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Butter Side Down

How cold fusion researchers battle the innate perversity of inanimate objects and exploding parameter space

by Jed Rothwell

When you drop a piece of buttered toast off a table, it usually lands on the floor butter side down. Robert A. J. Matthews described the reason in a 1995 paper. [1] As toast slides off a plate, friction at the edge produces torque. The toast begins to spin. It makes only one half turn before it reaches the floor. You can demonstrate this with a paperback book. Place it on the edge of a table face up, and gently push it until it tumbles off. Most of the time, it will land face down. Matthews examined the phenomenon more closely, building a "House that Jack Built" chain of cause and effect. The toast makes a half turn because it falls about a meter. Matthews explains:

> . . . If tables were a lot higher—around 3 metres high—the problem of toast landing butter-side down would go away, as the toast would have enough time to complete a full rotation.
>
> *So why are tables the height they are?* Simple: to be convenient for humans.
>
> *So why are humans the height they are?* Using a simple chemical bonding model of the human frame, I show that there is a limit to the safe height for bipedal, essentially cylindrical creatures like humans. The limit is around 3 metres . . . This limit, in turn, sets a maximum height on tables suitable for creatures with human articulation of about 1.5 metres—which is still not high enough to prevent toast from landing butter-side down.
>
> Digging deeper again, he discovers:
>
> The formula giving the maximum height of humans turns out to contain three so-called "fundamental constants of the universe." The first—the electromagnetic fine-structure constant—determines the strength of the chemical bonds in the skull, while the second—the gravitational fine-structure constant—determines the strength of gravity.

Matthews describes other fundamentals such as the atomic Bohr radius, which "dictates the size of atoms making up the body." In short, he demonstrates it is no accident you usually end up with butter in your carpet. That outcome is built into the fabric of the universe.

Why haven't cold fusion experiments been scaled up? Why haven't researchers learned to make the results stand out? After twelve years of painstaking replication attempts, most experiments produce a fraction of a watt of heat, when they work at all. Such low heat is difficult to measure. It leaves room for honest skeptical doubt that the effect is real. Some experiments have been scaled up successfully, and a few have produced spectacular excess heat for days at a time. Edmund Storms has seen up to 4 watts occasionally, although his cells usually produce no more than a third of a watt. With his new line of research, he hopes to produce a watt or more consistently. If he succeeds he will hold a gala “One What / Watt?” party to celebrate. Ohmori and Mizuno routinely input about 100 watts and output 130 or more (30 watts excess), but the heat is sporadic and difficult to distinguish from the violent fluctuations of glow discharge plasma. Other researchers have seen 5 or 10 watt reactions lasting for many days. Michael McKubre has seen enough high heat to characterize the effect as “. . . neither small nor fleeting,” [2] He finds it difficult to bring about the effect, but when it does finally appear, he is certain it is real. Other signatures of cold fusion have occasionally appeared at spectacular levels. Tritium has been measured at hundreds and even thousands of times above background, enough to swamp the detectors in a few cases.

Yet most results are marginal. When more power is applied to a bigger cathode, the reaction refuses to scale up, for unknown reasons. Most experiments are hemmed in by the same basic laws that cause toast to land butter side down. Many limitations are prosaic, such as the scale of the instruments or the maximum electric power an off-the-shelf laboratory power supply generates. Experiments can be made larger, but they would be more difficult to operate, more expensive, and perhaps not as convincing.

Scale is not the only problem. Many researchers are defeated by exploding parameter space. There are countless ways to do an experiment, but only a few that work. A researcher is faced with too many choices, which would take a lifetime to explore. A choice made a year ago may have doomed the project, when someone selected the wrong cathode material. A researcher may not realize he should polish the cathode. The experiment fails without this step, and the rest of the skilled labor poured into the project is in vain. Because there is no theory, progress depends upon wasteful trial and error, and blindly following recommended procedures. To get a sense of how many variations there are, and how long it takes to test them, consider a recent paper by Mizuno. [3] It explores the effect of voltage and electrolyte temperature on heat production in glow discharge electrolysis. To prepare this one paper, and explore these two parameters, Mizuno performed approximately 300 experimental runs lasting several hours each, including preparation time. He observed excess heat 80 times. Voltage and temperature were systematically varied; all other parameters, such as the cathode material and shape, were held as stable as he could make them. This series of tests took three years. At this pace, a systematic exploration of material composition might take hundreds of man-years.

Many invalid claims are caused by ignorant mistakes. Many researchers have failed to protect against noise, particularly changes in room temperature. This produced embarrassing false positive results at leading laboratories including the NHE, and it may have hidden real excess heat elsewhere. There is no excuse for such mistakes, but they are not surprising. Experts in other fields make similar blunders. Wall Street gurus fell for the dot-com craze. Computer programmers make errors described in introductory textbooks, such as badly named variables. This weakness of human nature is why we must see independent replication before we can believe a result.

Most researchers use traditional, water-based calorimeters, which have not improved much since 1900. There are several different kinds, and it is important to select the right one for the job. A limitation or inaccuracy in one type may not be a problem in another. When Mizuno began glow discharge experiments, he used flow calorimetry. The intense radio frequency (RF) noise from the glow discharge affected the thermocouples, so he switched over to a bomb calorimeter for a while. With this method, heat builds up inside a well-insulated cell. Total energy can be computed by comparing temperatures before and after the run, when the RF is not present and cannot affect the measurement. A flow calorimeter can be run indefinitely, for hours or days, whereas a bomb calorimeter reaches its limits in about twenty minutes, after which it either stops storing energy and loses track, or it explodes (hence the name). [4] A bomb calorimeter would not work with a Fleischmann-Pons experiment, which runs for weeks. But the glow discharge runs for only fifteen minutes before the cathode disintegrates, so the short time limit does not matter.

