On the possibility of nuclear transformation in low-temperature plasma from the viewpoint of conservation laws

D.V. FILIPPOV, L.I. URUTSKOEV
RECOM Inst. Kurchatov, Moscow

ABSTRACT. The potentiality of a hypothetical collective process of low-energy nuclear transformations is shown to be compatible with the known fundamental conservation laws. The possibility of such processes was suggested by the results of the experiments [1] on the electric explosion of metallic foils in liquids. It is also shown, that while considering the nuclear processes – both known and novel ones – which proceed with participation of weak interactions, one has to take into account the mass of electron in spite of its smallness in comparison with the nuclear binding energy. Within the frame of the respectively enhanced accuracy, it is shown that the condition of nuclear stability with respect to β-decay and K-capture appears to be the minimum of mass defect on isobars, that not always coincides with the widespread condition of the minimum of nuclear mass.

Main ideas of our approach

1 In nuclear processes, nuclear and atomic physics are not detached, as it is commonly believed.

2 The change ***of atomic electronic states*** may influence the rate of ***nuclear*** decay and the condition of ***nuclear*** stability, and may redistribute the channels of ***nuclear*** decay.
This is not an exotic. It is confirmed with experiments. It is necessary to search for ways to use it.

3 The changes of atomic electronic states may be caused by application of a strong magnetic field.

4 The possibility of a hypothetical collective process of low-energy nuclear transformations is shown to be compatible with the known fundamental conservation laws.

1 Introduction

The nuclear transformation of chemical elements on a macroscopic scale (~ 10^{19}-10^{20} nuclei per shot) have been observed in the experiments [1] on the electric explosion of metallic foils in liquids. Specifically, in the experiments on the electric explosion of titanic foils the transformation of Ti^{48} yields rather wide spectrum of chemical elements that results in a substantial distortion (~ 10%) of isotopic ratio in the remains of titan. The group by V.D. Kuznetsov (Joint Institute for Nuclear Research, Dubna, Moscow region) obtained similar results in a follow-up verification experiment (namely, via an independent analysis of electric discharge's products for the case of an independent certification of essential input materials of the experiment). The first attempt to construct a phenomenological model of the nuclear transformations has been undertaken by F.M. Pen'kov of the same group.

The observed nuclear transformations [1] radically differ from conventional nuclear reactions. These include:

- input and output energies per initial/final atom are small and do not exceed 10 keV per synthesized atom;
- there is no release of free neutrons;
- there is no remnant radioactivity, i.e. non-stable isotopes are not synthesized.

The absence of remnant radioactivity suggests the transformation to be not a result of stochastic nuclear collisions or known nuclear decays. The results of the mass spectrometry analysis [1] show no contradiction with the energy conservation law within the accuracy of measurements.

The results of the experiments [1] suggest the possibility of a hypothetical *collective* process of low-energy nuclear transformations, which might be compatible with the known fundamental conservation laws. We will try to construct a phenomenological model for such a process without specifying the very mechanism of transformation. Anyway, to sustain the known fundamental conservation laws in the hypothetical *collective* process we have to appeal to the known fundamental interactions as probable constituent parts of this process. An attempt to interpret the observed nuclear transformation [1] as caused only by strong interactions didn't' allow us to reproduce the isotopic distribution of experiment's products. Therefore, in constructing a phenomenological model for interpreting the low-energy nuclear transformations in the experiment, we have to allow for the weak interaction as being capable of producing the p-n transitions and possessing the smallest change of energy per atom in the process. Note that the respective changes are still large in comparison with experimental observations so that only a hypothetical collective process may resolve this difficulty.

2 Condition of nuclear β-stability

We study the problem of nuclear β-stability. We show that

- the necessary and sufficient condition of nuclear β-stability appears to be the minimum of the mass of atom (not of nucleus!) on the isobar (i.e. for A=const where A is the total number on nucleons in the nucleus).

The processes of K-capture and β-decay transform the nucleus with conservation of the number of nucleons, that corresponds to a shift along the isobar (A=const). In such nuclear reactions with participation of weak interactions, one has:

$$ {}_{Z}^{A}X \to {}_{Z+K}^{A} Y + ke^{-} + k\overline{v_e} + Q \, , $$

(where ν_e is electron-type neutrino, k is the number of electrons involved in reaction; k can be positive – in the case of β-decay, or negative – in the case of K-capture). The released (Q>0) or absorbed (Q <0) energy is calculated as follows:

