CF-MATTER AND THE COLD FUSION PHENOMENON*

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The working concept of “cf-matter,” defined as “neutron drops in a thin neutron liquid” as described in previous papers, is used to explain complex events, especially nuclear transmutations, in cold fusion phenomenon (CFP). In samples used in CF experiments, the cf-matter contains high-density neutron drops in surface/boundary regions while in the volume it contains only a few of them, in accordance with experimental data. Generation of various nuclear transmutations, the most interesting features in CFP, are explained naturally if we use the concept of the cf-matter. Qualitative correspondence between the relative isotopic abundance of elements in the universe and the number of observations of elements in CFP is shown using more than 40 experimental data, sets. This facts is an evidence showing statistically that CFP in transition-metal hydrides/deuterides is a low energy version of nuclear processes occurring in the stars catalyzed by, specific neutrons in the cf-matter formed in surface/boundary regions of CF materials.

1 Abundance of Elements in the Universe

A characteristic of stability of nuclides is relative isotopic abundance in the universe. A data is given in Tables 1 and 2 picked up from Table III of' Suess et al.[1)] The relative abundance of the observed stable species depends oil the process of creation, which may have singled out particular nuclear types for preferential formation and also depends on the nuclear stability limits.[2)]

These characteristics of nuclides in the stars (and the primordial universe) given in Tables 1 and 2 should be closely related to appearance of new nuclides in experimental observations of CFP if the processes in CF materials have some common nature to those, in the stars. It is probable that the more stable a nuclide is, the more often observed the nuclide produced in complex processes occurring in CF materials.

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Table 1: Relative isotopic abundance in the universe (I). Light even-even nuclei (A < 60) at around abundance peaks from Table III of Suess et al.1) The “Log_{10}H” in the second row stands for “Log_{10} relative abundance.”

Nuclides	${}^{11}_{5}$B	${}^{12}_{6}$C	${}^{14}_{7}$N	${}^{16}_{8}$O	${}^{20}_{10}$Ne	${}^{24}_{12}$Mg	${}^{27}_{13}$Al	${}^{28}_{14}$Si	${}^{31}_{15}$P
Log_{10}H	1.3	6.6	6.8	7.3	6.9	5.9	5.0	6.0	4.0
Nuclides	${}^{32}_{16}$S	${}^{36}_{17}$Cl	${}_{18}$A	${}_{19}$K	${}^{40}_{20}$Ca	${}^{45}_{21}$Sc	${}_{22}$Ti	${}_{23}$V	${}_{24}$Cr
Log_{10}H	5.6	4.0	5.2	3.5	4.7	0.4	3.4	2.3	3.9
Nuclides	${}^{55}_{25}$Mn	${}^{56}_{26}$Fe	${}^{59}_{27}$Co	${}^{58}_{28}$Ni	${}_{29}$Cu	${}^{64}_{30}$Zn			
Log_{10}H	3.8	5.8	3.3	4.4	2.3	2.7			

Table 2: Relative isotopic abundance in the universe (II). Heavy nuclei (element) (A > 88) from Table III of Suess et al.1) The "Log_{10}H" in the second row stands for "Log_{10} relative abundance."

Nuclides	${}^{88}_{38}$**Sr**	${}^{90}_{40}$**Zr**	${}_{42}$Mo	${}_{44}$Ru	${}_{46}$Pd	${}_{47}$Ag	${}_{50}$Sn	${}_{52}$**Te**	${}_{54}$**Xe**	${}_{56}$**Ba**
Log_{10}H	1.2	1.5	0.4	0.2	0.08	0.04	0.12	0.67	0.60	0.56
Nuclides	${}^{139}_{57}$La	${}_{58}$Ce	${}_{59}$Pr	${}^{139}_{77}$Ir	${}_{78}$Pt	${}_{79}$Au	${}_{80}$Hg	${}_{82}$**Pb**	${}_{83}$Bi	
Log_{10}H	0.30	0.35	0.06	0.09	0.21	0.02	0.05	0.07	0.02	

2. Formation of the cf-matter

By the mechanism shown in previous papers,4-6) the cf-matter (interacting particle feature) is formed in boundary/surface regions when there are the neutron valence bands (independent-particle feature) mediated by hydrogen isotopes in *fcc/hcp* transition-metal hydrides/deuterides and proton conductors where hydrogen isotopes are in states with extended wave functions

In a homogeneous neutron star matter, i.e. a neutral medium composed of high density (n_G) neutrons, protons and electrons, as the simulation by Negele et al.7) had shown, there appears the Coulomb lattice of neutron drops ${}^{A}{}_{Z}\triangle$ in a thin neutron liquid (with a density of n_b) by the self-organization. In the case of the cf-matter in CF materials, there is a crystal lattice, which seems to make appearance of the Coulomb lattice of neutron drops easier as experimental facts in CFP suggest than in the neutron star matter.

