Outline of Polyneutron Physics

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The Elements

Element	Charge	
Nt	0	neutrium
H	1	
He	2	
Li	3	
Be	4	
B	5	
C	6	
N	7	
O	8	

Terminology: $^{1}\mathrm{Nt}$ = neutron

$^{A}\mathrm{Nt}$ = polyneutron (neutrium isotope)

Concept

Nuclear physics is incomplete
It can be extended to include polyneutrons
Polyneutrons explain cold fusion phenomena

Mass Excesses

Element	Charge	Mass Excess		
Nt	0	$\Delta(^1\mathrm{Nt}) = 8.071$		
H	1	$\Delta(^1\mathrm{H}) = 7.289$	$\Delta(^2\mathrm{H}) = 13.126$	$\Delta(^3\mathrm{H}) = 14.950$
He	2	$\Delta(^3\mathrm{He}) = 14.931$	$\Delta(^4\mathrm{He}) = 2.425$	
Li	3	$\Delta(^6\mathrm{Li}) = 14.086$	$\Delta(^7\mathrm{Li}) = 14.908$	
O	8	$\Delta(^{16}\mathrm{O}) = -4.737$	$\Delta(^{18}\mathrm{O}) = -0.782$	

$$^2\mathrm{H} + {}^2\mathrm{H} \longrightarrow {}^3\mathrm{H} + {}^1\mathrm{H} + \mathcal{E}_1$$

$$\mathcal{E}_1 = 13.126 + 13.126 - 14.950 - 7.289 = 4.013 \text{ MeV}$$

$$^2\mathrm{H} + {}^2\mathrm{H} \longrightarrow {}^3\mathrm{He} + {}^1\mathrm{Nt} + \mathcal{E}_2$$

$$\mathcal{E}_2 = 13.126 + 13.126 - 14.931 - 8.071 = 3.250 \text{ MeV}$$

$$^2\mathrm{H} + {}^2\mathrm{H} \longrightarrow {}^4\mathrm{He} + \mathcal{E}_\gamma$$

$$\mathcal{E}_\gamma = 13.126 + 13.126 - 2.425 = 23.827 \text{ MeV}$$

Polyneutron Binding

Assume BCS model for polyneutron fluid.

Pairs of neutrons of opposite spin and momentum attract each other.

Neutrons attract each other forcefully and directly.

Not weakly and indirectly as for electrons via phonons.

With strong interaction and full access to momentum space polyneutrons will be strongly bound.

Collective binding of neutron pairs is expected to be much stronger than binding of electron pairs.

Polyneutron Mass Excess

Experiment shows near zero binding for ^{4}Nt.

$$4\Delta(\mathrm{n}) = 32.284 \qquad \Delta(^4\mathrm{Nt}) \approx 32$$

Full binding per neutron not achieved for polyneutrons smaller than a coherence number A_c.

I assume $A_c = 12$ neutrons to achieve full binding.

I assume a liquid drop model for the polyneutron mass excess.

$$\Delta(^A\mathrm{Nt}) = a_v A + a_s A^{2/3} \qquad (A \geqslant 12)$$

The mass excess is a minimum at $A = 12$, and for $A<12$ it rises abruptly toward $\Delta(^4\mathrm{Nt})$.

Consequence: Reactions that generate polyneutrons ^{A}Nt are endothermic for $A<12$.

Approach

Accept the reality of established nuclear effects
seen in electrolysis and transmutation experiments.

Accept the established principles of nuclear physics.

Extend the scope of nuclear physics to include polyneutrons.

Approach (continued)

Polyneutron mass excesses $\Delta(^{A}\mathrm{Nt})$ determine reaction energies.

Assume a liquid drop model

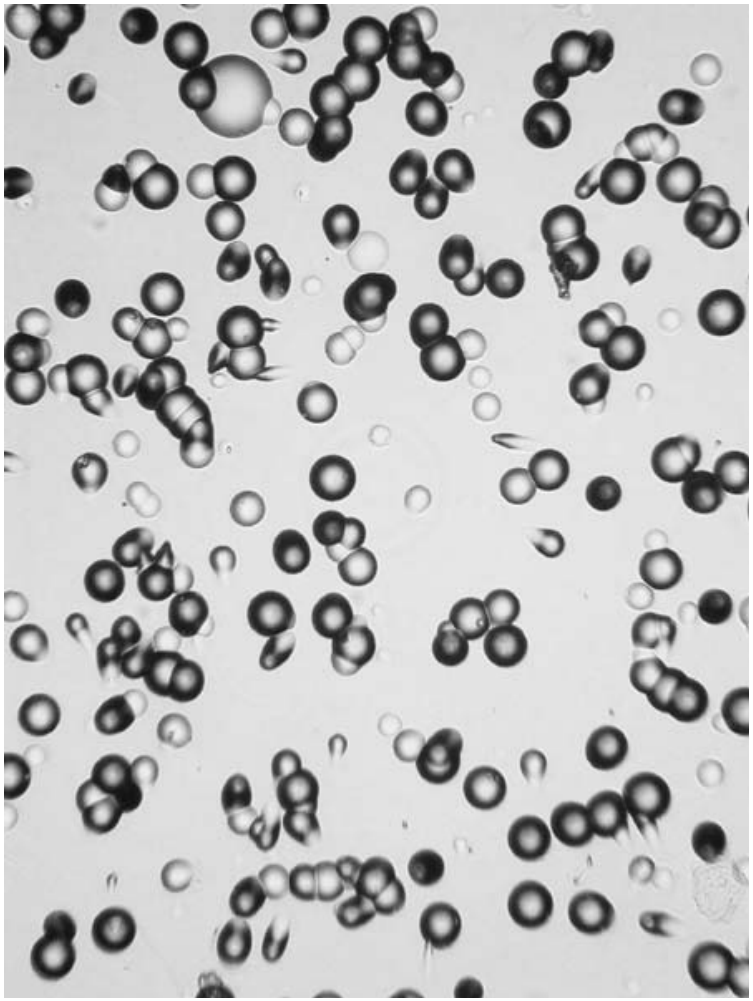
$$\Delta(^{A}\mathrm{Nt}) = a_v A + a_s A^{2/3} \qquad (A \geqslant 12)$$

The model implies

$$\begin{aligned} D &= \Delta(^{A+1}\mathrm{Nt}) - \Delta(^{A}\mathrm{Nt}) \\ &= a_v + (2/3) a_s A^{-1/3}. \end{aligned}$$

