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Letter to the Editor

A Particle Physicist's View on the Nuclear Cold Fusion Reaction

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Abstract

There are two different types of scientists who believe in the reality of the nuclear cold fusion. The researchers, who observed the excess energy by experiments, belong to the first type. On the other hand, a small number of theoreticians, who are working on the physics of the magnetic monopole, know that the nuclear reaction of the zero incident energy proceeds when the system involves a magnetic monopole. Since the former group still lacks a theory of the nuclear cold fusion based on the first principle of the natural law, I believe it is fruitful to explain to the former group how the theoretician of the particle physics comes to arrive at the conclusion that the nuclear cold fusion must occur if a magnetic monopole exists, in the framework of the quantum theory.

Keywords: Change of penetration factor, Charge quantization condition, Magnetic monopole, Nuclear cold fusion, Origin of non-reproducibility

From the charge quantization condition of Dirac [1], which says that $^*ee/c = \hbar/2$, where e and $^*e$ are the smallest electric and the magnetic charges, respectively, the magnetic counterpart of the "fine structure constant" is determined: $^*e^2/\hbar c = 137.036/4$. It means that the monopole is accompanied by a superstrong magnetic Coulomb field $\vec{B} = {}^*e\hat{r}/r^2$. If we remember that the nucleon has the magnetic dipole moment $\kappa_{\text{tot}}(e/2m_{\text{p}})\vec{\sigma}$, where κ_{tot} is 2.793 and -1.913 for the proton and for the neutron, respectively, the interaction hamiltonian between the monopole and the nucleon is $H^{\text{dip}} = -(\kappa_{\text{tot}}/4m_{\text{p}})(\hat{r}\cdot\vec{\sigma})F(r)/r^2$, in which $F(r)$ is the form factor of the nucleon. It is remarkable that the strength of this interaction potential H^{dip} is two or three times larger compared to the nuclear potential V^{nucl} at the separation $r = 0.5$ to 3 fm.

The kinetic energy term in the external magnetic Coulomb field is $H^0 = (-i\nabla - (Ze/c)\vec{A})^2/2m$, where the vector potential $\vec{A}$ must be chosen such that rot$\vec{A}$ is the magnetic Coulomb field. Since we already know the nuclear potential $V_{i,j}^{\text{nucl}}(r_{i,j})$ between the ith and the jth nucleon, the total hamiltonian of the nuclear system in the external Coulomb field becomes

$$H_{\text{tot}} = \sum_{j=1}^{A} H_j^0 + \sum_{j=1}^{A} H_j^{\text{dip}} + \sum_{i>j} V_{i,j}^{\text{nucl}}.$$

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Once the hamiltonian is given, it is the standard exercise of the quantum mechanics to calculate the physical quantities such as the energy level, radius of the orbit and the transition rate. The easiest one is the one-body problem in the external potential. The eigenfunction of the spin 0 charged particle, namely the eigenfunction of H^0, is known for long time (Tamm's solution), whose radial function is

$$R(r) = \frac{1}{\sqrt{kr}} J_\mu(kr), \quad \text{where} \quad \mu = \sqrt{(\ell + 1/2)^2 - q^2} > 0 \quad \text{and} \quad k = \sqrt{2mE},$$

in which q is the magnitude of the extra angular momentum, namely $q = Ze\,{}^*e$, and the range of the angular momentum ℓ is $\ell = |q|, |q|+1, |q|+2, \ldots$ Since the Bessel function is oscillatory and does not damp at large r, the system of spin 0 particle, and a monopole does not have bound state.

On the other hand, a particle of spin 1/2 forms bound states with the magnetic monopole when the anomalous magnetic moment ($\kappa_{\text{tot}} - 1$) is sufficiently large. For example, the system of the proton and the monopole has bound state, whose binding energy of the ground state is $-E = 0.188$ MeV and its radius of the orbit is $\sqrt{\langle r^2 \rangle} = 11.0$ fm [2]. We can treat the triton and the ^{3}He in the same way if the deformation of the nuclei is negligible. We found $1.52, 0.245$ MeV, and $3.82, 7.37$ fm, respectively, for the triton and for the ^{3}He [3]. The attractive force, which appear when the magnetic dipole moment of nuclei orients to the opposite direction of the magnetic monopole, is responsible for the formation of the bound state. We shall see the same attractive force changes the repulsive Coulomb barrier completely. Let us consider the t + p reaction. Suppose that the proton and the monopole form the bound state firstly, the potential felt by the approaching triton is the sum of the Coulomb potential and attractive potential mentioned above. The penetration potential V_1 is

$$V_1(x) = \frac{e^2}{x} - \kappa_{\text{tot}} \frac{e}{2m_{\text{p}}} \frac{{}^*e}{x^2}.$$

It is remarkable that although the peak of the Coulomb potential is around 1 MeV, the peak of $V_1(x)$ is lowered to 17 keV [3].

