Neutron Isotope Theory of LENR Processes

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Abstract– Neutron isotopes are characterized and their reactions with ordinary isotopes are described. A theory of LENR processes emerges.

Index Terms– LENR, Neutron Isotope, Nuclear Reaction, Theory

I. INITIAL ASSUMPTIONS

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 analytic tool, and that the coulomb barrier prevents LENR reactions between charged particles. It follows that every LENR 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 candidate neutral reactants.

The theory suggests that although rare in nature, neutron isotopes are captured and proliferated in LENR reactors [1,2].

II. NEUTRON ISOTOPE STRUCTURE

I view the ground state of a neutron isotope containing an even number of neutrons as a structure of neutron pairs consisting of contiguous nested pockets or boxes, each box containing a pair of neutrons having opposite spins. The pairs surrounding each box are treated as a classical confining structure, and the neutrons in each box are treated quantum mechanically as independent particles in that box. The number of boxes is equal to the number of neutron pairs. The ground state energy of this system is taken to be the ground state energy for a pair of neutrons in a box, summed over all boxes in the isotope. For an isotope composed of an odd number of neutrons, I envision a similar structure in which one of the boxes contains a single neutron.

An excited neutron isotope can have more than one box that contains a single neutron, and can have neutrons excited to states above the ground state of a particle in a box. However in this analysis I consider only low temperatures for which such excitations can be neglected.

Neutron isotopes are unstable. They undergo beta decays in which one or more neutrons become protons. Because the fraction of protons is small for isotopes of interest, the structure of a mix of neutrons and protons is essentially the same as that of a neutron isotope: Pairs of nucleons of opposite spin occupy boxes in the overall isotope structure, except for isotopes with an odd number of nucleons which have one box that contains a single neutron or proton.

III. LIQUID DROP MODEL

Neutron isotopes have different permutation symmetries than ordinary nuclei. Because neutrons are indistinguishable from each other the neutron isotope wave function remains 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 retains full permutation symmetry of nucleons in the neutron-proton mix. (In a more exact treatment the wave function would be slightly changed. But for now I neglect such changes except for the 0.78 MeV mass difference between a neutron and a proton and for the coulomb energies of multiply-charged nuclei.)

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

For all charged isotopes I indicate the number of protons by the chemical symbols H, He, Li, and so on. In order to distinguish permutation-symmetric atoms from ordinary atoms I mark the permutation-symmetric atoms with a subscript "s" as in H_s, He_s, Li_s, and so on. (As a symmetry reminder I also attach a subscript "s" to all multi-neutron isotopes, although lacking protons neutron isotopes are not chemical atoms.) And for all nuclei I indicate the total number of nucleons (neutrons and protons together) by a

superscript to the left of the chemical symbol. In this notation a neutron isotope composed of 100 neutrons is represented by $^{100}n_s$, a hydrogen atom with a permutation-symmetric nucleus that contains 100 nucleons including one proton is represented by $^{100}H_s$, and a carbon atom with a permutation-symmetric nucleus that contains 500 nucleons including 6 protons is represented by $^{500}C_s$.

Analysis of ordinary nuclei has shown that a liquid drop model can provide a good approximation of the masses of the various isotopes. I expect that similarly a liquid drop model can provide a good fit to the masses of neutron isotopes and their neutron-rich beta decay products. Here I propose such a model for the mass excesses of symmetric atoms, in which the expression $\Delta(X)$ stands for the mass excess of atom X in MeV. For the mass excess of a neutron isotope we have

$$\Delta(^{A}n_s) = A\Delta(n) - a_vA + a_sA^{2/3}. \qquad (1a)$$

The parameters a_v and a_s are expressed in MeV. They are independent of A and are chosen to fit the data insofar as possible. $\Delta(n)$ is the mass excess of a single free neutron; a_v is the binding energy per neutron in a large neutron isotope; and a_s is the reduction of binding energy per neutron at the surface of a neutron isotope. (Here the subscript "s" on a_s refers to "surface" rather than "symmetric.") For the mass excess of a symmetric hydrogen atom we have

$$\Delta(^{A}H_s) = (A-1)\Delta(n) + \Delta(p) - a_vA + a_sA^{2/3}. \quad (1b)$$

The parameters a_v and a_s are independent of the mix of neutrons and protons. One neutron mass excess $\Delta(n)$ has been replaced by one proton mass excess $\Delta(p)$.

In general the mass excess of $^{A}Z_s$ containing Z protons and A−Z neutrons is

$$\Delta(^{A}Z_s) = (A-Z)\Delta(n) + Z\Delta(p) - a_vA + a_sA^{2/3} + a_cZ(Z-1)A^{-1/3}. \qquad (1c)$$

In this expression the term $a_cZ(Z-1)A^{-1/3}$ is the reduction in binding energy associated with the coulomb energy of the Z protons. The coefficient a_c is independent of A and Z.

