Possible Explanation of He-4 Production in Pd/D_{2} System by TNCF Model

Masayuki OHTA[1], Hideo KOZIMA[2], Mitsutaka FUJII[3],
Kunihito ARAI[4] and Hitoshi KUDOH[3]

[1] Osaka Univ., [2] CFRL, [3] Yokohama National Univ. and
[4] Materials and Energy Research Institute Tokyo Ltd.

Introduction

Cold Fusion Phenomenon

Excess Heat

^{4}He

Tritium and Neutron $t/n = 10^4 \sim 10^9$

Nuclear Transmutaion etc.

$d - d$ reaction

$$\begin{aligned} d + d &= t\,(1.01\ \text{MeV}) + p\,(3.02\ \text{MeV}) && :1, \\ &= {}^3\text{He}\,(0.82\ \text{MeV}) + n\,(2.45\ \text{MeV}) && :1, \\ &= {}^4\text{He}\,(76.0\ \text{keV}) + \gamma\,(23.8\ \text{MeV}) && :10^{-7}. \end{aligned}$$

⇒ **cannot explain CF phenomenon.**

Model

Trapped Neutron Catalyzed Fusion (TNCF) Model

Premise (Basic):

Premise **1**: Existence of trapped neutron.

Premise **2**: The trapped neutron reacts in the surface layer of solid.

Premise **3**: Low reaction rate in volume (except in special situation such as at high temperature)

$$\begin{aligned}
n + {}^6\mathrm{Li} &= {}^4\mathrm{He}\ (2.1\ \mathrm{MeV}) + t\ (2.7\ \mathrm{MeV}).\\
t + d &= {}^4\mathrm{He}\ (3.5\ \mathrm{MeV}) + n\ (14.1\ \mathrm{MeV}).\\
&\Rightarrow\quad t/n \approx 10^6.\\
n + p &= d\ (1.3\ \mathrm{keV}) + \gamma\ (2.22\ \mathrm{MeV}).\\
n + d &= t\ (6.98\ \mathrm{keV}) + \gamma\ (6.25\ \mathrm{MeV}).\\
d + d &= t\ (1.01\ \mathrm{MeV}) + p\ (3.02\ \mathrm{MeV}),\\
&= {}^3\mathrm{He}\ (0.82\ \mathrm{MeV}) + n\ (2.45\ \mathrm{MeV}).\\
n + {}^A\mathrm{X} &= {}^{A+1}\mathrm{X} + \gamma.\\
n + {}^A\mathrm{X} &= {}^{A-1}\mathrm{X} + 2n. \qquad \text{etc.}
\end{aligned}$$

Premise (for simplicity, about calculation):

Premise **4**: Product nuclei of a reaction lose all their kinetic energy in sample except they go out without energy loss.

Premise **5**: A nuclear product observed outside of the sample has its initial energy.

Premise **6**: The amount of the excess energy is the total liberated energy in nuclear reactions.

Premise **7**: Tritium and ^{4}He are generated in the sample.

Premise (for simplicity, about structure of sample):

Premise **8**: The thickness of surface layer is 1 μm (electrolysis).

Premise **9**: The path length of triton generated by fusion reaction is 1 μm.

Premise **10**: Efficiency of detector is 100% except otherwise described.

Premise (for simplicity, about calculation of N_Q):

Premise **11**: Number of nulear reaction N_Q is calculated from the next relation unless the reaction is identified: N_Q = Excess Heat Q (MeV) / 5 (MeV).

Analysis

Neutron Production Observed by T. Bressani et al. (Ti/D)[1]

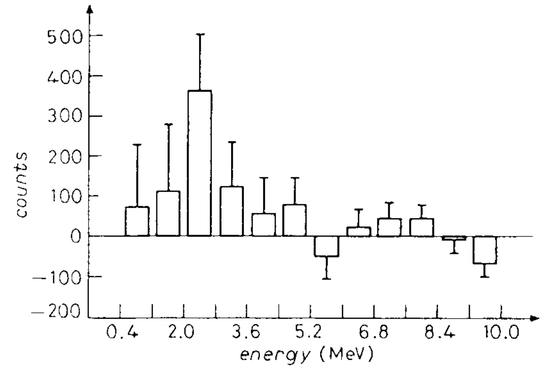


Fig. 1. – Difference of the neutron energy spectrum measured in the runs «down» and that measured in the runs «up», normalized to the same time. The errors are the statistical ones.

