International Journal of Modern Chemistry, 2013, 5(1): 29-43

Modern Scientific Press

*International Journal of Modern Chemistry*

Journal homepage: www.ModernScientificPress.com/Journals/IJMChem.aspx

ISSN: 2165-0128

*Florida, USA*

*Exploration*

# Potential Exploration of Cold Fusion and Its Quantitative Theory of Physical-Chemical-Nuclear Multistage Chain Reaction Mechanism

**Yi-Fang Chang ***

*Department of Physics, Yunnan University, Kunming, 650091, China*

* Author to whom correspondence should be addressed; E-Mail: yifangchang1030@hotmail.com.

*Article history*: Received 5 June 2013, Received in revised form 5 July 2013, Accepted 7 July 2013, Published 10 July 2013.

**Abstract:** Cold fusion is very important and complex. One of main difficulties of cold fusion is the explanation on appearance of nuclear reaction. Based on the standard quantum mechanics, we propose the physical-chemical-nuclear multistage chain reaction theory, which may explain cold fusion. Since cold fusion is an open system, synergetics and laser theory can be applied, and the Fokker-Planck equation is obtained. Using the corresponding Schrödinger equation and the nonlinear Dirac equation, and combining the multistage chain reaction theory, the quantitative results agree completely with some experiments on cold fusion. Finally, we discuss some new researches, for example, the nonlinear quantum theory, catalyzer and nanomaterial, etc., and propose the three laws of cold fusion: (1) The time accumulate law, (2) The area direct ratio law, and (3) The multistage chain reaction law.

**Keywords:** cold fusion; physics; chemistry; multistage chain reaction; quantum mechanics; synergetics; equation; theory.

## 1. Introduction

Since Fleischmann and Pons proposed the experiments of cold fusion [1], its development is undergoing much rise and fall. On the one hand, cold fusion has been confirmed by more and more various experiments [2-4]. On the other hand, early stage Ziegler et al. observed no nuclear fusions in the electrochemical experiments in cold nuclear fusion [5]. Sun and Tomanek calculated and found a cold-fusion reaction of deuterium very improbable [6]. The rate of tunneling of nuclei to classically forbidden small relative separation, in a fully interacting quantum-mechanical many-body system in equilibrium, is rigorously bounded above by a value calculable in terms of the Born-Oppenheimer potential between the nuclei. Leggett and Baym applied exact upper bound on barrier penetration probabilities in many-body systems to cold fusion, in which the bound can be related to the affinities of helium and deuterium atoms to the metal in question, and shows that the allowed rate of tunneling of deuterons is far too small to be consistent with inferred rates of fusion [7]. Szalewicz et al. analyzed the fusion rates for hydrogen isotopic molecules of relevance, and found that in light of the reported d-d fusion rate, the excess heat is difficult to explain in the experiment of cold fusion [8]. Hassam and Dharamsi examined semi-classically the reduction in bond length of the deuterium molecule in the presence of electronic charge concentrations, and discussed implications for cold nuclear fusion [9]. Burrows discussed the enhancement of cold fusion in metal hydrides (deuteride) by screening of proton and deuteron charges [10]. Horowitz calculated the rate of nuclear fusion from tunneling in very dense metallic hydrogen in the core of Jupiter, and discussed cold nuclear fusion in metallic hydrogen and normal metals [11]. Deakin et al. searched X rays excited by charged-particle fusion products in a Pt-Pd electrolytic cell with $Li-D_2O$ electrolyte [12].

Chambers et al. discussed an upper limit on cold fusion in thin palladium films, and found no evidence to support the hypothesis that the heat-producing reactions within deuterium-charged palladium are nuclear in nature [13]. Southon et al. obtained an upper limit of $10^{-23}s^{-1}$ for neutron emission for the cold fusion rate per d-t pair [14]. Balke et al. obtained the limits on neutron emission from cold fusion in metal hydrides [15]. Roberts et al. obtained the energy and flux limits of cold-fusion neutrons using a deuterated liquid scintillator [16]. Ichimaru reviewed nuclear fusion in dense plasmas [17], in which the fundamental nuclear reactions are classified to the usual binary processes and few-particle processes, and the possibility of electron-screened cold fusion is remarked. Those analyses are applied to the dense astrophysical plasmas.

In the experimental results some new elements, which do not exist in the beginning of experiments, appear. For instance, a large number of triton appears [18], the abundance ratio of Sr-88 to Sr-86 shifts [19]. It shows that the nuclear reaction, including nuclear fusion and fission, must exist in those experiments. Jeitler et al. compared experimental data with theoretical calculations for epithermal effects in muon-catalyzed fusion, which predicted strong resonances and shown qualitative agreement with the observed experimental data, but yielded molecular formation rates that differed substantially from the observed values [20]. Gupta et al. studied nuclei at the neutron-drip line, and found that the light neutron-halo nuclei play an important role for both cold fusion reactions and exotic cluster decay studies of heavy nuclei at the neutron-drip line, and used the quantum mechanical fragmentation theory for cold fusion reaction [21].

