Purchase the electronic version here: http://www.trunity.net/depaulENV101/

Course Description

A general introduction to the scientific background of some of the important environmental problems facing urban areas, the nation and the world. Its purpose is to make the student aware of these major problems, their causes, and their interrelationships as background for the student as he or she encounters these problems in other courses.

Course Learning Outcomes

Upon completion of ENV 101, students will be able to:

- Explain what is environmental science.
- Describe science as a process and the methods of modern science.
- Describe the interdisciplinary nature of environmental science and its major concepts and theories.
- Using a systems approach:
    - Describe the four major components of the earth's realms and their interrelationships.
    - Describe the fluxes of energy and matter between these cycles.
- Be able to describe the scientific basis of the major environmental issues facing society today.
- Describe the impacts of contemporary human activities on the earth's processes.

Overview of the Scientific Inquiry Domain:

Courses in the Scientific Inquiry domain are designed to provide students with an opportunity to learn the methods of modern science and its impact on the world around us. Courses are designed to help students develop a more complete perspective about science and the scientific process, including: an understanding of the major principles guiding modern scientific thought; a comprehension of the varying approaches and aspects of science; an appreciation of the connection among the sciences; the fundamental role of mathematics in practicing science; an awareness of the roles and limitations of theories and models in interpreting, understanding, and predicting natural phenomena; and a realization of how these theories and models change or are supplanted as our knowledge increases.

Students will take three courses in this learning domain. The Quantitative Reasoning course (or placement out of the course through the placement tests) is a prerequisite for all courses in this domain. Students must complete one course with a laboratory component. The other two courses can be any course offered for Scientific Inquiry credit.

Scientific Inquiry - Goals and Learning Outcomes:

Below are listed the learning goals and outcomes for the Science Inquiry Domain. Each goal is listed followed by learning outcomes associated with the goal. Most of this document conforms to the National Science Education Standards.

1. Students will understand the major principles guiding modern scientific thought. Students will demonstrate a mastery of the science content knowledge of their SID courses.

2. Students will know that science, technology, and math serve as mechanisms for inquiry into the nature of the universe. Students will:

a. identify questions that can be answered through scientific investigations
b. design and conduct a scientific investigation to test a scientific hypothesis
c. use appropriate tools and techniques to gather, analyze, and interpret data to support or refute a scientific hypothesis
d. develop descriptions, explanations, predictions, and models using evidence
e. describe relationships between evidence and explanations using critical and logical thinking
f. recognize and analyze alternative explanations and predictions
g. communicate scientific procedures and explanations
h. use mathematics in all aspects of scientific inquiry

3. Students will understand and appreciate the interrelationships among science, technology and math. Students will:
   a. use technology and mathematics to identify a problem or design a solution to a problem
   b. give examples of how science and technology inform and influence each other

4. Students will understand and appreciate the role of science in society and in their lives. Students will:
   a. provide examples of how science and technology impact our lives, and how social needs and concerns impact our development of technology and scientific investigation
   b. develop positive attitudes towards science, technology, and mathematics
   c. establish an ongoing experiential/service-learning interest in science, technology, and mathematics

5. Students will understand the nature of science, technology, and mathematics. Students will:
   a. provide examples of the abuse of science, including the representation of unfalsifiable claims as science and other forms of pseudoscience,
   b. explain the strengths and limits of scientific inquiry
   c. explain the difference between evidence and inference, and the provisional nature of scientific explanations by providing examples of how our understanding of the workings of the world has changed in the past,
   d. explain the difference between probability and certainty, and describe what is meant by uncertainty in the context of science, technology, and mathematics.

Scientific Inquiry: Science as a Way of Knowing (SWK)

This course is a pilot course for the Science as a Way of Knowing (SWK) designation in the Scientific Inquiry Domain. Below are listed the additional learning goals and outcomes for this designation. Each goal is listed followed by learning outcomes associated with the goal.