3. Coulomb lattice in the cf-matter

Several features of the characteristics of the Coulomb lattices of neutron drops (clusters of neutron, proton and electron) in neutron star matter are tabulated in Table 3.7) In this table, we added the proton-to-neutron ratios $\underline{x}$ of palladium, iron, and carbon nuclei averaged over isotopes by natural abundance, which are 0.77, 0.87, and 1, respectively.

In the work by Negele et al.,7) it was shown that a neutron star appears as a stable state when the density n_G of the neutron star matter increased from 3×10^{35} to about $10^{38}\mathrm{cm}^{-3}$. If we change the parameter n_G to the opposite direction, we will reach a situation where appear various atoms, principally the situation where elements are created in the stars; the more stable a nuclide is, the higher its production rate becomes. Comparing isotopic abundances in the universe (Tables 2 and 3) to experimental data of nuclear transmutation in CFP, we can show that CFP in CF materials is a similar process to those producing elements in the stars.

Table 3: The theoretical 7) and extrapolated to $n_G = 1 \times 10^{30}$ cm^{-3} values of the lattice constant *a* of Coulomb lattice, the proton-to-neutron ratio $\underline{x}$ in the neutron drops $^{A}Z\triangle$ (n-p clusters) and background neutron density n_b as functions of n_G, the density of the original neutron gas, where n_b is the density of the neutron liquid surrounding the neutron drops. The density of nucleons init neutron drop $n_\triangle$ is approximately constant and equal to 10^{38} cm^{-3} in the range where simulation is performed; $n_\triangle \approx 10^{38}$ cm^{-3}. For reference, *a* and $\underline{x}$ for the lattice of Pd metal and $\underline{x}$, of Fe and C nuclei (all averaged over isotopes with natural abundances) are added along with extrapolated values of n_b corresponding to their $\underline{x}$.

n_G cm^{-3}	5×10^{37}	5.7×10^{36}	6×10^{35}	1×10^{30}	Pd	Fe	C
n_b	4×10^{37}	5×10^{36}	2×10^{35}	1×10^{29}	10^{27}	10^{22}	10^{16}
a (A)	4×10^{-4}	7×10^{-4}	9×10^{-4}	2×10^{-3}	2.5		
$\underline{x}$	0. 28	0. 45	0. 53	0.75	0.77	0.87	1
n_b / n_Δ	4×10^{-1}	5×10^{-2}	3×10^{-3}	1×10^{-9}	5×10^{-11}	10^{-16}	10^{-22}

4. Interaction of the cf-matter with extraneous nuclides in terms of experimental data

We assume that the cf-matter is formed in surface/boundary regions of CF materials when there are formed neutron valence bands.[4,5] We concentrate at nuclear transmutations in CFP in this paper, while other events are naturally accompanied with them. It should be pointed out here about emission of light particles and photons from CF materials sometimes measured in experiments. The cf-matter is formed principally in boundary/surface regions of CF materials and dissipation of liberated energy in the unclear reactions is confined in the cf-matter. When the place where the nuclear reaction occurs is on the border of the cf-matter very close to a surface of the sample, however, it is possible light particles and/or photons are emitted outward to be measured outside. Especially, emission of neutrons with up to more than 10 MeV is observed often as an example of this mechanism.[8)]

5. Production of New Nuclides in CFP

There are very many data of the nuclear transmutations (NTs) in CFP.

In Table 4, we give a summary of experimental data sets obtained mainly after 1996 showing broad production of new elements (Elements) with a number of papers reporting them (No. of papers). In this table, about 40 data sets*) are counted including such productions of Ag (from Pd) and Fe (from C and others), which is not necessarily obvious but frequently occurring. A relation of frequency N_{ob} of the observations of elements in CFP and “Log$_{10}$H relative abundance” in Tables 1 and 2 will be discussed later.

