NUCLEAR PROCESSES IN HYDROGEN-LOADED METALS

NUCLEAR REACTIONS IN SOLIDS

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Miley et al. and, independently, Mizuno et al. claim to have observed nuclides produced in Ni ($Z = 28$) when an electrolytic light-water cell is used. Miley et al. use thin layers of Ni ($\leq 5 \times 10^{-6}$ cm) and claim that the effect is reproducible. The secondary nuclides are distributed in a wide range of Z and A and show nuclides with $Z < 28$ and accumulations at $Z = 48$ and 78. If the nuclides at $Z = 48$ and 78 are Ni-Ni fusion, they can be produced only when the original Ni nuclei gain sufficient kinetic energy to overcome the Ni-Ni repulsive Coulomb barrier.

The foregoing data are discussed in terms of current physics. In particular, it is assumed that the gain of kinetic energy derives from an impulsive increase of absolute nuclear binding energies of Ni due to a high rate of capture of orbital electrons and consequent almost instantaneous multiple $p \to n$ transitions. Under this hypothesis, neutrino emission should be detected during nuclear transmutation.

INTRODUCTION

The present paper discusses in terms of current physics the results of Miley et al.[1] for nuclear transmutations exhibited by Ni in an electrolytic water cell. An example of the results published by Miley et al. is shown in Fig. 1, where the nuclides observed in three intervals of Z (zones I, II, and III) have been classified. Miley et al. and Mizuno et al. claim not to observe neutrons and high-energy gammas during transmutation.

It has been argued that the effect could be attributed to fission processes. However, zone III in Fig. 1 shows the presence of secondary nuclides with $Z > Z_0 = 28$ and $A > A_0 = 58$, 60, and 62, which demonstrates that the process cannot be fission of Ni. Because fission requires $Z^2/A > 45$ (in Ni, $Z^2/A \sim 13 \div 15$), it can only follow the fusion of 2 to 3 Ni nuclei.

Zone I of Fig. 1 shows the presence of nuclides with $Z > Z_0$ or $Z < Z_0$ and shows that in this region, nuclides with $Z < Z_0$ are about six times the one with $Z > Z_0$. I propose that this is the indication of an $e^- p \to n \nu$ capture process. If so, such a process could be demonstrated by detecting neutrinos emitted during transmutation. The presence of nuclides with $Z > Z_0$ can be attributed to a second-order capture of positrons emitted by unstable nuclides.

Electron capture is possible if electrons have energy above a threshold (in Ni, this is ~3 MeV, while the Fermi energy is $\sim 8 \div 10$ eV). So, to have electron capture, electrons must gain energy. The only accelerating field present in the metal is the Coulomb field of nuclei. That can be effective only on electrons lying outside the Fermi levels. In the following, we consider the possibility that the proton gas inside the metal lattice produces electrons that for short time intervals are not bound to the Fermi levels.

In a homogeneous system, electron and proton gas behaves as two independent and interpenetrating gases. The presence of inhomogeneities (like a surface or the boundary of a metallic bulk) contributes to an increase in the electron density and then in the Fermi energy of the electrons. The consequence is to make possible a degree of recombination $e - p$ to form H atoms in proximities of anisotropies. In this step, few kilo-electron-volt photons can be emitted.

Miley et al. used Ni layers of 500-Å thickness. Other observations[2] indicate that the production of nuclides, when observed in a thick electrode, shows a marked increase near the surface.

