

COLD NUCLEAR FUSION: A HYPOTHESIS

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Synopsis

A mechanism for low-temperature nuclear fusion reactions is described, in which first deuterium atoms donate their electrons to the conduction band of a metallic-crystal lattice, and second thermal motion allows bare deuterons to begin to approach each other, and third loose non-orbiting electrons from the conduction band shield the deuterons from their mutual electrostatic repulsion, until they become close enough together that they can be influenced by the strong nuclear force. This “electron catalysis” is similar in some respects to the well-studied phenomenon known as “muon catalysis.” Additionally, Quantum Mechanics (QM) allows for a large number of electrons to be involved, which in turn allows the energy of the fusion reaction to be distributed among many particles. The net result is that the overall reaction is the very simple $D+D\rightarrow He^4$, with no significant nuclear radiation of any sort released.

The author acknowledges that a hypothesis is just a guess, an attempt to create an explanation for certain observations. Additional observations are required before the guess can be considered to be anything more than that. The first version of the hypothesis was posted on the Internet in 2000, and now only exists at www.archive.org. This version of the hypothesis incorporates some additional material to explain a “typical” lack of nuclear radiation. There is some irony in that, detailed in Part Seven.

The first four parts of this paper contain a lot of background information, presented partly so that the interested and less-informed reader might gain an understanding of the subject, and partly to allow a “check” of how this hypothesis has been put together. Obviously if an error exists in the background information presented here, the conclusion that depends on it may be faulty.

1. Background: The Strong Nuclear Force and Potential Energy

One of the particles found in the atomic nucleus—the proton—possesses an electric charge, and two protons in close proximity will experience an electromagnetic-force interaction (of the “electrostatic” variety) in which they tend to strongly repel each other. This repulsion must be overcome if they (or many protons) are to persist together in an atomic nucleus. Since complex atomic nuclei do exist, it is apparent that there does exist a mechanism for overcoming electrostatic repulsion, and that mechanism is generally called “the strong nuclear force.”

In trying to understand how the strong force worked, a particular particle was hypothesized, to “mediate” or “carry” the force between nucleons. That particle was discovered

and is now known as the “pion”; it can interact with a nucleon in a trillionth of a trillionth of a second. Later, it was discovered that nucleons were themselves composed of smaller particles (“quarks”), and the strong force had to be involved in a different way (involving a different mediating particle, the “gluon”) to hold quarks together. It happens that pions are also made from quarks and that interactions involving pions and nucleons are mostly sufficient for explaining both how nucleons hold together in a complex nucleus and how nuclear fusion can occur (so quarks and gluons can be mostly ignored here).

An additional relevant point involves the concept of “potential energy.” This is known to take the form of mass, for particles that interact via the strong force. That is, if a nuclear reaction releases energy, the particles that have reacted can be measured to have lost mass. Before the reaction occurs, the energy-to-be-released can be said to only “potentially” exist, although more accurately it can be said that the reaction simply converts some mass into some energy, that energy and mass are different forms of a larger concept, often referred to as “mass/energy.”

2. Background: Anti-particles and Virtual Particles and Cloudiness

Over the years physicists have discovered that every electrically charged particle can exist in two varieties that are identical to each other in almost every way, the primary exception being that they have opposite electric charges. One particular “set” of charged particles appears to be what most of the matter in the Universe is constructed from, so we call that set “ordinary matter.” Any matter that is constructed from the opposite set of charged particles is called “anti-matter.” It is also known that almost every electrically neutral particle appears to be constructed from smaller charged particles. It is more commonly known that when ordinary matter and anti-matter interact with each other, they can destroy or “annihilate” each other, entirely converting their mass into energetic particles. It happens that some neutral particles (the neutral pion, for one), consist of quarks that can annihilate each other, and some neutral particles (like the neutron), consist of quarks that cannot annihilate each other. And as we might expect, the neutron is a much-longer-lasting particle than the neutral pion!

