Cold Fusion 101: Introduction to Excess Heat in the Fleischmann-Pons Experiment at MIT

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The introductory cold fusion course offered at MIT during its Independent Activities Period (IAP) in 2012 returned for its second consecutive year recently with much anticipation. While MIT officials still reportedly do not recognize cold fusion or its viability, the fact that it has entered the academic domain, albeit through the less-structured IAP agenda, is certainly noteworthy especially for those scientists fighting for public acknowledgement of this field since 1989—not to mention a place to go and get an education from this massive collection of data.

The saga surrounding cold fusion science is almost as famous as the phenomenon itself and in a sense, it is a quasi-historic event that it has even come this far, given the many years of unwarranted abuse, unending ridicule, reportedly financial and career loss, unimaginable political battles and other scientific hindrance that cold fusion proponents had (and continue) to endure. But things are a bit better. Twenty-four years later, one can now walk into an MIT classroom, listen to an academic lecture on the subject and learn that the phenomenon is real and reproducible, and see that the growth of this science has produced growing companies dedicated to cold fusion—just to name a few of its advances.

While other cold fusion courses at other institutions are reportedly in the works, and cannot be confirmed as yet, having a particularly prestigious institution such as MIT opening its doors, not for a conference, but for an academic course on this topic, in this venue, is commendable.

IAP at MIT, for those not familiar with it, is a special four-week program where students can choose from a vast array of non-credit and for-credit short coursework offered only during the month of January each year. Cold Fusion 101 was a non-credit introductory course open to MIT and non-MIT students alike, as well as the public. Prof. Peter Hagelstein (BA, MS, Ph.D., MIT Professor of Electrical Engineering) taught the course from January 22-25 and Dr. Mitchell Swartz (Sc.D., EE, MD, JET Energy, Inc.) from January 28-29.

At the beginning of the course, as well as the remaining days, Room 4-153 in the Electrical Engineering building was nearly packed with a blend of about 35 to 40 students, entrepreneurs, engineers, physicists and curious members of the community; the class size ebbed and flowed throughout the six-day event. Attendees came from as far away as Spain, China, Germany and Switzerland. But they also traveled from California, Pennsylvania, New York and throughout Massachusetts.

In addition to MIT students, undergrads from Worcester Polytechnical Institute attended the class for their case study work, looking at the impact of cold fusion technology on society. Barry Simon, a layman and local musician/carpenter, who produced a short, popular YouTube film on cold fusion focusing on last year's course data and the five months demo from JET Energy, attended in hopes of producing a future video on the subject. Many thought the course was "great" and said they were glad they came.

Jeremy Rys filmed the lectures, which can be accessed from Cold Fusion Now's (http://coldfusionnow.org) YouTube channel: http://www.youtube.com/user/ColdFusionNow/

Day One — January 22, 2013

Prof. Peter Hagelstein began the first two-hour class with an overview of how cold fusion began—its science, the structure, materials and output of the Fleischmann-Pons (F-P) effect, and skeptics' arguments. He began by discussing the long slog cold fusion has had since 1989, when the announcement became public, and a then-and-now walk-through on how cold fusion advanced. (Cold fusion, for those who are new to the science, is also known as lattice-assisted nuclear reactions, LANR, low-energy nuclear reactions, LENR, and condensed matter nuclear science, CMNS). Hagelstein presented a clear, cogent and smooth weave of physics theory and experiments, pausing to encourage questions, carefully following through with "take away messages."

Hagelstein punctuated the lecture by saying that studying and working in cold fusion was dangerous to one's health. "Working in this field can destroy your career, personal and professional life. I know people who have lost their jobs because of expressing an interest in this area. . .or get support arranged for people or try to help," he explained. Many veteran cold fusioneers have stated that they can attest to these conclusions as well. Attendee Robert Honders, an electrical engineer from New York, said that he was not discouraged by the difficulties of getting into cold fusion research and came because he wanted to learn how to build a hydro furnace to duplicate Rossi (Italian cold fusion inventor). He said several times that, "The course was excellent. (Hagelstein) gave insight to foundational theories."

Hagelstein noted that he was contacted multiple times by companies wanting to hire, but he said that there was no training or a way to get experience or come up to speed. There are controversial areas that are not settled, he said, but that was not a reason for denying presentation of a course, especially since controversial issues are presented in other courses as well.

After addressing the difficulties of getting into cold fusion research, Hagelstein kicked off the first part of the course with the technical science and engineering of cold fusion. He reviewed the origin, extent and basis of the observed excess energy from active cold fusion systems. After clearly explaining why excess energy is so important—including its high energy production efficiency, the potential of distributed energy systems and the implications of all this for both condensed matter science and physics—Hagelstein began itemizing and clarifying several experimental and theoretical issues. He spoke about the roles of palladium, palladium hydrides (palladium filled, aka "loaded" with an isotope of hydrogen) and the method/difficulties of metals actually loading with hydrogen, including the locations where the hydrogen settles, the active cold fusion sites and the means of hydrogen entry.

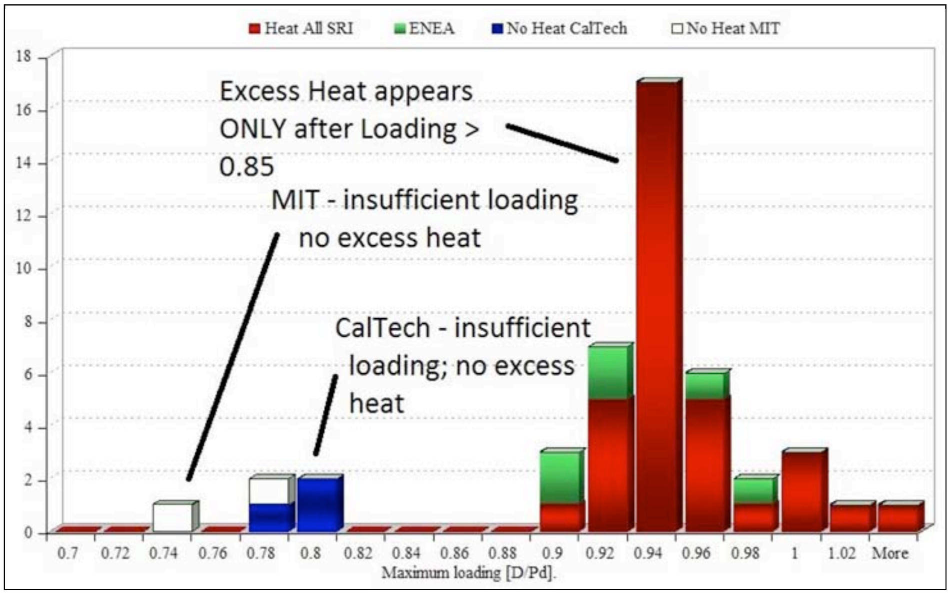
Hagelstein coupled some of the exact reasons why F-P succeeded whereas so many "good scientists from good laboratories" could not initially replicate their experiments. These other labs were just not successful in the early 1990s. They were unable to get repeatable results later achieved, because they were unable to get the requisite highly loaded palladium that is unconditionally required for achieving active deuterium fusion, which is the desired cold fusion effect. The solution did lie in solubility, diffusion and high loading which is on the difficult-to-achieve side of what he explained was the "miscibility gap" (the region of loading where almost all of the loaded palladium systems reside).