In the context of natural science content:

1. **Students will understand the scientific worldview.** As a result of their learning in this course, students will be able to:
   a. Identify the types of questions that can and cannot be answered by science, and recognize the strengths and limitations of science in answering questions about the natural world.
   b. Critically evaluate the assumptions that underlie scientific investigations.
   c. Substantiate the claim that scientific knowledge is durable but can evolve with new evidence and perspectives.

2. **Students will understand the nature and process of science.** As a result of their learning in this course, students will be able to:
   a. Connect evidence to the predictions made by theories and hypotheses, and then assess the extent to which the presented evidence supports or refutes a scientific claim.
   b. Evaluate the role of creativity, curiosity, skepticism, open-mindedness and diligence of individuals in scientific discovery and innovation.
   c. Recognize the uncertainty inherent in the scientific approach and evaluate scientists' efforts to minimize and understand its effect through experimental design, data collection, data analysis and interpretation.
   d. Evaluate the role of communication, collaboration, diversity and peer review in promoting scientific progress and the quality of scientific evidence and ideas, and ensuring compliance with ethical standards.
   e. Determine the extent to which science both influences and is influenced by the societies and cultures in which it operates.
   f. Apply scientific approaches to problem solving and decision-making in their own lives, and evaluate how scientific knowledge informs policies, regulations, and personal decisions.

Course Policies

1. **Texts and Supplies.** The following are required:

   The required textbook for the class is called *Environmental Science*, written by Professors Cutler Cleveland and Robert Kaufmann. Purchase the electronic version here: http://www.trunity.net/depaulENV101/

   Calculator (any)

2. **Sources of help.** I will hold office hours from 12-1 pm on Mondays (or by appointment).

   Students who feel they may need an accommodation based on the impact of a disability should contact me privately to discuss their specific needs. All discussion will remain confidential. To ensure that you receive the most reasonable accommodation based on your needs, contact me as early as possible in the quarter (preferably within the first week or two of the course) and be sure to contact the following office for support and additional services: Center for Students with Disabilities (CSD), #370, Student Center, LPC, 773.325.1677.

3. **Academic Integrity.** According to the DePaul University Student Handbook, "Violations of academic integrity include, but are not limited to, the following categories: cheating; plagiarism; fabrication; falsification or sabotage of research data; destruction or misuse of the university's academic resources; alteration or falsification of academic records; and academic misconduct." <u>This includes copying lab reports!! Working in groups does not mean copying answers!!</u>

   The Handbook also states that "[f]aculty members … have the authority and the responsibility to make the initial judgment regarding violations of academic integrity in the context of the course that they teach. They may impose sanctions up to and including failure of a course at their own discretion in cases involving a violation of academic integrity policies." For more information, see the Student Handbook online at http://www.depaul.edu/~handbook.

4. **Excused Absences.** NO MAKE-UP EXAMS will be given and NO LATE ASSIGNMENTS will be accepted, except for situations that involve a medical emergency or a death in the immediate family. <u>Verification will be requested.</u> Please contact me about absences as soon as possible in order to fill out an absence form.

5. **Quizzes.** There will be a quiz over each chapter in the textbook. See the schedule below for quiz dates.

6. **Homework.** There will be a daily homework assignment. See the schedule below for Homework dates.

7. **Exams.** Exams will be essay exams that can be worked on from home.

8. **Grades.** Your course grade will be based on the following:

Midterm Exam	25%
Final Exam	25%
Homework	25%
Quizzes	25%

The following grading scale will be used to determine your course grade.

≥ 92% you will be guaranteed an	A
90-91	A-
87-89	B+
82-86	B
79-81	B-
76-78	C+
71-75	C
68-70	C-
65-67	D+
60-64	D
< 60	F

