The Cold Fusion

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Abstract

In conventional thermonuclear fusion process of atomic nuclei, one critical condition is how to make them close together or pass through the Coulomb barrier between themselves. Although the thermonuclear fusion has been understood well with the conventional theory in nuclear physics, cold fusion, which has been issued with Fleischmann-Pons experiment in 1989, or nuclear fusion at room temperature in general is not explained with the conventional theory. However, if nuclear force inside the nucleus is considered as the spin-spin magnetic interaction of nucleons initiated by electric polarization between proton and neutron, there is an alternative way to understand cold fusion. Since the electric polarization between nucleons can be induced by an external electric field, the electric polarization can be an important clue to understand cold fusion, such as the nuclear fusion of deuterium nuclei absorbed into the lattice structure of palladium.

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Introduction

It has been known that the most abundant atom in the Universe is hydrogen, while the most stable atom is iron; specifically, iron-56 that has 8.8 MeV binding energy per nucleon. Through the nuclear reactions such as nuclear fusion if atomic number is lower than iron or nuclear fission if atomic number is higher than iron, atomic nuclei can be reached to the most stable atom iron. In the meantime, the mass defect in nuclear reaction is corresponded to the energy released due to the mass-energy equivalence principle.

The process of nuclear reactions can be taken slowly as in nuclear plants or abruptly with triggering the chain-reaction in nuclear weapons. In natural phenomena, if an atomic nucleus is unstable as in radioactive materials, nuclear fission process is occurred spontaneously; however, nuclear fusion is not spontaneous because of the threshold reaction energy to penetrate the Coulomb barrier, which is caused by the positive-positive repulsive electrostatic interaction between atomic nuclei to be fused in nuclear reaction; thus, the atomic nuclei need kinetic energies to pass through the Coulomb barrier. If two atomic nuclei, let's say light nucleus such as proton or deuteron, are fused in nuclear fusion reaction, the atomic nucleus needs to pass through the Coulomb barrier between the nucleus and the other to be fused; hence, the nucleus needs a kinetic energy to pass through the coulomb barrier; thus, a high temperature environment is necessary for those atomic nuclei, which is one mechanical method we have known using kinetic energies of atomic nuclei, which is a direct enforcement against the repulsive electrostatic interactions between atomic nuclei to make the environment for nuclear fusion process.

In classical theory, the nucleus cannot go through the Coulomb barrier as long as the kinetic energy of nucleus is not higher than the potential energy of Coulomb barrier. In fact, it is almost impossible for the nucleus to pass through the Coulomb barrier because the potential energy of the Coulomb barrier, $V(r) \propto r^{-1}$, if the two nuclei get close to each other in the femtometre-scale distance[2], is too high for the nucleus to overcome the Coulomb barrier. In addition, classical physics cannot explain the phenomenon that the nucleus can go through the Coulomb barrier even if the kinetic energy of nucleus is lower than the potential energy of Coulomb barrier; however, in quantum mechanics, the probability passing through the Coulomb barrier can be

[2] $1\ \mathrm{fm} = 10^{-15}\ \mathrm{m}$: length-scale in Nuclear Physics

estimated with gamow factor (Gamow factor - wikipedia) by virtue of the wave nature and the uncertainty principle in quantum mechanics.

It has been considered in general, which is in consensus among physicists, that one necessary condition in nuclear fusion is such high temperature as in the core of the Sun $\left(16\times10^{6}\ \text{K}\right)$ with which atomic nuclei can have enough kinetic energies to overcome the coulomb barrier. Naturally, the research of nuclear fusion has been focused on how to make a similar situation as inside the Sun (Barbarino 2023, World Nuclear Association 2022). By the way, we need to know whether the mechanical method to overcome the Coulomb barrier is unique or not, which is using kinetic energies of atomic nuclei in the state of hot plasma.

Since cold fusion was announced at a press conference at the University of Utah in 1989, the name itself has been a symbol of junk science to the general public because it was not accepted by mainstream of scientific community (LENR 2023, Scott and al. 1989). Nevertheless, researches have been conducted by some people interested in cold fusion in a variety of ways, such as LENR, LANR, LCF, etc. (Researches in Cold Fusion). However, the major problem in cold fusion research is the consistency and/or reproducibility that is necessary conditions in a scientific research. In addition, there is no acceptable or at least plausible theory to explain for the results in cold fusion experiments. To make a long story short, something really happens, which is probably nuclear fusion reaction, but it cannot be understood with conventional theory in nuclear physics. First of all, we need to review the mechanism of nuclear fusion reaction that we have known with the conventional theory and compare it with cold fusion experiments.

