Cold Fusion

Clean Energy for the Future

Talbot A. Chubb

Cold Fusion

Clean Energy for the Future

Talbot A. Chubb

Internet Edition, April 2008
Prepared by New Energy Times

Publication funding provided by

Cold Fusion Energy Research Co.
(Planned precursor to Cold Fusion Energy Foundation)

Cold Fusion

Clean Energy for the Future

Talbot A Chubb

Dedicated to Yoshiaki Arata and Yue-Chang Zhang.

Professor Arata recently wrote the following in reference to his cold fusion studies using nanometer palladium.

> "D_2 gas instantly penetrate into the specimen and D atoms change into **^{4}He** instantly (no need time) and nuclear Fusion (**^{4}He** and energy) is established perfectly under the following equation:
>
> **^{2}D+ ^{2}D = ^{4}He + thermal energy**
>
> .....
>
> It is considered that this phenomena is the highest result in this century."

Preface

This book has been made possible by the scientists, supporters, and organizers who have kept cold fusion alive for nearly two decades, and their families who have sacrificed so much in this effort. I want to thank those who have expended their careers in this task. I want to thank those who have been my teachers, both in person, and in their papers and text books. I want to especially thank Fleischmann and Pons, who discovered cold fusion, Arata and Zhang, who pioneered nanometal cold fusion, and Scott Chubb, who has been my main teacher in metal physics and many-body theory. I want to thank those who have remained largely anonymous while helping in the thankless effort of keeping cold fusion alive.

The author wishes to thank Pete McQuillin for advice and help in planning this book, Constance Chubb and Scott Chubb for help with the figures used in the manuscript, Mike Melich for help with the Supplements, and Xing Zhong Li, James Kurfess, and Marianne Macy for providing editorial input and calling my attention to errors and deficiencies in my writing.

Opportunity Knocks

This book tells the story of cold fusion. We have a serious energy and environment problem. We also have an economic and social problem. We seek a healthy, happy society in which medical problems are addressed, needy older people are cared for, and children are educated to love learning and enjoy fellowship. The solutions to these social problems are labor intensive, yet need to be addressed without imposing excessive economic insecurity on the recipients. But we should not be discouraged. There are new technologies available to help us meet these needs. Cold fusion is one such technology. It can be a big help along the way to a better and more exciting world.

Opportunity knocks. On the one hand, the price of oil has reached $90 per barrel, and the cost of gasoline exceeds $3.00 per gallon. The level of carbon dioxide in the atmosphere increases every year. World temperatures have risen over the past decade, and there are worries about a potential rise in sea level. Loss of habitat threatens animal and plant diversity. On the other hand, science and technology advances have made it possible to add an essentially limitless fuel supply to our menu of available energy sources. This new energy source provides 10 million times the energy per pound of oil and gas. The new energy fuel is the heavy hydrogen component of water, including sea water. The fuel is available to all nations. This new energy is radiationless cold fusion. Cold fusion is a new form of nuclear energy that avoids all the worries associated with today's nuclear power plants. It does not use uranium. It has no atom bomb potential, hence its use can greatly reduce the possibility of atom bomb proliferation, leading to a more secure world. It avoids the radioactive waste products of nuclear power plants, which eliminates the waste storage problem and worries about contamination of the land. Its energy production does not require large centralized power plants. It can be used for off-grid home heating and generation of household electricity. The radiationless cold fusion process is a catalytic process involving a metal solid.

The main goal of this book is to make the reader aware of recent laboratory studies that show that cold fusion is real and that it can likely produce commercial power within a few years, assuming that a modest research effort is supported.

The book starts with examining how cold fusion relates to ordinary chemistry and physics. Next comes a discussion of various forms of atomic power, followed by a discussion on quantum mechanics, followed by a brief history of cold fusion research beginning with the discovery announcement by Drs. Martin Fleischmann and Stanley Pons. The final part discusses the quantum mechanics of chemical orbitals, their relation to electron quasiparticles in metals, and how heavy hydrogen quasiparticles can undergo fusion.

Clean energy fusion began with the discovery of radiationless cold fusion, announced in 1989. The discovery stimulated great controversy. The early development history was filled with conflicting claims and experiment failures. The physics community decided that an error had been made, and research funding faded away. The workers who persisted in their studies organized a series of International Conferences on Cold Fusion. Studies reported on were published in a series of Proceedings publications now known as *Proc. ICCF1* through *Proc. ICCF13.* Other papers were published in standard journals.

To reduce controversy, different names have been used to describe the radiationless cold fusion process. One of the names is Low Energy Nuclear Reactions (LENR), which led to the LENR.org website. Another name is Chemical Induced Nuclear Reactions (CANR), which led to the LENR-CANR.org website. A professional society was incorporated under the name International Society for Condensed Matter Nuclear Science (ISCMNS). Osaka University physicists Arata and Zhang, who have carried out pivotal cold fusion studies using nanometals, prefer the name "Solid Fusion", and have also used the name "Solid State Fusion".

CONTENTS

CONTENTS

A NEW SCIENCE

A Starter Lesson in Cold Fusion

This starter lesson is in the form of a science tutorial designed to provide a background for understanding cold fusion, a radiationless form of fusion energy, and its difference from other energy sources. It has been written for students and non-professional readers.

A Science Tutorial

There are now four distinct types of energy production: 1) chemical energy, that powers our cars and most of our civilization, 2) nuclear fission energy, as used to generate about 15% or our electricity, 3) plasma fusion nuclear energy, which powers the sun and most stars, and 4) cold fusion nuclear energy, which initially appeared as unexplained heat in the laboratory studies of a pair of experimenters. The three types of nuclear energy produce 10 million times as much heat per pound of fuel than occurs with chemical energy. How do these types of energy differ?

Protons and Electrons. The Hydrogen Atom

Nature has provided us with 2 types of stable charged particles, the proton and the electron. The proton is heavy, normally tiny, and has a positive charge. The electron is light, normally diffuse and fuzzy, and has a negative charge. The positive charge and the negative charge attract each other, just like the north pole of a magnet attracts the south pole of a magnet. When you bring 2 magnets together with the north pole of one facing the south pole of the other, they pull together, bang! When they bang into each other they release a little bit of energy in the form of heat, but it is too small an amount to easily measure. To pull the magnets apart you have to do work, which is another way of saying you have to use up energy. It's almost like pulling a rock back up a hill. Rolling the rock down a hill actually creates a little heat, and pulling the rock back up the hill takes energy.

In the same way the positive charge of the proton pulls on the negative charge of the electron and they stick together, releasing energy in the process. The simplest atom is a hydrogen atom, designated H. The hydrogen atom is nothing but one fuzzy electron hugging a compact proton. The proton is the nucleus of the hydrogen atom. If you knock the electron off the hydrogen atom you get a positive ion H^+, which is nothing more than a lone proton. An ion is the name applied to an atom or molecule that has lost or gained one or more electrons, hence is no longer electrically neutral.

Other Atoms

Other atoms (oxygen, nitrogen, iron, etc.) have different numbers of protons inside them, which means they all have different plus charges. The nucleus of the helium atom has 2 protons inside it, hence has plus 2 charge, and requires 2 electrons to neutralize its charge. When 2 electrons stick to it, it becomes a helium atom. The oxygen nucleus has 8 protons and has charge 8. When 8 electrons stick to it, it becomes an oxygen atom. The nitrogen atom has 7 electrons, while iron atoms have 26. But all the atoms are built more or less the same way, with a compact positively charged nucleus embedded in a cloud of fuzzy electrons. The fuzzy cloud surrounding the hydrogen nucleus is shown in Figure 1.2,1 The difference in size between the compact nucleus and the fuzzy electrons is enormous. The sun has a diameter only about 100 times that of the earth. The electron cloud in an atom has a diameter which is about 100,000 times that of the nucleus. This is a big number. If a proton was increased in size to be the width of a blade of grass and placed in the center of a football field, the electron cloud would enclose the whole football field. Cube these numbers to get the difference in volumes.

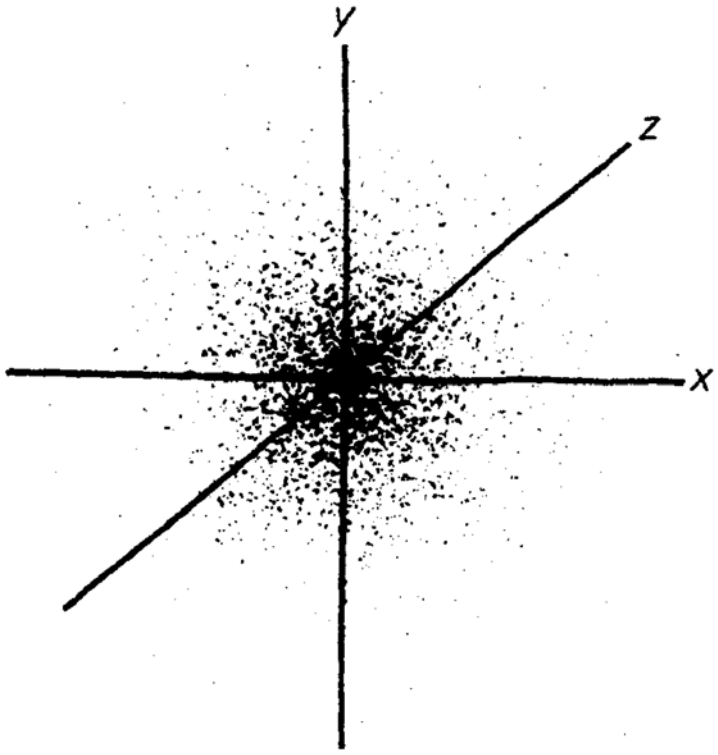

Fig. 1.2,1 A hydrogen atom consists of a proton embedded in a fuzzy cloud of electron charge. This figure is a computer plot of electron density taken from "Chemistry, experimental foundations" by R.W. Parry, L.E. Steiner, R.L. Tellefsen,. and P.M. Dietz (Prentice Hall, Inc., Englewood Cliff, NJ, 1970).

Chemical Energy

The atoms, all electrically neutral, can actually join with each other and release more energy. This is another way of saying that they can join into more stable configurations. The negatively charged electrons in an atom try to configure themselves so as to get as close as possible to their positively charged nucleus, but their fuzzy nature requires that they take up a certain volume of space. However, if they join together with the electrons of another atom they can usually find a tighter configuration that leaves them closer to their positively charged nuclei. For example, 2 hydrogen atoms can join together into a more compact configuration if each hydrogen atom contributes its electron to a 2-electron cloud, which the separate protons share. In this manner they form a grouping of the 2 electrons in a single cloud, together with the 2 isolated protons spaced apart from each other but still within the electron cloud. The result is a heat-producing chemical reaction in which 2 H atoms combine to form a hydrogen gas molecule. The H_2 configuration is the hydrogen molecule, and when you buy a tank of hydrogen gas, H_2 molecules is what you get. Furthermore, the 2 electrons of the H_2 molecule and the 8 electrons of the O atom can find a still more compact configuration by combining their electrons to create the water molecule, plus heat. The water molecule is really a single cloud of electrons in which are embedded the three point-like nuclei to form a minimum energy configuration. So when we burn oil or coal, we change the configuration of the electrons to produce more stable arrangements of point-like nuclei embedded in electron clouds, liberating heat. So much for chemical energy.

Strong Force and Neutrons

We have slid over one point. How does Nature construct a nucleus containing two or more protons in the first place? After all, each of the protons has a positive charge, and the positive charges repel each other very strongly when they are separated by a tiny distance, equal to the distance across a nucleus. The repulsion of like charges is just like the repulsion between the north poles of two magnets when they are pushed together the wrong way. Something must overcome this repulsion, or else the only kind of atoms we would have would be those of hydrogen. Fortunately, this is not what we observe. The answer is that there is a second kind of force which acts on protons. This is the strong nuclear force. The nuclear force is a very strong attraction but requires particles to almost sit on each other to have any effect. It is often called "the strong force". Also, there is a second kind of heavy particle, which is just like a proton, except that it has no positive or negative charge. It is not pushed away by the proton's plus charge. This other kind of particle is called the neutron, since it is electrically neutral. A peculiar fact of life is that it exists in stable form only inside a nucleus. When not in the nucleus it changes into a proton, an electron and a very light anti-neutrino in about 10 minutes. But it lasts forever inside a nucleus.

Nuclear Fusion

The neutron and the proton very strongly attract each other once they get close enough together, and then they combine to form a highly stable pair called a deuteron, which we designate D^+. The single deuteron, when it combines with a single electron, forms the heavy hydrogen atom called deuterium, designated D. A second nuclear reaction, called **fusion**, occurs when two deuterons make contact. When they can be forced together so as to make contact, the 2 deuterons fuse, making a doubly charged particle. The grouping of 2 protons and 2 neutrons is even tighter than the proton-neutron grouping in the deuteron. When neutralized by 2 electrons, the new particle is the helium atom, designated He. Larger groupings of neutrons and protons exist in nature and serve as the nuclei of carbon, nitrogen, oxygen, and iron, etc. atoms. All of these groupings are made possible by the strong force, which is felt between protons and neutrons only when they are in contact or share the same nucleus-size volume of space.

Nuclear Fission

Normal nuclear energy power plants are powered by nuclear **fission** energy, not **fusion** energy. During the early history of the universe massive stars were formed. In the explosion of these massive stars, lots of different types of nuclei were formed and exploded back into space. Second and later generation stars and planets were formed from this mix, including the sun. In the explosion process probably every possible stable configuration of protons and neutrons was produced, plus some almost-stable groupings, such as the nucleus of the uranium atom. There are actually 3 different types of uranium atom nuclei, called uranium-234, uranium-235, and uranium-238. These "isotopes" differ in their number of neutrons, but they all have 92 protons. The nuclei of all uranium atoms can go to a lower energy configuration by ejecting a helium nucleus, but this process occurs so rarely that the Earth's uranium has already lasted over 4 billion years.

The uranium nuclei are unstable in another way. In general, groupings of protons and neutrons are happiest if they have about 60 protons-plus-neutrons. The uranium nuclei contain more than three times this number. So they would like to split in two, which would release a lot of heat. But nature doesn't provide a way for them to split apart. They have to first go to a higher energy configuration before splitting in two. However, one of the three forms of uranium nucleus found in nature called uranium-235 and designated ^{235}U, gains the needed energy if it captures a neutron. The energized nucleus that results from neutron capture then splits apart with the release of an enormous amount of energy, and incidentally with release of additional neutrons. The additional neutrons can then split more uranium-235 nuclei, keeping the reaction going. This is what

happens in nuclear power plants, where the heat, which is the end product of the nuclear splitting process, is used to boil water, generate steam, and turn electrical generators. (One also gets lots of radioactive products, which are a nuisance to dispose of safely and constitute an environmental hazard lasting many human generations.)

Hot Fusion

We are now also in a position to understand hot fusion (plasma fusion) nuclear energy. As mentioned in lesson 5, the groupings of protons plus neutrons is most stable when the numbers of neutrons and protons approximate those found in the nucleus of an iron atom. Just as uranium has too many neutrons plus protons to be comfortable, so the light elements like hydrogen, helium, carbon, nitrogen and oxygen have too few. If the nuclei can be made to make contact under proper conditions, they can combine to create more stable groupings, plus heat. This is the process of fusion. Nature has found a way of doing this in stars like the sun. All Nature has to do is heat compressed hydrogen hot enough and wait long enough and plasma fusion will occur. If Nature were to start with deuterium, which already has a paired proton and neutron, the task would be relatively easy in a star. Temperature is a measure of how much speed an atom of a given type has as it bangs around inside a cloud of such atoms. The higher the temperature, the higher the speed and the closer the atoms get to each other momentarily during a collision. In a star the temperatures are high enough that all the electrons quickly get knocked off the atoms, so one is really dealing with a mixed cloud of electrons and nuclei, called a plasma. At very high temperature the nuclei occasionally get close enough during collisions for the pulling-together short range nuclear force to turn on. Then the nuclei can stick together and go to a lower energy grouping of protons plus neutrons, releasing heat.

There is an international hot plasma fusion nuclear energy program, which is an attempt to carry out this process in the lab using deuterium and mass-3 hydrogen (whose nucleus is a compact grouping of 1 proton and 2 neutrons) as the gas. Hot fusion requires that the gas plasma be contained at temperatures of hundreds of millions of degrees, which can be done with the help of magnetic fields, but only for 1 or 2 seconds. The hope is to contain the gas for longer times. During the period of high temperature containment nuclear reactions occur during collisions. The main form of energy release is ejection of high energy neutrons and protons. The proton energy quickly converts to heat. The neutron energy can also be converted to heat, but makes the equipment highly radioactive. It then becomes difficult to repair the equipment, which could make hot fusion a poor candidate for commercial power production. In any case hot fusion power is a dream that is still probably at least 50 years away. It has been impossible to keep the hundred million degree gas away from the container for more than 1 second.

Electrical instabilities occur in the plasma gas. In the most successful experiment a power output of 16 Megawatts was achieved for less than 1 second, and the fusion energy produced was less than the energy used to heat and confine the gas. But most scientists view hot fusion as the only way to achieve fusion power. Plasma fusion produces less radioactivity than fission power, is relatively environmentally benign, and has a virtually limitless fuel supply on earth. (more than a billion years at present energy usage rates).

Cold Fusion

Cold fusion promises a less costly and non-radioactive way of releasing nuclear fusion energy. Cold fusion relies on a different way of letting the protons and neutrons in one nucleus make contact with those in another nucleus, so that the nuclear force can bring them into a more stable configuration. Nuclei have sometimes been modeled like drops of liquid. For water droplets to combine, they must make contact. The same joining together occurs with nuclei. The requirement for any nuclear reaction to occur is that the reacting nuclei either make contact or come to share the same volume of space. The sharing condition is called particle overlap. In plasma fusion particle overlap is brought about briefly by banging the nuclei together so as to overcome momentarily the repulsion of the two positive charges which try to keep the particles apart. In cold fusion particle overlap conditions are achieved by making deuterium nuclei act as extended fuzzy objects like electrons in a metal, instead of like tiny points. The fuzziness is dictated by the famous Heisenberg uncertainty principle. When an electron is part of an atom, its fuzzy volume is called an "orbital". The conduction electrons in a metal are in very extended orbitals. Cold fusion occurs when the deuterons are in metal-type electron "orbitals".

A cold fusion reactor, i.e., an apparatus that promotes cold fusion, makes deuterons behave like electrons in a metal. When a heavy hydrogen atom is added to a metal, it loses its electron to the metal. The deuteron moves into the metal and occupies a position where it is surrounded by the metal atoms. The metal atoms are in an ordered array, which is embedded in a sea of electrons, called the "fermi sea". The atoms make room for the deuteron and the fermi sea neutralizes the deuteron's positive charge. Each deuteron has its own little volume. This is **not** the form of hydrogen that supports cold fusion. To get two or more deuterons to share the same volume one most go one step further. In a metal, electrical current is carried by the fermi-sea electrons, which act more like vibrating matter waves than like point particles. This behavior is part of the famous wave-particle duality of quantum mechanics. If electrons did not become very extended objects inside solids, there would be no transistors and no present day computers.

The wave-like form of electron inside a metal is called a "quasiparticle". The secret of cold fusion is that one needs quasiparticle deuterons. This need for quasiparticle geometry has not been recognized. Once a quasiparticle deuteron is created, its positive charge is shared between many local volumes. The deuteron has been "partitioned". The repulsion force between two such deuterons is enormously reduced and no longer keeps the deuterons cleanly separated. The nuclear strong force comes into play, pulling the partitioned deuterons together to form a stable helium nucleus in quasiparticle form. Nuclear reaction energy heats the metal without release of dangerous radiation.

To study cold fusion the experimenter has to entice some of the deuterons to assume the quasiparticle form. The cold fusion experiments discussed in this paper demonstrate the radiationless release of cold fusion heat. Five years ago no one knew how to do it reliably. New materials in the form of clusters of metal atoms called nanometals have greatly improved reliability. Since cold fusion promises more than a billion years of energy without the problems of global warming or radioactivity, an urgent effort should be made to learn how to make commercially affordable heaters.

Atomic Power

Fission Power

More about atomic energy. Atomic energy is the same as nuclear energy. It has a bad reputation because of its radioactive waste and its association with the atom bomb. A group of major countries is seeking a safer form of nuclear power (less contamination), and has undertaken a global program on plasma fusion energy, called ITER, to meet this goal.