The H atoms so formed will be attracted through an electric dipole force by nuclei and can easily form atomic clusters. The orbital electron energy and phonon distribution are sufficient to trigger a plasma oscillation in

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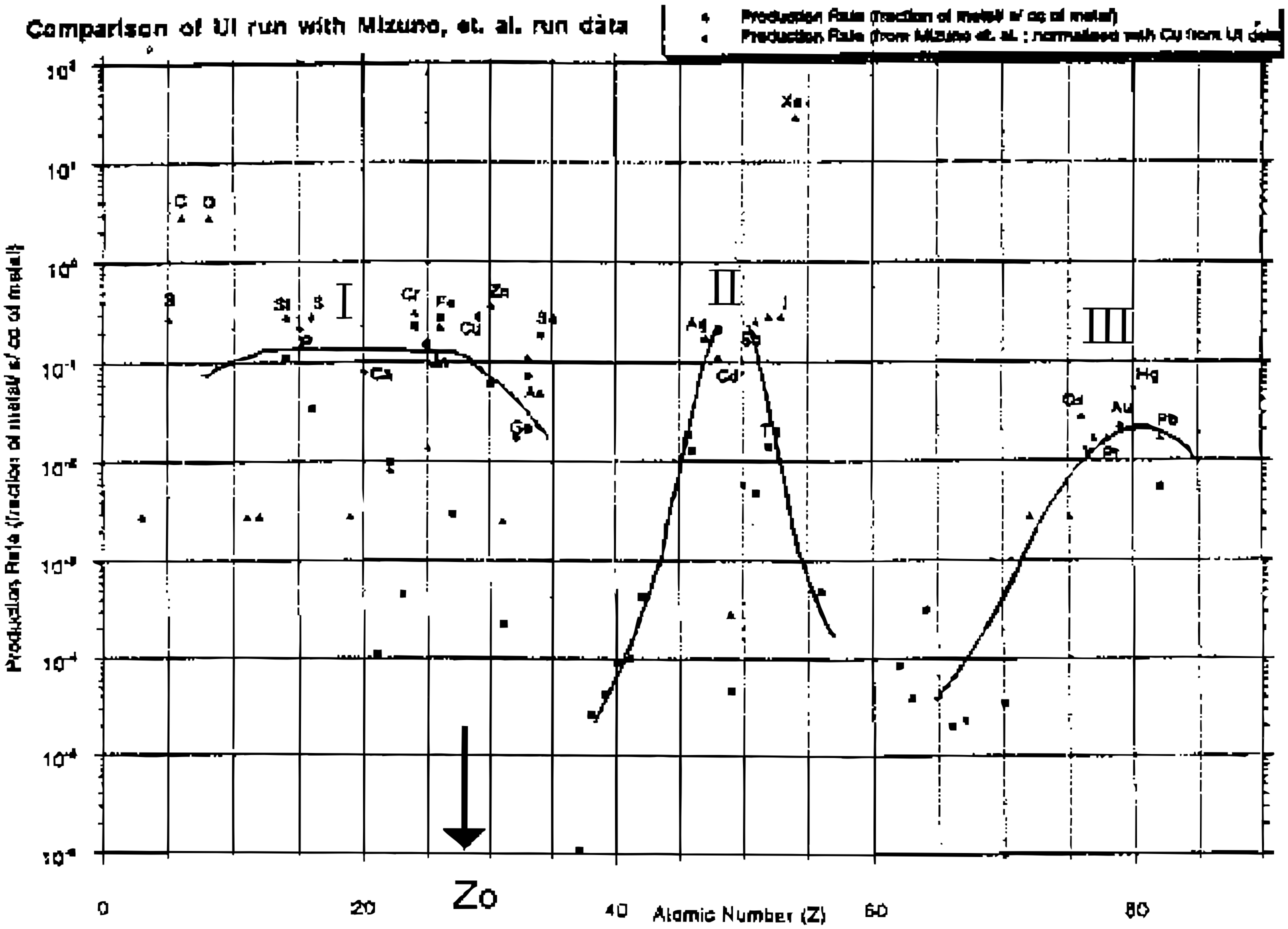

Fig. 1. Data from Miley et al. and Mizuno et al.

the cluster that separates positive and negative charges, producing a number of free electrons in a condition to be accelerated by nuclei and then captured. If $\bar{n}$ is the number of H atoms in a cluster, this is also the number of neutrinos emitted in a single process. Therefore, the emission of neutrinos must possess a time modulation in groups of $\bar{n}$. The capture of the $\bar{n}$ electrons takes a time τ that can be easily estimated to be $\tau < 10^{-12}$ s.