The development of QM, to explain events at very small scales, came with a number of unexpected consequences. One of them was a prediction, since verified, that something that might look like a perfect vacuum, a volume empty of all matter, is nevertheless not empty. All through that volume,

large numbers of subatomic particles are popping into existence out of Nothingness, persisting for a tiny fraction of a second and then vanishing again, back into the Nothingness from whence they came. They are known as “virtual particles,” and they normally pop into existence in pairs—a matter particle accompanied by an anti-matter particle. Every type of elementary particle that can possibly exist is a member of the set of virtual particles, popping/persisting/vanishing. This includes electrons, protons, neutrons, gluons, quarks, and of course pions, among many others. It happens that the pions that are involved in the strong force, holding nucleons together or causing nuclear fusion to occur, are always virtual pions. A peculiar fact about virtual particles is that no way exists to directly detect them during their moments-of-persistence. We can only detect side-effects of their having been there (such as the fact that lots of protons do stably exist together in the average complex atomic nucleus, or the observed energy that is released as a result of nuclear fusion). An even more peculiar fact is that, despite the inability (not-possible-even-in-theory) to directly detect virtual particles, *while* they exist, they are identical in every way to ordinary non-virtual particles. That is one of the keys to the hypothesis described in Part Eight of this document.

Another key is the fact that QM often describes a particle in an inexact or “uncertain” way. Statistics are a huge part of QM, and this most especially applies to the position or location of a particle. In general, the less mass/energy that a particle possesses, the less exactly its location can be specified. For a very light particle like the electron, the total amount of uncertainty in specifying its location gives us the impression it might be anywhere within a rather voluminous region, rather like a cloud. Indeed, QM can give us the impression that sometimes the electron should be considered as existing simultaneously at every single point within that cloud.

3. Background: Deuterons and Nuclear Fusion

The “deuteron” is a particle that consists of just one proton and one neutron locked together by the strong nuclear force. It is typically found associated with an electron, and together they qualify as a member of the set of hydrogen atoms. On Earth about one hydrogen atom out of every 6500 is deuterium-hydrogen, with a deuteron as its nucleus. (Deuterium is sometimes called “heavy hydrogen,” since a deuteron has twice the mass of the more-common hydrogen nucleus, and thus water made from pure deuterium is known as “heavy water.”)

For it to be possible for two deuterons to fuse together, two things must have already happened to prepare the way. First, the electron normally associated with each deuteron must be stripped off. This is normal at extremely high temperatures, but that is not the only way it can happen, as described in Part Five. Second, the two deuterons must closely approach each other, despite the mutual repulsion they experience due to electromagnetic interactions. Extreme temperatures and/or pressures can make that happen, too, and thus do the stars shine as a result of many individual fusion reactions in their cores. It is obvious that if cold fusion can actually happen at ordinary temperatures and pressures, there must be another way to do this thing—and at least one such is known, as described in Part Four.

Before getting to that, though, it is necessary to describe something known as the “interaction cross-section.” This is basically a measure of the volume of space surrounding a

particle, in which it can significantly interact with a second particle. For the strong nuclear force, this range is pretty limited, but two deuterons *must* get within that range before they have any significant chance of fusing.

One way to describe the limits of the range of the interaction cross-section is to discuss virtual pions a bit more. It has already been mentioned that they can basically pop into temporary existence everywhere and all the time, but it needs to be said that while they exist, they can move a short distance before they vanish again. (This is normally highly related to the “cloudiness” of the particles. The less mass that virtual particles possess, the greater is the size of their cloud of possible locations, meaning the farther they can travel before they must vanish.) For the strong force, the distance that virtual pions can traverse (and pions are mid-dling-weight particles) is closely linked to the range of the interaction cross-section. (For different nuclei there are other complicating factors that can affect the range, which don’t concern us here.)

The simplest interaction between virtual pions and two adjacent deuterons goes something like this: In the space between the deuterons, a pair of pions pops into temporary existence. These are electrically charged (not all pions are neutral, and while every pion consists of one quark and one anti-quark, the charged pions do not contain mutually-annihilatable quarks). The negatively charged pion approaches the positively charged proton in one deuteron, while the positively charged pion approaches the neutron in the other deuteron. If the deuterons are close enough, the two pions will both be absorbed and vanish (ending their temporary existence) and the strong force (via plenty more virtual pions) will now be affecting the two deuterons, working to make them approach even more closely, against their mutual electrostatic repulsion, for final merging/fusing.

