Experimental Implications of Neutron Isotope Theory

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Initial Assumptions of the Theory

The neutron isotope theory of low energy nuclear reactions (LENR) is based on the assumptions that no new fundamental particles are required, that quantum mechanics is the appropriate analytical tool, and that the coulomb barrier prevents LENR reactions between charged particles. It follows that every observed reaction must involve at least one neutral reactant. Potential neutral reactants are limited to neutrons and to isotopes of the neutron. (Note that neutron isotopes, although not widely recognized or studied, are not new fundamental particles.) Finally the experimental scarcity of neutrons in LENR phenomena leaves neutron isotopes as the only significant neutral reactants.

Neutron Isotope Symmetry

Neutron isotopes have different nuclear symmetries than ordinary nuclei. Because neutrons are indistinguishable from each other the neutron isotope wave function must remain unchanged by any permutation of them. When a neutron isotope undergoes beta decay in which a neutron is replaced by a proton, I assume that the wave function of the resulting hydrogen nucleus remains unchanged by any permutation of the neutron-proton mix.

In order to distinguish between ordinary atoms and atoms having permutation-symmetric nuclei I indicate the number of protons in an ordinary nucleus by the chemical symbols H, He, Li, and so on. For neutron isotopes and their sequential beta decay atoms I use the symbols in bold print **n**, **H**, **He**, **Li**, and so on including **n** for nuclei with no protons. And for all nuclei I indicate the total number of nucleons (neutrons and protons together) by a superscript to the left of the chemical signal. In this notation a neutron isotope composed of 100 neutrons is represented by $^{100}\mathbf{n}$, a hydrogen atom with a permutation-symmetric nucleus that contains 100 nucleons including one proton is represented by $^{100}\mathbf{H}$, and a carbon atom with a permutation-symmetric nucleus that contains 100 nucleons including 6 protons is represented by $^{100}\mathbf{C}$.

In what follows I refer to permutation-symmetric nuclei as symmetric nuclei, and I refer to atoms having symmetric nuclei as symmetric atoms. The stability of ordinary matter suggests that symmetric nuclei are a few MeV per nucleon more massive than ordinary nuclei.

Symmetric Atom Reactions

The theory suggests that interactions between neutron isotopes and deuterium (^{2}H) can support a family of reactions that maintain a concentration of ambient neutron isotopes within an active reaction volume. This is analogous to the interaction between neutrons and uranium that maintains a concentration of ambient neutrons in an ordinary

nuclear reactor. I begin by considering the various reactions that might be expected for a neutron isotope $^{A}\mathbf{n}$ that is immersed in deuterium gas.

These reactions include neutron isotope growth with deuterium fuel and ordinary hydrogen ash that are capable of increasing the size of a neutron isotope without limit,

$$\begin{aligned} {}^{A}\mathbf{n} + {}^{2}\mathrm{H} &\rightarrow {}^{(A+1)}\mathbf{n} + {}^{1}\mathrm{H} \\ {}^{(A+1)}\mathbf{n} + {}^{2}\mathrm{H} &\rightarrow {}^{(A+2)}\mathbf{n} + {}^{1}\mathrm{H} \\ {}^{(A+2)}\mathbf{n} + {}^{2}\mathrm{H} &\rightarrow {}^{(A+3)}\mathbf{n} + {}^{1}\mathrm{H} \\ &\ldots \text{ and so on.} \end{aligned} \tag{1}$$

They also include beta decays of symmetric atoms to other symmetric atoms containing one more proton and one more electron,

$$\begin{aligned} {}^{A}\mathbf{n} &\rightarrow {}^{A}\mathbf{H} \\ {}^{A}\mathbf{H} &\rightarrow {}^{A}\mathbf{He} \\ {}^{A}\mathbf{He} &\rightarrow {}^{A}\mathbf{Li} \\ &\ldots \text{ and so on,} \end{aligned} \tag{2}$$

until the build-up of nuclear charge makes further beta decay endothermic. In addition alpha decay becomes possible for nuclear charge ≥ 2,

$$\begin{aligned} {}^{A}\mathbf{He} &\rightarrow {}^{(A-4)}\mathbf{n} + {}^{4}\mathrm{He} \\ {}^{A}\mathbf{Li} &\rightarrow {}^{(A-4)}\mathbf{H} + {}^{4}\mathrm{He} \\ {}^{A}\mathbf{Be} &\rightarrow {}^{(A-4)}\mathbf{He} + {}^{4}\mathrm{He} \\ &\ldots \text{ and so on.} \end{aligned} \tag{3}$$