The nuclear transmutations are phenomenologically classified into four groups; NT$_{A}$, NT$_{D}$, NT$_{F}$, and NT$_{T}$, i.e. nuclear transmutations (NT) by absorption, by decay, by fission and by transformation, respectively. The first three types of NTs are induced by a transfer of a nucleon cluster $^{a}_{z}\delta$ between the cf-matter (or a neutron drop $^{A}_{Z}\triangle$) and a nuclides $^{A'}_{Z'}X$ followed by various nuclear processes in the systems to produce the final stable nuclide $^{A''}_{Z''}X''$. Then the isotopic ratio of the produced elements will differ from the natural abundance ratio. In the case of NT$_{T}$, we can expect the same isotopic ratio as the natural one as explained below.

Table 4: Elements observed more than once in Cf experiments (Z > 3). Number of papers reporting the observation, N_{ob}, is calculated from 40 papers mainly after 1996.

Elements	$_{3}$Li	$_{5}$B	$_{6}$**C**	$_{8}$O	$_{9}$F	$_{11}$Na	$_{12}$**Mg**	$_{13}$**Al**	$_{14}$**Si**	$_{15}$P
N_{ob}	3	1	5	1	4	1	6	9	12	1
Elements	$_{16}$S	$_{17}$**Cl**	$_{19}$**K**	$_{20}$**Ca**	$_{21}$**Sc**	$_{22}$**Ti**	$_{23}$V	$_{24}$**Cr**	$_{25}$**Mn**	$_{26}$**Fe**
N_{ob}	6	6	6	9	1	6	2	13	6	19
Elements	$_{27}$Co	$_{28}$**Ni**	$_{29}$**Cu**	$_{30}$**Zn**	$_{31}$Ga	$_{32}$Ge	$_{33}$As	$_{34}$Se	$_{35}$Br	$_{37}$Rb
N_{ob}	4	10	11	13	1	3	1	1	2	2
Elements	$_{38}$Sr	$_{39}$Y	$_{40}$Zr	$_{41}$Nb	$_{42}$Mo	$_{46}$Pd	$_{47}$**Ag**	$_{48}$Cd	$_{49}$In	$_{50}$Sn
N_{ob}	5	1	1	1	5	3	7	3	2	3
Elements	$_{51}$Sb	$_{52}$Te	$_{54}$Xe	$_{55}$Cs	$_{56}$Ba	$_{59}$Pr	$_{62}$Sm	$_{63}$Eu	$_{64}$Gd	$_{66}$Dy
N_{ob}	1	2	2	1	4	1	1	1	1	1
Elements	$_{67}$Ho	$_{70}$Yb	$_{72}$Hf	$_{75}$Re	$_{76}$Os	$_{77}$Ir	$_{78}$Pt	$_{79}$Au	$_{80}$Hg	$_{82}$**Pb**
N_{ob}	1	1	1	1	2	2	2	2	2	6

The isotopic ratios observed in experiments differ sometimes from those calculated from natural abundances while does not differ in others. The cause of the discrepancy due to the processes of NTs will give a key to investigate nuclear reactions in CFP.

In these processes, no emission of photons and/or light nuclides to outside is expected to occur different from reactions in free space except the processes that occur on the border of the cf-matter at surfaces of the sample.

5-1) *Nuclear Transmutation by Absorption (NT$_{A}$)*

The nuclear transmutation by absorption, NT$_{A}$, is a result of a process where a nuclide $^{A}_{Z}X$ simply absorbs a cluster $^{a}_{z}\delta$ of ν (= a − z:) neutrons and ν' = z protons from the cf-matter: $^{A}_{Z}X + {}^{a}_{z}\delta = {}^{A+a}_{Z+z}X$. In this process, the more stable the final nuclide $^{A+a}_{Z+z}X$, the more frequent it will be produced.

