Low radiation fusion through bound neutron tunneling

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Abstract

To achieve low radiation fusion one considers bound neutron tunneling in the MeV range. It is found that the probability for bound neutron tunneling is larger then tunneling through a coulomb barrier for Ni Li interaction below the energy for fusion conventional Ni Li fusion. The theory from basic quantum mechanic tunneling principles are compared with the e-cat device. It is found that bound neutron tunneling fusion could explain isotope abundance, energy production and burn rate from an e-cat test run done by a third party collaboration.

Bound neutron tunneling

Tunneling is a known process in nuclear physics. Alpha decay in heavy nuclides and low energy proton capture in for example Li p interaction is explained by tunneling through a Coulomb barrier. These examples deals with nucleon above the free energy so the particles could be free. What will be considered here by the simplest quantum mechanic model is tunneling between 2 potential well created by two nucleons. The idea is that bound neutron tunneling should be considerable larger than coulomb barrier tunneling. Bound neutron tunneling should give ground state ground state interaction if the neutron energy level is close in the two considered nucleus. To calculate the different in tunneling probabilities one could considered basic quantum mechanics. In the WBK approximation the transmission coefficient T for a potential barrier is given by

$$T = e^{-2\int dx\sqrt{\frac{2m}{\hbar}(V(x)-E)}}$$

where m is the mass of the tunneling particle, $\hbar$ is the planck constant, $V(x) - E$ is the difference between the energy level and the potential and the integration limit is between the barrier wall.

In the following example interaction between Ni, Li and p is considered. First one considered the outer wall point for different energies from coulomb interaction where the coulomb potential is given by

Table 1: Distance in fm between nuclides due to Coulomb repulsion

Nuclide	100 keV	500 keV	1 MeV	2 MeV
Ni p	230	44	20	8.7
Ni Li	347	136	66	31.5
Li p	23	3.8	1.3	0.09
Li Li	72	13	5.1	1.4
Ni Ni	6500	1300	650	323

Table 2: Tunneling exp coefficients for coulomb repulsion

Nuclides	100 keV	500 keV	1 MeV	2 MeV
Ni p	151	24	8	2
Ni Li	1426	274	130	60
Li p	5.6	0.3	<0	<0
Li Li	37	5	1	<0

$$V\left(x\right)=\frac{ke^{2}Z_{1}Z_{2}}{x}$$

where Z_i is the charge of the different nuclides. The radius for different energies in the keV-MeV range is given in 1. Next one considered Coulomb barrier tunneling for the same energies if one assumes the radius of the Ni and Li nuclides to be 4 and 2 fm. The exponential coefficient $\int dx\sqrt{\frac{2m}{\hbar}\left(V\left(x\right)-E\right)}$ is shown in tab. 2 here only coefficient for particles above the coulomb barrier are set to below 0.

For bound neutron tunneling one here consider the reactions $^{7}Li \rightarrow^{6} Li+n*$ and $^{64}Ni \rightarrow^{62} Ni+2n*$. The potential depth is thought to be constant and calculated from differences in binding energies between the nuclides. All binding energies are from ref. [2].

For Lithium $BE_{Li7}-BE_{Li6}\cong 7$ MeV is used while Nickel gives $0.5*(BE_{Ni64}-BE_{Ni62})\cong 8$ MeV. The coefficients is calculated in tab. 3. Could one then consider tunneling for protons also but there one has to ad the coulomb barrier and also for the considered nuclides the last proton binding energy is

Table 3: Tunneling exp coefficients for -7(Li) and -8(Ni) MeV n*

Nuclides	100 keV	500 keV	1 MeV	2 MeV
Ni p	196,9469	39,3894	19,6947	9,8473
Ni Li	295,4203	118,1681	59,0841	29,5420
Li p	21,1015	4,2203	2,1101	1,0551
Li Li	63,3044	12,6609	6,3304	3,1652
Ni Ni	5514,5124	1102,9025	551,4512	275,7256

considerable lower $BE_{Li7} - BE_{He6} \cong 10$ MeV. Comparing the coefficients for coulomb tunneling with bound neutron tunneling one finds that Ni Li interaction near the coulomb barrier is a great interaction for the purpose. The reaction also leaves energies in the desired MeV range which could be used to create a chain reaction to trigger more Li Ni interaction. For example the energy released in $^{7}Li +^{58} Ni \rightarrow {}^{6}Li +^{59} Ni$ is 1.7 MeV.