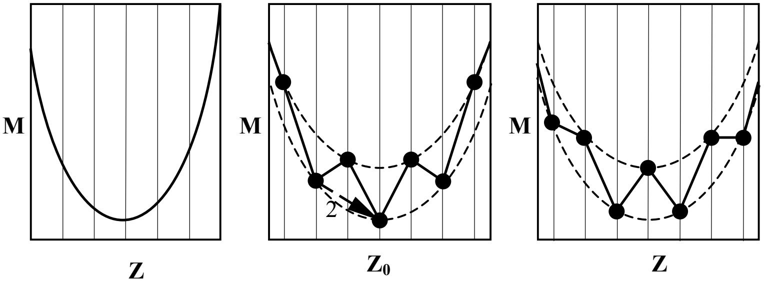
$$ Q = M_N(A_x, Z_X) - M_N(A_Y, Z_Y) - k.m_e $$

where $M_N(X)$ is the mass of nucleus; m_e is electron's mass. According to definition of nuclear binding energy W , one has:

$$ M_N(A,Z) = (A-Z)\cdot m_n + Z\cdot m_p - W_N(A,Z) $$

where m_p is proton's mass, m_n , neutron's mass. From these equations it is easy to obtain:

$$ Q = M_A(A_X, Z_X) - (M_A(A_Y, Z_Y) $$



- a - - b - c -

Fig.1. Mass of atom, $M_A(Z)$, on the isobar (A=const) for the case of odd A (figure a), even A and even Z_0 (b), **even A and odd Z_0 (c); Z_0 – location of minimum of $M_A(Z)$.**

As known, the sufficient condition of nuclear stability has the form of the requirement for the reaction of β-decay to be endothermic $Q<0$. It is equivalent to the condition of the minimum of the mass of atom (not of nucleus!) on the isobar. It is well-known that the dependence $M_N(Z)$ may be represented as a parabola for odd A, and as a broken line between two parabolas for even A (see Fig. 1).

A number of textbooks in nuclear physics contain the incorrect statement that the minimum of nuclear mass on the isobar is the condition of nuclear stability. Indeed, let us look at the relation – for the nucleus of electric charge Z – between the mass of nucleus, $M_N(Z)$, and that of atom, $M_A(Z)$, and the binding energy of the nucleus W(Z):

$$M_N(Z) = M_A(Z) + I(Z) - Z \cdot m_e ,$$

$$W(Z) = M_A(Z) - A \cdot m_n + Z \cdot \tilde{m} ,$$

where $\tilde{\mathrm{m}} = \mathrm{m}_\mathrm{n} - \mathrm{m}_\mathrm{p} - \mathrm{m}_\mathrm{e} = 782.3\,\mathrm{kev}$, m_e is electron mass. The allowance for electron mass in these relations may seem to be not essential and incapable of changing the minimum of $M_N(Z)$ in Z, as compared with that of

$M_A(Z)$. One should, however, allow for the fact that nuclear electric charge may be an integer only. Therefore, in the case when the minimum of the function $M_A(Z)$ in Z is close to a half-integer, the addition of relatively small value $Z \cdot m_e/M_A(Z)$ may change the closest integer by the unity.

As far as the function $M_A(Z)$ differs from $M_N(Z)$ by addition of a linear term, qualitatively these functions behave similarly, but the minimums of $M_N(Z)$ function can be shifted toward larger values of Z. Similarly, the maximums of the binding energy W(Z) on isobars can be shifted towards smaller values of Z as compared to minimums of $M_A(Z)$ function.

Indeed, a simple analysis of the database [2] on the binding energy of nuclei and on mass defects shows that

(i) *all* the stable isotopes realize the *minimum* of $\Delta M(Z)$ and the *maximum* of $\Phi_F(Z)$ (note that the stability of five isotopes residing in the center of the plateau between two stable isotopes, namely ^{40}K, ^{50}V, ^{138}La, ^{176}Lu, ^{180}Ta, agrees with this statement);

(ii) more than 30 isotopes, which realize the *minimum* of M(Z), are unstable with respect to K-capture; these include, e.g., ^{71}Ge (11.4 days), ^{72}Se (8.4 days), ^{73}As (80.3 days), ^{82}Sr (25.6 days), ^{100}Pd (3.6 days), ^{118}Te (6 days), ^{125}I (59.4 days), ^{131}Cs (9.7 days), ^{178}W (21.6 days), ^{181}W (121.2 days), ^{195}Au (186.1 days), ^{201}Tl (72.9 hours);

(iii) more than 40 isotopes, which realize the maximum of the binding energy W(Z), are β-active; these include, e.g., ^{33}P (25.3 days), ^{47}Sc (3.3 days), ^{66}Ni (54.6 hours), ^{67}Cu (61.83 hours), ^{72}Zn (46.5 hours), ^{197}Pt (19.9 hours), ^{209}Pb(3.3 hours).

One more confirmation is that a number of natural isotopes which do not possess minimal value of the function $M_A(Z)$, are unstable, though they are the long-lived ones (see Table 1).

Isotope	Natural abundance %	Channels of nuclear decay	Energy of nuclear transition, keV	Half life, years
^{40}K	0.012	β^- 89.3	1311	$1.277 \cdot 10^9$
		$\varepsilon(\beta^+)$ 10.7	1505	
^{48}Ca	0.187	β^-	278	$6 \cdot 10^{18}$
^{50}V	0.25	β^- 17	1037	$1.4 \cdot 10^{17}$
		$\varepsilon(\beta^+)$ 83	2208	
^{87}Rb	27.85	β^-	283	$4.75 \cdot 10^{10}$
^{96}Zr	2.8	β^-		$3.8 \cdot 10^{19}$

Isotope	Natural abundance %	Channels of nuclear decay	Energy of nuclear transition, keV	Half life, years
^{113}Cd	12.22	β^-	316	$7.7\cdot10^{15}$
^{115}In	95.77	β^-	496	$4.4\cdot10^{14}$
^{123}Te	0.9	ε	53	$>10^{13}$
^{138}La	0.09	β^- 33.6	1044	$1.05\cdot10^{11}$
		$\varepsilon(\beta^+)$ 66.4	1738	
^{176}Lu	2.59	β^-	1192	$3.78\cdot10^{10}$
^{187}Re	62.6	β^-	2.66	$4.35\cdot10^{10}$
^{180}Ta^{m}	0.012	γ	75.3	$1.2\cdot10^{15}$

Table 1. Unstable natural isotopes.