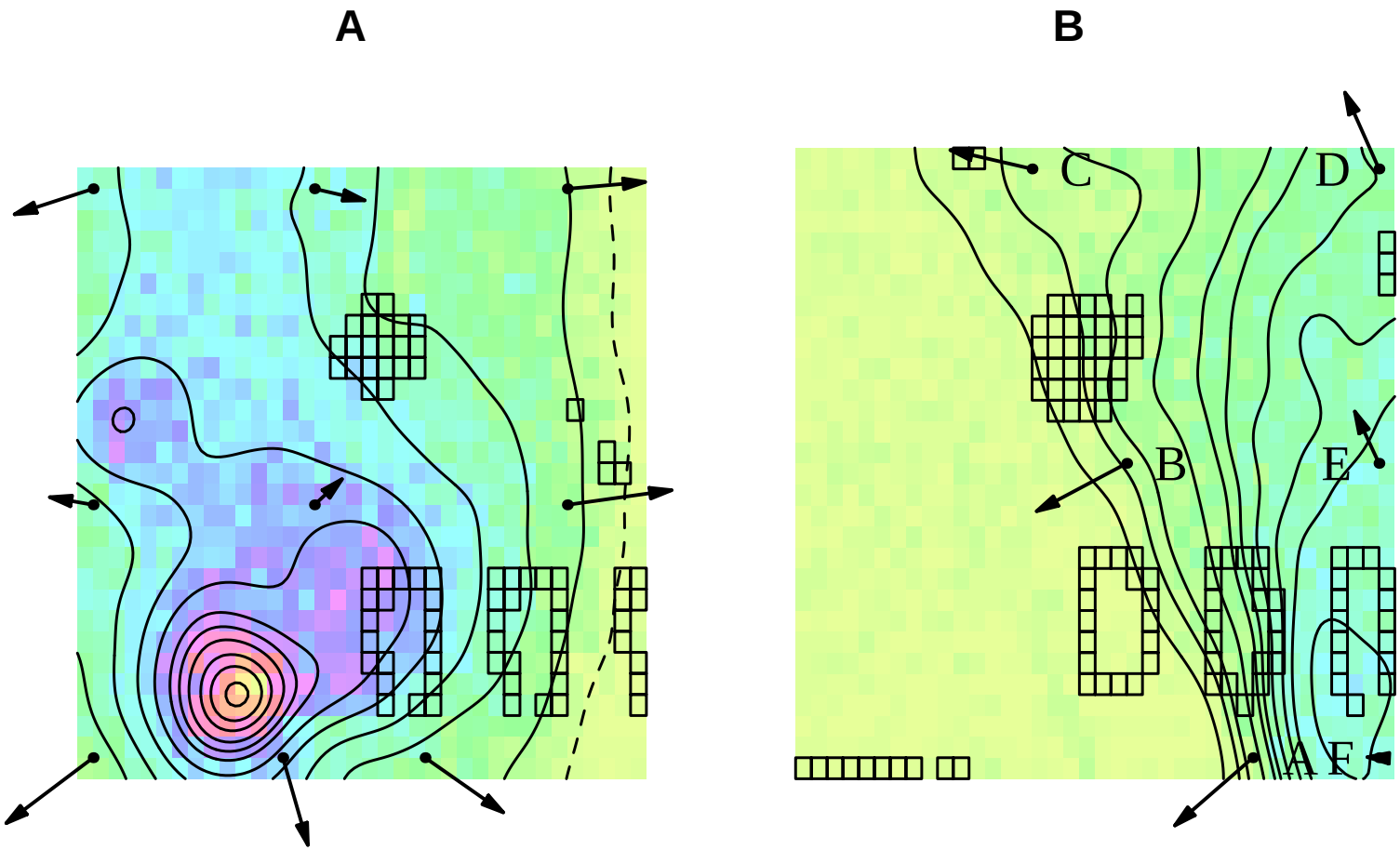
When the magnitude of A is not known,
cold fusion experiments constrain the value of D.

Particle shower evidence



Particle shower in the O/H vapor over an electrolyte (detail).

Particle shower (track density)



Particle shower in the O/H vapor over an electrolyte (track density map).

Summary of shower evidence

Electrolysis experiment with Li_2SO_4 in H_2O electrolyte, platinum anode, nickel cathode, glass container.

Shower of particles originated in O/H vapor above electrolyte.

Approximately 150,000 2-MeV alpha particles.

Particles emanated from a compact source.

Compact source moved out from between detector chips.

Decay rate of source diminished with time.

Shower Interpretation

A nuclear process began in the O/H vapor.

Reaction was supported by a chain reaction between polyneutrons and oxygen-18.

It depleted oxygen-18 in reaction volume.

It built up a compact cloud of reaction products.

Reaction products absorbed residual polyneutrons.

Polyneutrons were eliminated and reaction ceased.

Reaction products decayed, emitting alpha particles.

Composite Nuclei

An ordinary nucleus and a polyneutron in contact can stick together.

They are bound to each other by a reduction in surface energy over the area of contact.

They form a "nuclear molecule."

An example is $^{16}O^{A}Nt$.

These composites must be stable (except for beta decay) if they are to participate in polyneutron reactions.

Composite Nuclei (continued)

Transfer of neutrons between ^{16}O and ^{A}Nt must be endothermic.

$$^{16}\mathrm{O}\,^{A}\mathrm{Nt} \longrightarrow {}^{(16\pm X)}\mathrm{O}^{(A\mp X)}\mathrm{Nt} + \mathcal{E} < 0. \qquad \text{(All } X\text{)}$$

Equivalently

$$^{16}\mathrm{O} + {}^{A}\mathrm{Nt} \longrightarrow {}^{(16\pm X)}\mathrm{O} + {}^{(A\mp X)}\mathrm{Nt} + \mathcal{E} < 0. \qquad \text{(All } X\text{)}$$

^{16}O is inert with respect to polyneutrons.

Many other ordinary isotopes are inert (see W. Collis poster).

Composite Mass Excess

$$\Delta(^{16}\mathrm{O}^{\mathrm{A}}\mathrm{Nt}) = \Delta(^{16}\mathrm{O}) + \Delta(^{\mathrm{A}}\mathrm{Nt}) - \mathcal{E}_B$$

The binding energy $\mathcal{E}_B > 0$ is a new parameter of the theory.

