From the History of Cold Fusion Research, **10**, pp. 1 – 10 (September 2015)

Trapped Neutron Catalyzed Fusion Model (TNCF Model) for the Cold Fusion Phenomenon and the Neutron Behavior in Solids*

Hideo Kozima
Cold Fusion Research Laboratory
597-16 Yatsu, Aoi, Shizuoka, 421-1202, Japan

*This paper was originally published in the *CFRL News* (*Cold Fusion Research Laboratory News*) **No. 96** (2015.08.15).

The trapped neutron catalyzed fusion model (TNCF model) where assumed existence of thermal neutrons in CF materials, a phenomenological approach, to the science of the cold fusion phenomenon (CFP) is reviewed with attention to the behavior of neutrons in solids.

1. Introduction

As has been shown in books and papers published since 1994 and in the Series "From the History of CF Research" in which this paper takes a place, the phenomenological approach using the TNCF model (Trapped Neutron Catalyzed Fusion model) has shown that the trial to construct the Science of the Cold Fusion Phenomenon (CFP) arranging experimental facts in a proper position with this model is useful to explain systematically various too complicated experimental facts to understand scientifically even if the premises composing the model have not necessarily been elucidated quantum mechanically.

This situation of the science of the CFP reminds us the history of the continental drift theory when Alfred Wegener published the fourth edition of his book "*The Origin of Continents and Oceans*" in 1928 [Wegener 1966]. Defending his phenomenological approach to the explanation of the observation on the geodetic, geophysical, paleontological, biological and paleoclimatic facts, he wrote in the Foreword of the book as follows;

"*It is only by combining the information furnished by all the earth sciences that we can* *hope to determine "truth" here, that is to say, to find the picture that sets out all the known facts in the best arrangement and that therefore has the highest degree of probability. Further, we have to be prepared always for the possibility that each new discovery, no matter which science furnishes it, may modify the conclusions we draw*.

It is well known that the phenomenological assumption of the continental drift proposed by Wegener was explained scientifically by the plate techtonics developed in the late 1950s and early 1960s.

For the benefit of readers, we have posted the *Foreword* by A. Wegener to the book [Wegener 1966] at the CFRL website (next to the News No. 96):
http://www.geocities.jp/hjrfq930/News/news.html

2. Phenomenological Approach – the Trapped Neutron Catalyzed Fusion Model

The TNCF model (Trapped Neutron Catalyzed Fusion model) was proposed at ICCF4 held at Hawaii, USA on 1994 [Kozima 1994]. The model was a phenomenological approach based on experimental facts obtained in these five years after the declaration of the discovery of the cold fusion phenomenon (CFP) in 1989 by Fleischmann et al. [Fleischmann 1989]. These experimental facts obtained by the time were too complicated to understand by the sciences on principles established in 20th century and were also looked upon with deep suspicion.

One of the premises of the model is the existence of the so-called "trapped neutrons" in the CF materials with thermal energies interacting only with nuclei at irregular positions in the materials. Even if the model has given qualitative or even semi-quantitative explanations for the experimental facts [Kozima 1998 (Sec. 11), 2006 (Sec. 3.2)], the reality of the assumed existence of the trapped neutrons has been questionable.

To investigate the reality of the trapped neutrons in CF materials, we have examined behavior of neutrons in solids. A possible formation of neutron bands in solids is suggested [Kozima 1996, 1998a] in analogy to the electron bands formation based on the quasi-free electron approximation. Several papers on the quasi-bound states of neutrons in solids are cited already in our books. The paper by Hino et al. [Hino 1998] used Fabry-Perot magnetic thin film resonator to trap neutrons in quasi-bound states. The more extensive references will be given in the next section.

Furthermore, we have developed another type of neutron band formation, similar to the tight-binding approximation of the electron band, using a possible interaction of lattice nuclei mediated by occluded hydrogen isotopes [Kozima 2004a, 2004b].

The fundamental step to the neutron band formation by the former quasi-free approximation is, in reality, worked out in several experiments using ultra-cold neurons

(UCN's) as surveyed in the next section. The justification of the latter tight-bound approximation took place its first step in our works (e.g. [Kozima 2006 (Sec. 3.5)]) will be given in another work.

