CONVENTIONAL SOURCES OF FAST NEUTRONS IN "COLD FUSION" EXPERIMENTS

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In "cold fusion" experiments with heavy water a source of neutrons is the dissociation of deuterium induced by alpha particles emitted by natural occurring radioisotopes. We evaluate the rate of fast neutron emission as a function of the concentration of U, Th, Rn in contact with deuterium and discuss the possibility that the neutrons claimed to have been observed in "cold fusion" experiments could be due to this conventional source.

Alpha particles of ^{212}Po (8.8 MeV) and of ^{214}Po (7.8 MeV), which are radon daughters, can dissociate deuterium through the reaction

$$\alpha + d \rightarrow \alpha + n + p \,. \qquad (1)$$

If the alpha particle emitters are located inside the electrodes, this reaction will occur only when the metal is loaded with deuterium. During electrolysis, a large amount of radon might be desorbed from the porous electrodes into the heavy water, thus faking the kind of observed signals in "cold fusion" experiments.

The alpha particle energy for reaction (1) at threshold is 6.6 MeV in the laboratory system or 2.2 MeV total energy in the center of mass. The neutrons have a spectrum extending up to 3.1 MeV, with a large fraction above 2 MeV. The cross section for this reaction was measured by Schutz in 1938 to be 1 mb at 8 MeV [1]; it has more recently been measured to be 0.3 b at 19 MeV [2]. The energy dependence of this cross section is dominated near threshold by Li* intermediate states [3]. Therefore we would expect a cross section of about 100 mb for an alpha particle energy of 8 MeV in the laboratory system.

Due to these arguments and to the fact that no new measurements of the cross section of reaction (1) have been performed near threshold since 1938 (to our knowledge), the following calculations have assumed arbitrarily a value of 0.1 b for the cross section at 8 MeV, giving an interaction length of 1.5 m in heavy water. If the deuterium is in a chemical form like TiD_2, or inside palladium (D/Pd = 0.6), the microscopic concentration of deuterium is probably close to that of heavy water.

Uranium and thorium, the parents of the naturally occuring radioisotopes are normally present in material at the ppm (μg/g) level. Experiments designed to observe very rare processes (solar neutrinos, double beta decay, dark matter searches, ...) must measure many materials to select those with very low radioactivity. Radium can also be present at the level of few pCi per gram, even in the absence of uranium contamination.

In a closed system, uranium is in equilibrium with all its daughter products, and the activity of each of these species is the same. Fig. 1a shows a diagram of uranium decay products. The long half life of ^{238}U (4.5×10^9 yr) determines the activity. Radon is gaseous and the equilibrium of the decay chain can be broken if ^{222}Rn escapes. A chemical treatment to obtain pure uranium can also break the equilibrium. The