To also consider n tunneling in proton reaction one should also consider the following properties that could enlarge n tunneling compared to coulomb tunneling

- p rate versus n rate

In a bound nucleon the potential well depth that bound the neutron is in the order of 50 MeV while the kinetic energies considered for outer nucleus is only MeV over the ground. If one then theoretically bound the outer particle in the same radius as the neutron nucleus the frequency that the proton and neutron hit the wall with is 50 times higher for the neutron. This should increase the neutron coefficient compared to proton with $Ln\left(50\right)/2 \cong 2$, which is not enough to bring neutron tunneling above coulomb.

- BE distribution

Considering the bound level from free neutron level is not good for calculating the binding energy since this give a total binding energy lower than the calculated one. Consider the level from a level distribution where the sum of level should give the total binding energy gives the highest level much closer to the free neutron energy. The potential height outside the nucleus is then coming from the rearrangement of level inside the daughter nucleus. This should have some time delay that allows the runaway neutron to get far enough away from the nucleus to avoid strong interaction. The result is then that the V-E part of the tunneling coefficient is lowered.

- p-wave

The basic tunneling calculation doesn't consider higher order of partial waves actually the outer neutron in Li and Ni is in p-wave which have a considerable large probability to be outside the potential wall.

To find the tunneling rate for bound neutron one could consider the case where the outer nucleus is thought of being constant. The inner neutron is then thought of hitting the wall with a rate calculated from the bound neutron kinetic energy. The kinetic energy is in the range of 10-100 MeV and a nucleus radius in the fm range then give a frequency in the order of 10^{-21} Hz. Tab. 4 shows the tunneling rate for the probabilities considered in tab. 3. Here one sees that Li p have a rate of 2 Hz at 100 keV which means that bring proton up to 100 keV would give a considerable large starting rate for the fusion to start.

Overbound deuterium

If bound neutron tunneling would work through a proton bridge no deuterium would be created since the total binding energy for deuterium is only 2.2 MeV

Table 4: Tunneling rates for -7(Li) and -8(Ni) MeV n* with $f_{n*} = 10^{21}$ Hz

Nuclides	100 keV	500 keV	1 MeV	2 MeV
Ni p	0	$1 * 10^{-18}$	$1.7 * 10^{3}$	$2 * 10^{13}$
Ni Li	0	0	0	$4 * 10^{-7}$
Li p	2	$5 * 10^{17}$	-	-
Li Li	0	10	$3 * 10^{16}$	-
Ni Ni	0	0	0	0

while the bound neutron lies 7 MeV below the free neutron energy. The proton bridge is then an overbound deuterium state. In normal case an overbound system would quickly absorb energy from the surrounding to the ground level but for such a large overbound state the only possibility to absorb energy is to interact with nucleon scale energy and not atomic scale. The lifetime of the state could be calculated from the retransmission coefficient. First consider the transmission coefficient as the comparison of amplitudes:

$$T = \frac{|A_N|^2}{|A_d|^2}$$

where A_N is the amplitude of the wave by the nucleon and A_d is the amplitude of the wave at the deuterium.

The amplitudes are found by continuum considerations at the barrier wall

$$Ae^{ik_0 x=0} = Be^{-kx=0}$$

here the wall is is considered to exist at x=0. If one instead consider a overbound system the wall would have been reduced from 0 to -x but the frequency is still the same.

The continuum formula is now instead

$$Ae^{ik_0(-x)} = Be^{-k(-x)}$$

The amplitude square of the complex phase is still 1 but for the real one its now $B^2 e^{-2k(-x)}$ instead.

The transition coefficient is then increased by

$$T_{d*}/T_N = e^{-2*k*(-x)}$$

The -x is the difference between the deuterium potential well radius and the Li/Ni one ie in the range of fm.