Other Ways to Improve Signal to Noise Ratio

There are other ways to improve results besides making a bigger cathode, but these other techniques soon run into their own set of roadblocks. Background electrolysis power can be reduced by bringing the anode and cathode closer together. Most are only a few millimeters apart, which is about a close as they can be in a handcrafted cell. Background electrolysis power can also be reduced by increasing the concentration of salts in the electrolyte. Many experts feel cathodes would work better at a higher operating temperature, perhaps 80 to 300°C. This calls for a pressurized, sealed cell, which is more complicated and dangerous than a regular glass cell at atmospheric pressure. Many researchers, frustrated by their inability to increase the signal, have concentrated instead on decreasing the noise. They build elaborate and expensive calorimeters. This can become a distraction, draining away time they should devote to improving materials and electrochemistry. Ultimately, researchers hope to find improved methods of making or operating the cells that will boost the cold fusion reaction itself. Conventional electrochemical tricks such as bringing the anode and cathode closer together add nothing to our knowledge of cold fusion.

Scaling Up Might Not Help

With some cathode materials and calorimeter types, scaling up may actually reduce confidence in the result, even if excess heat increases. Electrolysis input power may increase more than the excess heat, drowning it out. Or the overall heat, including input, may be too high to measure easily.

Some researchers who claim milliwatt reactions with thin film wire are satisfied with their own calorimetry. They say the excess heat signal is strong enough to be measured with confidence. Making it larger would not serve any scientific purpose. They say they are too busy to scale up, and they will make real progress by concentrating on goals such as developing a theory. Others doubt these results, and would prefer to see 10 or 100 times more wire. The devices are the size of a computer chip, and reasonably inexpensive to fabricate, so building a ten by ten array of them would not be out of the question.

Some reactions cannot be scaled up because electrolysis input power would make the cell boil. This is harder to fix than you might imagine. Edmund Storms tried a variety of methods before coming up with a cell for a Seebeck calorimeter with “cooling fins”—tubes extending from the cell filled with electrolyte, which increase surface area. (Figure 1.) This kind of glassware cannot be purchased. Storms makes much of his own equipment from scratch. He blows his own glass, so he can innovate in ways that researchers who buy materials cannot.

Figure 1. A cell made by E. Storms for a Seebeck calorimeter, with "cooling fins"—tubes extending from the cell filled with electrolyte, which increase surface area. These fins would defeat the purpose with an isoperibolic calorimeter.

Any method of cooling is likely to take up more room with a bigger cell, which can make the whole apparatus unwieldy. You would not think so, because a cell is a small, hand-held object. Making it a little larger should not matter. But a cell is often placed inside a box, which is inside another box, to shield it from ambient temperature changes. It may be several layers inside, like a wooden Russian Nesting Doll (Figure 2). When the core object—the cell—grows bigger, the outer containers must grow proportionally. The innermost container is usually a cube 20 to 40 cm per side. Some containers have room to spare for an extra large cell. Others are stuffed with cooling fans, pumps, magnetic stirrers, ambient temperature thermocouples, IR sensors, neutron detectors, and so on. The inside of a Seebeck calorimeter is particularly crowded, because it is expensive real estate. The small Seebeck calorimeter shown in Figure 3 costs $6,000. The innermost chamber is a cube 18 cm on each side. The fan on the right keeps the cell from boiling over. Another method of shielding is to place the cell in a water bath, usually the size of a picnic cooler. Researchers with plenty of money use expensive laboratory-grade baths with precisely controlled temperatures. Researchers working on a shoestring use actual picnic coolers.

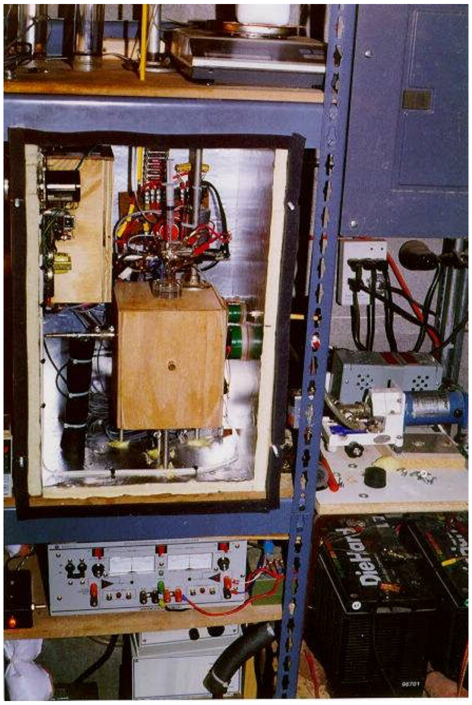

Figure 2. To guard against ambient temperature fluctuations, calorimeters are often arranged with boxes inside of boxes, like wooden Russian Nesting Dolls (Matrioshka). This calorimeter was actually made of wood, by E. Storms.