The parameters a_v, a_s, a_c must be determined by the data. At present the only criterion available is that all reactions claimed to be exothermic in this analysis are indeed exothermic when using the current parameter values

$$a_v = 2.60 \text{ MeV}$$
$$a_s = 4.12 \text{ MeV} \qquad (1d)$$
$$a_c = 0.1 \text{ MeV}.$$

These current values are expected to change and to improve as the theory matures.

IV. SYMMETRIC ATOM REACTIONS

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

I begin by considering the various microscopic reactions that might be expected between neutron isotopes $^{A}n_s$ and deuterium. 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,

$$\begin{aligned} ^{A}n_s + {}^{2}H &\rightarrow {}^{(A+1)}n_s + {}^{1}H \\ {}^{(A+1)}n_s + {}^{2}H &\rightarrow {}^{(A+2)}n_s + {}^{1}H \\ {}^{(A+2)}n_s + {}^{2}H &\rightarrow {}^{(A+3)}n_s + {}^{1}H \\ {}^{(A+3)}n_s + {}^{2}H &\rightarrow {}^{(A+4)}n_s + {}^{1}H \\ &\dots \text{ and so on.} \end{aligned} \qquad (2)$$

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

$$\begin{aligned} ^{A}n_s &\rightarrow {}^{A}H_s \\ {}^{A}H_s &\rightarrow {}^{A}He_s \\ {}^{A}He_s &\rightarrow {}^{A}Li_s \\ &\dots \text{ and so on,} \end{aligned} \qquad (3)$$

until the build-up of nuclear charge makes further beta decay endothermic. In addition alpha decay with ^4He ash becomes possible for nuclear charge $Z \geq 2$,

$$\begin{aligned} ^{A}He_s &\rightarrow {}^{(A-4)}n_s + {}^{4}He \\ {}^{A}Li_s &\rightarrow {}^{(A-4)}H_s + {}^{4}He \\ {}^{A}Be_s &\rightarrow {}^{(A-4)}He_s + {}^{4}He \end{aligned} \qquad (4a)$$

…and so on finally to ordinary helium, tritium and neutron ash in reactions

$$\begin{aligned} {}^{6}He_s &\rightarrow {}^{4}He + 2n \\ {}^{6}H_s &\rightarrow {}^{3}H + 3n. \end{aligned} \qquad (4b)$$

Because reactions (2–4) do not increase the number of symmetric isotopes, there must be other reactions that do. Otherwise there could be no chain reaction to create and sustain the concentration of ambient neutron isotopes required for macroscopic LENR. The theory proposes that this function is served by neutron isotope fission reactions such as

$$
\begin{aligned}
{}^{A+B+10}n_s + {}^{40}Ca &\rightarrow {}^{A}n_s + {}^{B}n_s + {}^{50}Ca + 39\ \text{MeV} \\
{}^{A+B+16}n_s + {}^{58}Ni &\rightarrow {}^{A}n_s + {}^{B}n_s + {}^{74}Ni + 43\ \text{MeV} \\
{}^{A+B+22}n_s + {}^{104}Pd &\rightarrow {}^{A}n_s + {}^{B}n_s + {}^{126}Pd + 38\ \text{MeV}
\end{aligned} \qquad (5)
$$

…and others.

The indicated reaction energies are approximations subject to revision as the theory matures. LENR can proceed provided such reactions increase the number of symmetric isotopes at a rate that exceeds the losses from reactions (4b) and from diffusion to beyond the reaction volume. Neutron isotope fission is discussed more fully in Section X below.

V. HEAT AFTER DEATH

In one of their experiments Pons and Fleischmann [3] boiled away the liquid from an operating electrolytic reactor until the reactor was dry, after which they observed that it continued to produce thermal energy with an intensity that persisted with a half-life of about an hour. This they termed "heat after death." In this experiment, all isotopes necessary for a chain reaction were present in the dry reactor (deuterium in the solid electrolyte residue and Pd in the cathode). Growth reactions (2) had terminated and the chain reaction had ceased. Yet thermal energy production continued from beta and alpha decays in reactions (3) and (4) as the population of symmetric isotopes shrank and finally disappeared via reactions (4b). The duration of heat after death is consistent with the rates of beta and alpha decay expected in reactions (3–4).

VI. HEAT AND HELIUM

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

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

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

$$
{}^{A+4}n_s \rightarrow {}^{A}n_s + {}^{4}He. \qquad (7)
$$

Together at steady state these amount to

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

independent of the parameters a_v, $a_{s,}$ and a_c.