Polyneutron growth

Oxygen-18 supports polyneutron growth.

$$^{18}\mathrm{O} + {}^{\mathrm{A}}\mathrm{Nt} \longrightarrow {}^{16}\mathrm{O} + {}^{(\mathrm{A}+2)}\mathrm{Nt} + \mathcal{E}$$

$$\mathcal{E} = \Delta(^{18}\mathrm{O}) + \Delta(^{\mathrm{A}}\mathrm{Nt}) - \Delta(^{16}\mathrm{O}) - \Delta(^{(\mathrm{A}+2)}\mathrm{Nt}) > 0$$

$$3.955 + (a_v A + a_s A^{2/3}) - (a_v(A+2) + a_s(A+2)^{2/3}) > 0$$

$$3.955 - 2a_v + a_s(A^{2/3} - (A+2)^{2/3}) > 0$$

A constraint on the values of a_v, a_s, and A.

When the magnitude of A is unknown the constraint is

$$3.955 - 2D > 0.$$

Polyneutron fission

Oxygen-18 also supports polyneutron fission.

$$^{18}\mathrm{O} + {}^{\mathrm{A}}\mathrm{Nt} \longrightarrow {}^{16}\mathrm{O}^{(\mathrm{A}-22)}\mathrm{Nt} + {}^{12}\mathrm{Nt} + {}^{12}\mathrm{Nt} + \mathcal{E} \qquad (\mathrm{A} \geqslant 34)$$

$$\mathcal{E} = \Delta({}^{18}\mathrm{O}) + \Delta({}^{\mathrm{A}}\mathrm{Nt}) - \Delta({}^{16}\mathrm{O}) - \Delta({}^{(\mathrm{A}-22)}\mathrm{Nt}) + \mathcal{E}_b - \Delta({}^{12}\mathrm{Nt}) - \Delta({}^{12}\mathrm{Nt}) > 0$$

$$3.955 + \mathcal{E}_b - 2\mathrm{a}_v + \mathrm{a}_s(\mathrm{A}^{2/3} - (\mathrm{A}-22)^{2/3} - 2(12)^{2/3}) > 0$$

A constraint on the values of $\mathrm{a_v}, \mathrm{a_s}, \mathcal{E}_b$, and A.

Chain Reaction

Growth and fission reactions support a chain reaction.

$$^{18}\mathrm{O} + {}^{\mathrm{A}}\mathrm{Nt} \longrightarrow {}^{16}\mathrm{O} + {}^{(\mathrm{A}+2)}\mathrm{Nt} \qquad (\mathrm{A} \geqslant 12)$$

$$^{18}\mathrm{O} + {}^{\mathrm{B}}\mathrm{Nt} \longrightarrow {}^{16}\mathrm{O}^{(\mathrm{B}-22)}\mathrm{Nt} + {}^{12}\mathrm{Nt} + {}^{12}\mathrm{Nt} \qquad (\mathrm{B} \geqslant 34)$$

Runaway chain reaction is not observed.
Chain reaction must stop.
Otherwise oxygen would explode.

Reaction products must act to remove polyneutrons
and stop the reaction.

Direct composite production

When ^{A}Nt interacts with ^{18}O to form ^{16}O and $^{(A+2)}$Nt
it can happen that the products directly form a composite:

$$^{18}\mathrm{O} + {}^{A}\mathrm{Nt} \rightarrow {}^{16}\mathrm{O}^{(A+2)}\mathrm{Nt} + \mathcal{E}.$$

The energy $\mathcal{E}$ can be absorbed by low-lying excitations
of the polyneutron component $^{(A+2)}$Nt.

This reaction is more exothermic than the growth reaction

$$^{18}\mathrm{O} + {}^{A}\mathrm{Nt} \rightarrow {}^{16}\mathrm{O} + {}^{(A+2)}\mathrm{Nt}$$

that is required for a chain reaction.

I assume that direct composite formation, being the more complex process, occurs at a slower rate and can be neglected.

Polyneutron capture

Composites can capture polyneutrons:

$$^{16}\mathrm{O}^{\mathrm{A}}\mathrm{Nt} + {}^{\mathrm{B}}\mathrm{Nt} \longrightarrow {}^{16}\mathrm{O}^{(\mathrm{A}+\mathrm{B})}\mathrm{Nt} + \mathcal{E}.$$

The only change in energy is a reduction in surface energy.

$$\mathcal{E} = \Delta({}^{\mathrm{A}}\mathrm{Nt}) + \Delta({}^{\mathrm{B}}\mathrm{Nt}) - \Delta({}^{(\mathrm{A}+\mathrm{B})}\mathrm{Nt}).$$

The reaction is exothermic for all A and B.

Because there is no competing reaction there is time for $\mathcal{E}$ to be absorbed by low-lying excitations of the ${}^{(\mathrm{A}+\mathrm{B})}\mathrm{Nt}$.

Polyneutron Decay (1)

Polyneutrons can undergo beta decay.

$$^{A}\mathrm{Nt} \longrightarrow {}^{A}\mathrm{H}_{p}^{+} + \mathrm{e}^{-} + \bar{\nu}$$

(Or in abbreviated notation $^{A}\mathrm{Nt} \longrightarrow {}^{A}\mathrm{H}_{p}$.)

Symbol H denotes a nucleus with one proton (hydrogen).
Subscript p denotes fully paired nuclear symmetry.

$$\begin{aligned}\Delta(^{A}\mathrm{H}_{p}) &= \Delta(^{A}\mathrm{Nt}) - \Delta(^{1}\mathrm{Nt}) + \Delta(^{1}\mathrm{H}) \\ &= \Delta(^{A}\mathrm{Nt}) - 0.782.\end{aligned}$$

Polyneutron Decay (2)

Coulomb energy of charged nucleus is $Z(Z-1)\mathcal{E}_c$.

Polyneutron undergoes successive beta decays

$$^{A}\mathrm{Nt} \longrightarrow {}^{A}\mathrm{H}_p - 0.782 \qquad \text{exothermic}$$

$$^{A}\mathrm{H}_p \longrightarrow {}^{A}\mathrm{He}_p - 0.782 + 2\mathcal{E}_c \qquad \text{exothermic}$$

$$^{A}\mathrm{He}_p \longrightarrow {}^{A}\mathrm{Li}_p - 0.782 + 6\mathcal{E}_c \qquad \text{exothermic}$$

$$^{A}\mathrm{Li}_p \longrightarrow {}^{A}\mathrm{Be}_p - 0.782 + 12\mathcal{E}_c \qquad \text{endothermic}$$

Beta decay stops at $^{A}\mathrm{Li}_p$.

Polyneutron Decay (3)

Decay continues via emission of alpha particles.

