Nuclear Physics Approach

A Model for Neutron Emission from Condensed Matter

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Abstract

We propose a quantum-mechanical model for the neutron emission from condensed matter. This model is based on two new phenomena: the tunnel disintegration of an ionized deuterium molecule and the subsequent dipole disintegration of a deuteron. We calculated the probabilities of the neutron emission from condensed matter by considering the mechanisms of the dipole disintegration, especially the transition from the ground state to the decaying state. The results of the numerical calculation can successfully explain the important features of the neutron energy spectrum : the 2.45-MeV peak, the high-energy component at 3 ~ 7 MeV, and the large T/n ratio. This indicates that the 2.45-MeV neutrons can be predicted by the dipole disintegration of the deuteron instead of the d-d nuclear fusion.

1. Introduction

Since 1989, the nuclear events in condensed matter has attracted attention. Many researchers have expended much effort to elucidate the mechanisms of these phenomena in metal such as palladium and titanium. Most of the researchers believing the nuclear events in condensed matter expect that the phenomenon arises from the d-d nuclear fusion and consequently this phenomenon is termed the cold nuclear fusion. According to new experiments, these nuclear events present three important features: (i) The neutron-energy spectrum shows the peaks at about 2.45 MeV and at 3 ~ 7 MeV (Takahashi *et al.*, 1990; Nakada *et al.*, 1993). (ii) T/n ratio is extremely large ($10^4 \sim 10^9$) (Iyenger and Srinivasan, 1990). (iii) The correlation between excess heat and nuclear products is little. These experimental results, however, are not consistent with the d-d nuclear fusion from the following reasons. The neutron emission due to the d-d nuclear fusion presents the 2.5-MeV peak in the neutron-energy spectrum. Additionally the neutron-emission rate is almost equivalent to the tritium-emission rate. Therefore we can not ascribe the above three features to the cold nuclear fusion.

In this paper, we propose a quantum-mechanical model against the cold nuclear fusion to explain the neutron emission from condensed matter by predicting two new phenomena: the tunnel disintegration of an ionized deuterium molecule on metal surface and the subsequent dipole disintegration of a deuteron. On the basis of the quantum theory Tani proved that the fusion probability of the two nuclei in a composite system such as a free diatomic molecule is exactly zero (unpublished; For example, see Tani and Kobayashi, 1993). From this standpoint, a qunatum-mechanical composite system (nuclei and electrons in molecular state) should turn into another system (nuclei and electrons in continuous spectrum state), if the two nuclei in the composite system penetrate into the region which would be insurmountable on the classical theory. Therefore the two nuclei can not approach each other to zero separation but on the contrary the composite system disintegrates, which we termed the tunnel disintegration. Therefore when an ionized diatomic molecule interacts so strongly with such metal as palladium and titanium in its surface region, the two nuclei pass through the barrier and consequently the molecule disintegrates with the electron transition to the continuous-spectrum states. The intensive excitation of collective modes will occur in the surface region simultaneously with the tunnel disintegration. As a result instantaneous strong localized electric field will be induced at the position of D_2^+. The electric field will excite the dipole oscillations between proton and neutron in the deuteron, and consequently the dipole disintegration of the deuteron will occur.

We calculated numerically the probabilities of the neutron emission from condensed matter on the basis of this model. In contrast to our previous paper (Tani and Kobayashi, 1993), we considered the mechanisms of the dipole disintegration in detail. Our numerical results are consistent with the experiments. Therefore we believe that our model is valid for explaining the mechanisms of the nutron emission from condensed matter.

2. Mechanisms of the Dipole Disintegration of a Deuteron

2.1. Tunnel Disintegration of D_2^+

The tunnel disintegration of D_2^+ (molecular explosion) will be accompanied by the release of energy of $\sim$ 30 eV. Simultaneously the released energy will induce the intensive excitation of collective modes, which yields instantaneous strong localized electric fields at the position of D_2^+. If, however, the electric field varies quickly, any nuclear events cannot occur. On the other hand, if the electric field varies slowly as compared with the characteristic period ($\sim 10^{-21}$ s) of the nuclear motion, the deuterons emitted from the collapsed D_2^+ can absorb energy from the localized electric field and consequently any nuclear events will occur.

