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Emission of Charged Particles in the Cold Fusion Phenomenon

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Abstract

We summarize experimental data sets of charged particle emission obtained after 1990 and investigate them from our point of view that the whole experimental data obtained in the CFP from excess energy to nuclear transmutation through emissions of neutron and light charged particles should be interpreted consistently if these phenomena have a common cause in the physics of the cold fusion phenomenon.

Based on the TNCF model proposed by us in 1993 at ICCF4 held in Hawaii, USA, we have given a consistent explanation of the data of charged particles emitted from CF materials in accordance with other data obtained in the CFP from excess energy generation to nuclear transmutation through neutron emission.

We confine our investigation in this paper to the experiments where are used no artificial excitations by such particles as proton, deuteron or photon with energies more than 1 keV. In our opinion, the physics of events caused by energetic particles in CF materials belongs to the low energy nuclear physics under the influence of CF materials even if it is a part of the solid-state nuclear physics or condensed material nuclear science.

1. Introduction

The cold fusion phenomenon (CFP) is a name used to express nuclear events as a whole including excess energy production and nuclear transmutations occurring in condensed materials composed of host elements (transition metals; Ti, Ni, Pd, and carbon) and hydrogen isotopes (H and D). The cold fusion is the name used to express the events observed by pioneers in this field at the earlier stage from 1989 and the name CFP stands for the field born from the original concept of the pioneers.

The most solid evidence of nuclear reactions is the change of a nucleus to another and this is detected by observing the change itself (nuclear transmutation) and emission of neutron and charged particles accompanied to the transmutation. The experimental data sets including the nuclear transmutation and excess energy production obtained mainly in 20th century had been analyzed successfully by our TNCF model [Kozima 1998, 2006] assuming a new state of neutrons in solids composed of host elements and hydrogen isotopes.

On the other hand, detection of the charged particles has been one of main targets for confirmation of nuclear reactions involved in the CFP. The detection of charged particles as they are emitted from nuclei has difficulty in elimination of severe influence of charged particles surrounding the cold fusion (CF) materials with little success. So, the observation of tritons and alpha particles has been mainly done as detection of tritium ($^{3}_{1}H$) and helium-4 ($^{4}_{2}He$) in CF and surrounding materials in electrolytic systems. Another problem related to the charged particle observation is difficulty to measure other observables simultaneously to identify nuclear reactions causing the emission of the charged particle and the other observables.

However, the use of CR-39 solid-state particle detector in the CFP proposed by Chinese group in 1989 [Li 1990] made the measurement of charged particles practical and applied frequently in recent years. Frequency and accuracy of detection of charged particles in electrolytic systems have been extensively increased in these several years by the use of the CR-39 detector even if there remains ambiguity in identification of charged particles and determination of their energies.

The CFP has been investigated for more than 20 years in various materials mainly in transition-metal hydrides and deuterides and sometimes in proton conductors and such organic compounds as polyethylene. And we know much about its complicated effects from excess heat generation to heavy nuclides production by nuclear transmutations through emissions of proton, deuteron, neutron, alpha-particle and gamma and X-ray from CF samples in non-equilibrium condition without artificial excitation.

On the other hand, there are trials to check effects of external excitations on the CFP. To enhance the nuclear reactions in and accompanying emission of charged particles from CF materials, artificial excitation by energetic particles (electron, proton and deuteron) and laser beams has often been applied. The results obtained by these experiments have shown enormous enhancement of the *d-d* fusion reaction by sometimes 9 orders of magnitude by 1 keV deuteron irradiation on PdD samples.

The artificial excitation surely enhances the cause-effects relation in the CFP but also add complex factors to the analysis. The effects obtained in these experiments with artificial excitations are a part of the CFP but with complication including an extra factor to the original cold fusion phenomenon. So, we will confine our discussion in this paper only to the genuine CFP without artificial excitation by particles and photons with energies larger than 1 keV.

In this paper, we give a review on the experimental data of charged particles emission from CF materials leaving the explanation of CR-39 track detector to another paper presented at this conference [Kozima 2013a]. We explain our TNCF model in relation to the charged particle emission in the CFP. We will then give finally a consistent explanation of the data of charged particles emitted from CF materials based on our model in accordance with other data of neutron emission and nuclear transmutation in addition to the excess energy generation in the CFP.

2. Emission of Charged Particles in the CFP and Use of CR-39

The detection of the charged particles has been one of main techniques for confirmation of nuclear reactions involved in the CFP as explained in the Introduction of this paper. The detection of charged particles as they are emitted from nuclei has difficulty to avoid severe influence of charged particles surrounding the cold fusion (CF) materials. Therefore, the observation of tritons and alpha particles has been mainly replaced by detection of tritium (${}^{3}_{1}H$) and helium-4 (${}^{4}_{2}He$) in CF and surrounding materials in electrolytic systems. The first trial to detect tritium in the electrolytic system where observed tremendous excess heat was performed by the pioneers of this field and the result was reported in the first paper announcing the cold fusion phenomenon in a PdD_x system [Fleischmann 1989]. The experimental data sets reporting observation of tritium were compiled in our books [Kozima 1998 (Sec. 6.4). 2006 (Sec. 2.6)]. On the other hand, the first detection of helium atoms in Pd samples which generated excess heat was reported by Morrey et al. in 1990 [Morrey 1990]. The experimental data sets reporting observation of helium were compiled in our books [Kozima 1998 (Section 6.5), 2006 (Sec. 2.8)].

Direct detection of charged particles from CF samples has been performed in systems without liquids, i.e. in systems in vacuum (See Sections 2.2 and 2.3). However, the use of the solid-state particle detector made possible detection of charged particles in gaseous and liquid systems. The first proposal to apply the solid-state particle detector CR-39 in the field of the CFP was made by Chinese scientists as early as 1991 [Li 1991]. It is emphasized that CR-39 has high sensitivity and low background and need not any high voltage power supply; therefore, it has low electronic noise and is particularly suitable for experiments in the high pressure vessel such as used by Frascati group in Italy (e.g. [De Ninno 1989]).

Recently, the CR-39 has been used frequently due to its advantages of high sensitivity and low background rather easily and some easy conclusions seem to be deduced. We have to careful to deduce a conclusion from limited data as always noticed in our daily experience as typically expressed in the famous Buddhist parable for our self-reproach [Appendix Tittha Sutta].

One of the most important demerits of the use of CR-39 detector is the limitation to simultaneous use of this detector with apparatuses to observe other observables such as excess energy, neutron, tritium and nuclear transmutations. With several quantities observed simultaneously, we can access the entity of the physics occurring in the material more effectively. Another demerit is the lack of time resolution for the occurrence of nuclear reactions (cf. next section).

2.1 Experimental data of charged particle emission in the CFP

From the first stages of the investigation of the cold fusion phenomenon (CFP), the charged particles, proton, triton and helium-3 and helium-4, expected from the presumed nuclear reactions between deuterons are main targets of search. While Chinese scientists noticed efficacy of the use of CR-39 for the CF research as early as 1991 [Li 1991], they have recognized the qualitative nature of this detector. Therefore, quantitative investigation of the emitted charged particles in the CFP moved slowly as summarized in this Section.

2.1.1 Merits and demerits of CR-39 detector in the CFP

As is discussed in our previous paper [Kozima 2013a], there are several difficulties to be overcome in identification of charged particles and their energies by using the CR-39 detector at present.

Besides these difficulties, there are other problems inherit in the CFP where we do not know physics of the nuclear reactions in CF materials at present. Therefore, it will be useful to recognize the characteristics of the plastic solid-state particle detector CR-39 in relation to the CF researches. Because we do not know the true mechanism of the cold fusion phenomenon (CFP), it is necessary to obtain as many observables as possible hopefully them simultaneously. Merits and demerits of the CR-39 detector necessarily relate to these points.

Merits.

As is expressed in the paper by X.Z. Li, CR-39 detector has high sensitivity and high efficiency without dead time and needs not any high voltage power supply resulting in low background noise [Li 1991]. In addition to these characteristics preferable for the CF research, it is very convenient to measure several charged particles simultaneously such as protons, deuterons and tritons expected from the *d-d* reactions (3.6) and (3.7) below. The CR-39 detector is also easy to use close to CF materials where occur nuclear reactions minimizing the energy loss by interaction with other particles.

Demerits.

First of all, the complex mechanisms of latent track formation in the detector make the identification of charged particles and determination of their energies qualitative.

In principle, the CR-39 detector has cumulative nature and needs a definite length of time to accumulate signals of charged particles emitted by reactions in CF materials. It is, therefore, not possible to determine the temporal characteristics of events in the CFP. Also, this characteristic is not compatible with simultaneous measurements of such dynamical variables as rates of excess energy production and of neutron emission.