$^{A}\mathrm{Li}_p \longrightarrow {}^{(A-4)}\mathrm{H}_p + {}^{4}\mathrm{He}.$

We have the series of decays

$$\begin{aligned}
{}^{A}\mathrm{Nt} \longrightarrow {}^{A}\mathrm{H}_p \longrightarrow {}^{A}\mathrm{He}_p \longrightarrow {}^{A}\mathrm{Li}_p \longrightarrow {}^{(A-4)}\mathrm{H}_p + 4\mathrm{He} \\
{}^{(A-4)}\mathrm{H}_p \longrightarrow {}^{(A-4)}\mathrm{He}_p \longrightarrow {}^{(A-4)}\mathrm{Li}_p \longrightarrow {}^{(A-8)}\mathrm{H}_p + 4\mathrm{He} \\
{}^{(A-8)}\mathrm{H}_p \longrightarrow {}^{(A-8)}\mathrm{He}_p \longrightarrow {}^{(A-8)}\mathrm{Li}_p \longrightarrow {}^{(A-12)}\mathrm{H}_p + 4\mathrm{He}
\end{aligned}$$

And so on until the series ends with $^{15}\mathrm{Li}_p$,$^{14}\,\mathrm{Li}_p$,$^{13}\,\mathrm{Li}_p$ or $^{12}\mathrm{Li}_p$.
(Removal of four more neutrons would shrink them to A$<$12.)

Polyneutron Decay (4)

The final steps involve coordinated beta and alpha decays.

$$
\begin{aligned}
{}^{15}\mathrm{Li}_p &\longrightarrow {}^{11}\mathrm{B} + {}^{4}\mathrm{He} \\
{}^{14}\mathrm{Li}_p &\longrightarrow {}^{10}\mathrm{B} + {}^{4}\mathrm{He} \\
{}^{13}\mathrm{Li}_p &\longrightarrow {}^{9}\mathrm{B} + {}^{4}\mathrm{He} \\
{}^{12}\mathrm{Li}_p &\longrightarrow {}^{4}\mathrm{He} + {}^{4}\mathrm{He} + {}^{4}\mathrm{He}.
\end{aligned}
$$

Although decay removes polyneutrons from the system, decay alone cannot stop a chain reaction.

(Elimination rate is proportional to fission rate and cannot surpass fission rate.)

Neutron suppression (correlation barrier)

Neutron production cannot be ruled out by energetics.

$$^{7}\mathrm{Li} + {}^{A}\mathrm{Nt} \longrightarrow {}^{4}\mathrm{He} + {}^{A+2}\mathrm{Nt} + {}^{1}\mathrm{H} + 1.39\mathrm{MeV}$$

promotes polyneutron growth and helps to sustain chain reactions.

$$^{7}\mathrm{Li} + {}^{A}\mathrm{Nt} \longrightarrow {}^{4}\mathrm{He} + {}^{A+2}\mathrm{H_p} + {}^{1}\mathrm{Nt} + 1.39\mathrm{MeV}$$

is exothermic with exactly the same energy.

Neither can be ruled out by energetics or quantum selection rules.

In the neutron reaction a proton must tunnel through a potential barrier to join the fully paired state $^{A+2}\mathrm{H_p}$.

The barrier is associated with integration of a localized proton into a collectively paired state. The proton must pass through a barrier of unbound interactions with a small number of neutrons as its wave function spreads out.

A correlation barrier.

Chain reaction in a quiescent medium

The reactions that sustain a chain reaction are polyneutron growth and polyneutron fission, both of which are fueled by ^{18}O.

The reactions that act to oppose a chain reaction are depletion of ^{18}O, capture of polyneutrons by composites, and polyneutron decay.

In a quiescent medium the opposing reactions overwhelm the growth and fission reactions and the chain reaction stops.

The role of electrolysis

We have seen that a chain reaction stops because of loss of ^{18}O and buildup of $^{16}O^{A}Nt$.

But reaction does not stop during electrolysis. How is this possible?

Stirring and mixing associated with bubble formation
add fresh ^{18}O and remove $^{16}O^{A}Nt$ from the reaction volume.

This prevents the ratio of $[^{16}O^{A}Nt]$ to $[^{18}O]$
from reaching the critical level for stopping the reaction.

Reaction can continue at a steady rate.

The role of electrolysis (continued)

Other means of mixing seem to be effective.

There is evidence that mechanical mixing
will keep a reaction going.

There is evidence that bubbling associated with boiling
will keep a reaction going.

Composite decay

Beta decay of composite $^{16}O^{A}Nt$ is endothermic.

(Increase in coulomb energy exceeds decrease due to replacing a neutron by a proton.)

The simplest exothermic possibility is simultaneous coordinated beta/beta/alpha decay.

$$^{16}O^{A}Nt \rightarrow {}^{16}O^{(A-4)}Nt + {}^{4}He \qquad (A \geqslant 16)$$

$$\mathcal{E} = -2.425 + 4a_v + 1.108a_s > 0$$

Composite decay (continued)

Successive beta/beta/alpha decays generate a stream of alpha particles.

$$^{16}\mathrm{O}^{\mathrm{A}}\mathrm{Nt} \longrightarrow {}^{16}\mathrm{O}^{(\mathrm{A}-4)}\mathrm{Nt} + {}^{4}\mathrm{He}$$

$$^{16}\mathrm{O}^{(\mathrm{A}-4)}\mathrm{Nt} \longrightarrow {}^{16}\mathrm{O}^{(\mathrm{A}-8)}\mathrm{Nt} + {}^{4}\mathrm{He}$$

$$^{16}\mathrm{O}^{(\mathrm{A}-8)}\mathrm{Nt} \longrightarrow {}^{16}\mathrm{O}^{(\mathrm{A}-12)}\mathrm{Nt} + {}^{4}\mathrm{He}$$

(and so on)

Several hundred alphas can be emitted from a single composite.

Composite decay (final steps)

Composites $^{16}O^{12}Nt$, $^{16}O^{13}Nt$, $^{16}O^{14}Nt$, $^{16}O^{15}Nt$
cannot decay by emitting an alpha and shrinking the composite.

The resulting $^{16}O^{A}Nt$ would have $A<12$ and high energy.