3. Neutrons in Solids

The neutron as a elementary particle has the wave-particle duality. The wave nature of the neutron is noticed from the first in relation to the interference with periodic arrangements of atoms and nuclei and applied to investigate material structure using the neutron scattering.

We have also notice the wave nature of the neutron in relation to the trapped neutron catalyzed fusion model (TNCF model) for the cold fusion phenomenon and reviewed the nature of the neutron [Kozima 1998 (Sections 12.2 – 12.4)]. Even if our knowledge about interaction of neutrons with matter was scarce at that time, we have noticed the quasi-bound state of neutrons in solids (e.g. [Hino 1998]).

Looking for historical basis of the neutron-solid interaction, we noticed profound research originating from the work by E. Fermi in 1936 [Golub 1990, Fermi 1936]. There are many works on the neutron trapping in crystals due to the strong interaction in addition to that due to the magnetic interaction as surveyed in the next subsection lacking however the formation of the neutron band we have noticed in our previous works due, perhaps, to the finite life of free neutrons. We will give our opinion on this problem and our answer in another forthcoming paper.

(ア) Quasi-free neutron approximation

The ultra-cold neutrons (UCN's) have been extensively investigated in these more than 30 years in relation to the fundamental researches of the nature of the neutron and also to its application [Golub 1990].

In the process of the investigation, the techniques to trap neutrons as long as possible in traps made of material surfaces and magnetic fields are developed.

The following figures give us a typical feature of neutron-matter interaction due to the strong interaction (nucleon-nucleon interaction) of a neutron and atomic nuclei in lattices [Scheckenhofer 1977, Steinhauser 1980].

Figures 3.1 – 3.3 show the neutron wave reflection characteristics described by a Schroedinger equation the same to that for an electron wave. (We can use parallelism for electrons and neutrons in this section.)