Furthermore, if we solve the third eigenvalue problem of the electron–monopole system, we shall find an eigenstate whose radius is one half of the electron Compton wave length namely 193.8 fm, and the monopole–proton system is shielded by the electron cloud. Therefore, the penetration potential $V_1(x)$ should be changed to the shielded Coulomb:

$$V_2(x) = \frac{e^2}{x} \exp\left[-2m_{\text{e}}x\right] - \kappa_{\text{tot}} \frac{e}{2m_{\text{p}}} \frac{{}^*e}{x^2}.$$

It is interesting to compare the penetration factor P for various potentials, in which P is

$$P = \exp\left[-2\tau\right] \quad \text{with} \quad \tau = \sqrt{2\mu_{\text{red}}} \int_a^b \sqrt{V(x) - E}\, \mathrm{d}x/\hbar,$$

where μ_{red} is the reduced mass and $[a, b]$ is the region of the penetration, and we shall put $E \to 0$ hereafter. In vacuum, $V(x)$ is the Coulomb potential, and if we choose $[a, b]$ as [1 fm, 1 Å], the penetration factor P is 5.33×10^{-106} and 6.78×10^{-92}, respectively, for d + d and for p + t. These values are forbiddingly small. On the other hand, if the magnetic monopole is involved, and so V_2 is used in place of V, P of $({}^*e - \text{d}) + \text{d}$ changes to 6.22×10^{-9}. Concerning the p + t case, there are two ways of penetration, $({}^*e - \text{p}) + \text{t}$ denotes penetration, in which the proton is trapped by the monopole at first. The penetration factors P of p + t are 5.39×10^{-4} and 2.93×10^{-7}, respectively, for $({}^*e - \text{p}) + \text{t}$ and for $({}^*e - \text{t}) + \text{p}$. Since these P have reasonable values, we can expect to find the double bound state $(\text{d} - {}^*e - \text{d})$

or $(\mathrm{p} - {}^{*}e - \mathrm{t})$. However, since the size of the orbits are around several fm, the nuclei quickly fuse to become more stable nucleus ^{4}He. If we remember the spin 0 particle such as ^{4}He cannot form the bound state with the monopole, the ^{4}He must be emitted with the kinetic energy around 20 MeV. There remains a fresh magnetic monopole, which starts to attract surrounding nuclei again. In this way the nuclear cold fusion reaction proceeds by the help of a single magnetic monopole.

If we remember the magnetic monopole is the rare particle and if the existence of a monopole in the reaction region is responsible for the nuclear cold fusion, we expect that we have to wait for long time before the cold fusion reaction start to occur. Since in the ordinary experiment, the process that a monopole moves into and stops in the reaction region is governed by the probability, the occurrence of the nuclear cold fusion is sporadic, therefore we cannot expect the 100% reproducibility of the nuclear cold fusion. In order to recover the reproducibility of the ordinary sense, we must do the much more difficult experiment to examine the existence of the monopole along with the measurement of the excess energy.

Addition to the Abstract

Up to this point, in order to solve the problem rigorously, we considered simplified system, in which a magnetic monopole is fixed in the region where the density of the fuel nuclei is high. In the actual experiment we must stop the floating magnetic monopole. The most clean experiment will be done if we can trap the monopole electromagnetically. However, there are other methods to trap the monopole. Rare earth metal such as Eu or Gd, which has large magnetic moment (several Bohr magneton), can trap the monopole by aligning the spins of the atoms of the lattice spherically around the monopole. The estimated trapping energy is around 10 keV at the room temperature ($T = 300^{\mathrm{o}}$C). Other metals, which have large magnetic permeability, such as Pd or Ni can also trap the magnetic monopole. If we consider that Pd can absorb large amount of D_2, Pd must be a good choice as the cathode.

Our primary purpose is to understand the basic mechanism of the nuclear cold fusion. In carrying out such a program, introduction of the bias, which often arises from the desire to "explain" observed phenomenon in haste, causes the fatal error. The standard mathematical manipulation of the quantum system starting from the given hamiltonian is effective in avoiding such a bias. When we simulate the quantum system there is the limitation on the number of participating particles A. So we shall restrict ourselves to the smallest system of the nuclear transmutation D + D $\rightarrow$^{4}He, whose nucleon number is $A = 4$. It is desirable that the phenomenon is static or close to static for the simplicity of the mathematical treatment. Therefore, the violently fluctuating system such as the plasma discharge is not suitable for our purpose.

