Earth Science and Deuterium Nuclear Reactions

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The Origins of Heat, Elements, and Water

By

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PREFACE

In my boyhood, I had a question about why our Earth had the extremely high composition of 78.8% nitrogen. However, I could not find a clear answer in those days. Indeed, the significant question has still not been entirely resolved, and has been overlooked without consensus.

Since Fleishman and Pons (1989), and Jones *et al*. (1989) reported the possibility of the nuclear fusion of deuterium induced by electrochemical means in palladium at ambient temperatures, much work on the reproducibility of nuclear fusion has been carried out. We participated in the studies titled "Low-temperature elastic anomalies and heat generation of deuterated palladium" (Fus. Tech., **31**, 300 (1997)) and "Possible dynamic interaction of deuterons between tetrahedral and octahedral interstices of palladium lattice at cryogenic temperatures" (Fus. Tech., **34**, 151 (1998)), which were based on the experimental confirmation of cold nuclear fusion and the theoretical mechanism for nuclear fusion reactions. The nuclear fusion reaction put me in mind of my past question. After that I changed the research title from "**cold fusion**" for palladium to "**warm fusion**" in the Earth's interior regions. However, the formation of nitrogen was interpreted to be not exothermic nuclear fusion but endothermic nuclear transmutation at a lower mantle under high temperatures > 2510 K and pressures > 58 GPa. I found that the formation of a helium nucleus from two deuterons *i.e.*, fusion requires necessarily a direct force due to the exchange of two neutral pions, which do not actually compose the deuteron nucleus. This discovery founding assisted the following investigations.

The fact that in 2005 and 2007 scientists at KamLAND and Borexino detected signals of antineutrinos $\bar{\nu}_e$ (*i.e.*, "geoneutrinos") produced inside the Earth provoked me to start to work on heat generation in Earth's inner portions. I postulated that the generation of heat is the result of the three-body nuclear fusion of deuterons confined in hexagonal FeDx core-centre crystals; the reaction rate is enhanced by the combined attraction effects of high-pressure (~364 GPa) and high-temperature (~5700 K) and by the physical catalysis of neutral pions: $^2D + ^2D + ^2D \rightarrow 2\,^1H + ^4He + 2\,\bar{\nu}_e$. In order to do justice to this hypothesis, I compared electron pressure-temperature conditions in the cores of Earth, Jupiter, Saturn, and brown dwarfs. Succeeding these results, for a long-standing 'helium concentration paradox' of ^3He and ^4He isotopes and 'heat-to-helium imbalance', I proposed that their isotopes were generated as the result of two- and three-bodies nuclear fusion of deuterons confined within hexagonal FeDx core-center crystals. Recently, we have encountered many great disasters such as a super-typhoon, large scale earthquakes and volcanic eruptions. Since these events cannot be explained by only global warming derived from greenhouse effect by carbon dioxides, we can attribute their causes to the active movement of mantles arising from the thermonuclear fusion which occurs at the centre of Earth. This research will cast new light on the explication and prevention of these disasters.

Lastly, from contradiction in conventional oxygen formation theory based on photosynthesis, I came to grips with possible generation problems for nitrogen, oxygen and water from Earth's interior portions, based on deuterium nuclear transmutation. The new knowledge could lead to great happiness for species that require plenty of oxygen and water. Furthermore, we proposed that the formation of the 25 elements with smaller atomic numbers than iron resulted from an endothermic nuclear transformation of two nuclei confined in the natural compound lattice core of Earth's lower mantle at high temperatures and pressures.

These hypotheses are expected to give rise to a new era of Earth science.

CHAPTER 1

INTRODUCTION

Our Earth, which is the largest rocky planet in the solar system, has atmospheres and climates that are friendly to life. All animals and plants have evolved corresponding to environmental changes, because Earth is geophysically active. Therefore, it is a very important to study changes of the Earth's environment, such as generation of heat, composition changes of atmospheric gases, volume changes of water, and creation of elements, in terms of Earth science from the Archean era to the present time.

On Earth, convection in the silicate-dominated mantle drives volcanism and plate tectonics. It has been believed that the internal heat is partly left over from the Earth's formation and partly produced by radioactively in the mantle. However, the question of the origin of heat remains open. We postulate that the generation of heat has derived from deuteron thermonuclear fusion in Section 3.1. To do this hypothesis justice, we compared electron pressure-temperature conditions in the cores of Earth, Jupiter, Saturn, and brown dwarfs in Section 3.2.

The details on the origin of nitrogen, which exists so abundantly in Earth's atmosphere, are missing. An attempt to give a possible answer to the question as to why nitrogen exists so abundantly in the Earth's atmosphere concluded that it was as a result of endothermic nuclear transmutation of carbon and oxygen atom pairs in the carbonate lattice of the upper mantle containing crust, as will be seen in Sections 4.1 and 4.2. All animals and plants need oxygen to unleash the energy they scavenge from their environment. Plants do it by using carbon dioxide gas to produce oxygen during photosynthesis. However, the amounts of oxygen calculated from photosynthesis are extremely small compared to the oxygen content in the present atmosphere. Thus, the consensus on the origin of the abundance of oxygen on Earth appears to be misplaced (see Section 4. 3). Water is an essential substance for the origin and evolution of life, the stability of the surface environment, and the movement and thermodynamic revolution of the planetary interior such as plate tectonics and mantle convention. Although the present consensus for the origin of the Earth's water is derived from bombardment of a late veneer of asteroids with water, this mechanism is unlikely to be the dominant source of sea water. In Section 4.3, the formation of water is postulated as the result of the endothermal nuclear transmutation of carbon and oxygen nuclei confined in the carbonate lattice of the Earth's mantle.