Cold Fusion (Fleischmann–Pons experiment)

It is not such a big machine used in the thermonuclear fusion, which needs magnetic or inertial confinement of hot plasma, but a small table-top device for electrolysis of heavy water at room temperature, in which metallic palladium (Pd) is used for cathode. In the experiment, ionized deuterium atoms are attracted to cathode; some of them are absorbed into the palladium lattice. Once in a while, an excessive heat has been observed in the palladium cathode, which cannot be considered as an electrochemical process. As a possible explanation for the excessive heat occurred in the palladium cathode, the nuclear fusion has been proposed but not accepted in general.

Criticism: There have been some counter-evidences why scientific community don't accept the possibility of cold fusion as well as the reproducibility of experimental results: In conventional nuclear fusion process, it is supposed that the distance between two nuclear particles should be made on order of femtometre (the size of nucleus) for nuclear fusion[3], and that protons or neutrons should be detected as the secondary particles in the fusion process. Firstly, the distance of inter-atomic spacing inside a palladium lattice is $\sim 2.6\times10^{-10}\,\mathrm{m}$ that is still too far to take a nuclear reaction if compared with the distance, $r_\mu \sim 2.56\times10^{-13}\,\mathrm{m}$, in the muon catalyzed fusion. The second, if nuclear fusion reactions take place, there should be protons or neutrons detected because the reactions are expected as:

$$\mathrm{D} + \mathrm{D} \rightarrow \mathrm{T} + \mathrm{p}\ (50\%)\,;\ \mathrm{D} + \mathrm{D} \rightarrow\ {}^{3}\mathrm{He} +\ \mathrm{n}\ (50\%)\,;\ \mathrm{D} + \mathrm{D} \rightarrow\ {}^{4}\mathrm{He} + \gamma\ (\sim 10^{-7}).$$

Rebuttal: In conventional thermonuclear fusion process, the Coulomb barrier is supposed to be built from repulsive electrostatic interactions only between two nuclear particles because others are supposed be in the distance far enough to be ignored and their interactions are in arbitrary directions. On the other hand, if the nuclear fusion occurs between deuterium nuclei absorbed inside the palladium lattice in the experiment of cold fusion, the Coulomb barrier between deuterium nuclei inside the palladium lattice can be different from in the thermonuclear fusion process, in which the repulsive electrostatic interaction is considered only between two nuclear particles; then, the branching ratio in nuclear fusion reactions also can be different in cold fusion. However, there has been no theory or even no plausible explanation how it can be different from the conventional thermonuclear fusion.

In Fleischmann–Pons experiment, it has been known that the excessive heat occurred once in a while, the time of which cannot be estimated, and at one of many setups for the table-top experiment, which seems to be random; hence, the unpredictable rareness of the event, which is occurring the excessive heat, was the main reason that cold fusion experiment was debunked. Since then, many experiments done by persistent researchers show that nuclear fusion itself, generating the excessive heat in palladium lattice at room temperature, is true, which is called Fleischmann-Pons effect although it is not explained with conventional theory in nuclear physics, and that the unexpected reproducibility is due to the conditions, such as D/Pd ratio, temperature, current density, etc., to trigger the nuclear fusion reaction (Staker 2023, Storms

[3] $1\ \mathrm{fm} = 10^{-15}\,\mathrm{m}$ (femtometre); $r_\mu \sim a_0/m_\mu$ $\left(m_\mu \sim 207 m_e\right.$; Bohr radius : $\left. a_0 \sim 0.5\times10^{-10}\ \mathrm{m}\right)$

2022, Storms 2016, Letts and Hagelstein 2008, McKubre and al. 2003). On the other hand, to explain thermonuclear fusion, in which nuclear particles are in the form of thermal plasma, the conventional theory evaluates the probability to pass through the Coulomb barrier between two nuclear particles, which is naturally adapted in the fusion process; only two nuclear particles are involved in the nuclear fusion reaction although the circumstance, in which many hot nuclear particles interact with many others, is considered with phenomenological factors (Iliadis 2013). However, except the probability passing through the Coulomb barrier, we don't know the detail how the nuclear particle, actually with reduced mass of the two nuclear particles, pass through the Coulomb barrier. For example, we don't know how the repulsive interaction stops and the attractive fusion process starts, and what distance between the nuclear particles it starts at.