There are many experimental data, showing production of new nuclides explicable only by NT$_{A}$ if we do not use concepts outside the realm of modern physics. Production of following nuclides are explained by $\mathrm{NT_A}$:

$_{24}\mathrm{Cr}$ from $_{22}\mathrm{Ti}$, $_{26}\mathrm{Fe}$ from $_{22}\mathrm{Ti}$, $_{30}\mathrm{Zn}$ from $_{28}\mathrm{Ni}$, $^{40}_{19}\mathrm{K}$ from $^{39}_{19}\mathrm{K}$, $^{41}_{19}\mathrm{K}$ from $^{39}_{19}\mathrm{K}$, $^{43}_{19}\mathrm{K}$ from $^{39}_{19}\mathrm{K}$, $^{89}_{37}\mathrm{Rb}$ from $^{85,87}_{37}\mathrm{Rb}$, $^{134}_{55}\mathrm{Cs}$ from $^{133}_{55}\mathrm{Cs}$, $_{42}\mathrm{Mo}$ from $_{38}\mathrm{Sr}$, $_{48}\mathrm{Cd}$ from $_{46}\mathrm{Pd}$, $_{50}\mathrm{Sn}$ from $_{46}\mathrm{Pd}$, $_{52}\mathrm{Cd}$ from $_{46}\mathrm{Pd}$, $_{56}\mathrm{Ba}$ from $_{46}\mathrm{Pd}$, $_{59}\mathrm{Pr}$ from $_{53}\mathrm{Cs}$, $_{82}\mathrm{Pb}$ from $_{74}\mathrm{W}$, $_{82}\mathrm{Pb}$ from $_{46}\mathrm{Pd}$.

Some reactions producing nuclides with large decreases of Z and A occur and are explained as a result of $\mathrm{NT_F}$ (cf. Section c) below). However. it is probable to assume reactions where occur transfer of a cluster of nuclides $^{a}_{z}\delta$ from a nuclide $^{A}_{Z}X$ to a neutron drop $^{A+a}_{Z+z}\Delta$ as inverse processes of the normal $\mathrm{NT_A}$. Some examples of these reactions are productions of following nuclides:

$_{26}\mathrm{Fe}$ from $_{28}\mathrm{Ni}$, $_{27}\mathrm{Co}$ from $_{28}\mathrm{Ni}$, $_{25}\mathrm{Mn}$ from $_{28}\mathrm{Ni}$, $_{24}\mathrm{Cr}$ from $_{28}\mathrm{Ni}$, $_{42}\mathrm{Mo}$ from $_{46}\mathrm{Pd}$, $_{77}\mathrm{Ir}$ from $_{78}\mathrm{Pt}$, $_{76}\mathrm{Os}$ from $_{78}\mathrm{Pt}$, $_{78}\mathrm{Pt}$ from $_{79}\mathrm{Au}$, $_{76}\mathrm{Os}$ from $_{79}\mathrm{Au}$, $_{30}\mathrm{Zn}$ from $_{46}\mathrm{Pd}$.

We include these reactions in $\mathrm{NT_A}$ hereafter.

5-2) *Nuclear Transmutation by Decay ($\mathrm{NT_D}$)*

One of the most frequently detected NTs in CFP from early days of research is the nuclear transmutation by decay ($\mathrm{NT_D}$).

The nuclear transmutation by decay, $\mathrm{NT_D}$ is a result of a process where the nuclides $^{A+a}_{Z+z}X$ (a=1, z=0) thus formed decays by emission of light nuclides, *n, p*, or α, to form a new nuclide $^{A'}_{Z'}X'$.[8] Many data showing production of nuclides with increase of proton number by one are explained successfully by this mechanism with $\nu = 1$ and $\nu' = 0$ as shown in the analyses by the TNCF model.[8,9] In this process, the probability of the nuclide production will be governed by stability of $^{A+1}_{Z}X$ and also by that of the final nuclide $^{A+1}_{Z+1}X'$ (β decay) or $^{A-3}_{Z-2}X'$ (α decay).

Several examples of this mechanism are production of following nuclides:

$^{4}_{2}\mathrm{He}$ from $^{6}_{3}\mathrm{Li}$, $^{8}_{3}\mathrm{Li}$ from $^{11}_{5}\mathrm{B}$, $_{14}\mathrm{Si}$ from $_{13}\mathrm{Al}$, $_{20}\mathrm{Ca}$ from $_{19}\mathrm{K}$, $_{23}\mathrm{V}$ from $_{22}\mathrm{Ti}$, $_{29}\mathrm{Cu}$ from $_{28}\mathrm{Ni}$, $_{38}\mathrm{Sr}$ from $_{37}\mathrm{Rb}$, $_{47}\mathrm{Ag}$ from $_{46}\mathrm{Pd}$, $^{135}_{54}\mathrm{Xe}$ from $^{134}_{55}\mathrm{Cs}$, $_{79}\mathrm{Au}$ from $_{78}\mathrm{Pt}$, $_{80}\mathrm{Hg}$ from $_{79}\mathrm{Ag}$.