The discharge of carbon dioxide gases by burning fossil fuels is warming the Earth. On the other hand, great disasters such as super-typhoons, large scale earthquakes, and volcanic eruptions occur frequently. These disasters cannot be explained by global warming alone. They might be derived from the active mobility of plate tectonics and mantle convention based on increased amounts of mantle. Although plants and ecosystems possess a remarkable capacity to adjust to new conditions, scientists feel concern about the occurrence of catastrophic responses beyond the thresholds. The findings in this study provide new insights into Earth science, which are based on nuclear fusion and transmutation, and into provision against disasters. To the best of our knowledge, no work has been carried out previously on nuclear studies of Earth science, especially deuteron nuclear reactions.

On the other hand, stellar nucleosynthesis is a widely acknowledged theory for the formation of all elements in our universe; traditionally we say the highest mass stars transmuted lighter elements into heavier elements lighter than iron. In Section 4.4 we propose that the formation of the 25 elements with smaller atomic numbers than iron resulted from an endothermic nuclear transformation of two nuclei confined in the natural compound lattice core of the Earth's lower mantle at high temperatures and pressures.

CHAPTER 2

NEUTRAL PION-CATALYZED HELIUM FUSION

2.1 Neutral pion-catalysed fusion in a palladium lattice [1]

2.1.1 Formation of ^{4}He

In a previous paper [2], elastic parameters (Young, shear and bulk moduli, Lame parameter, Poisson's ratio, and Debye temperature) and shear damping anomalies accompanied by the generation of excess heat (not < 6 W) were observed between 116 and 190 K in the deuterated palladium $PdD_{0.719}$. However, we could not observe any neutron emission, giving negative evidence for the formation of ^{3}He as an "ash" when we assume that dynamic reaction is a nuclear fusion. Thus, we interpreted the dynamic interaction as a mixture effect of the interstitial small deuterons jumping from the tetragonal site to the octahedral one along the [111] directions and electrostatic attraction due to the charge transfer in the chains, *i.e.*, an alternating tetrahedral-octahedral site array with the help of the electron-phonon charge density wave (CDW) coupling. The generation of heat was associated with the collective electrons derived from the palladium atoms and neutral pions between deuterons [3]:

$$e^- + {}^2D \rightarrow D^o + \nu + \gamma, \qquad (1)$$

where ν and γ are neutrino and photon, respectively. In contrast to this cryogenic reaction, many research groups [4-7] have reported the generation of heat during electrolysis of PdDx at an ambient temperature. Therefore, we must consider another explanation for the heat generation.

Our interest lies in studying the dynamic interaction of deuterons confined in the palladium lattice, assuming that the two deuterons are fused to a helium atom through the catalytic help of neutral pions derived from collective resonance electrons excited in the palladium atoms. The central problem of this study is to explain how the deuterons react with each other when there exists a potential barrier so high that it should not be possible for the deuterons to draw near as interactive deuterons. For experimental confirmation, a question is raised as to whether compressive forces exerted by the metal structure could lead to such a confinement of deuteron pairs at the necessary close proximity [8-11].

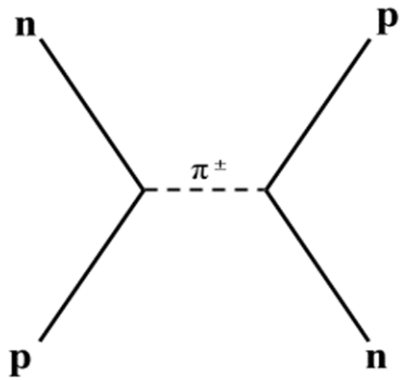

Fig. 1. Schematic representation of proton-neutron attractions mediated by positively and negatively charged single pions in a deuteron nucleus.

First, we consider a possible nucleonic reaction of deuterons followed by the formation of ^{4}He, provided that the generation of heat arises from the helium nuclear fusion. The deuteron is an *np* state whose isospin wave function is antisymmetric, where *n* and *p*are neutron and proton, respectively. In the symmetric meson theory, the nuclear forces are connected with a particular mixture of positive, negative, and neutral meson fields. Thus, the first order internuclear force between *n* and *p* is mediated by charged pions, π^+ and π^-. The Feynman diagram is described in **Fig. 1**. Strictly speaking, we must consider an emission and simultaneous absorption of a neutral pion π^o from *p* and/or *n*. However, the secondary contribution is very low, compared with the first one. Consequently, the π^o has actually nothing to do with the *np* state of the deuteron. In other words, the deuteron is a rare atom, which lacks a neutral pion.

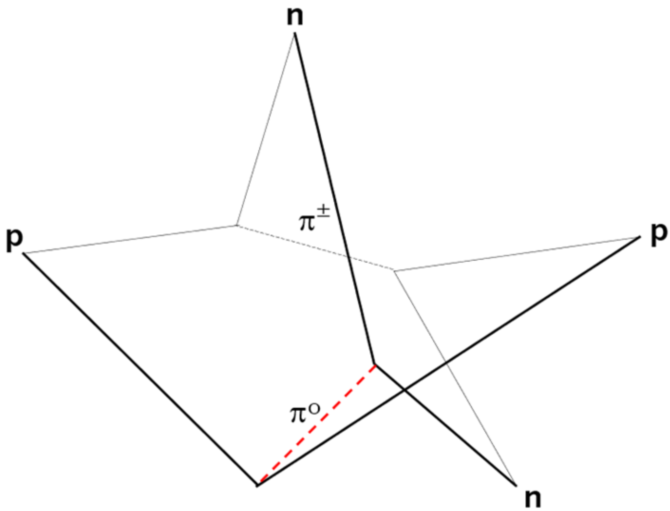

Fig. 2. Schematic representation of two proton-neutron attractions mediated by positively and negatively charged and neutral single pions in the helium nucleus. Fine and bold solid lines present attractive mediation by charged and neutral pions, respectively.