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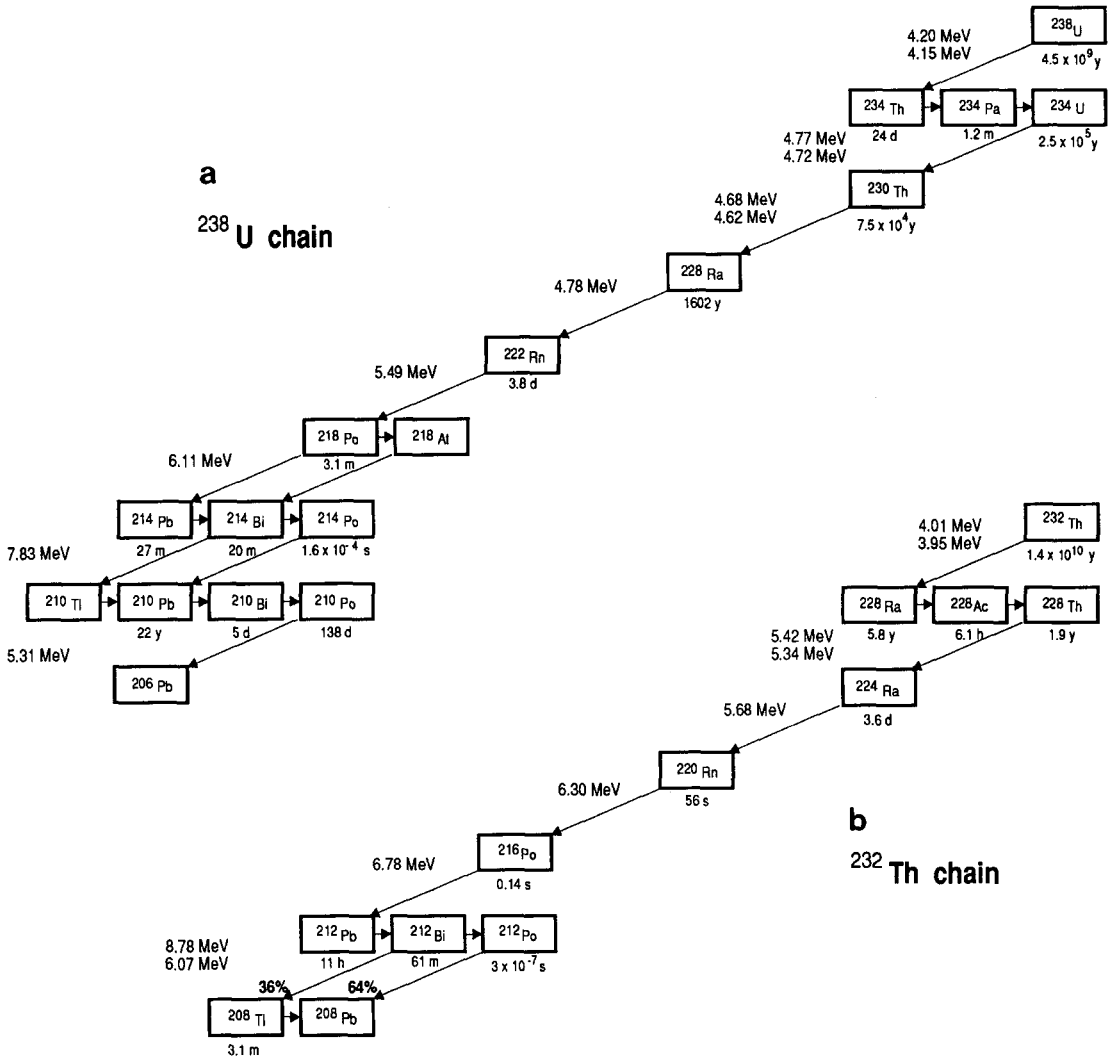

Fig. 1.

^{214}Po decays with a half life of 150 μs by emitting an alpha particle of 7.8 MeV.

Thorium (^{232}Th, $t_{1/2}=1.39\times10^{10}$ yr) is responsible for another family (fig. 1b) of radionuclides. ^{220}Rn is a member of this family. Among the daughters ^{212}Po decays with a half life of 0.3 μs by emitting an alpha particle of 8.8 MeV (branching ratio: 64%). ^{208}Tl decays by emitting a gamma of 2.61 MeV (branching ratio 36%) with a half life of 180 s.

After travelling some 28 μm in heavy water (10 μm in titanium or 5 μm in palladium), the alpha particle has lost enough energy to be below threshold of reaction (1). If titanium sponge is used, the size of the grains composing the sponge must be considered. The probability of interaction (1) for an alpha particle emitted with 8 MeV of kinetic energy can be computed for the cases of interest (assuming $\sigma=0.1$ b):

- in heavy water, the probability is 1.6×10^{-5},
- deuterium combined into metal, the probability is 0.6×10^{-5},
- in pure deuterium, the probability is 6×10^{-5}.

To reproduce the signal detected by Jones et al. [4]

of 4×10^{-3} neutrons/s it is therefore necessary to assume that the alpha particles interact in heavy water (the efficiency of 1% to detect fast neutrons in the counter is assumed) and that the activity in the apparatus is around 50 000 Bq of ^{214}Po (uranium series) or of ^{212}Po (thorium series). Nevertheless this contamination seems high if it is due only to uranium or thorium. Moreover, if the interactions occur on deuterium inside the metal, the contamination would have to be three times higher. However, it is common to find samples of precious metals like palladium, with activities of 1000 Bq/g [5].

Radon is present in the air naturally. In houses, the walls contain radionuclides and emit radon continuously. Quantities vary strongly, but typical values are above 20 Bq/m^3 [6] or a concentration of 5 atoms of radon per 10^{19} "air molecules". The half life of ^{222}Rn is 3.82 d. The other short lived isotope ^{220}Rn ($t_{1/2}=55$ s) is also present.

Radon, like other gases, is adsorbed easily in the kind of materials used in "cold fusion" experiments. Sponge or rough surfaces increase dramatically the adsorption capacity, even at room temperature. Table 1 shows measured values of adsorption of rare gases on charcoal at 0°C [7]. Thus the adsorption capacity for radon is clearly not a limiting factor, but rather the amount of radon present in the air. The quantity needed to explain the activity quoted above is around 3×10^{10} atoms of ^{222}Rn or 2×10^{9} atoms of ^{220}Rn. Whether radon was present at this level in the materials used in the experiments depends on the adsorption before and during the experiment.