Conversely, there is no natural β-stable isotopes of atomic mass 5 and 8 because they are unstable with respect to the following decays: $^5He \rightarrow {}^4He + n$, $^8Be \rightarrow 2\cdot{}^4He$, which are due to strong interaction.

Also, there is natural isotope $^{180}Ta^m$ which is a long-lived ($1.2\cdot10^{15}$ years) isomer (i.e. a nucleus in an excited state). Such a long lifetime may be explained by the large difference of spin values in isomer (9-) and ground (1+) states.

Note that the «intrinsically» β-stable isotopes are those, which possess absolutely minimal atomic mass M_A on the isobar, because the isotopes which correspond to local minima, may decay to attain absolute minimum via either double $\beta^{\pm}$-decay or double K-capture (Fig. 1b). The probability of such processes is small, though. E.g., the double β^--decay was detected for ^{82}Se (10^{20} years), ^{100}Mo (10^{19} years), ^{128}Te ($2.2\cdot10^{24}$ years) and ^{150}Nd ($>10^{19}$ years). For these isotopes, the ordinary β^--decays are energetically forbidden. Such a situation differs from the double β^--decay of ^{96}Zr which is unstable with respect to ordinary β^--decay as well ($^{96}Zr \rightarrow {}^{96}Nb \rightarrow {}^{96}Mo$).

3 The β-stability of ionized atoms

Now we consider the problem of the impact of atom's ionization on the β-stability of atomic nucleus. This assumes the allowance for:

- the change of the energy of electron atomic states (because nuclear electric charge strongly influences the atomic ionization potentials);
- the possibility of the capture of ejected β-electron into the bound state in the atom.

Note that the very presence of atomic electron allows the possibility of the K-capture which, from energy minimization viewpoint, is preferable as compared to positronic β^+-decay. Therefore, one can expect the following most probable and detectable effect. As far as full ionization of the atom eliminates the possibility of K-capture, and the positronic β^+-decay requires energy change, which, as compared to K-capture, is larger by the value $2\cdot m_e$ (2·511 keV), the following statement holds true.

- The nuclei, which are unstable with respect to K-capture with energy release of less than 1 MeV, should be stable if the atom is fully ionized.

Further, in analyzing the energy release in reactions with weak interactions, we use the well- known Thomas-Fermi approximation for atomic electron density. Thus, for the ionization potential of complete ionization one has:

$$I(Z) \cong 20.8 \cdot Z^{7/3} eV \cdot$$

This equation works well for large values of Z. As to small values of Z, for which the Thomas-Fermi approximation is not good, the ionization potential is small as compared to the energy released in considered nuclear reactions. In the case of hydrogen-like ion (i.e. ion with a single residual electron), the ionization potential is described well with the approximation:

$$I^{le}(Z) = 13.6 \cdot Z^2 eV \cdot$$

Note that the difference between ionization potentials of neighboring elements, $I(Z+1)–I(Z) \propto Z^{4/3}$, rises, with growing Z, slower than hydrogen-like ionization potential, and besides, for the majority of atoms (namely, for $Z>7$) one has:

$$I(Z+1) - I(Z) < I^{le}(Z) < I^{le}(Z+1) \,,$$

It is easy to derive the following relation for the energy released in the K-capture of the last residual electron in the hydrogen-like ion:

$$Q = Q_0 + I(Z) - I(Z-1) - I^{le}(Z) < Q_0 \,,$$

where Q_0 is the energy released in K-capture in the neutral atom. The ionization of atom obviously reduces the energy released in K-capture. Our analysis of the database on the binding energy of nuclei, has lead us to the following conclusion.

- A number of nuclei are found, which are unstable with respect to K-capture in the neutral atoms and should be stable if the atom is highly (not fully yet) ionized

^{163}Ho (4570 y.), ^{193}Pt (50 y.), ^{194}Hg (444 y.), ^{202}Pb ($5.25\cdot10^4$ y.), ^{205}Pb ($1.53\cdot10^7$ y.)

Similarly to last equation for β-unstable nuclei, the energy released in β-decay, Q, also decreases under complete ionization of the atom:

$$Q = Q_0 + I(Z) - I(Z-1) < Q_0\,,$$

However, for β-unstable nuclei the situation is complicated with the possibility of capturing the ejected β-electron by the atom into bound atomic state under high ionization of the atom – whereas above equation pertains only to the case when ejected β-electron is not captured by the mother atom and freely escapes from the atom.