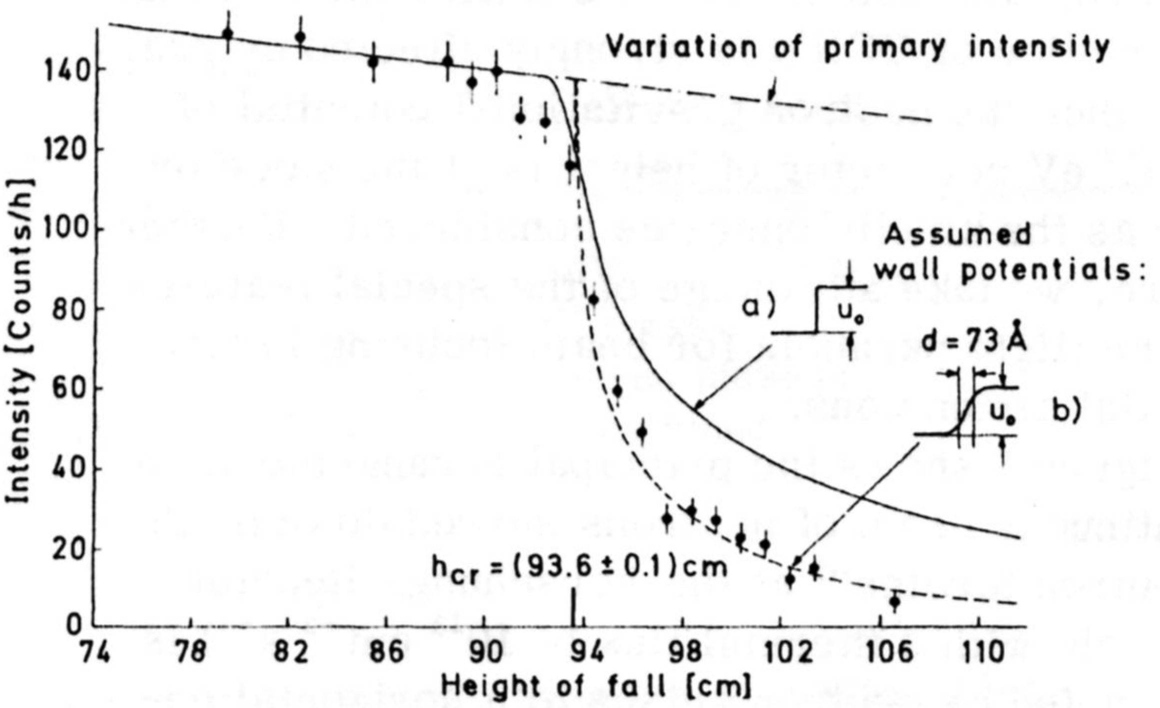

Fig. 3.1. Measured intensity reflected from a glass mirror (points) compared to theoretical curves for (a) a step function, and (b) a smoothed step function for the wall scattering potential. ---, calculation for mono-energetic neutrons; —, calculation for the instrumental resolution. Assumption (b) may be a model for a hydrogenous surface contamination. [Scheckenhofer 1977 (Fig. 3)]

In Fig. 3.1, the abscissa "height of fall" (z) is used to designate the quasi-momentum k_z perpendicular to the potential (step function) according to the relation

$$k_z = (m/\hbar)\,(2gz)^{1/2}, \qquad (3.1)$$

where m is the neutron mass, g is the acceleration due to gravity.

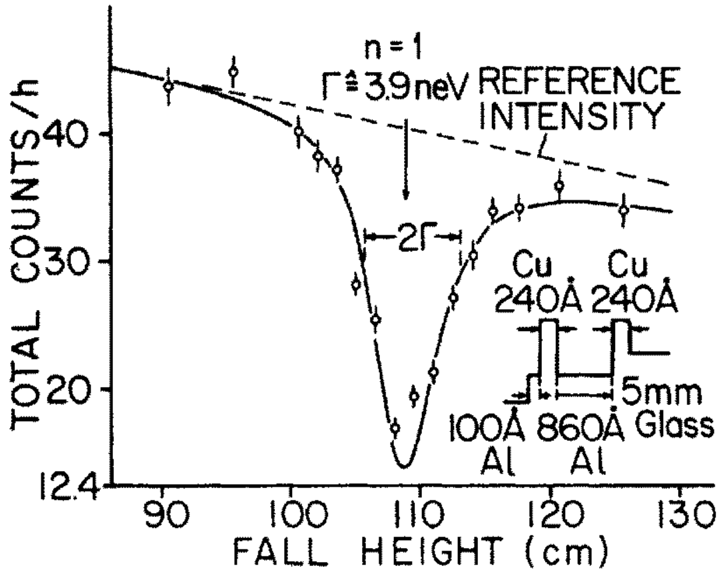

Fig. 3.2 Reflected intensity measured as a function of the fall height for a target with nominal layer thicknesses: Al (100 A), Cu (240 A), Al (860 A), and Cu (240 A). The substrate is glass. Potential functions representing these layers are shown in the inset. The intensity minimum at 108.5 cm corresponds to $n = 1$ (the second stationary state). The solid curve is an exact solution of the one—dimensional Schrödinger equation for the multistep potential representing the target and includes the instrumental resolution broadening. [Steinhauser 1980 (Fig. 2)]

In Figs. 3.2 and 3.3, the abscissa “Fall Height” (z) correspond to the “Height of Fall” in Fig. 3.1 and express the quasi-momentum k_z as explained above using the relation (3.1).