Hagelstein returned to the history of the field, referring to and (inaccurate) "negative" DOE reports of 1989 and 2004. Since discussion of DOE reviews were in general not part of the course, Hagelstein did not delve further into the subject.

Hagelstein further explained, however, that the big issue was that the experiments were attempted at the "best" labs by very good scientists, and they were not able to confirm it, that the effect itself is unexpected, and in contradiction with what would be expected from condensed matter physics and from nuclear physics. Richard Garwin constitutes an example of one of the most powerful physicists in the world who was and is skeptical of the existence of the effect. The point is that given what is known, and given the lack of confirmation early on, there was plenty of reason for skepticism. He added that all of this motivates us to try to understand the experiment better.

Hagelstein touched slightly on the early MIT Plasma Fusion Center (Phase II) experiments. One member of the group noted the long battle with the Alibagli group, who later demonstrated to have "shifted the curve" of only the heavy water portion (not the ordinary water portion) so as to make it look like there was no excess heat, which would have indicated the presence of excess energy. Hagelstein said, however, that this long battle with the MIT group was interesting and important for sociological reasons; but it was not intended to be part of the course, so he did not go into it.

Hagelstein also referred to the famous Harwell experiment which reported negative results, although they did have energy bursts in only their heavy water set-up (run in electrical series with their ordinary water set-up). Although, Hagelstein said, small positive deviations within the noise are just that. One member of the class pointed out that even the Harwell data clearly demonstrated 10-15% excess power during the portion of the run shown. Hagelstein explained that such a small amount was insufficient (as were the bursts of excess energy in only the heavy water side of their set-up). Hagelstein then addressed the negative results of the well-respected Bell Labs investigation. Like the other famous groups, they too could not report positive results.



Loading of Pd with deuterium as a predictor of success [McKubre, ICCF15].

The lectures continued to expand on the question of "why": Why was there failure of most, but success of some, investigations of cold fusion? One attendee asked if they used the "same hardware" as F-P. The Harwell group did not. And the paradigms used were different. Hagelstein pointed out that there were many properties of the metal and its hydride that F-P did not consider at the time, but which throughout the years, as many only later learned, have played a key role. Most importantly, for analysis of the differences between success and failure, much discussion revolved around the PdD lattice and the need for very high loading with an almost 1-to-1 ratio of deuterons (heavy hydrogen) to the palladium. Also differing was the exact composition and structure of the critical metal, palladium. Many labs actually used "different sources of metal from around the world." And there were differences between them, too. Differences in structure have a marked impact on the loading, and the reasons for this were discussed in detail on Day 2. It was found by several groups that excess heat requires high loading, as was covered also on Day 2.

Hagelstein specifically reviewed how, and why, certain investigators only had negative results for a number of reasons. For example, he covered the early exploratory efforts, and ingrained positions, of electrophysicist Nate Lewis, and the Caltech group, who were not able to demonstrate any excess power, bursts of energy or excess energy. Garwin, who was associated with IBM at the time, was also included (although not an author of their paper).

Hagelstein moved the discussion along to kinetic issues involving the loading of the palladium. Deuterium goes in via the Volmer reaction, and out via the Tafel reaction; there are simple models available for both reactions. The models (discussed on Day 2 as well) describe the loading in the low to modest current density regime of the F-P experiment. The idea is that Volmer and Tafel is essentially all that is going on in the low current density regime. At higher current density, Volmer and Tafel still work, but other processes come into play. The models tell you that when the loading is high, the deuterium comes out at a faster rate. The loading of the CalTech cathodes (up to a D/Pd ratio of 0.80) is consistent with literature values, and seemingly also consistent with the models.

If so, then how does one get to the higher loading needed to see the excess heat effect? For example, SRI found that no excess heat was seen unless the peak D/Pd loading reached about 0.95 somewhere in the cathode history; and a threshold near 0.85 was observed at the time of excess heat production. Data was shown from experiments done at SRI, Energetics and ENEA Frascati, showing much higher loadings than the literature values, which was hard to understand given that the basic model would seem to preclude such high loading.

So, how to make sense of the much higher loading seen at SRI, Energetics and ENEA Frascati? The argument given is that the average cathode has a very large level of internal leaks, pathways such as from dislocations and cracks, so that it becomes very hard to attain high loading. In "good" cathodes, the internal leaks are minimized, which can reduce the level of internal leaks by more than 1000. At ENEA, Violante and his team anneal to samples, so as to get grain sizes on the order of the foil thickness, which thus minimizes internal leaks.

The big issue here, Hagelstein said, was that he has considered proposing conditions under which D_2 forms in the metal. Since the electron density is too high, it doesn't. So then he focused on vacancies, where the electron density is lower. But there aren't many vacancies in the metal. So how does one arrange for them? By looking into the thermodynamics, and noticing that vacancies are actually stabilized with H or D addition. At a loading of 0.95 near room temperature, vacancies then become thermodynamically preferred. Hagelstein proposed this to be connected with the observation at SRI that cathodes which worked had a peak loading of about 0.95. Since vacancies diffuse very slowly, he said, just stabilizing them is not enough. One needs to make new surface, which is done by codeposition. In the codeposition experiments (going back decades), excess heat turns on immediately (within an hour) after codeposition, which supports the notion. Codeposition at low current density gives no excess heat, which, he said, is consistent with not making vacancies. Letts recently succeeded in demonstrating excess heat with codeposition at much higher current density (with reduced Pd in the electrolyte). In these experiments the excess heat was seen to turn on promptly following codeposition.