4 The bound-state β-decay

The theory of β-decay with the capture of ejected β-electron into the bound state in the atom (i.e. when β-electron doesn't escape from the atom and occupies a bound atomic state) was developed in [3 – 6]. Such a decay is obviously an inverse process with respect to K-capture. It was noticed that such a decay broadens the volume, in the phase space, of the final state and, hence, increases the probability of the decay.

Similarly to above equations, one has the following relation for β^--decay of the nucleus in the fully ionized atom with the capture of β-electron by the atom:

$$Q = Q_0 + I(Z) - I(Z+1) + I^{le}(Z+1) > Q_0\,.$$

It is seen that under full ionization of the atom the bound-state β-decay appears to be energetically preferable as compared to β-decay of the neutral atom. Our analysis of the database gives the following conclusion.

- A number of nuclei are found, which are stable in the neutral atom and should be unstable with respect to bound-state β-decay if the nucleus is bare (i.e. under full ionization of the atom):

$$^{163}\mathrm{Dy},\ ^{193}\mathrm{Ir},\ ^{205}\mathrm{Tl}.$$

As far as the K-capture decreases the charge of the nucleus and the β^--decay increases it, stabilization of the nucleus with respect to K-capture, and the enhancement and/or onset of the bound-state β-decay, result in a shift of the stability threshold towards larger values of Z, as formulated below.

- Under high degree of atom's ionization, the β-stability threshold moves towards larger values of Z, i.e. towards decreasing the neutron/proton ratio in the nucleus.

The calculation of the ratio of probabilities for β-decay into, respectively, bound and free state of ejected β-electron is similar to conventional calculation of the ratio of probabilities of K-capture and positronic β^+-decay [7].

The probability of nuclear β-decay is proportional to the volume of phase space of the final state of electron-neutrino compound system. For the decay in energy-continuum state, such volume is a sum of the states of emitted electron, which covers all the directions of electron momentum and the energies less than nuclear transition energy (the momentum's direction and the energy of neutrino are determined, in turn, by the energy-momentum conservation law). The above volume is known to be proportional to the Fermi integral function (in atomic units $\hbar = \mathrm{c} = \mathrm{m_e} = 1$):

$$\mathrm{f(Z,E)} = \int_1^{\mathrm{E}} \mathrm{F}\left(\mathrm{Z},\varepsilon\right)\cdot\varepsilon\sqrt{\varepsilon^2-1}\cdot(\mathrm{E}-\varepsilon)^2\,\mathrm{d}\,\varepsilon$$

were E is the energy of nuclear transition; Z, nuclear electric charge. For E >> 1 the Fermi function is well approximated with the dependence:

$$\mathrm{f}{\sim}\mathrm{E}^5/30.$$

For the decay in the bound state of the emitted electron, the above volume depends on the direction of neutrino's momentum only, because electron's energy is fixed to be the energy of the bound state. In this case the volume of phase space is proportional to

$$p^2=(E-1-\varepsilon_K)^2/c^2,$$

were $\varepsilon_K<<1$ is the energy of the bound state

- For all the allowed nuclear transition, the appearance of unoccupied electron state in the atom increases λ, the constant of β-decay, by the value Δλ (in atomic units $\hbar = c = m_e = 1$):

$$\frac{\Delta\lambda}{\lambda}=\frac{\pi}{2}\cdot\frac{\left|\Psi_e(R)\right|^2\cdot(E-1)^2}{f(Z,E)}\sim\frac{2\pi\cdot(\alpha\cdot Z)^3\cdot(E-1)^2}{N^3\cdot f(Z,E)}\sim 60\pi\left(\frac{\alpha Z}{E}\right)^3,$$

where $\varnothing_e(R)$ is the value of electron's wave function in the point of nucleus location, $\alpha=1/137$ is the fine structure constant, N, principal quantum number of unoccupied state of electron in the atom. The second relation is derived within the approximation of hydrogen-like atomic state of electron.

It is seen from the above that the ratio Δλ/λ for the decay's channel with small transition energy E has to exceed Δλ/λ of decay with larger energy.

The role of the bound-state β-decay is most essential just for

(i) transitions with small energies, and

(ii) nuclei with large Z

similarly to enhancement of the K-capture channel, as compared to positronic β^+-decay, with decreasing nuclear transition energy and increasing nucleus' electric charge. For the majority of heavy nuclei's β^--decays there is a number of excited states of the daughter nucleus, available for such a β^--decay. Therefore, the relative shift Δλ/λ is higher for transitions with smaller value of energy E, i.e. for transitions to upper-lying (i.e. excited) states of the daughter nucleus. We calculated the ratio of decay constants (i.e. of decay probabilities) in the bound, λ_b, and free, λ_c, states of ejected β-electron. For β^--decay of the fully ionized heavy atoms with small transition energy the ratio λ_b/λ_c may be as large as $10^3\div10^4$. This implies that the presence of unoccupied electron states may rise up the probability of nuclear β^--decay by the factor of several thousands.

The theory of bound-state β-decay has been experimentally confirmed in the works [8, 9]. In the work [9] it was experimentally shown that full ionization of atom ^{187}Re decreases the half-lifetime by a factor of 10^9, from $4.3\cdot10^{10}$ years for neutral atom to 33 years for bare nucleus.. The peculiarity of ^{187}Re stems from the fact that the bound-state β-decay of the fully ionized atom may go via nuclear transition to the excited state of ^{187}Os (9.75keV).