Today's atomic power is mainly a classical nuclear physics discipline. It is concerned with generation and capture of free neutrons, and the splitting of uranium and plutonium atoms. Generation of massive amounts of heat by uranium fission is made possible by three aspects of nuclear physics. First, the most stable nuclei are those corresponding to mid-mass elements with a mass somewhat heavier than iron. Language-wise, protons and neutrons are lumped together and called nucleons. The lowest energy arrangement of nucleons is the most stable nucleus. The iron we mine is a mixture of 4 different nuclei, each having a different mass. This is to say that iron has 4 stable isotopes. The most abundant form of iron nucleus is the iron-56 isotope, which is written ^{56}Fe. It has 56 nucleons, of which 30 are neutrons and 26 are protons. The other isotopes have the same number of protons, but a different number of neutrons. The uranium used in nuclear power plants is the uranium-235 isotope, written ^{235}U. It has 143 neutrons and 92 protons. It is a much less stable than ^{56}Fe in the sense that its binding energy per nucleon is much lower than that of ^{56}Fe and much lower than that of other elements in the mid-mass portion of the Periodic Table of elements. At the beginning of WWII it was already known that if a uranium nucleus could be split into two pieces, a lot of energy would be released.

Nuclear power became available when a way was found to split a uranium nucleus into 2 pieces. In nuclear power plants it is not the ^{235}U nucleus that splits. It is its neighbor isotope ^{236}U. When ^{235}U absorbs a neutron, it becomes ^{236}U in a highly excited state. The over-energized ^{236}U nucleus has too much vibration energy and flies apart in 2 pieces: it undergoes fission. The reason that ^{236}U is so highly excited is that even-numbered nuclei are generally much more stable than neighboring odd-numbered nuclei.

The 2 fragments produced by fission of uranium have a higher neutron/proton ratio than other nuclear configurations in the mid-mass range of elements. The excess neutron/proton ratio makes the fission fragments unstable and highly radioactive. As a result, neutrons inside the nucleus want to decay into protons plus electrons and antineutrinos, in a process called beta-decay (β-decay). The emission of β-rays (high energy electrons of nuclear origin) is frequently accompanied by emission

of gamma-rays (high energy x-rays of nuclear origin). Successive conversion of neutrons into protons eventually creates stable nuclear end-products.

Plutonium-239 is a man-made nuclear fuel produced when the most common form of uranium, ^{238}U, absorbs a neutron. The ^{238}U isotope is about 140 times more plentiful than the ^{235}U isotope in mined uranium. The reaction sequence is

$$^{238}U + n \rightarrow {}^{239}U \rightarrow {}^{239}Np + \text{electron} + \text{antineutrino} + \text{gamma} \ ;$$

$$^{239}Np \rightarrow {}^{239}Pu + \text{electron} + \text{antineutrino} + \text{gamma} \ ,$$

where n is a neutron, Np is Neptunium, and Pu is plutonium. ^{239}Pu is a synthetic nuclear fuel and acts much like ^{235}U.

Operation of a commercial nuclear power plant depends on a neutron chain reaction. When a ^{236}U nucleus splits in two, it produces free neutrons in the fragmentation process. On the average, more than one free neutron is produced. It would take one free neutron per fission to keep a chain reaction going if no free neutrons escaped or were lost in "sterile" absorptions that do not produce fission. But some neutrons are always absorbed in non-fission reactions. The power plant operator must ensure that just the right number of neutrons get absorbed in "sterile" absorptions. Otherwise, heat production will either increase exponentially, or die down exponentially. The power plant maintains a desired number of free neutrons by mechanically inserting or removing a control rod containing a non-fissionable neutron absorber, like cadmium or boron. In contrast, the bomb maker seeks to make the increase in number of free neutrons as fast as possible.

As you can see, the physics of commercial power plants is much the same as that of an atomic bomb. There is a difference in the $^{235}U/^{238}U$ ratio in the fuels employed. But guaranteeing that no bombs are being made in a nation running its own nuclear power plants is a difficult task. This task is assigned to an international monitoring agency. Nuclear proliferation is probably the most serious problem threatening the survival of a not very peaceable 6-billion person world society.

Fusion Power

The alternate way of harnessing nuclear energy is fusion. Nuclear fusion is the process that powers the sun. The enormous amount of hot hydrogen gas in the center of the sun supports a very low rate of nuclear reaction, in which normal hydrogen H is slowly being converted into helium over the course of a few billion years. The gradual release of nuclear fusion energy is sufficient to keep the center of the sun very hot. The energy gradually leaks out of the sun in the form of infrared, visible,

and ultraviolet light. The visible light energizes the biosystem of Earth, of which we are a part.

The fusion process in the sun is called "plasma fusion". The global community has committed billions of $ to develop plasma fusion as an alternative form of nuclear energy, with the goal of generating electricity with less radioactive waste than produced by fission, while tapping an essentially endless supply of heavy hydrogen fuel. Unfortunately, plasma instability problems associated with containing the required super hot plasma have delayed the development process. There is no guarantee of success. Some would say that the likelihood of commercial success in the 21st century is small. Although the radioactivity problem is small compared to that of uranium fission, it is not negligible. Radioactive equipment is costly to repair. The amount of future effort in this area is uncertain.

In addition to plasma fusion, fusion has been made to occur at laboratory equipment temperature. Laboratory temperature fusion is called "cold fusion". There are two forms of cold nuclear fusion energy that have been demonstrated in the laboratory. The first discovered form was observed in 1956, in a reaction called "muon-catalyzed fusion". Muons are radioactive unstable particles that were first identified in cosmic rays, and subsequently found as secondary decay products in nuclear physics accelerator experiments. There are 3 types of muons: positive, negative, and neutral. The negative muon is very much like a heavy electron. Its mass is ~200 times that of an electron. It is an unstable "meson". The negative muon decays into an electron and a muonic antineutrino in about 2 microseconds (2.1×10^{-6} s). If you mix negative muons and hydrogen gas, you end up with very small hydrogen ionic molecules like H_2^+ in which the separation between paired hydrogen nuclei is about 200 times smaller than in a normal H_2 molecule. In terms of volume ratio, which determines density, the factor is 8 million. The element hydrogen H has 3 isotopes, ^1H, ^2H, and ^3H. These are often designated H, D, and T, where D stands for deuterium and T stands for tritium. H and D are stable isotopes, whereas T is a man-made radioactive isotope. Nuclear physicists generally use "d" for the deuterium nucleus, which is called a deuteron. Muon-catalyzed fusion works best with the DT^+ muonic molecule, but also is observed with the D_2^+ muonic molecule. The reaction process always creates copious neutrons, energetic particles, and sometimes gamma-rays. The process was explained quantitatively by J. D. Jackson in 1957. Many studies have been carried out to see whether there could be some way of efficiently producing enough negative muons to make muon-catalyzed fusion a practical energy source. The process is not a good candidate for future energy production. The energy required to replace the decaying muons turns out to be greater than the electrical energy that could be produced.

The clean energy cold fusion discussed in this book is the second form of cold fusion. Unlike muon-catalyzed fusion, it does not depend on high density. It is a remarkably beneficent form of nuclear energy. It was discovered by two chemists, Martin Fleischmann and Stanley Pons (F-P), about 20 years ago. Because high densities are not involved, and because of a special "quantum" geometry that must be imposed, there is no emission of energetic particles or gamma rays allowed. The primary nuclear product is helium, which is a harmless gas. The response of the consensus science community was disbelief. Fusion heat production without radiation seemed too good to be true. Cold fusion violated the consensus view that chemistry can never affect nuclear physics. Fusion without neutrons and energetic particles violated every aspect of known fusion physics. Initial skepticism was increased by quick attempts to reproduce the F-P experiments. These first verification experiments showed little evidence of fusion heat. Even F-P had difficulty in reproducing their first results for a half year. Nevertheless, a few scientists accepted the initial published laboratory evidence. They questioned the majority view, respected the F-P data, and stuck to the rule that lab and observations are the boss. Eventually, F-P and a number of others obtained new evidence that some sort of nuclear process was being made to occur by chemical means. Today's evidence is conclusive.

During cold fusion's first decade, supporting evidence for heat production accumulated, but poor reproducibility of the F-P process persisted. Only the research team of Yoshiaki Arata and YueChang Zhang (A-Z), using nanometer size palladium powder, seemed to get consistent results If the F-P discovery was correct, there was some sort of instability or unknown factor involved. An inconsistent process is not the sort of thing one needs for generating home heat and electricity. It is not surprising that research support in this area has been lacking.

We now know a lot more about the F-P process than we did in the early 1990s. Conditions leading to heat production have been identified. Studies have shown a quantitative match between helium production and nuclear heat produced. Two types of instability that have plagued earlier work have been identified. A-Z methods involving a new type of fine metal powder have recently led to easier reproducibility. Empirical factors that control F-P heat production in bulk metal have been identified.

Cold fusion depends on a physical configuration that can only be understood in terms of quantum mechanics. However, one does not need quantum mechanics to understand the engineering and operation of the new experiments that have shown that workable cold fusion heaters can be built. But, one does need some quantum mechanics to understand why the cold fusion process works.

THE QUANTUM WORLD

Welcome to the quantum world. It is a quirky and interesting world. It is the source of the stunning advances in communication and computing technology that have revolutionized the way we live. Today's communication technology seems incredible to those who grew up in the pre-television world. In the 1940s Dick Tracy had a wrist watch radio like today's cell phone. He was a hero detective in the comics. What was dreamed about has become every day use. The first television screens were based on flying electrons directed towards points on a fluorescent screen inside a heavily evacuated picture tube. Images were in black and white. Today's wall-wide flat screens were 25th century dreams. During WWII, the computers used in calculations leading to the atomic bomb were carried out on mechanical adding and multiplication machines, or were done with slide rules based on logarithm mathematics. Today's portable computers were beyond imagination. In this century we are seeing a similar revolution in diagnostic medicine, where we identify proteins produced in response to an individual's genetic code. The idea that little semiconductor-based wafers could identify an individual's gene-directed protein production was just not conceivable 2 decades ago. Choosing medical treatments based on an individual's gene-influenced chemistry is just beginning.

Cold fusion is a product of the quantum world. It is part of what is called solid state physics, where strange quantum states describe equally strange and useful behaviors. Solid state physics is being harnessed in an incredibly diverse world of new devices. The peoples of today's world use these devices in every day living as they pursue their multi-tasking lives. Historically, changes have always occurred, but the scale and rapidity of changes are faster than ever. Part of the reason is that new discoveries in the solid state physics have opened incredible new opportunities. The first few years after new technologies become available are years of relatively rapid change. After a new area of discovery has been around for a while, the pace of development usually slows. Today's exceptional rate of change is probably due to globalization. The whole world contributes to today's advances, and the dominance of a few leading countries is a thing of the past. What is learned in country A is quickly passed on to countries B, C, and D. The advances in cold fusion would have been impossible without a global sharing of experiences and views.

In the near future the quantum world will start impacting the world of energy supply. It is none too soon. We are already producing oil at close to the maximum expected rate. This rate is unsustainable over even the present century. Discovery of adequate new oil supplies is considered unlikely. The technology that supports today's 6.6 billion people depends on resources that are going to decline. Moreover, the impact of this full utilization threatens many ecological systems that are valued by the

world community. The quantum world has already begun to affect the energy field by its development of solar cells and new battery materials. These inventions are useful and can provide relief during the transitional period when fossil fuel energy is still available. But it seems doubtful that they can adequately support the fast paced society to which we have become accustomed. The New Energy technology examined here is different. It taps a resource base that can support the energy needs of 6.6 billion people for at least a billion years. The new technology makes use of a relatively unfamiliar portion of the same quantum world that has given us today's solar cells. The timing is good. We are going to need a lot of new energy by mid-century, if not before. Those who worry about global warming say that we need it now.

Like most other technology advances, like the invention of steam engines and knitting machines, most people will enjoy the benefits of the devices while not understanding the details which make them practical. However, we are in a decision-making period, which makes it important that a larger number of people understand how cold fusion works and the principles that makes it possible. Decisions based on knowledge and understanding are needed to guide investment of intellectual effort, capital, and government support. Research, development, and economic strategy will determine how soon the fruits of discovery are enjoyed. The Clean Energy cold fusion field has recently reached the point of having demonstrated heat production in several devices, but very few understand the physical and chemical science that catalyzes the configuration change that enables the new fuel to fuse and release heat. Most experimenters only know that energy release can be made to occur, but they don't know why it works. We need more persons who understand what is happening and the opportunity that it presents.

This book is really in two parts. Part 1 addresses the classical current engineering world of energy. It includes the previous chapter, which describes uranium-based nuclear fission power, and also the high temperature option of plasma fusion power. These processes are labeled "classical" because they are not really part of the quantum world. It distinguishes cold fusion from both these two classical nuclear-based processes. Part 1 then goes on to discuss early cold fusion and so-called LENR (Low Energy Nuclear Reaction) experiments, and how they have evolved toward the engineering of cold fusion heaters. This evolution is discussed in the EXPERIMENT Section of Part 1. These experiments were carried out using classical techniques and without a detailed understanding of the quantum mechanics that underpins the cold fusion process. The EXPERIMENT Section addresses the experiments that have shown that cold fusion processes have been made to occur in the laboratory, and looks at the new materials that have ensured future success. It outlines the need for similar studies to make it a commercial success. The reader does not need to understand the quantum world to understand the nuts and bolts of the cold fusion option. Part 1 is largely

understandable in terms of ordinary chemistry and classical physics. It is expected that most readers will be primarily interested in Part 1, since it explains why cold fusion is a near term solution to the growing energy-environment crisis.

Part 2 is THEORY. Cold fusion theory is very interdisciplinary. Fortunately, most of THEORY is related to atom and molecular chemistry, and can be understood in terms of chemical orbitals. The language of orbitals lends itself to pictures, so that the underlying mathematics can be largely avoided.

10 Years of Confusion

This book focuses on F-P Clean Energy cold fusion. The name "cold fusion" was first applied to a room temperature fusion process now called "muon-catalyzed" fusion. Muon-catalyzed fusion produces lots of radiation. The story of the radiationless cold fusion controversy is pretty well known. See Wikipedia topics **Cold Fusion** and **Condensed Matter Nuclear Fusion**. 20 years ago two well known chemists, former master and student, had a crazy vision. They thought, "Could the separation between chemistry and nuclear physics be total?", as enshrined in scientific orthodoxy.* "Maybe the peculiar chemistry of hydrogen in palladium metal could allow a new form of nuclear fusion to occur. Maybe some strange and rejected claims from the past were real." These were two respected chemists. Professor Martin Fleischmann was a Professor at Southampton University and a Member of the Royal Society. His former student, Professor Stanley Pons, was Head of the Chemistry Department at University of Utah. Both Fleischmann and Pons (F-P) were authors of a large number of professional papers. They decided to get together and work in the lab, which is what they did during the late 1980s. And they saw some strange things. They sometimes seem to get back more heat flowing out of electrolysis cells than the energy they were adding in the form of electrical power. Was this extra heat energy the result of chemistry-induced nuclear fusion? If so, it was what they were looking for. They finally decided that their observations were valid. They announced their findings in 1989 and published their results in the *Journal of Electroanalytic Chemistry*. There was euphoria. But cooler heads said, "This can't be true". Thus began two decades of dispute, the "cold fusion" controversy which still continues.

Much has happened since that time. The world has become obsessed with global warming and the price of fuel. Societal conflict has engulfed the world's major oil producing countries. Revolutionary changes have evolved in relations between former world power contenders. Asian countries have become leaders in manufacturing and science. Mapping of genomes and identification of genes have created enormous new understandings in biology and medicine, and have led to recognition of the close kinship between the peoples of the earth. The new words in fashion are "common ancestor".

The world's rejection of cold fusion has not been universal. There have been important exceptions. Reifenschweiler published evidence that tritiated titanium powder decayed more slowly than normal radioactive

* The Fleischmann quotes in this Chapter are remembrances and interpretations of conversations between Fleischmann and the author.

tritium. His observations preceded the F-P announcement. Julian Schwinger, arguably the most profound of U.S. born theoretical physicists, resigned from the American Physical Society when they refused to publish his thoughts on cold fusion. He subsequently published his thoughts in the German journal *Zeitschrift fur Naturforschung*. Independent research teams headed by Mel Miles and Mike McKubre identified the cold fusion nuclear product, helium gas, which was measured in the theoretical expected amounts. Yoshiaki Arata and YueChang Zhang (A-Z), a second highly competent professor and former student team, repeatedly generated fusion heat using deuterided nanopalladium metal. Nonetheless, the conflict between accepted scientific theory and F-P cold fusion continued.

The first 10 years of cold fusion research is well documented in a sequence of international conferences and their published Proceedings. The first seven meetings were held in the US, Italy, Japan, Monaco, and Canada. More recent meetings have added China, France, and Russia to the hosting countries. The conference proceedings were published under a variety of names. The world conferences have come to be referred to as the International Conferences on Cold Fusion (ICCF), with the compilation of papers listed as *Proc. ICCF1* through *Proc. ICCF13*. There are also publications in a variety of refereed Journals, like *Fusion Technolog.,* the *J. Electroanal. Chem.,* and *Japan J. of Appl. Phys.* There has also been an independent series of important conferences on the Black Sea in Russia.

The individual ICCF conferences have been exciting and historic events. The F-P observations of radiationless nuclear fusion challenged accepted physics even more than had the discovery of high temperature superconductivity, which occurred a few years earlier. The first meeting was held in Salt Lake City at a time of great excitement. The ICCF1 Proceedings starts with three papers by McKubre *et al.*, Applebee *et al.*, and Schreiber *et al*, each of which presents strong evidence of radiationless fusion heat, called excess heat. Many of the characteristics of excess heat generation, like the occurrence of multiple-hour "bursts" of heat production and a need for high D/Pd ratio were present in these introductory papers. A special conference event was an encouraging talk by Nobel Laureate Julian Schwinger. Schwinger may be the most important US-born theoretical physicist. A year later, ICCF2 took place a few miles from where physicist Volta lived on the shores of Lake Como in Italy, and not far from where Mussolini met his dismal end. A fabulous location for a meeting. The meeting was a spirited one, challenging the rejection of cold fusion by the main stream physics community. One highlight was a presentation by Liaw showing evidence for fusion heat at 460 ^{o}C, using molten salt electrolysis to plate D^- ions onto palladium metal. M. Miles and B. Bush *et al.* presented the first evidence for helium production correlated with excess heat at the calculated heat per atom ratio. The ICCF3 conference took place in port city Nagoya, where

subway signs are in English as well as Japanese. Participants were hosted by Mr. Minaru Tayoda, best known for his company's motor cars. At the reception fabulous food and drink were served on tables decorated with beautiful ice carvings. In his welcoming talk he said "Cold fusion is not a matter to be studied by a single enterprise or nation. I have confidence that it will become the greatest asset as an eventual energy for mankind, to be shared among the world". Mr. Toyoda passed away before the Proceedings were published. At the time, Mr. Toyoda was supporting research institutes in Japan and France. McKubre *et al.* and Kunimatsu *et al.* reported more quantitative data showing the necessity of high D/Pd ratio in production of excess heat, Storms showed that Pd metal had to have near-formula density for heat production, and F-P show that a major production of excess heat occurs during boil-dry events, in which all electrolyte evaporates during the heat release event. The fusion heat was calculated from the heat of vaporization of the boiled water. Discussions were animated. Proceedings Editor H. Ikegami suggested that "cold fusion" would be better called "fusion in solid state".*

The scene was very different at ICCF4, which was sponsored by the Electric Power Research Institute (EPRI) on beautiful Maui Island in Hawaii, where the temperature and rainfall changes as you drive up the gentle side of a mountain, and the ocean carves a natural bridge at the ocean's edge. Among the memorable papers was one by Gozzi *et al.* At ICCF3 Gozzi had described a beautiful test assembly involving 10 cold fusion electrolysis cells and 60 large volume neutron detectors, all individually metered so that any heat release event in one of the electrolysis cells could be checked for neutrons recorded in neighboring counters At ICCF4 he described an improved torus of electrochemical cells and neutron detectors, and presented the carefully analyzed results. Cells 2, 4, 8, and 10 produced periods of 2 to 19 W of excess heat. After thorough data analysis the conclusion was that "There was no statistical evidence of neutron emission from the cells". This is strong evidence that the cold fusion process generates no detectable neutrons. Pons and Fleischmann reported on their observation that heat continues to be generated after boil dry events for a considerable period of time after electrolysis input power has ceased. They named the phenomenon "Heat after Death". Julian Schwinger gave his final thought-provoking talk, summarizing his thoughts on cold fusion. He suggested a connection between a ^{3}He reaction and ^{5}Li decay, both of which lead to ^{4}He. Further examination of his suggestion indicates the existence of an

* Arata and Zhang posted the name Solid State Plasma Fusion ("Cold Fusion") next to the entrance door to their lab at Osaka University.

excited state of ^{4}He near its ground state. The world's failure to support Schwinger's work will be a sad note in physics history. ICCF5, in Monaco was noteworthy as the first of the ICCF conferences at which A-Z presented their excess heat observations from nanometer Pd. Two of their run curves are included in Supplement 1.* Reifenschweiler reported on his discovery that tritium absorbed in small crystallites of titanium has reduced radioactivity. He had worked on portable neutron generators which used tritium stored in this form since 1961. His data show that imposition of lattice geometry onto tritium blocks the tritium nuclear decay process. McKubre *et al.* showed his important empirical formula that fits his team's observations of heat production in terms of measured experiment parameters: current density, D/Pd ratio, and the passage of deuterium into and out of a Pd metal surface. Again the meeting location was exciting and the presentation environment great, provided one didn't lose too much money at the gaming tables.