On the other hand, the helium nucleus is composed of two protons and two neutrons. These four nucleons are combined by the attractive mediation of charged and neutral pions π^+, π^-, and π^o (**Fig. 2**). Therefore, the formation of the helium nucleus from two deuterons *i.e.*, fusion requires necessarily a direct force due to the exchange of two neutral pions which do not compose the deuterium nucleus because the additional non-exchange part by the neutral pion substantially modulates the *n*, *p* force in the helium nucleus. Thus, the dynamic interaction of interest is presented by the following nuclear reaction:

$$^2D + {}^2D + 2\pi^\circ = {}^4He. \quad (2)$$

The neutral pion in Eq. (2) is provided by a fundamental process which is an electromagnetic interaction:

$$\gamma + \gamma = \pi^{o}, \tag{3}$$

From isospin symmetry, the photon in Eq. (3) is produced by the emission of excited electrons e* derived from the palladium atoms [12]:

$$e \rightarrow e^{*}, \gamma. \tag{4}$$

From Eqs. (2), (3), and (4), we get the following formula:

$$^{2}D + {}^{2}D + 4e^{*} = {}^{4}He. \tag{5}$$

The introduction of the neutral pions makes it possible to reduce considerably the internuclear distance between deuterons as if it were catalysis, as described later.

Since the process (2) suggests that the neutral pion plays an intrinsic role in the formation of helium, we must find the necessary and sufficient conditions for the dynamic reactions of deuteron pairs in a palladium lattice.

2.1.2 Condensation of deuterons and electric charge in a Pd lattice at vacancies

Because the probability of nuclear tunneling through a barrier of internuclear Coulomb repulsion is very small, we consider a driving force responsible for the close proximity of deuterons. Most of the specimens used in studies of nuclear effects in solid states are characterized by condensation of deuterons into the palladium lattice. Indeed, the electrolytic deuterium-loading into palladium gives rise to metastable solid phases alien to the thermal equilibrium Pd-D phase diagram [13]. Electrolysis is thus the best approach for the condensation of deuterons, because the deuteron contents charged from the gas phase in a high-pressure cell [14] and by implantation method [15] do not exceed those charged by the electrolysis method. For this reason, it is considered that the negative charge of vacancies transferred from a cathode by the principle of conservation of charge reduces the positive internuclear Coulomb repulsion between palladium and deuteron atoms, enhancing the close proximity of deuteron pairs. As can be seen from the thermal stability of deuterons at octahedral sites in ambient temperatures [16], the positively charged octahedral-site deuteron and the negatively charged tetrahedral-site vacancy are polarized dielectrics. Therefore, the PdDx can be treated as an assembly of small polarized dielectrics (electolet) in the atomic scaled electric field.

From a previous measurement [2] of Lamè parameters known as three-dimensional shears, it is shown that the palladium face-centered-cubic (fcc) lattice has strong rigidity. This dynamic interaction does not occur in solids lacking shear strength. Thus, the formation of β-PdDx ($x \geqq 0.85$) is a necessary condition for the formation of deuteron pairs or deuteron clusters. The more the condensation is enhanced, the more the electron charge density increases and the higher is the proximity of deuterons to each other.

2.1.3 Possible collective resonance and three-dimensional CDW

We now consider a sufficient condition for helium formation. As can be seen from the stepwise change of the longitudinal wave velocity in the previous paper [2], the reaction is associated with periodical motion of deuterons. Furthermore, the longitudinal wave interacts with the conducting electrons, especially collective electrons. The correlated electron motion, associated with many electrons in heavy atoms (e.g., Pd) analogous to hydro-dynamic or sound vibrations, is known as collective resonance. This model was suggested long ago by Bloch [17] and Jensen [18], but the Hartree-Fock approximation made this idea improbable in physical history. Since deuterium exists as itinerant deuterons in palladium, we expect a charge imbalance (CDW instability [19]) state in a PdDx lattice.

Since the atoms along three [100] directions are lined up in a chain (*i.e*, an alternating octahedral $D^{+\delta}$–$Pd^{10-\delta}$ array) in the deuterated palladium lattice, the breathing-mode-like displacement of the deuterons occurs along the [100] directions. A longitudinal deformation $\xi(z)$ of the phase $\varphi(z)$ of the $2k_F$ CDW along the chain direction z, induces charge redistribution $\xi u(z)$ with the wavelength $2\pi/\xi q$ and long range Coulomb forces, giving an optical frequency ($\omega^2 \neq 0$) at the longitudinal phason, which is a kind of collective mode, *i.e.*, excited state:

$$u(z) = \sqrt{\frac{2}{\omega_{2k_F}} \frac{\Delta}{g}} \cos\left(2k_F z + \varphi(z)\right) \qquad (6)$$

where g is the electron-phonon coupling constant, k_F the wave vector of the Fermi level, ω_{2k_F} is the phonon energy for the lattice of the wavenumber $2k_F$, and 2Δ is the energy gap at Fermi level.

The contraction of the deuteron octahedra around the $Pd^{10-\delta}$ atom leads to a confinement of deuteron pairs at the necessary close proximity. The rate of the confinement increases as the ratio of deuteron/vacancy increases. Since the CDW wavelength changes with the number of electrons, many electrons make the wavelength smaller, *i.e.*, the confinement stronger. It is known that the total oscillator strength in the collective resonance is approximately equal to the total number of oscillating electrons [20]; it is 10 for the 4*d* resonance in Pd. Therefore, palladium is one of the best elements for the confinement. When the collective motion of the excited state ceases in the palladium lattice, the photon emission abruptly occurs ($< 10^{-15}$ s) [Eq. (4)] and simultaneously creates neutral pions [Eq. (3)]. These pions could be "virtual" particles, that is, within limits of Heisenberg's Uncertain Principle. The neutral pion's lifetime $\approx 10^{-6}$ s. Thus, the considerable confinement of deuteron pairs could be attained by periodic attraction due to the collective resonance of many electrons.