The latter results in a substantial rise of decay probability because the newly open channel of β-decay corresponds to transition between nuclear states whose spin differs by the unity ($5/2^+ \rightarrow 3/2^-$) whereas β-decay to the ground nuclear state (transition $5/2^+ \rightarrow 1/2^-$) is forbidden, by the spin selection rules, to a higher extent. In the given case, full ionization of atom decreases the half-lifetime by the factor of 10^9, from $4.3 \cdot 10^{10}$ years for neutral atom to 33 years for bare nucleus

The above-mentioned papers treat the bound-state β-decay as being opened due to atom's ionization. There are, however, other ways to produce unoccupied electron states. For instance, B.B. Kadomtsev [10, 11] studies the problem of transformation of electron states in an atom in a strong magnetic field. It follows that the application of a strong magnetic field to a heavy atom produces unoccupied atomic levels in this atom and thus opens the bound-state β-decay channel.

Such an effect makes it reasonable to address the problem of the impact of a strong magnetic field on the fraction of delayed neutrons in nuclear power plant reactor. Now we turn to a model which implicitly relies on the possibility of the change of weak interaction (including the beta-decays) due to atomic processes.

5 A phenomenological model of nuclear transformation

Let's consider a hypothetical collective nuclear processes with participation of the weak interactions, satisfying eq.:

$$\sum_i {}^{A_i}_{Z_i}X_i \rightarrow \sum_j {}^{A_j}_{Z_j}Y_j + ke^- + k\bar{\nu}_e + Q \ ,$$

where X_i and Y_j are the nuclei with, respectively, nuclear mass A_i and electric charge Z_i (in units of electron's charge) – these include the case of the free neutron (A=1, Z=0), k is the number of electrons involved in reaction; k can be positive (in the case of β- decay) or negative (in the case of K-capture), or equal zero (in the case of strong interactions only). It is assumed that, in general case, there can be the replicating nuclei in both initial (X_i) and final (Y_i) sets of nuclei. It is well-known, that for known nuclear processes the laws of conservation hold for the energy, momentum, angular momentum, baryonic charge (which is the number of nucleons):

$$\sum_i A_i = \sum_j A_j \ ,$$

electric charge:

$$\sum_{i} Z_i + k = \sum_{j} Z_j ,$$

and lepton charge as well. Note that weak interactions may break the conservation of spatial parity.

We define the manifold $\Re$ of nuclear ensembles $\{X_i\}$: the element of $\Re$ is an ensemble of nuclei. Thus, the considered process represents a transition between two elements of $\Re$. The problem of constructing a phenomenological model of such a process, without specification of the mechanism of this process, may be formulated as follows: within the manifold of the nuclear ensembles $\Re$ one has to find ensembles $\{Y_i\}$ whose total energy is closest to that of the initial ensemble $\{X_i\}$, under condition of conservation laws for the following charges

- baryonic charge (the number of nucleons);
- electric charge;
- leptonic charge.

Remind that neutrinos may carry away a part of the released energy Q but its value may be much less than in the ordinary, non-collective reaction due to weak interaction – the hypothetical collective process may allow for neutrino to possess arbitrary small momentum

We shall describe the ensemble of nuclei $\{X_i\}$ as a set of integers $\{a_i\} \equiv \vec{a}$, where a_i – the number of nuclei X_i in the ensemble; the vector $\vec{a}_i$ is defined to be an ensemble consisting of a single nucleus X_i. On the manifold $\Re$ we define the norm:

$$\|\vec{a}\| \equiv \sum_{i} a_i A_i q_i ,$$

where

$$q_i \equiv q(X_i) \equiv M_A({}^1_1H) - \frac{M_A(X_i)}{A_i} ,$$

Using the isotopes data, it is easy to find that q(X)> 0 for all the known isotopes (including unstable ones), with the maximum q(X) being achieved at ^{56}Fe. The physical sense of the introduced norm is that it is the energy required for decomposing the nucleus to protons, i.e. decomposing the nucleus to protons and neutrons with the subsequent transformation of all the neutrons into protons:

$$X_i \rightarrow A_i \cdot {}_1^1H + (A_i - Z_i) \cdot e^- + (A_i - Z_i) \cdot \tilde{\nu}_e - Q\,, \qquad Q = \left\| \vec{a}_i \right\|.$$

Note that zero value of the norm corresponds to quasi-neutral ensemble consisting of protons and electrons only.