2.2 First experimental data obtained by Chinese researchers with CR-39 detector

The CR-39 plastic track detector was used first by several research groups in China for qualitative determination of the nuclear character of the CFP [Li 1991, Mo 1991, Shangxian 1991, Wang K.L. 1991, Wang S.C. 1991].

In the experiment by Mo et al. [Mo 1991], Pd and Ti foils in a stainless steel vessel were deuterized by D_2 gas with a pressure of 1 atm. The plastic track detector CR-39 and thermoluminescence detector (TLD) were used for the energetic charged particles and for the low energy EM radiation (the precursor of the former), respectively. They observed peaks corresponding to energies of about 5 MeV which does not fit with any conventional binary D-D reaction.

In the experiment by Shangxian et al. [Shangxian 1991], they observed intense bursts of charged particles which were reproducibly detected by using CR-39 detector during either a high voltage discharge between deuterated Pd electrodes or a non-equilibrium out-diffusion of deuterons in Pd.

In the experiment by S.C. Wang et al. [Wang S.C. 1991], CR-39 detector has been used in search for charge particles from PdD_x and TiD_x foils. From a Pd and Ti foils, they found etch pits on the detector whose track parameter suggested the charge particles with charges $Z = 2$ and $Z = 3$ are responsible for the etch pits. In order to identify the charge Z more accurately, they needed further calibration of the response of CR-39 using alpha irradiation under the condition of high-pressure D_2 gas and temperature cycle.

X.Z. Li reported a review article on the use of CR-39 in China together with his data [Li 1991]. He is not using the CR-39 detector recently for years due to its demerits (especially its qualitative nature and lack of time resolution) listed up above [Li 2012].

Their experimental data are tabulated in Table 2.1 and depicted in Fig. 2.1.

Table 2.1 Experimental data obtained by Chinese researchers

Authors and References	**Species**	**Energies of observed particle**
[Mo 1991]	?	5 MeV
[Shangxian 1991]	Bursts	?
[Wang K.L. 1991]	?	?
[Wang S.C. 1991]	?	2 and 3 MeV
[Li 1991]	?	$Z > 1$, $E > 5$ MeV

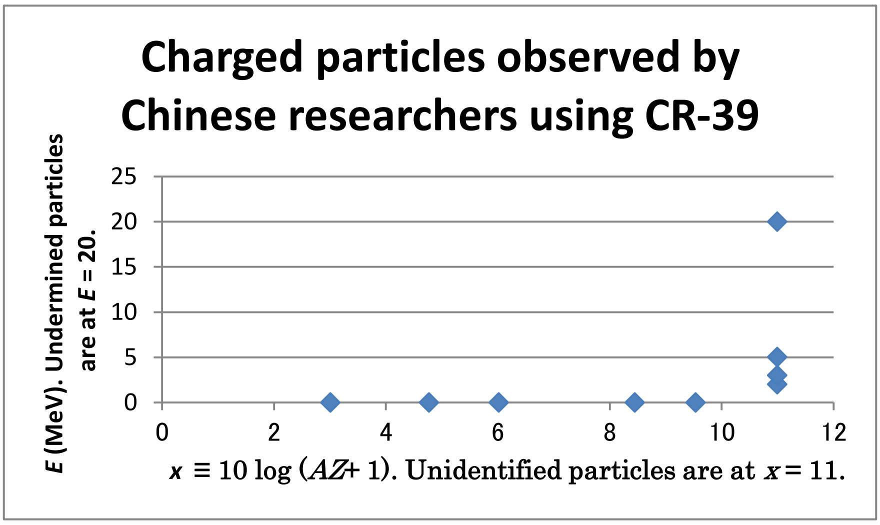

Fig. 2.1 Charged particles observed by Chinese researchers in 1990 – 1991 using CR-39 for the first time in the research of the CFP. The abscissa is $x = 10 \log (AZ + 1)$ and the ordinate is the energy E in MeV. Proton, deuteron, triton, ^{3}He and ^{4}He correspond to x = 3.01, 4.77, 6.02, 8.45 and 9.54, respectively. Data of unspecified particles are placed at x = 11 and undetermined energies are at E = 20 MeV. Marks on the abscissa are for identification of particles.

2.3 Experimental data sets showing emission of charged particles in the CFP

Emission of heavy charged particles is a decisive proof of nuclear reactions in the cold fusion phenomenon (CFP) and therefore has been investigated from the first stage of the research in this field. Several methods have been used for the detection of charged particles appropriate for the experimental setup. It is natural that the emitted charged particles were measured mainly in vacuum systems where the energy losses of the particle seem negligible.

2.3.1 Beddingfield et al.

Beddingfield et al. [Beddingfield 1991] have observed intense bursts of charged particles from thin Ti foils (Ti662 sample containing 6% V, 6% Al and 2% Sn) loaded by deuterium. The dimension of the foil was 1 cm × 2 cm × 100 μm.

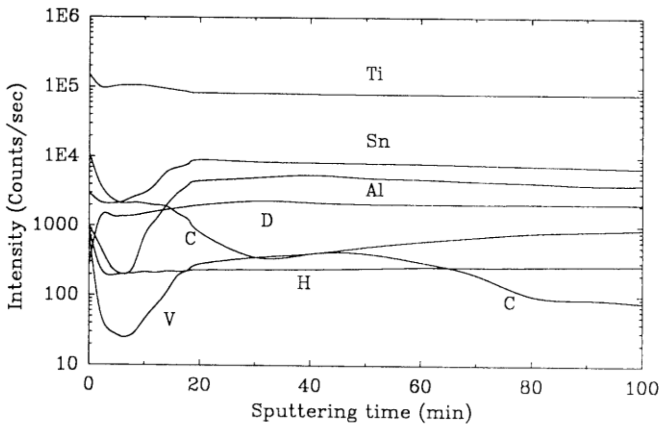

Fig. 2.2 SIMS elemental depth profile of one of the Ti-D samples [Beddingfield 1991]. The maximum sputtering time of 100 min. corresponds to a depth of about 2 μm.

It is very interesting to notice that they observed changes of density of the minor elements as shown in Fig. 2.2 [Beddingfield 1991 (Fig. 3)]. The decreases of Al, V and Sn in the surface region of a width of about 0.4 μm observed by Beddingfield et al. remind us the similar data obtained by Okamoto et al. [Okamoto 1993]. Okamoto et al. observed a decrease of Al and an increase of Si in the surface region of width about 0.5 μm which were explained by the nuclear transmutation catalyzed by trapped neutrons according to our TNCF model [Kozima 2003]:

$$n + {}^{27}_{13}\mathrm{Al} \rightarrow {}^{28}_{13}\mathrm{Al}^* \rightarrow {}^{28}_{14}\mathrm{Si} + e^- + \underline{\nu}_e \qquad (2.1)$$

where $\underline{\nu}_e$ is the antiparticle of the electron neutrino.

Similarly, the observation by Beddingfield et al. will be explained by the reactions (2.2) – (2.4):

$$n + {}^{27}_{13}\mathrm{Al} \rightarrow {}^{28}_{13}\mathrm{Al}^* \rightarrow {}^{28}_{14}\mathrm{Si} + e^- + \underline{\nu}_{e,} \qquad (2.2)$$

$$n + {}^{51}_{23}\mathrm{V} \rightarrow {}^{52}_{23}\mathrm{V}^* \rightarrow {}^{52}_{24}\mathrm{Cr} + e^- + \underline{\nu}_{e,} \qquad (2.3)$$

$$n + {}^{120}_{50}\mathrm{Sn} \rightarrow {}^{121}_{50}\mathrm{Sn}^* \rightarrow {}^{121}_{51}\mathrm{Sb} + e^- + \underline{\nu}_{e}, \qquad (2.4)$$

while they did not check increases of the elements Si, Cr and Sb corresponding to the observed decreases of Al, V and Sn, respectively.

If the nuclear transmutations expressed by Equations (2.1), (2.3) and (2.4) occurred according to the assumed formulae in free space, there might be a lot of radiation giving hazardous effects on people in the laboratory. However, the reactions in CF materials seem not to emit radiations outside due to absorption by atoms in them (beta decay) or due to a specific mechanism assumed in Equations (3.1) and (3.2) below (gamma decay).

It is desirable to check the sample used in the experiment by Beddingfield et al. repeatedly if it gives a temporal change or not. Such an investigation in any experiment in this field will give supplementary data to explore the physics of the CFP.