The simplest exothermic decays appear to be:

$$
\begin{aligned}
^{16}O^{12}Nt &\rightarrow {}^{24}Mg + {}^{4}He + \mathcal{E} \approx 28 \\
^{16}O^{13}Nt &\rightarrow {}^{25}Mg + {}^{4}He + \mathcal{E} \approx 28 \\
^{16}O^{14}Nt &\rightarrow {}^{26}Mg + {}^{4}He + \mathcal{E} \approx 30 \\
^{16}O^{15}Nt &\rightarrow {}^{27}Al + {}^{4}He + \mathcal{E} \approx 36
\end{aligned}
$$

These decays are very long-lived. (Simultaneous 4-5 beta decays and alpha decay. High coulomb barrier.)

Lifetimes may be measured in years.

Polyneutron from composite decay (1)

Consider the following decay:

$$^{16}\mathrm{O}^{\mathrm{A}}\mathrm{Nt} \rightarrow {}^{16}\mathrm{O} + {}^{4}\mathrm{He} + {}^{(\mathrm{A}-4)}\mathrm{Nt} + \mathcal{E} \qquad (\mathrm{A} \geqslant 16)$$

$$\mathcal{E} = \Delta({}^{\mathrm{A}}\mathrm{Nt}) - \mathcal{E}_b - \Delta({}^{(\mathrm{A}-4)}\mathrm{Nt}) - \Delta({}^{4}\mathrm{He}) < 0$$

This reaction produces a polyneutron and must be endothermic.

Otherwise many polyneutrons would be produced
from long-lived composites in the electrolysis vapor.

But chain reactions in the vapor are rare.

In consequence $\mathcal{E}_b < 0$ is required for all A,

$$-2.425 - \mathcal{E}_b + 4\mathrm{a_v} + 1.108\mathrm{a_s} < 0$$

Polyneutron from composite decay (2)

Consider the following decay:

$$^{16}\mathrm{O}^{\mathrm{A}}\mathrm{Nt} \rightarrow {}^{16}\mathrm{O}^{\mathrm{B}}\mathrm{Nt} + {}^{4}\mathrm{He} + {}^{(\mathrm{A}-\mathrm{B}-4)}\mathrm{Nt} + \mathcal{E} \qquad (\mathrm{A} \geqslant 16)$$

This reaction also must be endothermic.

$$\mathcal{E} = \Delta({}^{\mathrm{A}}\mathrm{Nt}) - \Delta({}^{\mathrm{B}}\mathrm{Nt}) - \Delta({}^{(\mathrm{A}-\mathrm{B}-4)}\mathrm{Nt}) - \Delta({}^{4}\mathrm{He}) < 0$$

$$-2.425 + 4a_v - 5.242a_s < 0$$

Polyneutron mass excess

Constraints on $a_v, a_s, \mathcal{E}_B$ and A have been obtained for a number of reactions, including

1. Polyneutron growth	exothermic
2. Polyneutron fission	exothermic
3. Composite formation	exothermic
4. Polyneutron shrinkage	exothermic
5. Composite alpha emission	exothermic
6. Composite polyneutron emission (1)	endothermic
7. Composite polyneutron emission (2)	endothermic.

These constraints are not tight enough to provide good approximations to a_v and a_s. Tighter constraints are required.

Natural reactors

Now at last we can address the question of the initial polyneutron.

Cosmic rays occasionally generate polyneutrons by spallation from heavy elements such as Pb, Bi, Th, U in water solution.

These polyneutons interact with ^{18}O and ignite chain reactions.

Occasionally reactions are ignited in a stream or under a waterfall where mixing and stirring are adequate to sustain them.

These are natural reactors.

Natural reactors (continued)

Natural reactors emit large numbers of $^{16}O^{A}Nt$ composites.

The composites decay in a few hours, except for

$$^{16}O^{12}Nt, \quad ^{16}O^{13}Nt, \quad ^{16}O^{14}Nt, \quad ^{16}O^{15}Nt,$$

some of which may last for years.

They mix in surface waters everywhere.

No longer do we need to wait for spallation.
A cosmic ray particle can liberate a polyneutron in the reaction:

$$\text{Cosmic Ray} + {}^{16}O^{A}Nt \rightarrow \text{Scattered Ray} + {}^{16}O + {}^{A}Nt.$$

Natural reactors will be ignited wherever mixing conditions are right.

Electrolysis revisited

A reactor will be ignited in an electrolysis experiment,
provided that the polyneutron is liberated in the bubbling region.

Chemically the composites $^{16}O^{A}Nt$ that form there are oxygen.

Their lifetimes for alpha decay grow longer as the composite
grows smaller (Larger coulomb barrier.)

Some have time to move from the electrolyte to the vapor
where they continue their decay.

Energetic particles in the vapor

A composite that reaches the vapor
soon after leaving the reaction region in the electrolyte
emits alpha particles at an initially high rate.

It can emit a hundred or so alpha particles in a short time.

With slow convection currents these alpha particles
will appear to have emanated from a compact source.

A composite that reaches the vapor
a longer time after leaving the reaction region
emits alpha particles at a slower rate.

With rapid convection currents their tracks
will be more randomly scattered over a detector chip.

Both patterns of tracks have been observed.

Giant particle showers

On occasion a cosmic ray can liberate a polyneutron
from a composite in the vapor.

Because the vapor is quiescent a chain reaction cannot be sustained.

But the reaction produces a giant shower of alpha particles
from decay of the hundreds of composites that did form
before the reaction stopped.

One such shower has been analyzed in detail.

Transmutation

All reactions involving polyneutrons are transmutations.

There are four types of transmutation:

1. Polyneutron transfer, which changes isotopic mass.
2. Catalysis of beta decay, which changes nuclear charge by $+1$.
3. Catalysis of electron capture (EC),
   which changes nuclear charge by -1.
4. Promotion of alpha capture, which changes
   nuclear charge by $+2$ and mass number by $+4$.

Beta decay catalysis

Consider the reaction between a polyneutron and a nucleus that is unstable against beta decay. An example is:

$$^{A}\mathrm{Nt} + {}^{135}\mathrm{Cs} \longrightarrow {}^{135}\mathrm{Ba}\,{}^{A}\mathrm{Nt}^{+} + \mathrm{e}^{-} + \bar{\nu}.$$

Beta decay and composite formation mutually catalyze each other.

Beta decay provides additional degrees of freedom (e^{-} and $\bar{\nu}$) that assist composite formation.

Composite formation provides additional degrees of freedom (low energy vibrational modes and bonding energy levels) that assist beta decay.

The product nucleus ^{135}Ba reaches its ground state.

Beta decay catalysis (continued)

An unstable composite need not wait for another polyneutron, for example:

$$^{141}\mathrm{Ce}^{\mathrm{A}}\mathrm{Nt} \longrightarrow {}^{141}\mathrm{Pr}^{\mathrm{A}}\mathrm{Nt}^{+} + \mathrm{e}^{-} + \bar{\nu}.$$

The product nucleus ^{141}Pr reaches its ground state.