4. Background: Fusion by Muon Catalysis

This phenomenon was originally observed in liquid-hydrogen bubble-tanks at various particle-accelerator facilities in the 1950s. “Cold fusion” it most certainly is!

The muon was discovered by physicists while they were searching to find the predicted pion. It is almost identical to an electron, except that it is 206 times as massive as an electron and it has a natural lifespan of about 2 microseconds (while electrons seem able to persist forever). Neither electrons nor muons are able to “feel” the strong nuclear force; they mostly interact with other particles via electromagnetic effects.

During its short lifespan a muon is able to do quite a bit. For starters, it can replace the electron in orbit around a hydrogen nucleus, and because it has 206 times more mass than the electron, it orbits 206 times closer. A “muonic” hydrogen atom is quite a tiny thing, compared to a normal hydrogen atom. It also might be called “electrically dense.” The electric charge of the muon is concentrated at the surface of the small volume of space which is a muonic hydrogen atom, while the charge of an electron in an ordinary atom is spread out over a much greater area. This fact allows the muonic atom to pass right through the electron shell of a neighboring hydrogen atom, simply because the electrostatic repulsion of that shell isn’t concentrated/dense enough, to make the muonic atom bounce off (as it can easily do for other and ordinary atoms).

Next, inside the electron shell there is an electrostatic

attraction between the muon-shell of the invading atom and the nucleus of the invaded atom. The muon actually both helps the nuclei of the two atoms to approach each other and electrically shields them from mutual electrostatic repulsion.

It happens that the muonic atom can approach the other atomic nucleus closely enough for the strong force to come into play, especially if the two hydrogens are both of the deuterium variety. Fusion occurs, even in liquid hydrogen, and the muon shoots out and becomes able to “catalyze” some more fusions in the same manner, before its short lifespan finally ends.

When muon catalysis was first discovered, it was quickly analyzed to find out if the reaction could form the basis of a power plant. Unfortunately, its lifespan is too short, by a factor of five or six. (Perhaps if the atoms of deuterium, which we want to catalyze to fusion, were squeezed closer together, by a factor of more-than-that? Might “inertial-confinement fusion” efforts benefit if a few muons were injected into the implosion? It is the author’s understanding that inertial-confinement fusion experiments involve a much higher squeeze than a mere factor of five or six.)

A not-formally-published analysis that the author once did, regarding muon catalysis, involved a fairly standard equation in particle physics that relates the energy and velocity of the reaction products to the probability that a particular reaction could occur (the higher the energy, the higher the velocities and the more closely the speed of light was approached, the less likely is the reaction). A speculation was formed that if the muon could somehow carry away some of the energy of the reaction of two fusing deuterons, then the reaction itself might take the form of $D+D\rightarrow He^4$, generally considered to be the “best” possible type of fusion reaction (and extremely rare in Nature). The analysis concluded that this might actually occur about 25% of the time—the muon leaves the scene of the fusion carrying quite a lot of energy and moves at a quite-high velocity—but the author knows of no tests that were conducted to measure the products of muon-catalyzed fusions in deuterium. It is still only a speculation that that possibility might ever occur.

The hypothesis described in Part Eight includes a mechanism by which a muon could be involved enough in a fusion reaction, despite not being able to “feel” the strong force, to carry away some of the energy of the reaction. This increases the author’s hope that the analysis just mentioned might have some validity, even if the percentage turns out to be erroneous, and a variation of that analysis has therefore become part of the hypothesis in Part Eight.

One other thing about muons needs to be mentioned here. If a muon replaces an electron in a heavy atom like gold or mercury or lead, it will tend eventually to replace one of the innermost electrons of that atom, and, because it will orbit the nucleus 206 times closer than that electron, it will actually be orbiting the nucleus within the periphery of the nucleus. It does so without “significantly interacting” with any of the nucleons. It simply orbits due to the electromagnetic force, and doesn’t normally do anything else. This means that under circumstances in which an electron (identical in most ways to a muon) might pass equally near a nucleus, we can expect that again no “significant interaction” will occur between the electron and any of the nucleons. The electromagnetic force might cause the electron to follow a hyperbolic path as it passes through the periphery of the nucleus, but nothing else need be expected.