Figure 1: neutron spectrum (T. Bressani et al.)

Neutron Production Observed by E. Botta et al. (Pd/D)[2]

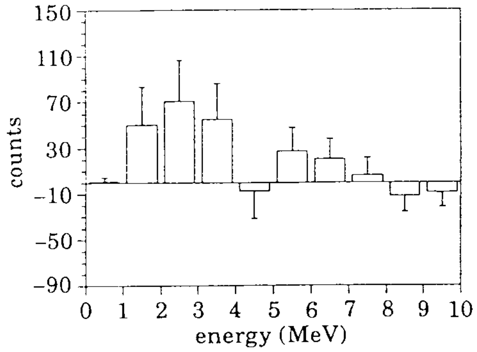


Fig. 7. – Neutron emission spectrum from the Pd/D system after the background subtraction: the error bars refer to the statistical error only and must be intended plus and minus.

Figure 2: neutron spectrum (E. Botta et al.)

Neutron Spectrum Predicted by TNCF model (Pd/Li/D(H))$^{3)}$

$$N_Y \; = \; 0.35 n_n v_n n_X l_0 S \sigma_{nX}.$$

where N_Y: number of reactions (/s), $0.35 n_n v_n$: flux of trapped neutrons, n_X: target density, l_0: thick of surface layer (1 μm), S: surface area, σ_{nX}: fusion cross section.

Table 1: Initial Conditions

Pd/Li/H System		Pd/Li/D System	
n_n (/cm^3)	1.0×10^{10}	n_n (/cm^3)	1.0×10^{10}
S (cm^2)	1.0	S (cm^2)	1.0
Time (s)	8.64×10^4	Time (s)	8.64×10^4
^{1}H	6.88×10^{19}	^{1}H	2.06×10^{17}
^{2}D	1.03×10^{16}	^{2}D	6.86×10^{19}
^{6}Li	3.44×10^{18}	^{6}Li	3.44×10^{18}
^{7}Li	4.29×10^{19}	^{7}Li	4.29×10^{19}
^{102}Pd	6.60×10^{17}	^{102}Pd	6.60×10^{17}
^{104}Pd	7.55×10^{18}	^{104}Pd	7.55×10^{18}
^{105}Pd	1.54×10^{19}	^{105}Pd	1.54×10^{19}
^{106}Pd	1.88×10^{19}	^{106}Pd	1.88×10^{19}
^{108}Pd	1.84×10^{19}	^{108}Pd	1.84×10^{19}
^{110}Pd	8.13×10^{18}	^{110}Pd	8.13×10^{18}

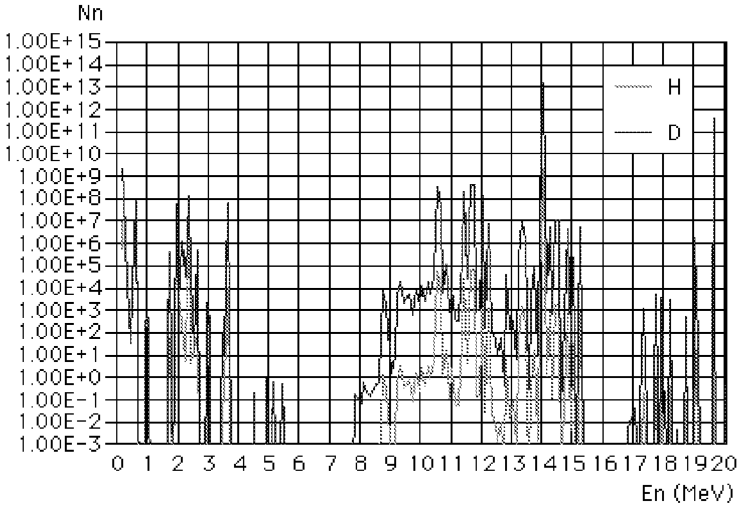


Figure 3: neutron spectrum (TNCF model)