Schedule

Class Date	Quiz (due BEFORE class)	Class Topic	Homework (complete AFTER class)
Mar. 31	-	Nature of Science Survey	-
Apr. 2	Ch. 1	Ch. 1 Environment and Society	Ecological Footprint
Apr. 7	Ch. 2	Ch.2 Energy and Matter	Mendeleev & Periodic Table
Apr. 9	Ch. 3	Ch. 3 Systems	Natural Selection
Apr. 14	Ch. 4	Ch. 4 Physical Systems	Plate Tectonics
Apr. 16	Ch. 6	Ch. 6 Material Cycles	Nitrogen Cycle & Dead Zone
Apr. 21	Ch. 5	Ch. 5 Energy in Biological Systems	Food Webs
Apr. 23	-	“	Darwin and Evolution
Apr. 28	Ch. 7	Ch. 7 Biomes	Climate Diagram
Apr. 30		**MIDTERM EXAM**	-
May 5	Ch. 9	Ch. 9 Carrying Capacity	Demography
May 7	Ch. 12	Ch. 12 Biodiversity	Endangered Species
May 12	Ch. 15	Ch. 15 Soil	Dust Bowl
May 14	Ch. 16	Ch. 16 Agriculture	GM Foods
May 19	Ch. 20	Ch. 20 Fossil Fuels	Cold Fusion
May 21	Ch. 22	Ch. 22 Renewable Energy	Alternative Energy
May 26	**-**	**UNIVERSITY CLOSED MAY 26 (MEMORIAL DAY)**	-
May 28	Ch. 14	Ch. 14 Ozone Depletion	Ozone Hole
June 2	Ch. 13	Ch. 13 Global Climate Change	Atmospheric CO_2 concentration
June 4	-	“	-
Monday, June 9 11:45 – 2 pm		**FINAL EXAM**	

Name ____

Cold Fusion: A Case Study for Scientific Behavior

Read the article "Cold Fusion: A Case Study for Scientific Behavior" which can be found on our D2L site OR at http://undsci.berkeley.edu/lessons/pdfs/cold_fusion.pdf (Follows within this PDF)

1. How did Pons, Fleischmann and their colleagues violate the following guideline for good scientific behavior?

"*Pay attention to what other people have already done*"

2. How did Pons, Fleischmann and their colleagues violate the following guideline for good scientific behavior?

"*Expose your ideas to testing*"

3. How did Pons, Fleischmann and their colleagues violate the following guideline for good scientific behavior?

"*Play fair: Act with scientific integrity*"

Name ____

4. How did Pons, Fleischmann and their colleagues violate the following guideline for good scientific behavior?

"*Openly communicate ideas and tests to others*"

5. How did Pons, Fleischmann and their colleagues violate the following guideline for good scientific behavior?

"*Assimilate the evidence*"

6. Evaluate the role of communication, collaboration, diversity and peer review in promoting scientific progress.

Cold fusion: A case study for scientific behavior

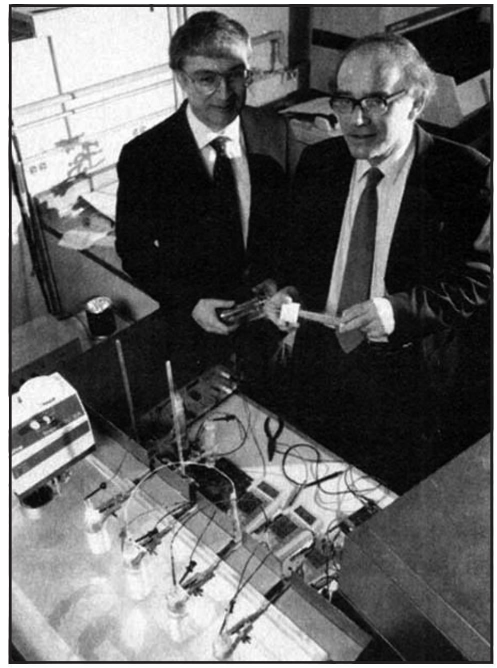


Figure 2. University of Utah chemists Stanley Pons (left) and Martin Fleischmann.

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.

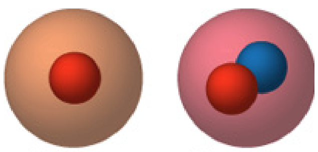


Figure 1. A hydrogen atom has only a single proton in its nucleus, whereas deuterium, a rarer isotope of hydrogen, has a proton and a neutron.