No gamma rays are emitted.

Polyneutron transfer

Transmutation rules:

1. Spin of ^{A}Nt is 0 for even A, and 1/2 for odd A.
2. Parity of ^{A}Nt is + for all A.
3. Neutron transfer must conserve spin and parity.

The polyneutron growth reaction is an example

$$^{18}\mathrm{O} + {}^{A}\mathrm{Nt} \rightarrow {}^{16}\mathrm{O} + {}^{(A+2)}\mathrm{Nt}$$

The minimum number of neutrons is transferred
even when transfer of additional neutrons would be exothermic.
(The products separate before additional neutrons have time).

Polyneutron transfer (continued)

A composite need not wait for another neutron, for example:

$$^{90}\mathrm{Y}^{\mathrm{A}}\mathrm{Nt} \longrightarrow {}^{94}\mathrm{Y}^{(\mathrm{A}-4)}\mathrm{Nt}.$$

The maximum number of neutrons is transferred.
(The products are bound together in a composite and cannot separate).

It can happen that beta catalysis and neutron transfer
are both exothermic. For example $^{90}\mathrm{Y}^{\mathrm{A}}\mathrm{Nt}$ can also decay

$$^{90}\mathrm{Y}^{\mathrm{A}}\mathrm{Nt} \longrightarrow {}^{90}\mathrm{Zr}^{\mathrm{A}}\mathrm{Nt}^{+} + \mathrm{e}^{-} + \bar{\nu}.$$

In this situation neutron transfer is assumed to be much faster,
and beta decay is neglected.

Alpha capture

Alpha capture can be exothermic in reactions such as

$$\alpha + T + {}^{138}\mathrm{Ba} \rightarrow {}^{142}\mathrm{Ce}^{++} + \mathcal{E}_\gamma$$

where T is the kinetic energy of the alpha particle.

The reactants must have no orbital angular momentum.

The maximum capture rate corresponds to dipole emission, as for spin-parity signature $(0^+) \rightarrow (0^+)$ in this example.

Capture rates for reactions with higher order multipoles are orders of magnitude smaller and are neglected.

Alpha capture continued

A polyneutron ^{A}Nt with even A has spin-parity signature 0^{+} in its ground state.

It has an excited state ^{A}Nt* with one spin reversed, giving spin-parity signature 1^{+}.

In consequence the composite ^{141}Ce^{A}Nt with spin-parity $(7/2)^{-}$ has an excited state ^{141}Ce^{A}Nt* with spin-parity $(5/2)^{-}$.

Alpha capture ^{137}Ba^{A}Nt $\longrightarrow$ ^{141}Ce^{A}Nt* $\quad (3.2)^{+} \longrightarrow (5/2)^{-}$ proceeds with dipole radiation.

Alpha capture ^{137}Ba^{A}Nt $\longrightarrow$ ^{141}Ce^{A}Nt $\quad (3.2)^{+} \longrightarrow (7/2)^{-}$ requires dipole radiation and proceeds at a negligible rate.

I assume that capture by ^{141}Ce^{A}Nt* is exothermic.

Reaction priorities

I assume that the likelihood of transmutation is greatest for neutron transfer, less for beta decay and electron capture, and least for alpha capture.

If neutron transfer is possible I choose it.

If neutron transfer is not possible I choose beta decay or EC, whichever is exothermic.

If both beta decay and EC are impossible I choose alpha capture.

Iwamura's experiments

Iwamura and associates have observed a number of transmutations.

Isotopes to be transmuted were deposited on the surface of a thin palladium foil facing deuterium gas at one atmosphere pressure.

The back side of the foil was exposed to vacuum, and a current of deuterium gas flowed through the film.

A thin oxide layer was embedded in the film close to the surface that faced the deuterium gas.

(I assume that the oxygen and the flowing deuterium sustained a chain reaction in the gas just upstream of the foil.)

Transmutation of cesium, strontium, and barium has been reported.

Transmutation of ^{133}Cs

Transmutation steps are symbolized as follows:

neutron transfer	$\longrightarrow \mathrm{n} \longrightarrow$
beta decay	$\longrightarrow \beta \longrightarrow$
alpha capture	$\longrightarrow \alpha \longrightarrow$

Transmutation of ^{133}Cs occurs by the following steps:

$$^{133}\mathrm{Cs} \longrightarrow \mathrm{n} \longrightarrow {}^{135}\mathrm{Cs}$$
$$^{135}\mathrm{Cs} \longrightarrow \mathrm{n} \longrightarrow {}^{137}\mathrm{Cs}$$
$$^{137}\mathrm{Cs} \longrightarrow \beta \longrightarrow {}^{137}\mathrm{Ba}^{\mathrm{A}}\mathrm{Nt}$$
$$^{137}\mathrm{Ba}^{\mathrm{A}}\mathrm{Nt} \longrightarrow \alpha \longrightarrow {}^{141}\mathrm{Ce}^{\mathrm{A}}\mathrm{Nt}^{\star}$$
$$^{141}\mathrm{Ce}^{\mathrm{A}}\mathrm{Nt}^{\star} \longrightarrow \beta \longrightarrow {}^{141}\mathrm{Pr}^{\mathrm{A}}\mathrm{Nt}$$

The resulting ^{141}Pr$^{\mathrm{A}}$Nt is stable, inert to neutron transfer, and inert to reaction with an alpha particle.

Comments

Methods for measuring nuclear charge will find Pr.

Methods for measuring mass break up composites and will find mass 141.