Once radon is adsorbed on the electrode, it decays as shown in fig. 1. After some 2 h ^{214}Po or ^{212}Po is present and produces alpha particles as explained above. Very different quantities of radon could be adsorbed by different electrodes during their storage prior to use in the experiments. Heating the electrodes is not sufficient to remove the adsorbed gases; the usual cleaning technique is to heat the titanium to 800°C in vacuum.

Table 1
Volume in cm^3 (STP) of adsorbed gas by 1 gr of charcoal for a partial pressure of 1 torr at 0°C [8]. For radon they are extrapolated values of the possible capacity. Values in titanium sponge are at least equal.

Gas	Z	cm^3/gr
Ar	18	0.058
Kr	36	0.34
Xe	54	1.58
Rn	86	>2.00

During electrolysis experiments, a large amount of gas is produced at the electrodes. This gas can remove the radon adsorbed on the electrodes or dissolved in the water, breaking the radioactive chain, so that the radioactive signal could disappear with time. In fact, a very efficient technique for purifying liquids containing undesirable dissolved gases is to bubble any pure gas through the liquid. The dissolved gases escape with the bubbles of pure gas. As an example of this technique, in solar neutrino experiments (Chlorine experiment, Gallex) as few as 10 radioactive atoms in a volume of more than 100 t of liquid can be removed merely by bubbling pure helium or nitrogen through the liquid [8]. Flushing with a volume of gas equal to ten times the volume of the liquid removes the dissolved impurities with an efficiency of 90%.

In the experiment of Jones et al. [4] runs 1–14 provide evidence for the emission of fast neutrons. Several important conditions change from run to run, the electrolyte is modified, heavy water is added, and the cell and the electrodes are changed. Moreover, the background measurements were made before and after, but not during the series of runs yielding positive results. Different pieces of equipment were used in the background measurement. In particular, if D_2O is replaced with H_2O, the type of background described above would obviously disappear. In addition, if LiOH is used as an electrolyte, lithium may migrate to the cathode where it can also be a source of fast neutrons due to (α, n) reactions. A yield of 4.7×10^{-6} neutrons per alpha particle per hole of a polonium source is quoted by Segrè [9].

An experiment performed by Scaramuzzi et al. [10], which claims to observe fast neutrons emitted from titanium in the presence of pressurized deuterium, can also be explained by natural radioactivity. Titanium cooled at liquid nitrogen temperature is a better adsorbant by several orders of magnitude than titanium at room temperature, so it would trap radon along with other gases present in the laboratory. In the presence of pressurized D_2, reaction (1) can take place, even more efficiently than in the electrolysis

experiment, as soon as enough $^{214}Po/^{212}Po$ has been produced from this fresh source of radon (about 2 h is necessary to reach the equilibrium activity). Once all the radon products have decayed, the signal will disappear as observed in this experiment and also in that of Jones et al. [3]. At the end of the experiment, some radon will be trapped again before the temperature rises, and neutrons will again be produced for a short time until the gases (including D_2 and radon) desorb from the titanium.

Another source of fast neutrons are the (α, n) reaction on ^{17}O and ^{18}O (threshold −0.58 MeV and 0.7 MeV, respectively). For alpha particle energies > 5 MeV above threshold (twice the Coulomb barrier), the cross sections are about 1 b [11], but the natural isotopic abundances of ^{17}O and ^{18}O are only 0.037% and 0.2%. The average energy of the produced neutrons is 3.5 MeV. Note that these reactions would also operate on light water.

A last source of neutrons come from the reaction

$$\gamma + d \rightarrow n + p\,. \qquad (2)$$

A 2.6 MeV gamma has a 10^{-3} probability of photodisintegration of the deuteron (for 10 cm of heavy water), leading however to neutrons of rather low energy (200 keV), below threshold in the experiment of Jones et al. [4], but which could have been detected with thermal neutron counters.

Conclusion. As long as the signal of neutrons in "cold fusion" experiments is small, careful experimental procedures are necessary to detect fast neutrons unambiguously in these devices. In particular, all elements of the experimental apparatus should be carefully outgassed before performing the experiment. Materials should be selected for low radioactivity. Background measurement capable of discerning artefacts due to natural radioactivity must be made.

Due to uncertainties in the cross sections of reaction (1) it is necessary to undertake experiments of electrolysis with known contamination of radium or thorium in the electrolytes, or radon in the electrodes. This program is now underway, using the neutron detectors operated by the Bugey collaboration [12] to allow the best neutron identification. With these measurements we will have enough information to evaluate the importance of this source of neutrons.

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