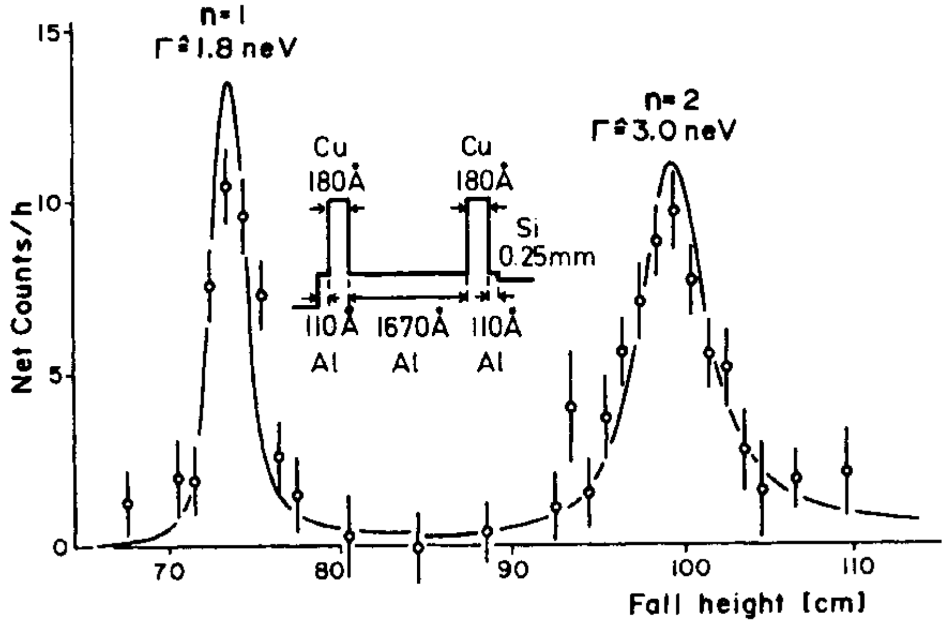

Fig. 3.3 Transmission data for a target with nominal layer thicknesses: Al (110 A), Cu (180 A), Al (1670 A), Cu (180 A), and Al (110 A). The substrate is silicon of 0.25-mm thickness. The two resonances observed correspond to n = 1 and n = 2. The data are compared to the solid curve calculated for a multistep potential. [Steinhauser 1980 (Fig. 3)]

The next one-step from above investigations to the band structure depicted in Figs. 3.4 and 3.5 is obvious one while the step is not traced due, perhaps, to the finite life of the neutron 889 ±3 s.

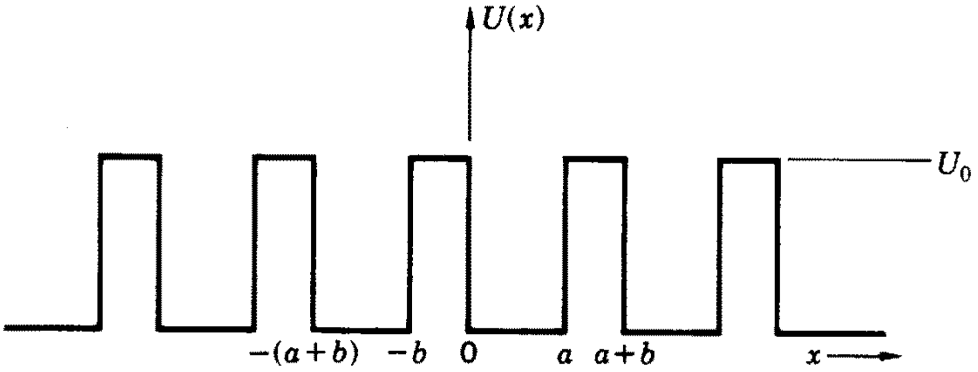

Fig. 3.4 Kronig-Penny potential $U(x)$ vs. x (After [Kittel 1976 (Fig. 7.4)])