Obviously, the capture of a single electron changes the binding energy of the original nucleus, which then becomes $\beta^{\pm}$ or γ active with a lifetime τ_d that in many cases is $\tau_d \gg \tau$. When $\bar{n}$ is low, only an excited Ni nuclide can be produced. When $\bar{n}$ is high, there is a time interval $(\sim 10^{-12})$ in which the nucleus of interest has performed a transition to a state with an anomalously high number of neutrons. As such, it has a higher binding energy because of the reduction of the repulsive Coulomb interaction. Consequently, the nucleus gains kinetic energy that (impulse is absorbed by lattice) can be sufficient to overcome Coulomb barriers and produce fusions.

THE MILEY ET AL. DATA COMPARED WITH ELECTRON NUCLEAR CAPTURE

The results of Miley et al. are interpreted in terms of electron nuclear capture by using current physics. Refer to Fig. 1 (where qualitative curves have been drawn), which shows the Miley et al. and Mizuno et al. results as published.[1] Similar results have been reported by several other observers. In the case of Miley et al. the initial state is Ni ($Z = Z_0 = 28$, and $A = A_0 = 58$, 60, and 62). Observing zone I of Fig. 1, and considering that around Z_0, nuclides are produced with $Z > Z_0$ and $Z < Z_0$, one may conclude that here the main process can be orbital nuclear capture of electrons from Ni nuclei.

In particular, it will be shown that experimental data indicate that when the absorbed H concentration $c = \mathrm{H/Ni}$ is >1, electrons bind to protons to form H-like atoms. These atoms are subject to dipole attraction toward the Ni nuclei, one toward another, to form clusters of $\bar{n}$ atoms (and $\bar{n}$ bound electrons) around Ni atoms randomly distributed in the lattice. The orbital kinetic energy of electrons ($\sim$13 eV) is sufficient to trigger plasma oscillations able to rule out a positive charge in the cluster. As a consequence, a cloud of n electrons falls to the nucleus through deeper and deeper quantum states in such a way as to gain enough energy to give rise to nuclear orbital capture from Ni nuclei.

The two elementary nuclear processes involved are

$$e^- + p \rightarrow n + \nu_e \tag{1}$$

and

$$e^+ + n \rightarrow p + \nu_e \ . \tag{2}$$

Equation (1) produces nuclides with $\Delta Z < 0$, while Eq. (2) produces nuclides with $\Delta Z > 0$.

The probability of Eq. (2) is much lower than Eq. (1) as it appears considering zone I of Fig. 1, which shows asymmetry with respect to Z_0. The reason is that Eq. (2) is a second-order process. To be more explicit, the capture of electrons follows a URCA schema:

$$e^- + Nucleus(A, Z) \rightarrow Nucleus\ (A, Z-1) + \nu_e$$
$$Nucleus(A, Z-1) \rightarrow Nucleus\ (A, Z) + e^{\pm} + \nu_e \ ,$$

which represents an infinite sink for electron energies.[3] Secondary electrons give rise to nuclear excited states that can decay in e^+ and are then absorbed [Eq. (2)]. The lifetime of process (2) is τ ($\gtrsim 10^{-6}$ s). If the rate of primary electron capture is

$$r \gg 1/\tau \tag{3}$$

after the absorption of $\bar{n}$ electrons, an excited intermediate nucleus $(A, Z - \Delta n_p)$ is formed, which will decay after a time $\tau_c \ll \tau$.