Hagelstein was asked why he was working in the area, since it was so dangerous. He pointed out that he was fully aware of the danger when he first started. "My calculation was that it was important to understand what was going on, and I was willing to accept whatever would come as a result of it. So, by now I have taken all the hits, and I have some freedom to put my time and energy into pursuing it. Some have argued that science shouldn't work this way, but I argue that science is an imperfect human endeavor, and that this is part of science."

Day Two — January 23, 2013

On Wednesday, January 23, Prof. Hagelstein spoke again about electrochemical models, loading, D_2 in metals, embedded atom theory, vacancies and stabilization of vacancies by loading. The discussion of electrochemical modeling was intended to underscore that the associated electrochemical models are really simple, that Volmer brings deuterium to the cathode and Tafel releases deuterium as gas. He reviewed the key points discussed the day before and noted that he was starting out focusing on conventional physics and physical chemistry issues, and that issues associated with new physics would come later. For example, issues associated with the Coulomb barrier and fractionating the large 24 MeV quantum would come later.

Hagelstein explained the introduction to the origin of the excess heat production in such F-P and (variant) cold fusion experiments with a discussion, and dissection, of electrochemistry. This is because the F-P systems, as well as many other cold fusion systems, are driven by an electric power source using two electrodes in a solution. Therefore, it is crucial to model correctly the successful experiments, and better understand the failures. "Loading D into Pd doesn't work," Hagelstein said, referring to the problem that the active site of the desired reactions appears to be in specific octahedral vacancies which are then surrounded by the highly loaded lattice. The PdD lattice is a simple face centered cubic (FCC) structure; therefore Hagelstein showed the structure initially so people could visualize it. Later on he used it in connection with different discussions. In talking about embedded atom theory, he spoke about how it was figured out that the O-sites have an electron density close to what H or D wants to see, so he could point at the O-site and argue why H or D sits there. He described embedded atom theory itself, which is very useful for understanding what H and D do in metals. If H, for example, is put into a background of electrons, the associated energy is found to be minimized at a particular electron density (near 0.069e-/Angstrom^3). Hagelstein said, "Looking at the PdH molecule, we find the H sits where the background electron density takes this value. We then come to the conclusion that H wants to see that electron density and looks for it in the Pd lattice." The O-sites have a slightly higher electron density, which is close enough for the H atoms. The electron density in Ni, and in Au, have even higher electron density at the O-sites, which he decided was why the solubility was lower.

When asked about the best way to measure loading, Hagelstein said, "that's a value judgment," referring to the resistance ratio and also noting how "it depends on the experiment." The vacancies in the lattice were shown to be a most important site for successful cold fusion, and they can be produced, for example, by codeposition, but can also anneal (disappear) and can be stabilized (by the loading itself). Hagelstein returned over and over to his embedded atom theory, which he has found to be very useful. He taught that this electrochemical model and analysis will help the cold fusion scientist/physicist to better think about the reasons for the requirement of high loading. He also said that there are lots of ways to measure loading, but people in the field rely on the resistance ratio primarily.

Hagelstein reemphasized the issue of speed in loading, fast versus slow loading and the competitive process which fosters deloading. Such full layout of the processes is needed to comprehend the basis for success and in doing so he referred to Green and Britz' models. For the deloading, he spoke about the role of dislocations and cracks in the average cathode, which generate many pathways that include many internal leaks. These can become "superhighways" of hydrogen loss, and there is an impossibility of compensating for the loss, as they develop into and through cracks and fissures. These can appear suddenly, and play their role in reducing stress internally after the loading.

Also with respect to Green and Britz, they did experiments and fitted data to standard models. One can get the beta parameter in the model from the Tafel curve, which they did. They also estimated the roughness factor. However, it became clear that the Green and Britz cathodes have large internal leaks, which is known since the loading achieved at moderate current density is so low.

A number of people in the room asked about the role of nickel and Hagelstein talked about the differences between Pd and nickel and the effect hydrogen had on each. For example, he said that hydrogen was not as able to penetrate and remain in nickel, which is why it is so much harder to load. He stressed that he was not saying "don't use nickel" but that distinguishing the important differences would be very helpful.

Hagelstein said he had wanted to spend a lot of time on Ni, but he ran out of days. What he did do was begin to incorporate Ni into the discussion earlier on. For example, NiH has a similar FCC structure. The background electron density profile for NiH is qualitatively very similar to that for PdH, but is higher, so the solubility is lower. Vacancies are created at lower loading near room temperature in NiH. Density functional calculations show that H_2 formation near a monovacancy in NiH is most closely related to D_2 formation near a monovacancy in PdD. The two problems are very closely related. There is now evidence for excess heat in connection with Ni codeposition at high current density. After further discussion of the differences, Hagelstein spoke about the products of cold fusion and energy produced by these products. He then explained why there is no commensurate ionizing penetrating energetic radiation (high energy gamma rays which in hot fusion would have been lethal). The "Take Away Message" for day two was that one must create these products to observe excess energy, including understanding the electrochemical models, internal leaks, H and D in Pd (and in Ni) and understanding important aspects of the experiment based on the ansatz that D_2 forms in vacancies in the PdD.

Day Three — January 24, 2013

On Thursday, January 24, Prof. Hagelstein continued to go into exquisite detail about the theories and experimental data that demonstrate how cold fusion works and further continued on the topic of "what's going on." These details included: what is the product from the fuel; what is the activation energy; why are the "normal," conventional productions of hot fusion not seen with cold fusion. The talk was generally about getting to the key theoretical problem, which is that ^4He is observed as a product, but that it has essentially no kinetic energy when born. In general there are no energetic nuclear products commensurate with the energy, which is a big problem for nuclear theory since the time of the famous chemist and physicist Ernest Rutherford's discovery regarding what happens when alpha particles (like a billiard ball) hit a material which we now know is composed of atoms comprised of a vast electronic cloud and an extraordinary little nucleus. The idea is that nuclei behave a bit like billiard balls, and so we can use our intuition to understand nuclear reactions. When energy is produced, we expect it to be divided up according to the inverse mass, which is a consequence of energy and momentum conservation. This is really important, since all nuclear reactions in nuclear physics work this way, and the F-P effect does not.