2.3.2 Yamaguchi et al.

The first reliable measurement of charged particles was performed by Yamaguchi et al. [Yamaguchi 1993] in a vacuum system with a heterostructure of deuterated Pd (MnO_x/Pd:D/Au). They detected α-particles and protons in addition to excess heat and helium-4. The α-particles with energies of 4.5 – 6 MeV and protons with an energy of 3 MeV were emitted from the oxide surface of their heterostructure sample.

2.3.3 Taniguchi et al.

Taniguchi et al. observed bursts of charged particles emitted from Pd foil cathodes of a D_2O (LiOD) electrolysis with electrolyte LiOD and Pt anode [Taniguchi 1993]. The energy of the burst particles corresponds to 0 – 0.3 MeV if it is proton and to 0 – 1.5 MeV if it is electron. A NE102a plastic scintillation counter was used to detect the charged particles.

Taniguchi also measured the strange structures in the charged particle spectrum in 4 – 10 MeV during D_2O electrolysis [Taniguchi 1994]. The peak patterns of the strange structure corresponded neither to that of any back-ground sources nor to that of the D-D reactions.

2.3.4 Karabut et al.

Karabut et al. [Karabut 1995] observed charged particles from a glow discharge system with cathodes of Pd, Zr, Nb, Mo and others at discharge voltages of 200 – 600 eV. They used CR-39 and SSB (silicon surface barrier) detectors. Types and energies of charged particles were determined by the energy shift between the two spectra obtained by with 2 mm sapphire plate and 0.1 mm aluminum foil. They concluded that the charged particles observed were He, Li, B, C nuclei with energies of 5 – 6 MeV.

2.3.5 Keeney et al.

Keeney et al. observed charged particles from 25-micron thick TiD_x foil samples under non-equilibrium conditions using a photo-multiplier tube, plastic and glass scintillators [Keeney 2006]. The charged particles are identified as protons with 2.6

MeV in one experiment and coincident charged particles consistent with protons and tritons. Their modest expression “It is possible that other nuclear reactions besides *d-d* fusion are involved” is scientific and appropriate in view of their limited results.

It is interesting to notice that one of the necessary conditions they demand for the observation of the charged particle emission is the loading of deuterium in the presence of LiD. This effect of Li on the CFP is also noticed in the experiment by Aizawa et al. introduced in Sec. 2.4.2 below. Discussion of the effect of lithium on the CFP will be given there.

2.3.6 Storms and Scanlan

Storms and Scanlan observed emission of charged particles having energy with peaks between 0.5 and 3 MeV in low-voltage gas discharge in deuterium with cathodes Al, Cu, Pd, Pd + Pt, Ti, etc. [Storms 2011]. They used a silicon surface barrier (SSB) detector and considered the particles to be deuterons.

2.3.7 Jiang et al.

Jiang et al. performed experiments on deuterium loaded Ti foil and powder at low temperature [Jiang 2011]. The silicon dioxide-passivated ion-implanted detectors with active area of 600 mm^2 were used. The depleted layer of the detectors is 100 μm. The observed charged particle from TiD_x foil sample is identified as proton having energy of about 2.8 MeV.

It is also too hasty in this case to conclude the *d-d* fusion reactions for the observed proton only from its energy of 2.8 MeV without detection of triton of 1.01 MeV and ${}^{3}_{2}He$ of 0.82 MeV or neutron of 2.45 MeV.

The data of the charged particles obtained by using detectors other than CR-39 introduced above is tabulated in Table 2.2 and depicted in Fig. 2.3.

Table 2.2 Experimental data of charged particles emitted from CF materials. Charged particles emitted from CF materials

Authors and References	Species	Energies of observed particle
[Beddingfield 1991]	? Burst	?
[Yamaguchi 1993]	α, *p*	4.5 – 6 MeV, 3 MeV
[Iida 1993]	α, ?	8 MeV, 5 MeV
[Taniguchi 1993]	? (*p*)	0 – 0.3 MeV
[Karabut 1995]	He	5 – 6 MeV
[Storms 2011]	?	0.5 – 3 MeV

[Jiang 2011]	*p*	2.8 MeV
[Keeney 2006]	*p*	2.6 MeV

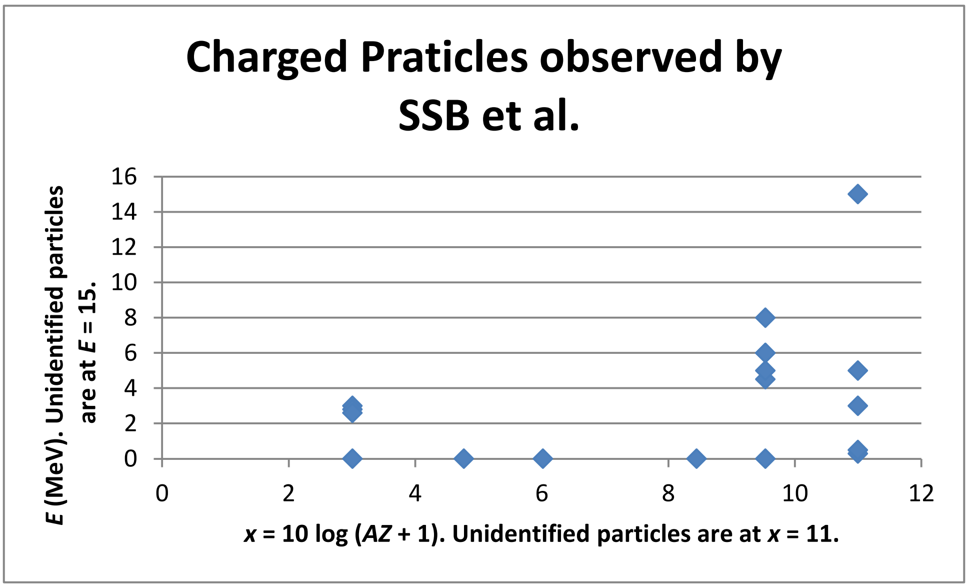

Fig. 2.3 Experimental data of charged particle observation. The abscissa is x = 10 log (AZ + 1) and the ordinate is the energy E in MeV. Proton, deuteron, triton, ^{3}He and ^{4}He correspond to 10 log (AZ + 1) = 3.01, 4.77, 6.02, 8.45 and 9.54, respectively. Data of unspecified particles are placed at x = 11 and undetermined energies are at E = 15 MeV. Marks on the abscissa are for identification of particles.

2.3.8 Data sets obtained by using artificial excitations

There are several experiments with artificial excitation with energetic particles having energies of more than 100 keV including the data by Iida et al. [Iida 1993] and Kasagi et al. [Kasagi 1993].

Iida et al. [Iida 1993] used 240 keV deuterons to irradiate Ti and Pd foils with thicknesses of 5 – 25 μm and 5 – 25 μm, respectively, and observed α-particles with energies of 5 and 8 MeV from Ti foils with Al_2O_3 layer on the surface after the deuterium implantation. They used Si-SSD detector placed behind the foil sample. Similarly, Kasagi et al. [Kasagi 1993] observed energetic protons with energies up to ~ 17.5 MeV when 150 keV deuterons were bombarded at highly deuterated Ti rods.

As noticed above in Introduction, however, we will confine our investigation in this paper to the cold fusion phenomenon (CFP) without such artificial excitation while these experiments with energetic particles have close relation to the CFP and surely contribute in elucidation of physics of the CFP.

2.4 Experimental Data obtained by using CR-39

Recently, the solid state detector CR-39 used by Chinese researchers in the early stage of CF research as introduced in Sec. 2.2 has been used fairly frequently in the experiments in the CFP to determine emission of charged particles.

One of the wonderful uses of CR-39 is the determination of high energy neutrons by the observation of charged particles caused by the neutron [Mosier-Boss 2008, 2009, Kozima 2010]. The triple tracks observed by Mosier-Boss et al. are interpreted as the detection of the three alphas generated by the breakup reaction of carbon-12 $^{12}C(n, n')3\alpha$ with the threshold energy of 9.6 MeV for the neutron to cause this reaction.

Other data to determine the species and their energies of charged particles emitted from CF materials have been given with an ambiguity as shown below and have to be contemplated further.

2.4.1 Experimental data obtained by Roussetski and his collaborators

Roussetski and his collaborators have used CR-39 detectors in their works to investigate nuclear reactions in CF materials. We cite hear only a few papers presented by them. The first paper by Roussetski in 1998 reported detection of charged particles by CR-39. He measured also neutrons by plastic scintillation counter with Cd and by $^3_2$He counter [Roussetski 1998]. He has given a paper at ICCF11 reviewing works done by his group [Roussetski 2006a]. To confirm validity of their measurements, they checked their method carefully using calibration tracks (or standards) of protons (up to 2 MeV) and of alphas (up to 20 MeV) [Roussetski 2006b].