In addition to reactions (1-3) there must be others that increase the number of neutron isotopes. Otherwise there would be no chain reaction to create and sustain the concentration of ambient neutron isotopes required for LENR. The theory proposes neutron isotope fission reactions such as

$$\begin{aligned} {}^{A+B+24}\mathbf{n} + {}^{104}\mathrm{Pd} &\rightarrow {}^{A}\mathbf{n} + {}^{B}\mathbf{n} + {}^{128}\mathrm{Pd} + 48 \text{ MeV} \\ {}^{A+B+12}\mathbf{n} + {}^{40}\mathrm{Ca} &\rightarrow {}^{A}\mathbf{n} + {}^{B}\mathbf{n} + {}^{52}\mathrm{Ca} + 43 \text{ MeV} \\ &\ldots \text{ and so on,} \end{aligned} \tag{4}$$

where the indicated reaction energies are approximations subject to revision as the theory evolves.

Reactions (1-4) are qualitatively different from the nuclear reactions of ordinary atoms. In the ordinary hot fusion reaction, $^{2}\mathrm{H} + {}^{2}\mathrm{H} \rightarrow {}^{3}\mathrm{H} + {}^{1}\mathrm{H}$, the energy released in the reaction ends up as kinetic energy of the $^{3}\mathrm{H}$ and $^{1}\mathrm{H}$ products. This is characteristic of reactions involving ordinary nuclei, which generally release their energy as kinetic energy of their products. Reactions involving neutron isotopes and other symmetric reactants are different. Symmetric nuclei tend to be very large, containing hundreds or thousands of nucleons. The excited states of a symmetric nucleus are very similar to each other and are strongly coupled. They can be described as combinations of nuclear phonons (quantized vibrations of a nucleus analogous to the quantized vibrations of an

ordinary solid). Because nuclear phonon wave functions are strongly coupled, they are mutually involved in nuclear reactions, and the energy released in a reaction ends up as nuclear phonon excitations. In this way the symmetric product nuclei absorb most of the reaction energy released. They become hot. The momenta and kinetic energies of the reaction products in reactions (1-4) are negligible after separation, and the reaction energy finally dissipates in the form of electromagnetic radiation as the hot product nuclei cool down.

I assume that beta decay reactions (2) are much faster than alpha decay reactions (3), with the consequence that charged symmetric atoms $^{A}\mathbf{Z}$ are most often found with maximum charge Z_{max}. The value of Z_{max} depends on A, and increases as A increases because the charge radius increases in proportion to $A^{1/3}$. Larger Z_{max} implies slower alpha decay because the rate of alpha decay is increasingly suppressed by the growing coulomb barrier. There is no limit to the slowing of alpha decay as A and Z increase, in consequence of which very large symmetric atoms can have very large Z_{max} and very long lives.

I assume that such large symmetric atoms exist in nature at very low concentrations. A rare long-lived isotope such as **O, F,** or **Ne** can survive for days, weeks, months, or years before a statistical excess of alpha decays (3) reduces its charge to zero generating a neutron isotope **n**. In this way decays of a rare long-lived isotope can randomly produce the rare **n** that can initiate LENR reaction in a suitable environment. The wait can be long in a laboratory that has not previously been exposed to active LENR. But the initial reaction generates populations of long lifetime **Z** isotopes that survive in the laboratory where they were formed until a second LENR reaction is attempted. The wait for initiation of a second reaction is shorter than it was for the first reaction, owing to the large number of long lifetime precursors generated by the first reaction that survive in the equipment and laboratory.

