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Research Article

# Low Energy Nuclear Reactions with Emission of Two Photons

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**Abstract**

We propose a new mechanism for inducing low energy nuclear reactions (LENRs). The process is initiated by an electromagnetic perturbation. The initial two body nuclear state emits a photon and forms an intermediate state which makes a transition into the final nuclear state with the emission of another photon. We need to sum over all energies of the intermediate state. Since the energy of this state is unconstrained, we get contributions from very high energies for which the barrier penetration factor is not necessarily small. By considering fusion of $^1$H and $^2$H to form $^3$He, we determine the conditions under which this mechanism leads to fusion at observable rates. We show that this mechanism works only inside a medium and not in free space. We show that a clear experimental signature of this process is emission of two photons in coincidence whose total energy is related to the Q value of this process. Hence this process can be confirmed or ruled by the presence or absence of such photons in the final state.


*Keywords:* LENR, electromagnetic perturbation, fusion, two photons emission, coincidence

## 1. Introduction

In recent papers [1], [2] we have studied the possibility that nuclear reactions may take place at low energies within the framework of the second order perturbation theory. We investigated this by considering two reactions

$$^1\mathrm{H} + {}^2\mathrm{H} + \gamma(\omega_\mathrm{i}) \rightarrow {}^3\mathrm{He} + \gamma(\omega_\mathrm{f}), \tag{1}$$

and

$$^1\mathrm{H} + {}^2\mathrm{H} \rightarrow {}^3\mathrm{He} + \gamma(\omega_1) + \gamma(\omega_2) \tag{2}$$

Here a $^1$H nucleus undergoes fusion with $^2$H nucleus to form $^3$He. The first process is assisted by the presence of a photon in the initial state while the second proceeds by spontaneous emission of two photons. Let $\vec{r}_1$ and $\vec{r}_2$ be the

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positions of the two initial state nuclei. The interaction Hamiltonian can be expressed as,

$$H_I\left(t\right) = -\frac{Z_1 e}{m_1 c}\vec{A}\left(\vec{r}_1, t\right)\cdot\vec{p}_1 + \frac{Z_2 e}{m_2 c}\vec{A}\left(\vec{r}_2, t\right)\cdot\vec{p}_2 + \frac{e^2 g_p}{2m_p c}\vec{\sigma}\cdot\vec{B} + \cdots \tag{3}$$

where $\mathrm{m_1}$ and $\mathrm{m_2}$ are the masses of the two particles, $\mathrm{Z_1}$ and $\mathrm{Z_2}$ their atomic numbers, $\vec{A}$ is the electromagnetic potential, $\vec{B}$ the magnetic field and $\mathrm{g_p}$ the proton g factor. Here we have included the magnetic moment term due to proton and have set $\vec{p}_1 = -\vec{p}_2 = -\vec{p}$. The transition amplitude at second order can be expressed as,

$$\langle f \mid T\left(t, t_0\right) \mid i\rangle = \left(-\frac{i}{\hbar}\right)^2 \sum_n \int_{t_0}^{t} dt' e^{i(E_f - E_n)t'/\hbar}\langle f \mid H_I\left(t'\right) \mid n\rangle \int_{t_0}^{t'} dt'' e^{i(E_n - E_i)t''/\hbar}\langle n \mid H_I\left(t''\right) \mid i\rangle \tag{4}$$

Here |i>, |n> and |f> are the initial, intermediate, and final states respectively and $\mathrm{E_i}$, $\mathrm{E_n}$ and $\mathrm{E_f}$ their eigenvalues. Here we need to sum over all energy eigenvalues $\mathrm{E_n}$. Hence, the sum over $\mathrm{E_n}$ gets contributions from very high energy eigenstates and has the possibility of evading the Coulomb barrier. The applicability of this mechanism has been investigated in detail in [1], [2].