For the collective resonance effect, Hagelstein [21] has reported that coherent neutron transfer reactions are based on phonon frequency shifts.

2.1.4 Helium formation with neutral pions

Last, we consider the intrinsic role of neutral pions in nuclear fusion by nuclear fusion. It is known that the pions within the nucleus allow nucleonic species to bond together and fuse with each other [22]. Kenny [23] has pointed out that attraction between deuterons could be seven times greater than in the case of nucleonic constituents thanks to pionic interactions, because pionic masses are about one-seventh that of either the proton or neutron and, thus, their interaction range is at least seven times that of their fellow nucleonic constituents based on mass alone. Since the neutral pion does not experience a Coulomb barrier [24], it can easily enter within an effective nuclear force field of deuteron pairs at close proximity.

According to symmetry meson theory [25] associated with a binding energy that tends to clump bosons together, we can write the interaction energy of two deuterons at separation *r* as follows:

$$U(R) = -\frac{C}{r^4}, \qquad (7)$$

where *C* is the coupling constant. Assuming the addition of two neutral pions increases the attraction force by a factor of 14, we obtain

$$r \cong 0.517 \qquad r_0 = 0.038 \text{ nm}, \qquad (8)$$

where r_o is equilibrium separation (0.074 nm) for a deuterium molecule in its gas or liquid phase. Therefore, the introduction of neutral pions reduces the separation of the deuteron nuclei and aids them in fusing with each other. Although the neutral pion is recognized as a non-exchange part in a nuclear strong field, it clearly plays a decisive role in the fusion of deuteron pairs. The effect of neutral pions on nuclear reactions in solids has been largely overlooked, as far as we know. Thus, the excitation of electrons and the resultant occurrence of pions in a palladium lattice are sufficient conditions for helium formation.

2.1.5 Calculation of fusion rate

Pions are responsible for all low-energy nuclear interactions and must be involved in the cold fusion interaction [24]. According to symmetry meson theory, we must add the effect of the neutral pion for the nuclear fusion of the deuterons. Here, we estimate the reaction rate for the neutral pion-catalyzed fusion of two deuterons.

In the Born-Oppenheimer approximation, the fusion rate R for the D-D reaction is proportional to the probability $|\Psi(0)|^2$, that is, the wave function

Ψ of the interacting D-D pair at the origin in the center-of-mass coordinate system [26],

R = $A\,|\,\Psi(0)|^2$, (9)

where A is the nuclear reaction constant. At very low energies, the cross section σ for Eq. (9) can be written in the formula [27]

$$\sigma = \frac{A}{V} C_0{}^2, \tag{10}$$

where V is the relative velocity of the incident particle and C_0 is the s-wave Coulomb penetration factor. When the finite size of the interaction volume is neglected, the Coulomb factor at low energies is

$$C_0^2 \cong 2\pi\eta_0 \exp(-2\pi\eta_0) \tag{11}$$

$$\eta_0 = \frac{e^2}{\hbar V}, \tag{12}$$

where η_0 is the Sommerfelt parameter. From Eqs. (10), (11), and (12), we obtain the familiar Gamow formula [28]:

$$\sigma = \frac{S}{E} 2\pi\eta_0 \exp(-2\pi\eta_0) = \frac{S}{E} exp\,(-\frac{\beta}{\sqrt{E}}) \tag{13}$$

where S is the astrophysical S-factor, and β is the Coulomb barrier tunneling constant.

Since the neutral pion in Eq. (3) is provided by the emission of two excited electrons, the velocity v of the neutral pion is given by

$$\frac{1}{2} m_\pi^0 v_{\pi^0}{}^2 = 2 \times \frac{1}{2} m_e (3 \times 10^6\ (Ref.29))^2, \tag{14}$$

$$m_{\pi^0} = 268\, m_e, \tag{15}$$

where m_{π^0} and m_e are the masses of the neutral pion and the electron, respectively. From Eqs. (14) and (15), we obtain v_{π^0} = 2.592 × 10^5 m/s.

When one neutral pion collides with one deuteron in Eq. (2), we find that

$$\frac{1}{2}m_{\pi}^{0}{v_{\pi^0}}^2 = \frac{1}{2}M'V^2 \qquad (16)$$

$$M' = m_p + m_n + m_{\pi^\pm} + m_{\pi^0}, \qquad (17)$$

where $m_p, m_n \; and \; m_{\pi^\pm}$ are masses of the proton (=938.27 MeV), neutron (=939.55 MeV) and charged pion (139.6 MeV), respectively. Hence, the velocity of the reduced mass of deuteron is

$$V = 6.354 \times 10^4 \text{ m/s}. \qquad (18)$$

To obtain the Coulomb factor C_0^2 in Eq. (11), we must calculate η_0.