5. Background: Metals, the Conduction Band, Alloys, and Hydrogen

In chemistry most of the chemical elements are described as having either “metallic” or “nonmetallic” properties. Some elements sometimes have properties of one and sometimes have properties of the other (tin becomes nonmetallic when the temperature drops low enough), and while these are called “transitional elements,” the key observation at a given moment for any of them involves whether or not its properties are metallic.

Metals have a set of properties which are generally widely known and mostly need not be discussed here. The particular property which concerns us is the ability of a metal to conduct an electric current. This property exists because most of the atoms in the metal contribute an electron into a shared pool which is known as “the conduction band.” Those electrons are able to freely move throughout the body of the metal, in-between its constituent atoms.

When different metals are mixed together (usually in the molten state), a thing known as an “alloy” is created and it generally remains true that most of the atoms in that alloy, regardless of type, have contributed an electron into the conduction band of the overall metal. (Alloys tend to be poorer conductors than pure metals, so it could well be true that many atoms fail to contribute.)

The chemical element hydrogen is normally a non-metal, but various theorists have reached the conclusion that it should be possible for hydrogen to exist in a metallic state. Special conditions such as extremely high pressures are expected to be required for metallic hydrogen to exist. Nevertheless, the idea that metallic hydrogen can exist at all automatically means two things which are very relevant to the hypothesis presented in Part Eight. First, for it to be metallic, it must have a conduction band. Second, for a conduction band to exist, each one of many individual atoms of hydrogen must have given away its sole electron into the shared pool! This means that metallic hydrogen is a place where loose nuclei can exist, “voluntarily” stripped of the electrons that normally prevent nuclei from getting anywhere near each other!

Another fact is that hydrogen is able to permeate certain metals, such as the element palladium, to a large extent. The extent can be truly remarkable. If you take an empty container and an equal container that surrounds a solid mass of pure palladium, and then apply pressure to feed hydrogen into the containers, you can actually pack more hydrogen into the solid palladium than you can pack into the empty container, at the same pressure! We might conclude from that observation the idea that the hydrogen is “alloying” with the palladium. It is quite logical that if hydrogen can exist in a metallic state, then it should also be able to exist as an alloying substance. So, isn’t it obvious that if a hydrogen can add its sole electron into the conduction band of the palladium, no different from some other atom in an alloy donating an electron, then the extraordinarily tiny bare hydrogen nucleus will be floating in the crystal lattice of the metal—and that greater numbers of tiny nuclei can fit in a given volume of space than can fit whole hydrogen molecules there?

One problem with the preceding is that the chemical bond between two hydrogen atoms is a fairly strong bond, and that if the molecule breaks in order for the atoms to form an alloy, then where did the energy come from to break

that bond? Is it possible that special circumstances apply, for example similar to the situation in which carbon dioxide and water—both types of molecules having high-strength chemical bonds—can almost effortlessly combine to form carbonic acid?

6. Background: Excess Heat Production in Special Electrolytic Cells

In 1989 the original cold fusion experiment was announced. Heavy water was electrolyzed using palladium electrodes and individual atoms of deuterium, released by the electrolysis process, may be presumed to have permeated into the palladium (one electrode only). In some of the test-cells, after a certain amount of electrolysis had occurred, a quantity of heat began to mysteriously appear. The researchers were unable to explain the source and magnitude of that heat, except by invoking nuclear fusion reactions between deuteriums inside the palladium. Apparently even the simple and reasonable chemical reaction $H+H\rightarrow H_2$ (involving deuterium and not ordinary hydrogen atoms), by occurring inside the solid palladium electrode, was not energetic enough to explain the observed heat (not to mention a couple of explosions that were claimed to have happened). Note that per Part Five, it might not be so reasonable to expect the $H+H\rightarrow H_2$ chemical reaction to occur, if it is normal for hydrogen molecules to break apart when being packed into the metal.