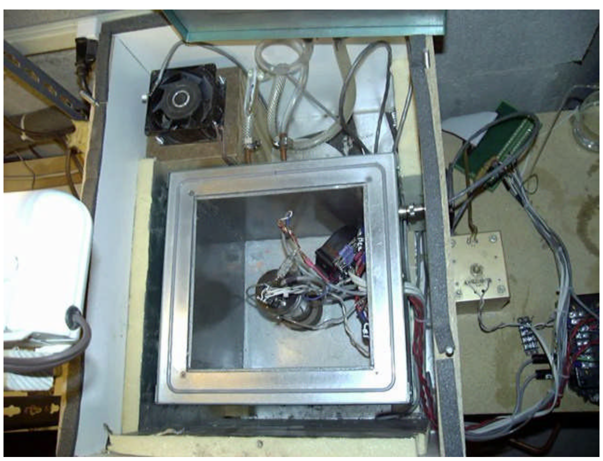

Figure 3. The Seebeck calorimeter used by E. Storms. The cell is placed in the center of the inner chamber, along with a fan. Water from the reservoir circulates through the envelope, keeping the reference temperature constant.

A larger cell with more water will have higher thermal inertia. It will take longer for the cell temperature to change in response to a change in the power level, which means it takes longer to calibrate. When the cell grows too large, it may take a full day to establish a single calibration point, and weeks to establish a curve, which is untenable.

After electrolysis finishes, another limitation may crop up. The cathode may not fit inside a scanning electron microscope or a mass spectrometer. A large cathode may have to be cut in half, which would probably contaminate it, defeating the purpose.

Laboratory equipment is designed for hand-held, hand-made samples. It would be annoying to make samples any larger, or smaller. The picnic coolers, constant temperature baths, power supplies, oscilloscopes, quadrupole mass spectrometers and so on are made in a size convenient for humans, like the breakfast table. They are small enough to be picked up by middle-aged researchers, and narrow enough to fit through ordinary doors. At Osaka University, ion beam cold fusion experiments are performed with an accelerator 30 meters long. It is housed in a warehouse-sized facility, equipped with overhead cranes that can pick up tons of equipment. Everywhere else, the research is conducted in cramped rooms with manual labor.

At NERL, we have been working on-and-off for several years to try to test a Hydrosonic Pump (TM) at our facility. We previously reported our positive results at the Hydrodynamics plant. [5] When we initially acquired a factory spare unit, it was 56 kW. This was much too large for our purposes. It made preparations very difficult. We rewired our AC electricity, transformers and hook ups. There were other problems; the original rotor unit was not matched correctly to the motor, and a replacement rotor unit needs professional precision realignment on a test stand. It would have been much easier and cheaper to test a miniature pump that consumes 10 watts. The test bed at Hydrodynamics, Inc. cost tens of thousands of dollars, and it was designed by the former dean of Mechanical Engineering at the Georgia Institute of Technology. It has been used to demonstrate convincing excess heat. We have not succeeded with less rigorous methods and fewer instruments.

Even after you go to the trouble to make a larger cell, and you manage to produce more heat without proportionally increasing the background, the statistical significance of the results may still go downhill. Suppose a flow calorimeter is used to measure 100 watts (including electrolysis). Most off-the-shelf, reasonably priced precision pumps and flow meters work best at flow rates up to ~60 ml per minute. At that rate, the outlet water would be 24° hotter than the inlet, which would degrade accuracy. Most researchers try to limit the difference to about 10°, because water has different properties at elevated temperatures, including a slightly different thermal capacity. Other problems would crop up, because the instruments would have to do two jobs at once: measure heat, and prevent overheating. Instruments designed for multiple purposes are usually not as good as dedicated ones.

In 1991, Tadahiko Mizuno conducted the only large-scale palladium cold fusion experiment on record. It was convincing and dramatic, but also uncontrolled, irreproducible and probably dangerous. It is described in his book.[6] Most cathodes weigh one gram or less. Mizuno used a 100-gram cathode in a closed cell. During two months of electrolysis, it produced 10 megajoules of excess heat in a normal cold fusion reaction. After electrolysis was turned off, instead of cooling, the cell went into heat after death mode, and threatened to go out of control. It was placed in a large bucket of water. All the water in the bucket evaporated and was replenished four times. Over ten days, the cathode generated another 85 megajoules, evaporating 17.5 liters of water. No one ever again tested such a large piece of palladium. Given the high cost of palladium and the unexpected risk this experiment developed, it would not be prudent. An experiment with 1,000 grams of palladium in a closed cell the size of a shoebox would be foolhardy. It would probably not produce any measurable excess heat, but if it worked as well as Mizuno's cathode, it would briefly produce thousands of watts before exploding violently enough to kill a person. Until cold fusion is better understood, and we can control it with confidence, there can be no thought of scaling up experiments, and certainly no thought of prototype generators or motors.

Practical Limits to Power Supplies and Money

Compared to normal electrochemistry, cold fusion calls for unusually high current density. Ohmori and Mizuno's glow discharge experiment require high voltage. The 200 V maximum of most off-the-shelf power supplies limits the size of the cathode to a plate 5 mm by 10 mm. A much larger cathode, say 20 by 20 mm, might produce much more excess energy, but it would require thousands of volts from a specialized power supply, which Mizuno cannot afford. (Several power supplies might be ganged together, but this would cause other problems.) Standard meters and power supplies are more reliable and easier to acquire than custom-built ones. Most cold fusion research is done on a shoestring. Researchers with middle-class incomes or retirement pensions pay for an endless parade of meters, scopes, power supplies, heavy water at $1,000 per bottle, precious metals and other materials. The machines pile up on every surface and under the tables. On any given day, most are broken or waiting for a software upgrade. (Figure 4.)

Figure 4. T. Mizuno (left) and his assistant T. Kawasaki (right) preparing a cell in 1999 (left). In most labs, machines and supplies and pile up on every surface and under every table. The day after you throw away a broken machine, you find you need a part that can only be had by scavenging that old, broken machine.