We considered the ^{3}P-state in the theoretical calculation, although the ^{3}P-state of the deuteron is not detected experimentally. Hence the dipole oscillation will be excited between proton and neutron in the deuteron. The amplitude of the dipole oscillation increases as the deuteron absorbs the energy from the localized electric field. The deuteron will disintegrate when the electric field reaches a threshold.

2.2. Process of Dipole Disintegration

We derived the formula for the probability of the dipole disintegration of a deuteron in the following procedure, where we assumed that the electric field starts to act on the deuteron at time $t = 0$ and the amplitude of the dipole oscillation attains to the maximum at $t = T$.

1. $t < 0$: *Deuteron in the Ground State*

Let the deuteron be in $^3S_1$-state before the energy absorption, since the primary purpose of this paper is to investigate the validity of the model. The state of the unperturbed deuteron can be represented by the Hamiltonian operator H_0 as follows: $H_0\psi_0^{(0)}(\mathbf{r}) = E_0\psi_0^{(0)}(\mathbf{r})$ for ${}^3\mathrm{S}_1$-state and $H_0\psi_k^{(0)}(\mathbf{r}) = E_k^{(0)}\psi_k^{(0)}(\mathbf{r})$ for ${}^3\mathrm{P}$-state.

2. $t = 0$: *Dipole Oscillation of Deuteron*

We represented the localized electric field as the pulselike form

$$f(t) = \epsilon_0\lambda t(2 - \lambda t)\exp(-\lambda t), \tag{1}$$

where $\lambda \ll 10^{21}s^{-1}$. We determined the ${}^3\mathrm{S}_1$-state and the ${}^3\mathrm{P}$-state of the deuteron in the electric field $f(t)$ directed along the z-axis. The Schrödinger equation is

$$i\hbar\frac{\partial\Psi}{\partial t} = H_r\Psi, \tag{2}$$

where $H_r \equiv H_0 - \frac{eM_n}{M}f(t)z$, z being the z-component of the relative vector $\mathbf{r}$ of the proton to the neutron, M the total mass, M_n the neutron mass, and e the elementary charge.

In the first approximation, the solution of Eq. (2) can be written as

$$\Psi(\mathbf{r}, t) = \psi_0^{(0)}(\mathbf{r})\exp(-iE_0t/\hbar) + \sum_k a_k^{(0)}(t)\psi_k^{(0)}(\mathbf{r})\exp(-iE_k^{(0)}t/\hbar), \tag{3}$$

where $a_k^{(0)}(t) = \frac{ieM_n}{\hbar M}\int_0^t f(t)z_{k0}^{(0)}\exp[i(E_k^{(0)} - E_0)t/\hbar]dt$ with $z_{k0}^{(0)} = \int\psi_k^{(0)\dagger}(\mathbf{r})r\cos\theta\psi_0^{(0)}(\mathbf{r})d\mathbf{r}$.

3. $0 < t < T$: *Deuteron in the Decaying State*

The direct transition from the ground state can not occur because of the low-energy nature of the phenomenon. Therefore we assumed a decaying state as an intermediate step prior to the dipole disintegration. The transition from the ground state to the decaying state will take place gradually by steps, since the deuteron can absorb only a little energy at a time. For $\lambda \ll 10^{21}s^{-1}$ the deuteron can form a quasi-stationary state at every step, which will be repeated until the deuteron attains to a final decaying-state. The ${}^3\mathrm{S}_1$-state parameters will change little by little during the self-regularization process, while the ${}^3\mathrm{P}$-state will not be affected.

We represented the quasi-stationary state at time t as

$$\psi_0^{(1)}(\mathbf{r}) = N[\psi_0^{(0)\prime}(\mathbf{r}) + \sum_k a_k^{(0)\prime}(t)\psi_k^{(0)}(\mathbf{r})\exp(-i(E_k^{(0)} - E^{(1)})t/\hbar)], \tag{4}$$

where $\psi_0^{(0)\prime}$ is the ${}^3\mathrm{S}_1$-state with energy E_0' at time t just before the energy absorption and N is a normalization factor. We assumed $\tilde{H}_0\psi_0^{(1)}(\mathbf{r}) = E^{(1)}\psi_0^{(1)}(\mathbf{r})$ where $\tilde{H}_0$ is an effective Hamiltonian.