We assume that the fast absorption of $\bar{n}$ electrons produces a nuclear state with lifetime τ_c, where n ($\geq \bar{n}$) neutrons bind[4] in a neutron cluster c. The transition is

$$(A, Z) \leftrightarrow c(n, 0) + (A, Z - n) \ . \tag{4}$$

The neutron cluster $c(n, 0)$ is formed within the original nucleus. After the time τ_c, the nucleus will decay in ν_e, electrons, etc. If $c(n, 0) = c(n)$ is a particle, the antisymmetry of its wave function requires

$$n = 6, 9, \dots \ .$$

In the transition Eq. (4), the nuclear absolute binding energy of the nucleus increases up to

$$B_{max} \sim Z \Delta n_p (\epsilon_{pp} - \epsilon_{np}) \ ,$$

where Δn_p is the increase of the neutron number and ϵ_{pp} and ϵ_{np} are the absolute interaction energy *pp* and *pn*, which differ at least for Coulomb interaction. Therefore, the nucleus can gain a kinetic energy (impulse is absorbed by the lattice)

$$\Delta W = B_{max} \ .$$

If $\epsilon_{pp} - \epsilon_{np} \sim 1$ MeV, in the case of Ni (estimated from experimental b energies and after correction for Coulomb interaction) and assuming $n = 6$,

$$\Delta W > 180 \text{ MeV} \ ,$$

which is precisely the value of the Ni/Ni Coulomb barrier.

Equation (4) leads to an intermediate state, holding for a time τ_c. At the end of this time, $c(n)$ can

1. be reabsorbed without decaying
2. decay in unstable nuclides and neutrons
3. interact with a nearby nucleus.

The data observed seem to suggest that the neutronic nuclei $c(n)$ are actually not emitted in Ni. This means that the characteristic of the Ni lattice is such as to not allow the foregoing options 1 and 2.

The introduction of the neutral nucleus $c(n)$ furnishes an explanation of the distribution in zones II and III of Fig. 1 but is not essential to this end because the needed increase of nuclear kinetic energy can be a mere consequence of the multiple fast electron absorption.

Two arguments may suggest the possibility that $c(n)$ is a real bound state:

1. In an experiment performed by Curzio et al. some time ago, it was observed in Ti the emission of unresolvable groups of neutrons,[5] which could represent the emission of $c(n, 0)$. However, this has not been proven.

2. In zone I of Fig. 1, the curve is asymmetric with respect to Z_0. Notice that $(\Delta Z_{max})_- = 13$, $(\Delta Z_{max})_+ = 7$ and that $(\Delta Z)_{tot} = (\Delta Z_{max})_- - (\Delta Z_{max})_+ = 6$ is the minimum number of neutrons required to build $c(n)$ as a bound state.

THE DYNAMICS OF ELECTRONS

We consider now the dynamic behavior of electrons. The H-Ni system considered here is simplified as a metallic lattice where two uncorrelated interpenetrating and interacting gases are present: the H (Bose Einstein) gas and the electron Fermi gas. The constituents of the Bose Einstein gas are Coulomb-screened protons. Because the screening is due to Ni band electrons, the screening charge is e.

To envisage a stationary state of the considered system, recall the following data observed in the Pd-H system,[6] which we assume also applies to H-Ni:

$$\frac{\chi^{(5)}_{\text{Pd-H}}}{\chi_{\text{Pd}}} \cong 1 \quad \text{when } c = \text{H/Pd} \leq 0.3 \ , \tag{5}$$

$$\frac{\chi^{(5)}_{\text{Pd-H}}}{\chi_{\text{Pd}}} < 0 \quad \text{when } c \geq 0.8 \ , \tag{6}$$

and

$$\frac{\gamma^{(5)}_{\text{Pd-H}}}{\gamma_{\text{Pd}}} \sim 0.16 \quad \text{when } c > 0.6 \ , \tag{7}$$

where γ is the linear temperature coefficient of the heat capacity and χ is the magnetic susceptibility.