Many desirable instruments would be too much of a bother to own, even if they cost nothing. They require frequent maintenance and calibration, and they take up too much space. Edmund Storms has often said he wants a Scanning Electron Microscope (SEM). I found a used one on the Internet for $13,800. Unfortunately it is in the Netherlands, and it is 14 years old. Storms explained that he cannot buy a pig in a poke. He would have to go to Europe to see the machine, and he would have to test it carefully, so it would better to look for one closer to home. "The problem with old, used equipment is that it generally doesn't work very well, this being the reason it is being sold. . . . There is nothing worse than having to fight equipment while also fighting nature."

Not a Zero Sum Game

Every step you take to improve an experiment complicates matters, and in the worst case it may actually work against you, causing larger errors. An experiment resembles a nightmare labyrinth, with an endless series of decision paths that lead to dead ends, or mysteriously double back to the starting point. There is no escape from the maze; it can only be built larger, with even more ways of getting lost. The paths are defined by the laws of nature, by design trade-offs, and by the limitations of money, time and effort. Yet this does not mean calorimetry is a zero-sum game, without hope of improvement or refinement. It means improvements come at a cost. Sometimes the cost is trivial. Ken Rauen recently dampened background temperature fluctuations from space heating by leaving a large bucket of water under the table. At the opposite extreme, this same problem was fixed by building Toyota's cold fusion research laboratory with precision heating and air conditioning, which cost hundreds of thousands of dollars. The fan in the Seebeck calorimeter shown in Figure 3 cools the sample and reduces position sensitivity, but the power it consumes must be measured, and this adds to the background noise of the output heat signal. A magnetic stirrer ensures temperature homogeneity, but the spinning magnet and the motor under the cell may add a little heat to the cell. This heat is probably too small to measure, but that fact must be confirmed during calibration.

Different Calorimeter Types, Pros and Cons

Here are some brief, informal descriptions of some calorimeter types often used in cold fusion. For technically rigorous definitions, see a textbook on calorimetry: [7]

Isoperibolic, also called static. The cell consists of a test tube immersed in a bath, or sitting in air. The power level is proportional to the temperature of the electrolyte compared to the surroundings. This is the oldest and most crude method. Improved versions include Pons and Fleischmann's half-silvered Dewar cell, which eliminates the effect of changing electrolyte levels, and the cell designed by Melvin Miles, in which the temperature is measured outside the cell wall, instead of in the fluid.

Reflux boiling. Pons and Fleischmann developed a metal cell to test cathodes held at high temperature, where the input to output ratio is favorable. [8] The electrolyte around the cathode boils continuously, the steam condenses in the upper part of the tube and returns to the lower section. Temperature is measured on the outside of the cell at the bottom where the hot water and cathode are located, and at the top section heated by the steam.

Flow, or mass flow. A stream of water, oil or other fluid is pumped through an envelope around the cell, or through a coiled tube inside the cell. A fraction of the heat escapes from the cell by radiation from the lid and various other paths, but most is recovered by the flowing water, where it is easily measured by first principles. It equals the flow in milliliters per second multiplied by the specific heat capacity of the fluid (4.18 joules per milliliter for water at room temperature). Although a flow calorimeter is less dependent upon calibrations than other types, it must be calibrated carefully to ensure it is working correctly, and to measure the recovery rate, which ranges from 80% to 98%. The recovery rate should be tested under a variety of conditions to be sure it is consistent.

Flow calorimeters are elegant in principle, but in practice they can be annoying Rube Goldberg contraptions. Expensive flowmeters tend to fill with sand or debris and stop working, so in most long-term experiments, a beaker is set on a precision computerized weight scale and filled by the circulating fluid. The beaker dumps out into the reservoir periodically, either under computer control, or with a siphon close to the top. The circulating water has to be purified, and mildew on the inside of the tubes fought with colloidal silver or bleach. At a certain laboratory, oil was used as the circulating cooling fluid. A hose popped out during the night, and the oil was pumped onto the floor. The next morning, before anyone realized what had happened, a group of distinguished visitors was ushered through on a tour. One of the visitors slipped and fell into the mess. [9]

Bomb calorimeter. As described above, the one used by Mizuno is a well-insulated container with a liter of electrolyte, which is more than most cells. No insulation is perfect; some heat is lost from the cell during the run, so a bomb calorimeter has some of the characteristics of an isoperibolic calorimeter. In practice, to measure the 30% excess that Mizuno usually observes, he must account for heat lost from the cell during the run. This is easily done, with equations based on the heat decay curve after the run. Some of the spectacularly successful runs would show excess heat even if he ignored this loss, but most would come out negative. Mizuno used the bomb configuration to demonstrate that although RF does affect performance, it makes little difference. Temperature readings during the run show the heat accumulating in spurts at times when the plasma covers the cathode surface. By comparing the last data point before the power goes off to the first one after it is off, Mizuno shows that RF lowers the temperature reading slightly.