Though the elaborate works by Roussetski and his collaborators have shown new features of the charged particle emission from CF materials of several types sometimes with artificial excitation, their data need more careful check in relation to other data in the CFP and in nuclear physics.

First of all, it is necessary to detect triton (1.01 MeV), proton (3.02 MeV) and $^3_2$He (0.82 MeV) simultaneously to conclude the occurrence of the *d-d* reactions:

$$d\ (\varepsilon) + d = t\ (1.01\ \text{MeV}) + p\ (3.02\ \text{MeV}), \qquad (2.\ 5)$$

$$= {}^3_2\text{He}\ (0.82\ \text{MeV}) + n\ (2.45\ \text{MeV}), \qquad (2.\ 6)$$

$$= {}^4_2\text{He}\ (76.0\ \text{keV}) + \gamma\ (23.8\ \text{MeV}). \qquad (2.\ 7)$$

The ratios of these reactions in free space are known to be $1 : 1 : 10^{-7}$.

Second, we want to have a consistent explanation of their data claiming observation of protons and alphas; (1) protons (1.4 – 1.7 and 5.6 – 7.8 MeV) and alphas (9.2 – 14.0 MeV) [Roussetski 2006a] and (2) protons (1.7 – 1.9 MeV) and alphas (10 – 13 and 15 – 17.5 MeV) [Roussetski 2006b].

As we will show in the next section, there are possibilities to expect various particles emitted and accelerated in CF materials according to our model which has been successful to give a consistent explanation for various events in the CFP. So, we should open our eyes in front of a vast field of unknown events to see a consistent view in accordance with principles and knowledge in physics not falling into the black hole where blinds were (cf. [Appendix]).

2.4.2 Heavy and light water electrolysis with Ni film cathode by Aizawa et al.

The CR-39 detector in the CF research is also used by Aizawa et al. in Iwate University [Aizawa 2012]. They have concluded the detection of charged particles in the experiment where electrolysis of D_2O and H_2O solutions is carried out under several DC current patterns using a Ni film cathode. A CR-39 track detector is set in close contact with the cathode to detect energetic charged particles. An impressive increasing in number of etch pits on the detector is occasionally observed without specification of species and energies of the charged particles responsible to the observed etch pits. Anomalous increase in the number of etch pits has been observed in 1 out of 7 and 2 out of 5 runs for D_2O and H_2O solutions, respectively. The result suggests that the nuclear reactions have been occurring on the Ni film cathodes during the light water electrolysis as well as the heavy water one. The common factors to increase the number of the anomalous etch pits in the CR-39 chip might be Ni film cathode, the long electrolysis time and Li in the electrolyte solution. All the results indicate that the reaction does not always takes place in every electrolysis experiment but occasionally does under the same experimental condition.

The important role of lithium isotopes for the emission of charged particles observed in this work reminds us several experimental facts related to the role of lithium observed hitherto. The nucleus ${}^{6}{}_{2}Li$ absorbs a thermal neutron with a fairly large cross section of 940.4 b to be ${}^{7}{}_{2}Li^{*}$ which decays into ${}^{4}{}_{2}He$ and ${}^{3}{}_{1}H$ (or t) as shown in Eq. (3.3) given in Sec. 3.1 below. This reaction has been used to explain several experimental data sets. Two of them are the detection of ${}^{4}{}_{2}He$ by Morrey et al. [Morrey 1998, Kozima 2006 (Sec. 2.8)] and depletion of ${}^{6}{}_{3}Li$ by Passell [Passell 2003]. Recently, Keeney et al. have shown important role of Li to give a positive result of charged particle emission from TiD_x foil as introduced in Sec. 2.3.5 [Keeney 2006].

2.5 Difficulty in simultaneous determination of particle species and their energies using CR-39

As we have shown in the review paper presented at JCF13 [Kozima 2013a], the interaction of an incident charged particle with atoms in a target material depends fundamentally on the velocity v_1 (or the ratio of the energy E_1 and the mass M_1) and the charge Z_1 of the incident particle and the atomic numbers Z_2's of the atoms in the target material even if we do not take into our consideration of the atomic structure of the target which is very important as shown by the recent work by Yamauchi et al. [Yamauchi 2005].

Therefore, determination of characteristics of the incident charged particle by the radiation damage or the nuclear track in the target material generated by the incident particle requires at least three independent physical quantities depending on the parameters v_1 (or the ratio of E_1 and M_1), Z_1 and Z_2's. If we use a calibration (or standard) nuclear tracks obtained by reference experiments using known particles with a definite energy, the deduced conclusion should be taken as a qualitative one especially when we do not know what kinds of particles are emitted.

To determine quantitative parameters of the incident charged particles observed by experiments [Kozima 2013a], we need elaborate procedure as illustrated experimentally by Kodaira et al. [Kodaira 2007] and theoretically in the next section in terms of the TNCF model.

3. TNCF Model and Its Conclusion on the Charged Particle Emission

The cold fusion phenomenon (CFP), a part of which was discovered in 1989 by Fleischmann et al. at first [Fleischmann 1989] and then by Jones et al. [Jones 1989], includes various events from excess energy production, neutron emission, and production of new elements by nuclear transmutation [Kozima 1998, 2004, 2006]. The events also include production of ^{4}He, emissions of charged particles, gamma and X-rays with a little probability compared to the events noted above.

The main events of the CFP except the emission of charged particles have been explained by us using the phenomenological TNCF model including a single adjustable parameter n_n (the density of trapped thermal neutrons); the experimental data sets until about 2005 have been explained in our books [Kozima 1998, Kozima 2006] and further explanations of neutron emission [Kozima 2010], nuclear transmutation [Kozima 2009], localization of nuclear reactions in the CFP [Kozima 2011a] have been given using the TNCF model. Furthermore, the complexity in the CFP has been pointed out [Kozima 2012] and qualitatively explained in conjunction with the basic assumptions presumed in the TNCF model [Kozima 2013b].

One of the most interesting results explained by the TNCF model is the ratios of numbers N_x's of events X's observed simultaneously. Determining the parameter n_n by the data of the number N_x of an event X, we can calculate the number N_y of another event Y using the model and compare the theoretical ratio $(N_x/N_y)_{th}$ thus calculated with the experimental value $(N_x/N_y)_{ex}$. As shown before [Kozima 1998 (Section 11.1), Kozima 2006 (Section 2.3)], we have obtained fairly good coincidence of these values in a factor about 3 as expressed by the following relation:

$$(N_x/N_y)_{th} = \alpha(N_x/N_y)_{ex}$$

with $\alpha \sim 3$.

Another quantitative explanation of the experimental data sets where observed nuclear transmutations from one nuclide to another has been given by the TNCF model [Kozima 1998 (Section 9.1), Kozima 2006 (Section 3.3.5), Kozima 2011b]. One of such quantitative explanations is the variation of Ti isotopes observed in Portland State University [Kozima 2006 (Appendix C7)]. The changes of the amount of ${}^{A}_{22}$Ti's (A = 46 – 50) during the experiment are consistently explained adjusting the single parameter n_n.

It is therefore natural to expect an explanation of the emission of charged particles introduced in Section 2 consistently to other data in the CFP by our TNCF model. We give a brief introduction of the model in this section and then an explanation of the data on the charged particle emission by our model.

3.1 The TNCF model

The TNCF (trapped neutron catalysed fusion) model proposed as early as 1994 at ICCF4 (Lahaina, Maui, Hawaii, USA, Dec. 6 – 9 (1993)) has been successfully applied to give a unified understanding of the cold fusion phenomenon (CFP) [Kozima 1994]. The model uses an adjustable parameter n_n with several premises based on the experimental facts and has given semi-quantitative relations between several observables measured simultaneously. The theoretical relations among observed values are in agreement with relations deduced from experimental data sets. We will give a brief review on the expected emission of charged particles from our model to compare with experimental data. Another important premise of our model is the emission of phonons in CF materials instead of photons in nuclear reactions in free space. This premise is based on the fact that there are no photons even if there are many nuclear products observed in the CFP and is going to be investigated from the quantum mechanical approach developed recently [Kozima 2008].