With the classical picture of nucleons modeled as composite objects with electric charge distributions and nuclear spins, it is considered that nuclear force inside the nucleus is originated from the spin-spin magnetic interaction of nucleons (neutron and proton) and their electric polarizations, in which neutron-proton magnetic paring is crucial for the stability of nucleus. In nuclear fusion process, for example, of a neutron and a proton, the electric polarizations of nucleons, in which electric polarization of neutron is induced by the positive proton; then, electric polarization of proton is induced against the polarized neutron, initiate the fusion process; firstly, an attractive interaction appears between the polarized nucleons; then, the spin-spin magnetic interaction of nucleons takes over (Kim 2022).

For example, let's think about the proton-proton fusion in thermonuclear fusion: if they get close up to a certain point, one of protons changes to a neutron with ejecting a positron (e^+), and the electric polarization is supposed to be occurred on the neutron for the positive proton and then on the proton for the polarized neutron. Thus, the polarized nucleons, proton and neutron, are attractive to each other, and the nuclear fusion process starts. In thermonuclear fusion process only two nuclear particles are considered with their kinetic energies to pass through the Coulomb barrier; hence, the conventional theory doesn't have even a clue what might affect on cold fusion, which is the nuclear fusion of deuterium nuclei absorbed inside the lattice structure of palladium.

Now, let's think about the electric polarization that is supposed to initiate nuclear fusion process: In thermonuclear fusion process, it is occurred when nuclear particles are getting close to each other; thus, the distance between them is a crucial measure in the fusion process. However, the distance between nuclear particles doesn't have to be such an important condition because an external electric field can induce the electric polarization.

In cold fusion experiment, the electric polarization can be occurred on deuterium nuclei inside the palladium lattice structure by external or internal causes, such as lattice vibration (phonon excitation), electric fields, pulse laser beams, etc., which have been suggested by many researchers to explain how to trigger or enhance the nuclear fusion process in cold fusion (LENR-CANR). In addition, with the NP magnetic pairing model of nucleus (Kim 2022), we can explain that nuclear fusion products in cold fusion can be different from the conventional hot nuclear fusion (thermonuclear fusion).