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 …

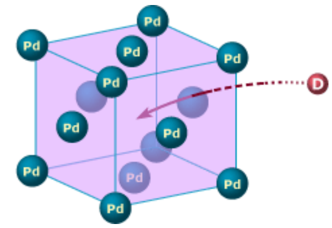


Figure 3.

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.

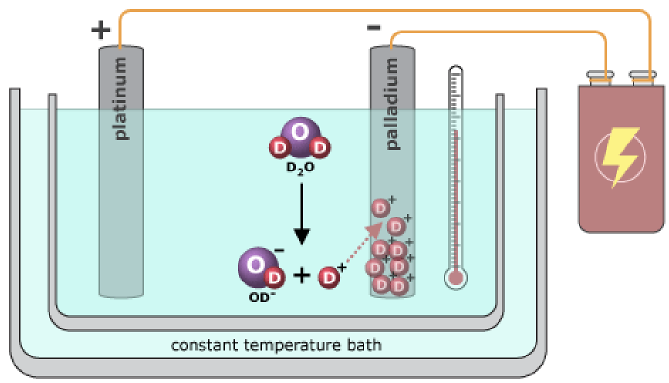


Figure 4. Pons and Fleischmann's fusion cell.

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

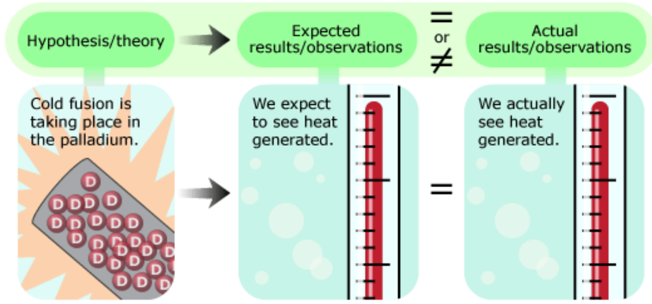


Figure 5.

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.

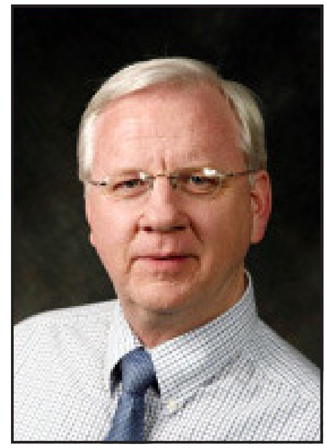


Figure 6. Retired Professor Steven E. Jones, Brigham Young University.

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

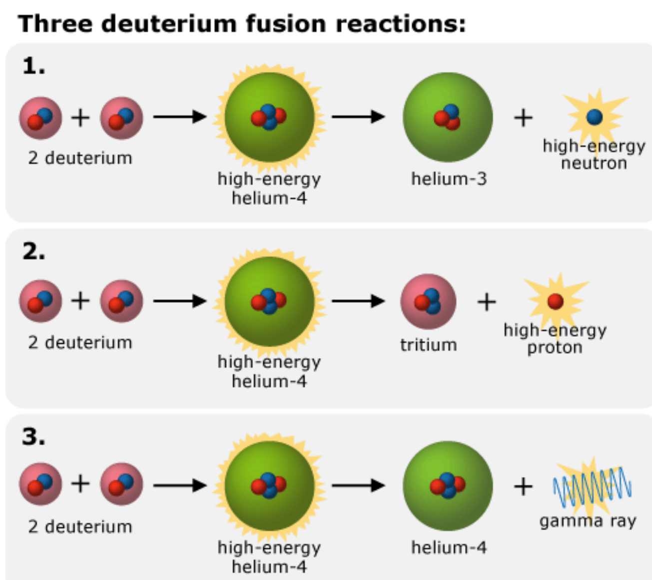


Figure 7.