Each succeeding conference has similarly had its share of noteworthy research results. The EXPERIMENT Section begins with ICCF6 and a visit to A-Z's laboratory at Osaka University. ICCF6 is also noteworthy for the first report of excess heat by Iwamura *et al.* using deuterium permeation through a Pd plate containing a metal oxide. EXPERIMENT will show that interfaces between an ionic oxide and nanometal will likely to play a key role in development of commercial cold fusion heaters.

* Supplements available on request from tchubb@aol.com.

EXPERIMENT

Trip to Japan

1996. We are on the way to ICCF6. Nephew Scott Chubb and your author have our transparencies ready for our talks. We will both be making presentations. We are headed for a luxury hotel on the Island of Hokaido in northern Japan. The luxury hotel looks out over a crater lake with embedded island, and onward towards the south coast of the island towards the rest of Japan. In Detroit we get on our plane for the big hop to the Tokyo airport, from which we will fly to Sapporo, which is the main city on Hokaido. Hokaido is a wintry island, on which the winter Olympics had recently taken place.

Our plane roared into the air. Within 20 minutes the pilot made an announcement. We would be returning to Detroit. They had shut down one engine. It had caught on fire. We would be flying around in circles, dumping gasoline onto the Michigan countryside before returning to the Detroit airport. An hour later, we descended and landed back in Detroit. Fire engines were lined up on both sides of the runway. We coasted to a stop, and began a long wait. After an hour or so the First Class passengers were permitted to debark the plane, but the rest of us had to wait several hours. Finally, we left the plane, but without our luggage. The Airline had found places for us to stay. The expectation was that the problem would be fixed and we would be off the next day.

Not so. It wasn't until afternoon that we were told that they were bringing our bags to the terminal and we could pick them up. The meeting on Hokaido had already begun. Fortunately, our talks were not scheduled near the start of the program. But the Airline had not found another transoceanic airplane to take us to Japan. By rescheduling we obtained seats on a suitable plane for our flight. Scott and I rescheduled and eventually reached Hokaido two days late.

The luxury hotel was a long way from the Sapporo airport, and all the busses that had been scheduled to carry attendees to the hotel were long since gone. By taking 2 passenger trains and a long and expensive taxi ride we finally arrived at ICCF6.

By the time we reached the hotel, we had missed some of the main talks, but arrived in time to make our theory presentations and to see many of our fusion friends. ICCF6, like all the later cold fusion conferences, was like a reunion of those that were still committed to finding out how cold fusion works. A lot of history had transpired. We were the survivors who somehow managed to continue research in the field. One reward was that we got to see beautiful Lake Toya and stay for a few days in a fabulous hotel. Some of the attendees are shown in Figures 2.2,1, 2.2,2 and 2.2,3, and 2.2,4.

Fig. 2.2,1 Physicist Mel Eisner made pioneering observations of cold fusion heat for Phillips Petroleum Co., shown here with daughters. He and the author were fellow students in physics.

Fig. 2.2,2 Solid state physicist Scott Chubb and nuclear physicist Tom Passell after exchanging views.

Fig. 2.2,3 Professor Yoshiaki Arata and Mrs. Arata enjoy view from hotel. They traveled to northern Hokaido before returning to Osaka.

Fig. 2.2,4 Drs. Arata and Zhang standing next to Arata Hall at Osaka University.

The most important paper in *Proc. ICCF6* is the paper presented by Arata and Zhang. The paper shows 3 excess heat results for 3 electrolysis runs using nanocrystal palladium (Pd-black) contained within a hermetically sealed vessel with a palladium cylinder wall, a so-called DS cathode. The run histories are plots of fusion power vs. time. A copy of the 3 run histories is contained in Supplement 1. (See footnote on page 17.) The upper left history labeled Fig. 8 showed heat production at an average of about 7 W of fusion heat over a period of more that 190 days from 3 grams of Pd black. In the study labeled Fig. 9 the deuterium pressure inside the DS cathode was metered during heat production. The inter-granular gas pressure reached 800 atmosphere. The level of heat power was about the same as in Figure 8. These runs repeated the excess heat production that had been reported in 3 earlier experiments.

The A-Z Pd-black results contrast with disappointing ICCF6 studies reported by McKubre *et al.*, who used solid palladium metal cathodes. The McKubre team tested 13 Pd rod cathodes and observed significant excess heat in only one. He discovered a suddenly deuterium deloading phenomenon in which the cathode suddenly lost deuterium from all its surface. To create conditions for cold fusion in bulk Pd metal one must create D/Pd ratios that correspond to highly non-equilibrium conditions. These conditions correspond to pressures far greater than can be achieved in the lab. It has subsequently been found by Chernov *et al.* (1999) and Tyurin and Chernov (2002), working at Tomsk University in Russia, that interstitial deuterium in metals store excitation energy that can suddenly be released locally and almost instantly spread throughout the metal bulk. When the excitation energy reaches the metal surface, it causes release of the above-equilibrium volumes of deuterium. This energy storage process does not exist in pure metals. It only occurs in hydrides and deuterides. The stored energy causes a local instability to produce rapid loss of gas from the whole surface of the bulk metal, which is what McKubre observed. This problem does not exist within the A-Z nanometal material. The nuclear reactive deuterium created by the A-Z protocol is almost in reversible chemical equilibrium with the intergranular deuterium gas which fills the gaps between their nanopowder grains. The difference between operating a system near reversible chemical equilibrium vs. operating a system that is maintained by highly irreversible chemistry makes the nanometal approach a preferred path toward commercial heat production. A-Z have subsequently achieved the steady heat production that is needed for practical heat production (2002).

7 kW from 3 kg

1996. A-Z report an excess heat run that produced an average fusion heat release of 7 W from 3 grams of Pd nanopowder throughout a period of almost 200 days. Multiply by 1000 and you get 7 kW using 3 kg of metal nanopowder for 200 days. 7 kW is a home heater.

7 Watts is not a high power. But deuterium fuel contains 20 million times as much energy per pound as charcoal. So a cold fusion heater would provide 7 kW of heat for 20,000 times longer than the run time of the A-Z experiment that provided a steady 7 Watts.

It is interesting to compare a 7-kW home heater running on charcoal with 7-kW cold fusion heater fueled by deuterium gas. The heat of combustion of charcoal is

7.26 kcal per gram of charcoal,
which is 7.26×10^3 gram-cal per gram charcoal
which is 3.04×10^4 Watt-sec per gram charcoal,
which is 3.04×10^7 Watt-sec per kg (2.2 lbs) of charcoal,
which is 3.04×10^8 Watt-sec per 10-kg (22 lbs) of charcoal,
which is 3.04×10^5 kW-sec per 10 kg of charcoal.

We have used the mechanical energy equivalent to heat which is:

4.18 Joules (Watt-second) = 1 gram-calorie.

A day is 8.6×10^4 seconds, so the 22-pounds of charcoal would provide 1 kW of heat power for 3.520 days, which means 0.503 days at 7 kW.

The deuterium fueled cold fusion heater provides 20 million times as much energy per kg as charcoal. Multiplying by 20 million, the 3.04×10^7 Watt-sec per kg of charcoal becomes 6.08×10^{14} Watt-sec per kg deuterium.

The fuel energy density is 6.08×10^{14} Watt-sec per kg of D_2 gas,
which is 6.08×10^{11} kW-sec per kg of D_2 gas,
which is 6.08×10^8 kW-sec per gram of D_2 gas,
which means one gram of D_2 gas would run a 7-kW heater run for 8.69×10^7 seconds

A year is 3.16×10^7 seconds, so 1 gram of D_2 gas would run the 7-kW heater for 2.75 years. A cubic foot = 28.3 liters. A cubic foot of D_2 gas at 1 atmosphere of pressure has a mass of 5.05 grams, which would run the heater for 13.9 years. One cubic foot at 10 atmospheres would run the heater for 139 years. People will buy their heaters with a lifetime supply of fuel.

Visiting the Arata-Zhang Lab

Dr. Arata had invited your author to visit his lab at Osaka University. After leaving the conference he flew to Osaka. Arata was delayed a few days in Hokaido, but YueChang Zhang returned to Osaka and became the author's guide. She showed him some local sites, including an amazing moat-protected fortress palace of a historic warlord who united southern Japan. The next day she took him to the A-Z lab on the Osaka University campus.

The A-Z cold fusion program is located in 2 buildings on the Osaka University campus. Arata's office is in Arata Hall, which was named in his honor for earlier work he had done in plasma fusion and welding technology. Among his many awards, he had received the Japan Academy Prize in 1985, and had been elected Member of Japan Academy in 1998, and Fellow of the American Society of Metals (ASM) in 1993. The A-Z lab is in an Osaka University research building down the street.

The A-Z lab filled a big room on the second floor of a University laboratory building. Next to the lab's entrance door was as sign which read:

Solid-State Plasma Fusion
("Cold Fusion")
Japanese Lettering

Entering the lab and on the right there was a styrofoam box containing two electrochemical cells using DS-cathodes inside separate Dewars, as shown in Fig. 2.4,1. The box cover was removed for the photograph. Total energy released in the cells was measured by water flow calorimetry. The water flow through each cell was circulated through a temperature controlled reservoir. The waters was pushed through the cells by separate positive displacement pumps. The inflow and outflow temperatures were metered. The equipment supporting the water flow system was to the left of the styrofoam insulation box. To the right of the box were the power supplies and metering equipment that powered the electrolysis and recorded current, voltage and temperature data, as shown in Figs. 2.4,1 and 2.4,2 At least one of the cells had been kept running during the ICCF6 meeting. Dr. Zhang checked the readings and said the cell was producing about 6 Watts of excess heat.

Further into the room on the right was a gas control manifold system which was used carry out pre-run tests on candidate Pd-black material. Pd-black material was not considered worth testing for fusion heat unless it showed an ability to absorb large amounts of hydrogen at sub-atmospheric pressure, as shown in Fig. 6 of their ICCF6 report. This pre-testing of nano-metal materials has been an important feature of the A-Z

program since 1992. As I remember, there was also a hooded assembly area where DS-cathode cylinders (also called DS-vessels) were filled with Pd-black before being thoroughly evacuated, sealed, and mounted inside the electrolysis cell hardware. The Pt-black contained adsorbed oxygen, which became adsorbed water after the start of their run.

In the center of the room was a welded stainless steel manifold system containing 2 quadrupole mass spectrometers, one programmed to repeatedly scan across the mass-4 peaks, and the other programmed to repeatedly scan across the mass-3 peaks. See Fig, 2.4,3. The manifold system was pumped down using oil free turbo pumps to minimize contaminants. The manifold included a small heating system to heat post-run powder samples using operator-controlled temperature steps. The manifold contained an adjustable valve to control the rate at which desorption gas was removed during sample heating, and valves to isolate the most tightly bound desorbed gas for detailed analysis. The outputs from the mass spectrometers were metered on a multiple pen strip chart recorder. All equipment was top quality, and the designs demonstrated high skill and careful planning.

Quadrupole mass spectrometers are simple, clean devices, but require skilled operation to achieve high mass resolution. A-Z routinely resolved the $^4He^+$ mass peak from the D_2^+ mass peak. Later in their program they were able in one run to resolve the $^3He^+$ peak from the DH^+ peak, but could not do this on a routine basis. The mass-3 peak separation is much smaller than for mass-4.. It was clear that Dr. Zhang knew the equipment in intimate detail. She had the same skilled touch and understanding that characterized her science heroine Dr. Chien Shiung Wu. Dr. Wu was the Shanghai scientist who, a generation earlier, had shown that left hand vs. right hand parity was not always conserved in nuclear reactions. Arata and Zhang functioned as a coordinated team. Dr. Zhang lived reasonably close to the lab and appeared to work a 14- to 16-hour day. Dr. Arata lived in Kobe and commuted by rail to the Osaka lab. Fortunately, there are good rail connections that made his commuting manageable.

Dr. Arata and Zhang worked toward a main goal of convincing themselves whether or not solid state fusion was real. Their strip chart recordings are clear and directly interpretable, and exist as lasting records of their results. Their publications make their results available to all who wish to study them. As a team they were not working in isolation. There was a collegial group of other scientists, mostly emeritus, with whom they discussed results and related science. One of Arata's close friends is Dr. H. Fujita, who gave a historic Honda memorial lecture on metal clusters. His specialty was studies made possible by design and use of a high resolution, high voltage electron microscope. His metal cluster studies have contributed to an understanding of the cold fusion process.

Arata arrived in Osaka and we went to Arata Hall. Fig. 2.4,4 shows a collegial sharing of views in a post-ICCF6 gathering in his office in Arata Hall.

Fig. 2.4,1 Two electrolysis cells using DS-cathodes monitored by water flow calorimeters are inside a styrofoam insulation box. The cells have been operating during ICCF8 conference.

Fig. 2.4,2 The cells are inside Dewars. Cooling water is provided by constant displacement pumps to the left. Current, voltage, and temperature readings are recorded by electronics to the right.

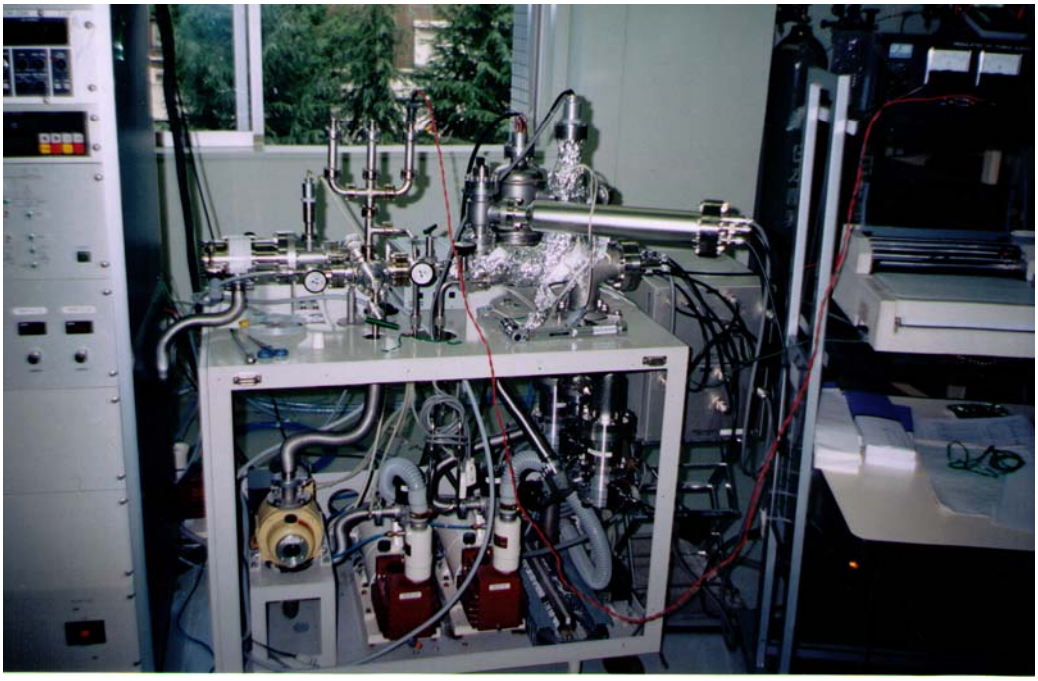

Fig. 2.4,3 Stainless steel vacuum system pumped down by turbine pump contains two quadrupole mass spectrometers that measure desorbed ^{4}He and ^{3}He gas. System contains programmed heater that heats post-run samples of Pd-black..

Fig. 2.4,4 Arata and Zhang discuss results with fellow scientists in Arata Hall

Nanometal Catalysis vs. Nuclear Bang

The discovery that nanometal deuterides can support cold fusion reactions occurred in 1992 with the first test of the A-Z DS-cathode concept. The first excess heat publication was their 1994 paper published in the *Proceedings of the Japan Academy* with title and abstract as follows:

"A New Energy *caused by* 'Spillover-Deuterium'"

Abstract: It was verified that a new kind of energy is caused by "Spillover-Deuterium" generated in a double structure (DS)-cathode with "Pd-black". Using this cathode, the authors confirmed the sustained production of a significantly abnormal amount of energy over a period of several months that could not be ascribed to chemical reaction energy. The chemical reaction energy of 0.1 [mol] Pd-black used is only 4 [kJ], but more than 200 [MJ] of excess heat was continuously produced for over 3000 [hr] at an average rate of 50-100 [kJ/hr] using a DS cathode with the same quantity of Pd-black. Intermittent operation over a period of two years using this structure proved the complete reproducibility of these results."

Spillover hydrogen is a name used in catalyst literature to describe a catalyst like Pd-black, for which the apparent area of the chemical-reaction catalyst is larger than a measured gas-adsorption catalyst area. A non-reactive gas like N_2 is used in the measurement of gas-adsorption area. The A-Z power rate 50-100 kJ/hr is the same as 14-28 Watts. The quantity 0.1-mol of Pd-black has a mass of 10.7 grams, which is somewhat more than the mass of Pd-black used in later experiments. The larger powder mass suggests that the first DS-cathodes may have had more inside volume and thinner walls than later versions.

There have been at least 13 A-Z heat-producing DS-cathode runs. The most important are the 1994 run shown in Supplement 1 page A1,4, the 1996 run discussed in Chapters 2.1-2.3, and the 2002 run on Supplement page A1,14. (Dates are publication dates) The main run plot for the 1994 paper shows the full run history, including an incubation period before cold fusion heat started. For the next roughly 8 runs A-Z did not plot the data accumulated during the incubation periods, where output heat equals input heat. For most readers, showing the data recorded during the incubation period would have had value, since a matching of measured total outflow heat power to input electrical power shows that the measurement of heat (calorimetry) has been properly carried out.

A more recent second goal of the A-Z program has been identification of nuclear fusion products, assumed to be mainly ^{4}He, but maybe sometimes containing minute amounts of ^{3}H and ^{3}He. These measurements were carried out using the quadrupole mass spectrometers described in the preceding Chapter. Their first observation of ^{4}He, and their later first observation of ^{3}He were exciting moments. The data proved to A-Z's satisfaction that the observed

excess heat was due to D + D fusion. A second part of Supplement 1 (See foonote p. 17) includes mass spectrometer observations which document the presence of the two helium gases following desorption from post-run palladium black or its ZrO_2 + nanoPd equivalent. No ^4He was ever seen in the desorption gases from materials that had not yet been processed inside a DS-cathode. A ^3He peak was seen in the one case mentioned. It is much more difficult to see the ^3He peal in the presence of DH molecules than to see the ^4He peak in the presence of D_2, because of the relatively small mass difference between ^3He and DH, as compared to the mass difference between ^4He and D_2. The A-Z papers are a story of the author's growing understanding, rather than a big attempt to convince readers that cold fusion is real. Dr. Arata tries to explain the thinking that has guided his research. Independent of such thinking he assumes that the data speak for themselves.