I assume that reactions (1) are much faster than reactions (2) and (3). A neutron isotope **n** introduced into deuterium gas will grow very rapidly via successive reactions (1) until finally a slower beta decay (2) changes it to **H**. Because **H** is charged the coulomb barrier prevents further interaction with deuterium, and only reactions (2) and (3) are possible. Then **H** undergoes beta decays (which I assume are faster than alpha decays) until it reaches a nuclear charge that makes further beta decay endothermic (for example **O**, **F** or **Ne**). Then it must wait for alpha decay to a smaller isotope having smaller nuclear charge for which beta decay can resume. Beta and alpha decays continue until the nuclear charge shrinks to zero producing a neutron isotope. The regenerated **n** then undergoes rapid growth again by reaction (1) to large size where it beta decays to **H** again, and then continues through a long chain of beta and alpha decays again, and so on as before. I envision this cycle to be continued indefinitely.

Reactions (1-3) change both the size and the charge of a symmetric atom, but they do not increase the number of symmetric atoms, nor do they often reduce the number. Reduction in the number of symmetric atoms is possible only with reactions such as

$$^{6}\mathbf{He} \rightarrow {}^{4}\mathrm{He} + 2\mathrm{n} \qquad (5)$$
$$^{6}\mathbf{H} \rightarrow {}^{3}\mathrm{H} + 3\mathrm{n}$$

that convert symmetric atoms into ordinary atoms, and that become exothermic for nucleon number less than or equal to about 6. I assume that shrinkage of a symmetric atom to this size is sufficiently improbable that it seldom happens. In consequence the aggregate number of symmetric atoms in an active reactor would decrease only slowly in the absence of fission reaction (4), and only a small contribution from reaction (4) would be required to maintain steady state. Most of the time symmetric atoms alternate between growth by reactions (1) and shrinkage by reactions (2) and (3), and only rarely do they reach a small enough size that they can convert exothermically to normal nuclei via reactions (5). This implies that reactions (1-3) and the power they generate are close to a steady state balance in a deuterium gas.

At steady state, four instances of reaction (1) consume ^{2}H and generate ^{1}H in the overall reaction

$$^{A}\mathbf{n} + 4(^{2}\mathrm{H}) \rightarrow {}^{A+4}\mathbf{n} + 4(^{1}\mathrm{H}), \qquad (6)$$

and two instances of reaction (2) together with one instance of reaction (3) consume $^{A+4}\mathbf{n}$ and generate ^{4}He in the overall reaction

$$^{A+4}\mathbf{n} \rightarrow {}^{A}\mathbf{n} + {}^{4}\mathrm{He}. \qquad (7)$$

Together at steady state these amount to

$$4(^{2}\mathrm{H}) \rightarrow 4(^{1}\mathrm{H}) + {}^{4}\mathrm{He} + 21\mathrm{MeV}. \qquad (8)$$

Neglecting a small steady state energy contribution from fission reactions (4), the liberation of 21 MeV of energy per helium atom agrees with observation to within the experimental and theoretical uncertainty.

Transmutation Experiments

Neutron isotope theory suggests that transmutations occur in two steps. The first step transfers neutrons from a neutron isotope to a target ordinary nucleus, producing an ordinary neutron-rich isotope of the target element. An example is

$$^{A}\mathbf{n} + {}^{23}\mathrm{Na} \rightarrow {}^{A-4}\mathbf{n} + {}^{27}\mathrm{Na}. \qquad (9)$$

In general the number of transferred neutrons (4 in this example) is the number that maximizes the energy released in the reaction. The second step is a series of beta decays of the ordinary neutron-rich nuclei,

$$^{27}\mathrm{Na}(300\mathrm{ms}) \rightarrow {}^{27}\mathrm{Mg}(9.5\mathrm{min}) \rightarrow {}^{27}\mathrm{Al}(\mathrm{stable}). \qquad (10)$$

Each decay is accompanied by characteristic gamma rays by which the decaying isotope can be identified. And time differences between gamma rays can reveal half-lives of decaying particles.