Steven Jones photo courtesy of Steven Jones

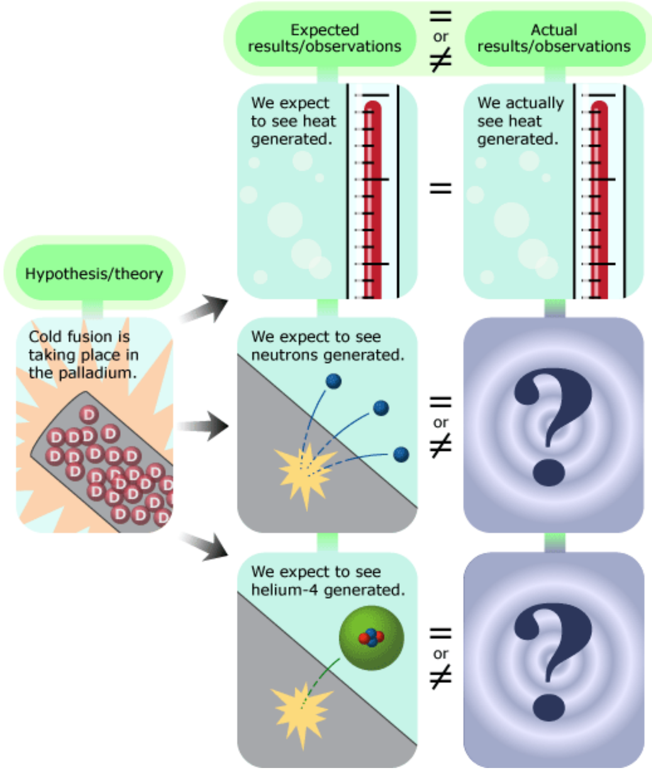


Figure 8.

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).

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

A scientist's code of conduct:

1. Pay attention to what other people have already done.
   Pons and Fleischmann's lack of knowledge about nuclear physics (and refusal to collaborate with other experts) hindered their study of cold fusion.
2. Expose your ideas to testing.
3. Assimilate the evidence.
4. Openly communicate ideas and tests to others.
5. Play fair: Act with scientific integrity.

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!

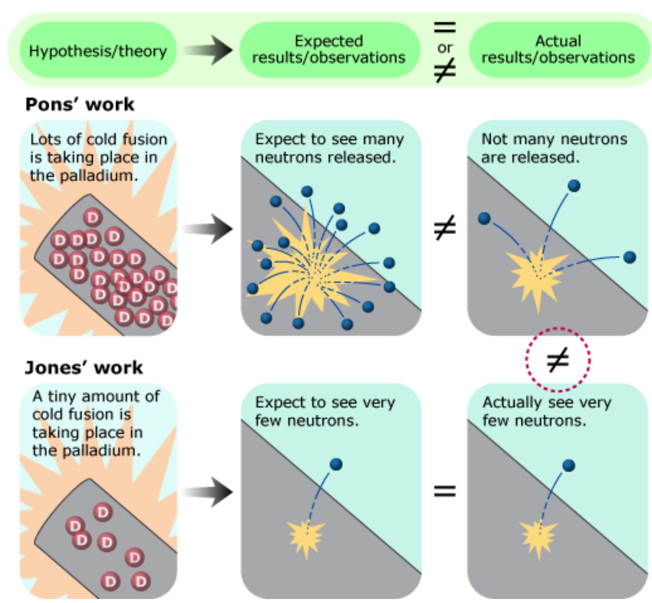


Figure 11.

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

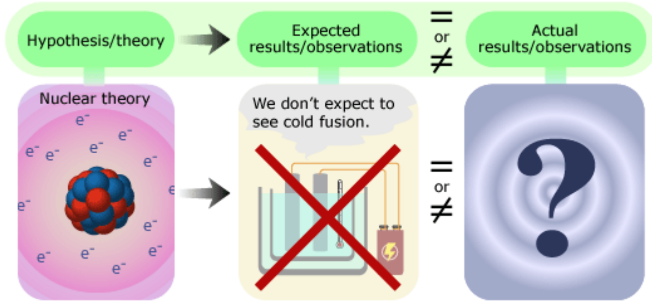


Figure 12.