In 2004 the US Department of Energy (DOE), in response to a request by some Low Energy Nuclear Reaction (LENR) scientists, asked the requesting scientists to prepare a Summary Document which would be examined by a DOE Review Panel made up of non-cold fusion scientists. This summary was published in *Proc. ICCF11* as Hagelstein *et al.* "New Physical Effects in Metal Deuterides". To help prepare the Summary Document your author was requested to provide information about the A-Z program. He examined the papers in his files and made copies of the published A-Z excess heat runs. These run plots are made available in Supplement 1, together with some of A-Z's mass spectra of desorbed gases. There were restrictions on the length of the Summary Document. The run plots were not included in the Summary Document. Only a small part of the discussion on A-Z's nano-Pd research could be included.

The Summary Document delivered to DOE was distributed to the members of the DOE review panel. Roughly a month later members of the DOE Review Panel assembled in Washington to hear a presentation by a few of the proponent authors of the Summary Document. McKubre was the main presenter-author of the experimental evidence for cold fusion. Later, in December 2004 DOE published "Report of the Review of Low Energy Nuclear Reactions", which is DOE's evaluation of the Review Panel's opinions. The key question examined was the validity of the observations of excess heat. The DOE evaluation states,

"The excess power observed in some experiments is reported to be beyond that attributable to ordinary chemical or solid state sources; this excess power is attributed by proponents to nuclear fusion reactions. Evaluations by the reviewers ranged from : 1) evidence for excess power is compelling, to 2) there is no convincing evidence that excess power is produced when integrated over the life of an experiment. The reviewers were split approximately evenly on this topic."

"The hypothesis that excess energy production in electrolysis cells is due to low energy nuclear reactions was tested in some experiments by looking for D + D fusion reaction products, in particular ^4He, normally produced in about 1 in 10^7 in hot D + D fusion reactions. Results reported in the review document purported to show that ^4He was detected in five out of sixteen cases where electrolytic cells were reported to be

producing heat. The detected ^4He was typically very close to, but reportedly above background levels. This evidence was taken as convincing or somewhat convincing by some reviewers; for others the lack of consistency was an indication that the overall hypothesis was not justified."

The Summary Document delivered to DOE can be downloaded by doing a Google Search for "New Physical Effects in Metal Deuterides", or by downloading www.LENR-CANR.org/acrobat, and then selecting hagelsteinnewphysica.pdf from a list of downloadable files. The Review Panel's evaluations can be downloaded by doing a Google Search for "Report of the Review of Low Energy Nuclear Reactions", or by downloading www.science.doe.gov/Sub/Newsroom/News_Releases /DOE-SC/2004/low_energy/CF_Final_120104.pdf .

Although DOE sought a review of cold fusion by peers, this goal was not accomplished, because of reasons described in the THEORY Section. Cold fusion is part of the quantum world, and more particularly, of the many-body quantum world of metals and semiconductors. Nuclear physics and nuclear engineering are not part of the quantum world of metals and semiconductors. Nuclear physics is mostly part of the impact collision world of scattering studies and plasma fusion. Nuclear physicists have been unable to accept that the many-body quantum world can create conditions for nuclear reaction. They have been unable to accept that it can prevent emission of energetic particles and gamma rays, while providing a coupling between nucleus and lattice that dissipates nuclear reaction energy so as to heat the lattice.

It is asking too much of the nuclear community, including the panel members, to pass judgment on experiments that violate their core beliefs (knowledge). They belong to the wrong discipline, and cannot be considered peers. Chemists are more accepting. They live in the quantum world of chemical orbitals, and encounter metal and semiconductor quantum mechanics in their materials science. Mostly they defer to the nuclear community when it comes to nuclear reactions. There are chemists who are experts on the physical changes that are created by catalysis. Their field of interest can be considered part of the quantum physics of orbitals. However, most would consider the geometric changes required to enable hydrogen ions to behave like metal electrons to be outside their specialty. Cold fusion is made possible by geometric changes of embedded D-ions. Change from near-point geometry to 2-dimensional periodic symmetry can be catalyzed by nanometals in interface contact with ionic crystals. Change for near-point geometry to 3–dimensoinal periodic symmetry can be catalyzed by nanometals loaded beyond stoichiometric lattice symmetry. These catalyzed changes, and maybe others, ccause embedded deuterons to change into a quasiparticle geometry which enables cold fusion. This intellectual mismatch between the nuclear physics discipline and the many-body physics discipline is what has led to this chapter being called "Nanometal Catalysis vs. Nuclear Bang".

Metal Oxide + Nanometal Composites

Metal oxide + nanometal composites are a new class of materials that have been demonstrated to be catalytically active in supporting cold fusion using deuterium fuel. A metal oxide + nanometal is a combination of small oxide crystals in interface contact with a nanometal form of metal, such that the contacting layer of metal adjusts to the lattice structure of the oxide. We call such material an "oxide-nanometal composite" (ONC). At present only one form of oxide-nanometal composite has been tested as a catalyst for cold fusion heat production. In the test a zirconium-palladium ONC generated a continuous 10 Watts of excess heat when used in a standard A-Z DS-cathode electrolysis cell. The test run was A-Z's first production of excess heat using a nanometal other than Pd-black. In a second study a "DS-cathode vessel" was filled with zirconium-palladium ONC and exposed to D_2 gas at elevated temperature and pressure. No electrolysis was involved. Continuous heat at an estimated 0.5 Watt was observed. The tested zirconium-metal ONC was a ZrO_2,nanometal Pd composite with 0.33 Pd/Zr atom ratio. In an unrelated program, gas permeation studies were carried out by Iwamura *et al.* in which a permeation flow of deuterium was forced through a Pd plate containing diffusion-impeding structures. These internal structures were produced by sputtering layers of calcium oxide (CaO) and Pd onto a Pd substrate. The sputtered layers are thought to be somewhat equivalent to a CaO-palladium ONC. Electrolysis driven permeation flow produced a reported >1.0 Watt of excess heat in five tests. The Iwamura "ONC catalyst" composition could be described as a CaO-nanoPd layer. It would seem that stable ionic crystals other than ionic oxides could be used to produce catalysts of the same general type.

As discussed later under THEORY, a metal oxide + nanometal composite is thought to be able to create a stable lattice interface between a very chemically stable ionic crystal (very negative Gibbs Free Energy) and a more morphable, electrically conductive metal material. A nanocrstalline metal is especially morphable and can adjust itself to fit commensurably onto the ionic crystal surface. An exact fit interface is called an epitaxy interface. An epitaxy interface layer provides a periodic environment of the type needed to make deuterium ions behave like the conduction electrons of a metal.

Information on metal oxide nanometal composites was first published in 2002 by Yamaura *et al.* from the Institute of Materials Science at Tohoku University in Sendai, Japan. Their paper provides details of the protocol used in producing the zirconium-palladium ONC. A molten alloy of Zr and Pd is rapidly frozen by a spin-cooling ribbon-forming process. In the next steps the thin ribbon of amorphous alloy is oxidized at a relatively low temperature and pulverized into a powder before use. The authors characterized the powder's internal structure using x-ray and electron

scattering. They used electron microscope imagery to "photograph" the internal distribution of nanometal in the ZrO_2, and its embedded shapes. The research team also carried out laboratory tests showing the material's remarkable ability to absorb hydrogen gas. Similar hydrogen absorption studies were carried out by A-Z prior to examining the composite's excess heat production properties at Osaka University. The high absorption capacity of the powder was confirmed.

At Osaka University a sample of ZrO_2 + nanoPd composite was tested for its ability to generate nuclear fusion heat. A-Z used the powdered composite to replace commercial Pd-black in their standard electrolysis test cell. It was their first use of a nanometal in a form other than commercial Pd-black. Using their standard electrolysis procedure to pressurize the sample with deuterium, they produced a stable output of cold fusion heat at a 10-Watt level for a period of 3 weeks. The amount of Pd in the sample was a few grams. Their work was published in 2002, the same year as the Yamaura *et al.* study. Their daily output of heat was remarkably steady. It did not seem to show the fluctuations in power that were seen in their Pd-black runs. The data may show a component of fluctuation that does not alter mean energy production, though the relatively rapid power fluctuations may be a metering problem or an illusion. In any case, the data indicate an improved stability in heat production. The data run is the same 2002 test run discussed in the preceding chapter. [See Supplement 1, Figure 5 on page A1-14]

The A-Z 2002 test showed that ZrO_2 + nanoPd composite provides an effective cure for two problems that have hampered other researchers in their use of nanoPd catalyst. Good repeatability has not been much of a problem for A-Z . The McKubre team, using a DS-cathode assembled, filled with Pd-black, evacuated, and sealed by A-Z, had the same excess heat results as A-Z had when they operated a control experiment prepared at the same time. Both experiments were run with the same protocol. This experiment duplication showed that the technology was transportable between laboratories. But other experimenters have handled their nanopowder differently from A-Z, and have had difficulty producing comparable fusion heat. The problem seems to be that new investigators have followed the normal instructions used by chemists and engineers in preparing catalyst for promoting chemical reactions. They have chemically reduced their catalyst before use. In contrast, A-Z vacuum clean their Pd-black before sealing it off under vacuum, but generally do not chemically reduce it. Commercial Pd-black has an oxide coating that subsequently gets chemically reduced when deuterium diffuses through the wall of the DS-cathode, leaving A-Z's Pd-black nancrystals coated with adsorbed D_2O. Evidence for this is that substantial adsorbed water was found in a mass-spectrometer desorption analysis of post-run powder in a study by Oliver at the Pacific Northwest Lab. The oxygen in the water had to come from surface oxide on the

sealed-off Pd-black, since there was no other oxygen available. The presence of water showed that the A-Z Pd-black had not been chemically reduced before being hermetically isolated. The adsorbed water present in Pd-black prepared using the A-Z protocol probably plays the same role as the ZrO_2 in the work using ZrO_2 + nanoPd composites.

An example of inexperienced cold fusion experimenters treating Pd–black prepared in accord with instructions for preparing chemical catalysts prior to use is found in a study by G. Schmidt and T. Chubb. Dr. Schmidt designed and built a system designed to study heat production from Pd-black at pressures as high as 30,000 psi (2000 atmospheres) and temperatures up to 350 ºC. The search for fusion heat was unsuccessful, but the deleterious effect of rigorous chemical reduction of Pd-black was discovered. Before-run and after-run powder samples were sent to Asraf Imam at the Naval Research Lab (NRL) for x-ray diffraction study. Imam's Bragg diffraction spectra are shown below in Fig. 2.6,1. The before-run spectrum shows unusually broad line widths, which means that the effective grain size was a few nanometers, despite the manufacturer's characterization of the material size as 0.3 micron (300 nanometers). The after-run spectrum shows that the x-ray diffraction line widths had narrowed, which means that grain size had grown and that the nanometer properties had been lost. The powder was not essentially different from bulk Pd metal. This also means that the nanocrystal metal form is a higher energy configuration than bulk metal. As chemists and physicists know, such material seeks to go to lower energy. When 2 nanometal crystals make mutual contact, they transition to a lower energy state by merging together, losing such properties as being able to store hydrogen in anomalously high amounts, and losing the ability to promote cold fusion reactions. This crystal merging process also takes place when a clean nanocrystal Pd makes contact with ordinary Pd metal. The clean nanocrystals grow into the metal surface. and become part of the Pd bulk metal. This phenomenon does not occur when the nanoPd makes contact with stainless steel. The measurements and crystal merging observations are discussed in Supplement 2.

One concludes that the new composites have two important properties. First, they prevent the nanometal crystals from making with each other by surrounding them with inert metal oxide crystal. Second, they provide a highly periodic interface between the nanometal and ionic crystal, an interface that catalyzes the cold fusion reaction. Their fabrication protocol is clearly defined, and matches a protocol suggested by Imam and Hubler at NRL. Prior to their reading the Yamaura *et al.* paper, Imam and Hubler explained how such material could be made.

The role of ionic solid + nanometal interfaces will be discussed further in the THEORY section. However, it is worth noting that two 2007 material science papers relevant to the interface layer have been published in *Physical Review Letters*. A paper by K.J. Franke *et al.* is titled

"Achieving Epitaxy between Incommensurate Materials by Quasicrystalline Interlayers". The paper discusses the *locking into registry* that can occurs when different materials make epitaxy contact. This locking into registry can lower system energy if perfect crystalline order by somewhat incommensurate partners does not extend to the actual interface contact. The other paper, by G. Barcaro *et al.* is titled "Epitaxy, Truncations, and Overhangs in Palladium Nanoclusters Adsorbed on MgO (001)". This paper is a solid state physics modeling paper that uses a standard procedure called density functional calculation. It calculates the minimal energy configuration for a number of perfect and imperfect metal clusters in epitaxial contact with a crystal phase of the metal oxide MgO. The metal clusters studied are smaller than 30 atoms, so they are smaller than nominal nanoPd crystals. For many of the imperfect metal clusters, energy is minimized when *locking in registry* occurs. Disorder in the deposited metal and strong ordering in the metal oxide are properties that make the new composites able to promote cold fusion.

Dr. Yamaura expresses his views as to where the anomalously large amount of hydrogen, (or deuterium), absorbed into his oxide-nanometal composite goes. His view is that the extra hydrogen is associated with the nanometal surfaces, and not with the nanometal interior. His views should be taken seriously. His view fits a picture in which most of A-Z's anomalous deuterium atoms occupy vacancy sites and interstitial locations in the somewhat imperfect region of metal adjacent to the actual interface. The metal monolayer that binds to the ionic crystal can be epitaxial (exact fit). As discussed in the THEORY section, the epitaxial interface can be shared with a geometrically ordered, quasiparticle form of deuterium, which is nuclearly reactive.

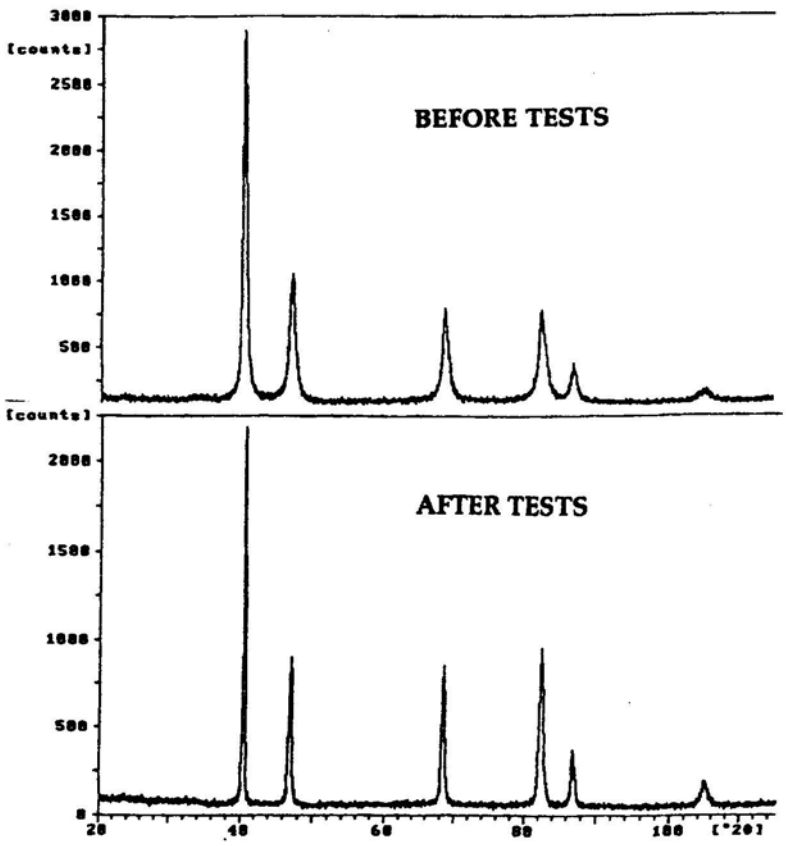

Fig 2.6,1 Bragg reflection spectrum of pre-run and post-run Pd-black used in high pressure studies by G. Schmidt and T. Chubb at the University of New Mexico. Bragg spectra were recorded by Dr. Imam of the US Naval Research Laboratory (NRL). The Pd-black was thoroughly pumped down, chemically reduced, and pumped down again before being pressurized with D_2 gas and tested for fusion heat at elevated temperature. No heat at 1-watt level was observed. Broad spectral lines of purchased Pd-black indicate nanostructure. Post-run spectral show the same narrow lines that characterize bulk Pd, which means the nanocrystals had grown together to form bigger crystals. Study shows importance of **not** including chemical reduction in protocol for preparing Pd-black for use in DS-cathode studies.

Slow Burn Simplicity

There is a parallel between how one burns carbonaceous fuel and how cold fusion "burns" deuterium. In burning carbonaceous fuels there is a contrast between the slow combustion of charcoal and the flaming fire that consumes wood logs. When one burns charcoal in the backyard grill, one first prepares the charcoal by soaking it with igniter fluid and igniting the fluid vapors so as to get local portions of the charcoal red hot, or one heats the charcoal with a propane flame until portions of the charcoal are red hot. Once red hot, the charcoal is quietly consumed, producing enough heat by its combustion (exothermic reaction with air) to keep itself at reaction temperature. In the log fire, one ignites newspaper under some kindling which has been strategically placed within or under the log pile. The burning newspaper raises the local temperature of the kindling wood to a point where gaseous flammable vapors are distilled from the kindling wood. These gaseous hydrocarbon-rich vapors burn, heating some of the logs, distilling off more gases from the logs. The burning of the decomposition gases when combined with desorption of new decomposition gases is a self-stimulating process. We call it fire. The fire continues until the wood runs out of enough decomposable material to maintain the flaming fire. Residual charcoal is left. Combustion ends when the slow burning residual charcoal is insufficient to keep the remaining charcoal at combustion temperature.

At the ICCF13 conference in Russia, a paper by the author was presented that calculated the heat produced by a slow burn process in a previously published cold fusion experiment. The earlier experiment was a 2004 A-Z gas loading study using zirconium-palladium ONC.

The Caucuses mountains extend from the Caspian Sea to the Black Sea and along the northern coast of the Black Sea almost to the Crimea peninsula. A railroad hugs this north coast, passing through tunnels on its to way to the present, somewhat disputed boundary between Russia and Georgia. Close to this boundary is the airport of the bustling Russian city of Sochi. On the western side of Sochi is the resort and conference facility of Dagomys, which has been the host site of several Former Soviet Union (FSU) conferences on cold fusion and related subjects. Last year (2007) Dagomys was the host site for the ICCF13 conference on Low Energy Nuclear Physics (LENR). Your author has attended two conferences at Dagomys, and one at a Moscow State University conference site a few miles west. This year he prepared a presentation for ICCF13 titled "Cold Fusion Heaters". He was unable to attend, but was honored to have his talk presented by Michael McKubre of SRI. He wrote a paper for the conference which will be published in the *Proceedings of ICCF13*. Figure 2.7,1 is taken from this Proceedings.

In 2004, Arata and Zhang were able to work together for less than 2 months. During this time they developed plans for a gas loading study using ZrO2 + nanoPd composite material, built the test equipment, and carried out the first laboratory tests on this material, together with comparison studies using Pd-black. This period included 17 days of test time. Despite this severe time limitation they obtained pioneering data that was presented at ICCF12. They showed for the first time that cold fusion reactions could be made to occur in palladium material through the use of gas loading of a nanometal at elevated temperature. Their ICCF12 Proceedings paper provided information that was not presented in conference talk. This added information enables one to estimate the amount of cold fusion power that was liberated during the study. This analysis is part of the author's *Proceeding of ICCF13* paper, and is the basis of this discussion on slow-burn fusion. For more detail the reader is directed to Supplement 3.

We have already discussed the 2002 A-Z production of cold fusion heat using electrolysis onto a DS-cathode. Steady heat was produced at a 10-Watt level for 3 weeks. Basically the same geometry was used in the A-Z 2004 lab studies. Instead of calling the inner cylinder with Pd wall a DS-cathode, A-Z called it an "inner vessel". The inner vessel was surrounded by an "outer vessel" made of stainless steel. Both inner and outer vessels were vacuum tight, and were independently evacuated before lab tests were started. The outer vessel, which surrounded the inner vessel, was connected to pressure tight tubing through which deuterium gas could be fed by opening a needle valve during the test. The outer vessel was surrounded by a cylindrical electrical heater element, which in turn was within a cylinder of insulation. Both outer and inner vessels were instrumented to provide continuous recording of temperature and pressure.