Neglecting the small energy contribution from fission reactions (5), and the compensating small energy loss of kinetic energy carried by neutrinos in reactions (3), the liberation of 21 MeV of energy per helium atom in (8) agrees with observation to within the experimental uncertainty.

VII. NEUTRONS

It is a remarkable feature of LENR reactions that they produce negligible numbers of neutrons and gamma rays. Yet knock-on neutrons are expected from the impact of alpha particles from reactions (4a) on deuterium fuel in the reaction medium. Neutron isotope theory requires that such neutrons be eliminated before they can be detected, being absorbed in reactions of the form

$$
\begin{aligned}
n + {}^{A}He_s &\rightarrow {}^{A-1}H_s + p + 0.2\text{MeV} \\
n + {}^{A}Li_s &\rightarrow {}^{A-1}He_s + p + 0.4\text{Me} \\
n + {}^{A}Be_s &\rightarrow {}^{A-1}Li_s + p + 0.6\text{MeV}
\end{aligned} \qquad (9)
$$

and so on,

thus accounting for the absence of neutrons in LENR.

VIII. GAMMA RAYS

Most beta and alpha decays leave the final nucleus in an excited state, which decays by emission of one or more gamma rays in the range 0.1–10 MeV. Although gamma rays are expected from isolated reactions (3–5), the following analysis shows they are not expected in LENR reactions that support high densities of neutron isotopes.

Consider the reaction

$$
{}^{A}n_s + {}^{40}Ca \rightarrow {}^{A-10}n_s + {}^{50}Ca \qquad (10a)
$$

in which ten neutrons are transferred from a neutron isotope to ^{40}Ca. The resulting ^{50}Ca undergoes the beta decay

$$
{}^{50}Ca \rightarrow {}^{50}Sc^{*} \qquad (10b)
$$

with a half-life of 13.9 sec. The star on Sc^{*} indicates a transient excited state, lasting perhaps 10^{-9} sec prior to gamma ray emission. Because of the high density of $^{A}n_s$ isotopes in an LENR reaction it is likely that one will come in contact with the Sc^{*} before it has a chance to emit a gamma ray. In that case we can have the reaction

$$
{}^{A}n_s + {}^{50}Sc^{*} \rightarrow {}^{A}n_s + {}^{50}Sc\,. \qquad (10c)
$$

In this reaction the excitation energy of the $^{50}Sc^{*}$ is taken up by an increase in kinetic energy of the $^{A}n_s$ and here is no gamma ray emission. This reaction is similar to internal conversion, in which the energy of an excited nucleus is given to an orbital electron and there is no gamma [4].

The ^{50}Sc is also beta unstable and decays to $^{50}Ti^*$ with a half-life of 102.5 sec,

$$^{50}Sc \rightarrow {}^{50}Ti^* \qquad (10d)$$

followed by

$$^{A}n_s + {}^{50}Ti^* \rightarrow {}^{A}n_s + {}^{50}Ti\,, \qquad (10e)$$

again without emission of a gamma ray. Overall in reactions (10a–10e) we have the transmutation of ^{40}Ca to ^{50}Ti without emission of gamma rays.

IX. TRANSMUTATION OF ORDINARY NUCLEI

Neutron isotopes can react exothermally with most ordinary nuclei, transmuting the ordinary nuclei to heavier elements. Transmutations occur in several 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 from Section VIII is

$$^{A}n_s + {}^{40}Ca \rightarrow {}^{A-10}n_s + {}^{50}Ca + 43\ \text{MeV}. \quad (11)$$

In general the most probable number of transferred neutrons is the number that maximizes the energy released in the reaction (10 neutrons in this example).

Neutron transfer is followed by a series of beta decays of ordinary neutron-rich nuclei that ends when a stable transmutation product is reached. In this example

$$^{50}Ca(13.9s) \rightarrow {}^{50}Sc(102.5s) \rightarrow {}^{50}Ti. \qquad (12)$$

The overall transmutation is $^{40}Ca \rightarrow {}^{50}Ti$. This transmutation has been observed by Iwamura [5], along with transmutations Sr → Mo [6], Cs → Pr [6], Ba → Sm [7], and many others.

X. NEUTRON ISOTOPE FISSION

Neutron isotope fission reactions are closely related to transmutation reactions. In general, to every transmutation reaction

$$^{A+B+C}n_s + {}^{D}Z \rightarrow {}^{A+B}n_s + {}^{C+D}Z \qquad (13)$$

there corresponds fission reaction

$$^{A+B+C}n_s + {}^{D}Z \rightarrow {}^{A}n_s + {}^{B}n_s + {}^{C+D}Z. \qquad (14)$$

Transmutation reaction (13) is expected to be more exothermic than fission reaction (14) because (in a liquid drop model) the surface energy of a pair of droplets ($^{A}n_s + {}^{B}n_s$) is larger than that of the single droplet ($^{A+B}n_s$) they form when combined.