For probable k values the T_{d*}/T_N difference are in the range of 10^{-5}. If one choose the 100 keV p-Li interaction from tab. 4 one finds a transmission rate of seconds and retransmission in microsecond. But at the same time 100 keV protons has the speed of approx. 10^5 m/s so that during the lifetime of the overbound deuterium it will travel far in the Ni/Li material and therefor works as a bridge for bound neutrons.

Table 5: Energy levels for n* in $X \rightarrow Y + n*$ reaction in keV

Nuclide	^{7}Li	^{63}Ni	^{64}Ni
n	-7251.09	-6837.77	-9657.44
2n	-12915.07	-17433,64	-16495.20
n in 2n	-6457.54	-8716,82	-8247.6

Table 6: Energy released in X+n* from different n* sources in keV

Nuclide	n*^{7}Li	n*^{64}Ni	n*^{63}Ni	2n*^{64}Ni
^{58}Ni	1748.17	-658.18	2161.49	3891.79
^{59}Ni	4136.65	1730.30	4549.97	2712.67
^{60}Ni	569.05	-1837.30	982.37	1893.24
^{61}Ni	3344.79	938.44	3758.11	938.44
^{6}Li	0	-2406.35	413.32	-7211.49
^{23}Na	-291,6	-2697,95	121,72	-524,47
^{62}Ni	-413,32	-2819,67	0	0
^{64}Ni	-1153,00	-739,68	-739,68	-1445,26
^{7}Li	-5218,46	-7624,81	-4805,14	-7211.49

Why the E-cat works through bound neutron tunneling

There's already a device that could prove fusion through bound neutron tunneling. The device is called e-cat and run properties is described in ref [1] hereby refereed to as the lugano report.

Energy released in bound neutron tunneling

First step to calculate energy released in Ni-Li burning. Tab 5 shows the energy levels for the considered bound neutrons. The released energies is then calculated in tab 8. Values for energy forbidden reactions is also calculated. The lugano report shows that for some ash powder grain there's a complete burn to ^{62}Ni while there's some rest from ^{6}Li, ^{7}Li and ^{23}Na. Comparing energy allowed process with energy forbidden one finds that burning to ^{62}Ni is allowed while no burning above ^{62}Ni, ^{7}Li and ^{23}Na is possible. If the burning was due to thermal neutrons there should be burning to neutron richer isotopes in ^{62}Ni, ^{7}Li and ^{23}Na. One also sees that ^{23}Na burning should be possible with $n*$ from ^{63}Ni which suggest that ^{64}Ni neutron tunneling is due to a $2n*$ process.

Table 7: The required neutrons to burn all nickel to ^{62}Ni

Nuclide	Δn	Nat. Ab.	$n * N_{nat}$
^{58}Ni	4	0.68	2,72
^{60}Ni	2	0.26	0,52
^{61}Ni	1	0.01	0,01
^{64}Ni	-2	0.01	-0,01
Tot			3,24

Table 8: Energy released in Ni Li bound neutron burning

Nuclide	$\sum E_n$ rel. to ^{62}Ni (keV)	Nat. Ab.	Ni/Li ratio	E (keV)
^{58}Ni	38803,01	0.68	0.24	6237.84
^{60}Ni	18416,01	0.26	0.24	1158
^{61}Ni	10595,88	0.01	0.24	28.99
^{64}Ni	-16495,2	0.01	0.24	-36.62
^{7}Li	-7251,09	0.95	0.76	-5235.28
Tot				2152.92

Specific energy

If all the energy released by the e-cat is due to Li-Ni bound neutron interaction one could calculate the Li/Ni ratio from number of neutron transfers. The number of neutrons needed to burn all nickel to ^{62}Ni is

$$Nr_n = \sum \Delta n * N_{nat}$$

where Δn is the number of neutrons to ^{62}Ni and N_{nat} is the natural abundance ratio. Nr_n is calculated in tab 7 to 3.24 which means that for each Ni atom one needs 3,24 Li atoms to complete nickel burning. This also gives a Ni/Li weight ratio of 2.57.

From the ratio 3.24 one could calculate the Ni Li abundance to Ni 24% and Li 76%.