Using Eq. (18), we obtain

$$\eta_0 = \frac{e^2}{\hbar V_{M'}} = 33.51. \qquad (19)$$

Here, we consider the screening effect for the Coulomb repulsion to enhance the fusion probability of a D-D pair. As mentioned above, the total number of oscillating electrons in collective resonance for palladium is ~10. Since the screening by many electrons can be apparently treated as one electron with all their masses, the effective change of the D^+ reduces e/10 by the electron charge screening effect. This means

$$\eta = \frac{1}{10}\eta_0. \qquad (20)$$

From Eq. (11) we obtain

$$C_0^2 = 2\pi \times 3.3\,513\exp(-2\pi \times 3.3513)$$
$$= 21.056 \times 7.163 \times 10^{-10}$$
$$= 1.508 \times 10^{-8}. \qquad (21)$$

Next, we consider A in Eq. (10). Here, it should be noted that Jackson [27] has reported that the negative meson should be able to act as a catalyst a very large number of times during its lifetime and the reaction rate for D-D reaction in the mesonic molecule will be of the order of 10^6 times that of the observed rate. Hence, by analogy we infer that the rate can be treated as A = 2 $\times 10^{-8}$ cm^2/s, with the catalytic help of neutral pions. Thus, we obtain

$$\sigma = \frac{2.0 \times 10^{-8} \times 1.508 \times 10^{-8}}{6.354 \times 10^{6}}$$

$$= 4.617 \times 10^{-23}\ cm^2 = 46.167\ barn \quad (22)$$

When we consider a pion exchange force between deuterons, we see that the force enhances the *S* factor as a function of the force [6]. We apply the effect by the charged pions to that by the neutral pion. Because the addition of two neutral pions increases the *S* factor (= 10^6) by four orders of magnitude over the conventional two charged pions, Eq. (13) gives

$$E = \frac{10^6\ (keV\ barn)}{46.167\ (barn)} \times 7.163 \times 10^{-10}$$

$$= 1.522 \times 10^{-5}\ keV = 0.0155\ eV. \quad (23)$$

This value is a plausible one as cold fusion with the D-D system. Substituting σ = 46.167 barn, $S = 10^6$, $E = 1.552 \times 10^{-5}$ keV into Eq. (13) gives for the Coulomb barrier tunneling constant

$$\beta = 0.078. \quad (24)$$

Thus, we have

$$\sigma = \frac{10^8}{E} \exp\left(\frac{-0.078}{\sqrt{E}}\right) \quad (25)$$

The nuclear reaction rate/cm^3 is given by

$$R = N_D N_{coh} V_{M''}\ \sigma, \quad (26)$$

where N_D is deuterium number of density and N_{coh} is a multiplicity of factor according to lattice-site conditions. If $N_D = 10^{22}$ pair/cm^3 and N_{coh} = 10 (Ref. 30), we obtain

$R = 10 \times 10^{22}\ (1/cm^3) \times 10(1/cm^3) \times 6.534 \times 10^4\ (cm/s) \times 4.617 \times 10^{-23}\ (cm^2) = 3.017 \times 10^7$ fusion/s/cc

$\cong 3.02 \times 10^{-5}$ W/cc. (27)

As the maximum rate,

$R_{max} = 10^{22} \times 10 \times 6.5 \times 10^{6} \times 10^{6} \times 10^{-24}/0.0155$

$\approx 4 \times 10^{13}$ f/s/cc

= 40W/cc. (28)

These values are reasonable for the cold fusion of helium.

2.1.6 Conclusion

This study makes necessary and sufficient conditions for the formation of a helium nucleus from two deuterons *i.e.*, nuclear fusion in a palladium lattice clear. The fusion requires necessarily a direct force due to the exchange of two neutral pions, which do not actually compose the deuteron nucleus. The neutral pions are provided by two photons, which are produced by the emission of excited collective electrons derived from the palladium atoms. The introduction of the pions makes it possible to reduce remarkably an internuclear distance, enhancing the fusion rate for helium formation. The dynamic interaction is interpreted as the result of the condensation of deuterons into octahedral interstitial sites by electrolysis and the contraction of the deuteron octahedra around the $Pd^{10\cdot 8}$ atom with the help of the electron-phonon charge-density wave coupling.

2.2 Physical role of neutral pions for the nuclear fusion of He [31]

2.2.1 Electromagnetic interaction mediated by photons for two deuterons

An atomic nucleus is composed of neutrons and protons, but we cannot find electrons and neutrinos in the nucleus at first glance. However, it has been recognized that these light particles, which are lepton with isospin 1/2, are not contained originally in the nucleus, but are generated in nuclear transmutation processes such as β decay and helium formation in the sun.

Since the composite model, in which the nucleus was composed of proton and electrons, was knocked out by the discovery of neutrons, wide credence has been given to a concept that electrons cannot exist in a nucleus [32]. However, as far as the nucleus is a constituent element of the atom, the distribution of the electron in the nucleus is not perfectly zero without violation of the uncertainty principle in spite of its extremely small volume. On the other hand, the generation process for neutrino has not been entirely resolved. We have to take another look at the generation process.

Our first interest lies in studying a possibility of the coexistence of electrons and neutrinos in the nucleus from a new angle on particle physics with lower energy. Although the neutrinos have three families or three flavor eigenstates (ν_e, ν_μ and ν_{tau}) associated with the three charged leptons (the electron, the muon and the tau), we use the electron neutrino with the lightest mass in this study. As far as we know, no previous research has been done on the coexistence of electrons and neutrinos in the nucleus, except for the nuclear reaction of excited electrons and neutrinos in solids [33].

Next, we investigate an enhancement effect of the coupled electron and neutrino for nuclear cold fusion, in addition to the catalytic effect of neutral pions.

In the previous section, we showed that the formation of a helium nucleus from two deuterons *i.e.*, fusion, requires a direct force due to the exchange of two neutral pions which do not actually compose the deuteron nucleus (Please see Eq. (2)).