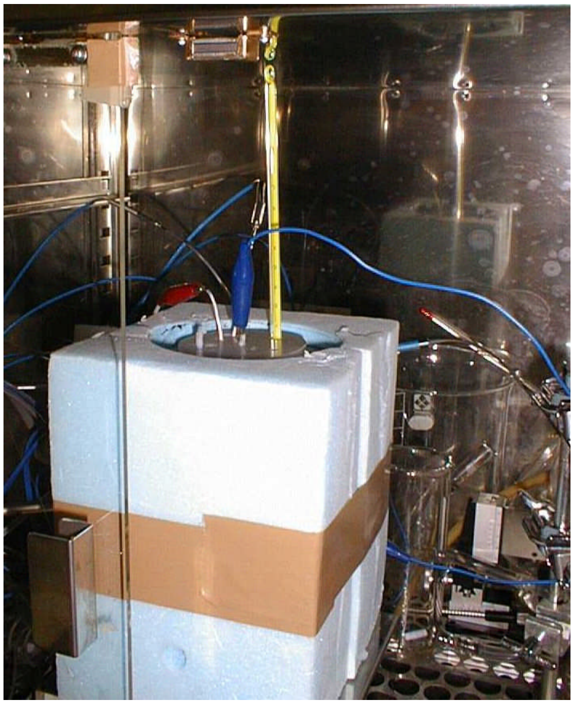

Figure 5. Mizuno's bomb calorimeter placed on a magnetic stirrer inside an air-cooled incubator. It is an ordinary Pyrex 1-liter beaker encased in Styrofoam. The mercury thermometer at the top confirms the thermocouple readings.

Boil-off. This is Ohmori's technique for measuring heat from the glow discharge reaction. A cell with an open top containing about 200 milliliters of electrolyte is placed on a precision digital weight scale. The entire cell including the electrolyte weighs just over 300 grams. Weight is recorded periodically in a lab notebook. After glow discharge begins, the water in the cell boils rapidly. In a 20-minute run I observed, the weight fell from 316 to 282 grams. The 34 grams of lost water is multiplied by the heat of vaporization of water to determine how much heat was carried off. After power is turned off, the heat decay curve is used to determine how much energy radiates from the cell while the water boils. Total enthalpy equals heat carried off by vapor plus heat radiated.

These calorimeter types are not absolute. They overlap. One type may be made over into another, sometimes merely by moving a few tubes, turning off a pump, or repositioning the temperature sensors. An isoperibolic and flow calorimeter can be combined in what Scott Little calls a "dual mode" calorimeter. [10] However, changes in the electrolyte temperature will be small because most of the heat is removed by the cooling fluid, and the ratio of electrolyte temperature to heat will be unpredictable if you adjust the flow rate, so this method has limited value.

The Seebeck envelope, or Calvet calorimeter is a radically different design. The instruments listed above are based on the specific heat of water, oil, or some other fluid. A Seebeck calorimeter is fully electronic. It is a cube with specially made inside walls, an envelope, and a steel shell on the outside. Embedded in the six inside walls are thousands of Seebeck effect thermocouples, linked electrically in series. When an object inside the box emits heat, it causes voltage to flow through the chain of thermocouples. Theoretically, it does not matter where the object is located in the box; the voltage should be the same for a given power level. In actual tests Seebeck calorimeters are found to be slightly position sensitive, so care should be taken to place the sample in the same spot in every test, close to the center of the cube. A Seebeck calorimeter is sensitive to small changes in power levels. It is stable, and convenient to work with. It has a fantastic dynamic range, from milliwatts to hundreds of watts. The operating temperature ranges over hundreds of degrees; you can put the Seebeck box itself inside a refrigerator or an oven, and it will still accurately track the power level of the sample. Like an isoperibolic calorimeter, a Seebeck depends upon calibrations, not first principle calculations. You run an electric heater inside the box at 1 watt, then 2, 3 and 4 watts to determine how much voltage each watt of heat produces: the calibration constant. This takes a day or two. Unfortunately, this calibration constant changes every time you remove the lid and bolt it back on again. It may shift as much as 100 milliwatts from one run to the next, although the value is never far from the mean for all runs. For maximum precision, the Seebeck must be recalibrated for every run. This is time-consuming, especially when an experiment requires that the cell be taken out of the box, tested, and then put back in again several times.

Seebeck calorimeters can be scaled up to practically any size. Some are big enough to hold adult human beings. One of the first confirmations of cold fusion was performed by Richard Oriani using as Seebeck designed to hold a baby. [11] However, even the smallest models are expensive.

Although Seebeck calorimeters are not dependent upon the specific heat of water, water from a constant temperature bath may be circulated through the envelope to create a uniform background reference temperature, as shown in Figure 3. There is no need to keep track of the circulation flow rate. A small number of precision thermocouples are used with other calorimeter types. Thousands are used in the Seebeck calorimeter, which is why it costs more. Despite the expense, years ago Ben Bush enthusiastically recommended Seebeck calorimeters made by Thermonetics, Inc. [12] They were later used successfully by John Dash, [13] Edmond Storms, [14] and

Michael McKubre. [15] W. -S. Zhang et al. have successfully used Seebeck calorimeters made in Sweden. [16]

Main Sources of Error

Edmund Storms says the following main sources of error affect various types of calorimeters. These problems are listed in the order of importance:

Single-wall Isoperibolic

1. Inability to know the average interior temperature. This can be fixed by measuring the temperature at the cell wall, instead of in the fluid.
2. Variations in the external environment temperature. This can be controlled with reasonably inexpensive techniques such as a flowing water envelope or an air envelope (a large box) regulated with precision thermostats. The temperature can be held to within 0.01°C in air, or 0.001°C in water.
3. Variations in the thermal conductivity of the thermal barrier. The material should be carefully selected.
4. Variations in the stability of the thermistor temperature readings. More expensive instruments are called for, if more precision is needed.

Flow-type

1. Variations in flow rate, real or imaginary. Real variations occur when the pump wears out, or the tubes are blocked by debris. Imaginary variations occur when the flow meter malfunctions. With practice, you can tell these apart. It can be challenging when the flow really does change and the flowmeter goes haywire at the same time.
2. Inhomogeniety in the temperature of the jacket.
3. Variations in the stability of the thermistor temperature readings.