3.1.1 Trigger reactions.

A trapped thermal neutron assumed in our TNCF model can fuse effectively in the free space by following reactions (3.1) and (3.2) with a proton and a deuteron with fusion cross sections 3.32×10^{-1} b and 5.5×10^{-4} b, respectively:

$$n + p = d \text{ (1.33 keV)} + \gamma \text{ (2.22 MeV)}, \tag{3.1}$$

$$n + d = t \text{ (6.98 keV)} + \gamma \text{ (6.25 MeV)}. \tag{3.2}$$

The gammas in these reactions in free space should be read as phonons ϕ s in CF materials. The same translation should be done in reactions formulae which appear in this section hereafter. The first reaction (3.1) will be effective in protium systems and the second (4.2) in deuterium systems.

In the electrolytic systems with electrolytes including lithium, the trapped thermal neutron can fuse with the ${}^{6}_{3}$Li and ${}^{7}_{3}$Li nuclei in the surface/boundary regions electroplated on the cathode by the reactions (3.3) and (3.4) below with large cross sections $\approx 1\times10^{3}$ b and 4.54×10^{-2} b, respectively:

$$n + {}^{6}_{3}\mathrm{Li} = {}^{4}_{2}\mathrm{He} \text{ (2.1 MeV)} + t \text{ (2.7 MeV)}. \tag{3.3}$$

$$n + {}^{7}_{3}\mathrm{Li} = {}^{8}_{3}\mathrm{Li}^{*} = {}^{8}_{4}\mathrm{Be}^{*} + e^{-} + \underline{\nu}_{e} + 13\ MeV, \tag{3.4}$$

$${}^{8}_{4}\mathrm{Be}^{*} = {}^{4}_{2}\mathrm{He} \text{ (1.6 MeV)} + {}^{4}_{2}\mathrm{He} \text{ (1.6 MeV)} \tag{3.5}$$

When there are other nuclides like ${}^{10}_{5}$B and ${}^{3}_{2}$He, there will be following reactions (in free space);

$$n + {}^{10}_{5}\mathrm{B} = {}^{7}_{3}\mathrm{Li} \text{ (1.01 MeV)} + {}^{4}_{2}\mathrm{He} \text{ (1.78)}. \tag{3.6}$$

$$= {}^{7}_{3}\mathrm{Li}^{*} \text{ (0.85 MeV)} + {}^{4}_{2}\mathrm{He} \text{ (1.47 MeV)}. \tag{3.7}$$

$${}^{7}_{3}\mathrm{Li}^{*} = {}^{7}_{3}\mathrm{Li} + \gamma \text{ (0.48 MeV)}. \tag{3.8}$$

$$n + {}^{3}_{2}\mathrm{He} = t \text{ (0.17 MeV)} + n \text{ (0.50 MeV)}. \tag{3.9}$$

In other electrolytic systems, nuclear reactions n – ${}^{23}_{11}$Na [Bush, R.T. 1992], n – ${}^{39}_{19}$K [Bush, R.T. 1992, Notoya 1996], n – ${}^{88}_{37}$Rb [Bush, R.T. 1993] participate in the CFP as trigger reactions.

The thickness of the surface/boundary regions will be assumed as 1 μm throughout analyses [Kozima 2006 (Premise 8)] although it has been determined as 1 – 10 μm in experiments (allowing one order of magnitude uncertainty in the determined value of the parameter n_{n}). Also, the abundance of the isotope ${}^{6}_{3}$Li will be assumed as the natural one, i.e. 7.4 % except otherwise described in our analyses.

As was already explained, the photons generated in reactions (3.1), (3.2) and (3.8) in free space are supposed to become phonons in CF materials due to strong interactions of neutrons in them and the liberated energy is thermalized in solids throughout our phenomenological treatment. This is one of most serious premises in the TNCF model and waits quantum mechanical explanation in the physics of the CFP.

3.1.2 Breeding reactions.

The energetic particles generated in the trigger reactions induced by trapped neutrons in surface/boundary regions in CF materials can induce other nuclear reactions with nuclides, especially with abundant deuterons/protons in a deuterium/protium system.

When there is an energetic neutron emitted by the above trigger reactions, we expect various reactions including following elastic collisions, knock out collisions, and splitting reactions;

$$n\,(\varepsilon) + p = n'\,(\varepsilon') + p\,(\varepsilon''), \qquad (3.10)$$

$$n\,(\varepsilon) + d = n'\,(\varepsilon') + d'\,(\varepsilon''), \qquad (3.11)$$

$$n\,(\varepsilon) + {}^{A}_{Z}\mathrm{X} = {}^{A}_{Z}\mathrm{X}\,(\varepsilon') + n\,(\varepsilon''), \qquad (3.12)$$

$$n\,(\varepsilon) + d = n' + p + n'', \qquad (3.13)$$

$$n\,(\varepsilon) + {}^{A}_{Z}\mathrm{X} = {}^{A-1}_{Z}\mathrm{X} + n + n', \qquad (3.14)$$

$$n\,(\varepsilon) + {}^{A}_{Z}\mathrm{X} = {}^{A-A'+1}_{Z-Z'}\mathrm{X}' + {}^{A'}_{Z'}\mathrm{X}''. \qquad (3.15)$$

In these equations, we have used a symbol $n(\varepsilon)$ for an energetic neutron with an energy ε to discriminate it from the thermal neutron expressed as n (or $n(\varepsilon)$ with $\varepsilon = 0$ later) in Equations (3.1) – (3.9).

The triton with an energy ε = 2.7 MeV (or 6.98 keV) generated in the reaction (3.3) (or (3.2)) described as $t(\varepsilon)$ can pass through the crystal along the channelling axes on which is an array of occluded deuterons or can proceed a finite distance with a path length ℓ_t ($\simeq$ 1－10 μm) determined by the interaction with charged particles in the crystal. In the process of penetration through a crystal, the triton can react with a proton or a deuteron by the following reactions on the path with a length 1 μm [Kozima 2006 (Premise 9)]:

$$t\,(\varepsilon) + p = {}^{4}_{2}\mathrm{He}\ (0.09\ \mathrm{MeV}) + \gamma\ (19.9\ \mathrm{MeV}). \qquad (3.16)$$

$$t\,(\varepsilon) + d = {}^{4}_{2}\mathrm{He}\ (3.5\ \mathrm{MeV}) + n\ (14.1\ \mathrm{MeV}). \qquad (3.17)$$

The cross section of the reaction (3.17) is $\sigma_{\text{t-d}} \cong 1.4 \times 10^{-1}$ b for ε = 2.7 MeV and 3.04×10^{-6} b for 6.98 keV.

The elastic collisions (3.10) – (3.12) of an energetic neutron having an energy ε with a nuclide in the sample give energy ε's to the target nuclei. When ε is 14.1 MeV, the target nuclei p (${}^{1}_{1}$H), d (${}^{2}_{1}$H) and ${}^{4}_{2}$He will have maximum energy of 14.1, 12.5 and 8.0 MeV, respectively, by a head-on collision. Thus, there is a possibility to measure a proton with energy less than 14 MeV accelerated by slanted collision or decelerated from the maximum by electromagnetic interactions with charged particles in the CF material.

One of the flaws in CF researches has been not trying to detect higher energy neutrons up to 15 MeV expected to be generated in this reaction (3.17) except a few cases [Kozima 2010]. Recently, Mosier-Boss et al. observed a $^{12}C(n, n')3\alpha$ reaction caused by a high energy neutron with an energy more than 9.6 MeV as introduced in the beginning of Sec. 2.4 [Mosier-Boss 2008, 2009].

In these reactions (3.11) – (3.15), the original high-energy neutron loses its energy to be thermalized or generates another low energy neutron to be trapped in the sample (breeding processes Eqs. (3.13) and (3.14)) or generate transmuted nuclei (Equations (3.14) and (3.15)).

The deuteron having an energy up to 12.5 MeV accelerated elastically by the neutron with 14.1 MeV (Eq. (3.11)) can fuse with another deuteron by two main modes by the reactions with a fairly large cross section of the order of 0.1 b each and by a minor mode with a negligible branching ratio about 10^{-7} :

$$d\ (\varepsilon) + d = t\ (1.01\ \text{MeV}) + p\ (3.02\ \text{MeV}), \qquad (3.18)$$

$$= {}^{3}_{2}\text{He}\ (0.82\ \text{MeV}) + n\ (2.45\ \text{MeV}), \qquad (3.19)$$

$$= {}^{4}_{2}\text{He}\ (76.0\ \text{keV}) + \gamma\ (23.8\ \text{MeV}). \qquad (3.20)$$

The branching ratios of these three reactions in the free space with ε up to a few MeV are, as is well known, $1 : 1 : 10^{-7}$.