In such a formulation, the problem assumes a search for the ensembles $\{b_i\} \equiv \vec{b}$ with the norm, close to that of the initial ensemble $\{a_i\} \equiv \vec{a}$, i.e. $\left| \|\vec{b}\| - \|\vec{a}\| \right| < \varepsilon$, where ε is a small. It is easy to check, that transition from ensemble $\vec{a}$ to ensemble $\vec{b}$ implies the nuclear reaction:

$$\sum_i a_i \cdot {}_{Z_i}^{A_i}X_i \rightarrow \sum_i b_i\, {}_{Z_i}^{A_i}X_i + N_H \cdot {}_1^1H + ke^- + k\tilde{\nu}_e + Q\,,$$

where

$$N_H = \sum_i (a_i - b_i) \cdot A_i$$

is the number of released (N_H> 0) or annihilated (N_H <0) protons,

$$k = \sum_i (a_i - b_i) \cdot (A_i - Z_i)$$

is the number of released (k> 0) or annihilated (k <0) electrons,

$$Q = \sum_i (b_i - a_i) \cdot A_i \cdot q_i$$

is the released (Q>0) or absorbed (Q<0) energy. Introduction of the norm allows to substantially simplify the problem of selecting the combination of nuclei because while selecting the combination $\vec{b}$ it is actually possible not to watch for the conservation of electric and baryonic charges. The conservation laws for these charges are fulfilled by subsequent calculation of the numbers of protons and electrons.

Hence we came to an algebraic task. Assuming that the binding energy and, hence, the norms $Q_1 = \|\vec{a}_1\|$ and $Q_2 = \|\vec{a}_2\|$ of two nuclei X_1 and X_2 are known precisely and are the rational numbers, the ratio Q_1/Q_2 can be represented as a ratio of two integers N_2/N_1. In this case, two combinations $N_1 \cdot X_1$ and $N_2 \cdot Y_2$ have *equal* energies. That is, the transformation $N_1 \cdot X_1 \rightarrow N_2 \cdot Y_2 + \ldots$ can occur without the change of energy. However the coefficients derived in this case (i.e. the number of particles in the ensemble) can be so large that the respective transformation will be of no practical interest. The suggested example illustrates, however, only the theoretical opportunity of finding the combinations with very close energies. Practically, numerical selection of combinations is limited by the accuracy of measurements of nuclear binding energies ($\Delta Q \sim 1$ keV).

In constructing the model of transformation, we introduce a nucleon-exchange elementary act which is defined as an exchange of nucleons within a cluster consisting of initial nuclei. The change of energy in each nucleon-exchange elementary act should not exceed 10÷30 keV. The numerical model contains a number of parameters:

1. the range of allowable energy changes in the nucleon-exchange elementary act;
2. the size of the cluster in the nucleon-exchange elementary act;
3. the number of nucleons redistributed between the nuclei in the cluster

The number of possible ways to decompose the initial cluster containing N nucleons amounts to $\sim 2^N$, that is so great that it is obviously impossible to consider all the combinations. It appears, however, that two first parameters may be roughly evaluated from experimental data so that only the third parameter has to be varied to attain the convergence to final result. This strategy allows to substantially diminish the number of combinations under search. If the number of redistributed nucleons is less than 30 and the changes of energy in the nucleon-exchange elementary act is less than 30 keV, for the case of initial ensemble consisting of 5÷10 isotopes, about $10^4 \div 10^6$ nucleon-exchange elementary acts are found to satisfy these conditions.

The final result of calculation is obtained by averaging over all relevant nucleon-exchange elementary acts, which allows for statistical weights of each nucleon-exchange elementary acts in the given initial distribution of nuclei. The resulted final distribution of nuclei indicate the nuclei that have appeared and disappeared in the transformation process. For example, the experimental data and calculation result of transformation of Ti+VCl_3+H_2O is shown in Fig.2

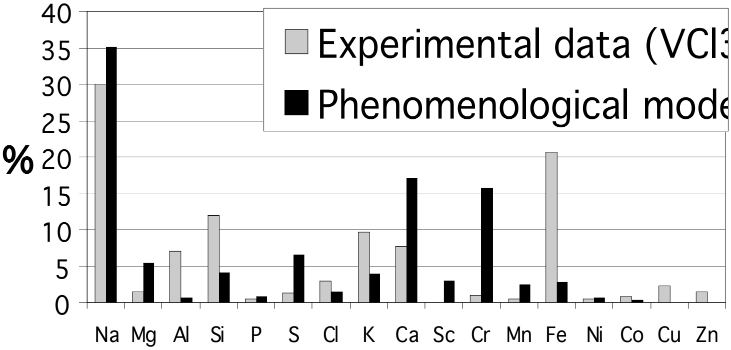


Fig. 2. Distribution of elements in experiment's products

For testing the phenomenological model, the transformation of the titanic foil, during its electric explosion in the water and glycerin, has been considered. In this case, in particular, the following nucleon-exchange elementary acts are found for the minimal energy changes, namely |Q|<1 keV (i.e. when the change of energy is less than the accuracy of measurements of nuclear binding energy):

$$2\cdot{}^{49}_{22}\mathrm{Ti} + 4\cdot{}^{1}_{1}\mathrm{H} \to 4\cdot{}^{4}_{2}\mathrm{He} + {}^{40}_{19}\mathrm{K} + {}^{46}_{22}\mathrm{Ti} + \mathrm{e} + \mathrm{o(1kev)}$$

$${}^{51}_{23}\mathrm{V} + {}^{48}_{22}\mathrm{Ti} + {}^{18}_{8}\mathrm{O} \to {}^{57}_{26}\mathrm{Fe} + {}^{23}_{11}\mathrm{Na} + {}^{37}_{17}\mathrm{Cl} + \mathrm{e} + \mathrm{o(1kev)}$$