^{4}He Production Observed by E. Botta et al. (Pd/D)$^{4)}$

Experimental

System: D_2 gas loading system
Sample: Pd sheet (size $8\times1\times1\cdot10^{-2}$ cm^3)
plated by Au at both ends (length 1.5 cm, thickness 15μm) with Cu electrodes

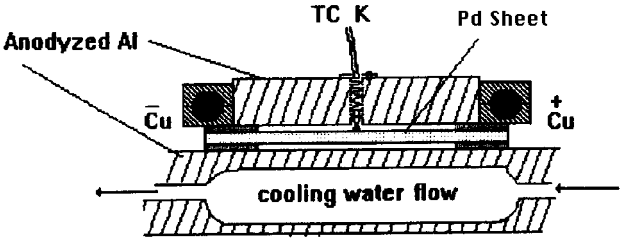


Figure 4: Pd Sheet (E. Botta et al.)

Operation: Vacuum control 10^{-6} mbar → D_2 gas was introduced. (2.7 bar) →
Current was applied. → Gas analysis.
Average D/Pd: 0.80±0.02
Total Time: 117 h

Results

Table 2: Operations and Results

Time (h)	D/Pd	I (A)	duration (h)	Gas Analysis	^{4}He
18	0.48±0.02	150 max 125 mean	0.3	No	No
65	0.66±0.02	225 max 100 mean	2	No	No
95	0.83±0.02	300 max 175 mean	1	Yes	No
117	0.80±0.02	440 max 330 mean	0.4	Yes	Yes

Number of Observed ^{4}He: $(5.3 \pm 0.7) \times 10^{18}$ (96~117 h)

Analysis (TNCF model)

$$\begin{aligned} n\ +\ d &= t\ (6.98\ \text{keV}) + \ \gamma\ (6.25\ \text{MeV}). \\ t\ +\ d &= {}^4\text{He}\ (3.5\ \text{MeV}) + n\ (14.1\ \text{MeV}). \end{aligned}$$

$$\begin{aligned} n\ +\ {}^A\text{Pd} &= {}^{A+1}\text{Pd}^*, \\ {}^{A+1}\text{Pd}^* &= {}^{A-3}\text{Ru} + {}^4\ \text{He} + Q. \end{aligned}$$

Threshold energies are a few MeV. → Next Section.

$$N_{\text{He}} = 0.35 n_n v_n n_{\text{Pd}} V \xi \sum_A \sigma_{nA} \frac{n_A}{n_{Pd}}.$$

where $v_n = 2.2 \times 10^5 \text{cm s}^{-1}$, $n_{\text{Pd}} = 6.88 \times 10^{22} \text{cm}^{-3}$, $V = 8 \times 1 \times 1 \cdot 10^{-2} \text{cm}^3$,

$N_{\text{He}} = 5.3 \times 10^{18}/(21 \times 60 \times 60)$, $\xi = 0.01$ (in volume), 1 (in surface layer),

σ_{nA} : 0.303 b (A = 106), 8.504 b (A = 108), 0.227 b (A = 110),

$\frac{n_A}{n_{Pd}}$: 27.33%(A = 106), 26.71%(A = 108), 11.81%(A = 110).

Trapped Neutron Density:

$$n_n = 6.94 \times 10^{12}\ \text{cm}^{-3}.$$

→ consistent with values of n_n determined by other experimental data.

Excess Heat (theoretical prediction):