Transmutation reactions such as (9) are closely are closely related to fission reactions such as (4). In general, to every transmutation reaction

$$^{A+B+C}\mathbf{n} + {}^{D}Z \rightarrow {}^{A+B}\mathbf{n} + {}^{C+D}Z \qquad (11)$$

there corresponds a fission reaction

$$^{A+B+C}\mathbf{n} + {}^{D}Z \rightarrow {}^{A}\mathbf{n} + {}^{B}\mathbf{n} + {}^{C+D}Z. \qquad (12)$$

Although reactions (11) and (12) are both transmutation reactions, I term reaction (12) a fission reaction because of the essential role of fission reactions (4) in supporting chain reactions. Transmutation reaction (11) is expected to be more exothermic than fission reaction (12) because (in the liquid drop model) the surface energy of a pair of droplets ($^{A}\mathbf{n} + {}^{B}\mathbf{n}$) is larger than that of the single droplet ($^{A+B}\mathbf{n}$) they form when combined.

Growth reaction (1) increases by one the number of neutrons bound in symmetric nuclei. And each of reactions (11) and (12) decreases the number by C. If the rate of reaction (1) is less than C times the sum of the rates of reactions (11) and (12) the number of neutrons bound in symmetric nuclei will shrink, symmetric nuclei will shrink and disappear, and reaction will cease. In order for a chain reaction to exist the rate of reaction (1) must be greater than C times the rates of reactions (11) and (12) summed over every element Z in the reaction volume (there may be more than one such element Z). This requires that the concentrations of elements Z be sufficiently small. Under these conditions reaction (12) assures that there will remain a small net growth in the number of symmetric nuclei, and that a chain reaction can be established.

Iwamura and his associates have investigated transmutation in a gas reactor. The active element is a palladium sheet 0.1 mm thick and about 25 mm square, the top surface of which is coated with alternating thin layers of CaO and Pd. This surface is exposed to deuterium gas and the bottom surface is exposed to vacuum. During operation deuterium enters the Pd sheet at the top and emerges from the bottom. LENR was observed to produce heat, X-rays, and transmutations of elements that had been deposited in atomic thickness on the top of the Pd/CaO complex. Transmutations included Ba → Sm, Cs → Pr, Sr → Mo, and many others.

The theory suggests that the palladium sheet need not participate directly in LENR. Its role is to support the active CaO/Pd and target element layers, and to allow D to flow through them as it reacts with them. As the D flows through, the massive isotopes **He**, **Li**, **Be**, **B**, …, which are insoluble in Pd are collected at the CaO/Pd surface complex that supports the transmutation target element. In this way the gas reactor concentrates the reactants for a chain reaction and the element to be transmuted in a thin reaction volume at the upper surface of the supporting palladium sheet.

Transmutation reactions begin with transfer of neutrons from a neutron isotope to an ordinary element, as in reaction (11). The product is a neutron-rich isotope of the target element that with few exceptions is unstable against beta decay. Because neutron transfer reactions have symmetric products that absorb the reaction energy as nuclear phonons, such reactions do not produce products with appreciable kinetic energies, nor do they produce gamma rays. On the other hand the transmutation products are ordinary isotopes that emit characteristic gamma rays by which they can be identified when they decay. Such identification of the products of transmutation of target elements would provide a body of quantitative data that could distinguish among theories.

The presence of gamma rays in transmutation experiments is a vital necessity of neutron isotope theory. If they are not found the theory will have been disproven and will have to be abandoned. For this reason I give highest priority to the confirmation of transmutation gamma rays.

Fluid Deformation Experiments

It is well known that shear deformation of a fluid (liquid or gas) speeds the rate of reaction between atoms in the fluid. This happens because mechanical flow is much faster than diffusion for bringing potential reactants close enough to each other to react. In Fleischmann-Pons reactors the maelstrom of bubble activity at an active cathode increases the rates of growth reactions (1) by a very large factor. Great numbers of symmetric isotopes are created there and are carried by convection currents throughout the electrolysis cell. Reactions far from the cathode proceed at a leisurely pace limited by the small fluid shear rate in quiescent fluid. Using a nickel cathode and an ordinary water electrolyte Oriani has observed energetic particles from LENR reactions in the electrolyte and in the vapor over the electrolyte.