The A-Z 2004 study operated the new test facility so as to compare behavior under 4 conditions. In all 4 runs the previously evacuated assembly was first heated to a steady 140 ^{o}C using the cylindrical heater. The heater was first operated at a relatively high power to quickly heat the assembly, and then the heater power was gradually reduced to a low maintenance power level as the 140 ^{o}C temperature was approached. After vessel temperatures were stabilized, deuterium gas was flowed into the outer vessel at a controlled rate, with flow stopped when the interior pressure reached about 100 bar (atmospheres). In one run H_2 was used instead of D_2. The results were as follows:

In Run 1 the assembly was studied with the inner vessel containing no test powder and using D_2 gas. The inner vessel, being further from the cylindrical heater, approached steady state with the inner vessel temperature being and remaining lower than the outer cylinder temperature.

In Run 2 the assembly was studied with the inner vessel filled with previously evacuated Pd-black test powder and using H_2 gas inflow. Again, the inner vessel, being further from the cylindrical heater, approached steady state with the inner vessel temperature being and remaining lower than the outer cylinder temperature. There was no indication of fusion energy release.

In Run 3 the inner vessel was filled with evacuated Pd-black and the input gas flow was D_2 gas. In the third run there was the same transient rise in temperature during gas inflow, but as steady state was approached, the inner vessel temperature became and remained higher than the outer vessel temperature. This reverse in steady state temperature difference indicated that cold fusion heat was being generated within the inner vessel.

In Run 4 the inner vessel was filled with evacuated ZrO_2 + nanoPd composite and the input gas flow was D_2 gas. In the third run the inner vessel temperature approached steady state with the inner vessel temperature being and remaining higher than the outer vessel temperature. But his time the steady state temperature difference was about 6 times that shown in Run 3. Also the temperature of the whole assembly rose from about its initial steady value of 140 ^oC to a steady value about 183 ^oC. The increase in temperature difference suggests that the ZrO2-nanoPd composite was about 6 times more effective in catalyzing cold fusion than the Pd-black.

The author's ICCF13 paper used the observed rise in inner and outer vessel temperatures to estimate the amount of cold fusion power being liberated in Run 4. Figure 2.7,1 shows the basis of the calculation. The estimated heat output was 0.6 Watt, which is quite a bit less than the 10 Watts observed during the A-Z 2000 electrolysis run. This lower fusion rate indicates an important difference between "slow burn" and a "self-stimulated burn" behaviors. On the other hand, the 0.6 Watts suggests that a small increase in fusion heat relative to the electric energy that powered the heater could result in the continuous production of cold fusion heat with the electrical heater turned off. The reactor assembly would subsequently be kept hot solely by cold fusion generated heat. Demonstrations of continuous heat with no input power would make it difficult for skeptics to deny the reality of the cold fusion process.

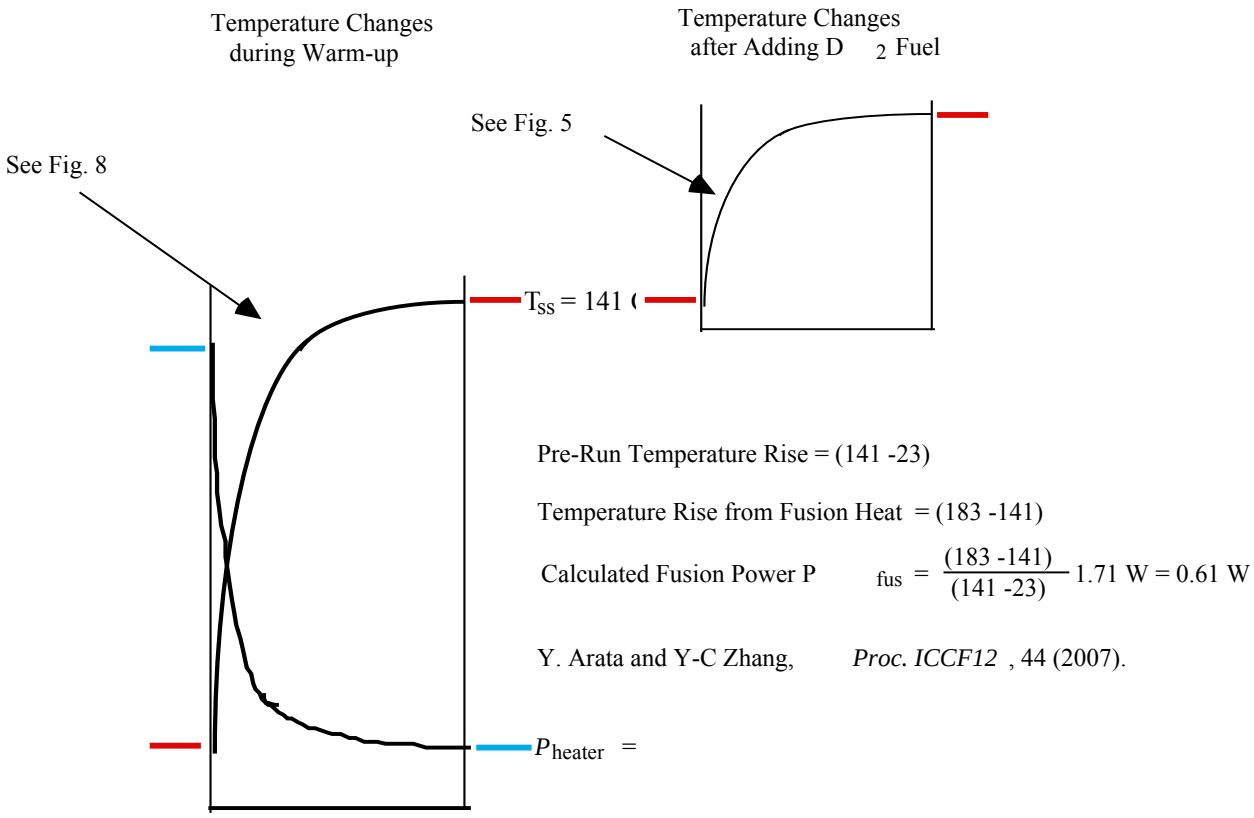

Figure 2.7,1. Temperature and heater power history used in calculating cold fusion power produced by gas loading of ZrO_2, nanoPd composite. Data for the lower left plot were taken from Figure 8 of the A-Z *Proc. ICCF12* paper. Data for the upper right plot were taken from Figure 5. The calculated fusion power assumes that fusion power and heater power affect the temperature of the outer ss vessel equally. The heater power at temperature stabilization was 1.7 W. Fusion power that resulted from the inflow of 100-bar D_2 raised the temperature of the apparatus a further 42 ^oC, which means that 0.6 W was added to the constant heater power of 1.7 W.

Self-Stimulating Fire

The work carried out by A-Z during the 2002 to 2006 period has set the stage for development of cold fusion heaters. It may be that A-Z's 2004 use of direct gas absorption into metal oxide nanometal composites will prove the best route to commercialization. This process would belong to the slow burn category. However, the estimated heat output thus far achieved by gas loading is relatively low. It may be that a better route to early practicality would be to make use of the full range of technical understanding that has been accumulated by the global community over the last 18 years. Key learnings are listed below. They suggest a competing approach which involves developing closed loop heaters that combine deuterium fluxing, high deuterium chemical potential, and oxide-nanometal interfaces.

One of the important discoveries that came out of past excess heat experiments using bulk Pd cathodes was a formulation by McKubre *et al.* of an empirical law relating fusion heat generation to operating parameters which were measured during F-P type electrolysis. This formula was used to model the electrochemical experiments carried out by the SRI team. It involves the product of 3 factors: deuterium concentration above a threshold value, current density above a threshold value, and the in and out deuterium flow through the full surface of the cathode during operation of the electrolysis cell. Net inflow and outflow flux were found to be equally effective. The McKubre formula is

$$P = M\,(x-x_o)\,(I-I_o)^2\,\left|dx/dt\right| \text{ Watts}$$

where P is generated heat power in Watts, M is a data-fitting constant, x is deuterium concentration in the metal electrolysis cathode defined by D/Pd ratio, x_o is a threshold ratio which must be exceeded for production of measurable fusion heat, which is typically about 0.85, I is palladium metal cathode current density in Amperes/cm^2, I_o is the threshold cathode current density at which measurable heat first appears, and $\left|dx/dt\right|$ is a deuterium fluxing term which measures the net flow of deuterium into or out of the palladium metal cathode. The remarkable thing about this equation is that it fits the data and doesn't care whether the fluxing term is positive or negative. In either case there is a flow of deuterons inside the Pd metal. When fluxing is present, deuterons are moving through the metal. As we shall see below, there is other evidence that deuterium fluxing is an important ingredient affecting fusion rate, and there is some theoretical justification for why fluxing should be important.

The McKubre equation was fit to the data shown in Figure 7 of the Summary Document which was written for the DOE Review. The fit was discussed on pages 5 and 6 of the Summary Document. The equation

provided a good fit to two multi-day "bursts" of cold fusion heat which occurred during the much longer M-4 SRI experiment. The M-4 study was the one that produced convincing evidence for ^{4}He production at 23.8 MeV per helium atom inside a hermetically sealed cold fusion apparatus

A second important discovery was made by Iwamura *et al.*, who explored the production of heat by electrolysis-driven deuterium permeation flow through a palladium reactor plate. The reactor plate contained 5 pairs of sputtered-implantedCaO and Pd layers. Their excess heat observations were reported at ICCF7. In a 1999 paper the Iwamura team listed 5 runs, in which fusion heat at times exceeded 1 Watt. No heat was observed with permeation plates not containing internal CaO-Pd sputtered layers. Because CaO is an ionic crystal with a highly negative free energy like that of ZrO_2 (both are very chemically stable), the oxide layers are expected to be in the form of small crystals, while the sputtered Pd is likely to have been initially disordered. There would seem to be a similarity between the Iwamura interfaces and those present in the Yamaura-fabricated ZrO_2-nanoPd composites. In the Iwamura studies the deuterium permeation flow was driven by heavy water electrolysis in which the front surface of permeation plate served as the electrolysis cell cathode. Gas was continuously pumped away from the back surface of Iwamura's permeation plate, thereby maintaining a pressure drop during operation. It seems highly likely that the D/Pd ratios in Iwamura's plates were significantly below the threshold value x_o appearing in the McKubre empirical equation. Permeation implies a high rate of deuterium fluxing (flow), which may have compensated for Iwamura's relatively low D/Pd ratio. These observations of excess heat support the view that deuterium fluxing is important factor in heat generation.

F-P type electrolysis uses overvoltage electrolysis of heavy water to create a non-equilibrium deuterium chemical potential inside a Pd-metal cathode. However, a high deuterium chemical potential can be achieved without incurring the energy cost of dissociating heavy water if one uses a fuel cell type of solid electrolyte cell. The feedstock for fuel cells is deuterium gas, which replaces the heavy water used by F-P. A high deuterium chemical potential in Pd metal was demonstrated by Biberian in a fuel cell study described in *Proc. ICCF11*. It is easy to envision the use of solid electrolyte fuel cells on both input and output surfaces of a permeation type plate reactor. The operator could change the balance between deuterium fluxing rate and front surface deuterium chemical potential, while achieving high values of both. Closed-loop operation of a fuel cell-driven, closed-loop system would greatly reduce the parasitic power loss that occurs with heavy water electrolysis cell operation. The author thinks that this approach is a candidate for practical cold fusion heat production.

A-Z made an important step towards commercial cold fusion room heaters when they published the hydrogen absorption characteristics of ZrO_2-nanoNi and ZrO_2-nanoNi,Pd composites, starting from Zr,Ni and Zr,Ni,Pd alloys. These composite materials presumably had been manufactured at the Institute for Materials Science at Tohoku University. A-Z reported on their H_2 absorption properties in *Proceedings of ICCF10* in 2003. The ZrO_2 + nanoNi composite was as good an H_2 absorber as ZrO_2 + nanoPd, whereas the ZrO_2 + nanoNi,Pd alloy composite, which contained a 0.18 Pd/Ni atom ratio, absorbed twice as much gas. To my knowledge none of these composites have been tested in a DS-cathode electrolysis cell for generation of fusion heat. If the heat production from deuterided ZrO_2 + nanoNi composite is as good as that from ZrO_2 + nanoPd composite, the cost problem associated with use of palladium goes away. Since the oxide-nanometal composites have not shown an aging problem, there would then seem to be no serious barrier to cold fusion heater development.

Pressurized Gas Heaters

The quickest road to cold fusion room heaters may be to build on the Arata-Zhang gas loading work using metal oxide nanometal composites described in their ICCF12 paper at elevated temperature, as discussed in the Chapter on Slow Burn Simplicity. Such heaters would require a start-up heater to raise a portion of the heater assembly to operating temperature. It's just like using lighter fluid to start burning charcoal. The A-Z tests with ZrO_2-nanoPd composites indicate that with a larger volume apparatus heated to 140 ^oC the operator could turn off the auxiliary heater and the apparatus would continue to generate heat. The decreased surface/volume ratio that goes with a larger assembly reduces the heat loss/heat generation fraction. Therefore it seems probable that with a large assembly of the tested type, continuous heat production with no power input can be achieved. Once achieved, the heater would stay hot using only cold fusion reaction heat. The escaping cold fusion heat would continue to heat the room without consumption of electrical power. Convective heat flow like that present with hot water radiators would then heat the room. The heater could be turned off by using cold water to cool the inside of the heater below reaction temperature. The Turn-off cooling would be like adding cold water to a boiling-hot kettle.

Unfortunately, palladium is a costly noble metal. The cost of the Pd used in the assembly would be too high to be used in a commercial device. The good news is that it may well be possible to use nanoNi to the replace nanoPd. It has not yet been shown that deuterium gas + ZrO_2-nanoNi nanocomposite will produce cold fusion heat. However, as previously mentioned, the A-Z nanometal fusion program from its start in 1994 has used the absorption properties of test nanometal at low hydrogen pressure as a criterion for recognizing good fusion-producing material. If a batch of Pd powder has the hydrogen absorbing characteristics of Pd metal filings, then the material is not useful. Pd metal filings have the same absorption properties as bulk Pd metal. At 1 atmosphere of pressure, the equilibrium value of H/Pd is about 0.7 at room temperature. The ratio does not increase much in value with pressure. With good nanometal powder hydrogen absorption creates a H/Pd ratio significantly greater than 1. With ZrO_2-nanoPd at 100 atmosphere, the H/Pd ratio is almost 3. The encouraging information is that the hydrogen absorption properties of ZrO_2-nanoNi composites have been measured, and they are as good as those of ZrO_2-nanoPd. (Replacing about 15% of the Ni atoms with Pd creates a composite with absorption properties that are considerably higher than those of either ZrO_2-nanoPd composite or ZrO_2-nanoNi composite.) These data were reported by A-Z at the ICCF10 Conference in 2003, and published as Figure 5 in the *Proceedings ICCF10* (2006), p.144.

From an engineering perspective, the metal oxide-nanometal composites seem to catalyze the production of nuclearly reactive deuterium in accord with a near-equilibrium reversible chemistry process. A near chemical equilibrium process means that the chemical portion of the overall reaction is not bothered by instability-stimulated loss of deuterium. This is not the case when bulk Pd is used. The freedom from chemical instability minimizes development problems. In the development plan outlined later, testing of ZrO_2-nanoNi composite for heat generation is given highest priority.

Closed-Loop Circulation Solid Fusion Heater

We now describe a self-stimulated developmental cold fusion heater that makes use of a closed-loop deuterium circulation system driven by a pair of solid-electrolyte fuel-cell based electrolysis cells. The inflow cell drives circulation, and the outflow cell either drives or impedes deuterium circulation under operator control. The concept heater uses an assembly containing a metal reactor plate interfaced with either one or two solid-electrolyte layers. The assembly is mounted inside a gas containment enclosure pierced with hermetically sealed electrical feed-through fittings. The enclosure is filled with deuterium gas D_2. The containment enclosure contains a metal reactor plate capable of absorbing deuterium. During heat generation operation it is subject to the diffusion flow of deuterium in response to an internal deuterium density gradient. The reactor plate is fabricated so as to contain internal layers of metal oxide in contact with sputtered Pd and oriented parallel to the plate's surface, and of construction such that the layers impede, but do not prevent deuterium diffusion flow within the reactor plate. The two exterior faces of the reactor plate are each coated with a solid state electrolyte. Each solid electrolyte layer is overcoated with a metal foil which is capable of dissolving deuterium. Metal foil, solid electrolyte, and contacting surface of the reactor plate form an electrolysis cell. There are two cells. There is an inflow electrolysis cell through which deuterium flows before entering the reactor plate, and an outflow electrolysis cell through which deuterium flows after leaving the reactor plate. The rims of the reactor plate, the two electrolyte layers, and the two metal foils are coated with an electrical insulator, which constitutes an annular rim insulator. The annular rim insulator is penetrated at the metal plate's rim with an electrical conducting wire, which passes through a feed-through fitting that penetrates the containment vessel wall so as to permit connection to an external source of voltage and current outside the containment enclosure. Separate electrical wires make contact with the two metal foils, and pass through the wall of the containment enclosure through separate metal feed-through fittings. All wire passages through the walls of the containment enclosure are vacuum-tight sealed. A hermetic gas input tube penetrates the containment enclosure wall. The input tube is used to introduce deuterium gas into the cell during a preparation period during which a desired initial quantity of deuterium dissolves into the various metal components and a desired initial quantity of deuterium gas fills the containment enclosure. The gas input tube can be sealed off before the process operation. The concept cell is shown in Figure 2.10,1.

During the process operation, deuterium gas is absorbed into the positive electrode of the inflow electrolysis cell. The absorbed deuterium converts into ion form, then passes through the front electrolysis cell and enters the front layer of the reactor plate, flows through the reactor plate where a portion is subject to conversion to quasiparticle form at internal CaO-palladium interfaces, then mostly passes out the back surface of the reactor

plate into the outflow electrolysis cell with its covering metal foil, and re-enters the gas volume of the containment enclosure as deuterium gas. It thereby completes a closed-loop circulation path. This deuterium circulation is driven by serial voltage potentials applied across the inflow and outflow electrolysis cells. The interface flow process converts some of the diffusing deuterium into a nuclearly active configuration. As described in THEORY, paired deuteron quasiparticles undergo exothermic cold fusion reactions. Released nuclear energy converts into heat within the reactor plate. Subsequent heat transfer flow delivers the generated heat to a user application.

