Collective neutron reduction model for neutron transfer reaction

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November 18, 2014

Abstract

Calculation of how to transfer neutrons from a bound state to a short lived free state at the bound energy level has been done. The important process is to keep the nucleons outside the Pauli barrier to prevent them to enter. A calculation that compares tunneling frequency with the time it takes to thermal absorb energy up above the Pauli barrier was done. The result is that if the nucleon is kept near the nucleus the probability to drag a nucleon out is higher than for a low energy nucleon to enter from outside. Also a chain reaction to first drag nucleons out of the nucleus and then fill them at the first free states to achieve ground state ground state transition has been proposed.

Tunneling probabilities

The simple transmission coefficient T to tunnel through a barrier is given by

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

where T is the transmission probability m is the mass of the tunneling particle in MeV $\hbar = 197$ MeV/fm is the reduced planck constant and $V(x) - E$ is the height of the barrier. If one wants to drag a neutron out of a nucleon with a proton one needs the condition $T_{p_{in}} < T_{n_{out}}$. To do this one reduce the incoming proton neutron energy to increase the height of the tunneling barrier. Also below the energy of the last bound state the proton/neutron are not allowed to enter the nucleus because of the Pauli principle so an infinite high Pauli barrier are added to potential.

^7Li proton/neutron system

The energy released in$^7Li+n \rightarrow ^8 Li$ is 2 MeV so if one places a incoming neutron below that tunneling out is the only possibility. But for that one also needs an attractive neutron potential. For a proton one need to ad a barrier by setting the proton below the free proton energy. At 100 keV the exponent of the tunneling out probability for a neutron is 23 while the tunneling in probability for a proton is only 5.6. If the proton set at -4 MeV an extra exponent of $\int dx\sqrt{\frac{2m}{\hbar^2}3} = 18$ are given to the proton so the probability for extracting a neutron is at the same scale as absorbing the proton. The proton are still allowed to enter since the energy level for the last bound proton in ${}^7Li + p \rightarrow {}^8Be$ is -17 MeV.

Life time of the nucleon below the free energy

If a nucleon is set free at a energy below the free energy it will absorb the thermal energy until it is out of the barrier. Since it is in a barrier the probability function will be a real exponential function and it will be delocalized and will find and will enter at the first free state in a nucleon that it will found. The free state energy are given by the energy level of the last bound nucleon. If a nucleon is trapped below any free state the time it will take to find the first free state is given by

$$t_{abs} = s_{abs}/v_{abs}$$

where t_{abs} is the length the nucleon travels to absorb enough energy to enter at the first free state,v_{avg} is the average speed of the nucleus in the material and s_{abs} is the length it travels to absorb the necessary energy. The minimum traveling length could then be found from

$$s_{abs} = \Delta E/E_{atom} * s_{atom}$$

where ΔE is the energy that is needed to reach the first free state, E_{atom} is the average thermal energy per atom and s_{atom} is the radius of the atom approx. around 10^{-10} m. The absorption time should be compared with the frequency of which the nucleons are transmitted out of the nucleus

$$f_{out} = T_{out} f_n$$

where f_{out} is the frequency of nucleons tunneling out, T_{out} is the probability of a tunneling event and f_n is the internal frequency of the nucleon. Setting $f_{out} = 1/t_{abs}$ gives the necessary probability for a nucleon to tunnel out rather than absorb to the nucleon.

For an average calculation v_{avg} could be set to approx. 10^6 m/s from a kinetic energy of 100 keV range. f_n are approx. 10^{21}Hz for a neutron inside a nucleus. E_{atom} are chosen around 1500 K. For nickel the heat capacity is 26 $J/molK$ so that E_{atom} are aprrox. 1 eV/atom. This means that the average life time is approx. 10^{-10} s before thermal absorption to a free state is possible for a 100 keV kinetic energy nucleon that need to absorb around 1 MeV. Table 1 shows the probabilities for different missing energies. The interesting starting reaction is the 1 MeV case where a neutron could be dragged out of ${}^{64}Ni$ which has a low neutron energy level at -8.8 MeV for the reaction ${}^{64}Ni \rightarrow^{63} Ni + n^*$. This while absorbing a -7.2 MeV neutron from ${}^7Li \rightarrow^6 Li + n*$ would require

ΔE	t_{abs} (s)	$f_{out}(Hz)$	T_{out}	$r_n(fm)$
0.1	10^{-11}	10^{10}	10^{-11}	19
1	10^{-10}	10^{9}	10^{-12}	21
2	10^{-9}	10^{8}	10^{-13}	21,3

Table 1: The probability where tunneling out of the nucleon is equally probable as enter by fusion for a neutron. ΔE is the needed energy to absorb before entering is possible in MeV, P_{out} is the probability and r_n is the tunnel distance for a -8.8 MeV neutron for that probability.