Initially the hydrogen released during electrolysis goes into solution in the electrolyte. When the hydrogen concentration gets high enough bubbles form and grow. This happens quickly with a nickel cathode, but not with a palladium cathode. Because hydrogen is highly soluble in palladium, much of the dissolved hydrogen diffuses directly into the palladium without bubble formation. The fluid shear deformations associated with bubble growth are fewer and smaller than with a nickel cathode which does not soak up and remove significant hydrogen from solution in the electrolyte. In consequence a given power into electrolysis produces less fluid shear with a Pd cathode than with a Ni cathode. LENR reaction is less likely. Only when Pd has been saturated with deuterium does the flow of deuterium into Pd cease. Then bubble formation becomes stronger and LENR reaction can become robust.

With proper compositional balance bubble formation is strong, and is usually concentrated at surface imperfections that enhance the rate of bubble nucleation. Nuclear reaction is fast near a nucleation site. Available ^{2}H is consumed in a flash of chain reaction in which growing bubbles, expanded by heat, accelerate the rate of fluid shear and the rate of nuclear reaction. The temperature can rise high enough to melt the cathode surface. The bubble nucleation site is blown free of electrolyte, shutting down electrolysis at that site. Active electrolysis then must shift to other sites. In this way electrolysis is concentrated at "hot spots". After a flash of reaction there is a short period of time during which the bubble nucleation site cools down, electrolyte returns, and electrolysis resumes. New bubbles appear at the site of the old. The new bubbles grow and support a new flash of reaction. Overall I expect a sparkling of flashes of thermal energy in the electrolyte over the surface of the cathode.

Heat After Death Experiments

According to neutron isotope theory, LENR reactions associated with Fleischmann-Pons reactors occur primarily in the electrolyte. Electrolysis generates gas bubbles that grow in the electrolyte. Bubble growth causes mechanical shearing of the

electrolyte. Mechanical shearing increases the neutron isotope growth rate by many orders of magnitude. This is the significant role of electrolysis.

Pons and Fleischmann discovered heat after death. They boiled away the liquid from an operating electrolytic reactor until the reactor was dry, after which they observed that the reactor continued to produce thermal energy with an intensity that diminished with a half life of about an hour. In this experiment, all isotopes necessary for a chain reaction were present (deuterium in the solid LiOD electrolyte residue and Pd in the inactive cathode). But the chain reaction ceased. Because there were no bubbles, there was no fluid shearing, and no appreciable neutron isotope growth. Thermal energy production resulted only from beta and alpha decays in reactions (2) and (3) as the population of massive isotopes shrank and finally disappeared via reactions (5).

Mizuno observed heat after death during operation of an electrolytic reactor after input power was turned off. The reactor continued to produce thermal energy for several days with no evidence of diminishing intensity. Reaction was stopped by disassembly of the reactor. The reactor had liquid electrolyte, with active fluid shearing by bubble growth at the cathode, and shearing by convection throughout the volume of electrolyte. The reactor was large and had relatively smaller surface area relative to volume, hence smaller relative rate of loss of neutron isotopes through the reactor walls. It may have had concentrated shearing at a boiling hot spot.

A number of heat after death experiments suggest themselves. For these experiments I envision a calorimeter containing an electrolyte, a removable anode/cathode combination to create and sustain LENR, a thermocouple to measure fluid temperature, a moderate speed stirrer to induce fluid shear throughout the volume of liquid, a small high speed stirrer to create very large shear rate in a small volume (to mimic the bubble-induced shear of electrolysis), and a small but powerful heater to create a localized source of boiling. The electrolyte can include LiOD in D_2O, or Li_2SO_4 in ordinary water, or other; and the cathode can be palladium or nickel or other.