$$Q \sim 1.8\ \text{MJ (for } 7.56 \times 10^4\ \text{s).}$$

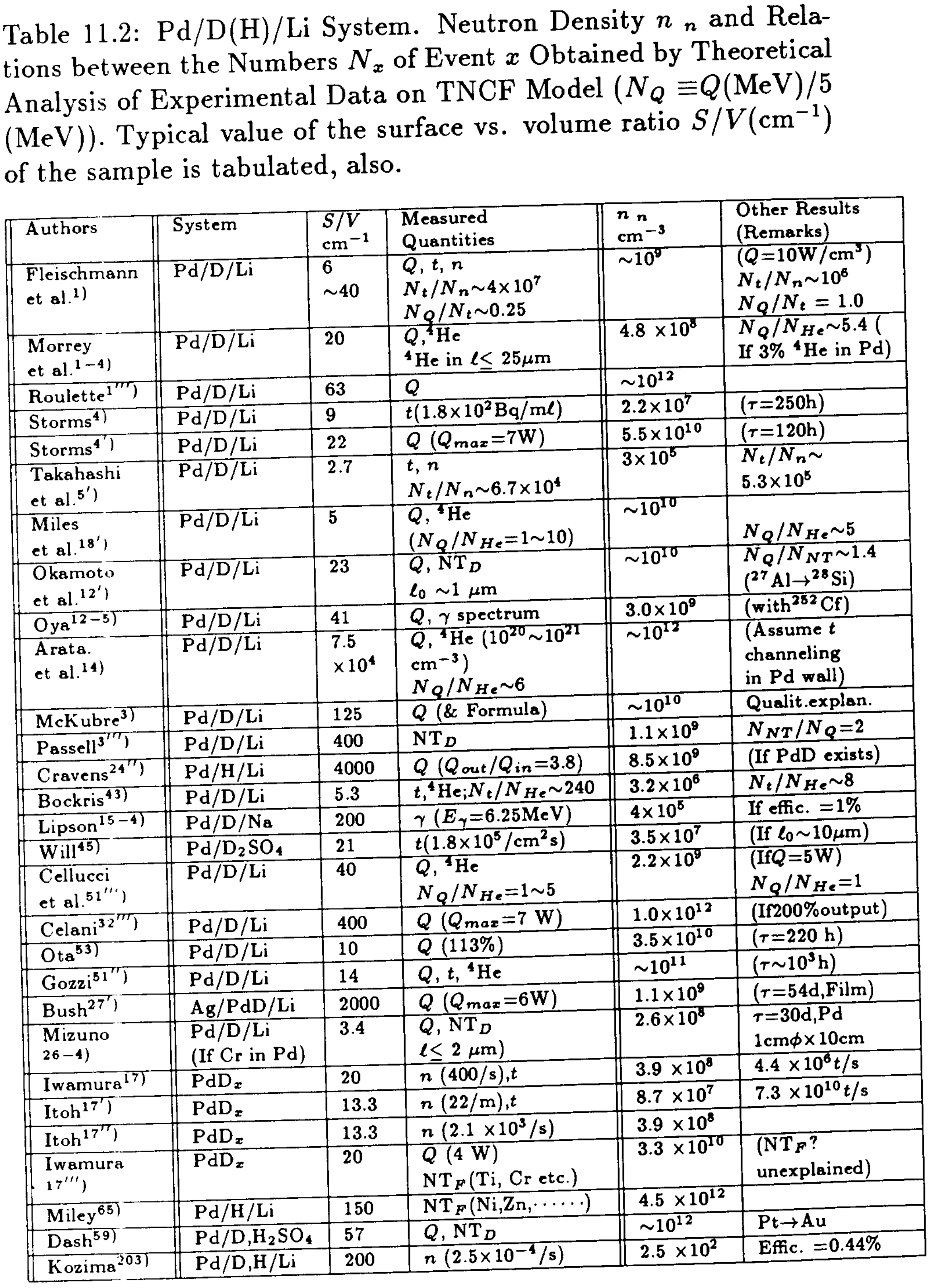


Table 11.2: Pd/D(H)/Li System. Neutron Density n_n and Relations between the Numbers N_x of Event x Obtained by Theoretical Analysis of Experimental Data on TNCF Model ($N_Q \equiv Q$(MeV)/5 (MeV)). Typical value of the surface vs. volume ratio S/V(cm^{-1}) of the sample is tabulated, also.