Smolanczuk investigated the production of even-even superheavy nuclei in cold fusion reactions [22], and proposed a relatively simple model which reproduces the measured formation cross sections of deformed superheavy nuclei synthesized in cold fusion reactions [23], and calculated the excitation functions for the production of superheavy nuclei in cold fusion reactions [24]. Further, he calculated the formation cross sections of superheavy elements in cold fusion reactions [25], and proposed a handy formula and calculated the cross sections for asymmetric and symmetric cold fusion reactions for producing superheavy nuclei [26]. Some new approaches of theoretical mechanism are researched. For example, Kozima considered neutron Mossbauer effect [27]. Kirkinskii and Novikov developed a nuclear fusion mechanism in metal crystal structures at low energies, which uses an approach for the estimation of electron screening in metals which is based on the dynamic account of the outer metal electronic shells deformation during counter motion of two deuterons near their sites boundary [28]. Computer simulation agrees with experimental data on excess hear output. Li proposed the selective resonant tunneling model, and calculated the cross section of deuteron-triton sub-barrier fusion with a square-well nuclear potential [4].

In 21 century, Hofmann and Munzenberg described the experimental methods for the discovery of the heaviest elements, and measured excitation functions for the one-neutron evaporation channel of cold-fusion reactions [29]. We introduced some experimental progress and theoretical researches on cold fusion [30]. Grillon et al. studied deuterium-deuterium fusion dynamics in low-density molecular-cluster jets irradiated by intense ultrafast laser pulses, and shown that nuclear fusion occurs not only in the hot plasma core, but also in the cold outer region by collision processes in some conditions [31]. Gherghescu et al. studied the charge density influence on cold fusion barriers [32], and the shell effects in cold fusion reactions [33], and investigated the isobaric cold-fusion channels for synthesis [34]. Adamian et al. investigated the isotopic composition of the projectile nucleus in the production of superheavy nuclei in cold fusion reactions [35], and possibilities of production of new isotopes of superheavy nuclei in cold and hot complete fusion reactions [36], and discussed the transfer-type products accompanying cold fusion reactions [37]. Naranjo et al. observed nuclear fusion driven by a pyroelectric crystal [38], and Saltmarsh reviewed the technology on warm fusion [39]. Gupta et al. discussed theory of the compactness of the hot fusion reaction $^{48}Ca+^{244}Pu\rightarrow^{292}114*$ as the next possible best reaction for forming the cold compound nucleus [40]. Gherghescu and Nagame investigated cold-fusion reactions for synthesis of $^{276}114,^{286}114$ and $^{290}114$ [41]. For the nucleus-nucleus interaction in Pb-based cold fusion, Mitsuoka et al. measured excitation functions for quasielastic scattering of $^{48}Ti, ^{54}Cr, ^{56}Fe, ^{64}Ni$ and $^{70}Zn$ projectiles on a $^{208}Pb$ target, and derived the barrier distributions from quasielastic backscattering [42]. Within the concept of the dinuclear system, a dynamical model is proposed for describing the formation of superheavy nuclei in complete fusion reactions by incorporating the coupling of the relative motion to the nucleon transfer process. Feng et al. [43] calculated the capture of two heavy colliding nuclei, the formation of the compound nucleus, and the de-excitation process by an empirical coupled channel model. They investigated systematically evaporation residue excitation functions in cold fusion reactions and compared with available experimental data, and obtained maximal production cross sections of superheavy nuclei in cold fusion reactions with stable neutron-rich projectiles. They analyzed systematically isotopic trends in the production of the superheavy elements Z=110, 112, 114, 116, 118, and 120, and proposed optimal combinations and the corresponding excitation energies.

In this paper the physical-chemical-nuclear multistage chain reaction theory of cold fusion is proposed, and some new researches are discussed. Furthermore, the three laws of cold fusion are proposed.

## 2. Quantum Cold Fusion, Physical-Chemical-Nuclear Multistage Chain Reaction Mechanism and Synergetics

At the present one of main difficulties is impossible explanation of appearance of nuclear reaction by a standard theory, because the penetration factor is too small. But, cold fusion is very complex, and includes possibly different nuclear, physical and chemical processes. The chemical reactions include also oscillation, condensation, catalyst and self-organization, etc. [44]. We have proposed the physical-chemical-nuclear multistage chain reaction mechanism [45]: (a) The electrons appear, which may combine the internal conversion theory of cold fusion; (b) The electrons react with deuterons or protons, and form bineutrons or neutrons; and (c) The bineutrons or neutrons enter into nuclei, and then nuclear reactions happen. According to this theory, the first chain reactions are:

$$\begin{aligned} & e^- + D \to 2n + \nu_e, \\ & 2n + D \to {}^4H^* \to {}^4He + e^- + \bar{\nu}_e, \\ & e^- + D \to 2n + \nu_e \end{aligned} \qquad (1)$$

The second reactions are

$$\begin{aligned} & e^- + p \to n + \nu_e, \\ & n + p \to D, \\ & e^- + D \to 2n + \nu_e \end{aligned} \qquad (2)$$

Of course, neutrons may react with other nuclei, e.g., Pd. But, in this case Pd seems to be mainly an absorbent by which deuteron plasmas are formed. From this we discussed the multistage ignition condition in cold fusion [46].