Begin exploration of heat after death by establishing a reaction with power on. Reaction occurs rapidly in the bubbling volume at the cathode, and elsewhere more slowly throughout the fluid due to convection. Turn off the power and remove the anode/cathode device. Heat after death then proceeds on its own in the calorimeter, where it is easy to study. Its half life should be at least as long as Pons and Fleischmann's dry heat. Swirl the fluid in the calorimeter. The faster the swirl the greater the shear rate, the larger the contribution from reaction (1), and the longer the half life of heat after death. Shear is faster than diffusion for moving along a neutron isotope to the neighborhood of a deuterium nucleus with which it can react and grow. Add a potential fission-inducing element in the middle of heat after death, to see how the lifetime is affected. Find the optimum fission-promoting element and its optimum concentration for maximizing the lifetime of heat after death. Reaction may become self-sustaining as convection currents rise and take over from swirling. Or one can cause more violent localized shearing, for example with a small high-speed propeller, and generate neutron isotopes locally as with electrolysis. Or one can cause violent shearing by boiling at a submerged heater. After boiling is established, external power can be shut off. This may be what Mizuno had: boiling at a hot spot, sustained there by the high reaction rate generated by the high shear rate.

This may be a path to generating useful power. Explore the parameter space for power output without power input. With ^{2}H fuel find the optimum reactor size and optimum boiling sites (there may be several or many) to maximize power output. Then progressively explore substitution of ^{1}H for ^{2}H in the fluid. It may be possible that a properly designed boiler could run on the ^{2}H in ordinary water. If not, how small can the concentration of ^{2}H be? The reactor might work better with steam instead of water. Find a level of stirring or shearing that makes a steam reactor self-sustaining. Here the shearing might be achieved by forcing steam through the pores of a filter, or through a pebble bed of tiny glass beads.

The goal is red hot steam, as thick as kerosene, flowing out of the reactor into a steam turbine at the speed of a pistol bullet, all with ordinary water if possible. That would be a power source that could compete with fossil fuels.

Experimental Results Explained by the Theory

Here is a list of some of the experimental results discussed above for which neutron isotope theory offers explanations. These were accepted as experimental facts to be explained, and they provided guidance for the development of the theory.

- Irreproducibility of reaction
- Deuterium fuel, helium ash
- Absence of neutrons (Hagelstein criterion met)
- Heat/Helium ratio
- A trace of tritium
- Transmutations
- Sparkling infrared heat flashes on cathode surface.
- Cathode surface melting and damage.
- Electrolytic reactor heat after death after boiling dry.
- Heat after death in liquid electrolyte.
- Particle shower in H+O vapor over electrolyte.
- Necessity of loading palladium cathode with deuterium.

Other Research Opportunities

Having developed the theory to the point where the preceding experimental results can be explained and understood, it is possible to make predictions against which the theory in its present form can be tested, and to outline additional research opportunities the theory suggests. These include

- ^{1}H product with ratio $^{1}H/^{4}He = 4$.
- ^{2}H is the fuel and ^{1}H is inert in ordinary water reactors.
- Transmutation products are ordinary nuclei.
- Almost all natural isotopes undergo transmutation.
- Most transmutation products are radioactive.
- Gamma rays are expected from transmutations.
- Investigate X-ray intensity for power measurement.
- Optimize D flow rate and CaO thickness in gas reactor.
- Heavy elements transmute to transuranic elements.

- Wet heat after death lifetime greater than dry heat after death lifetime.
- Neutron emission at end of heat after death.
- Inelastic neutron capture by symmetric nuclei.
- Explore heat after death from minutes through days.
- Faster electrolyte swirl gives longer heat after death.
- High localized shear rate gives longer heat after death.
- Boiling at localized hot spot gives longer heat after death.
- Reaction rate strongly influenced by minor additives.
- Boiling hot spot may support sustained reaction.
- Energetic particles outside the reactor.
- Particle decays within solid CR39 detector plastic.
- Steam reactor may operate at very high temperature.
- Exploding wire reaction may result from exceedingly high shear rate.
- Microphone may detect micro-explosions of sparkling reaction.
- Explore radioactive transmutation products for nuclear medicine.

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