7. The Controversy

In response to the announcement, many physicists concluded that the experiment must have contained some sort of flaw. Where was the radioactive and easily detectable nuclide tritium that is commonly produced in fusions between deuterons? Where were the gamma rays? And where were the irradiated-into-radioactivity pieces of laboratory equipment, due to neutrons that are also commonly released in fusions between deuterons? How could deuterium atoms lose their electrons and approach each other closely enough to fuse? And worst of all, why was the experiment so difficult to duplicate? (But even the expert chemists who announced the discovery could not produce excess heat every time; why should physicists that are generally less-expert at chemistry expect it to be easy?)

There is some irony in the fact that the most-desired fusion reaction, from the theoretical standpoint, is $D+D\rightarrow He^4$, and the possibility that cold fusion can deliver it is ignored while physicists ask where the reaction products are, from less-desired fusion reactions!

8. The Hypothesis

The author hopes that Part Five of this document adequately explains how individual deuterium atoms, once released by electrolysis, could exist in “bare” form inside solid palladium. That is, one of the two “obvious” questions stated in Part Seven may have an acceptable answer. And certainly there is no reason to worry about how whole molecules can break apart, if the deuterium/hydrogen enters the palladium as individual atoms, thanks to electrolysis.

Perhaps one way to verify that part of the hypothesis is to try pressuring pure deuterium gas into a piece of palladium. If excess heat appears after enough gas has been added, then using electrolysis is not necessary, and the excess heat would

still need to be explained. Note that in this particular case the simple chemical reaction $H+H\rightarrow H_2$ cannot be the answer, simply because this experiment starts with deuterium molecules (H_2^2), and nothing special was done to break them apart. As Sherlock Holmes pointed out: “When the impossible has been eliminated, then whatever remains, however improbable, must be the truth.” If fusion is indeed occurring inside the palladium, then deuterium atoms *must* give up their electrons somehow, first. Part Five described something that may be improbable, hydrogen being an alloying substance, but can any reader show that it is impossible?

Next, the lack of tritium and neutrons is easily explained if the particular fusion reaction that occurs is always the ideal $D+D\rightarrow He^4$. However, that reaction yields considerably more energy than the reactions that yield tritium (plus a proton) or a neutron (plus He^3), and does not offer any easy way to “dump” that energy. The normal way for the reaction-energy to be carried off, in fact, is for one of the other two reactions to occur! This hypothesis therefore must offer a mechanism for carrying away the very considerable energy of the ideal deuteron-fusion reaction, even to the extent that no gamma rays need be produced.

Let us approach that mechanism by first considering muon catalysis in more detail. It has already been described how two virtual pions can, at maximum range, begin the process by which the strong nuclear force can cause two nearby deuterons to eventually fuse. Note that for one of the pions to reach the nucleus of the muonic atom, it must pass through the “shell” of the orbiting muon. That was described as being a fairly dense thing, in comparison to the electron shell around an ordinary atom. However, the virtual pion is a single particle and qualifies as being even “denser,” so it can be expected to pass through the muon shell. Nevertheless, both the pion and the muon are electrically charged, and while the virtual pion exists, it is identical to a non-virtual pion. Therefore it is completely reasonable to think that the muon and the pion should interact with each other through the electromagnetic force. What will the result be?

The virtual pion is very likely travelling at high speed toward the nucleus of the muonic atom (when virtual particles pop into existence, they may be moving at any speed up to almost the speed of light). When it is absorbed by a nucleus some potential energy becomes converted into kinetic energy (the nucleus starts to move somewhere). The amount that gets converted depends only on how much time has passed since the virtual pion popped into existence (the more time, the less potential energy is converted), and has nothing to do with the speed of the pion at the moment of absorption. This means that the pion could collide with the muon and pass some energy to it, before being absorbed! The “bookkeeping” of virtual-energy events will then require that, during the absorption of the virtual pion, the converted potential energy will be divided into some kinetic energy for the nucleus and some kinetic energy for the muon.

There will be many virtual pions involved in causing two deuterons to fuse. There will be many opportunities for interactions with the muon to give it more kinetic energy. And perhaps some percentage of the time (25%?) the muon will gain so much energy, at the expense of the colliding deuterons, that when they finally fuse they will stick together as a helium-4 nucleus.