Transmutation of ^{88}Sr

Transmutation of ^{88}Sr occurs by the following steps:

$$
\begin{aligned}
^{88}\mathrm{Sr} \longrightarrow \mathrm{n} \longrightarrow\ & ^{90}\mathrm{Sr} \\
^{90}\mathrm{Sr} \longrightarrow \mathrm{n} \longrightarrow\ & ^{92}\mathrm{Sr} \\
^{92}\mathrm{Sr} \longrightarrow \beta \longrightarrow\ & ^{92}\mathrm{Y}^{\mathrm{A}}\mathrm{Nt} \\
^{92}\mathrm{Y}^{\mathrm{A}}\mathrm{Nt} \longrightarrow \mathrm{n} \longrightarrow\ & ^{94}\mathrm{Y}^{(\mathrm{A}-2)}\mathrm{Nt} \\
^{94}\mathrm{Y}^{(\mathrm{A}-2)}\mathrm{Nt} \longrightarrow \beta \longrightarrow\ & ^{94}\mathrm{Zr}^{(\mathrm{A}-2)}\mathrm{Nt} \\
^{94}\mathrm{Zr}^{(\mathrm{A}-2)}\mathrm{Nt} \longrightarrow \mathrm{n} \longrightarrow\ & ^{96}\mathrm{Zr}^{(\mathrm{A}-4)}\mathrm{Nt} \\
^{96}\mathrm{Zr}^{(\mathrm{A}-4)}\mathrm{Nt} \longrightarrow \alpha \longrightarrow\ & ^{100}\mathrm{Mo}^{(\mathrm{A}-4)}\mathrm{Nt} \qquad \mathcal{E} \approx 5 \text{ (very slow)} \\
^{100}\mathrm{Mo}^{(\mathrm{A}-4)}\mathrm{Nt} \longrightarrow \mathrm{n} \longrightarrow\ & ^{102}\mathrm{Mo}^{(\mathrm{A}-6)}\mathrm{Nt} \\
^{102}\mathrm{Mo}^{(\mathrm{A}-6)}\mathrm{Nt} \longrightarrow \beta \longrightarrow\ & ^{102}\mathrm{Tc}^{(\mathrm{A}-6)}\mathrm{Nt}
\end{aligned}
$$

and on for many more steps

Because the alpha reaction is very slow $^{96}\mathrm{Zr}^{(\mathrm{A}-4)}\mathrm{Nt}$ composites accumulate at nearly the rate ^{88}Sr is depleted.

Transmutation to molybdenum isotopes takes place more slowly.

Transmutation of ^{138}Ba

Transmutation of ^{138}Ba occurs by the following steps:

$$^{138}\text{Ba} \rightarrow \alpha \rightarrow {}^{142}\text{Ce}$$
$$^{142}\text{Ba} \rightarrow \alpha \rightarrow {}^{146}\text{Nd}$$
$$^{146}\text{Nd} \rightarrow \alpha \rightarrow {}^{150}\text{Sm}$$
$$^{150}\text{Sm} \rightarrow \text{n} \rightarrow {}^{152}\text{Sm}$$
$$^{152}\text{Sm} \rightarrow \text{n} \rightarrow {}^{154}\text{Sm}$$
$$^{154}\text{Sm} \rightarrow \text{n} \rightarrow {}^{156}\text{Sm}$$
$$^{156}\text{Sm} \rightarrow \beta \rightarrow {}^{156}\text{Eu}$$

and on for many more steps

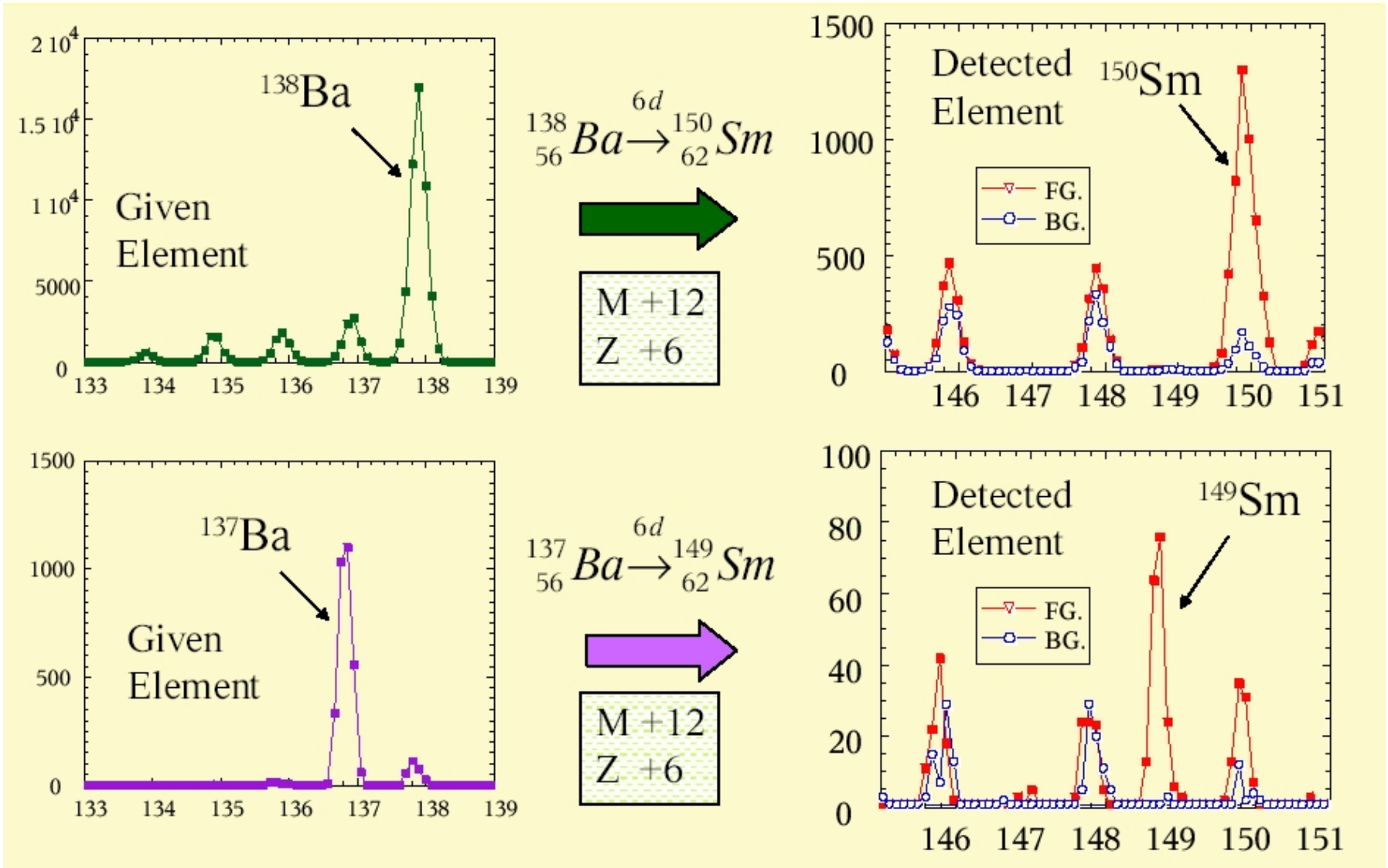
Transmutation products include the four samarium isotopes ^{150}Sm, ^{152}Sm, ^{154}Sm, and ^{156}Sm.