$${}^{48}_{22}\mathrm{Ti} + 2\cdot{}^{40}_{18}\mathrm{Ar} + {}^{16}_{8}\mathrm{O} \to {}^{15}_{7}\mathrm{N} + {}^{37}_{17}\mathrm{Cl} + {}^{38}_{18}\mathrm{Ar} + {}^{54}_{24}\mathrm{Cr} + \mathrm{o(1kev)}\mathbb{S}$$

$$2\cdot{}^{47}_{22}\mathrm{Ti} + 2\cdot{}^{40}_{18}\mathrm{Ar} + {}^{12}_{6}\mathrm{C} \to {}^{16}_{8}\mathrm{O} + {}^{34}_{16}\mathrm{S} + {}^{46}_{20}\mathrm{Ca} + 2\cdot{}^{45}_{21}\mathrm{Sc} + \mathrm{o(1kev)}$$

$$5\cdot{}^{16}_{8}\mathrm{O}+2\cdot{}^{12}_{6}\mathrm{C}+\mathrm{e}\rightarrow{}^{23}_{11}\mathrm{Na}+2\cdot{}^{1}_{1}\mathrm{H}+2\cdot{}^{15}_{7}\mathrm{N}+{}^{20}_{10}\mathrm{Ne}+{}^{29}_{14}\mathrm{Si}+\mathrm{o(1kev)}$$

$$6\cdot{}^{50}_{23}\mathrm{V}+3\cdot{}^{13}_{6}\mathrm{C}+{}^{46}_{22}\mathrm{Ti}+{}^{50}_{22}\mathrm{Ti}\rightarrow{}^{57}_{26}\mathrm{Fe}+3\cdot{}^{14}_{7}\mathrm{N}+{}^{42}_{20}\mathrm{Ca}+6\cdot{}^{49}_{22}\mathrm{Ti}-\mathrm{e}+\mathrm{o(1kev)}$$

$$8\cdot{}^{48}_{22}\mathrm{Ti}+3\cdot{}^{16}_{8}\mathrm{O}+6\cdot\mathrm{e}\rightarrow{}^{9}_{4}\mathrm{Be}+{}^{18}_{8}\mathrm{O}+4\cdot{}^{49}_{22}\mathrm{Ti}+2\cdot{}^{50}_{22}\mathrm{Ti}+{}^{52}_{24}\mathrm{Cr}+{}^{57}_{26}\mathrm{Fe}+\mathrm{o(1kev)}$$

$$11\cdot{}^{48}_{22}\mathrm{Ti}+2\cdot{}^{16}_{8}\mathrm{O}+4\cdot\mathrm{e}\rightarrow{}^{4}_{2}\mathrm{He}+{}^{12}_{6}\mathrm{C}+{}^{37}_{17}\mathrm{Cl}+7\cdot{}^{49}_{22}\mathrm{Ti}+{}^{53}_{24}\mathrm{Cr}+{}^{55}_{25}\mathrm{Mn}+{}^{56}_{26}\mathrm{Fe}+\mathrm{o(1kev)}$$

It would be a mistake to consider the above nucleon-exchange elementary acts as nuclear reactions resulted from a simultaneous collision of a large number of nuclei. These examples describe transitions from one state into another, while the mechanism of transition is not clear yet. It is possible to assume only, that there is some (probably resonant) transition due to influence of a novel interaction.

Note that in solving the above problem the number of the processed nucleon-exchange elementary acts is as large as $10^5 \div 10^6$, so that the above-mentioned examples are the illustrations only. We have to emphasize that if we consider transformations of a large number of nuclei and allow mutual transformation of protons and neutrons, it is possible to find final ensembles with the energies close enough to that of initial ensemble, namely with the difference within the range of chemical binding energies (~100 eV/atom). Good qualitative agreement between experiment and such a modeling may be illustrated with the fact that both in the experiment on electric explosion of titanic foil in the water and in the results of modeling, no elements appear which are heavier than zinc.

The outlined model requires much work to do to be completed. It is, anyway, significant to analyze, first of all, the opportunity of the model to predict qualitatively the effects which might be seen in the experiment. The results of such an analysis for a particular case are given below.

Our analysis of the probes of deposits in the electric discharges loaded on titanic foil, have shown a decrease of the amount of vanadium which was major impurity in the titanic foil. The numerical modeling predicts the following qualitative effects which might be observed in the case of transformation of a substantial amount of vanadium, namely:

distortion of the natural isotopic ratio of iron towards an increase of the isotope ^{57}Fe.

Interestingly, just an increase of the amount of ^{57}Fe appears to be a distinctive feature of the transformation of vanadium, and this prediction does not depend on the parameters of modeling: always the isotopic ratio of ^{57}Fe substantially exceeds the equilibrium natural isotopic ratio. For the case of initial compound system V+H_2O, if transformation is modeled in terms of nucleon-exchange elementary acts with the number of displaced nucleons less than 10 and with the change of energy in such an act less than 20 keV, the results of modeling predicted an increase of isotopic ratio of ^{57}Fe up to 15% against its natural ratio of 2.2% only. Similar modeling for the initial compound system Ti+H_2O doesn't give distortion of isotopic ratio of ^{57}Fe. Therefore the net result for the compound V+Ti+H_2O has to give less than 15% ratio of ^{57}Fe in the final state. Anyway, the proposed model predicts, at least qualitatively, a noticeable increase of isotopic ratio of ^{57}Fe with respect to its natural value just thanks to transformation of vanadium.