More precisely, χ decreases steadily with increasing c to reach a negative value when $c > 0.8$ [result (7) ensures that at high c, $m^* \sim m$]. At $c = 1$, the system has performed a transition from paramagnetism to diamagnetism.

At H concentration = 1, the system can be described as having a single Coulomb-screened proton in each cell,[7,8] with only one screening unbound electron per each proton. The electron energy (the Fermi electron) is too low (~7 eV) to give rise to an electron-proton combination (the energy needed is ~13 eV). It is proposed as a key hypothesis that the presence of anisotropies in the metal lattice gives rise to the formation of H atoms inside an Ni-H system. This is impossible in homogeneous and isotropic lattice metals, where the energy difference between e and p makes a direct recombination impossible without resorting to indirect and complex processes.

If anisotropies are present, however, the proton density n_p can change appreciably:

$$\Delta n_p = \bar{n}_p f(Q) \ ,$$

where $\bar{n}_p$ is the density averaged in the volume of the sample considered and $f(Q)$ is a function of the point Q in the sample. When $\Delta \bar{n}_p > 0$, two effects are present:

1. an increase of the electron density ($\Delta n_e \sim \Delta n_p$) and a corresponding increase of the Fermi energy ϵ_F
2. no change of the proton energy.

For instance, the surface of a sample is a region of maximum anisotropy. In fact using elementary arguments, one can estimate that the proton density on a depth of the order of 10 to 100 Å is $n_p \sim 2\bar{n}$.

In this case the Fermi energy becomes ~12 eV, which is not too far from the recombination energy. Hydrogen atoms produced through recombination are attracted by Ni nuclei (and attract each other) to form atomic clusters centered on nuclei formed by $\bar{n}$ H atoms. The phonon distribution (the temperature) can give rise to a pulse of plasma oscillation (the bound electrons have the appropriate energy ~13 eV for the trigger). In this event, positive and negative charges separate out. Because all levels of Ni are filled and fall toward the Ni nucleus, the $\bar{n}$ added electrons gain through Coulomb acceleration the energy necessary to be captured from the nucleus.

Needless to say, the rate of falling electrons can be very high. In fact, the migration time to nucleus of electrons inside the atomic cluster can be as low as 10^{-12}. A reduction of temperature should reduce the probability of the plasma oscillation. Therefore, the experiment performed at different values of T could be illuminating for the importance of the presence and behavior of the atomic cluster and the plasma oscillation.

CONCLUSIONS

The considerations presented and discussed to understand the Miley et al. effect are based on three main points:

1. the possibility that a fast rate of electron capture gives rise to a neutron cluster inside the nucleus, with the consequence of increasing the kinetic energy of the nucleus, thus producing inelastic nuclear reactions
2. the possibility that at high H concentrations, clusters of several H atoms are formed in the presence of dishomogeneities around atoms of the lattice
3. the possibility that plasma oscillations separate out electrons of the plasma that will fall toward the nucleus, suffering local acceleration and then nuclear capture.

We stress the necessity of obtaining the following further information to test the meaning of the exposed considerations and the validity of the hypotheses:

1. to search for neutrino emission during transmutation, proving that the fundamental step of the process is electron nuclear capture
2. to repeat the Miley et al. experiment by using metals with several different electrical conductivities
3. to search for low-energy protons and neutrons
4. to repeat the experiment at different temperatures (this requires metal filling with H gas).

The model discussed here implies the emission of secondaries like excited nuclei, neutrons, gamma rays, and X rays:

1. neutrons from a lack of nuclear recombination and internal decay of the excited neutron cluster $c(n)$
2. gamma rays from electron acceleration and decay of excited nuclides as well as inelastic collisions of decay electrons with the metal lattice after they are emitted by radioactive products from the nuclear transmutations
3. soft X rays (a few kilo-electron-volts) from the electron capture emitted during the electron-accelerating process.

An alternative class of explanations might be based on other processes like the proton-proton chain for production of solar energy (standard solar model), but that requires energies that are not available here.

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