Authors	System	S/V cm^{-1}	Measured Quantities	n_n cm^{-3}	Other Results (Remarks)
Fleischmann et al.$^{1)}$	Pd/D/Li	6 $\sim$40	Q, t, n $N_t/N_n \sim 4\times10^7$ $N_Q/N_t \sim 0.25$	$\sim10^9$	(Q=10W/cm^3) $N_t/N_n \sim 10^6$ N_Q/N_t = 1.0
Morrey et al.$^{1-4)}$	Pd/D/Li	20	Q, ^{4}He ^{4}He in $\ell \leq$ 25μm	4.8 $\times10^8$	$N_Q/N_{He} \sim 5.4$ (If 3% ^{4}He in Pd)
Roulette$^{1''')}$	Pd/D/Li	63	Q	$\sim10^{12}$	
Storms$^{4)}$	Pd/D/Li	9	t(1.8$\times10^2$Bq/mℓ)	2.2$\times10^7$	(τ=250h)
Storms$^{4')}$	Pd/D/Li	22	Q (Q_{max}=7W)	5.5$\times10^{10}$	(τ=120h)
Takahashi et al.$^{5')}$	Pd/D/Li	2.7	t, n $N_t/N_n \sim 6.7\times10^4$	3$\times10^5$	$N_t/N_n \sim$ 5.3$\times10^5$
Miles et al.$^{18')}$	Pd/D/Li	5	Q, ^{4}He (N_Q/N_{He}=1$\sim$10)	$\sim10^{10}$	$N_Q/N_{He} \sim 5$
Okamoto et al.$^{12')}$	Pd/D/Li	23	Q, NT$_D$ $\ell_0 \sim$1 μm	$\sim10^{10}$	$N_Q/N_{NT} \sim 1.4$ (^{27}Al$\rightarrow^{28}$Si)
Oya$^{12-5)}$	Pd/D/Li	41	Q, γ spectrum	3.0$\times10^9$	(with^{252}Cf)
Arata. et al.$^{14)}$	Pd/D/Li	7.5 $\times10^4$	Q, ^{4}He ($10^{20}\sim10^{21}$ cm^{-3}) $N_Q/N_{He} \sim 6$	$\sim10^{12}$	(Assume t channeling in Pd wall)
McKubre$^{3)}$	Pd/D/Li	125	Q (& Formula)	$\sim10^{10}$	Qualit.explan.
Passell$^{3''')}$	Pd/D/Li	400	NT$_D$	1.1$\times10^9$	N_{NT}/N_Q=2
Cravens$^{24'')}$	Pd/H/Li	4000	Q (Q_{out}/Q_{in}=3.8)	8.5$\times10^9$	(If PdD exists)
Bockris$^{43)}$	Pd/D/Li	5.3	t,^{4}He;$N_t/N_{He} \sim 240$	3.2$\times10^6$	$N_t/N_{He} \sim 8$
Lipson$^{15-4)}$	Pd/D/Na	200	γ (E_γ=6.25MeV)	4$\times10^5$	If effic. =1%
Will$^{45)}$	Pd/D$_2$SO$_4$	21	t(1.8$\times10^5$/cm^{2}s)	3.5$\times10^7$	(If $\ell_0 \sim$10μm)
Cellucci et al.$^{51''')}$	Pd/D/Li	40	Q, ^{4}He N_Q/N_{He}=1$\sim$5	2.2$\times10^9$	(IfQ=5W) N_Q/N_{He}=1
Celani$^{32''')}$	Pd/D/Li	400	Q (Q_{max}=7 W)	1.0$\times10^{12}$	(If200%output)
Ota$^{53)}$	Pd/D/Li	10	Q (113%)	3.5$\times10^{10}$	(τ=220 h)
Gozzi$^{51'')}$	Pd/D/Li	14	Q, t, ^{4}He	$\sim10^{11}$	($\tau \sim 10^3$h)
Bush$^{27')}$	Ag/PdD/Li	2000	Q (Q_{max}=6W)	1.1$\times10^9$	(τ=54d,Film)
Mizuno 26$-$4)	Pd/D/Li (If Cr in Pd)	3.4	Q, NT$_D$ $\ell \leq$ 2 μm)	2.6$\times10^8$	τ=30d,Pd 1cm$\phi\times$10cm
Iwamura$^{17)}$	PdD$_x$	20	n (400/s),t	3.9 $\times10^8$	4.4 $\times10^6 t$/s
Itoh$^{17')}$	PdD$_x$	13.3	n (22/m),t	8.7 $\times10^7$	7.3 $\times10^{10} t$/s
Itoh$^{17'')}$	PdD$_x$	13.3	n (2.1 $\times10^3$/s)	3.9 $\times10^8$	
Iwamura 17''')	PdD$_x$	20	Q (4 W) NT$_F$(Ti, Cr etc.)	3.3 $\times10^{10}$	(NT$_F$? unexplained)
Miley$^{65)}$	Pd/H/Li	150	NT$_F$(Ni,Zn,$\cdots\cdots$)	4.5 $\times10^{12}$	
Dash$^{59)}$	Pd/D,H$_2$SO$_4$	57	Q, NT$_D$	$\sim10^{12}$	Pt$\rightarrow$Au
Kozima$^{203)}$	Pd/D,H/Li	200	n (2.5$\times10^{-4}$/s)	2.5 $\times10^2$	Effic. =0.44%