The conducted follow-up experiment on electric explosion of titanium foil in the solution of vanadium salts (VCl_3 and NH_4VO_3) did confirm this item put forward for verification. In particular, the isotopic ratio of ^{57}Fe in the discharge's products was found to be 3.7±0.5% that exceeds its natural value by a value of about three experimental errors. Such a confirmation suggests the proposed approach to modeling the transformation of elements to be reasonable and fruitful.

6 Discussion and conclusions

The major conclusion of the paper is that the potentiality of a hypothetical collective process of low-energy nuclear transformations is shown to be compatible with the known fundamental conservation laws. This claim is suggested by our successful attempt for a phenomenological description of such a process – first of all, by a number of successful qualitative predictions verified by the experiment.

Specifically, comparison of the results of modeling with experimental data show that the known fundamental conservation laws allow the existence of a hypothetical collective process of low-energy nuclear transformations which may manifest itself in the following way.

1. This process may proceed at small input/output energies per participating atom, namely those of the scale of chemical energies.
2. The final ensembles with values of energy closest to that of the initial ensemble appear to consist of stable isotopes, if the initial ensemble consists of stable isotopes as well.

In other words, the success of the proposed phenomenological model may be considered as an indirect evidence for

(i) probable collective nature of a hypothetical process of nuclear transformation and,
(ii) probable importance of weak interactions in describing the above process (more precisely – the importance of proton-neutron transformations due to the known fundamental interactions, namely, weak interaction, or some unknown ones).

Completion of the proposed model, even without specification of the mechanism of transformation, will allow making a preliminary estimates of the expected production of elements from the given input elements, and what is even more important, estimating the relevant input elements to produce requested output elements

It looks like now there are no theories capable of describing the phenomenon under consideration. Though the mechanism of transformation of nuclei is not understood yet, it is natural to assume that there is some catalyst which may unite nuclei in a cluster and thus create a conditions for a resonance, which might initiates an exchange of nucleons. We consider the George Lochak's magnetic monopole to be one of possible candidates for such a catalyst. Magnetic monopole, proposed by Lochak, is a lepton, i.e. participates in the electroweak interactions and can be treated as a magnetically excited state of neutrino. Such a monopole is massless (or nearly massless), very light (from the viewpoint of energy scale) and can be born, for example, in electromagnetic phenomena in a condensed matter [1, 12].

References

[1] Urutskoev L.I., Liksonov V.I., Tsinoev V.G. Experimental detection of a "strange" radiation and the transformation of chemical elements. Applied Physics (in Russian), 2000, v. 4, pp. 83-100.

[2] Audi G., Wapstra A.H. The 1995 update to the atomic mass evaluation. Nuclear Physics A595 vol. 4, p. 409-480 (1995).

[3] Bahcall J.N. Theory of bound-state beta decay.// Phys. Rev., 1961. v. 124. #2. p. 495.

[4] Batkin I.S. On the problem of bound-state β decay.// Izvestia USSR Acad. Sci. (USSR Acad. Sci. Reports), Series Physics, 1976. v.40. #6. p. 1279.

[5] Takahashi K., Yokoi K. Nuclear β-decays of highly ionized heavy atoms in stellar interiors.// Nucl. Phys., 1983. v. A404. p. 578.

[6] Takahashi K., Boyd R.N., Mathews G.J., Yokoi K. Bound-state beta decay of highly ionized atoms.// Phys. Rev., 1987. v. C36. #4. p. 1522.

[7] Preston M.A. Physics of the nucleous.// London: Palo Alto, 1962.

[8] Jung M., Bosch F., Beckert K, et al. First observation of bound-state β^- decay.// Phys. Rev. Lett., 1992. v. 69. #15. p. 2164.

[9] Bosch F., Faestermann T., Friese J., et al. Observation of bound-state β^- decay of fully ionized ^{187}Re: ^{187}Re – ^{187}Os cosmochronometry.// Phys. Rev. Lett., 1996. v. 77. #26. p. 5190.

[10] Kadomtsev B.B. Heavy atom in a superstrong magnetic field.// Zh.E.T.F. (Sov. Phys. JETP), 1970. v. 58. #5. p. 1765.

[11] Kadomtsev B.B., Kudryavtsev V.S. Substance in a superstrong magnetic field.// Zh.E.T.F. (Sov. Phys. JETP), 1972. v. 62. #1, p. 144.

[12] Volkovich A.G., Govorun A.P., Gulyaev A.A., Zhukov S.V., Kuznetsov V.L., Rukhadze A.A., Steblevskii A.V., Urutskojev L.I. Observations of effects of isotope ratio distortions in Uranium and breakdown of secular distribution for Thorium-234 under condition of electric explosion.//Brief communications on physics (P.N. Lebedev Physics Institute), 2002. #8. p.45.