The neutral pion is provided by two photons, which are produced by the emission of excited collective electrons derived from the palladium atoms. The introduction of the pions makes it possible to reduce remarkably the internuclear distance, enhancing the fusion rate for helium formation. On the significant role of neutral pions in nuclear fusion, we explained that the pion could easily enter within the effective nuclear force field of deuteron pairs at close proximity, because the neutral pion does not experience a Coulomb barrier [24]. Then we investigated the necessary and sufficient conditions for the cold fusion of helium in a solid lattice in terms of elementary particle physics. Since the mass of the field quantum determines the range of potential and force, and the maximum distance *L* that the virtual particles are allowed to travel, the Heisenberg uncertainty relation is given by the Yukawa formula [34]

$$L \leqq c\Delta t \approx h/m_p c, \tag{29}$$

where c, t, m_p, and h are the velocity of light, time, proton mass, and Planks' constant, respectively. The interaction for deuterium atom pairs is schematically shown in **Fig. 3**, along with charge pion-mediated *pn* interaction in the deuteron:

$$p + e^- \leftrightarrow p + e^-. \tag{30}$$

The Pd lattice for the confinement of deuteron pairs plays the same role as magnetic field confinement in hot nuclear fusion, because the attractive interaction between the deuterium atom and the electron is mediated by a massive photon with 5.2 keV. However, the physical role of the electron and the electron neutrino in nuclear fusion is not yet clear.

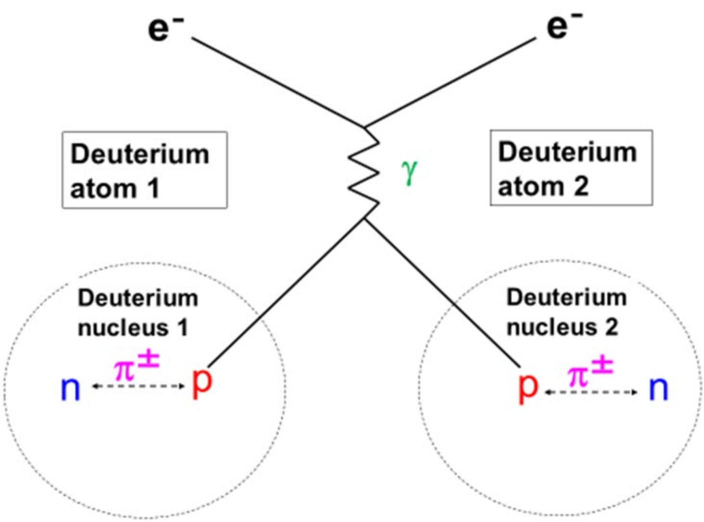

Fig. 3. Schematic representation of electromagnetic interaction, $p + e^- \leftrightarrow p^+ + e^-$, mediated by the photon γ for two deuterium atoms, D_2, where p and n are the proton and neutron, respectively.

2.2.2 Coupled electron and neutrino in electroweak interaction

For the generation of neutrinos and electrons, the β-decay is the most familiar physical phenomenon. The following relation of the β-decay describes a weak interaction between the lepton and nucleon [35]:

$$\mathrm{n} + \nu \leftrightarrow \mathrm{p} + \mathrm{e}^{-}. \quad (31)$$

This formula shows that four particles form two groups: (n, ν) with neutral charge and (p, e^-) with negative charge. Since p and n have the quark structure *uud* and *ddu*, respectively, we can rewrite Eq. (31) as the form:

$$d + \nu \leftrightarrow u + \mathrm{e}^{-}. \quad (32)$$

Equation (32) indicates that the four elementary particles form two groups; (d, ν) and (u, e^-). In this formula, barion and lepton numbers, and the negative charge of -1 are preserved before and after reaction. As far as quarks are permanently confined inside the nucleons, we must consider the interaction in the narrow region of the nucleus. However, as a matter of fact, Eq. (32) has been treated in utter disregard of the above-mentioned physical condition. Then we consider confirmation of Eq. (32), in terms of the standard model in particle physics. The Fermi elementary particle interaction between proton and neutron is shown in Fig. 4, using the Feynman diagram. For this purpose, we use the lightest deuterium nucleus with one proton and one neutron, as a representative one.

In **Fig. 4**, the weak interaction of Eq. (32), which involves the exchange of an electric charge, is mediated by the charge intermediated vector boson $\boldsymbol{W}^{\pm}$ between the u and d quarks in the different nucleons. On the other hand, both the neutrino and antineutrino in the proton and both the electron and antielectron e^+ in the neutron are mediated by the neutral intermediate boson Z^o:

$$\nu^{+} \leftrightarrow \mathrm{e}^{-} + \mathrm{e}^{+}. \quad (33)$$

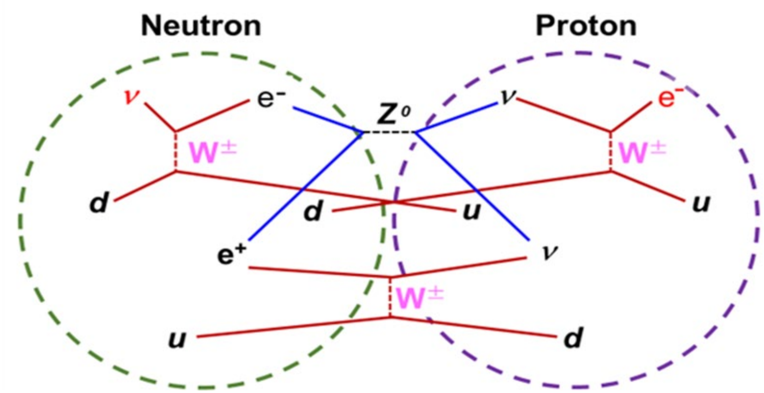

Fig. 4. Schematic representation of elementary particle interactions, $d + \nu \leftrightarrow u + e^-$ and $e^- + \nu \leftrightarrow e^+ + \nu^-$, mediated by W and Z^0 bosons in the proton and neutron deuterium atom, respectively, where u and d are up and down quarks, respectively. The reaction $e^- + \nu \leftrightarrow e^- + \nu$ is eliminated.