Inside a piece of deuterium-soaked palladium, we now

start with the notion that some fraction of the deuterium atoms have donated their electrons to metal's conduction band, and have become bare deuterons. We know that they have some thermal energy, and every now and then two of the deuterons should happen to begin approaching each other. Normally, even discounting the electron shells they usually possess, they cannot get very close to each other, because they electrostatically repel each other.

However, things are far from normal here, because the deuterons are literally floating through "clouds" of "cloudy" electrons in the conduction band of the palladium. At any given moment, especially because the deuterons are able to electrostatically attract electrons, 10 or 100 or 1000 or even more electrons might, thanks to QM, be spending small parts of their time (and cloudiness-of-location) in-between the two deuterons. The net effect is that those electrons collectively shield the deuterons from each other, preventing electrostatic repulsion, exactly as a muon can. Furthermore, since none of those conduction-band electrons are in orbit around either deuteron, the electrons can approach the deuterons arbitrarily closely—we should be able to expect some of those electrons to pass right through the deuterons without, as described in Part Four, "significantly interacting" with their nucleons.

It now seems reasonable that the two deuterons actually can approach each other closely enough for the strong nuclear force to come into play. Please note a significant difference between this simple *allowing* of the deuterons to randomly meet, compared to a catalyzing muon's effective attraction of one nucleus to another, as described in Part Four. Fusion is practically guaranteed when a muon is involved, but in a metal's conduction band, thermal deuterons can fuse only if they randomly happen to be on a nearly perfect collision course (imperfection is related to their interaction cross-sections). And because deuterons are so tiny, it logically follows that a great many deuterons need to be loaded into the conduction band, before significant quantities of fusions become probable.

If two deuterons can almost meet in a metal's conduction band, then there will be virtual pions zipping across the distance between them. And now, instead of there being a muon for some of the pions to interact with, there may be 10 or 100 or 1000 or even more electrons for the pions to interact with. To properly grasp the full possibilities here, simply recall that a pion can interact with a nucleon in a trillionth of a trillionth of a second. That means if the whole fusion reaction takes place in a trillionth of a second, there is still time for a trillion virtual pions to zip across the distance between them! How many of those pions can kick a different electron, and give it some energy? Every time that happens, less energy is left for the fusion to cause an He-4 nucleus to break apart. Or for a gamma ray to be emitted, either.

The preceding, then, is the hypothetical mechanism that allows the ideal fusion reaction for deuterons to occur inside palladium metal. Can this hypothesis explain any other things? Perhaps. For example, some very recent experiments involving a very thin layer of palladium have been showing signs of less-than-ideal fusion reactions. This could most obviously be a consequence of there being enough electrons in the conduction band to initiate fusion, but not enough (three-dimensionally) to carry away enough energy so that only the ideal reaction occurs. Next, it is the author's under-

standing that Jupiter and Saturn appear to be somewhat warmer than expected. They are not big enough to create fusion as stars do, but they are 90% hydrogen and do have enough gravitation for some of that hydrogen to be compressed into the "metallic" state. In this case the ordinary protium-hydrogen would be providing a conduction-band "cloud" in which deuterons could float and eventually find mates. Fusions could be happening at a slow rate, despite non-stellar magnitudes of gravitation.

It is traditional to now suggest an experiment to test the hypothesis of conduction-band electrons catalyzing fusion reactions: Construct a small spherical pellet of frozen deuterium molecules. Surround it with a thin shell of frozen hydrogen (ordinary "protium" molecules). Place the pellet in an "Inertial Confinement Fusion" test-device. Blast the pellet with a limited amount of energy from multiple directions. This will cause the shell of the pellet to explode and the body of the pellet to implode. We want a *limited* implosion only. Specifically, we only want to implode the pellet to the point—and not beyond that point!—where it forms metallic hydrogen. In this case we would have metallic deuterium, of course, complete with a conduction-band of electrons. If the hypothesis presented in this essay is correct, there should be some evidence of fusion occurring as that small piece of metal explosively decompresses. Some of those fusions may even be of the ordinary varieties that yield tritium and He-3, due to the small quantity of metal involved.

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- In 2000 the author posted a less complete version of this document on the internet, which now can only be found at <http://web.archive.org>; use WayBack Machine to search for http://www.halfbakery.com/idea/Cold_20Nuclear_20Fusion

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