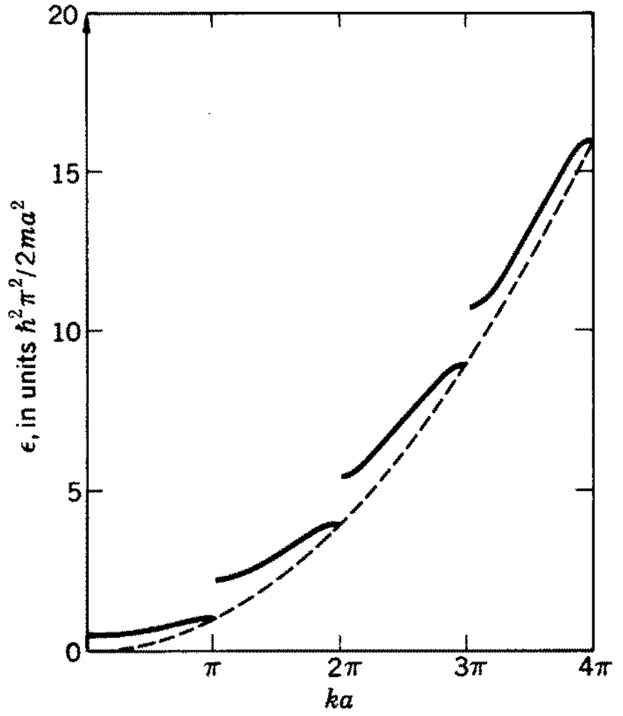

Fig. 3.5 Band structure ε vs. ka of Kronig-Penny potential where ε is the energy of electron, k is the wave number and a is the width of potential well as depicted in Fig. 3.4 (After [Kittel 1976 (Fig. 7.6)])

The investigation of the neutron band formed by tight-binding of wavefunctions in lattice nuclei effective in the cold fusion phenomenon (CFP) will be given in another paper. The neutron in this band is free from beta disintegration but is able to react with alien nuclei in surface and boundary layers.

4. Conclusion

The development of experimental investigation on the cold fusion phenomenon (CFP) in this quarter of a century have substantiated existence of nuclear reactions in CF materials (e.g. PdD_x, NiH_x, and so forth) at near room temperature without any acceleration mechanism. This fact has been partially confirmed by scientists outside this field in many documents and papers including the DOE Report published in 2004 [DOE 2004].

Despite of the increasing reality of the CFP, we have not achieved establishment of its science yet. As we have referred in Introduction of this paper to the continental drift assumption by A. Wegener, such an incomprehensible question as that solved only by the plate techtonics should be investigated phenomenologically as A. Wegener did. We might be able to add the CFP to the incomprehensible questions for which a phenomenological approach is inevitable and useful..

We have tried to give a self-consistent explanation of wide-spread various experimental facts obtained in this field using a phenomenological approach. Fortunately enough, it may be possible to say that our approach has been fairly successful to give qualitative and sometimes semi-quantitative explanations for experimental values of observables and for numerical relations between observables.

In application of our model, we used a key premise, existence of the "trapped neutrons" with a density n_n, an adjustable parameter, in CF materials [Kozima 1994, 1998, 2004a, 2006]. A justification of the premise based on the quantum mechanical investigation has been tried in several papers [Kozima 2004a, 2006, 2009]. The trial is in its infantile stage at present even if a hint to justify the premise was depicted [Kozima 2006 (Sec. 3.7)].

In the *Preface* to his book [Golub 1990], R. Golub cited a word by Maier-Leibnits as follows;

"Maier-Leibnitz once said that he was always surprised to see how a simple little idea could grow and grow until it resulted in something large and complex with implications for other fields of research." [Golub 1990 (Preface)].

We hope that the idea of the "trapped neutron" in CF materials becomes "the simple little idea" Maier-Leibnits told.

References

[DOE 2004] "*Report of the Review of Low Energy Nuclear Reactions*." http://www.science.doe.gov/Sub/Newsroom/News_Releases/DOE-SC/2004/low_energy/CF_Final_120104.pdf. This report is posted at the *New Energy Times* website: http://newenergytimes.com/v2/government/DOE2004/7Papers.shtml

[Fermi 1936] E. Fermi, *Ricerca Scientifica* **7** (1936) 13

[Fleischmann 1989] M. Fleischmann, S. Pons and M. Hawkins, "Electrochemically induced Nuclear Fusion of Deuterium," *J. Electroanal. Chem*., **261**, 301 – 308 (1989).

[Golub 1990] R. Golub, D.J. Richardson and S.K. Lamoreaux, *Ultra-Cold Neutrons*, Adam Hilger, Bristol, 1990, ISBN 0-7503-0115-5.