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:

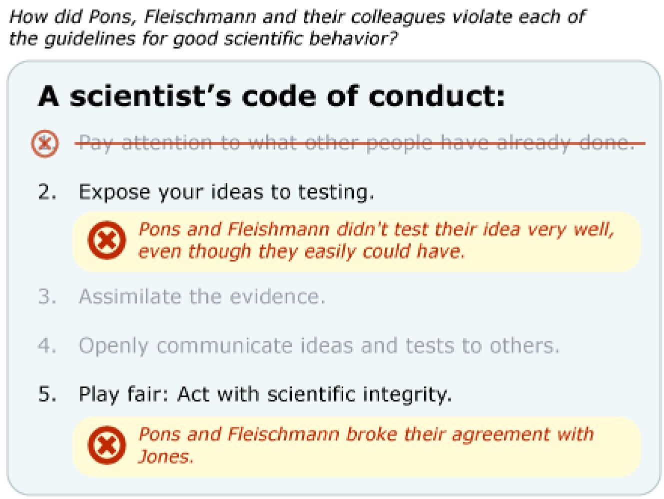


Figure 14.

- 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.

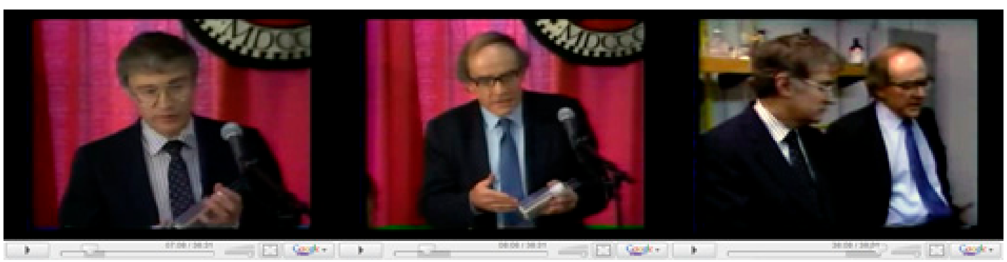


Figure 16. Pons (left) and Fleischmann at the March 23, 1989, University of Utah press conference. These clips are taken from a video of the press conference, viewable on YouTube.

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

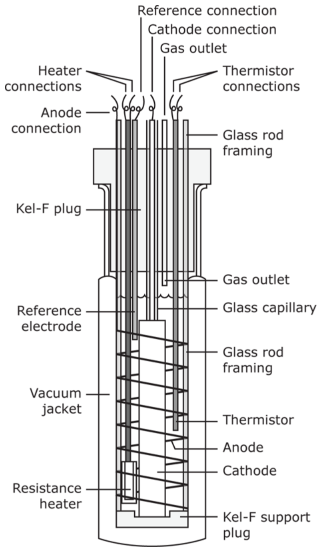


Figure 17. A diagram of Pons and Fleischmann's cold fusion cell from one of their published papers.

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.

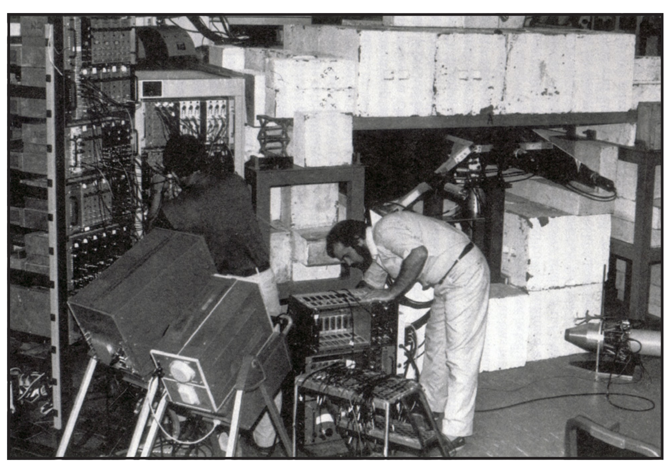


Figure 19. A team of scientists from Yale University, Brookhaven National Laboratory, and Brigham Young University was one of the groups attempting to replicate the results of Pons and Fleischmann. Here, crew members tune the electronics for their experimental setup.