Transmutation of ^{137}Ba

The isotope ^{137}Ba is stable, inert to neutron transfer, and requires quadrupole γ emission for alpha capture.

On the time scale of Iwamura's experiments it is inert.

Iwamura data



Iwamura data reviewed

A signal at mass 149 was observed for enriched ^{137}Ba as target, but not for natural ^{137}Ba as target.

^{137}Ba (enriched) $\rightarrow$	^{149}X	
3090	188	6.1%
^{137}Ba (natural) $\rightarrow$	^{149}X	
7700	6	0.1%

No signal for natural ^{137}Ba shows that ^{149}X is not produced.

Signal for enriched ^{137}Ba suggests contamination.

Possibly ^{133}Cs^{16}O.

Comparison with theory

Transmutation of ^{133}Cs.

Iwamura: Sr $\longrightarrow$ ^{141}X atom for atom
^{141}Pr detected (XPS, TOF-SIMS)
Interpreted as ^{133}Cs $\longrightarrow$ ^{141}Pr.

Theory: ^{133}Cs $\longrightarrow$ ^{141}Pr.

Transmutation of natural Sr (83% ^{88}Sr)

Iwamura: Sr $\longrightarrow$ ^{96}X atom for atom
No XPS reported.
Interpreted as ^{88}Sr $\longrightarrow$ ^{96}Mo.

Theory: ^{88}Sr $\longrightarrow$ ^{96}Zr followed by
slow loss to further transmutations
including ^{100}Mo and ^{102}Mo.

Comparison with theory continued

Transmutation of natural Ba (72% ^{138}Ba)

Iwamura: Ba $\longrightarrow$ ^{150}X observed
No XPS reported.
Interpreted as ^{138}Ba $\longrightarrow$ ^{150}Sm.

Theory: ^{138}Ba $\longrightarrow$ ^{150}Sm followed by
loss to further transmutations
including ^{152}Sm, ^{154}Sm, and ^{156}Sm.

Transmutation of enriched ^{137}Ba

Iwamura: ^{137}Ba $\longrightarrow$ ^{149}X observed
No XPS reported.
Interpreted as possible ^{137}Ba $\longrightarrow$ ^{149}Sm.
Review of data shows no ^{149}Sm

Theory: No ^{149}Sm.

Polyneutron mass excess

In order to fit the model to Iwamura's transmutation data it was necessary to assume a value for $D = \Delta(^{A+1)}\mathrm{Nt}) - \Delta(^{A}\mathrm{Nt})$.

The foregoing analysis constrains the value of D to the range

$$1.31 < D < 1.76.$$

This range is plausible when tested against other restrictions on D.

In consequence $D \approx 1.5$ MeV is my best current estimate.

Excess energy

Polyneutrons shrink in interaction with the stable isotopes of many elements including palladium.

$$^{A}\mathrm{Nt} + {}^{X}\mathrm{Pd} \rightarrow {}^{(A-2)}\mathrm{Nt} + {}^{(X+2)}\mathrm{Pd} \qquad A \geqslant 14$$

The restriction $A \geqslant 14$ applies because $\Delta(^{A}\mathrm{Nt})$ rises rapidly for $A < 12$, and the reactions turn endothermic.

After shrinking to ^{12}Nt polyneutrons no longer interact with Pd.

They are free to diffuse within the Pd until they escape or decay to charged particles.

Excess energy continued

During shrinkage each polyneutron releases about 3A MeV, or about 50 MeV for each one expected to reach Pd.

If a small quantity of deuterium is present in the palladium, additional reactions become possible.

$$^{12}\mathrm{Nt} + {}^{2}\mathrm{H} \rightarrow {}^{13}\mathrm{Nt} + {}^{1}\mathrm{H}$$
$$^{13}\mathrm{Nt} + {}^{2}\mathrm{H} \rightarrow {}^{14}\mathrm{Nt} + {}^{1}\mathrm{H}$$

These reactions regenerate ^{14}Nt and release about 8MeV.

At low deuterium concentrations polyneutron size alternates between ^{12}Nt and ^{14}Nt, generating 8MeV each cycle.

The rate of energy generation increases roughly in proportion to the concentration of deuterium.

Excess energy continued

When the deuterium concentration is high enough ($\approx$ 100% loading) the growth rate reaches or exceeds the shrinkage rate.

Mean polyneutron size increases, enabling the fission reaction

$$^{A}\mathrm{Nt} + {}^{2}\mathrm{H} \rightarrow {}^{1}\mathrm{H}^{(A-22)}\mathrm{Nt} + {}^{12}\mathrm{Nt} + {}^{12}\mathrm{Nt}$$

and igniting a deuterium chain reaction inside the palladium.

In Arata's experiments the effective loading can exceed 100%, allowing the chain reactions to last longer before they die.

The effective loading can be increased by removing the Pd black.

The optimum situation may be pure deuterium in a cavity that can be reached by polyneutron diffusion through the cavity wall.

Major unfinished business

• Deuterium reactions.
Single neutron transfer. Larger mass excesses for odd-A polyneutrons.
Chain reaction? Energetic alphas as required for Iwamura?
Mechanism for igniting and sustaining Iwamura reaction?
Constraints on D, a_v, a_s. Compatability with ^{18}O?

• Radioactive waste remediation
All radioactive nuclei transmuted to stable nuclei.
Th, U, transuranics, all support polyneutron growth and fission.
They are fuels that can support waste remediation.

• Extension of BCS
Extend to strong interaction, no limitation on particle momenta.
Extend to small particle numbers. Can this fit both a_v and a_s?
Spin-flip energy (Needed for alpha capture interpretation)?

Appraisal

• Do I believe polyneutron theory?
Yes in concept. Polyneutrons are key agents for CF phenomena.
They avoid the coulomb barrier, gamma radiation and neutrons.
They offer explanations for transmutation and excess energy.
Not in detail. Other choices for key parameters may be required.

• Should experimenters believe the theory?
Not yet. But it has suggested novel experiments in the past
(Particle showers in the vapor, energetic particles behind the cathode).
It suggests novel future experiments, including:
Resolution of ^{96}Zr vs ^{96}Mo in ^{88}Sr transmutation,
Guidelines for searches for other transmutations,
Extension of Arata's research,
Exploration of Th and U as fuels for power and remediation.
And it provides a mental framework for interpretation of results.

• Should theoreticians believe the theory?
No. But they should have open minds.
There are plenty of new theoretical questions that need attention.