We determined the ${}^3\mathrm{S}_1$-state parameters by an iterative method:

(i) Choose $\psi_0^{(0)\prime} = \psi_0^{(0)}$ with $E_0' = E_0$ as a trial function and put $a_k^{(0)\prime}(t) = a_k^{(0)}(t)$.

(ii) Calculate $E^{(1)} = (\psi_0^{(1)}, \tilde{H}_0\psi_0^{(1)})$ with $\tilde{H}_0 = H_0$ by assuming a square-well potential.

(iii) Replace E_0 by $E^{(1)}$.

(iv) Find the ${}^3\mathrm{S}_1$-state parameters (the well depth V_s and the radius r_s) with the ${}^3\mathrm{P}$-state parameters (V_p and r_p) unchanged.

(v) Recalculate $a_k^{(0)}(t)$ by using $\psi_0^{(0)}$ with the new ^{3}S$_1$-state parameters.

(vi) Replace $\psi_0^{(0)\prime}$ and $a_k^{(0)\prime}(t)$ by $\psi_0^{(0)}$ with the new ^{3}S$_1$-state parameters and the recalculated $a_k^{(0)}(t)$ in Eq. (3) with $E_0' = E^{(1)}$, respectively.

We repeated this procedure until $E^{(1)}$ exceeds a criterion energy (-0.02 MeV).

4. $t = T$: *Maximum Amplitude of Dipole Oscillation*

The dipole disintegration of the deuteron will occur when the amplitude of the dipole oscillation attains to the maximum.

5. $t > T$: *Dipole Disintegration of Deuteron*

We expressed the Hamiltonian operator of the deuteron in the decaying process as

$$H_r = \tilde{H}_0 + V_{res}(r) - \frac{eM_n}{M} f(t) z, \tag{5}$$

where V_{res} denotes a residual interaction. For $t > T$ the solution of Eq. (2) with Eq. (5) can be written as

$$\Psi(\mathbf{r},t) = \psi_0^{(1)}(\mathbf{r}) \exp[-iE^{(1)}(t-T)/\hbar] + \sum_{\ell,m} \int a_{E\ell m}(t) \psi_{E\ell m}^{(0)}(\mathbf{r}) \exp[-iE(t-T)/\hbar] dE, \tag{6}$$

where $\tilde{H}_0 \psi_{E\ell m}^{(0)}(\mathbf{r}) = E \psi_{E\ell m}^{(0)}(\mathbf{r}) (E > 0)$. The probability that the neutron of the energy between E and $E + dE$ is emitted due to the nuclear dipole oscillation is

$$\sum_{\ell,m} |a_{E\ell m}(\infty)|^2 dE. \tag{7}$$

We assumed that the residual interaction can be written as a delta-function type: $V_{res}(r) = -\gamma V \delta(r-a)$, where γ is a length to make $\gamma\delta(r-a)$ a dimensionless quantity and a and V are adjustable parameters. The effective Hamiltonian can be approximately represented as

$$\tilde{H}_0 = -\frac{\hbar^2}{2\mu} \triangle_r + V_0(r). \tag{8}$$

We simplified the calculation by assuming a square-well potential: $V_0(r) = V_s^{(1)}$ for $r \leq r_s^{(1)}$ and $V_0(r) = 0$ for $r > r_s^{(1)}$, where $V_s^{(1)}$ and $r_s^{(1)}$ are the parameters of the ^{3}S$_1$-state at the decaying state.