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.

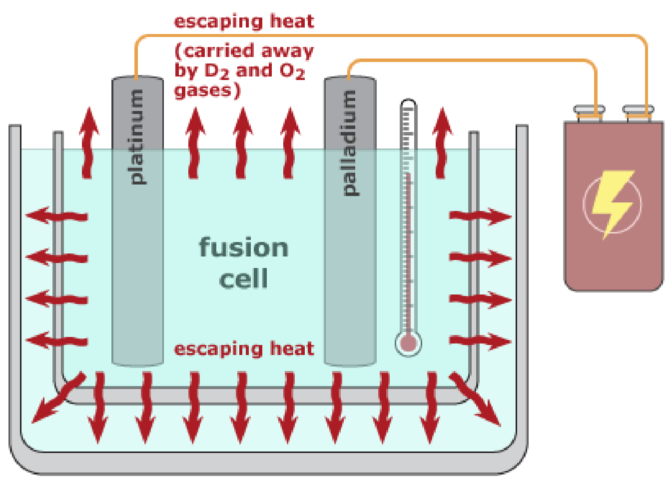


Figure 20. To really know how much heat is being produced by the fusion cell it is necessary to estimate how much heat is escaping from it.

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?

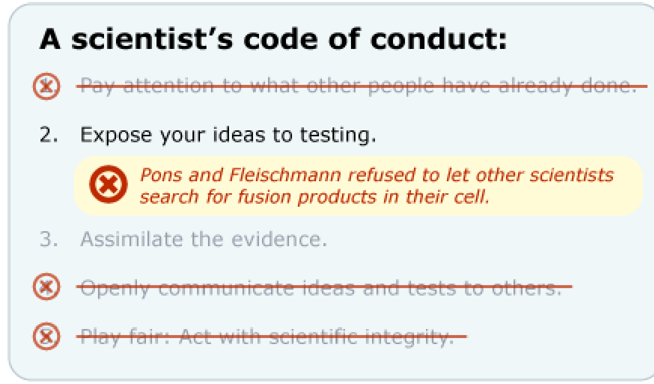


Figure 21.

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).

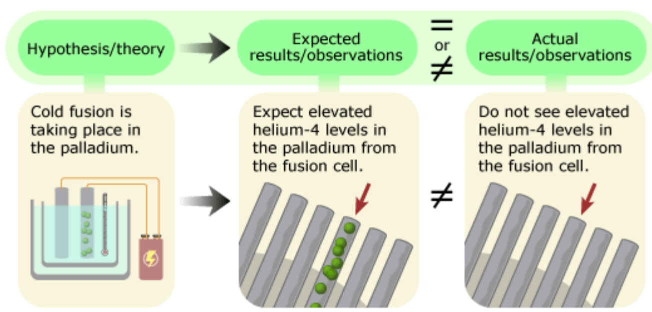


Figure 22.

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.

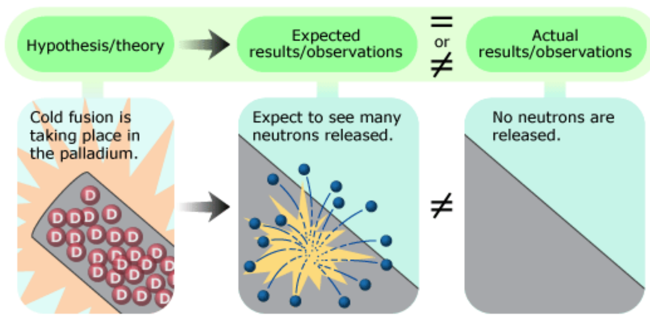


Figure 24.

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

A scientist's code of conduct:

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

~~Expose your ideas to testing.~~

3. Assimilate the evidence.

Despite the evidence against it, Pons and Fleischmann refused to give up the idea that they had produced cold fusion.

~~Openly communicate ideas and tests to others.~~

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

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 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).

Figure 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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