In the case of solids with protium but deuterium, the following breeding reaction between the energetic deuteron and a proton is possible (in the free space):

$$d\ (\varepsilon) + p = {}^{3}_{2}\text{He}\ (5.35\ \text{keV}) + \gamma\ (5.49\ \text{MeV}). \qquad (3.21)$$

The following reaction is also probable with the energetic deuteron:

$$d\ (\varepsilon) + {}^{3}_{2}\text{He} = {}^{4}_{2}\text{He}\ (3.67\ \text{keV}) + p\ (14.68\ \text{MeV}). \qquad (3.22)$$

Depending on the situation in CF materials, the trapped thermal neutron can induce such trigger reactions as the reactions (3.1) – (3.9) and the energetic particles generated in them can sustain the breeding chain reactions (3.10) – (3.22) producing a lot of excess heat and/or the nuclear products.

The energetic gamma emitted by the reaction (3.15) (and (3.18)) in free space can induce the dissociation of a deuteron as follows;

$$\gamma\ (\varepsilon) + d = n\ (\varepsilon') + p\ (\varepsilon'') \qquad (\varepsilon > 2.2\ \text{MeV}) \qquad (3.23)$$

We have to read the gammas in Equations (3.20) – (3.23) in free space as phonons in CF materials as explained already above on the end of Sec. 3.1.1.

The particles generated by nuclear reactions catalysed by the trapped neutrons assumed in the TNCF model are summarized in Tables 3.1 and 3.2 for the trigger and breeding reactions, respectively. In the tables, the reactions are divided into protium and deuterium systems and designated by equation numbers in this paper.

Table 3.1 Reactions Generating Charged Particles in the TNCF Model (Trigger Reactions). The reaction (4.1) in the 3rd line and a-column in this table will be referred as 3-a (T4.1) in the following.

	a ***Protium system***	b ***Deuterium system***	c ***Additional Agent***
1 ***n***	(4.9)*	(4.9)*	$^{3}_{2}$He*
2 ***p***			
3 ***d***	**(4.1)**		
4 ***t***	(4.3)* (4.9)**	**(4.2)** (4.3)* (4.9)**	$^{6}_{3}$Li* $^{3}_{2}$He**
5 **$^{3}_{2}$He**			
6 **$^{4}_{2}$He**	(4.3)* (4.5)** (4.6)***	(4.3)* (4.5)** (4.6)***	$^{6}_{3}$Li* $^{7}_{3}$Li** $^{10}_{5}$Be***

Table 3.2 Reactions Generating Charged Particles in the TNCF Model (Breeding Reactions). The reaction (4.18) in the 2nd line and b-column in this table will be referred as 2-b (T4.2) in the following.

	a ***Protium system***	b ***Deuterium system***	c ***Additional Agent***
1 ***n***		**(4.12)** (4.13)* **(4.17)** **(4.19)** (4.22)** **(4.23)**	$^{A}_{Z}$X* $^{3}_{2}$He**
2 ***p***	**(4.10)** (4.22)*	**(4.18)**	$^{3}_{2}$He*
3 ***d***		**(4.11)**	
4 ***t***		**(4.18)**	
5 **$^{3}_{2}$He**	**(4.21)**	**(4.19)**	
6 **$^{4}_{2}$He**	**(4.16)**	**(4.17)** **(4.20)** (4.22)*	$^{3}_{2}$He*

To generate some particles in the CF materials composed of a host material and a hydrogen isotope, it is necessary to have an additional nucleus (or agent) used often in the experiments as tabulated in the fourth columns of Tables 3.1 and 3.2. The most famous agent is $^{A}_{3}$Li (A = 6 and 7) included in electrolyte for electrolytic systems. The equations including these agents are asterisked in these tables for readers' convenience.

As seen from the Tables, we can expect emission of various particles from CF materials where occur cold fusion reactions and we can observe these neutrons and energetic charged particles if it is possible to catch them before they dissipate their energy.

The particles expected by the TNCF model to be emitted in the CFP tabulated in Tables 3.1 and 3.2 are depicted in Fig. 3.1 using an abscissa 10 log (AZ + 1) to discriminate particles with different proton and mass numbers, Z and A, respectively. Neutron, proton, deuteron, triton, ${}^3_2$He and ${}^4_2$He correspond to 10 log (AZ + 1) = 0, 3.01, 4.77, 6.02, 8.45 and 9.54, respectively.

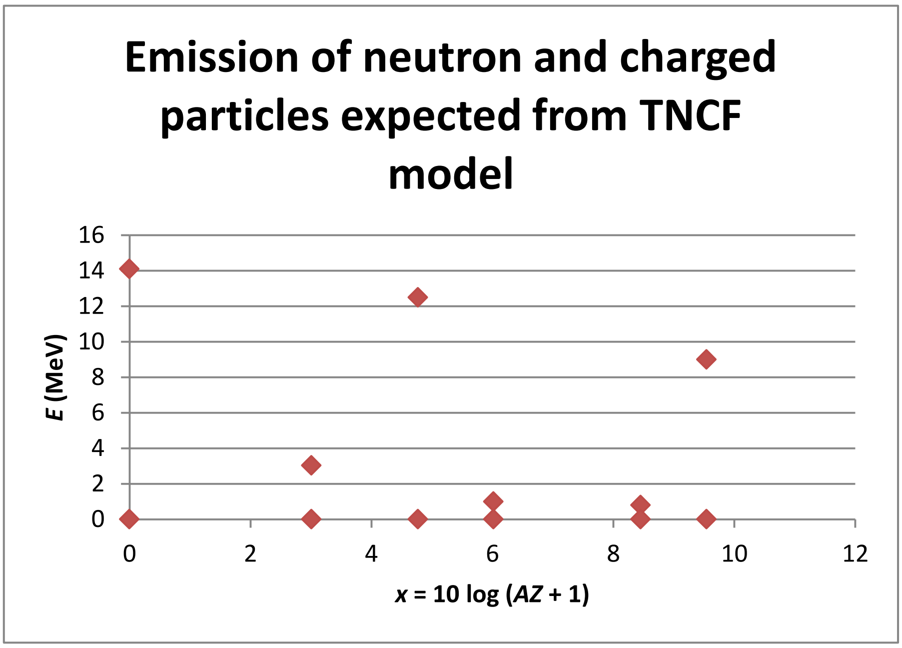

Fig. 3.1 Emission of neutron and charged particles expected from TNCF model. The abscissa is 10 log (AZ + 1) and the ordinate the maximum energy E in MeV expected for particles. Neutron, proton, deuteron, triton, ^{3}He and ^{4}He correspond to 10 log (AZ + 1) = 0, 3.01, 4.77, 6.02, 8.45 and 9.54, respectively. Marks on the abscissa are for identification of particles.

3.2 Explanation of experimental data of charged particle emission in the CFP

Considering the success of unified explanation of various experimental data sets from excess heat generation to nuclear transmutations through neutron emission by the TNCF model [Kozima 1998, 2006], we can expect an explanation of charged particle emissions from CF materials consistent to experimental data of other observables. We summarize first the probable emission of charged particles given in Sec. 3.1 based on the TNCF model and then give comparison of the theoretical expectation with the experimental data.

3.2.1 Probable emission of charged particles from CF materials

From above explanation of the TNCF model, we can deduce possible emission of charged particles in the CF materials as summarized in Table 3.1 for trigger reactions and Table 3.2 for breeding reactions. In principle, the charged particles can be emitted or accelerated by the reactions (3.1) – (3.21) if we do not care their probability. In reality, we have to consider the probability of particle emission in relation to the situation of the CF material where occur nuclear reactions. We survey here the possible emission of charged particles in deuterium and protium systems separately.

(1) Deuterium system

The most probable trigger reaction in the deuterium system will be the reaction between the trapped neutron and the occluded deuteron (Eq. (3.2)) with a cross section 5.5×10^{-4} b (assuming the trapped neutron has a thermal energy) resulting in a triton (6.98 keV) and a phonon (in the CF material) instead of a photon in free space. The triton thus generated loses its energy by the electromagnetic interaction with other charged particles in the CF material or makes such breeding nuclear reactions as (3.17) (and possibly (3.16)) generating secondary nuclides ${}^{4}_{2}He$ and neutron.

(2) Protium system

The most probable trigger reaction in the protium system will be the reaction between the trapped neutron and the occluded proton (Eq. (3.1)) with a fairly large cross section 3.32×10^{-1} b (assuming the trapped neutron has a thermal energy) resulting in a deuteron (1.33 keV) and a phonon (in the CF material). The deuteron thus generated loses its energy by the electromagnetic interaction with other charged particles in the CF material or makes such breeding nuclear reactions as (3.18) and (3.19) (and possibly (3.20)) generating secondary nuclides p (${}^{1}_{1}H$), t (${}^{3}_{1}H$), ${}^{3}_{2}He$ and n (and ${}^{4}_{2}He$).