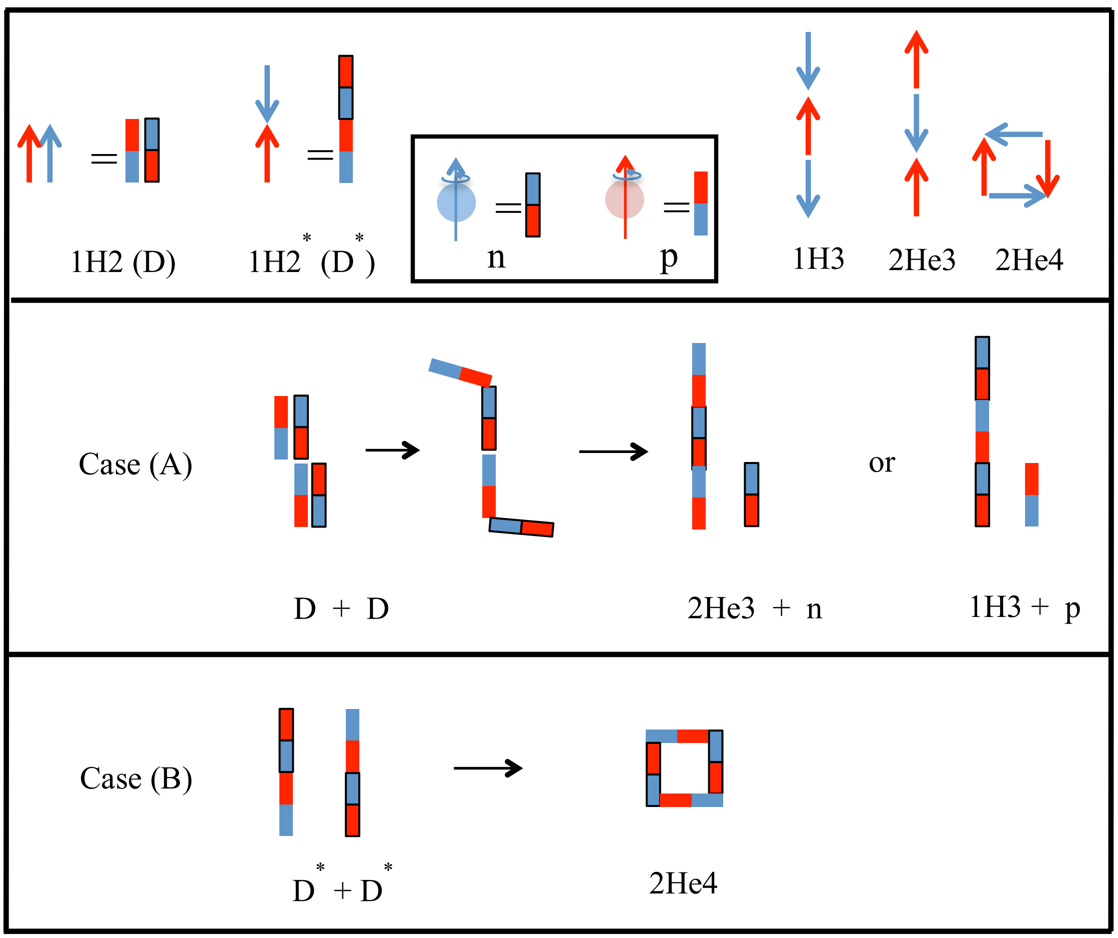

Figure 1: nuclear fusions of deuterons: D + D and D^* + D^*

Figure (1) shows the nucleus spins and corresponding magnetic moments using arrows and small bar magnets for proton and neutron, deuteron (D) in triplet state ($s = 1$) and deuteron (D^*) in singlet state ($s = 0$), Tritium (1H3), Helium-3 (2He3), and Helium (2He4). The Case (A) shows the interaction of two deuterons (D + D) as in a conventional hot fusion process; firstly, neutron and proton start the NP paring with electric polarization, in which we can suppose that the magnetic connections of a proton and a neutron on the other side of each deuteron get weaker as shown in Figure (1); thus, it ends with nuclear products: Helium-3 and a neutron (50%) or Tritium and a proton (50%), those of which are equally possible. However, let's say, if deuterons are in singlet state $(s = 0)$ with electric polarization inside the lattice of palladium deuterated[4], it is natural to expect the nuclear fusion product is helium (2He4) as shown in the Case (B).

Discussion

Since cold fusion was claimed in 1989, it has been considered as pseudoscience or crackpot because it could not be explained with the conventional theory for thermonuclear fusion and the experimental events occurring the excessive heat, which might be an evidence of nuclear fusion, could not be reproducible but close to random events, which was also unexplainable. Since then, many experiments by researchers in the world show that the reproducibility of experimental results is dependent on the condition to trigger the nuclear fusion in deuterated palladium, and cold fusion itself seems to be accepted by some people, still not in general though. However, there isn't any acceptable or plausible theory to explain cold fusion, yet.

As an alternative way to understand nuclear fusion, if the NP magnetic pairing model of nucleus is considered, we can find a way to understand cold fusion because the electric polarization, which is supposed to initiate nuclear fusion process in the model, can be induced on the deuterium nuclei absorbed into the lattice structure of palladium with external interactions, such as lattice vibration (phonon excitation), pulse laser beams, etc., and the helium (2He4) can be dominant in the nuclear fusion products as shown in Figure (1), which is different from thermonuclear fusion (hot fusion).

[4] Actually, it needs to be investigated whether the singlet state of deuteron can be made with electric polarization.

By the way, in quantum physics we can explain the tunneling effect through the Coulomb barrier: the wave function describing a physical object in the theory cannot be localized, which means, it can go inside the barrier and exist outside passed the barrier. Now, we can ask whether the wave function itself in quantum physics is ontological reality for the physical object or the representation of wave nature in natural phenomena. Anyhow, we don't ask 'how' but we can evaluate the probability of interaction or transition between two quantum states, before and after, with an interaction term, which is the Coulomb barrier here.

In thermonuclear fusion, the distance between nuclear particles is unique criterion for them to be fused and hot plasma of nuclear particles is necessary to overcome the Coulomb barrier. Anyhow, the conventional theory for thermonuclear fusion is not enough to be a general theory applicable for any situation of nuclear fusion reactions; especially, it is not applicable for cold fusion, in which nuclear fusion is triggered by external interactions on deuterated palladium, not by the kinetic motions of deuterons absorbed in the palladium lattice. It's such a shame that cold fusion has been debunked for more than 30 years in the name of scientific consensus.

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