## 2. Results and Discussion

The mechanism described in section 1 requires a very high energy intermediate state, denoted by |n> in Eq. (4). For large values of $\mathrm{r} = |\vec{r}_2 - \vec{r}_1|$, the potential is nearly zero and this wave function behaves approximately as free particle wave function $\sin(\mathrm{k_n r} + \phi)$, where $\mathrm{k_n}$ is the wave number and $\phi$ the phase shift. In order for the matrix element $<\mathrm{n}|\mathrm{H_I(t'')}|\mathrm{i}>$ to take significant values, we need another high energy particle. This is provided by the emitted photon, which for the current process may have energy of the order of 5 MeV. Hence, we may argue that the state |n> balances the momentum of the emitted photon and in the sum over n we may simply include just this one state. This single high energy state then contributes to the second matrix element $<\mathrm{f}|\mathrm{H_I(t')}|\mathrm{n}>$, leading to a substantially increased transition rate. However, the mechanism does not work in this simple manner. Explicit calculations [1], [2] show that the matrix element $<\mathrm{n}|\mathrm{H_I(t'')}|\mathrm{i}>$ cannot be approximated by a delta function and we cannot just set the wave number $\mathrm{k_n}$ equal to that of the photon. The main reason is that the wave function |n> deviates very strongly from free particle (zero potential) wave function at small values of r. Hence, we obtain contributions from a wide range of energy eigenvalues $\mathrm{E_n}$ (or $\mathrm{k_n}$) of the intermediate state |n>. The matrix element shows rapid oscillations about 0 as a function of $\mathrm{E_n}$ and we find that the sum (or integral) over $\mathrm{E_n}$ leads to very small values if we use free space (absence of medium) eigenfunctions.

However, the situation can be very different in medium where the eigenfunctions may be greatly modified at large distances [2]. In [1], [2] we suggested several possibilities of medium modification of eigenfunctions which can lead to enhanced rates. Here we briefly describe the mechanism proposed in [2]. Let us first recall that, due to spherical symmetry, the free space eigenfunctions behave as $\sin(\mathrm{k_n\, r} + \phi)$ at large values of r. However at large distances, it may not be reasonable to assume spherical symmetry in medium. Hence the wave function may be significantly modified. In [2] we assumed cylindrical symmetry along the z-axis. We ignore the center of mass motion, assuming it to be located at the origin of the coordinate system and focus on the relative motion. The relative coordinates are denoted by (z, $\rho$, $\theta$). We assume that the potential is negligible in the region $\rho_1 < \rho < \rho_2$. Here $\rho_1$ is of order 1 atomic unit and $\rho_2$ is determined by the lattice structure and is assumed to be of order 5 atomic units or larger. In this gap region, it is reasonable to assume that the eigenfunctions behave as linear superpositions of $\sin(\mathrm{k_z\, z})$ and $\cos(\mathrm{k_z\, z})$. With such wave functions, we find that the reaction rates can be much larger in comparison to what is obtained without a medium. Here we are using cylindrical coordinates and $\mathrm{k_z} \approx \mathrm{k_n}$ is the wave number which determines the z dependence of the wave function. Indeed, the rate was found to be large enough to lead to an observable signal. Hence, we conclude that low energy nuclear reactions are possible given suitable medium conditions. We point out that the assumed wave functions are very reasonable if the medium displays cylindrical symmetry. At short distances, we can expand such wave functions in spherical harmonics and only a few leading order terms dominate for the energy scale relevant to the problem. Furthermore, if the medium satisfies different symmetry conditions, we expect that a suitable generalization of our mechanism may still be applicable in some cases.

Our mechanism leads to a directly testable experimental prediction. It was found [1], [2] that the reaction involving emission of two photons (Eq. (2)) has much higher rate in comparison to the reaction shown in Eq. (1). In fact, the rate of the latter reaction is too small and not observable. The process in Eq. (2) leads to emission of two photons in coincidence with total energy roughly equal to the Q value of the process, which is approximately equal to 5.4 MeV. Here we need to account for a small energy loss due to nuclear recoil and due to propagation in medium. Due to the production of two photons in coincidence, the process provides a clean signal which can be tested in future experiments.

## References

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