5-3) *Nuclear Transmutation by Fission ($\mathrm{NT_F}$)*

The nuclear transmutation by fission, $\mathrm{NT_F}$, is a result of a process where the nuclides $^{A+a}_{Z+z}X$ ($a \gg 1$) suffers fission producing several nuclides with nucleon and proton numbers largely shifted from the value A + a and Z + z, respectively.[8,13] The mass spectra of nuclear products in the nuclear transmutation by fission, $\mathrm{NT_F}$, observed in CFP can be explained as fission products of unstable nuclides $^{A'+a}_{Z'+z}X'$ formed by the above process similar to fission of $^{235}\mathrm{U}$ induced by a fast neutron. In this process, the mass spectrum is determined by stabilities of product nuclides.

There are many experimental data showing production of various medieval mass-number nuclides simultaneously. It is possible to explain dispersion of mass spectrum by the liquid-drop model of nucleus popular in nuclear physics assuming formation of extra-neutron rich nuclides from pre-existing nuclides in the systems absorbing several neutrons from the cf-matter.13)

There occur simultaneous productions of such many elements as follows: Mg, Al, Si, S, Cl, K, Ca, Cr, Mn, Fe, Co, Ni, Cu, Zn, Os, Ir.

In experiments where observed many new elements simultaneously, explanation of the results by NT_F seems most appropriate even if there remains a possibility to explain them by successive transmutations by NT_A, NT_D and/or NT_T.

5-4) *Nuclear Transmutation by Transformation* (NT_T)

The nuclear transmutation by transformation, NT_T, is a result of a process where a neutron drop ${}^{A}_{Z}\Delta$ in the cf-matter transforms itself into a stable nuclide ${}^{A}_{Z}X$ in the material. Naturally, the more stable a neutron drop ${}^{A}_{Z}\Delta$ is, the more frequent a nuclide ${}^{A}_{Z}X$ will be produced.

When products of nuclear transmutation are observed alone, it seems to be explained by NT_T if the new elements have mass number A less 50 and that shifts from pre-existing nuclides by more than 10. The nuclear transmutation by transformation, e.g. ${}^{A}_{Z}\Delta$ into ${}^{A}_{Z}X$ seems probable only if there are neutron drops with stability that is sensitive to environment.

Products possibly explained by NT_T (cf. Tables 1 and 2) are as follows:

${}^{12}_{6}C$, ${}^{24}_{12}Mg$, ${}^{28}_{14}Si$, ${}^{32}_{16}S$, ${}^{35,37}_{17}Cl$, ${}^{40}_{20}Ca$, ${}^{56}_{26}Fe$, ${}^{58}_{28}Ni$, ${}^{208}_{82}Pb$.

The production of Fe is observed very often in electrolytic experiments, in arcing between carbon rods and in others and is possibly explained as a result of NT_T.

6. Relation of CFP Data with Abundances of the Elements

We can see correspondence of nuclear products of NTs in CFP with the abundances of the elements given in Section 1.

The most remarkable statistical data is seen in overall correspondence between the frequency N_{ob} observing elements in CFP (Table 4) and the relative abundances $\log_{10}H$ of elements in the universe (Tables 1 and 2) as shown in Figs. 1 and 2. This qualitative correspondence between two data (N_{ob} and $\log_{10}H$) may be explained as follows.

Here, we point out only several of the most remarkable characteristics of them.

i). Accordance of $\log_{10}H$ and N_{ob}: There are several peaks with coincidence of N_{ob} and $\log_{10}H$ at Z = 14 (Si), 20 (Ca), 26 (Fe), 38 (Sr), and 82 (Pb). In these peaks, the one at Z = 26 (Fe) is the most remarkable despite the isotopic abundance of elements in the universe is in a logarithmic scale. Quantitative explanation of these data will need to use concrete experimental conditions.

ii). Discrepancy between $\log_{10}H$ and N_{ob}: Missing data in CFP at Z = 7 (N), 8 (O), 10 (Ne), 18 (Ar), and 40 (Zr) are noticeable. The first four of them may be explained as a result of difficulty in their observation. About the last one (Zr), we have no idea to explain the discrepancy, at present. The remarkable peak at Z = 47 (Ag) is a characteristic of CFP explained by NT_D, from Pd that does not exist in the stars.