Hagelstein demonstrated that several meticulous experiments have documented that helium (^4He) is made as the product of cold fusion from the deuterium which is loaded at very high levels into the palladium lattice. He laid out experimental support that correlated ^4He production to the observed excess energy. Hagelstein said that he thought that ^4He is produced directly in the ground state from the D_2 initial state. That is what happens in his models.

As the lecture progressed, Hagelstein showed how it became clear that there are, in fact, several correlations of ^4He production with the excess energy observed. He reviewed experiments showing ^4He correlation with excess energy in experiments of Miles and Bush, of Gozzi, and the SRI replication of the Case experiment. Hagelstein said that there has been shown a time-correlation between the helium production and excess power production in the Gozzi experiment. He said that Bush and Miles demonstrated it was there; Gozzi showed that it was correlated in time with the excess power; SRI provided important confirmations, but beyond that they made the best measurement in his view of the Q-value. The issue is that some of the He is retained in the PdD (which was obvious from the Gozzi experiment).

One class attendee asked why there were not more of these experiments done. Hagelstein quickly pointed out that helium measurements are difficult because of both atmospheric contamination and confusion with materials of similar mass (that is D_2), and that meticulous efforts are required to shield the experiments from the atmosphere (by metal flasks, for example) and that expensive equipment is required to make the discriminating measurements required. As a result, this type of work is very hard to do, he said, and expensive; simply put, there has not been enough funding.

Hagelstein also discussed what happened after the helium was produced. To get out of the lattice (to be observed in the gas phase), the helium must be produced near the surface, since the bulk diffusivity is so low. The real-time measurements of helium in the Gozzi experiment support the conjecture that helium is produced within less than a micron from a surface. Hagelstein has proposed that helium buildup can poison the vacancies, preventing further reactions. If so, then one can understand the observed dependence of excess heat on temperature, since you get the same T-dependence as for He diffusion. Hagelstein also proposed that the big advantage of nano-scale devices (such as the JET Energy NANORs®) is that the helium doesn't have to diffuse very far, so that the power level can be much higher. He suggested that this could be tested, by measuring the dependence of Pxs on T, and by doing systematic experiments with NANORs of different Pd sizes.

Hagelstein began to discuss the activation energy required to get the desired reactions. And, to further emphasize this, he included as well a discussion of the role in changing cell temperature on activity of cold fusion systems. He went through the data of several experimenters in the field, including Dennis Cravens, who demonstrated observation of heavy water cells increasing output with a temperature rise, although the light water system showed no such excess power increment for the same increasing temperature. Hagelstein then followed that up with corroboration from other experimenters, including early recognition of this effect, an increase in excess power in time following a brief temperature rise (usually due to a calibrating pulse), as was seen by Fleischmann, Storms and Swartz. All these similar effects, he said, demonstrated that this was a reproducible effect in active cold fusion systems. He explained that the point of all this was that excess power was observed to increase with T, and that the dependence is consistent with the proposed mechanism of He blocking and subsequent diffusion. He noted that there are some experiments which show little T-dependence. The proposal here is that you only get it when excess power is limited by the He diffusion bottleneck, so experiments where the excess power is low would not be expected to show such a T-dependence. Recent analysis of the Letts two-laser experiments appears to be consistent with this.

Regarding activation energy, Hagelstein also discussed the Letts laser experiment which activates specifically required, key phonon modes in the lattice. "Theorists say 'jump,' experimentalists say, 'how high,'" Hagelstein explained, noting that not all phonon modes are equal, but some are especially helpful. He discussed the issue in the two-laser experiment by saying, specifically, that they got indirect evidence as to where the nuclear energy is going. He said, "We might infer that the energy goes into compressional optical phonon modes at the Γ-point when the beat frequency is around 8.5 THz, and compressional optical phonon modes at the L-point when the beat frequency is near 16 THz."

Since some of the following discussion would focus on models, Hagelstein gave a brief tutorial on Hamiltonians. The formalism is very useful because you can see what is in a model by looking at the terms in the Hamiltonian. For the hydrogen atom, one sees kinetic and potential energy in the Hamiltonian. In the classical case, this leads to planetary orbits. In the quantum case, this leads to the hydrogen orbitals. The presumption for the class is that people know how to solve the models once the Hamiltonian is specified. The big issue is to understand what is in the model in the first place.

Hagelstein explained that the absence of commensurate energetic radiation provided the biggest challenge to theory. From his perspective, the obvious solution was to work with models in which the large MeV nuclear quantum was fractionated into a very large number of much smaller quanta. Such a thing is unprecedented in physics. However, there are analogs that are helpful to think about. In high harmonic generation, thousands of optical photons are combined to produce collimated X-rays. Corkum proposed a mechanism to account for this, but the mechanism is particular to the intense laser problem (and doesn't carry over to the PdD problem). But it does given an existence proof that coherent energy exchange can occur with thousands of small quanta exchanged for one large one. The spin boson model is one of the most widely studied in physics (having been popularized by Cohen-Tannoudji), and it shows a weak version of the effect.

Hagelstein later explained that the transition proposed is from D_2 to ^{4}He. The number of quanta is hundreds of millions, instead of thousands. Corkum's mechanism shows that substantial conversion is possible in principle. The spin boson model came out of the work of Bloch and Siegert, and Cohen-Tannoudji popularized it in modern times.

"In my model," Hagelstein said, "the mass energy is initially converted into hundreds or thousands of excitations in other nuclei, and then converted to THz phonons, and then thermalized to produce heat."

Hagelstein's "Take Away Message" is that the lattice is key, and physicists' theories are not inconsistent with cold fusion. The big issue is that a mechanism is needed to fractionate a large quantum, and we have some analogs in physics showing that such things can happen, but not with as much fractionating power as we require. The spin boson model shows a weak version of the effect. Hagelstein asked what limits the model, and found that it was a destructive interference effect within the model. After trying a large number of modifications of the model (none of which made much difference), he found that adding loss to the model broke the destructive interference. The resulting lossy version of the spin boson model was found to allow efficient coherent energy conversion under conditions of fractionation. He pointed out that this was a mathematical "toy" model, which was useful to study the mechanism, but it remained to connect it with the physics problem.