The process of the synthesis of superheavy elements (SHEs) is not yet understood completely. Denisov and Hofmann made an attempt to describe the cold fusion reactions [47]. The process of the formation of SHEs is subdivided into three steps. (1) The capture of two spherical nuclei and the formation of a common shape of the two touching nuclei. Low-energy surface vibrations and transfer of few nucleons are taken into account in the first step of the reaction. (2) The formation of a spherical or near spherical compound nucleus. (3) The survival of the excited compound nucleus due to evaporation of neutrons and $\gamma$-ray emission in competition with fission. A lowering of the fission barrier was taken into account, which arises from a reduction of shell effects at increasing excitation energy of the compound nucleus. The following reactions were analyzed in detail: ($^{58}$Fe, $^{64}$Ni, $^{70}$Zn, $^{78}$Ge) + $^{207}$Pb, ($^{50}$Ti, $^{54}$Cr, $^{58}$Fe, $^{59}$Co, $^{62,64}$Ni, $^{65}$Cu, $^{66,68,70}$Zn, $^{71}$Ga, $^{74,76,78}$Ge, $^{75}$As, $^{80,82}$Se) + $^{208}$Pb, ($^{58}$Fe, $^{64}$Ni, $^{70}$Zn, $^{78}$Ge) + $^{210}$Pb, and ($^{50}$Ti, $^{54}$Cr, $^{58}$Fe, $^{64}$Ni, $^{70}$Zn, $^{78}$Ge) + $^{209}$Bi. The presented model describes well the available experimental cross-section data and allows for predicting cross-section values for the synthesis of so-far unknown heavier elements. Swiatecki, et al., described a method of estimating cross sections for the synthesis of very heavy nuclei by the fusion of two lighter ones [48]. In order to verify methods of calculating the fission-evaporation competition in reactions used to synthesize new super-heavy nuclei in cold and hot fusion reactions, Siwek-Wilczynska et al. analysed experimental data and tests the fission-evaporation competition in the deexcitation of heavy nuclei [49]. Ichikawa et al. estimated the fusion-barrier for approaching ions in cold-fusion reactions in a model [50]. They calculated the fusion potential for approaching ions in the two-body channel in the macroscopic-microscopic model with the quadrupole vibrational zero-point energy, and compared results with data from 10 experimental cold-fusion reactions and with the Bass barriers. It shown well-established fission and fusion valleys, and the calculated quantities are consistent with the observed optimal energies for evaporation-residue formation. Ichikawa and Iwamoto estimated the decrease of the Coulomb-barrier height between colliding partners due to charge polarizations in the entrance channel for cold-fusion reactions, and shown the difference between the charge polarization of light and heavy nuclei and the decrease of the Coulomb barrier height [51]. Ismail and Seif discussed a simple straightforward method, which predicts the dependence of barrier distributions on different deformations and interprets nuclear orientation for Coulomb barrier distributions, and estimated the configurations of the interacting nuclei which lead to hot and cold fusion, respectively [52].

In synergetics a basic equation is the Fokker-Planck equation [53,54]:

$$\frac{\partial f}{\partial t} = -\nabla_q [A(q,t) f] + \frac{1}{2}\sum_{i,j} \frac{\partial^2}{\partial q_i \partial q_j}[B_{ij}(q,t) f]. \qquad (3)$$

Here $f$ is the probability distribution function of particles, q is the space place, A and B correspond to the drift and diffusion coefficients. This is also an important equation in plasma. Its solution of the steady state is:

$$f(q) = N\exp[-\frac{2}{Q}V(|q|)] = N\exp[\frac{2}{Q}\int_{q0}^{q} A(q)dq]. \quad (4)$$

Let the vector of probability current density is

$$S_i = A_i f - \frac{1}{2}\sum_j \frac{\partial}{\partial q_i}(B_{ij} f), \quad (5)$$

the equation (3) becomes to a conservative form:

$$\frac{\partial f}{\partial t} + \nabla_q S = 0. \quad (6)$$

This corresponds to the conservation equation of particle number.

The nonlinear Dirac equations describe fermion with interaction, whose simplified form is

$$\gamma_\mu \partial_\mu \psi + m\psi - l_0^2 |\psi^2| \psi = 0. \quad (7)$$

Here $l_0^2$ is a general nonlinear factor. Using a way like soliton-solution [55], let

$$\eta = (\gamma_\alpha x_\alpha - \gamma_0 ut)/(1+u), \quad (8)$$

in which u is the soliton velocity, so the Eqs. (7) becomes

$$\frac{d\psi}{d\eta} = -m\psi + l_0^2 |\psi^2| \psi. \quad (9)$$

Its solution is

$$|\psi|^2 = \frac{m}{2l_0^2[1+\exp(2m\eta + c)]}. \quad (10)$$

When $x_\alpha = 0, \eta = -\gamma_0 ut/(1+u)$,

$$|\psi|^2 = \frac{m}{2l_0^2[1+\exp(-at+c)]} \quad (11)$$

where $a = (2m\gamma_0 ut)/(1+u)$. When t=0, $|\psi|^2 = m/2l_0^2(1+e^c); t \to \infty, |\psi|^2 = m/2l_0^2$. The solution (11) is a jump soliton, and is analogous to the Fig. 7 and Fig. 9 of Ref. [56], which are the relations between time and the heat transfer coefficient. Here $|\psi|^2 = \psi^*\psi$ is a probability density, which is direct proportional to the particle density and to the particle number of reaction. Heat is bigger with the bigger number, which shows the bigger heat transfer coefficient. So $|\psi|^2$ is direct proportional to the heat transfer coefficient, Eq. (9) can approximately describe the experimental results of cold fusion.