Here, since the masses of $\boldsymbol{W}^{\pm}$ and Z bosons are extremely large, 80.375 [36] and 91.187 GeV [37], respectively, we can calculate their Compton wavelengths as 2.46 and 2.16×10^{-18} m, respectively. Thus, the two group particles (u, e^-) and (d, ν) must bind together by a weak force in a very narrow region of around $(2.2—2.5)\times10^{-18}$ m. For a proton, the total positive charge (+1) of three quarks cancels the negative charge (-1) of the electron, while the neutron has positive and negative electrons for a total electric charge of zero. As a result, we can see that one electron and one neutrino exist in the proton and neutron, respectively. Furthermore, ν and e^- are coupled as an s-wave boson of spin 0, because the electroweak force requires that the spins are opposed to each other due to boson exchange [38]. Since the size of both the lepton and quark is less than 10^{-18} m and the nucleus size is around 10^{-15} m, we can assume that the u and d quarks are surrounded by spherically symmetrical balls of electrons and neutrinos blurred by the time-exposure of its rapid motion in the nucleus, respectively. Furthermore, although the standard model in particle physics does not specify how many quark–lepton pairs constitute the family [39], a limit number exists, as far as we treat natural atomic elements with atomic numbers up to around 110; three pairs must assign for one proton–neutron pair. In other words, the three kinds of pairs must intrinsically be assigned for one proton–neutron pair, but this problem has been overlooked in high-energy particle physics.

2.2.3 Electron distribution in electroweak interaction

In the previous section, with a view to explaining coexistence of electron and neutrino in nucleus, a necessary role of weak interaction was shown. Notwithstanding the necessary condition, we feel a new question arises as to why the existence of electrons in a proton does not violate the uncertainty principle. Next, we consider the possibility of the existence of an electron in a proton in terms of electroweak interaction.

If a light particle such as an electron exists in a nucleus, it cannot be generally confined in the nucleus because of the large uncertainty of the momentum. However, the uncertainty determining the position of the electron in nucleus decreases as speed of the electron increases. This means probability of existence for electron in nucleus is not zero.

In atoms, nucleus and electrons are bound together by electromagnetic force of mediated photon (Fig. 3) for two deuterium atoms, D_2.

In general, the strength of force for boson exchange interaction is proportional to the square of an effective interacting zone of a boson or in inverse proportion to the square of a boson mass. In calculating the strength of photons, we cannot make use of the latter's relation, because of photons with zero mass. Since the Compton wavelength of the electron is 3.86×10^{-13} m, we can use the wavelength as the interacting zone of the photon. Similarly, the Compton wavelength, *i.e.*, the interacting zone, of the ***W*** boson in weak interaction is 2.46×10^{-18} m. Thus the zone ratio of the electromagnetic interaction to the weak one is around 4.04×10^{-11}.

Here, since one electron corresponds to one proton in atoms, we can assume that the electron of atoms takes one's share of both electromagnetic and weak interactions in proportion to the effective zone ratio in the normalization of electromagnetic and weak interactions regardless of their coupling constants. In other words, the weak force mediator is lodged with the (u, e^-) group for a brief time. From the effective zone ratio, we can obtain 2.07×10^{-5} eV as the electron mass associated with the weak interaction. This value is close to the electron neutrino mass, 10^{-5}—10^{-6} eV [40], extrapolated from the masses of muon and tau neutrinos obtained in Super-Kamiokande collaboration. This indicates that the ratio of the lepton mass is almost equivalent to the ratio of the quark ones, leading to a possible answer for an unexplained problem in the standard model in particle physics, i.e., why the ratio of the lepton mass within the first family is so large compared with the ratio of the quark ones. And we can also answer why only the first family is needed to make up the ordinary protons, neutrons, and electrons in the universe. The electrons and neutrinos coexist with quarks in the "nucleon vessel" of the atom which is firmly bound by electromagnetic interaction. On the other hand, the other two families exist only ephemerally after the electrons are completely separated from the nucleus by high-energy collisions. Although nuclear behaviors at low temperature have not aroused much interest from researchers, because most nuclei have an enormous energy of the order of a few MeV, we cannot ignore the role of the electrons in atoms associated with *u* and *d* quarks in particle physics. Further study for this interesting area is called for.

2.2.4 Physical Role of Electrons and Electron Neutrinos in Nuclear Fusion

In the previous section, we reported the possible coexistence of an electron and an electron neutrino in a nucleus, based on weak interaction in *β*-decay. Provided that the electron of an atom takes it share of both electromagnetic and weak interactions as according to zone ratio, we can see that one electron and one neutrino can exist in a proton and a neutron, respectively.

When a helium atom is formed from two deuterons, quarks, electrons and neutrinos must be mediated by the charged and neutral intermediated bosons, ***W*** and $\boldsymbol{Z^0}$ (**Fig. 5**), respectively, as a result of the mediation of charged and neutral pions:

$u + e^- \leftrightarrow d + \nu,$ (34)

$e^+ + \bar{\nu} \leftrightarrow e^- + \nu,$ (35)

$e^- + \nu \leftrightarrow e^- + \nu.$ (36)

From Fig. 5, the addition of neutral pions is equivalent to the double addition of Eq. (36), *i.e.*, two e^-–ν pairs. Thus the addition of e^- and ν pairs enhances the fusion reaction.