These problems can be ameliorated with more expensive instruments.

Seebeck

1. Variations in the Seebeck voltage caused by nonuniform temperature within the envelope.
2. Variations in the reference temperature.

Wishful Thinking and Pathological Science Do Exist

The skeptics are partly right when they describe cold fusion as fulfilling some of Irving Langmuir's criteria for pathological science: "the maximum effect that is observed is produced by a positive agent of barely detectable intensity . . . The effect is of a magnitude that remains close to limit of detectability, or many measurements are necessary because of the very low statistical significance of the results." This describes some cold fusion experiments, although fortunately others have produced dramatic, incontrovertible evidence. Some marginal results may be real, but those which cannot be reproduced in other labs are probably caused by random noise and wishful thinking.

Having acknowledged this, let us note that Langmuir's characteristic is normal for many fields, such as epidemiology. Some mainstream physics experiments yield a definite yes or no answer, but others produce only a statistical probability. The confirmation of the top quark is a good example of the latter. It was based upon a few barely detectable events, out of several billion collisions. The experiment cannot be reproduced at other laboratories because it is so difficult, and it would require building another giant multi-billion dollar complex like Fermilab's Collider Detector Facility (CDF). The public relations section of Fermilab explains: [17, 18]

> The discovery of the top quark was not a "Eureka" event—not the sudden sighting of the long-sought particle. "We discovered the top quark not in one lightning stroke, but over a long period of time, event by event," says physicist Nick Hadley, a DZero collaborator. "No single piece of evidence, no matter how strong, was enough to let us claim a discovery. We couldn't be sure we had found the top quark until we had seen so many events with the right characteristics that there was almost no chance the statistics were fooling us into making a false claim."

Many famous experiments which the history books say produced a clear-cut answer were actually based on statistics. The 1919 observations of a solar eclipse "confirmed" the special theory of relativity, by showing that light is displaced by the gravity of the sun. Einstein predicted a displacement of 1.7 arc-seconds. However, an older Newtonian theory also predicted a shift, of 0.84 arc-seconds. Observations were made from two locations. At one, 8 good quality photographs were taken, with a mean value of 1.98, and 18 poor quality plates were made with a mean value of 0.86. At the second site, 2 poor quality plates were made, with a mean value of 1.62. It seems like a split decision, but Eddington showed that the good photographs supported Einstein. Presumably he did not data select, defining "a good plate" as "one that supports relativity." [19]

Most cold fusion experiments must be repeated many times because the effect is difficult to detect, and calorimetric errors and artifacts are more common that researchers realize. You can only feel confidence the heat is real when you have seen it many times, and taken steps to ensure it is real.

Using Different Techniques and Different Instruments to Guard Against Artifacts

When an experiment is repeated ten, twenty or hundreds of times, and several excess heat events occur, the researcher has several opportunities to verify the heat. Even though most of the runs are duds, the cumulative verification of many positive tests is reassuring. Heat which is only measured once in 100 test runs would make me nervous, even if it showed up that one time with a high signal to noise ratio. When heat appears, a good experimentalist—who has been trying for weeks to make it come—will shift gears and try to make it go away instead. He may gently shake or agitate the cell. Artifactual heat from a thermal gradient will vanish; real heat will remain. He will look for negative heat excursions, in which the temperature drops below the calibration point. This "anomalous cold" proves the instruments are malfunctioning, because a large burst of anomalous cold violates the laws of thermodynamics. (Small bursts can come from limited, weak endothermic chemical reactions.) The NHE managers thought the cells made by Fleischmann and Melvin Miles were producing anomalous cold, because they accidentally calibrated after excess heat began. They set the calibration curve about 100 milliwatts above the actual zero line. Mistakes can cut both ways, producing false excess, or hiding real excess.

An experienced experimentalist looks for signs the heat is real. The heat should look like it is coming from a badly controlled natural phenomenon, like a fire in a jumble of wet firewood. It should be unpredictable, and unresponsive. It should not correlate well with any single control parameter. When heat correlates with current density in a fixed ratio, and it tracks changes in the current the moment they occur, it is almost certainly an artifact. With real cold fusion heat, when you increase current, the heat does nothing at first. A half-hour later, or perhaps the next day, it may increase, but then again it may not. Current has an indirect controlling effect on the reaction. When other conditions are right, higher current increases loading, which changes surface conditions, which may intensify the reaction. There are other telltale signs of an artifact. Heat that always climbs to 320 milliwatts and stays there, describing a straight line on the graph, is an artifact. Heat that builds up steadily despite changes in current and other control parameters is probably caused by instrument drift.

The best way to confirm heat is to use a different calorimeter. Unfortunately, few scientists do this. Melvin Miles brought cathodes from China Lake to the NHE laboratory in Hokkaido. After they were cleaned up, the ones that worked in California still produced excess, and the ones that did work before still did not work. Storms uses three kinds of calorimeter: isoperibolic, flow and Seebeck. When he moves cathodes from one to another he sees similar responses from all three, but not precisely the same. This is very reassuring. Mizuno changed the calorimeter configuration as many different ways as he could, and he confirmed excess heat with every configuration.