Since cold fusion is an open system, into which the input of energy is sustained, and which is kept far from an equilibrium state, we suppose that cold fusion is analogous to laser. Therefore, for cold fusion we introduce the amplitude equation of single-mode laser [53]:

$$\frac{db}{dt} = (-C_0 + kD)b - \frac{4g^2k}{\gamma}b*bb + F(t) = -\alpha b - \beta b*bb + F(t), \qquad (12)$$

where b is the amplitude, D is the reversal number of atom, F(t) is a random force, $\gamma$ is a relaxation time. The Eq. (12) is analogous to the nonlinear equations of fermion, in which the amplitude corresponds to the wave function. Conversely, if the Eq. (9) adds a random force F(t), it will become the Eq. (12). For the equation (12), we introduce a potential [53]:

$$V(b) = \frac{1}{2}\alpha b^2 + \frac{1}{4}\beta b^4. \qquad (13)$$

1). If $\beta$ =0, the equation is namely linear, the phase transformation does not appear. 2). If $\beta \neq 0$, the equation is nonlinear. When V=0, $b = \pm\sqrt{-2\alpha/\beta} = \pm\sqrt{m/l_0^2}$ corresponds to the steady limit cycle. The non-equilibrium phase transformation will happen.

The laser equation depends on three factors: field strength, polarization and reversal number of atoms. While the conditions realized cold fusion are a certain voltage, electric current density and the deuterium-palladium ratio. If two types of conditions are one-one corresponding, on a similar plan to laser, we will obtain the equation of cold fusion and corresponding conclusions. Based on the above conditions, when the keeping time of electric current approaches a threshold value, cold fusion may be realized. Therefore, the order parameter is $\alpha = C_0 - kD$. When the reversal number, i.e., the D-Pd ratio D is very small, D < $C_0/k$ and $\alpha$ > 0, the potential of cold fusion is symmetrical and unsteady, the nonlinear part may be neglected, the nuclear reaction is preserved only by the quantum stochastic process, which is analogous to self-radiation. If D =$C_0/k$ and $\alpha$ = 0, the phase transformation will appears, and the phase of cold fusion is formed. If D >$C_0/k$ and $\alpha$ < 0, the potential, which likes to the Higgs mechanism, will form a sub-steady state of breaking symmetry.

## 3. Quantitative Calculations on Cold Fusion

The Fokker-Planck equation [54] corresponds to the Schrödinger equation of the steady state

$$\frac{d^2\psi}{dx^2} + \frac{8\pi^2}{h^2}m[E - U(x)]\psi = 0. \qquad (14)$$

According to the barrier penetration of quantum mechanics, the penetration factor is

$$d \approx \exp[-\frac{4\pi}{h}\int_a^b \sqrt{2m(U-E)}dr]. \qquad (15)$$

If U is the Coulomb potential $ke^2/r$, $a$ = R is the distance of interaction between incident particle and target, b = $r_0 = ke^2/E$,

$$d \approx \exp[-\frac{4\pi}{h}\sqrt{2m}(\frac{ke^2}{\sqrt{E}}arctg\sqrt{\frac{ke^2}{RE}-1}-R\sqrt{\frac{ke^2}{R}-E})]. \quad (16)$$

For $D+Pd^{106}$, because m = 1876.0289MeV/$c^2$, R = 1.25 $A^{1/3} = 5.9158\times10^{-13}$cm, k = Z = 46, even if E = 240 KeV, $d \approx 9.64827\times10^{-52}$. It is too small. According to the physical-chemical-nuclear multistage chain reaction theory, for the reaction (1a), m = 0.511 MeV, E = 220 eV is the energy of electron, k = Z = 1, R = 1.5749 $\times10^{-13}$ cm, so the penetration factor of electron-deuteron is d = 1.7767 $\times10^{-13}$. Since the section ratio between deuteron and D-atom is about 3.814 $\times10^{-11}$, the penetration probability of nuclear reaction between an electron (whose energy is E = 220 eV) and a D-atom is 6.777 $\times10^{-24}$, and the number of D-atom is $1.6\times10^{15}/cm^2$. It is consistent with Jones experiment [2] and with Manduchi result [57]. Since the current density

$$\rho = 400mA/cm^2 = 2.5\times10^{18}\,electron/scm^2, \quad (17)$$

the size of a rod cathode 0.4 $\times$ 1.25 = 0.5 $cm^2$, and t = 6 day = 6 $\times$ 24 h = 5.184 $\times10^5$s in Fig. 1 of Ref. [56], the total rate is 2.712 $\times10^{10}$ / $scm^2$. From the total reaction

$$D+D\to{}^4He+\nu_e+\bar{\nu}_e, \quad (18)$$

i.e. $$D+D\to{}^4He+23.9\,MeV, \quad (19)$$

the total released energy is 2.69 $\times10^4$ J. It agrees completely with this result 26 KJ in the Fig. 1 [56].