3.2.2 Explanation of experimental data by the TNCF model

The theoretical expectation of charged particle emissions in the CFP depicted in Fig. 3.1 is compared with experimental data explained in Section 2 and depicted in Figs. 2.2 and 2.3. The data plotted in Figs. 2.2, 2.3 and 3.1 are accumulated in Fig. 3.2.

Figure 3.2 shows that the energies of the observed charged particles (blue points) are below the expected maximum values (red points) from the TNCF model proposed by us. It is natural to have experimental points (blue) below the theoretically expected points (red) because the charged particles loose their energies in the course of their arrival at the detectors used in experiments.

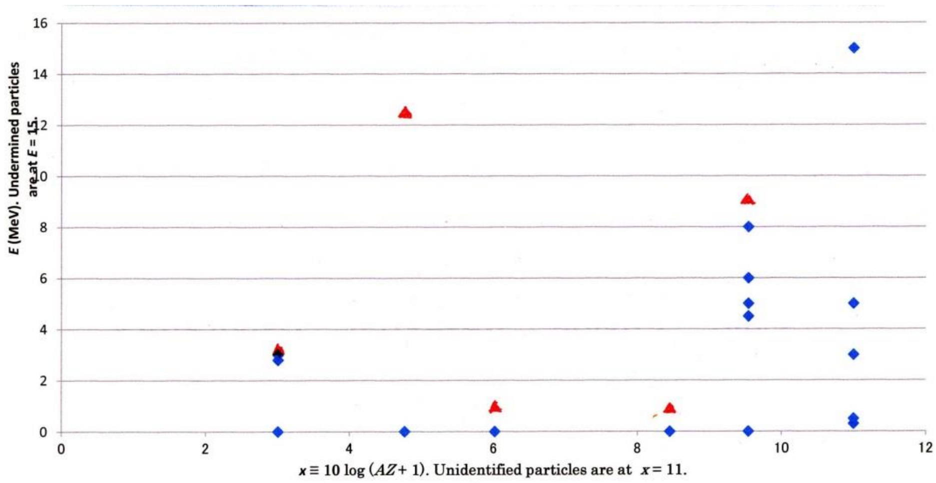

Fig. 3.2 Comparison of experimental data (blue) explained in Section 2 and theoretical expectation (red) explained in this section of charged particles emitted in the cold fusion phenomenon (CFP). The abscissa is x = 10 log (AZ + 1) and the ordinate is the energy E in MeV. Proton, deuteron, triton, ${}^{3}_{2}$He and ${}^{4}_{2}$He correspond to 10 log (AZ + 1) = 3.01, 4.77, 6.02, 8.45 and 9.54, respectively. Data of unspecified particles are placed at x = 11 and undetermined energies are at E = 15 MeV. Marks on the abscissa are for identification of particles.

4. Discussion and Conclusion

Number of experimental data sets observing charged particles in the CFP is few compared to other events due to the difficulty to catch them as they have born. As we have shown in this paper, we could give a phenomenological explanation for the reliable data on the emission of charged particles by our TNCF model consistently with other events in the CFP such as excess energy generation, neutron emission and nuclear transmutation.

The claims made by some researchers that the *d-d* fusion reactions in the CF-materials have been confirmed using only data of protons with about 3 MeV are not persuasive due to existence of alternative explanations for the data and also to the lack of simultaneous observation of triton and ${}^{3}_{2}$He expected from Equations (3.18) and (3.19) as we had discussed already.

Confining our consideration for experiments without artificial excitations with energies more than 1 keV, we can exclude *d-d* fusion reactions from fundamental mechanisms in the CFP by two reasons. The first reason is that the two-body reaction of independent particles occurs with a probability proportional to square of the density x of the particle and behaves as x^2 as shown in Fig. 4.1 [Kozima 2013b (Fig. 1.3)]. This dependence of the reaction probability y on the density x has no critical density for the reaction and is in contradiction with our common knowledge on the dependence of effects on their causes in the CFP. We can pick up an excellent data set out of many such examples the extensive work of McKubre et al. showing the excess energy generation with a critical density of about D/Pd ~ 0.8 [McKubre 1993].

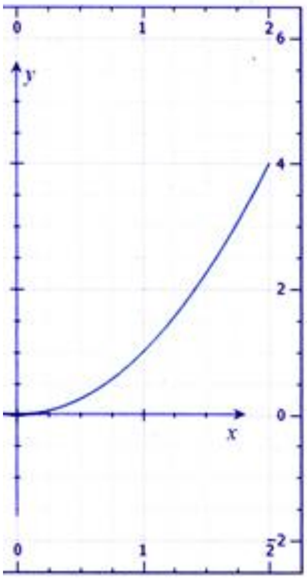

Fig. 4.1 Two-body reaction occurs without a critical density where the reaction rate y of independent particles is proportional to the square of the density x: $y = cx^2$ [Kozima 2013b]. Some of examples applicable to this relation are the combination of Na and Cl in an aqueous solution of NaCl and d-d fusion reactions in plasmas and in PdD_x lattice)

The second reason is that the detection of the protons with energies of about 3 MeV is not sufficient to conclude the occurrence of the d-d reactions (3.18) – (3.20) due to the existence of alternative candidates for them as discussed in Section 3. If we can observe a triton with 1.01 MeV, a proton with 3.02 MeV and a helium-3 with 0.82 MeV (and hopefully a neutron with 2.45 MeV) simultaneously in an experiment without artificial excitation, then it is possible to conclude that the d-d reactions (3.18) and (3.19) have occurred as fundamental reactions in the CFP. Even in this case, it is possible that these reactions occurred as a result of the breeding reactions with $\varepsilon \neq 0$ (cf. Sec. 3.1.2).

In the CF experiments, there are too many sources to produce charged particles with energies around 1 – 3 MeV as we have shown in Sections 3.2.1 and 3.2.2. Therefore, it is very difficult to determine unambiguously the reaction producing charged particles observed by an experiment.

In the case of neutron with an energy of 2.45 MeV, there are no alternative sources of neutron emission of this energy and we may be able conclude that the reaction (3.19) has occurred with little ambiguity.

It is somewhat strange to seek fanatically the *d-d* fusion reactions for explanation of the CFP in deuterium systems discarding the fact that there are a lot of examples of the CFP in protium systems as we have often claimed (e.g. [Kozima 1998 (Chap. 7), 2006 (Sec. 2.2.1)]. In particular, Hioki et al. [Hioki 2013] have shown recently excess energy generation in PdH_x and PdD_x systems in the same apparatus interchanging hydrogen and deuterium successively. This is decisive evidence showing existence of another cause (or other causes) resulting in the excess energy generation than *d-d* fusion reactions if we are looking for a common cause of the CFP in both protium (H) and deuterium (D) systems.

Such episodes as the conclusion of *d-d* fusion reactions by Roussetski et al. deduced from insufficient data and as the long–lasted negligence of PdH_x systems by some researchers in the CFP remind us the Buddhist parable of ten blinds touched an elephant cited in Appendix to this paper. At any time, it is necessary to avoid mistakes due to our narrow-mindedness and shortsightedness. Especially in scientific research, we would like to realize our standpoint clearly in the investigation of such complex phenomenon as the cold fusion one occurring in multi-component, non-equilibrium, open dynamical systems [Kozima 2013b].

The cold fusion phenomenon (CFP) including various events from excess energy generation to nuclear transmutation through particle emissions of neutron, proton, deuteron, triton and alpha is challenging us its scientific explanation that is too difficult to many scientists who gave up their trial to enjoy the effort to give consistent understanding of the complex events in the CFP.

We have tried to give a phenomenological explanation of the CFP using a model (TNCF model) with an adjustable parameter n_n which is determined by an experimental data of an observable and gives a consistent explanation of another observable when there are several observables measured simultaneously. It seems that the TNCF model is fairly successful by now to give a unified understanding of various events in the CFP.

If a model is effective to give a unified understanding of a new phenomenon including various events, the CFP in our case for example, we might be able to consider that the model will be reflecting some truth hidden behind the phenomenon observed by experiments. It is therefore valuable to check the model a little further. The most serious assumptions of the TNCF model are 1) existence of the “trapped neutrons” and 2) nuclear reactions with emission of phonons in solids but not photons in free space.

The existence of the trapped neutrons in CF materials has been explained by possible formation of neutron bands mediated by occluded protons or deuterons in our works [Kozima 2004, 2006 (Sec. 3.5.2), Kozima 2009a].

The nuclear reactions with emission of phonons but not photons, on the other hand, have been left untouched by now.

