V.A. Kirkinskii

Yu.A. Novikov

THEORETICAL MODELING OF COLD FUSION

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Convincing experimental evidences of nuclear fusion at low energies have been obtained during last years, but there is not satisfactory quantitative theory of this principally important phenomenon yet. An original model of a nuclear fusion mechanism in metal crystal structures at low energies is developed. It uses a new approach for estimation of electron screening in metals, which is based on dynamic account of outer metal electronic shells deformation during counter motion of two deuterons near their sites boundary. Computer simulation of deuterium behavior in the palladium deuteride crystal structure has shown that the calculated rate of nuclear reactions agrees in order of magnitude with the values deduced from experimental data on excess heat output.. Crucial factors for fusion feasibility are indicated.

Autor's E-mail address: kirkinsk@uiggm.nsc.ru

Contents

Hypotheses concerning the nature and the mechanism of cold fusion

Since 1989 more than two thousands of works have been published, in which different hypotheses were expressed and theoretical models offered as an argument for the cold fusion experimental data. A level of models development is rather various: from statements in general terms to attempts to make quantitative estimates. To get some notions on a diversity of theoretical ideas about the nature and the mechanism of cold fusion we will list references to the specific works, which can be subdivided into eight groups. The accepted classification is close to the offered in the review (Chechin et al., 1994), in comparison with which less developed hypotheses and subsequent works are also included.

1. Acceleration models

1.1. "Fractonuclear models" (Derjagin et al., 1986; Golubnichii et al., 1989 a,; Lipson, 1989 a; Tzarev, 1990, 1991; Cohen, Davis, 1989; Joyce, 1989; Gac et al., 1989; Goldanskii, Dalidchik, 1989; Pool, 1989; Takeda, Takizuka, 1989; Zelenskii, Rybalko, 1990; Zhang, 1991; Chechin, Tsarev, 1994; Yasui, 1992; Chechin et al., 1994; Kuhne, 1994);

1.2. Collaps at the phase transformation (Cassandro et al., 1989; Tabet, Tenenbaum, 1990 a, b);

1.3. Phenomena occuring at phase transformations (Varaksin et al., 1991; Krasnostchekov et al., 1991);

1.4. Parametric oscillation of crystal lattices during formation of dislocations (Fedorovich, 1991, 1992, 1993 a, b, 1995);

1.5. Formation of solitons as the result of shock waves of decompression, their focusing at diffraction and reflecting on phase boundaries (Filimonov, 1990);

1.6. Reaction $D^+ + D^-$ on an electrode (Jorne, 1990);

1.7. Acceleration due to a difference of electric potential on a surface of an electrode (Fleischman, Pons, 1989; Lin et al., 1990; Rabinovitz, Worledge, 1990; Gonsales-Martin et al., 1993);

1.8. "Lattice-quake" model of nuclear reactions under the action of high-energy particles generating at usual "Rutherfords" D + D reactions (Arata, Zhang, 1995);

1.9. Acceleration of deuterons under the action of collective power transmission from crystal electron subsystem excited by a current (Kazachkovskii, 1996).

2. Reduction of Coulomb barrier owing to electron screening

2.1. Model of spherical electron cloud (Harrison, 1964; Rabinovitz, 1990 b);

2.2. Thomas-Fermi's model (Vaselli, 1989; Fujita, 1989; Karasevskii et al., 1989; Kim, 1991);

2.3. Polarization of electrons (Feng, 1989);

2.4. Screening by coupled electrons (Davydov, 1989);

2.5. Floating electron layer in the Maxwell model of plasma (Hora et al., 1990, 1993, 1998);

2.6. Models on the basis of the band theory of metals (Baljan et al., 1989; Rambaut, 1994; Azbel, 1990);

2.7. Plasma model of electron screening (Seeliger, Measter, 1991);

2.8. Account of peculiarities of function of dielectric permittivity of palladium deuteride (Ichimaru et al., 1989, 1990; Ichimaru 1993; Demidenko, Simakov, 1993);

2.9. High effective mass of electron (Koonin, Nauenberg, 1989; Parmenter, Lamb, 1989, 1990; Masitov, 1989; Bhattacharjee et al., 1989; Bussard, 1990; Rabinovitz, Worledge, 1990);

2.10. Interferential effects at a diffusion of deuterium in metals (Fimin, 1996);

2.11. "Dynamic pairing" of two deuterium atoms in palladium deuteride (Komarov et al., 1990);