Moreover, the physical-chemical-nuclear multistage chain reaction theory agrees qualitatively with the following experimental facts on cold fusion: (1) A large number of neutron and photon does not appear, since no photon produces in the theory, and neutron joins the chain reaction. (2) The released heat is delayed, since the chain reaction needs a process, and must provide electrolysis long time. (3) The three deuterons react, which is a result of the chain reaction. A main characteristic of this mechanism is that helium and neutrino appear in a final state, which is an important judgment on the theory.

## 4. New Research on Cold Fusion

Recently, Zagrebaev and Greiner discussed nuclear reactions leading to the formation of new superheavy elements and isotopes, and analyzed cold and hot synthesis, fusion of fission fragments, transfer reactions, and reactions with radioactive ion beams along with their abilities and limitations [58]. Wang et al. investigated the orientation effects of interacting deformed nuclei on the interaction potential energy surfaces, and the evaporation residue cross sections of some cold fusion reactions leading to superheavy elements within the dinuclear system model [59]. Pei et al. investigated the fission barriers of compound superheavy nuclei [60]. Feng et al. analyzed systematically the production of new superheavy Z = 108-114 nuclei with ${}^{238}U, {}^{244}Pu$, and ${}^{248,250}Cm$ targets [61]. Denisov and Khudenko calculated the $\alpha$ decay of even-even superheavy elements, which can be formed by possible cold and hot fusion reactions [62]. Dworschak et al. measured the penning trap mass on nobelium isotopes, in which the heavy nuclides were produced in cold-fusion reactions [63]. Umar et al. investigated the entrance channel dynamics of hot and cold fusion reactions $^{70}Zn{+}^{208}Pb$ and $^{48}Ca{+}^{238}U$, and calculated excitation energies and capture cross sections of superheavy formations [64]. Smolanczuk evaluated chances of synthesis of transactinide nuclei in cold fusion reactions using radioactive beams [65].

Cold fusion used often the resonance tunneling theory, which includes coherent tunneling and sequential tunneling. Wersinger et al. studied a simple model for the nonlinear saturation of instability by nonlinear mode coupling, whose solutions of the resonant three-wave coupling equations show that changes include bifurcations to increasingly complicate periodic motions, the chaotic motions and a strange attractor [66]. It is possibly related with cold fusion.

It is known, when the ionization component is exceeded 1/1000, plasma may be derived from electric, thermal or optical action. The ionization energy of deuterium is about 150 eV, and the ionization wavelength is $\lambda$ = 12400A/15 = 800A. In cold fusion the characteristics of plasma are: 1). The room temperature is T = 300 K, and the electron (ion) temperature is 220eV $\approx 2.552\times10^6$ K. 2). The Debye length is $\lambda_D = 6.9\sqrt{T/n}$ cm. 3). The electric potential is V $= Qe^{-r/\lambda_D}/4\pi\varepsilon_0 r$ . 4). The oscillation frequency of plasma is f = 9000 $\sqrt{n}$ /s, here n is a density. The cold fusion phenomena through electrolysis should be related with plasma, and produce the nonlinear wave and resonance. Therefore, cold fusion phenomena should be related with the nonlinear quantum theory [55]. Cold fusion may be obtained from the nonlinear effect, which derives from the nonlinear quantum mechanics and the nonlinear electromagnetic force. In plasma and its equations, cold fusion is obtained from the strange attractor of energy, which is derived from chaos.

The soliton, which is easier for penetration, chaos and synergetics [53] may be obtained from the nonlinear wave, the nonlinear equations and the nonlinear interactions. Cold fusion corresponds to a condensed state, which may be described by the fractal. The nonlinearity possesses the self-focusing, the self-induced transparency and the recurrence of system under the periodic boundary condition, etc [67].

Existed part of electronic cloud is redounding to the barrier penetration. Cold fusion appears under the critical conditions for the D/Pd ratio and the time accumulate, and it is a chaos point, which corresponds to the chain reaction.

The cold fusion phenomena and its cycle should be related with catalyzer, and produces the nonlinear term. The cold fusion catalyzed by $\mu$ is also a possible multistage reaction. In the room temperature a distance between D-D is 0.74A, and a fusion rate is $10^{-64}\sec^{-1}$ /D-D. Schwinger proposed p+D→ $^{3}He$ +energy of crystal lattices, and the nonlinear process exists.

Cold fusion is also a macroscopic quantum effect. We research the possible relations between various macroscopic quantum phenomena and the extensive quantum theory, which has different quantum constants but similar formulations with quantum mechanics. Using the geometric average method, three different values of the quantum constants of man, cell and macromolecule with different scales may be derived [68]. In cold fusion deuterium and helium (pp + nn) are probably composed of a similar Cooper pair way. Now a key of cold fusion is the penetration factor d, which depends on mass m, energy E, electric potential U and time accumulated according to Eq. (15). Such cold fusion may be controlled.