[Hino 1998] M. Hino, N. Achiwa, S. Tasaki, T. Ebisawa, T. Akiyoshi and T. Kawai, "Observation of Quasi-bound States of Neutron in Fabry-Perot Magnetic Thin Film Resonator using Larmor Precession," *Physica* B, Vol. **241 – 243**, pp. 1083 – 1085 (1998). The revised and enlarged version of this paper is published in the following journal:

M. Hino, N. Achiwa, S. Tasaki, T. Ebisawa, T. Kawai and D. Yamazaki, T. Kawai and D. Yamazaki, “Measurement of Spin-precession Angles of Resonant Tunneling Neutrons,” *Phys. Rev.* **A61**, 013607-1 – 8 (2000).

[Kozima 1994] H. Kozima, “Trapped Neutron Catalyzed Fusion of Deuterons and Protons in Inhomogeneous Solids,” *Trans. Fusion Technol*. **26**, 508 – 515 (1994). ISSN 0748-1896.

[Kozima 1996] H. Kozima, “Neutron Band, Neutron Cooper Pair and Neutron Life Time in Solid,” *Proc. 3rd Russian Conf. Cold Fusion and Nuclear Transmutation*, p. 224 – 230 (1996). And also *Cold Fusion* **16**, 4 – 9 (1996).

[Kozima 1998] H. Kozima, *Discovery of the Cold Fusion Phenomenon* (Ohtake Shuppan Inc., 1998), ISBN 4-87186-044-2.

[Kozima 1998a] H. Kozima, “Neutron Band in Solids,” *J. Phys. Soc. Japan*, **67**, 3310 – 3311 (1998). And also, *Elemental Energy* (*Cold Fusion*) **28**, 30 – 34 (1998).

[Kozima 2004a] H. Kozima, “Quantum Physics of Cold Fusion Phenomenon,” in *Development of Quantum Physics Researches – 2004*, pp. 167 – 196 (F. Columbus and V. Krasnoholovets, ed.), Nova Science Publishers Inc., New York, ISBN 1-59454-003-9.

[Kozima 2004b] H. Kozima, “Solid State-Nuclear Physics of Cold Fusion Phenomenon,” *Report of Cold Fusion Research Laboratory* **2-1**, 1 – 35 (2004); http://www.geocities.jp/hjrfq930/Papers/paperr/paperr.html

[Kozima 2005] H. Kozima, “CF-Matter and the Cold Fusion Phenomenon,” *Proc. ICCF10*, pp. 919 – 928 (2005), ISBN 981-256-564-7.

[Kozima 2006] H. Kozima, *The Science of the Cold Fusion Phenomenon*, Elsevier Science, 2006. ISBN-10: 0-08-045110-1.

[Kozima 2009] H. Kozima, “Non-localized Proton/Deuteron Wavefunctions and Neutron Bands in Transition-metal Hydrides/Deuterides,” *Proc. JCF9* (March 28 – 29, 2009, Shizuoka, Japan), pp. 84 – 93 (2009), ISSN 2187-2260. And also *Reports of CFRL (Cold Fusion Research Laboratory)* **9-3**, pp. 1 – 10 (October, 2009); http://www.geocities.jp/hjrfq930/Papers/paperr/paperr.html

[Shyam 1995] A. Shyam, M. Srinivasan, T.C. Kaushik and L.V. Kulkarni, “Observation of High Multiplicity Bursts of Neutrons during Electrolysis of Heavy Water with Palladium Cathode using the Dad-Time Filtering Technique,” *Proc. ICCF5*, pp. 181 – 187 (1993), IMRA Europe, 1995.

[Scheckenhofer 1977] H. Scheckenhofer and A. Steyerl, “Diffraction and Mirror Reflection of Ultracold Neutrons,” *Phys. Rev. Lett*., **39**, 1310 – 1312 (1977).

[Steinhauser 1980] K.A. Steinhauser, A. Steyerl, H. Scheckenhofer, and S.S. Malik, "Observation of Quasibound States of the Neutron in Matter," *Phys. Rev. Lett*., **44**, 1306 – 1309 (1980).

[Wegener 1966] Alfred Wegener, *The Origin of Continents and Oceans,* Translated from the 4th Revised German Edition by John Biram, Dover publications, Inc., New York, 1966, *Library of Congress Catalog Card Number*: 66-28270