A summary of this day's arguments starts with ^{4}He being observed as a product, and that it is born with very little energy. In light of Rutherford's picture of how nuclei work, this is very hard to understand. The approach Hagelstein proposed was to study models in which the large nuclear quantum was fractionated into a very large number of smaller quanta. Examples are known in physics where coherent energy exchange occurs with the conversion of small quanta in to large quanta, so there is nothing in principle that goes against physics in such proposal. The only problem is that the conversion is not as extreme as required to account for the Fleischmann-Pons experiment. After about a decade of searching for models that could do the job, the lossy spin boson model was found to have sufficient power to show coherent energy exchange under conditions where a very large quantum is fractionated. The connection between this toy model and the physics would be discussed on Day 4.

At the end of this day, the discussion only got far enough along to begin thinking about the problem in a useful way, and setting up the discussions for the next day and did not get to a theory that works yet to describe the experiments and were only postulated around toy mathematical models thus far.

Day Four — January 25, 2013

On Friday, January 25, Prof. Hagelstein focused on mathematical and physical models for coherent energy exchange under conditions of fractionation, and on the Karabut collimated X-rays, which appear to show this effect. He discussed the mechanism(s) of how ^{4}He is formed in the deuteron loaded palladium (PdD). He examined the products usually seen in hot fusion and conventional fusion reactions, and compared those observed amounts with what is observed with cold fusion. They are not the same amounts. And, it was explained, this has been the issue which has driven the skeptics (usually high energy and hot fusion physicists) to essentially ignore the results of hundreds of cold fusion experimenters and what now amounts to probably ten thousand experiments around the world.

Given what is observed, considering those two detection materials, Hagelstein noted that any produced (*de novo*) ^{4}He must be "born" with energies below 10 keV or less, and that the upper limit for neutron production must be less than 0.01 neutrons/joule. As he said the day before, the message is that the ^{4}He is born with very little energy. It is impossible, in his view, for it to be born with lots of energy, and then slow down quickly. That would result in big neutron signals.

These values of kinetic energy, and the amounts produced, are way below what is observed in conventional fusion. He further said that what is under discussion is a new kind of physical mechanism that has not been seen before, that is independent of incoherent fusion reaction channels. Different rules apply for a coherent reaction. In essence, the point of the theory exercise under discussion is to figure out how it works, and what the rules are.

The "Take Away Message" was that helium is produced as a product in amounts commensurate with the energy produced. Furthermore, the lattice incredibly, yet indelibly, changes the products seen with cold fusion compared to hot fusion (fewer X-rays and Bremsstrahlung, few neutrons and much more palpable heat). With that, Hagelstein directed the class to the final set of issues regarding how the lattice actually enables these differences.

He brought up the energy exchanges predicted in his spin boson "toy" model which he introduced the previous day, and now embarked on a detailed tutorial of the modified spin boson model and an expanded Hamiltonian to now include coupling parameters. He continued from his previous teaching of quantum energy exchange to include the expected characteristics based on coherence involving an entire lattice.

Hagelstein later explained that about twelve years ago, he found a mathematical model that could show energy exchange under conditions where a large quantum was fractionated. He was able to use that to construct a toy mathematical model (donor-receiver model) that demonstrated all the functionality that you would need for a real model. But, a toy is much less than a real physical model. And over a decade he had nothing but failures trying to go from the toy model to a real model. Later he described the recent advances that have led to a real physics model that makes use of the mechanisms from the toy model.

First, he demonstrated that "destructive interference" in the spin boson model limits its use in cold fusion because it cannot handle the number of phonons and atoms in a complete lattice. The reason the lossy spin boson model works, and can fractionate a large quantum, he said, is because the loss eliminates the destructive interference that prevents things from working in the normal spin boson model. The donor-receiver model was the simple generalization that could apply as a toy model to excess heat production based on D_2/^{4}He transitions. The headache was always how to connect the toy model to the real world, he said.

Second, Hagelstein discovered that there was no need for any heroics to "overcome" the Coulomb barrier. Since the new coherent models work differently than conventional incoherent reactions, the tunneling factor only comes in once (rather than twice as in incoherent models).

More than a decade ago Hagelstein showed that the coherent rate from the donor-receiver model was linear in the coupling matrix element (incoherent reaction rates are quadratic in the coupling matrix element). As a result, a coherent model has no problem getting rates to match with experiment with the Coulomb barrier accounted for properly. Incoherent mechanisms will never be able to get high enough rates to do the job, he said.

At a talk years ago, Hagelstein was presenting results from his models and Takahashi argued that they were no good because energy was sometimes going from the phonons to the nuclei. Hagelstein argued then that with a more sophisticated version that took into account dissipation that the model would not work that way. However, afterwards it occurred to him that it would be pretty convincing if he could design an experiment where vibration energy was turned into nuclear energy. So, he went through such a design. In the end, the design was a monstrosity that would convert THz vibrations to collimated X-rays near 1.5 keV. But then it occurred to him that Karabut's experiment did exactly that, and it was much less of a monstrosity. So, for him, Karabut's experiment is the key to everything.

Hagelstein continued with two more additions to his model. "I used the model to calculate out Karabut's experiment, and found that for it to work, there must be a really strong coupling between nuclei and phonons, one that was not in the physics books. That led to a new kind of model based on relativistic coupling which has exactly such an effect," he said. Last year he presented a derivation of the relativistic coupling, which was not so well understood at the time. Since then, he had much better arguments. In recent times, Hagelstein put together a version of a physics-based model that made use of this new coupling, and the results agreed wonderfully with the Karabut experiment. Pulses are observed in the Karabut experiment, and his model predicts pulses. He tried to model the pulses directly based on the model, and he found consistency between the observed pulse parameters and other experimental parameters. This was very encouraging. But last October Hagelstein found that the model was broken. Since then he has been fixing it. The new version of the model was not finished at the time of the IAP class, so only a brief summary was given. In essence, the coupling of the phonons with the metal electrons was proposed to make up for the part of the model found to be broken.

The issue is, he said, that relativistic physics includes out of the box a very strong coupling between the center of mass momentum and internal nuclear degrees of freedom. Normally this very strong first-order coupling is eliminated by a generalized Foldy-Wouthuysen (FW) rotation. The only conceivable explanation of how the Karabut experiment works is that there had to be some fine print that says FW is not always applicable. This is unprecedented in that part of physics. The FW rotation is thought always to be applicable. But he found that the same rotation usually works on the spin boson model, under conditions where destructive interference inhibits fractionation. So, since fractionation occurs in that model, the analogous FW rotation acts as if it breaks.