For the nanomaterial, their exteriors and adsorption effect may increase bigger, it should be beneficial to cold fusion. Because the nanomotes as catalyzer may raise the reaction rate 10~15 times, and usual metal catalyzers are just Fe, Co, Ni, Pd and Pt.

## 5. Discussion and Conclusions

Cold fusion seems to show the imperfection of quantum mechanics. It is probably related with the extensive quantum theory [69-72]. According to Eq. (15), $\ln d \propto -h^{-1}$, if h is bigger, and $\ln d$ will also be bigger.

The nuclear reactions and the nuclear phenomena are the complex process. For instance, we have discussed a possibility on violation of Pauli exclusion principle in nuclei and their collisions at high pressure, high energy and so on [73]. In particular, time accumulate continuously in cold fusion. According to the physical-chemical-nuclear multistage chain reaction theory, the explanation of cold fusion is also possible based on the known quantum mechanics. Finally, we propose the three laws on cold fusion: (1) The time accumulate law, (2) The area direct ratio law, and (3) The multistage chain reaction law.

In a word, cold fusion as a new possible energy is very important, and is worth further researching.

## References

[1] Fleischmann, M.; Pons, S. Electrochemically induced nuclear fusion of deuterium. *J. Electroanal. Chem.* **1989**, *261*: 301-306.

[2] Jones, S. E.; Palmer, E. P.; Czirr, J. B.; et al. Observation of cold nuclear fusion in condensed matter. *Nature*, **1989**, *338*: 737-739.

[3] Nakamitsu, Y.; Chiba, M.; Fukushima, K.; et al. Study of cold nuclear fusion with electrolysis at low-temperature range. *Nuovo Cimento*. **1994**, *A107*: 117-128.

[4] Li, X. Z.; Tian, J.; Mei, M. Y.; et al. Sub-barrier fusion and selective resonant tunneling. *Phys. Rev*. **2000**, *C61*: 024610.

[5] Ziegler, J. F.; Zabel, T, H.; Cuomo, J. J.; et al. Electrochemical experiments in cold nuclear fusion. *Phys. Rev. Lett*. **1989**, *62*: 2929-2932.

[6] Sun, Z.; Tomanek, D. Cold fusion: How close can deuterium atoms come inside palladium? *Phys. Rev. Lett*. **1989**, *63*: 59-61.

[7] Leggett, A. J.; Baym, G. Exact upper bound on barrier penetration probabilities in many-body systems: Application to ‘‘cold fusion’’. *Phys. Rev. Lett*. **1989**, *63*: 191-194.

[8] Szalewicz, K.; Morgan, J. D.; Monkhorst, H. J. Fusion rates for hydrogen isotopic molecules of relevance for ‘‘cold fusion’’. *Phys. Rev*. **1989**, *A40*: 2824-2827.

[9] Hassam, A. B.; Dharamsi, A. N. Deuterium molecule in the presence of electronic charge concentrations: Implications for cold fusion. *Phys. Rev.* **1989**, *A40*: 6689-6691.

[10] Burrows, A. Enhancement of cold fusion in metal ‘‘hydrides’’ by screening of proton and deuteron charges. *Phys. Rev*. **1989**, *B40*: 3405-3408.

[11] Horowitz, C. J. Cold nuclear fusion in metallic hydrogen and normal metals. *Phys. Rev*. **1989**, *C40*: R1555-R1558.

[12] Deakin, M. R.; Fox, J. D.; Kemper, K. W.; et al. Search for cold fusion using x-ray detection. *Phys. Rev*. **1989**, *C40*: R1851-R1853.

[13] Chambers, G. P.; Eridon, J. M.; Grabowski, K. S. Upper limit on cold fusion in thin palladium films. *Phys. Rev*. **1990**, *B41*: 5388-5391.

[14] Southon, J. R.; Stark, J. W.; Vogel, J. S.; Waddington, J. C. Upper limit for neutron emission from cold d-t fusion. *Phys. Rev*. **1990**, *C41*: R1899-R1900.

[15] Balke, B.; Cox, L.; Fackler, O.; et al. Limits on neutron emission from ‘‘cold fusion’’ in metal hydrides. *Phys. Rev*. **1990**, *C42*: 30-37.

[16] Roberts, D. A.; Becchetti, F. D.; Ben-Jacob, E.; et al., Energy and flux limits of cold-fusion neutrons using a deuterated liquid scintillator. *Phys. Rev*. **1990**, *C42*: R1809-R1812.

[17] Ichimaru, S. Nuclear fusion in dense plasmas. *Rev. Mod. Phys*. **1993**, *65*: 255-299.

[18] Fleischmann, M.; Pons, S.; Preparata, G. Possible theories of cold fusion. *Nuovo Cimento*. **1994**, *A107*: 143-156.

[19] Fox, H. (ed.). *Cold Fusion Source Book*. Minsk, Belarus, **1994**.

[20] Jeitler, M.; Breunlich, W. H.; Cargnelli, M.; et al. Epithermal effects in muon-catalyzed dt fusion: Comparison of experimental data with theoretical calculations. *Phys. Rev*. **1995**, *A51*: 2881-2898.