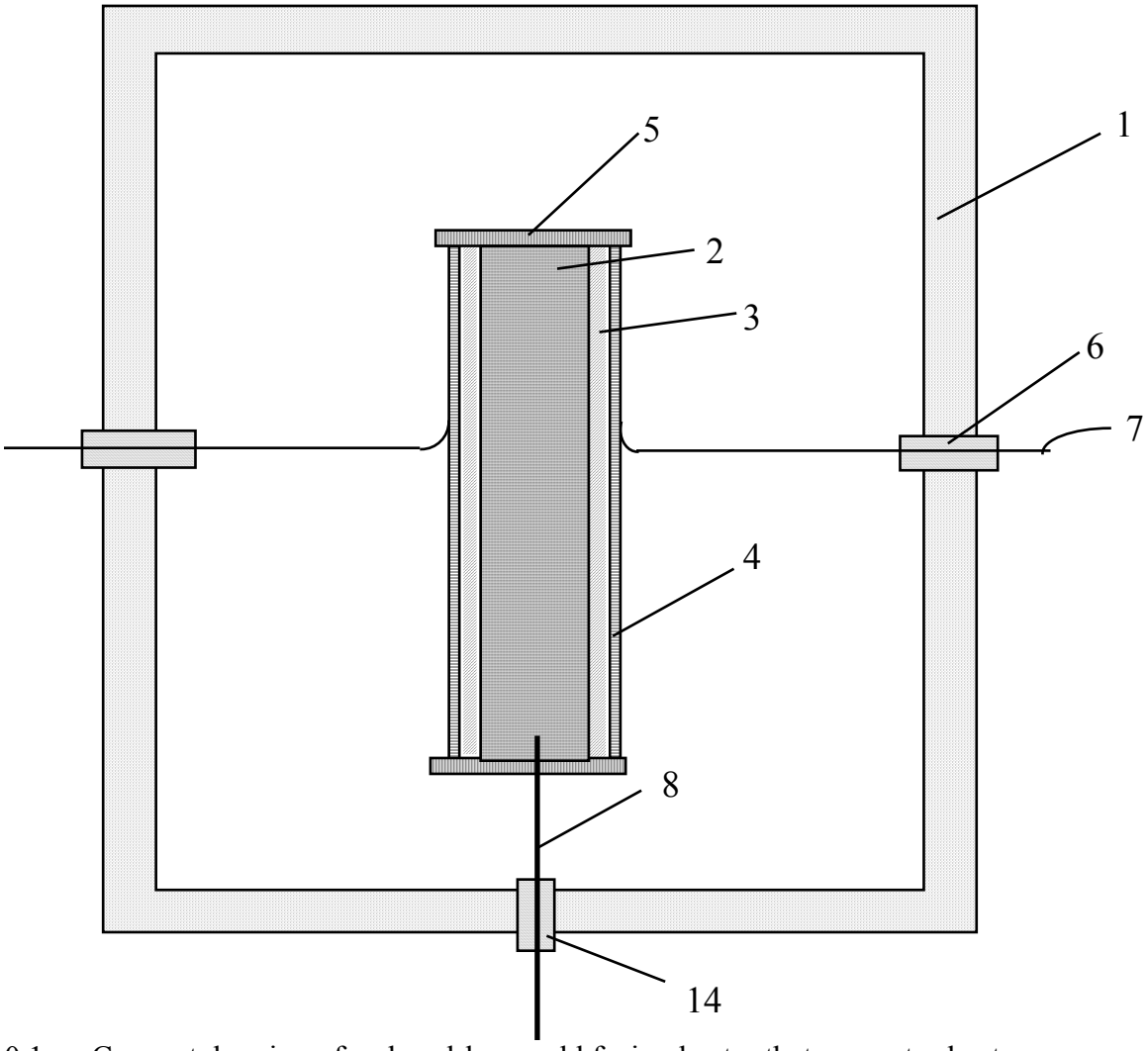

Fig. 2.10,1. Concept drawing of a closed-loop cold fusion heater that generates heat from closed-loop circulating deuterium gas. The closed-loop heater uses a permeation process employed by Iwamura *et al.* in studies reported in 1999. It also operates at higher deuterium chemical potential (effective pressure), and can make use of ionic solid-nanometal composites pioneered by Arata and Zhang. Item 1 is a pressure tight enclosure, Item 2 is a cold fusion reactor plate containing inclusions that provided ionic oxide-nanometal interfaces, Left and right items 3 are solid electrolyte layers, and Left and right items 4 are metal foils that cover and make contact with the solid electrolyte layers. Item 5 designates a gas tight, insulating surface. The inflow metal foil converts D_2 gas into D^+ ions, and the outflow metal foil converts D^+ ion into D_2 gas, completing a closed-loop circulation flow. Cold fusion occurs in the ionic solid-nanometal interfaces where deuterium is present in a quasiparticle geometry.

Cold Fusion Development Plan

An active research and development plan is needed to make commercial cold fusion heaters a reality. It is important to organize the core program around skills that relate to the A-Z research successes. The overall program should be a broad one, and address both deuterium flow processes and elevated temperature gas loading, plus their combined use. The development of composite materials and their characterization should share top priority along with testing for cold fusion heat. Testing of ZrO_2 + nanoNi composite for excess heat is especially important. It is about 500 times less expensive than Pd on a per atom basis. The program should be one that provides research and development funding over the long term. The inclusion of a basic research component is almost essential. The potential for application is large.

The structure and means for an effective development plan are to be determined (TBD).

Today's world wide research effort in the cold fusion and related cold fusion areas is in trouble. The present generation of dedicated scientists that have kept the cold fusion art advancing are growing old and disappearing as active hands-on workers. There are almost no young scientists doing active research, or studying the pertinent science. The history of successful experiments is almost unknown to both teachers and students, and the research publications describing these studies are not archived in most libraries. There is no consensus on theory. Almost the entire "cold fusion" community is thinking in terms of high density configurations or energized deuteron concepts. These classical concepts can only explain forms of fusion which produce energetic particle emission. Cold fusion is not that kind of fusion. Geometric quantum symmetries prevent cold fusion from producing high energy emissions. Solid state cold fusion physics enables nuclear energy to heat a hosting metal by solid state mechanisms that resemble the heating of a wire by an electrical current.

In terms of resources available in the US, one plan for the future would be the establishment of a government supported effort with a minimum commitment of 5 to 10 years. One cannot expect top quality young professionals to take the risk of joining an effort that does not guarantee stable employment. It usually takes as much as 3 years for a scientist entering a new field to learn enough to make a positive contribution. Things are better if there is an active group already present. If you consider one or two competent professionals to be such a group, there are only a few such groups in the US. The Departments of Energy and Defense are potential sponsors, and the fact that the space exploration program will greatly benefit suggests that NASA could be a potential sponsor. There is difficulty in getting government support as long as

professional scientific organizations fail to seriously examine the cold fusion option,. A positive step would be for Congress to fund the National Academy of Science to examine the cold fusion field.

Other support possibilities should be explored. A profit-motivated enterprise could take a long term view and invest in what they would initially feel to be high risk, high payoff technology. There is a danger in this approach. If the enterprise sought to protect its early efforts by Patent rights, its work would not be shared with the global community, and it would in turn be isolated from the cooperative world effort that has kept this research alive thus far. This problem could be avoided if the profit-motivated enterprises agreed to openly share all the results they obtained during the initial years of their work. They would be basing their hope for future profit on the expectation that the accumulating corporate expertise and the research by-products would provide them a technical advantage, leading to commercial success in the market place.

Another option would be for a Foundation or other non-profit individual or organization to provide the financial support needed. It would be most effective if the benefactor found a way to build on a currently successful program. Technology leadership is in Japan, but even the Japanese effort is fragile. A non-profit's support of an international program would be the surest means for quickly bringing cold fusion energy to commercial reality. Commitment over a 5 - 10 year period is more important than dedication of a larger amount of funds for a shorter period.

In structuring the development effort, it is important that materials research and characterization play a key role. Materials research is needed in conjunction with laboratory studies on heat generation and process reproducibility, which in turn are needed for guiding device design, testing, and engineering. Over the near future, duplication of effort should be encouraged and not avoided. It is advised that some of the materials development and evaluation studies should be done in close proximity and/or be closely coupled to the design and testing of developmental cold fusion heaters. Experiment and testing will probably continue to guide theory rather than theory guide experiment over the next few years. Both theory and modeling need to be supported. Theory should include both solid state computer modeling of candidate materials and a more basic modeling of the underlying physics process.

Other countries face similar problems. Maybe a multinational program could sponsor the needed research.

THEORY

An Interdisciplinary Science

The biggest obstacle thwarting the development of cold fusion as a clean energy for the future is THEORY, not EXPERIMENTS. It is a hesitation of the engineering and science communities to recognize that the quantum physics of metals can be applied to the reaction physics of nuclear science. The nuclear engineering and science communities know that cold neutrons can flow into selected uranium nuclei, energizing the nucleus in a manner that releases some 230 MeV of nuclear energy. But they see no way by which a positively charged deuteron can enter a nucleus at room or boiling water temperature. This is a problem since for cold fusion to occur, two deuterons must join each other to create a helium nucleus and release heat. Ironically, the theory disconnect is mainly due to the same specialization that has led to the rapid technology advance that has made present day society possible.

The technology that explains cold fusion is multiply interdisciplinary. Cold fusion seems most easily explained using the languages of chemistry and metal physics, but it also requires inputs from nuclear physics and other specialties. Chemistry builds on atom and molecular physics, while the physics of metals is part of material science and has a parallel in the astrophysics of white dwarf stars. All of these are part of quantum science and subject to its disputed interpretations and its mathematical languages.

Despite all these apparent complications, cold fusion is not more difficult to understand than many of the specialties that make modern life possible. We all understand the law of conservation of energy, and that one can convert stored chemical energy into heat by burning fossil fuels. There are additional rules similar to conservation of energy that apply to the submicroscopic world of quantum mechanics. Once these theory requirements are recognized, most of cold fusion science can be understood.

Listening to Chemistry

The mystery of cold fusion is based on the mystery of chemistry. Ever since Rutherford showed that the negative and positive charges that make up an atom have a structure in which most of the positive charge is located in a hard nucleus at the center of the atom, there has been the mystery as to what keeps the negatively charged electron matter from falling into and combining with the positive nucleus at its center. After all, the pull of the positively charged nucleus at the center of the electron "cloud" is vastly stronger than the pull of gravitation. Maxwell's theory of electromagnetism says that a moving localized electron charge must continuously lose energy if it is confined within a closed volume like that of an atom. Something else must be going on.

There are two things going on. It turns out that an electron requires more volume to "live in" when its kinetic energy is low than when it's kinetic energy is high. Also, when it occupies this volume, there is no room for another electron with the same low energy to be in that same volume. The first of these rules is the so-called Heisenberg uncertainty principle, and the second is Pauli's exclusion principle. Without these two governing principles there would be no atoms, no molecules, and none of us humans trying to figure out the rules. With these rules operating, electrons crowd in as tightly as possible around the positively charge nucleus. Some people think of an atom as mostly empty space, which is true from the point of view of a radioactive decay particle like the alpha particles used by Rutherford in his famous scattering experiments. But if one views things from the electron's point of view, the atom is fully packed with electron matter crowded around the nucleus as tightly as possible.

Chemistry describes the many ways in which electrons can organize themselves to get close to the nucleus. In general, electrons seek to organize themselves so as to create the lowest possible energy arrangement. In molecules, there are multiple nuclei, and when there are more than 2 atoms, there are multiple geometric arrangements that can be formed. The atomic nuclei seek locations such that their combined system of "point-like" nuclei and space-occupying electrons are in the lowest energy configuration. Some geometric arrangements of the atoms can lead to a lower energy than other arrangements of the same atoms. Both are valid molecules, but only one has the lowest energy and is therefore the most stable. The other configurations can be almost as stable and equally useful as long as the geometric changes required to get to a lower energy shape are blocked by a high enough energy barrier.

Returning to atoms, the organized volumes that electrons fill in their attempt to minimize energy for the various atoms of the Periodic Table are called atomic orbitals. Each of these orbitals has its own shape and electron matter density distribution.* These orbitals have names. Figure 1.2,1 on page 9 shows the shape and density distribution of an *s*-orbital. The electron density distribution is spherical and describes the hydrogen atom. As one moves across the Periodic Table to atoms containing more electrons, the orbital shapes assume surprising form. Once you get to atoms having 5 or more electrons, you encounter the *p*-orbital. Figure 3.3,1 shows the density distribution of a *p*-orbital, such as describes the outermost electron of the boron atom.

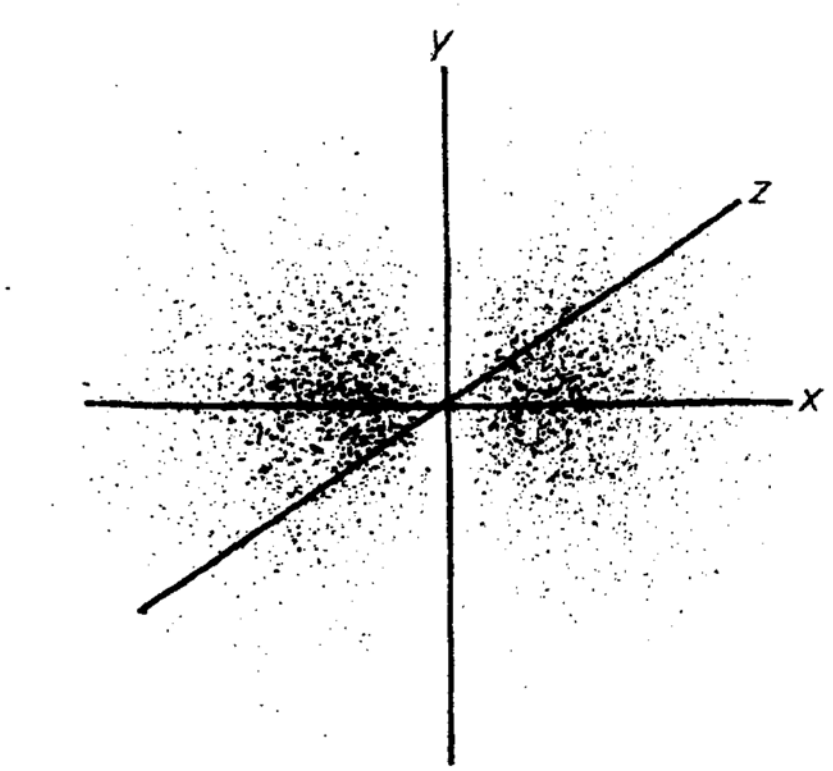

Fig. 3.3,1 The *p*-orbital of the outermost electron of the boron atom. The orbital is occupied by a single electron. The orbital is best pictured as a distribution of electron density which is partitioned into two halves, and which is continuously and smoothly present throughout the dotted volume. The electron matter is "coherently partitioned", yet behaves as a single entity, which is to say that the separated pieces are "entangled". The sum of pieces is the electron. The electron is best thought of as a quantum-of-mass of electron matter.

* The textbook used by American University is "Chemistry, The Central Science" by Brown, LeMay, and Bursten. It describes orbitals as **probability density** or **electron density** distributions (pp. 231-232). Electron density fits Penrose's "The Road to Reality", as discussed in Chapter 3.8.

The electron density distribution of the boron *p*-orbital illustrates a key aspect of submicrosopic physics. The *p*-orbital of the boron atom is occupied by a single electron. The electron density of the single electron is split equally between the two lobes despite the fact that the electron density at the node between the two lobes is zero. Each lobe is occupied by half of a single electron. The electron density of the single electron is split equally between the two lobes despite the fact that the rules of classical physics says this partitioning cannot happen. Each lobe contains half of the electron's matter. The electron is coherently partitioned into two halves. The two halves of the *p*-orbital are "entangled". This situation exists because the split electron shape minimizes system energy. Mathematically, one must sum over the two density distributions to get what we call an electron. Energy minimization, coherent partitioning, and entanglement are distinguishing features in the physics of cold fusion.

The same split-density distribution situation applies to the carbon atom, which has two *p*-orbitals, each occupied by a single electron, and nitrogen has three *p*-orbitals, each occupied by a single electron. In nitrogen the three *p*-orbitals are oriented along the x, y , and z directions of space (e.g., up-down, north-south, and east-west.).

Chemistry is mostly the chemistry of isolated molecules. The nuclei in the centers of atoms forming molecules can be arranged in an enormous variety of geometric configurations. Some arrangements are very simple, like the straight line geometry of the carbon dioxide molecule CO_2. Some are in the form of a "ring", like the carbon atoms in the benzene molecule. Some are like the pulled wishbone of a chicken The water molecule H_2O has this angular form. The 2 legs of the wishbone form an angle of 105^o. In each molecule there are some electrons that are shared between 2 or more atoms. These shared electrons are called bonding electrons, or bonds. The bonding electrons are really orbitals, and have their own distinctive density distributions. The bond types and their geometries are an important part of modern chemistry. Their shapes and volumes can be visualized just like the electron matter orbitals of atoms. The bonding volume is densely packed with electron matter, and can be pictured in the same manner as atom orbitals.

Listening to Metal Physics

The physics of metals is an extension of the chemistry of molecules as applied to very large molecules with a periodic arrangement of metal atoms. Metals have a somewhat higher density than the typical molecule. The abnormally high density of metal crystals means an abnormally high electron density. The abnormally high electron density in combination with periodic array order creates a special type of chemical orbital consisting of a many interconnecting lobes in a lattice array. When an electron fills this orbital, it is called a quasiparticle. A grouping of array orbitals sharing the same array structure is called a band, and the electron occupants are called band state electrons. These band state electrons are the electron quasiparticles. They are the charge carriers that flow through the metal when a wire carries an electric current.

The huge abundance of electron quasiparticles is what makes a metal different from other crystalline solids. A solid having a much smaller number of the electron quasiparticles is called a semiconductor. Non-conducting solids like ionic crystals, covalent solids, and plastics have no quasiparticles. The enormous collection of quasiparticles in a metal is called a fermi sea, named after Nobel Laureate Enrico Fermi. The fermi sea electrons populate a near continuum of energy levels up to a maximum energy level called the fermi level. The electron fermi sea neutralizes embedded metal ions. The metal atoms became positive ions when they donated their outer electrons to the common pool, i.e., the fermi sea.

The number of interconnecting lobes in an electron quasiparticle orbital is enormous. Whereas a *p*-orbital consists of 2 lobes (potential wells) on opposite sides of an atom's nucleus, a metal quasiparticle orbital can consist of 10^{15} communicating potential wells. This number is 100,000 times Earth's population. The Pauli exclusion principle that limits occupation of chemical orbitals to no more than 2 electrons per x, y, z state, also applies to quasiparticle orbitals. Pauli exclusion limits the electron density even at high pressure, preventing shrinkage that would otherwise occur. As in molecules, the relatively large volume required by the electrons in the solid is what determines the density of the solid. Among other things Pauli physics prevents the shrinkage of the Earth under the pull of its own gravity.

The type of orbital (chemical vs. quasiparticle) occupied by an electron depends on its environment. During battery operation, an electron belonging to an ion in a battery's electrolyte enters the battery's metal anode and converts from a chemical orbital form to an electron quasiparticle orbital form. It joins the electron fermi sea. Electron quasiparticles then flow through the wires of the electrical circuit, arrive

at the battery's metal cathode, and convert back to molecular orbital form as they re-enter the electrolyte.

The job of the cold fusion reactor designer is to create a situation where deuterons initially in heavy water or deuterium gas enter a metal and convert to deuteron quasiparticle form. This conversion can be made to occur in small sub-volumes of a metal crystal, consisting of 10^3 potential wells. This spread-out orbital form creates a very low density type of deuteron matter in which each deuteron's charge is coherently partitioned into many small fractional pieces. The quasiparticle deuterons have their own multi-lobe orbital structure, which means that they occupy their own set of communicating potential wells. When two suitably paired quasiparticle deuterons are occupying the same set of potential wells, there is a pairing of fractional charges present in each well, but the amount of opposing charge present is too small to keep the fractions apart. Coherent partitioning means that the fractional pieces are "entangled", which means that one must sum over all the pieces to see what really happens. Even after summing over all the pieces, the deuterons have made contact. Having made contact, the paired quasiparticles fuse in response to the nuclear strong force.

A quasiparticle fusion event can be pictured as taking place in 2 steps. Prior to the first step, all the quasiparticle deuterons in a given volume were paired with all the other quasiparticle deuterons in what is called a many-body system. They formed their own multi-lobe swimming pool. The resulting density distribution of deuteron positive charge was neutralized by negatively charged electron matter borrowed from the electron fermi sea. The number of electrons borrowed from the fermi sea equals the number of quasiparticle deuterons in their many-body system. This process of neutralization is called dressing. Dressing means that a portion of the electron fermi sea coexists in the deuteron's potential-well volumes and limits the range of the dd-repulsion electric field that tries to keep the deuteron matter in separated-deuteron form. The mathematics uses a screening radius, designated r_{sc}, to measure the range-limiting effect on the dd repulsion force. This screening radius appears in the equation that quantifies the effectiveness of the fermi sea's ability to support the dressing process.

In the first reaction step, several things happen. A selected dd pair meeting "spin-zero" requirements, as specified in the next chapter, segregates itself from the deuteron many-body system and gets neutralized (dressed) by its own 2-electron portion of the electron fermi sea. The isolated dd pair then undergoes a change in its internal structure. The internal geometry of the 2-deuteron system shrinks to nuclear density, either spontaneously or in response to a momentum shock probably associated with a new deuteron changing from localized to quasiparticle geometry, or vice versa. In this stimulated reaction picture, the momentum shock is delivered to the many-body deuteron

system and its dressing electron fermi sea matter. The shock momentarily creates a "resonance" condition in which the energy of the total system containing the initial deuteron pair state momentarily equals the total system energy of the collapsed state. The shock causes a transient relative motion between the deuteron pair and its hosting metal, which causes a so-called "momentum scan". The change in dd internal structure is accompanied by a small transfer of momentum to the hosting metal.