2.12. Peculiarities of screening in ion traps (Violante, De Ninno, 1997).

3. Specific quantum effects

3.1. "Transmission resonance" - reactions in a periodic sublattice of a deuterium (Turner, 1989; Bush, 1991; Kim et al., 1994);

3.2. Interference of wave functions, improved Coulomb barrier transmission coefficient (Kim, Zubarev, 1993; Kim et al., 1994);

3.3. Coherent interaction of deuterons (Vaidya, 1991);

3.4. Nuclear reactions stimulated by a crystal lattice (lattice induced nuclear chemistry) - a formation of a Bose-Bloch condensate (Chubb, Chubb, 1990, 1991, 1993);

3.5. Nonequilibrium Fermi-condensation of atoms of a deuterium in microcavities and in other crystal defects (Vysotskii, Kuz'min, 1994; Matsumoto, 1990, 1991; Greenland, 1990; Dienes, 1991; Nordlander et al., 1989);

3.6. "Mössbauer synthesis" D + D + (Me) → ^{4}He + (Me)* (Christos, 1989);

3.7. Neutron transfer during quantum electrodynamics interaction of

deuterons with extra "external" nucleus: D + D + C' → p + T + C' (Danos, 1990; Danos, Belyaev, 1991);

3.8. Quantum electrodynamics confinement of electrons by deuterons (Jandel, 1990);

3.9. "Exotic deuterium plasma", in which internuclei distances are diminished by virtue of thermal movements (Fedorovich, 1994);

3.10. Participation of electrons in nuclear reactions accompanied by a change of the channels of D+D nuclear reaction ratio (Chatterjee, 1990);

3.11. "Superradiance" model: collective interaction of deuterons with plasmons of metal with transmission of an energy, releasing in nuclear reactions, to an electron subsystem (Bressani et al., 1989; Preparata, 1990 a, b, 1991 a, b, 1994, 1996);

3.12. Movement of particles with an oscillating charge in frameworks "of the unitary quantum theory " (Sapogin, 1994, 1997);

3.13. Overcoming the Coulomb barrier due to "torsion effects" (Shipov, 1995);

3.14. Boson condensation (Waber, 1996).

4. Interaction of deuterons and phonons

4.1. Modification of a potential of interaction under oscillations of atoms in crystal lattice (Schwinger, 1990 a-c; Baldo et al., 1990; Crawford, 1992; Tisenko, 1993; Rambout, 1994; Liu, 1996);

4.2. Transmission of nuclear reaction energy to phonons (Schwinger, 1990 a, b; Hagelstein, 1990, 1994, 1998; Swartz, 1996);

4.3. Action of long-lived large scale fluctuations of an energy in a crystal lattice (Rao, Chaplot, 1994);

4.4. Reactions under the action of the localized oscillatory modes of deuterium atoms (Petrillo, Sacchetti, 1989).

5. Exotic chemistry

Hypotheses for an existence of atoms and molecules with electrons located closer to the nucleus of deuterium:

5.1. Formation of hydrogen atoms with electron-binding energy 27.21 eV (Mills, Farrel, 1990; Mills, Kneizys, 1991);

5.2. Formation of hydrogen atoms with electron-binding energy ~ 50 keV (Maly, Va'vra, 1993);

5.3. Formation of molecules D_2 and D_2^+ with the internuclear distance ~0.03 nm (Cerofolini, Re, 1990; Grysinsky, 1990; Barut, 1990; Moijes, 1991);

5.4. Existence of metastable bound states of a deuterium in palladium (Gann, Pochodyashchii, 1990).

6. Catalysis by heavy particles:

6.1. by μ-meson (Frank, 1947; Alvarez et al., 1957; Zeldovich, Gershtein, 1960);

6.2. by heavy biquarks (Shaw et al., 1989);

6.3. by superheavy negatively charged hadrons (Rafelski et al., 1990);

6.4. by heavy neutral and charged hadrons ("erzions") (Bazshutov, Wereshkov, 1992,1993);

6.5. by "eleptino" – long-lived neutral composite bozon by a system (Nedospasov, Mudretskaya, 1997).