1.1 MeV for the reaction $^{64}Ni + n^* \rightarrow ^{65} Ni$. The neutron will then need to be held at least at 21 fm from the nickel nucleon which is far outside the Pauli barrier which starts at approx. 4 fm.

Free neutron pair

Two free neutrons can't for a bound pair but in heavy nucleons they can. So to form a free neutron pair one must set the energy of the neutrons to the one they have in a nucleon where they could form a pair. For example neutrons forms pairs in nickel so a neutron that lies at the last bound energy level of nickel isotopes could attract neutrons to drag them out of other nucleons.

If a neutron is transmitted from a nucleon to a proton/neutron below ground state they will probably form a short lived state where the average energy is equal. So for a -7.2 MeV neutron absorbed by a -8.9 MeV neutron the average energy level will be set to -8 MeV. The ground level of such a state will probable be close to the energy level in the original nucleon ie -8.9 MeV so the neutrons will first then emit energy down to the ground level of the short lived bound state and then absorb energy up to the first free enrgy level of a nearby nucleon.

Proton sources

A proton could also be tunneling out to a nearby neutron. Iron is a good candidate for that. If the neutron is from ^{64}Ni the neutron is -9.6 MeV below free energy level. The most common isotopes of iron is ^{54}Fe and ^{56}Fe. The reaction $^{54}Fe + n* \rightarrow {}^{55}Fe$ and $^{56}Fe + n* \rightarrow {}^{57}Fe$ are then energetic forbidden for a -9.6 MeV neutron. From table 2 we see that the proton energy lies lower than the neutron. From formula ? one also derives that the energy difference lies below the extra tunneling barrier for protons. This means that the most probable reactions would be $^{54}Fe \rightarrow ^{53} Mn + p*$ and $^{56}Fe \rightarrow ^{55} Mn + p*$ for a low energy neutron kept near the iron nucleon. The advantage with protons are that they always attract neutrons so at this low energy they could be used to drag more neutrons out of Lithium and Nickel while not risk to be absorbed.

The protons could also be reabsorbed by a nucleon that have a lower energy level than iron. For an overbound free pn state the energy levels for the proton

	n	p	ΔE
^{54}Fe	-13.3	-8.8	4.5
^{56}Fe	-11.2	-10	1.2

Table 2: Energy levels for last bound nucleon in ^{54}Fe and ^{56}Fe

	n	p
^{6}Li	7.25	5.6
^{58}Ni	9	3.4
^{60}Ni	7.8	4.8
^{61}Ni	10.6	5.8

Table 3: Energy released in $X + p/n \rightarrow Y$ reactions in MeV

and the neutron are probably similar so at the same time the neutron absorption energy should be higher. The free proton and neutron would probably interact so that they are at the same energy levels. For example the reaction $^{27}Al + p^* \rightarrow^{28} Si$ starts at a proton energy of -11.5 MeV while $^{27}Al + n^* \rightarrow^{28} Al$ starts at neutron energies -7.7 MeV. For ^{6}Li and Nickel isotopes we see from table 3 that neutron absorption is more probable. The levels for proton are also above the energy level for protons from an iron source.

Collective reduction

In special cases where the neutrons and protons could be held near the nucleons a chain reaction could occur. This will give a short lived state of many delocalized nucleons below free ground state for a short time until they once again have absorbed energy to enter a nucleon. The possible chain reactions are shown in table 4. The advantage of this is a pure ground state ground state transition between nucleons that is almost free of exited state if there where a way to push down the nucleons at the start. To push down the nucleons in energy one could use a magnetic field to split energy levels so the nucleons could step down until they reach the level where no absorption is possible and instead they drag more neutron/protons out of the nucleons. Another way to push down the nucleons is to let them enter in between states so that they will emit energy while going

nn	np
$^{7}Li + p \rightarrow {}^{6}Li + n^* (-7.2)$	$^{7}Li + p \rightarrow {}^{6}Li + n^* (-7.2)$
$^{64}Ni + n*(-7.2) \rightarrow {}^{63}Ni + n*(-8.9) + n*$	$^{64}Ni + n*(-7.2) \rightarrow {}^{63}Ni + n*(-8.9) + n*$
$^{7}Li + n^* (-8.9) \rightarrow {}^{6}Li + 2n^* (-8)$	$^{54}Fe + n*(-8.9) \rightarrow {}^{53}Mn + p*(-8.8)$
	$^{7}Li + p^* (-8.8) \rightarrow {}^{6}Li + p^* + n^*$

Table 4: Chain reactions for nn and np systems the energy in the parenthesis are MeV below ground state.

down to the nearest state. If they enter below the ground state they will loose energy until they hit the bottom of the potential or is transmitted to another state.