The second step is the transfer of 23.8 MeV of nuclear energy from the quasiparticle helium nucleus to the hosting metal. The shock transfer of momentum described above makes a potential fusion reaction irreversible. The new helium nucleus is born with its internal nuclear matter in a state of intense internal vibration. From the point of view of the nucleus, the helium-4 is in a highly excited internal state. It is born at a high energy level. After collapse, the internal structure of nuclear matter has the same dd form that it had before collapse. The protons and neutrons describing the internal nuclear structure have retained their paired deuteron form, designated (d,d). The deuterons have retained their proton-neutron bonds. This (d,d) nuclear structure can also be written (pn,pn). The most stable form of helium-4 nucleus has an internal structure which has mainly neutron-neutron plus proton-proton bondings. This lower energy, more stable configuration can be written (nn,pp). The de-excitation transfer of 23.8 MeV of nuclear energy to the outside world is thought to occur in a cascade of discrete steps. It is thought that these transfers are accompanied by momentum impulses given to the hosting metal lattice at the edge limits of the good interface area, where the interface encounters the larger enclosing metal. The electron screening (dressing) becomes impaired at the edge boundaries of the good crystallite interface area. It is thought that momentum impulses should also occur perpendicular to the interface.

Regardless of process details, reaction energy cannot be released in the form of energetic particles or gamma rays. These conventional emitted quanta have point-like geometries which do not match onto the lattice geometry of the partitioned nucleus form. The geometric mismatch guarantees that the cold fusion process is radiationless. (See Reifenschweiler disussion on p. 17)

Geometries Compared

Fig. 3.4,1 illustrates the deuteron quasiparticle orbital geometry that makes cold fusion possible. The top row shows calculated spatial distributions of adsorbed H atoms located on two different faces of Ni surface crystal. Since the H and D chemistries are the same, the Figure

compares the chemical orbital of a deuteron confined within a potential well with that of a deuteron quasiparticle orbital. The right side picture applies to the deuterons that are responsible for cold fusion. The deuteron has adjusted to the 2–dimensional symmetry of the surface crystal. The bottom row drawings show the difference between 2 deuterons in adjacent chemical orbitals and 2 paired deuteron quasiparticles. The 2 adjacent chemical orbitals resemble a D_2 molecule, whereas the paired deuteron quasiparticles resemble spin-paired electrons. The paired deuteron quasiparticles share the same volume. In quantum language, they have "overlapping wave functions".

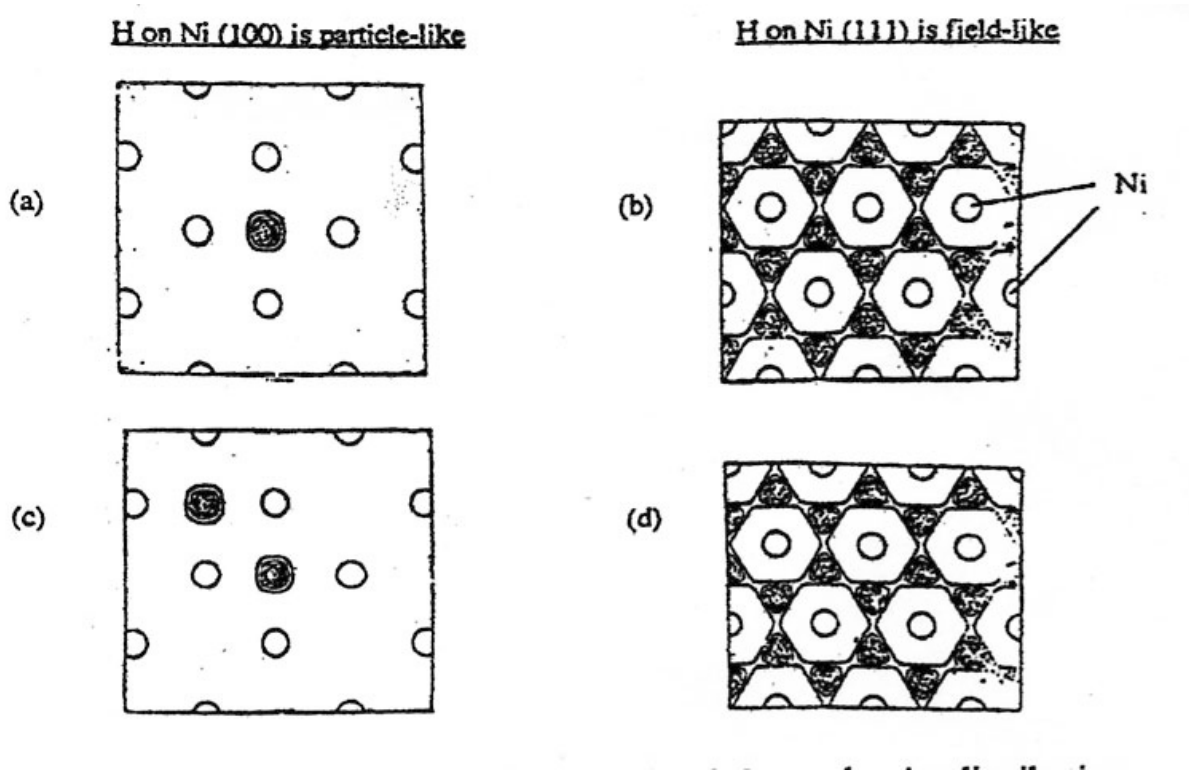

Fig. 3.4,1 The figure is based on calculated charge density distributions of H^+ on Ni surfaces by R. Nieminen. 1a shows the chemical orbital of a H^+ ion confined within a potential well on the Ni crystal surface designated (100). 1b shows the quasiparticle orbital of an excited state H^+ ion on the Ni crystal surface designated (111). The quasiparticle H^+ ion (proton) is coherently partitoned among a large number of potential wells. These calculations apply equally to deuterons. 1c illustrates the geometry of two deuterons confined within adjacent potential wells on Ni (100). 1d illustrates the geometry of two coherently partitoned quasiparticle deuterons confined within a large number of potential wells on Ni (111). The two coherently partitioned quasiparticles share the same volume, have wave function overlap, and are able to fuse their internal structures in response to the nuclear strong force attraction.

Listening to Molecular Quantum Mechanics

The mathematics that permits calculation of the electron energy density distribution in an orbital uses Schrodinger *wave equation + wave function* physics. The wave function calculations resemble the classical physics calculations of the resonant tones of musical instruments. The mathematical solutions are called eigenstates, and the system energies are called eigenvalues. The configuration that corresponds to the lowest system energy is the ground state orbital. A chart showing the separations between allowed quantum-state energies is called an energy level diagram. The energy level diagram for the hydrogen atom was first calculated by Niels Bohr.

As wave function physics advanced and more complicated atoms were modeled, it became evident that predictions based on calculated orbitals did not match the organization of elements based on chemical properties, as shown in the Periodic Table. But the results did agree if there could be two electrons per calculated orbital. The second atom in the Periodic Table is helium. The ground state helium atom has 2 electrons in hydrogen's *s*-orbital. The *s*-orbital is shown in Fig. 1.2,1. The number of atoms per orbital was doubled. The doubling of the number of atoms per orbital required introduction of the concept of electron spin. The existence of spin meant that there was an additional degree of freedom present in the electron. This additional degree of freedom is also present in other fundamental particles, like protons and neutrons.

The idea that fundamental particles are point objects is not consistent with Heisenberg's uncertainty principle, which says that if you precisely define a particle's momentum, you can't give it a zero size. You must give it a small sub-submicrosopic "size", which gives it a moment of inertia and an associated degree of freedom. The point physics of submicroscopic objects, like idealized electrons in atoms, distributes the particle density of each of the electrons over a 3–dimensional continuum of space. The physics of real electrons recognizes that the non-point nature of the electron adds another degree of freedom. Experiments show that the new degree of freedom is restricted to two discontinuous values. Mathematically, the two values are represented by two allowed spin angular momentum vectors (arrows). The electron has been arbitrarily assigned an allowed spin magnitude with index number = 1/2, with a choice of two directions for the spin angular momentum axis . An electron with spin direction "up" is said to have spin +1/2, and an electron with spin direction "down" is said to have spin -1/2. In the helium atom the two electron spins have opposite directions. Their spin angular momentums cancel. The electron pair is a spin-zero pair.

The first orbital calculation that gave the known energy for the helium atom was achieved by Hylleraas. The physics requires that the modeler follow a second Pauli rule, which requires that a 2-particle spin-zero

system obey a symmetry constraint called "coordinate exchange symmetry". A 2-particle system of point objects has 6 degrees-of-freedom, which can be taken as the x y z spatial location of the center-of-mass of the combined system, plus 3 degrees-of-freedom to describe the internal dynamics of the 2-particle system. If the internal geometric structure is that of a diatomic molecule like D_2, the internal degrees-of-freedom express stretching vibrations along the system axis, plus two tumble modes about perpendicular axes. The Hylleraas solution has a different form. With the Hylleraas solution the energy minimizing solution has an internal structure with zero-separation between the 2 electrons, and no tumble or vibration motion. Instead, the two electrons of the helium atom overlap each other. If the electrons had the nuclear properties of deuterons, they would fuse.

The lesson for cold fusion is that if deuterons are going to be able to fuse at room temperature and pressure, they need to be subject to Pauli's requirement for coordinate exchange symmetry. This condition can be achieved under steady state conditions only if the energy-minimized solution of a 2-deuteron wave equation has the coordinate exchange symmetry form. Energy minimizing calculations show that this condition is satisfied if the deuterons have a quasiparticle geometry and the number of lobes in the quasiparticle wave function "orbital" exceeds about 1000.

As stated above, a two quasiparticle deuteron system has six degrees of x, y z freedom. One best thinks of the two deuterons as a single entity, and describes it in "center-of-mass,separation coordinates". One uses a position vector $\mathbf{r}_{cm}$ to describe the density distribution of the 2-deuteron entity in the metal lattice, and a separation vector $\mathbf{r}_{12}$ to describe the repeating internal structure that separates quasiparticle$_2$ from quasiparticle$_1$. The six degree-of-freedom wave function is written as the arithmetic product $\Psi(\mathbf{r}_{cm})\, g(r_{12})$. In this math $\Psi(\mathbf{r}_{cm})$ is the orbital wave function described in Chapter 3.4, and $g(r_{12})$ expresses anticorrelation, instead of the vibration and tumbling dynamics of the D_2 molecule. Function $g(r_{12})$ modulates the amplitude of the composite 2-deuteron system. Approximate calculations show that $g(r_{12})$ has essentially the value 1.0 when the number of orbital lobes is much greater than 1000, and a lower value when the number of lobes is smaller, but above a threshold number.

The form of $g(r_{12})$ is that of a "cusp function". Figure 3.5,1 pictures $\Psi(\mathbf{r}_{cm})$ and $g(r_{12})$ before fusion. The dips in the green $g(r_{12})$ function have sharp downward-facing points at their bottoms. One of these sharp points occurs in each unit cell of a "2–deuteron internal structure mathematical lattice". Function $g(r_{12})$ modulates the amplitude of the 6–degree-of-freedom wave function at each point in the 3-dimensional deuteron quasiparticle-occupied lattice, as defined by $\Psi(\mathbf{r}_{cm})$. Figure

3.5,2 shows the change in $g(r_{12})$ geometry that occurs during the wave function collapse step in the fusion process. This collapse is Step 1 in the nuclear reaction process.

Another important discovery in molecular chemistry and physics has been a recognition that the geometry of a molecule can be made to change to a second geometric structure that has almost the same energy. The condition producing this change is called a Feshbach resonance. The change occurs during an energy scan process. If one can alter the environment in a manner that changes the energy of one of the configurations differently from the other, one can at some point make the two energies equal. The energy changing process is called a resonance scan. A scan across a resonance can switch the system's internal geometry, leaving the location of the center-of mass unaffected. The physics of molecular quantum mechanics shows that a back and forth scan across a resonance can lead to an energy transfer to the hosting environment. As applied to the quasiparticle nuclear states involved in quasiparticle deuteron fusion, the scan process can lead to a transition from a pre-scan paired deuteron state to a pre-scan near-resonance metastable initial nuclear state, accompanied by transfer of a small amount of energy and momentum to the hosting metal environment. The metastable nuclear state is a high-energy excited state, many MeV above the helium-4 ground state. However, the transfer of even a small amount of energy to the hosting lattice makes the nuclear reaction irreversible. The possible role of nuclear resonance was pointed out by Xing-Zhong Li, the head of the Chinese cold fusion effort. Physicist Scott Chubb identified momentum shocks as a means of transferring energy to the hosting environment. A subsequent energy cascade process completes the transfer of nuclear fusion energy to the hosting lattice.

Six Degree-of-Freedom Quasiparticle Wave

Function

Fig. 3.5,1 Wave function amplitude in physical space $\Psi(\mathbf{r}_{cm})$ and wave function modulation factor in separation space $g(r_{12})$ for a 2 quasiparticle deuteron entity.

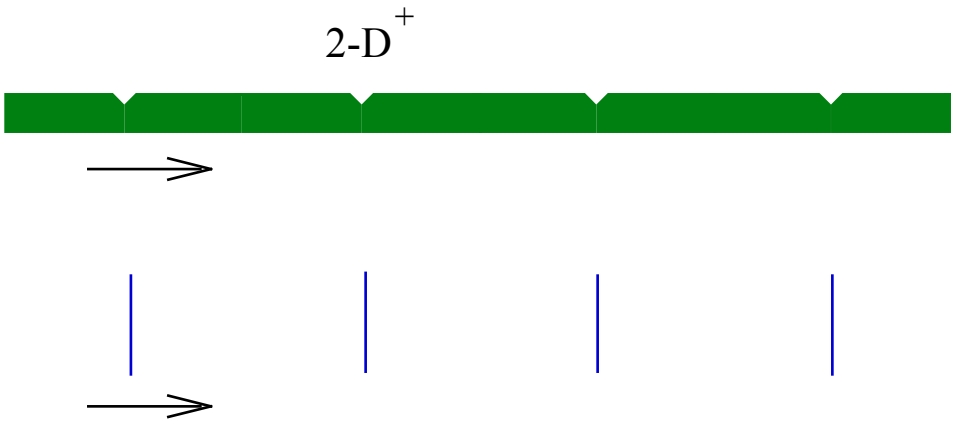

Fig. 3.5,2 Collapse transition of a quasiparticle 2-deuteron pair. The green image is the $g(r_{12})$ internal geometry function before collapse to nuclear dimension. The four blue vertical lines is the $g(r_{12})$ function after collapse to nuclear dimension.

Listening to Nuclear Physics

Nuclear physics began with the discovery of radioactivity and with Marie Curie's proof that its source was a new element called radium. Nuclear physics as an experimental science began with Rutherford's alpha particle scattering experiments that showed that an atom's positive charge is concentrated in a tiny nucleus at the center of an atom. The growth of nuclear physics up until the discovery of neutrons and their use to create new elements was dominated by high energy scattering experiments, which are direct descendants of Rutherford's work. All of these involve an interaction at a central point. This highly successful tradition makes the concept of quasiparticle nuclei almost impossible for nuclear physicists to accept. Nonetheless, it is important for cold fusion scientists to listen to the nuclear physics community.

Nuclear physics has provided a deep understanding of the internal structure of the nucleus, its internal dynamics, and the mechanisms by which an unstable nucleus emits decay products. The geometry of alpha particles, neutrons, electrons, gamma rays, positrons, neutrinos, etc. must match onto the initial and final nuclei participating in any nuclear decay process. Nuclear physicists have classified various ground and excited states of nuclei much like atom chemists and physicists have done with atoms and molecules. Spin, angular momentum, and wave function (orbital) symmetry are used in their classification scheme. Reactions are labeled in terms of initial and final states (feedstock and product). The cold fusion reaction involves two quasiparticle deuterons combining to produce one quasiparticle helium-4. Nuclear physics call this type of reaction a 0+ to 0+ transition.

The 0+ to 0+ transitions are relatively slow transitions if the initial and final states are separated by a small difference in energy. The lifetime of the initial state becomes especially long if the energy difference is very small, which is the situation that exists when the reaction product is produced by a resonance scan. This relatively long lifetime suggests that momentum shock stimulation plays a role in the cold fusion process . McKubre's formula for fusion heat production shows that deuterium inflow and outflow are needed for production of detectable heat in his experiments. His empirical formula supports this view.

Nuclear physics scattering experiments have shown that reactions induced by charged particles striking a nucleus occur only when the incident particle has high energy. The studies show that reaction rate decreases rapidly with particle energy, falling close to zero by 1000 electron volts. At room temperature, reactions are clearly impossible. This conclusion is undeniable as long as the reaction geometry is the same as used in nuclear physics scattering studies. That is why deuterons must

have a quasiparticle form if cold fusion reactions are to occur at normal metal densities and temperature.

The key characteristic of quasiparticle geometry is that the quantum-of-mass called a deuteron must occupy a many-lobe orbital. Ideally, each lobe is an equivalent potential well. In Rutherford scattering experiments there is a single identifiable location where an energetic particle recoil event has occurred. In Rutherford-type scattering experiments which result in a nuclear reaction event, there is a single identifiable location where the nuclear reaction has occurred. In contrast, in the cold fusion quasiparticle case there is no single location where the reaction takes place. Instead, the reaction takes place coherently and simultaneously at many locations. In the Rutherford scattering experiments one has a single-center target nucleus. In quasiparticle fusion one has an overlapping pair of many-centered deuterons which becomes a many-centered helium-4 nucleus. The Penrose interpretation of Schrodinger wave functions supports the reality of the quantum-of-mass picture in submicroscopic physics.

The cold fusion reaction is a catalytic reaction in which the physical form of the deuteron feedstock is converted from localized particle form to a lattice geometry form prior to reaction. In the lattice form, the deuterons are "coherently partitioned", which means that there is a fraction of each deuteron present in 1000 or more separate small volumes. These deuteron fractions are "entangled", which means that their mathematical sum is the mathematical original deuteron.

Cold fusion liberates nuclear energy in the form of heat by converting 2 deuterons into a helium-4 nucleus. The reaction liberates 23.8 MeV of energy per fusion event, which is about one tenth the energy liberated by splitting a uranium nucleus. Compared with uranium fission, cold fusion produces roughly 6 times more energy per pound of fuel.

Figure 3.6,1 illustrates the quasiparticle dd reaction. In the artist drawing, the initial state is the state which shows the paired deuteron quasiparticle located at an energy level 24 MeV above the helium-4 ground state. The 24-MeV level marks the energy of the quasiparticle deuteron pair both before and immediately after contraction to nuclear dimension, as described in Chapter 3.5. The amount of energy transferred during the resonance scan responsible for the contraction is too small to show on the chart. The stacks of small horizontal bars designate energy levels in a standard energy level diagram. The spacing between bars are the differences in excitation energy between adjacent vibration states inside the nucleus. The energy spacings within each of the vertical stacks are uneven and of the order of 100,000 electron volts. The adjacent stacks of horizontal bars are for the two internal geometries described in Chapter 3.4, namely a (d,d) pairing geometry and a (pp,nn) pairing geometry. A (dd) pairing is the same as a (pn,pn) pairing. These

nucleon pairings are like the zero-spin electron pairings in atoms. The pairings create spin-zero pairs from half-spin fundamental particles, as discussed in Chapter 3.5.

The two stacks of energy levels on the left compare the excitation states for a normal single-center nucleus with the two stacks of energy levels on the right, which show the corresponding excitation states for a many-centers nucleus. Note that the 0+ ground states for the (d,d) nucleus are at different levels. This difference in ground state energies is due to the reduction in work energy required to contract two deuterons to nuclear dimension in a many-centers helium-4 geometry as compared with the work energy required to contract two deuterons to nuclear dimension in a single-center geometry. Note that the partitioning of a (pp,nn) nucleus does not alter nucleus energy, because the (nn) pair has zero charge. There is no coulomb repulsion force between a (pp) pair and a (nn) pair. As a result, the (pp,nn) helium-4 many-centers ground state has the same energy as the (pp,nn) helium-4 single-center ground state.