Figure 5: Neutron Density$^{5)}$

Discussion

Effect of Background Neutron

Background (BG) neutron: $\sim 10^{-2}\ n/\mathrm{s}\cdot\mathrm{cm}^2$

Without BG neutron → null results

S.E. Jones et al$^{6)}$: Experiment in deep underground tunnel and in an old mine (Kamioka, Japan)

With neutron → positive results

G. Shani et al.$^{7)}$: Obsevation of neutron burst with neutron source

Decay Time

Trapped Neutron

The quasi-stability of trapped neutron (Premise 1). → Neutron Affinity.

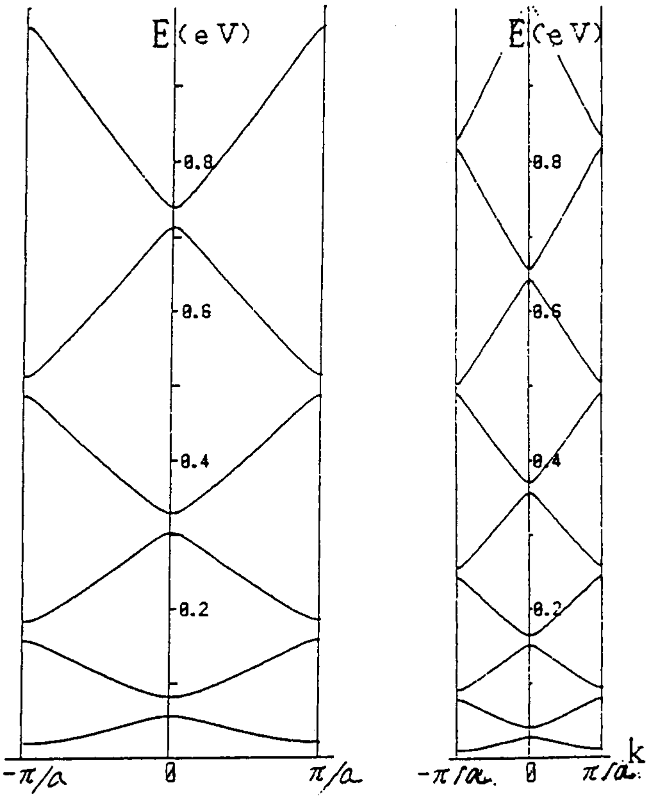
⇔ A free electron decays with a lifetime 887.4±0.7 s.

Nuclear Transmutation

Presence of trapped neutron → Decay time shorting of radioacive nuclei.
→ Lowering of the threshold energy for fission.

Neutron Band

Neutron Bloch Wave → Neutron Trapping



a) $a = 10^{-8}$ cm

, b) $a = \sqrt{2} \times 10^{-8}$ cm.

Figure 12.3: Band structure of the energy spectra of a neutron in crystals with different lattice constants. a) a = 10^{-8} cm and b) a = $\sqrt{2}$ × 10^{-8} cm. The energy ranges corresponding to the allowed bands differ in these two cases.

Figure 6: neutron band (TNCF model)$^{5)}$

Effect of Surface of The Sample

$$
\begin{aligned}
\xi &= 0.01 \text{ (for in volume)}, \\
&= 1 \text{ (for in surface layer)}.
\end{aligned}
$$

$$
\begin{aligned}
V(x) &= \alpha(x_0 - x) \qquad (x \leq x_0), \\
&= 0 \qquad\qquad\quad\; (x_0 < x).
\end{aligned}
$$