[21] Gupta, R. K.; Singh, S.; Munzenberg, G.; Scheid, W. Neutron-halo nuclei in cold synthesis and cluster decay of heavy nuclei: Z=104 nucleus as an example. *Phys. Rev*. **1995**, *C51*: 2623-2629.

[22] Smolanczuk, R. Production of even-even superheavy nuclei in cold fusion reactions. *Phys. Rev. Lett*. **1999**, *83*: 4705-4707.

[23] Smolanczuk, R. Production mechanism of superheavy nuclei in cold fusion reactions. *Phys. Rev*. **1999**, *C59*: 2634-2639.

[24] Smolanczuk, R. Excitation functions for the production of superheavy nuclei in cold fusion reactions. *Phys. Rev*. **1999**, *C61*: 011601.

[25] Smolanczuk, R. Formation of superheavy elements in cold fusion reactions. *Phys. Rev*. **2001**, *C63*: 044607.

[26] Smolanczuk, R. Cross sections calculated for cold fusion reactions for producing superheavy nuclei. *Phys. Rev*. **2008**, *C78*: 024601.

[27] Kozima, H. Neutron Mössbauer effect and the cold fusion in inhomogeneous materials. *Nuovo Cimento*. **1994**, *A107*: 1781-1784.

[28] Kirkinskii, V. A.; Novikov, Yu. A. A new approach to theoretical modelling of nuclear fusion in palladium deuteride. *Europhys. Lett*. **1999**, *46*: 448-453.

[29] Hofmann, S.; Munzenberg, G. The discovery of the heaviest elements. *Rev. Mod. Phys*. **2000**, *72*: 733-767.

[30] Chang, Y. F. Some experimental progress and theoretical researches on cold fusion. In: *The Progress of Research for MPMH 2000(8)*. Xinan Jiaotong University Press, **2000**, pp. 182-186.

[31] Grillon, G.; Balcou, P.; Chambaret, J. P.; et al., Deuterium-deuterium fusion dynamics in low-density molecular-cluster jets irradiated by intense ultrafast laser pulses. *Phys. Rev. Lett*. **2002**, *89*: 065005.

[32] Gherghescu, R. A.; Greiner, W. Charge density influence on cold fusion barriers. *Phys. Rev*. **2003**, *C68*: 044314.

[33] Gherghescu, R. A.; Greiner, W.; Munzenberg, G. Shell effects in cold fusion reactions. *Phys. Rev*. **2003**, *C68*: 054314.

[34] Gherghescu, R. A.; Nagame, Y. Isobaric cold-fusion channels for synthesis. *Phys. Rev*. **2006**, *C74*: 014611.

[35] Adamian, G. G.; Antonenko, N. V.; Scheid, W. Isotopic trends in the production of superheavy nuclei in cold fusion reactions. *Phys. Rev*. **2004**, *C69*: 011601.

[36] Adamian, G. G.; Antonenko, N. V.; Zubov, A. S. Production of unknown transactinides in asymmetry-exit-channel quasifission reactions. *Phys. Rev*. **2005**, *C71*: 034603.

[37] Adamian, G. G.; Antonenko, N. V. Transfer-type products accompanying cold fusion reactions.

*Phys. Rev*. **2005**, *C72*: 064617.

[38] Naranjo, B.; Gimzewski, J. K.; Putterman, S. Observation of nuclear fusion driven by a pyroelectric crystal. *Nature* **2005**, *434*: 1115-1117.

[39] Saltmarsh, M. J. Technology: Warm fusion. *Nature* **2005**, *434*: 1077-1078.

[40] Gupta, R. K.; Manhas, M.; Munzenberg,G.; Greiner, W. Theory of the compactness of the hot fusion reaction $^{48}Ca+^{244}Pu\rightarrow^{292}114*$. *Phys. Rev*. **2005**, *C72*: 014607.

[41] Gherghescu, R. A.; Nagame, Y. Isobaric cold-fusion reactions for synthesis of $^{276}114,^{286}114$ and $^{290}114$. *Phys. Rev*. **2006**, *C74*: 014611.

[42] Mitsuoka, S.; Ikezoe, H.; Nishio, K.; et al. Barrier distributions derived from quasielastic scattering of $^{48}Ti,^{54}Cr,^{56}Fe,^{64}Ni$ and $^{70}Zn$ projectiles on a $^{208}Pb$ target. *Phys. Rev. Lett*. **2007**, *99*: 182701.

[43] Feng, Z. Q.; Jin, G. M.; Li, J. Q.; Scheid, W. Formation of superheavy nuclei in cold fusion reactions. *Phys. Rev*. **2007**, *C76*: 044606.

[44] Chang, Y. F. Chemical reactions and possible entropy decrease in isolated system. *Int. J. Modern Chem*. **2013**, *4*: 126-136.

[45] Chang, Y. F.; Yu, C. Z. Internal conversion mechanism and multistage chain reaction theory of cold fusion. *Fusion Facts* (ICCF-5) **1995**, *6(11)*: 15-16.

[46] Chang, Y. F.; Yu, C. Z. The physical-chemical and nuclear multistage reaction mechanism and the multistage ignition condition on cold fusion. In: *Cold Fusion Source Book*. Belarus, Minsk, **1994**, pp. 72-74.