It is interesting that two properties characteristic to the nuclear cold fusion are sufficient to narrow down the basic mechanism of the cold fusion. The properties different from the ordinary nuclear reactions in vacuum are (1) D + D reaction produces ^{4}He with the kinetic energy close to the Q-value, whose value is 23.7 MeV, (2) such a reaction starts to occur sporadic way. It is well-known that in the ordinary reaction the low-energy D + D state goes to the final state p + t or n + ^{3}He with 50% each and to $\gamma + {}^4$He with very small rate, in which γ-ray carries almost all the energy Q away. If we remember from the conservations of the energy and the momentum that the reaction of (two body) $\rightarrow$ (one body) is forbidden when $Q > 0$, then the final states of the D + D reaction in vacuum mentioned above is easily understood. On the other hand, in the cold fusion, magnitude of the momentum $\vec{q}$ of ^{4}He is determined by $|\vec{q}|^2/2M_4 = Q$, where M_4 is the mass of ^{4}He. This apparent non-conservation of the momentum indicates the existence of the external potential $U(r)$ which absorbs the momentum transfer $-\vec{q}$. In our D + D $\rightarrow$ ^{4}He reaction, $cq \sim 400$ MeV, which is very large and imposes a stringent restriction on the external potential $U(r)$. Soft and spread $U(r)$ cannot do the job to receive such a large momentum transfer, and the uncertainty relation requires the size of $U(r)$ to be $\Delta r \sim 0.5$ fm. It is evident that such a highly localized potential $U(r)$ cannot be formed by the electron cloud, since its normal size is around 1 Å, moreover from the Dirac equation we know that the lower limit of the size of the electron packet is the electron

Compton wave length $\hbar/m_e c$, which is numerically 386.16 fm.

If we remember that the nucleus can respond only to three types of external fields, namely electric, magnetic or pionic fields, we can narrow down the candidate of the catalyzer which is the source particles of such external fields. When we select the candidate of the catalyzer, we must remember the required property of the catalyzer particle, namely it attracts the fuel nucleus (D), and it repels the product nucleus (^{4}He). The latter property is required to prevent for the produced particle to go back to the initial state (D + D). In summary the catalyzer particle must interact with the initial particle and the final particle oppositely. For the case of the electric field, whose source is the charged particle, for example if charge is negative it attract ^{4}He as well as D. For the pionic field, its source particle is other nucleus and the interaction arises from the ordinary nuclear potential, so it does not act oppositely to the particles of the initial, and the final states. On the other hand, for the case of the magnetic monopole, it attracts nucleus with magnetic moment such as D if its spin is oriented properly, however the spin 0 charged particle such as ^{4}He is excluded from the neighborhood of the monopole (Tamm's solution). Therefore, magnetic monopole is the only candidate as the catalyzer of the nuclear cold fusion reaction.

Finally, we must consider the non-reproducibility, which is the most important feature of the nuclear cold fusion reaction. Although most of the researchers know that the cold fusion does not start on demand, the reproducibility ratio, which must depend on the time duration of the experiments, is not well defined. It is instructive to consider an example how the non-reproducibility emerges from the fundamental law whose hamiltonian does not involve t and $\vec{r}$ explicitly, so the reproducibility in the microscopic level, and also the energy and the momentum conservation are guaranteed by the Noether's theorem. Let us consider a reaction A + B $\rightarrow$ AB in a container, and let N_{A} and N_{B} are the number of particles in the container. Suppose that, to increases the reaction speed, we add the catalyzer particle c whose number in the container is N_{c}. It is customary that the number of the catalyzer particle N_{c} is much smaller compared to N_{A} and N_{B}, however N_{c} as well as N_{A} and N_{B} are macroscopic numbers. We are going to examine the appearance of the fluctuation as $\langle N_{\mathrm{c}}\rangle$ decreases to small number. Since the distribution of N_{c} has spread $\sqrt{\langle N_{\mathrm{c}}\rangle}$ around $\langle N_{\mathrm{c}}\rangle$, for example for $\langle N_{\mathrm{c}}\rangle = 100$ the reaction speed has 10% uncertainty when we repeat the measurements. As $\langle N_{\mathrm{c}}\rangle$ decreases further, the uncertainty increases, and if $\langle N_{\mathrm{c}}\rangle$ becomes much <1, we must encounter an embarrassing situation. Namely the reaction does not proceed in almost all the experiment, but it occurs when a catalyzer particle comes into the container and stops in it. Occurrence of the reaction is sporadic and seldom. When we repeat experiments limited number of times we are most likely not to observe the reaction, however it does not necessarily mean that the reaction is not real. The nuclear cold fusion seems to belong to this category.

Most of the physicists welcome the magnetic monopole, since the monopole makes it possible to understand the discreteness of the electric charge in Nature and to symmetrize Maxwell equations with respect to the interchanges of the electric and the magnetic objects [1]. Despite the extensive search of the magnetic monopole, its existence is not confirmed. From the Table of the Particle Data Group [4], we can see that the search experiments have been done by using four types of devices: plastic, emulsion, counter, and induction. Among these the first three devices cannot detect the low-energy monopole. Although it is true that by induction method we can cover the low-energy monopole, there is some difficulty in detecting the very low-energy or floating monopole. In the first-half of this report, we saw that the floating magnetic monopole can make the nuclear cold fusion possible. And in the second-half of this report, we explained the logically inverse statement that the nuclear cold fusion occurs only when the magnetic monopole exists. So I am regarding the experimental apparatus of the nuclear cold fusion as the "detector" of the floating monopole. By observing that the magnetic monopole actually catalyzing nuclear cold fusion reaction, I expect to solve the two fundamental problems in physics, namely the existence of the magnetic monopole, and the basic mechanism of the nuclear cold fusion, simultaneously.

References

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