Hagelstein said that he gave a simple explanation why—there are loss mechanisms that do not rotate gracefully, so it makes more sense to just work the problem without the rotation. It follows that there are physical regimes associated with the relativistic coupling where the FW rotation is inappropriate—and this in his models is where the anomalies are.

The "Take Away Message," he said, was that his corrected CMNS Hamiltonian with all the additions was becoming asymptotic with what is actually being observed in cold fusion. "This Hamiltonian best describes the models," he concluded. Or, he added, that if you do the best physics at each step you can muster, the anomalies emerge naturally.

Day Five — January 28, 2013

After a weekend break, lectures resumed on Monday, January 28, led by Dr. Mitchell Swartz. He continued the talk regarding substantial experimental proof for cold fusion. Swartz outlined in his introduction a survey of the experimental aspects of cold fusion/lattice-assisted nuclear reactions (LANR), what he intended to cover, including the many aspects of the science, engineering and methods of calibration and verification of LANR phenomena that he and his team have uncovered. He said the first day would be only about aqueous cold fusion systems, and then, following that, he would focus on the most recent, exciting, dry, preloaded cold fusion nanomaterials.

Swartz presented what many consider the well-researched evidence for existence (and development) of cold fusion in an understandable four plus hours (two each day) of scientific detail, not only reviewing decades of cold fusion experiments but also presenting many how-to's of the successful processes. The reason we need cold fusion now, Swartz explained, is the fact that we simply do not have a reproducible, highly efficient clean source of energy production.

In this introductory portion of the lecture, Swartz shifted to a series of graphs and tables demonstrating the problems, inadequacies and terrible environmental effects produced by fossil, and other, fuels. For example, fossil fuels—which are the leading source of energy in the U.S.—produce growing pollution, unavoidable economic woes and indelible negative effects on both the environment and our way of life. Swartz detailed the impact of what further use of this energy source, and its secondary pollution, would be on our quality of life, including generating serious health and financial problems. He focused on recent news, including the tragic pollution situation in Utah which is another glaring indictment of that energy production system. For every gigawatt per day a city requires the "burning of 9,000 tons of coal. . . Each one of those makes (as pollution) yet another 30,000 tons of carbon dioxide (CO_2), 600 tons of sulfur dioxide (SO_2), 80 tons of nitrogen dioxide (NO_2) and tons of other pollutants. These obviously are things we could avoid with a cold fusion system," Swartz said. He then demonstrated how all those pollution problems go away with cold fusion. With LANR systems, the equivalent fuel is only about 4 pounds of heavy water to generate a small amount of helium per day.

Swartz also demonstrated that with wind and solar, the problems are the irregular driving forces; although geothermal energy production is useful, today it is simply not available for everybody due to the fact that it is only found in certain locations. Nuclear energy production from fission has helped, but has problems. Citing Fukushima as one example, he then showed recent photographs from Chernobyl which revealed a vast, unpopulated habitat useful only as contaminated animal wilderness.

Swartz shifted to hot fusion which unfortunately has a long history of technical and engineering failures. He continued, "When I first came to MIT in 1966 I thought I would work on hot fusion. The promise then was that we would have it in 50 to 60 years. Clearly, there are problems there." He noted the expected time to completion of the successful hot fusion system has not changed at all. Then, Swartz noted that for those who had actually worked in cold fusion, the scientists had learned that to get a well working system takes a lot of experiments.

"I don't think hot fusion is going to work the first time they do it (either). The problem with hot fusion," he explained, was that "you're going to get a reactor full of tritium that is radioactive, so the only light at the end of the tunnel, as I see it, is cold fusion." He concluded this section of the slideshow with a chance for real hope and change, symbolized by a picture of "light at the end of the tunnel," namely, cold fusion. In contrast to hot fusion, cold fusion does not make any significant amount of dangerous radiation, he said, nor does it make other materials radioactive. It has zero carbon footprint; one thing we can do is build it more efficiently, and scale it up so that we can have distributed energy systems. It could change everything.

Swartz then focused on another reason why LANR is important. The fuel is abundant. The fuel is everywhere all over the Earth, with one in every 6000 hydrogen atoms in ordinary water (rain and the oceans) being heavy hydrogen, from which deuteron and/or deuterium can be taken, and "then put that into our cold fusion reactor, where it makes *de novo* helium-4."

Swartz then discussed yet another reason why cold fusion is so important—its energy density. He reviewed what had been taught extensively the previous week regarding the products of cold fusion. The cold fusion community had discovered "that the amount of excess energy that comes out is commensurate with the amount of helium made as the product." Swartz directed the class to the hard facts that the helium (He^4) production is in quantitative agreement with the excess energy, as Mel Miles, Les Case and SRI had measured; and that the rate of He^4 production is commensurate with the power, as the Gozzi experiment had demonstrated. The important implication was that "the reason that cold fusion will turn out to be so useful is that we are getting out energy proportional to the difference between the two deuterons and the helium-4 times c (the speed of light) squared ($E=mc^2$)." This incredible quantitative amount is an advantage for this energy production method which will enable "a decrease in our reliance on foreign fuels, and (enable) incredible emission benefits" by removing contaminants and by "eliminating the greenhouse problem."

Swartz then showed how important this was by having the group closely examine the amount of energy available (energy density) for various fuels, ranging from well known materials such as TNT and oil, to even fuels for the human body (including butter and donuts). Cold fusion's loaded active materials have so much energy density that he needed a logarithmic plot to put all of this together.

He thus proved that compared to all other known conventional fuels, with cold fusion there is a massive amount of energy density, and when this amount of energy is successfully liberated, "we get orders and orders of magnitude more energy out for the same amount of mass." A "Take Home Point," he said, is that "with cold fusion we will have a very clean energy production system, with abundant fuel and zero carbon footprint."

Swartz then continued with the important and logical question: Does cold fusion have any utility? "Yes," he said, "Experimental results we have run over 24 years demonstrated that. It does have utility and it is real." He asked rhetorically, "How can we take some of you in the audience to learn these scientific techniques and convert us to a cold fusion economy?"