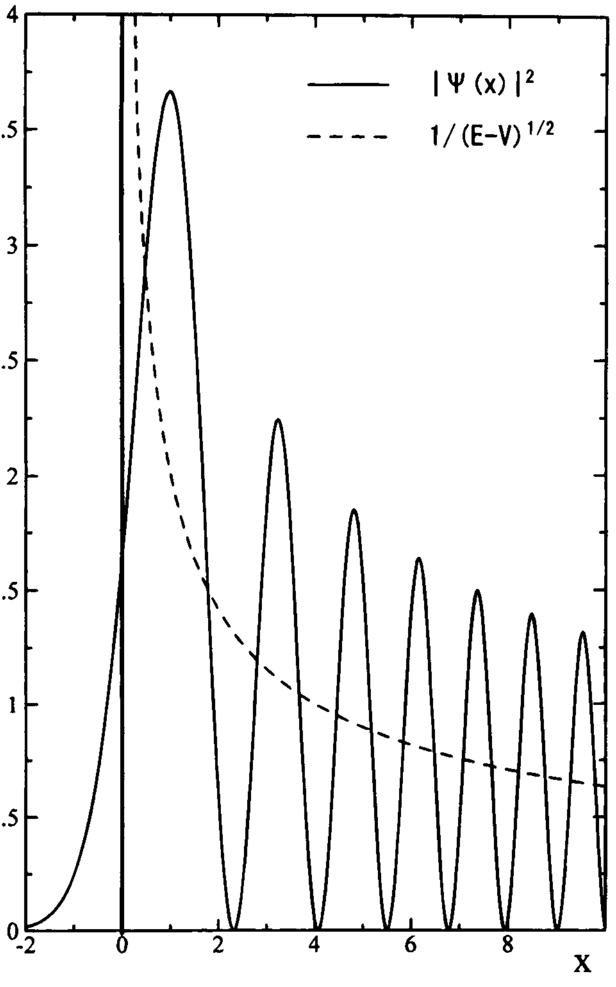


Fig. 1. Classical probability of existence (dotted line) and quantum mechanical probability density (solid line) of a particle with a mass m_n and an energy E (in arbitrary units) in the boundary region $x \sim 0$ determined by a condition $E = V(0)$ with a potential $V(x) = 0\,(x_0 \leq x)$, $= \alpha(x_0 - x)\,(x \leq x_0)$ for $\alpha = 1$.

Figure 7: behavior of neutron bloch wave at boundary (TNCF model)[8)]

Summary

TNCF model → TNCF theory

Key Factor: Correlation between the neutron Bloch wave and lattice nuclei.