7. Nuclear effects

7.1. Oppenheimer-Fillips effect (Ragheb, Miley, 1989; Paolo, 1989);

7.2. Narrow nuclear resonance (Shibab-Elden et al., 1989; McVally, 1989; Kim, 1990a; Zakowitch, 1991);

7.3. Interaction of the groups of deuterons considered as distinguished from bozons (Tsuchya, 1994);

7.4. Trapped neutron catalyzed fusion –TNCF (see for example, Kozima, 1994, 1995, 1998 a, b, 1999, 2000).

8. Other nuclear reactions

8.1. Electron capture forming bineutron: D + e → 2n + n; D + e → n* + n* + n (Anderman, 1990; Hagelstein, 1990; Pokropivnyi, Ogorodnikov, 1990; Russel, 1990; 1991a, b; Mayer, Reitz, 1991b; Yang, 1991, 1994; Istomin, Kaliev, 1994);

8.2. Fusion of deuteron and proton: D + p → ^{3}He (Schwinger, 1989; Kim et al., 1990);

8.3. Nuclear reaction of deuteron and light isotope of lithium: D + ^{6}Li → ^{4}He + ^{4}He (Frodl et al., 1990);

8.4. Transition of neutrons between nuclei under the action of a magnetic field (Hagelstein, 1990, 1991);

8.5. Electron capture with the formation π, γ and τ- hadrons (Mayer, Reitz, 1991a);

8.6. Polynuclear reactions

D + D + D → D (15.9 MeV) + ^{4}He (7.9 MeV)

D + D + D → D (4.75 MeV) + ^{3}He (4.75 MeV)

D + D + D + D → ^{4}He (23.8 MeV) + ^{4}He (23.8 MeV)

p + D + D → p (4.12 MeV) + ^{3}He (1.37 MeV)

D + p + D → p (19.0 MeV) + ^{4}He (4.76 MeV)

p + D + D + D → ^{3}He (16.8 MeV) + ^{4}He (12.6 MeV)

(Becker, 1989; Rabinowitz, 1990a; Kim, 1990; Takahashi, 1998, Arata, Zhang, 1996);

8.7. Cascade nuclear reactions catalyzed by deuterons:

D + D → ^{4}He; D + ^{4}He → ^{6}Li → ^{4}He + D + 23.8 MeV (Takahashi, 1989, 1991);

8.8. Self-compression of hydrogen clusters with formation of "itons", neutrons and bineutrons (Matzumoto, 1989, 1990);

8.9. Generation of neutrons by an embryo background neutron (Lipson et al., 1993; Lipson, Sakov, 1994);

8.10. Fission-fusion reactions induced by neutrons:

$n + {}^{6}Li \rightarrow {}^{4}He + 4n$; $n + {}^{7}Li \rightarrow {}^{4}He + T + n$; $T + D \rightarrow {}^{4}He + n$ (Kim, 1990);

8.11. Interchanging of neutron pairs between polyneutrons and nuclides (Fisher, 1992);

8.12. Nucleoweak interaction reactions: $D + D + e \rightarrow T + n + \nu_e$; $D + D + D^{+} + e \rightarrow T + T + \nu_e$; $p + D + e \rightarrow T + \nu_e$ (Chatterjee, 1991)

8.13. At participation of electropionic particles a deuteron, capturing an electron, turns to a D-meson which has some of the richest variety of decay schemas of all the elementary particles (Kenny, 1991);

8.14. Bonding between "Hydrex" ${}^{1}_{1}\vec{H}$, "Deutex" ${}^{2}_{1}\vec{H}$ and a nucleus - partner (Dufour et al., 1998):

$${}^{7}_{3}Li + {}^{1}_{1}\vec{H} \rightarrow {}^{4}_{2}He + {}^{4}_{2}He + 17.4\ MeV$$

$${}^{7}_{3}Li + {}^{2}_{1}\vec{H} \rightarrow {}^{5}_{2}He + {}^{4}_{2}He \rightarrow {}^{4}_{2}He + {}^{1}_{0}n + {}^{4}_{2}He^{+} + 15.1\ MeV$$

$${}^{194}_{78}Pt + {}^{2}_{1}\vec{H} \rightarrow {}^{190}_{76}Os + {}^{6}_{3}Li + 2.9\ MeV.$$

The reviews (Rabinovitz et al., 1994; Chechin et al., 1994) analyzed theoretical works on cold fusion in which qualitative and quantitative estimations of nuclear reactions rates were made. The reviewers came to the conclusion, that "despite of considerable efforts no theoretical

formulation of cold fusion has succeeded in quantitatively or even qualitatively describing the reported experimental results. Those models claiming to have solved this enigma appear far from having accomplished this goal".

We considered more extensive group of works (see references above), including those published after 1994. Though these works contain many interesting ideas, they do not allow to change fundamentally the estimates cited above. One of the reasons for this is the objective difficulty of cold fusion problem, which lies at the juncture of nuclear physics, solid state physics, electrochemistry and quantum chemistry. As a historical analogy, it may be helpful to recollect that the theory of superconductivity was developed almost half-century after the discovery of the phenomenon.