2.2.5 Creation of Electron and Neutrino Pairs

Last, we consider how the pairs are created before the fusion reaction. When palladium nuclei with even atomic numbers exist, there is a possibility that double β-decay, which is the second-order β-process, occurs [41].

$$(Z, A) \rightarrow (Z + 2, A) + 2e^- + 2\nu, \qquad (37)$$

where Z and A are atomic and mass numbers, respectively. Equation (37) is a nonequilibrium equation. Since palladium in nature has five isotopes with even atomic numbers, *i.e.*, ^{102}Pd, ^{104}Pd, ^{106}Pd, ^{108}Pd, and ^{110}Pd of 0.96, 10.97, 27.3, 26.7, and 11.8%, respectively [42], the corresponding element sets for Eq. (37) are ^{106}Pd ^{106}Cd, ^{108}Pd ^{108}Cd, and ^{110}Pd ^{110}Cd. For starting elements, ^{106}Pd, ^{108}Pd, and ^{110}Pd are plausible. As far as we know, no previous research has been done on the physical role of electrons and neutrinos in nuclear reactions, except for the nuclear reaction of excited electrons and neutrinos in solids [24]. This interesting area needs further work.

2.2.5 Conclusion

In this chapter, we investigated the possibility of the coexistence of coupled electrons and electron neutrinos in a nucleus, using electroweak interaction. In a nucleus, the weak interaction is mediated by the $\boldsymbol{W}^{\pm}$ boson between the u and d quarks in protons and neutrons, respectively, or neutrons and protons, respectively, while neutrinos and antineutrinos in protons and electrons and antielectrons in neutrons are mediated by the $\boldsymbol{Z}^{o}$ boson. From the Compton wavelengths of the electron and the $\boldsymbol{W}$ boson, the effective zone ratio of the electromagnetic interaction to the weak one is around 4.04×10^{-11}. Provided that the electron of an atom takes it share of both the electromagnetic and weak ones as according to zone ratio, we obtain 2.07×10^{-5} eV as the electron mass for the weak one, closing to an estimated neutrino mass of 10^{-5}—10^{-6} eV. This is a possible answer for why the ratio of the lepton mass within the first family is so large compared with the ratio of quark ones in the standard model. The electrons and the neutrinos are coupled as *s*-wave bosons in a nucleus.

From the view of particle physics, through the mediation of charged and neutral pions, the introduction of *s*-wave coupled electrons and neutrinos enhances cold fusion. The addition of neutral pions is equivalent to the double addition of Eq. (36), *i.e.*, two $e^- - v$ pairs. The electron and neutrino pair may come from the double *β*-decay formation of helium (Please see Eq. (36)).

In this nonequilibrium equation, ^{106}Pd, ^{108}Pd, and ^{110}Pd are plausible in nature. The sufficient conditions for this interesting area need further study.

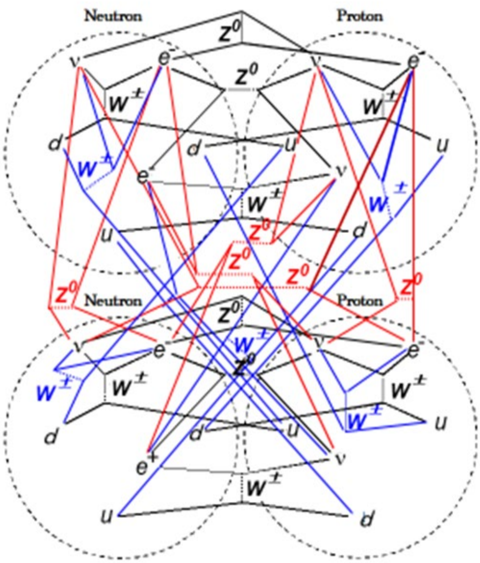

Fig. 5 Schematic representation of elementary particle interactions, $d + v \leftrightarrow u + e^-$, $e^+ + \bar{\nu} \leftrightarrow e^- + v$ and $e^- + v \leftrightarrow e^- + v$, mediated by ***W*** and Z^0 bosons in the proton and neutron of a deuterium nucleus, respectively, where *u* and *d*are up and down quarks, respectively. The black lines are *W* and Z^0 mediated interactions between protons and neutrons. *W* and Z^0 mediated interactions among protons and neutrons are blue and red lines, respectively.

CHAPTER 3

POSSIBLE NUCLEAR FUSION OF DEUTERONS IN CELESTIAL BODIES

3.1 Generation of heat in the Earth's inner core [43, 44]

3.1.1 Introduction

Our earth is still a young planet with substantial heat sources that are characterised by volcanic activity and earthquakes generated by the movement of tectonic plates. The theory of plate tectonics successfully explains various geological phenomena that occur on the continents and in the oceans of Earth, but the driving force behind plate motion has not been entirely resolved. Regarding the origin of the heat, the current consensus is that the flow of heat from the Earth's interior to the surface comes from two main sources: radiogenic heat and primordial heat. Primordial heat, which was generated during the initial formation of Earth, is the kinetic energy transferred to Earth by external impacts of comets and meteorites and the subsequent effects: gravity-driven accretion, friction caused by differentiation of the Earth's mantle structure (the sinking of heavy elements like Fe, and the rising of light elements like Si) and the latent heat of crystallization released as the core solidified [45].

Since Kuroda [46] first proposed that natural fission reactors were operating on Earth around two billion years ago, much attention has been focused on nuclear energy as the driving force of plate motion. Herndon [47] asserted the feasibility of planetocentric nuclear reactors and developed the concept extensively. Because there is very little U in iron meteorites, however, a nuclear reactor in the Earth's core or on other terrestrial planets seems unlikely [48]. Meijer and van Westrenen [49] reported nuclear fission of U and Th as heat generation sources at the