References

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Neutron Affinity

$$\eta \equiv -({}^{A+1}_{Z}M - {}^{A+1}_{Z+1}M)c^2.$$

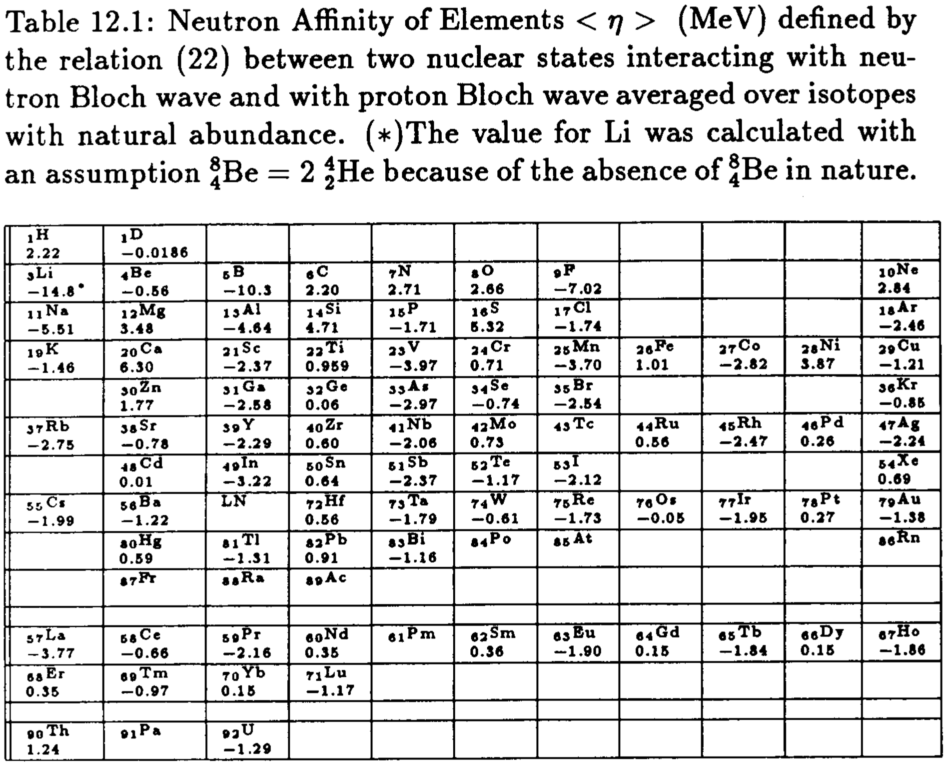

Table 12.1: Neutron Affinity of Elements $< \eta >$ (MeV) defined by the relation (22) between two nuclear states interacting with neutron Bloch wave and with proton Bloch wave averaged over isotopes with natural abundance. (*)The value for Li was calculated with an assumption ${}^8_4$Be = 2 ${}^4_2$He because of the absence of ${}^8_4$Be in nature.

$_{1}$H 2.22	$_{1}$D −0.0186									
$_{3}$Li −14.8*	$_{4}$Be −0.56	$_{5}$B −10.3	$_{6}$C 2.20	$_{7}$N 2.71	$_{8}$O 2.66	$_{9}$F −7.02				$_{10}$Ne 2.84
$_{11}$Na −5.51	$_{12}$Mg 3.48	$_{13}$Al −4.64	$_{14}$Si 4.71	$_{15}$P −1.71	$_{16}$S 5.32	$_{17}$Cl −1.74				$_{18}$Ar −2.46
$_{19}$K −1.46	$_{20}$Ca 6.30	$_{21}$Sc −2.37	$_{22}$Ti 0.959	$_{23}$V −3.97	$_{24}$Cr 0.71	$_{25}$Mn −3.70	$_{26}$Fe 1.01	$_{27}$Co −2.82	$_{28}$Ni 3.87	$_{29}$Cu −1.21
	$_{30}$Zn 1.77	$_{31}$Ga −2.58	$_{32}$Ge 0.06	$_{33}$As −2.97	$_{34}$Se −0.74	$_{35}$Br −2.54				$_{36}$Kr −0.85
$_{37}$Rb −2.75	$_{38}$Sr −0.78	$_{39}$Y −2.29	$_{40}$Zr 0.60	$_{41}$Nb −2.06	$_{42}$Mo 0.73	$_{43}$Tc	$_{44}$Ru 0.56	$_{45}$Rh −2.47	$_{46}$Pd 0.26	$_{47}$Ag −2.24
	$_{48}$Cd 0.01	$_{49}$In −3.22	$_{50}$Sn 0.64	$_{51}$Sb −2.37	$_{52}$Te −1.17	$_{53}$I −2.12				$_{54}$Xe 0.69
$_{55}$Cs −1.99	$_{56}$Ba −1.22	LN	$_{72}$Hf 0.56	$_{73}$Ta −1.79	$_{74}$W −0.61	$_{75}$Re −1.73	$_{76}$Os −0.05	$_{77}$Ir −1.95	$_{78}$Pt 0.27	$_{79}$Au −1.38
	$_{80}$Hg 0.59	$_{81}$Tl −1.31	$_{82}$Pb 0.91	$_{83}$Bi −1.16	$_{84}$Po	$_{85}$At				$_{86}$Rn
	$_{87}$Fr	$_{88}$Ra	$_{89}$Ac							
$_{57}$La −3.77	$_{58}$Ce −0.66	$_{59}$Pr −2.16	$_{60}$Nd 0.35	$_{61}$Pm	$_{62}$Sm 0.36	$_{63}$Eu −1.90	$_{64}$Gd 0.15	$_{65}$Tb −1.84	$_{66}$Dy 0.15	$_{67}$Ho −1.86
$_{68}$Er 0.35	$_{69}$Tm −0.97	$_{70}$Yb 0.15	$_{71}$Lu −1.17							
$_{90}$Th 1.24	$_{91}$Pa	$_{92}$U −1.29								

Figure 8: Neutron Affinity [5)]