We can see the problem in the physics of the CFP from a different point of view, physics of neutrons in solids. There have been several fields of works related to this problem classified into four themes;

1. Neutron trap by stratified structures [Kozima 2004 (Sec. 1), Ebisawa 1998]
2. Neutron guide similar to the wave guide for electromagnetic waves [Kozima 1998 (Sec. 12.3), Abele 2006]
3. Neutron bands mediated by hydrogen isotopes and trapped neutrons in them
4. Nuclear reactions catalyzed by the trapped neutrons with emission of phonons but not photons

The third one has been discussed in our papers [Kozima 2006 (Sec. 3.5.2), Kozima 2009a].

The fourth one is related to the assumption made in Eqs. (3.1) and (3.2), for example, that the gammas emitted in free space by these reactions are replaced by phonons in CF materials. This assumption may have a close relation to the assumption of the drastic shortening of decay times made to explain such nuclear transmutations as from ${}^{40}_{19}K$ to ${}^{40}_{20}Ca$, from ${}^{107}_{46}Pd$ to ${}^{107}_{47}Ag$, etc. [Kozima 2006 (Sec. 2.5.1.1)]. It should be explained by the interaction of trapped neutrons in the neutron valence bands with exotic unstable nuclei and phonons but is not accomplished yet. From our point of view, this is the most important remaining problem in the solid-state nuclear physics related to the CFP.

Conclusion

There are many trials to elucidate fundamental mechanisms of nuclear reactions in the CFP in this research field since its discovery in 1989 by Fleischmann, Pons and Hawkins [Fleischmann 1989]. In these trials we have had a few cases in which the conclusions have been deduced from biased selection of experimental data ignoring characteristics of the CFP as a whole, especially its lack of quantitative reproducibility and variety of products from not only in deuterium but also in hydrogen systems. This situation reminds us a famous parable told in Buddhist scriptures of the blind people who observed an elephant by hands [Tittha Sutta, Appendix]; Some said “The elephant is just like a water jar,” some said “The elephant is just like a winnowing basket,” some said “The elephant is just like an iron rod,” some said “The elephant is just like the pole of a plow,” and so forth depending on where they touched the elephant on.

The essential points of investigation of unknown phenomenon in common life and in science are the same. We have to collect as many facts as possible to give a consistent explanation for the whole facts and then look for a fundamental principle (or principles) for the explanation that is applicable also to other phenomena. Even if the heap of bricks are not a building itself, we may be able to construct a building out of the bricks heaped up by laborious efforts of our pioneers.

Thus, the next work we have to do in this field should be excavation of physics of the cold fusion phenomenon (CFP) hiding behind the premises of the TNCF model that have been successful to give a unified and consistent qualitative and sometimes semi-quantitative explanation of the CFP.

The premises of the existence of trapped neutrons and the phonon emission in CF materials instead of photons in free space are based on the experimental facts. The former is based on the absence of the CFP without thermal neutrons [Kozima 1998 (Chapter 8), 2006 (Sec. 2.2.1.1 and Appendix D (Topic 8), 2010] and the latter is on the data of no photon emission corresponding to other nuclear products. The latter premise should be investigated consistently with the former of trapped neutrons with a density n_n and the first steps for it have been given using an idea of the super-nuclear interaction between lattice nuclei mediated by interstitial hydrogen isotopes [Kozima 2006, 2009a].

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Appendix, "Tittha Sutta: Various Sectarians (1)" (Ud6.4)

I have heard that on one occasion the Blessed One was staying near Savatthi, in Jeta's Grove, Anathapindika's monastery. Now at that time there were many brahmans, contemplatives, and wanderers of various sects living around Savatthi with differing views, differing opinions, differing beliefs, dependent for support on their differing views. Some of the brahmans and contemplatives held this view, this doctrine: "The cosmos is eternal. Only this is true; anything otherwise is worthless."

Some of the brahmans and contemplatives held this view, this doctrine: "The cosmos is not eternal"... "The cosmos is finite"... "The cosmos is infinite"... "The soul and the body are the same"... "The soul is one thing and the body another"... "After death a Tathagata exists"... "After death a Tathagata does not exist"... "After death a Tathagata both does and does not exist"... "After death a Tathagata neither does nor does not exist. Only this is true; anything otherwise is worthless."

And they lived arguing, quarreling, and disputing, wounding one another with weapons of the mouth, saying, "The Dhamma is like this, it's not like that. The Dhamma's not like that, it's like this."

Then in the early morning, a large number of monks, having put on their robes and carrying their bowls and outer robes, went into Savatthi for alms. Having gone for alms in Savatthi, after the meal, returning from their alms round, they went to the Blessed One and, on arrival, having bowed down to him, sat to one side. As they were sitting there, they said to the Blessed One: "Lord, there are many brahmans, contemplatives, and wanderers of various sects living around Savatthi with differing views, differing opinions, differing beliefs, dependent for support on their differing views... and they live arguing, quarreling, and disputing, wounding one another with weapons of the mouth, saying, 'The Dhamma is like this, it's not like that. The Dhamma's not like that, it's like this.'"

"Monks, the wanderers of other sects are blind and eyeless. They don't know what is beneficial and what is harmful. They don't know what is the Dhamma and what is non-Dhamma. Not knowing what is beneficial and what is harmful, not knowing what is Dhamma and what is non-Dhamma, they live arguing, quarreling, and disputing, wounding one another with weapons of the mouth, saying, 'The Dhamma is like this, it's not like that. The Dhamma's not like that, it's like this.'

"Once, in this same Savatthi, there was a certain king who said to a certain man, 'Gather together all the people in Savatthi who have been blind from birth.'"

"'As you say, your majesty,' the man replied and, rounding up all the people in Savatthi who had been blind from birth, he went to the king and on arrival said, 'Your majesty, the people in Savatthi who have been blind from birth have been gathered together.'

"'Very well then, show the blind people an elephant.'

"'As you say, your majesty,' the man replied and he showed the blind people an elephant. To some of the blind people he showed the head of the elephant, saying, 'This, blind people, is what an elephant is like.' To some of them he showed an ear of the elephant, saying, 'This, blind people, is what an elephant is like.' To some of them he showed a tusk... the trunk... the body... a foot... the hindquarters... the tail... the tuft at the end of the tail, saying, 'This, blind people, is what an elephant is like.'

"Then, having shown the blind people the elephant, the man went to the king and on arrival said, 'Your majesty, the blind people have seen the elephant. May your majesty do what you think it is now time to do.'

"Then the king went to the blind people and on arrival asked them, 'Blind people, have you seen the elephant?'
"'Yes, your majesty. We have seen the elephant.'
"'Now tell me, blind people, what the elephant is like.'
"The blind people who had been shown the head of the elephant replied, 'The elephant, your majesty, is just like a water jar.'
"Those who had been shown the ear of the elephant replied, 'The elephant, your majesty, is just like a winnowing basket.'
"Those who had been shown the tusk of the elephant replied, 'The elephant, your majesty, is just like an iron rod.'
"Those who had been shown the trunk of the elephant replied, 'The elephant, your majesty, is just like the pole of a plow.'
"Those who had been shown the body of the elephant replied, 'The elephant, your majesty, is just like a granary.'
"Those who had been shown the foot of the elephant replied, 'The elephant, your majesty, is just like a post.'
"Those who had been shown the hindquarters of the elephant replied, 'The elephant, your majesty, is just like a mortar.'
"Those who had been shown the tail of the elephant replied, 'The elephant, your majesty, is just like a pestle.'
"Those who had been shown the tuft at the end of the tail of the elephant replied, 'The elephant, your majesty, is just like a broom.'
"Saying, 'The elephant is like this, it's not like that. The elephant's not like that, it's like this,' they struck one another with their fists. That gratified the king.
"In the same way, monks, the wanderers of other sects are blind and eyeless. They don't know what is beneficial and what is harmful. They don't know what is the Dhamma and what is non-Dhamma. Not knowing what is beneficial and what is harmful, not knowing what is Dhamma and what is non-Dhamma, they live arguing, quarreling, and disputing, wounding one another with weapons of the mouth, saying, 'The Dhamma is like this, it's not like that. The Dhamma's not like that, it's like this.'"
Then, on realizing the significance of that, the Blessed One on that occasion exclaimed:
Some of these so-called brahmans & contemplatives are attached. They quarrel & fight — people seeing one side.

"Tittha Sutta: Various Sectarians (1)" (Ud 6.4), translated from the Pali by Thanissaro Bhikkhu. *Access to Insight*, 12 February 2012,

http://www.accesstoinsight.org/tipitaka/kn/ud/ud.6.04.than.html .
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