Fission reaction (14) tends to be less probable than reaction (13) because it releases less energy; but it tends to be more probable because it provides an additional decay channel. Although the reaction energies and reaction probabilities are not yet well known, and are subject to determination and revision as the theory evolves, I note that the fission rate is positive provided that reaction (14) is exothermic.

In association with reactions (2), reactions (13) and (14) have other important implications for LENR. Growth reaction (2) increases by one the number of neutrons bound in symmetric nuclei. And each of reactions (13) and (14) decreases that number by C. If the rate of reaction (2) is less than C times the sum of the rates of reactions (13) and (14) 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 (2) must be greater than C times the rates of reactions (13) and (14) 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 (14) assures that there will remain a small net growth in the number of symmetric nuclei, and that a chain reaction can be established.

Reactions (2) and (5) are expected to be very rapid because they are not inhibited by the coulomb repulsions felt by reactions between charged reactants. Their mean free paths may be very small and the minimum size of an active reaction volume may be many orders of magnitude smaller than for an ordinary nuclear reactor.

XI. SYMMETRIC ATOMS IN NATURE

I assume that large charged symmetric atoms exist in nature at very low concentrations, their rate of alpha decay suppressed by a large coulomb barrier. These atoms may be formed from time to time in natural reactors around the earth, much as natural uranium reactors have formed in the past [8].

Long-lived symmetric atoms may survive for months or years before a statistical excess of alpha decays (4a) reduces their charge to zero generating a neutron isotope n_s. In this way decays of a long-lived isotope can randomly produce the rare n_s 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. This offers an explanation for the fact that many initial attempts to observe LENR were abandoned.

But an initial reaction generates populations of long-lifetime isotopes that remain in the reactor or escape from the reactor and survive in the laboratory until a second LENR reaction is attempted. The wait for initiation of a second reaction is shorter than it was for the first, owing to the large number of medium lifetime precursors generated by the first reaction that survive in the equipment and laboratory.

XII. REACTOR DESIGN

It is well known that shear deformation of a liquid speeds the rate of reaction between dissolved atoms. This happens because in liquids mechanical flow is much faster than diffusion for bringing potential reactants close enough to each other to react. The situation can be reversed in a solid material where the rate of mechanical flow is negligible relative to diffusion. It can also be reversed in a hot gas, where diffusion can mix reactants with great rapidity.

Various methods of reactant mixing can support various reactor designs. Two designs have had considerable success and others look promising.

In Fleischmann-Pons electrolytic reactors [9] deuterium released during electrolysis goes into solution in the electrolyte near a palladium cathode. As the deuterium concentration rises, bubbles form and grow. Bubble activity usually concentrated at cathode surface imperfections that enhance the probability of bubble nucleation. The turmoil of bubble nucleation and growth increases the mixing rate in the bubble deuterium gas. LENR reaction is fast. The rates of growth reactions (1) and of fission reactions (5) are increased and a chain reaction is initiated. As the chain reaction heats the gas, the rising temperature increases the diffusive mixing rate exponentially in an explosive reaction.

In this way we can understand the sparkling flashes of thermal energy in the electrolyte that cover the surface of a cathode as reported by Szpak et al. [10]: Available ^{2}H is consumed in a flash of chain reaction in which growing bubbles, expanded by heat, accelerate the rate of mixing of nuclear reactants. The temperature can rise high enough to melt the cathode surface. The bubble nucleation site is blown free of electrolyte and of most gas, 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 new flashes of reaction. The active volume of the nuclear reaction is on order of perhaps 10^{-5} cc, confirming that an active LENR reaction volume may be many orders of magnitude smaller than for an ordinary nuclear reactor.

In Rossi-type reactors, on the other hand, the LENR reaction takes place in a large volume of deuterium gas (or deuterium-hydrogen mixture) that is heated to high temperature by an electric heater [11]. LENR then proceeds largely by diffusive mixing of neutron isotopes and deuterium. This process can be exponential from the start, controlled only by reducing the heater power until heater power and reaction power together are less than the loss of power by radiation and conduction from the surface of the reactor. If reduction of heater power is insufficient, the Rossi reaction power rises exponentially and the reactor melts, releasing the gas and terminating the reaction.

XIII. A GOAL FOR NUCLEAR POWER

One goal for LENR power production is red hot steam, as thick as kerosene, flowing at the speed of a pistol bullet out of a reactor into a steam turbine. This would be an ideal power source to compete with fossil fuels.

XIV. ACKNOWLEDGEMENT

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