Mizuno conducted hundreds of glow discharge experiments with flow calorimetry, while holding conditions as closely identical as he could. He varied only the parameters he wished to explore. Later, to verify the effect was real, he performed additional runs while changing the calorimeter from flow, to isoperibolic, to a bomb calorimeter, and then back to a flow arrangement with improved instruments. Many of the runs with the new configurations showed excess heat at the same level it was observed with flow calorimetry. With glow discharge, the most difficult parameter to measure is input power. Mizuno switched in and out three different power meters, including a new-model, top-of-the-line Yokogawa PZ4000 meter the manufacturer recommended for this kind of noisy signal. He installed redundant methods of measuring every parameter: he measures input power with one or two recording power meters and with a general-purpose computer interface board. The results agree to within a fraction of a percent. He measures temperature with high precision platinum RTD (resistance temperature devices), and mercury thermometers. They agree to the smallest marked unit on the mercury thermometer. When different instruments based on different physical principles give the same answer, this enhances one’s confidence in the results. No one should have blind faith in instruments. Every reasonable step must be taken to confirm them. There is no such thing as the best way to measure heat. Every method has advantages and disadvantages, which sometime counterbalance one another.

Every Model Is an Approximation

Ohmori's glow discharge cathodes produce so much heat, he has the luxury of using a simple formula. In the boil-off method, he multiplies the mass of vaporized water by 540 calories per gram, and adds in the radiation losses based on the heat decay curve. In other runs he uses simple isoperibolic calorimetry, based on a first approximation taught in fourth grade science classes:

> Power = Delta T temperature * conversion factor

The conversion factor is determined by calibrating with a joule heater. The curve is straight at first: where 1 watt causes a 3° temperature elevation, 2 watts make it go up 6°, and 3 watts 9°. At 5 watts, the temperature is 15° above room temperature, or ~35°C. Significant heat is lost to water vapor, and the calibration curve starts to bend. You can still correlate temperature to power, but you must work up a more detailed model that correctly matches the shape of the curve. For example, here is Pons and Fleischmann's model for their modified Dewar cell, translated by them from their differential equation: [20]

> Change in the enthalpy content of the calorimeter = enthalpy input due to electrolysis - enthalpy content of the gas stream + excess enthalpy + calibration pulse energy + time dependent heat transfer coefficient * effect of radiation + effect of conduction.

Each of these terms is broken down into component parts in the actual equation. For example, the enthalpy content of the gas stream is defined as:

> 0.75 * (Partial pressure / Atmospheric pressure - Partial pressure) * Enthalpy of evaporation, which is measured in Joules * Degrees Kelvin^{-1} * mol^{-1}.

The calibration curve does not go straight up indefinitely, and it does not go straight down to zero, either. It never intercepts the origin (0, 0). The instruments always register some level of voltage. Figure 6 from Melvin Miles [21] shows that below a half-watt, linear predictability breaks down. The problem is not in the instruments. The model itself begins to fail at low power. Complexities that made no difference at 1 or 2 watts now begin to crowd in. In cells without a magnetic stirrer, inhomogeneity may become a problem. Because there is a source of heat in the water, the water temperature is different from one spot to another. The thermocouple or thermistor may not measure the average temperature. As power and temperature drop, the water becomes quiescent. Thermal gradients may develop, as warm water rises to the top and stays there, no longer mixed by convection. Areas of stale, unmoving water may develop next to the cell walls. Depending upon where the thermocouple is placed it may read too low or too high, and it may fluctuate back and forth. At very low power levels, reactions within the thermocouple or the power supplied to the thermistor begin to play a major role.

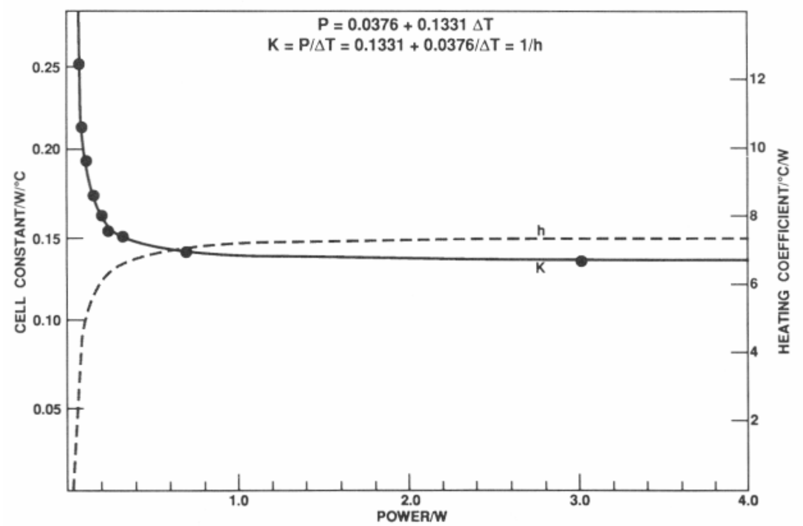

Figure 6. From M. Miles: effect of power level on the apparent cell constant (*K*) and heat-transfer coefficient (*h*).

As power falls lower and lower, you model the cell in more detail. You must employ better statistical techniques. Below a certain power level, perhaps 10 milliwatts, you reach the end of known physics. The model stops working, the textbooks no longer help.

In other fields of science, researchers have developed microcalorimeters capable of detecting heat at micro-watt levels, to measure things such as insect metabolism. They are nothing like traditional water-based calorimeters. They would probably not be suitable for cold fusion, with its high background from electrolysis power. Most microcalorimeters only have room for a 1 ml sample, and they can only measure at the micro-watt level; they would be overwhelmed by a 20 watt signal. [22] Microcalorimeters in astronomical applications can measure the impact of a single x-ray photon on a detector, with 7 electron-volt resolution. [23]

Cold Fusion Is Not About Calorimetry, But This Essay Is

The focus of this essay is calorimetry, first because the subject is easier for me to understand and explain than electrochemistry, materials or nuclear science. Second, calorimetry is at the heart of most experiments, and it has tripped up many unwary researchers. The calorimeter plays an active role in an experiment. A researcher must choose between many different calorimeter types. Some researchers feel that the wrong choice will interfere with the reaction, by keeping the cathode at room temperature. This prevents what Martin Fleischmann calls “positive feedback,” in which the cathode heats itself.