3. Results

We calculated numerically the probabilities of the neutron emission by assuming the pulse-like electric field represented by Eq.(1) with $\epsilon_0 = 5.0 \times 10^{18}$ V/m and $\lambda = 1.0 \times 10^{17}$ s^{-1}. We chose $E_0 = -2.226$ MeV, $V_s = -21.3$ MeV, and $r_s = 2.80$ fm as the ^{3}S$_1$-state parameters and determined the ^{3}P-state parameters to make the mixing ratio of ^{3}P-state to ^{3}S$_1$-state, $M(t) = \sum_k |a_k^{(0)}|^2$, as small as possible. Figure 1 illustrates the theoretical spectrum for the case of $E_k^{(0)} = E_p = -0.01$ MeV, $V_p = -18.7$ MeV, and $r_p = 4.68$ fm. The calculated spectra present the 2.45-MeV peak and the high-energy component at 3 ~ 7 MeV. The ratio of the probability of the neutron emission at 0 MeV and that at 2.5 MeV is ~ 10^4. The details will be published elsewhwere.

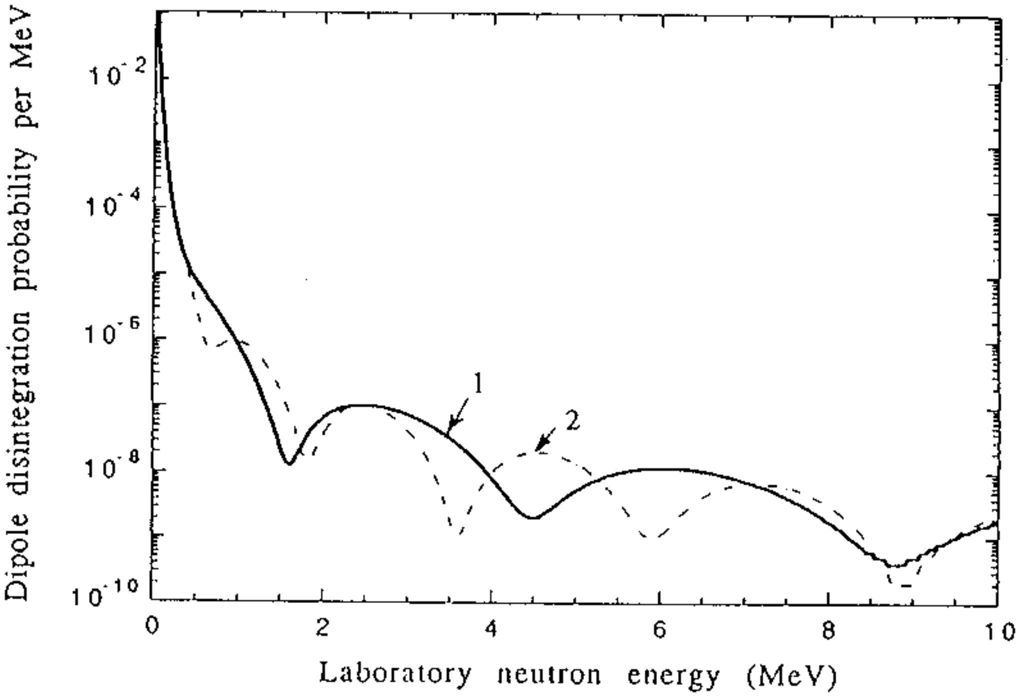

Figure 1. Dipole disintegration probability for: 1, $\epsilon_0 = 5 \times 10^{18}$ V/m, $\lambda = 2 \times 10^{17}$ s^{-1}, $V = 8.5 \times 10^{-2}$ MeV, and $a = 18.3$ fm; 2, $\epsilon_0 = 5 \times 10^{18}$ V/m, $\lambda = 1 \times 10^{17}$ s^{-1}, $V = 1.0 \times 10^{-1}$ MeV, and $a = 27.8$ fm. The energy of stationary neutron is twice the energy of laboratory neutron.

4. Conclusion

We summarized the three features of the experimental spectrum in Sect. 1. Our numerical calculation can successfully explain these features: the peak at 2.45 MeV, the high-energy component at 3 ~ 7 MeV, and the large T/n ratio. Therefore this model can predict the experimental neutron-energy spectrum. These results indicate that the 2.45-MeV neutrons can be predicted by the dipole disintegration of a deuteron instead of the d-d nuclear fusion. We should reconsider also the tunnel effect in such composite systems as muon.

Refernces

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