The energy released in total Ni-Li burning is calculated in tab 8 and found to be 2.1 MeV per nickel atom. The specific energy is then $E_{tot}/m_{Ni} = 36.7$ keV/u from $m_{Ni} = 58.7$u or $E_{tot}/m_{Ni} = 3.5$ MJ/kg. The total energy released in the lugano report where $5.8e3$ MJ. This suggest that approx. 2 g nickel was burned during the test.

Interaction rate

Using the nickel weight abundance in the fuel gives an approx. amount of nickel of 100g. This means that 2% of the Ni in the fuel was burned. The test was running for 2764800 seconds. This gives a nickel burn rate per second of $6e-9$ which should be the probability of a bound neutron interaction.

Theoretically one could calculate this from

$$f_i = P_{n*} * f_{n*} * P_{Hit} * Nr_{Mev} \tag{1}$$

where f_i is the nickel burn rate, P_{Hit} is the probability that a MeV energy nucleon hits a Ni nucleus, P_{n*} is the probability for bound neutron tunneling, f_{n*} is the neutron frequency inside the nuclide and Nr_{Mev} is the number of MeV particles each second. f_i could be approximately calculated. P_{Hit} is just a comparison of areas:

$P_{Hit} = Area_{nucleon}/Area_{NiSphere}$

Approx. values are $Area_{nucleon} \cong fm^2 = 10^{-30}m^2$ and with the nickel atomic radius of $1.2e-10$ m

gives the sphere area of $Area_{NiSphere} \cong \left(10^{-10}\right)^2 = 10^{-20}m^2$ so that P_{hit} is in the range of 10^{-10}. Nr_{Mev} could be calculated for a self burn phase. The number is achieved from

$$Nr_{Mev} = f_i * Nr_{Ni} \tag{2}$$

where f_i are the burn rate and Nr_{Ni} are the number of nickel atoms. This implies that there's a recurrent relation if something triggers the number of MeV particles to a specific value the interaction could enter a self burning phase until al nickel is transformed into ^{62}Ni. 100g nickel gives $Nr_{Ni} = 1.8e18$ nickel atoms and with the experimental value $f_i = 6e-9$ gives $Nr_{Mev} = 1.2e11$. Then using the MeV Ni Li tunneling prob gives average numbers of $P_{n*} = 10^{-29}$ and bound neutron frequency $f_{n*} = 10^{21}$. The theoretical f_i is then 10^{-9} in the same range as the experimental value.

Neutron abundance problem

The Ni/Li weight ratio should be 2,6 but from the fuel analysis one instead found 55/1. This means that there's a shortage of neutrons for Ni Li burning to a pure ^{62}Ni content in the ash. There is some solution for this problem. First is that the pure ^{62}Ni ash powder grain have the desired ratio and unburned Ni is hided in the other grains. Actually low Li ash powder grain seems to contain semi burned Ni with an unnatural abundance. The ^{58}Ni, ^{60}Ni and ^{62}Ni peaks is the same which is not the case of natural Nickel. Another solution is that at the working temperature at 1500^o C are above Lithium boiling point so that the lithium could be achieved through gas diffusion from Li rich Ni poor grains. A third solution is that the other components in the fuel also undergo some bound neutron tunneling. This leads to some analysis to nickel poor powder grains.

Discussion of nickel poor ash powder grains

The high Li6 low Ni ash contains two peaks 55 53 with the same height. This could be from bound neutron capture in iron. But if this where the case the short lived (minutes) isotope ^{53}Fe should decay to ^{53}Mn.

If the 53 peak is due to ^{53}Mn is a interesting case since ^{53}Mn don't exist naturally with a half life of 3,7 Million year. There's also a small peak at 66 but no at 64. The 66 peak could be zinc burned to ^{66}Zn. If the ^{66}Zn comes from natural zinc it should be a larger 64 peak but there's no 64 peak at the same time.

Conclusion and outlook

The e-cat is a possible working device with aid of bound neutron tunneling but for exact calculation one should do a detailed calculation with advanced quantum mechanic process including spin-orbit and 3d properties for tunneling probabilities. To further observe nuclear transmutation one could try to verify the existence and abundance of ^{66}Zn and ^{53}Mn in the ash.

References

[1] http://www.elforsk.se/Global/Omv%C3%A4rld_system/filer/LuganoReportSubmit.pdf

[2] http://www.nndc.bnl.gov/