Figure 1

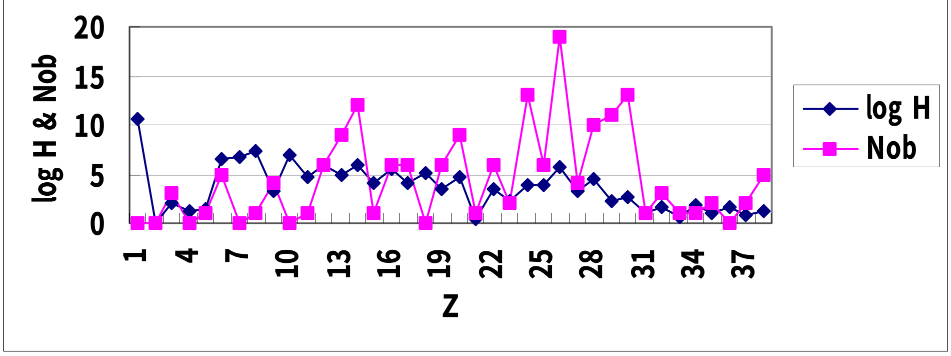
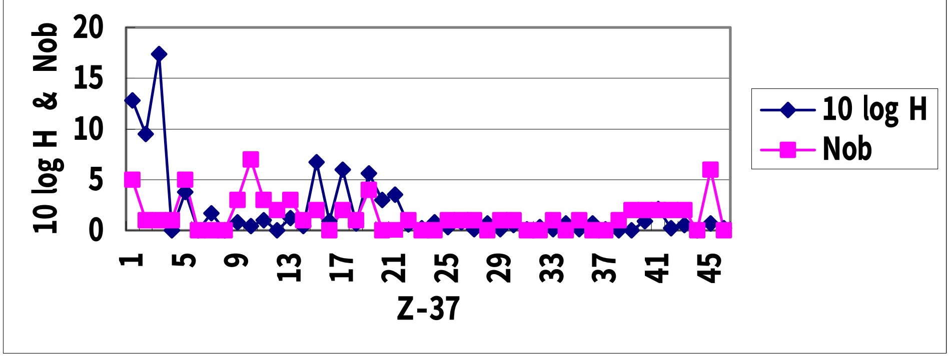


Figure 2



Figs. 1 and 2. Correspondence between the frequency N_{ob} observing elements in CFP and the relative abundances $\log_{10}H$ of elements in the universe for elements with atomic numbers Z = 3 —38 (Fig. 1) and Z = 39 —84 (Fig. 2).

Therefore, it is possible to conclude that the good coincidence of N_{ob} and $\log_{10}$H discussed above is an evidence showing similarity of mechanisms working in CF materials and in the stars to produce new nuclides. This mechanism to produce nuclides from chaotic states of nucleons according to their stability is called “mechanism by stability." The coincidence of data in astrophysics and in CFP is called “stability effect": The more stable a nuclide is, the more frequent it is produced.

Discussion

As shown in this paper, there is the stability effect, a good coincidence of the isotopic abundance of elements in the universe $\log_{10}H$ and frequency of observations of elements in CFP N_{ob}. This effect shows that the mechanism to produce new nuclides in CFP is a low energy, localized version of the mechanism working in the stars catalyzed by the cf-matter and nuclides in CF materials. Participation of neutrons as a catalyst makes nuclear reactions in CFP as effective to produce new nuclides as high-energy processes in the stars.

Isotopic ratios of new isotopes produced in CFP reflect characteristics of nuclear processes participating to the production processes. It is most probable that products by NT_T have similar isotopic ratios to natural ratios of the same element. Detailed investigation of these features will help to explore dynamics of nuclear interactions in the cf-matter.

Thus, variety of nuclear transmutations observed in CFP are qualitatively and consistently explained by the existence of the cf-matter worked out semi-quantitatively in previous papers.4,5)

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