To show how ridiculous the skeptics have been in maligning cold fusioneers, Swartz also showed a short slideshow of quotes from famous people who made what now can be considered foolish predictions against inventions in fields other than cold fusion—inventions that went on to help humanity. Their negative comments, as we now know, were all flawed and never came true. Skeptics "put down" the electric light, the rocket, airplanes, AC electricity, germs as the cause of disease, and on and on the examples went. For example:

- ". . .After a few more flashes in the pan, we shall hear very little more of Edison or his electric lamp. Every claim he makes has been tested and proved impracticable." *New York Times*, January 16, 1880
- "Professor Goddard. . .does not know the relation of action to reaction. . .He only seems to lack the knowledge ladled out daily in our high schools." *New York Times*, January 13, 1920
- "Heavier-than-air flying machines are impossible." Lord Kelvin, 1895
- "Fooling around with alternating current is just a waste of time. Nobody will use it, ever." Thomas Edison, 1889
- "There is not the slightest indication that nuclear energy will ever be obtainable. It would mean that the atom would have to be shattered at will." Albert Einstein, 1932
- "Louis Pasteur's theory of germs is ridiculous fiction." Pierre Pachet, 1872

Given the history of how flawed skeptics were against lesser quantities of evidence, it is presumed that those who debunked cold fusion will come to eat their words, as well.

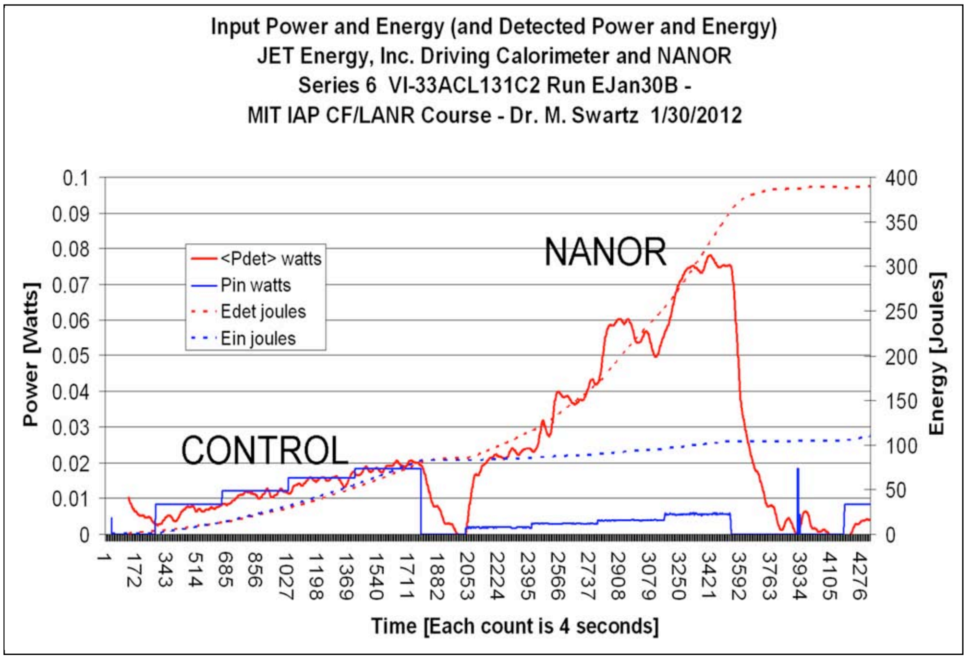
So what is cold fusion? What is LANR? Swartz talked about the materials involved in cold fusion/LANR, and how the lattice actually assists the desired nuclear reactions. He said, "We take a Group VIII (referring to the Periodic Chart) metal like palladium, occasionally nickel; we load it with hydrogen and make an alloy (the chemistry term, but also called a 'hydride') as product." He explained that these metals "that we load, fills as water fills a sponge," but in the case of LANR, what is filled is an isotope of hydrogen, either protons or deuterons (also called deuterium oxide, from heavy water, D_2O; but which is a heavier isotope of ordinary hydrogen). Swartz discussed the difficulties experimentalists face. He taught how loading is achieved with either an applied electric field intensity acting upon water, separating out the deuterium, which with palladium comes from the surrounding heavy water. "The problem we find is that when we load it we do not want to find cracks in this material," he explained, ". . .That with larger cracks, the loaded hydrogen comes out, and we do not get efficient loading." But when done correctly, he said, ". . .once we load it, and achieve other difficult aspects, we get out what we call 'excess heat' or 'excess energy.'"

In the next section of the talk, after discussion of the materials involved in the desired reactions, Swartz surveyed the methods of calibration of heat-producing reactions and systems. He detailed how there are now available many types of controls, time-integration, thermal waveform reconstruction, noise measurement and additional techniques, which are used, and are needed, for verification. He also pointed out several methods which are not accurate.

Swartz then spoke at great length of the importance of the role of deuteron flow (flux) and explained the differences between flow calorimetry, which can be inaccurate under some conditions where it is not calibrated, and the preferred method of measuring excess energy through the use of isoperibolic calorimetry, which Swartz said is the most accurate way of calculating excess energy generated.

Having discussed the materials, and methods of measuring excess energy accurately, Swartz segued to many examples of actual excess heat generated by a variety of cold fusion systems. He said, "When we're done, you'll hopefully understand why we get such a gain from making cathodes from metamaterials, phenomenal gain from optimal operating points and some control from heat after death."

Swartz showed graphs that were derived using aqueous nickel and palladium systems. He spoke about the early days of doing cold fusion with virtually no funding and showed pictures of cold fusion cells consisting of heavy water, which when ultrapure (low paramagnetic content) can cost thou-