[47] Yu.Denisov, V.; Hofmann, S. Formation of superheavy elements in cold fusion reactions. *Phys. Rev*. **2000**, *C61*: 034606.

[48] Swiatecki, W. J.; Siwek-Wilczynska, K.; Wilczynski, J. Fusion by diffusion. II. Synthesis of transfermium elements in cold fusion reactions. *Phys. Rev*. **2005**, *C71*: 014602.

[49] Siwek-Wilczynska, K.; Skwira, I.; Wilczynski, J. Tests of the fission-evaporation competition in the deexcitation of heavy nuclei. *Phys. Rev*. **2005**, *C72*: 034605.

[50] Ichikawa, T.; Iwamoto, A.; Moller, P.; Sierk, A. J. Barrier for cold-fusion production of superheavy elements. *Phys. Rev*. **2005**, *C71*: 044608.

[51] Ichikawa, T.; Iwamoto, A. Effect of charge polarization on the Coulomb barrier for cold-fusion reactions. *Phys. Rev*. **2005**, *C71*: 067601.

[52] Ismail, M.; Seif, W. M. Simple interpretation of nuclear orientation for Coulomb barrier distributions derived from a realistic effective interaction. *Phys. Rev*. **2010**, *C81*: 034607.

[53] Haken, H. *Synergetics: An Introduction*. Springer, **1977**; *Advanced Synergetics*. Springer, **1983**.

[54] Risken, H. *The Fokker-Planck Equation*. Springer, **1982**.

[55] Chang, Y. F. *New Research of Particle Physics and Relativity*. Yunnan Science and Technology Press, **1989**. *Abst. Phys*. **1990**, *93*: 1371.

[56] Fleischmann, M.; Pons, S. Calorimetry of the Pd-$D_2O$ system: from simplicity via complications to simplicity. *Phys. Lett*. **1993**, *A176*: 118-129.

[57] Manduchi, C.; Zannoni, G.; Milli, E.; et al. Anomalous effects during the interaction of subatmospheric D2 (H2) with Pd from 900 C to room temperature. *Nuovo Cimento*. **1994**, *A107*: 171-183.

[58] Zagrebaev, V.; Greiner, W. Synthesis of superheavy nuclei: A search for new production reactions, *Phys. Rev*. **2008**, *C78*: 034610.

[59] Wang, N.; Li, J.; Zhao, E. Orientation effects of deformed nuclei on the production of superheavy elements. *Phys. Rev*. **2008**, *C78*: 054607.

[60] Pei, J. C.; Nazarewicz, W.; Sheikh, J. A.; Kerman, A. K. Fission barriers of compound superheavy nuclei. *Phys. Rev. Lett*. **2009**, *102*: 192501.

[61] Feng, Z. Q.; Jin, G. M.; Li, J. Q. Production of new superheavy Z=108-114 nuclei with $^{238}U, ^{244}Pu$, and $^{248,250}Cm$ targets. *Phys. Rev*. **2009**, *C80*: 057601.

[62] Yu.Denisov V.; Khudenko, A. A. $\alpha$ decay of even-even superheavy elements. *Phys. Rev*. **2010**, *C81*: 034613.

[63] Dworschak, M.; Block, M.; Ackermann, D.; et al., Penning trap mass measurements on nobelium isotopes. *Phys. Rev*. **2010**, *C81*: 064312.

[64] Umar, A. S.; Oberacker, V. E.; Maruhn, J. A.; Reinhard, P. G. Entrance channel dynamics of hot and cold fusion reactions leading to superheavy elements. *Phys. Rev*. **2010**, *C81*: 064607.

[65] Smolanczuk, R. Synthesis of transactinide nuclei in cold fusion reactions using radioactive beams. *Phys. Rev*. **2010**, *C81*: 067602.

[66] Wersinger, J. M.; Finn, J. M.; Ott, E. Bifurcations and strange behavior in instability saturation by nonlinear mode coupling. *Phys. Rev. Lett*. **1980**, *44*: 453-456.

[67] Taniuti, T.; Nishihara, K. *Nonlinear Waves*. Pitman Advanced Publishing Program, **1983**.

[68] Chang, Y. F. Nanophysics, macroscopic quantum phenomena and extensive quantum theory. *Int. J. Nano & Mater. Sci*. **2013**, *2*: 9-24.

[69] Chang, Y. F. Development of Titius-Bode rule and cosmic quantum theory. *Publ. Beijing Astron. Obs*. **1990**, *16:* 16.

[70] Chang, Y. F. Development of Titius-Bode law and the extensive quantum theory. *Physics Essays* **2002**, *15*: 133-137.

[71] Chang, Y. F. Development of the extensive quantum theory and its applications in biology, chemistry and physics. *J. Jishou Univ*. **2006**, *27*(5): 34-38.

[72] Chang, Y. F. Quantized phenomena in astronomy and astronomic quantum theory. *Int. J. Sci*. **2013**, *2*(2): 58-73.

[73] Chang, Y. F. Test of Pauli's exclusion principle in particle physics, astrophysics and other fields. *J. New Ener*. **1999**, *4*: 31-43.