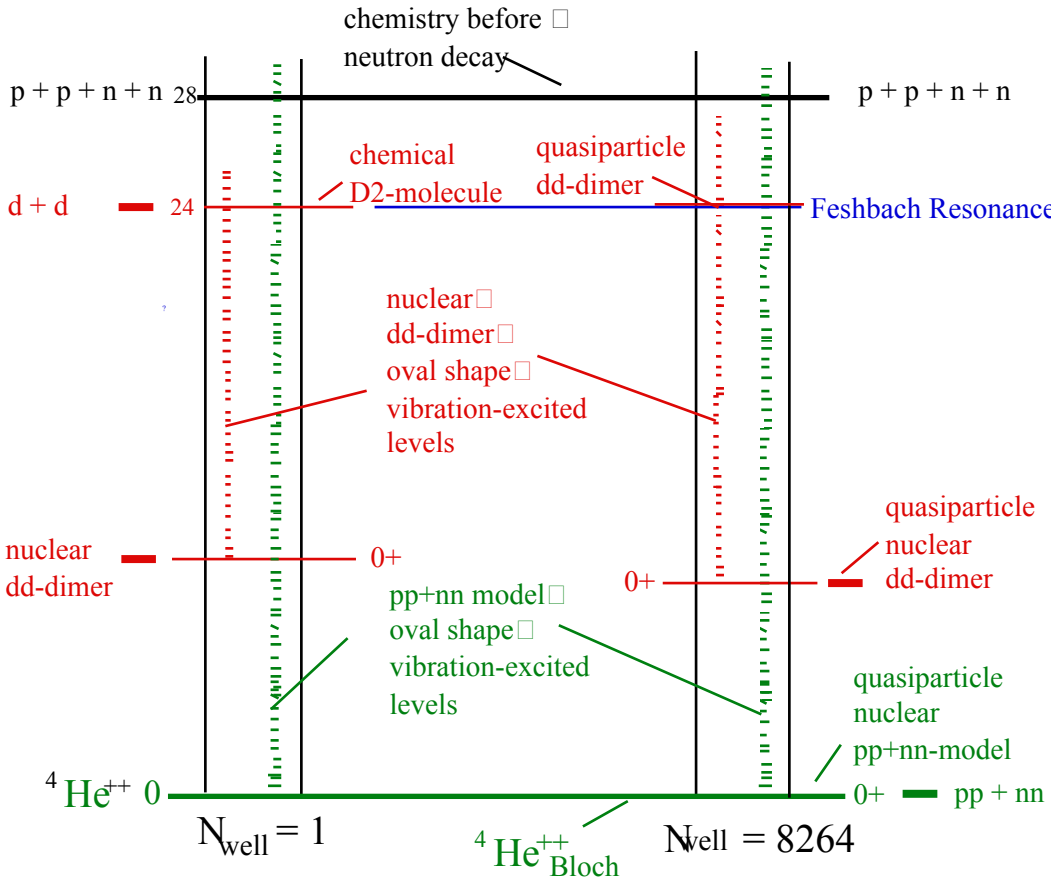

Fig. 3.6,1. Energy level chart for two internal structures of helium-4, and a comparison of energy levels for a single-center nucleus vs. a quasiparticle multi-center nucleus containing 8264 potential wells (orbital lobes). The initial paired deuterons before collapse to nuclear dimension is at 24 MeV above the ground state helium-4 nucleus. If one started with 2 free protons and 2 free neutrons, the starting state would have been 28 MeV above the helium-4 ground state.

Listening to Roger Penrose

Quantum Mechanics was developed to correct deficiencies discovered in the Maxwell-Faraday theory of electromagnetism. Maxwell's equations explain the generation of electromagnetic radiation (radio, infrared, visible, ultraviolet, x-rays, gamma rays) but were unable to explain the color spectrum of light emitted by hot metals and the sun. It was also unable to explain the existence of atoms consisting of a massive nucleus and a 2000 times lighter electron. It said that the electron should continuously lose energy and "fall" into the proton. The quantum theory provided a solution to the energy loss problem, and made quick progress in creating models that predicted the ultraviolet, visible, and infrared emission line spectrum observed. But the physics was hard to accept by many scientists. It seemed to violate common sense when the physics said you can't describe a particle's position and momentum at the same time (Heisenberg uncertainty principle). When multiple-particle systems were modeled, one had to add 2 Pauli constraints: the exclusion principle and the requirement for coordinate exchange symmetry. Also, certain compound particles were able to avoid the Pauli exchange rules. One had to add spin as a new "quasi-degree-of-freedom" to explain the Periodic Table of Elements. Spin also explained the existence of double line emission as seen in sodium vapor lamps.

The apparent violation of common sense and classical logic has led to endless arguments about the nature of Quantum Reality. It became popular to interpret the orbitals of chemistry as probability distributions, which permitted an experimenter to predict where a point-particle would be most likely found in a scattering experiment. This probability function description is called the "Copenhagen interpretation". Enrico Fermi avoided these philosophic discussions and just went ahead and used the wave equation and wave function to calculate expectation values for experiments. Nonetheless, the philosophic argument continues today.

Mathematician Roger Penrose takes the minority view that a wave function is much more than a probability distribution. Penrose is considered one of our greatest living scientists. He is Emeritus Rouse Ball Professor of Mathematics at Oxford University. His 2006 book "The Road to Reality" discusses his quantum reality views. His interpretation makes use of the concept of wave function collapse, which supports the electron density interpretation of an atomic orbital. When an incident x-ray hits an electron orbital it can cause a wave function collapse. The wave function collapse to point size is most likely to occur where the particle density is highest. The correlation between calculated electron density and collapse point is a common sense explanation for the success of the probability interpretation. This book accepts Penrose's wave function collapse picture. Penrose calls the collapse "a state reduction" and designates it by the symbol **R**. Prior to collapse a state can have a weakening density and growing volume, which he calls "unitary

behavior" (Schrodinger) evolution, designated **U**. A picture of the time evolution of a state is shown in Fig. 22.1 on page 529 of his book.

The theory used in this discussion of cold fusion seems consistent with the physics known before 1989, when cold fusion was announced. The language of chemistry seems especially appropriate, and adequate to visualize the cold fusion process as thus far understood. Treating 2-body systems as 6-degree-of-freedom objects, plus spin, seems to work. Worries about a need to produce a more precise theory should not be permitted to delay development of quasiparticle-based clean energy for the near future.

Role of Asymmetry

It may seem strange to approach the end of this discussion of a symmetry-based reaction model with a discussion of asymmetry. However, there is a parallel with the quantum physics of molecular spectroscopy. Simple molecules with strong infrared absorption are the ones with large dipole moments, like HCl and H_2O. Similarly, in nuclear physics, states that differ by 1 unit of angular momentum have relatively high nuclear reaction cross sections because they interact strongly with electromagnetic fields. The first step in a dd fusion reaction is a momentum transfer that occurs during a resonance scan between two energy states. Both the Iwamura CaO + sputtered Pd interface reactions and the Arata-Zhang ZrO_2 + nanoPd interface reactions have been shown to be good heat producers. Both provide a highly asymmetrical environment within which a quasiparticle deuterium many-body system can be hosted. The environment has high lattice symmetry in the plane parallel to the interface, and very asymmetric symmetry in the direction perpendicular to the interface, as shown in Figure 3.8,1.

There are in-plane momentum shocks which are generated when migrating deuterons transition from a localized chemical-form to a delocalized quasiparticle form, due to an essentially instantaneous shift in center-of mass. In the oxide-nanometal systems, there are also shocks that are produced in the direction perpendicular to the crystal-metal interface plane. Independent of any fusion reaction shocks, when a deuteron transitions from chemical orbital form to quasiparticle form and suddenly spreads over an interface area that provides 1000 potential wells, it suddenly imposes a jump in deuteron positive-charge density within the interface volume. In response, a 0.001 fraction of an electron quantum-of-mass moves from the metal's fermi sea and enters each unit cell of the same interface volume. The charge neutralization process is called "dressing". The Pauli exclusion principle applied to electron matter requires a sudden jump-increase in the thickness of the interface. This thickness increase forces an "instantaneous" recoil of the adjacent metal relative to the more incompressible bulk oxide crystal.

The migrating deuteron has created an asymmetrical recoil motion which is analogous to the momentum shock that occurs when a many-body solid-state system recoils as a unit during a momentum transfer between two contacting systems. Such momentum recoils are known to occur between crystallites and hosts during the radioactive decay of certain iron nuclei. The phenomenon is called the Mossbauer effect. It is a recoil effect that was discovered when a particular type of iron was hosted inside a solid crystallite. In the Mossbauer effect, the gamma ray emitted from a recoiling radioactive iron nucleus within a crystallite is resonantly absorbed by a non-recoiling non-excited atom of the same iron type located in a second iron hosting solid material, but only if the two

systems are physically moving slowly apart at the right relative velocity. The gamma ray then sees a momentum match and is absorbed.

In cold fusion reactors, the asymmetric momentum shock has a different origin and different form from that produced by a Mossbauer momentum recoil. The shock that occurs when a migrating deuteron changes its geometry has an acceleration-deceleration form. It produces a back and forth energy scan between interface and metal host, caused by a back and forth velocity spike. The resulting energy scan appears able to trigger Step 1 of the nuclear reaction process.

Momentum shock events of this type require that deuterons move inside the metal. This need for migrating deuterons seems to explain the reaction stimulation that accompanies deuteron fluxing, as specified in McKubre's empirical law based on his cold fusion heat observations.

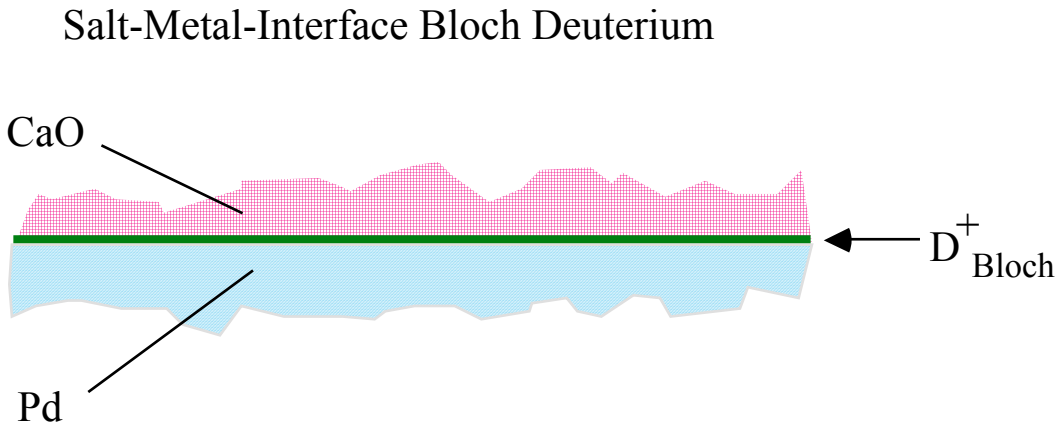

Figure 3.8,1 Asymmetric interface used by Iwamura's group in excess heat observations in 1999. The quasiparticle deuterium which occupies the CaO Pd interface is labeled D^{+}_{Bloch}. The interface provides an environment that enforces 2-dimensional periodic lattice symmetry within the interface plane, and asymmetric symmetry perpendicular. Entry of a deuteron into the interface volume creates a momentum shock perpendicular to the interface due to Pauli exclusion operating on the neutralizing electron matter. The shock provides a momentum scan that aids collapse of quasiparticle deuteron pair to nuclear dimension. This collapse is Step 1 of the nuclear reaction process

Listening to Cold Fusion

In summary, it is no accident that the phenomenon of cold fusion was discovered by chemists. Chemistry and related materials science are the original disciplines of the submicroscopic world. Although the centered-mass geometry of atoms was first discovered by Rutherford in an alpha-particle scattering experiment, the wave function orbitals that fill the atom and form the bonds binding atoms into molecules belong to chemistry and material science. Listening to Rutherford's energetic alpha particle, an atom is mostly empty space; listening to the electrons that pack the atom's volume, the atom is chuck full of matter. This packing is the maximum that is allowed by the Pauli exclusion principle, when subject to system energy minimization. From the point of view of the electron, the atom is a potential-energy well with no free space.

Pauli exclusion is the essential organizing principle of microscopic physics and chemistry. It is central to an understanding of both the Periodic Table of Elements and the internal structure of nuclei. If it were not for Pauli exclusion, all the atoms would look like hydrogen and helium. Pauli exclusion applies to electrons, protons, neutrons, and neutrinos. If one listens to the protons and neutrons, each proton consumes "proton space" and each neutron consumes "neutron space", just like each electron consumes "electron space" in an atom. The nuclei of all elements heavier than helium become larger in volume as one adds more protons and neutrons, just like the atom volume grows with added numbers of electrons as you move towards the higher atomic-number elements in the Periodic Table. When an attractive force, like the nuclear strong force, the Coulomb force, or gravity, is present and seeks to collapse a system of fundamental particles, the collapse proceeds until there is no free space. Note that the presence of electrons doesn't bother protons and neutrons, and neutrinos only worry about other neutrinos. An astrophysical example is the white dwarf star, where an electron lattice fights against the pull of gravity*. From the electron's point of view, the star's volume is a fully packed sum of electron orbitals. Pauli exclusion prevents collapse of the electron lattice. The electron-filled volume also contains a hot ion plasma. The moving ions co-exist within the electron lattice structure. Even neutrinos are subject to Pauli exclusion. In one model of dark matter, Pauli exclusion prevents collapse of a gravitationally bound lattice of sterile neutrinos, just like it prevents

* More accurately, gravity pulls mostly on the ions flying freely through the electron lattice. The gravity pull displaces the positive ions relative to the negatively charged electron structure. The force between the offset positively charged ions and the negatively charged electrons transmits the gravity force to the electrons.

the collapse of the electron support structure of a white dwarf star. Listening to the dark matter neutrinos, the neutrino halo within which our galaxy is embedded is a fully occupied compact volume.

Pauli exclusion is also the controlling principle in metals. There would be no solids of any kind if Pauli exclusion did not exist. A metal's electrons would combine with the embedded metal ions to produce a vanishingly small, high density entity. The physics modeling of a metal seeks a minimum energy solution in which the contraction pull between positive ions and the lighter, more voluminous electrons fight against Pauli exclusion. The resulting balance of forces produces the metals we use in the engineering world. The most effective protocol used by solid state scientists to model metals is called "density functional theory", which is based on the electron density interpretation of wave function amplitude.

Unfortunately, a number of important cold fusion scientists think that the electron density limit established by Pauli exclusion can be circumvented by special cluster geometries. Such cluster models are non-physical.

Interdisciplinary chemistry/physics scientists encounter a wide range of electron configurations and behaviors. Here are 7 of these electron configurations: **1)** the free electron that undergoes elastic collisions with ions in the interior of the sun and in the plasma fusion devices of the hot fusion program, **2)** the confined electron in the *s*–orbital of the hydrogen atom ground state, where it has existed unchanged in cold interstellar gas for 10 billion years, **3)** the coherently split hydrogen that resides equally in the two lobes in the *p*-orbitals of the boron, carbon, and nitrogen atoms, **4)** the aromatic hydrocarbon ring electron that shares the 6-lobe orbital of the benzene molecule with 5 other electrons, **5)** the 2–dimensional lattice symmetry electron that shares a million-lobe orbital with a million partners in a sub-micron graphene* crystallite, **6)** the 3-dimensional lattice symmetry electron that shares 10^{10} - 10^{15} potential wells with 10^{10} - 10^{15} other electrons in a microscopic metal crystal, and **7)** the 10^{24} electrons sharing 10^{24} potential wells with more than 10^{24} fermi-sea partners in a gram molecular weight of multi-crystalline bulk metal. These diverse morphologies are different forms of "the quantum-of-mass of electron matter". The quantum-of-mass of electron matter is called a particle when it is a free-flying entity in a hot plasma, and called a quasiparticle when it is a partner in an electron fermi sea, or when it is a conduction entity in a semiconductor. Similarly, the deuteron is a

* Graphene is a graphite crystal that is one atom-layer thick. The existence of graphene was discovered only a few years ago.

quantum-of-mass of deuteron matter. It has particle form when it serves as the nucleus of a deuterium atom, or when it serves as one of the pair of nuclei in a D_2 molecule. It has quasiparticle form when it serves as a partner in a dd cold fusion reaction. In its 2-dimensional symmetry quasiparticle form, it most closely resembles the quasiparticle electron hosted by a sub-micron graphene crystallite.

Returning to rules that govern the submicroscopic world, there are two additional physical principles that affect Pauli controlled structures. The first of these is the famous Heisenberg uncertainty principle. One thing that the uncertainty principle says is that the mathematical* ideal point particle is an abstraction that does not exist in the submicroscopic world. It says that even the electron, which is sometimes almost a point particle, has a non-zero moment of inertia, whereas a mathematical point object has a zero moment of inertia. Each of the fundamental particles: electron, proton, neutron, and neutrino, have both a non-zero moment of inertia and a rotation about this moment of inertia axis called spin. This combination means that near-point objects have angular momentum. Spectral observations show that the spin angular momentum can have either of two orientations: it can be "up", designated 1/2, or it can be "down", designated -1/2. These options constitute a new, but limited 2-value degree-of-freedom. Where you could put one electron before the discovery of spin, you could put two electrons after the discovery of spin. The spin choice doubles the number of electrons allowed in each orbital of the maximally packed atoms making up the Periodic Table. Because of spin pairing, half the pairs of conduction electrons in a metal overlap each other, despite their mutual repulsion. Metals have twice the density that they would otherwise have. Nonetheless, the discovery of spin does not change the primary controlling role played by Pauli exclusion.

The non-physical nature of the submicroscopic mathematical* point, combined with Pauli exclusion, leads to the possibility of spin-paired composite particles. One example is the spin-zero double electron that fills the lowest energy orbital of the helium atom. The spin-zero electron pair provides the most densely packed, minimum energy electron matter structure available to neutralize the helium atom's double-charge nucleus. In this pairing the two electrons have canceling spins and coinciding positions in physical x,y,z space. The 2 electrons sit on top of each other. If they were subject to the nuclear strong force attraction, they would fuse. When this mutual overlap configuration applies to deuterons, it creates the geometry that makes deuteron cold fusion generate heat. Unlike spin-zero paired electrons, spin-zero paired deuterons are subject to the nuclear strong force attraction. When they

* As in Penrose's Platonic mathematical world. See Roger Penrose, *The Road to Reality*, Chapter 1.

have an overlapping 2-particle wave function, the strong force attraction pulls them together to form a helium-4 nucleus with the same multi-lobe quasiparticle geometry. The reaction takes place at a multiplicity of points instead of at a single point. The 2-deuteron overlapping form of wave function is favored by energy-minimization mathematics if the number of lobes (potential wells) exceeds about 1000. It is interesting to note that the deuteron quasiparticles of the metal oxide + nanometal composites used by Iwamura's team, and probably also those used by Arata and Zhang, have a 2-dimensional lattice symmetry similar to that of the quasiparticle electrons in graphene.

Listening to cold fusion tells us how we can proceed to develop commercial cold fusion heaters and other devices. The problem has been: How do you get deuterons to behave like electrons in a metal? Two decades of experimentation tells us that the same type of overlap can be achieved with deuterons. Another thing the experimental studies have told us is that reactive deuterons do not need to reside in orbitals containing an incredibly large number of orbital lobes (potential wells), such as are routinely occupied by electrons in metals. Experimenters can use the flexibility of metal nano-structures to meet the deuteron's need for the more easily achieved lower number of potential wells required for multi-lobe orbital deuteron fusion.

The Japanese cold fusion experiments using metal oxides and nanometals suggest the presence of a nuclearly reactive deuteron material coating a metal oxide. Envision a coating of 30 deuterons plus 30 neutralizing electrons spread out over a 2000-atom surface of CaO crystal. This material would be a polarizable, electrically neutral coating with a thickness less than 3% of the thickness of the adjacent metal monolayer. All of the coating's thickness is due to Pauli exclusion acting on the electron matter component of the electrically neutral deuterium system. The polarizability of the coating helps stabilize the interface and minimize system energy, just as polarizable water layers stabilize metal ions in solution.

Cold fusion experiments have confirmed the very large amount of energy predicted by theory for a nuclear fusion reaction. This large energy release means that only a small reaction volume within a much larger volume of reactor material needs to be nuclearly active. As a result, a multiplicity of 2-dimensional interface volumes provide sufficient reaction volume for most applications. The nano-palladium work of Arata and Zhang, and the independent work of Iwamura's group, show two different ways to create and maintain nuclearly reactive deuterium. Building on these methods can give us the abundant clean energy the world will need within the next decade. We must somehow obtain the funding needed to support cold fusion heater development.