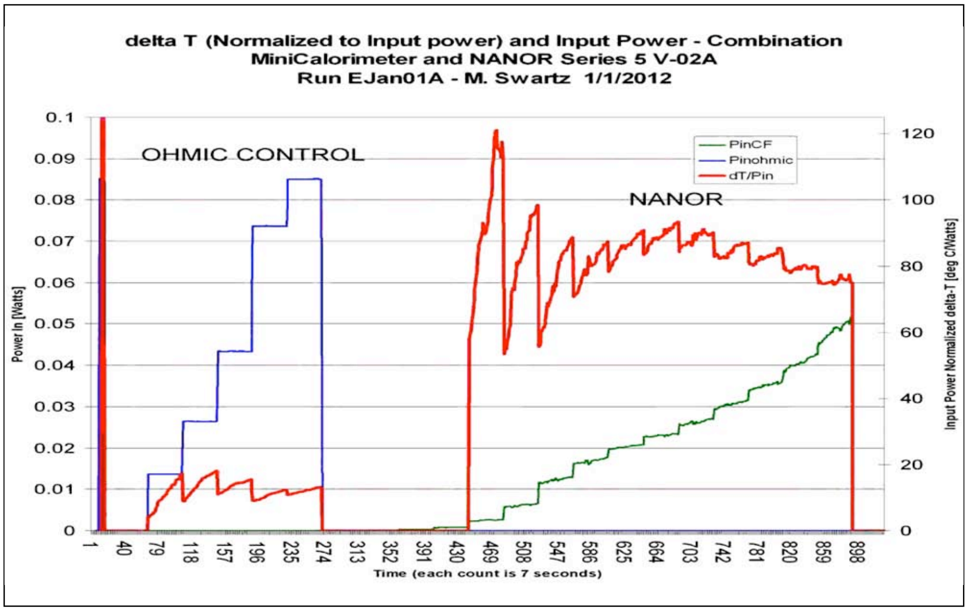
Electrical input and heat output of a two terminal NANOR®-type device Series 6-33ACL131C2, showing the calorimetric response at several input powers, for the device and the ohmic control.

sands of dollars per kilogram, and showed the expensive noble metals used for the electrodes. He showed pictures of hot cups of tea (or coffee) and the outputs quite sufficient to heat them. Over the years, cold fusion opponents have infamously, and arbitrarily, referred to heating these beverages as being the real barometer of success.

Swartz returned to the concept of deuteron flux. Then using the Navier-Stokes equation, he developed the flow equations for both protons and deuteron flow and applied them to both "conventional" cold fusion and in its variant, codeposition. In the latter, there is also flux of the palladium ions into the cathode which builds up a loaded compartment of active material.

The concept of deuteron flux then led to metamaterials, a major improvement of cold fusion systems. Swartz focused on the salient advantages of the LANR metamaterials with the PHUSOR®-type system, stating that it is one prime, extremely useful, example with high output. He then explained how he developed the invention of the coil-shaped palladium PHUSOR®-type cathode in a high impedance solution (which, he said, has since been issued two design patents). Although it differed in many ways from what others in the field used, it routinely produced high power gain and excess energy levels. His open demonstration of the PHUSOR®-type LANR system at MIT in 2003 confirmed that, and several graphs and photons from the week-long cold fusion demonstration were shown.

Swartz then shared another of his discoveries—optimal operating point (OOP) manifolds that organize LANR output by the amount of input power. He explained how he discovered the OOP experimentally and showed how in all LANR systems, no matter what the product (helium-4, heat or tritium production), and no matter what the system (palladium with heavy water, nickel with ordinary water and nanomaterials) all of these when plotted as a function of input power demonstrate a series of dots which assemble and show a distinct pattern. He went through the different regions, and showed where the reactions turn on and off, and how by plotting out the experiments this way, one could show consistency and reproducibility, time and time again. He demonstrated that OOP operation has shown the ability to determine the products of cold fusion, and why OOP manifolds demonstrate that cold fusion is a reproducible phenomenon, applicable to science and engineering. He also said that he had found OOPs in other colleague's experiments where they had not, and showed that their data also fit these curves.



Electrical input power and resulting output temperature rise [normalized to input electrical power] of a self-contained CF/LANR quantum electronic component, a Series V two terminal NANOR®-type device containing active preloaded ZrO_2/PdNiD nanostructured material at its core.

Returning to the experimental results and engineering methods developed to control cold fusion, Swartz then surveyed "heat after death" and its control for several useful applications, including the use of LANR systems to drive motors. He spoke about how active LANR systems can be used to generate tardive or late-occurring excess energy after conventional LANR, and explained that this was what Fleischmann and Pons had called HAD (heat after death). The important "Take Home Point," he said, was that there is an extraordinary amount of data and information that has been collected over the years. Asked later how he would sum up his talk, Swartz said, "experimental data rules."

Day Six — January 29, 2013

Emissions and energy for cold fusion systems was the focus of Dr. Swartz's lecture on Tuesday, January 29. He began with the discussion of experimental results, including the generation of excess heat from cold fusion in aqueous systems. He continued with the near infrared (IR) emissions observed from active LANR devices. He first demonstrated how dual calibrations are needed to correctly determine near excess heat from IR emission obtained from active LANR devices. As a result, unlike the previous SPAWAR detection of far IR from codeposition cells, these results were calibrated proving they were excess heat generated from active LANR. Discussion among the group was heated comprising the idea as to whether these interesting calibrated images and associated calorimetry were showing near IR output of thermal or non-thermal origin.

Swartz went on to speak about several years of efforts involving the generation of electricity from a variety of LANR systems, including the use of LANR-driven engines to generate electricity. He showed early attempts (pre-2000) covered in *Fusion Facts*, to his more recent attempts to close the feedback loop. Important fundamental engineering issues, such as inadvertent thermal and electrical dissipative losses in the feedback loop, resulted from voltage scaling, and especially from a fuel cell which he used to store the electrical energy. His pie chart showed the impact of other components, as each was considered and the measured results shown. The implications were presented, including a brief summary of problems in the feedback loop. He then focused the class from cold fusion to nanomaterials, which now hold worldwide intrigue. Of particular interest was his discovery of a new type of dry and preloaded nanomaterials, a LANR material which is producing phenomenal excess heat output.

After discussing these novel characteristics and electrical breakdown (avalanche) issues, which electric drive regions actually generate excess energy, Swartz presented the development of several types of NANOR® cold fusion electronic components. Using multiple ways of documenting the excess energy produced, Swartz presented the results of the latest series of such devices, as shown at MIT over several months in 2012 in the second series of open demonstrations of cold fusion by JET Energy, Inc.

He gave overviews of the R&D and directions where JET Energy is headed based on these observations and discoveries. The bottom line was that they have seen energy gains from 14 and greater. This was in conjunction with advanced driving circuits that were shown to have excess energy documented by temperature rise, heat flow and calorimetry—heralding their revolutionary potential to change the energy landscape in circuits, distributed electrical power systems, artificial internal organs, propulsion systems, space travel and more.

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