Despite the difficulties described here, calorimetry is actually the easiest part. The real challenge is materials, electrochemistry, nuclear measurements and, of course, theory. To put it another way, this essay hardly begins to describe all the ways a person can botch a cold fusion experiment.

Large bursts of excess heat have occurred in many different laboratories, often enough that we can be sure they do exist. Since they happen occasionally now, there must be a way to make them happen every time.

Footnotes

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1. R. Matthews, "Tumbling toast, Murphy's law and the fundamental constants," *European Journal of Physics*, 16 172-176 1995

2. M. McKubre, et al., *Development of Advanced Concepts for Nuclear Processes in Deuterated Metals*, EPRI TR-104195, Research Project 3170-01, Final Report, August 1994, p. 3A-19, http://lenr-canr.org/acrobat/McKubreMCHdevelopmen.pdf

3. Mizuno, T., et al., *Production of Heat During Plasma Electrolysis.* Jpn. J. Appl. Phys. A, 2000. **39**: p. 6055, http://lenr-canr.org/acrobat/MizunoTproduction.pdf

4. Mizuno's bomb calorimeter is glass surrounded by Styrofoam. There is no danger it will explode. The term is more often used to describe a rugged, steel cell used to measure the heat of combustion and other rapid chemical reactions. "Calorimeters of this type were soon given the name 'bomb calorimeter' because of the frequent explosion-like course of the reactions involved." - Hemminger, G. Hohne, *Calorimetry Fundamentals and Practice*, Verlag chemie, 1984, p. 177. College coursework instructions advise extreme caution. http://www-ec.njit.edu/~grow/Bombcal/BombCalorimeter.html

5. J. Rothwell, "Notes on Talks by James Griggs," Infinite Energy Magazine, #5/6, 1996

6. T. Mizuno, *Nuclear Transmutation: The Reality of Cold Fusion*, (Infinite Energy Press, 1998)

7. W. Hemminger, G. Hohne, *Calorimetry, Fundamentals and Practice*, Verlag Chemie, 1984 is considered one of the best, but unfortunately it is out of print.

8. Roulette, T., J. Roulette, and S. Pons. *Results of ICARUS 9 Experiments Run at IMRA Europe*. in *Sixth International Conference on Cold Fusion, Progress in New Hydrogen Energy*. 1996. Lake Toya, Hokkaido, Japan: New Energy and Industrial Technology Development Organization, Tokyo Institute of Technology, Tokyo, Japan, http://lenr-canr.org/acrobat/RouletteTresultsofi.pdf

9. Since the laboratory does excellent work and no one can be blamed for this sort of accident, it seems unkind to mention the name.

10. Storms, E., *Description of a dual calorimeter.* Infinite Energy, 2000. **6**(34): p. 22, http://lenr-canr.org/acrobat/StormsEdescriptio.pdf

11. R. Oriani, lecture at Hokkaido National University, October 1996

12. http://www.electriciti.com/~thermo/tc.html

13. Warner, J. and J. Dash. *Heat Produced During the Electrolysis of D2O with Titanium Cathodes*. in *8th International Conference on Cold Fusion*. 2000. Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy.

14. Edmund Storms, Taking the chill out of Cold Fusion, http://home.netcom.com/~storms2/index.html

15. McKubre, M.C.H., et al. *The Emergence of a Coherent Explanation for Anomalies Observed in D/Pd and H/Pd System: Evidence for 4He and 3He Production*. in *8th International Conference on Cold Fusion*. 2000. Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy, http://lenr-canr.org/acrobat/McKubreMCHtheemergen.pdf

16. Zhang, Z.-L., et al. *Measurements of Excess Heat in the Open Pd/D2O Electrolytic System by the Calvet Calorimetry*. in *8th International Conference on Cold Fusion*. 2000. Lerici (La Spezia), Italy: Italian Physical Society, Bologna, Italy, http://lenr-canr.org/acrobat/ZhangZLmeasuremen.pdf

17. *How Do We Know It's Top?* http://www.fnal.gov/pub/inquiring/physics/discoveries/top_quark_background/top95_how_do_we_know.html

18. I asked Robert Park of the APS whether he considers the Top Quark finding "pathological," since it is irreproducible and it fits several of Langmuir's criteria. He did not respond.

19. H. Collins, T. Pinch, *The Golem*, (Cambridge University Press, 1993), p. 49

20. M. Fleischmann, S. Pons, "Calorimetry of the Pd D_2O System: from Simplicity via Complications to Simplicity," *Proceedings Third Intern. Conf. Cold Fusion (ICCF3)*, (Universal Academy Press, 1993), http://lenr-canr.org/acrobat/Fleischmancalorimetra.pdf

22. Miles, M., B.F. Bush, and D.E. Stilwell, *Calorimetric principles and problems in measurements of excess power during Pd-D2O electrolysis.* J. Phys. Chem., 1994. **98**: p. 1948.

22. A micro-calorimeter large enough to fit a 200 g sample is being developed. See: http://www.irl.cri.nz/t830/services/microcal.htm

23. http://hea-www.harvard.edu/~juda/microcal/microcal.html