J. Condensed Matter Nucl. Sci. 3 (2010) 35–40

Research Article

Neutron Yield for Energetic Deuterons in PdD and in D_2O

Peter L. Hagelstein *

Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Abstract

To account for the excess heat in the Fleischmann–Pons experiment, it has been proposed that the reaction energy can be shared among a large number of deuterons. In order to help quantify how many deuterons are required to be consistent with experiment, we have computed the neutron yield for deuteron–deuteron fusion reactions in both PdD and in D_2O.

Keywords: Fleischmann–Pons effect, Correlation of neutrons with heat, Neutron yield for deuterons in PdD, Energy exchange with deuterons

1. Introduction

Takahashi and coworkers presented a useful assessment of the theoretical situation at ICCF5 [1], which remains relevant at the present time. Four scenarios were described, which we will outline here. In the first scenario, an aneutronic conventional fusion reaction is responsible for the excess heat, with the energetic fusion products hidden. In the second scenario, the reaction energy is communicated directly to the lattice, with no production of energetic particles. The third scenario is an exotic chemical or mechanical source for the energy, with weak associated nuclear emission. Finally, the fourth scenario is one in which the excess heat can be attributed to error.

Time and many experiments have provided ample evidence against the last of these scenarios, as there have been a great many replications of the excess heat effect. There have not appeared to the author's knowledge any credible proposal for exotic chemical or mechanical sources for the energy. To the contrary, the amount of energy produced in some experiments has been sufficiently large that there simply cannot be exotic chemical or mechanical sources. We have been interested in the second scenario since March, 1989; subsequently we reported on our progress at the ICCF conference series over the years.

However, in recent months we have developed an interest in the first scenario. Our interest has come about from a series of workshops that were held at the Naval Postgraduate School that were in part focused on the issue of mechanism.

*E-mail: plh@mit.edu

Some notable physicists were present, and after being exposed to some of the experimental results, their response was to put forth a number of proposals centered squarely within what Takahashi et al. described within their first scenario.

In these proposals, deuterons would in one fashion or another come together to produce ^{4}He, which would then carry away part of the reaction energy. The idea in these proposals was to try to have the overall mechanism remain consistent with one of the foundations of nuclear physics; that the reaction energy must be expressed as kinetic energy of the products as a consequence of energy and momentum conservation. At issue was the question of whether the reaction proceeds in a way consistent with the first scenario, or instead whether the reaction energy is communicated directly to low energy condensed matter degrees of freedom.

In the end, we were not able to come to an agreement. On the one hand, a spirited defense of the first scenario, energetic particles, and the established aforementioned foundation, was put forth; any radically new approach that would involve the direct communication of reaction energy to condensed matter modes was judged to be too farfetched to be worthy of serious consideration. On the other hand, an equally spirited argument was put forth that the proposals involving "hidden" energetic products was simply inconsistent with experiment.

So, in the months following these meetings, some effort on our part has gone into an attempt to quantify the situation with respect to the hidden particles. In the workshop discussions, the focus was on an energetic alpha as the hidden particle. However, in order to understand quantitatively the yield of observable products due to energetic alpha particles, one first has to understand the yield of energetic deuterons. The reason for this is that one important way that energetic alphas give rise to neutron emission is through energetic deuterons produced from head on collisions with the alpha particles. So, to begin the analysis, we first need to determine the yield of an energetic deuteron.

At ICCF15, Storms put forth ideas about an energy release mechanism in which MeV reaction energy would be shared among a large number of deuterons in a cluster [2]. In some ways these ideas are like proposals due to Kim [3], in which the reaction energy would be shared with a large number of deuterons which he has proposed to condense in a Bose–Einstein condensate. Our focus here is not on the issues, merits, or challenges associated with these proposals. Instead, the results that we have obtained are useful in helping to quantify how many deuterons the reaction energy

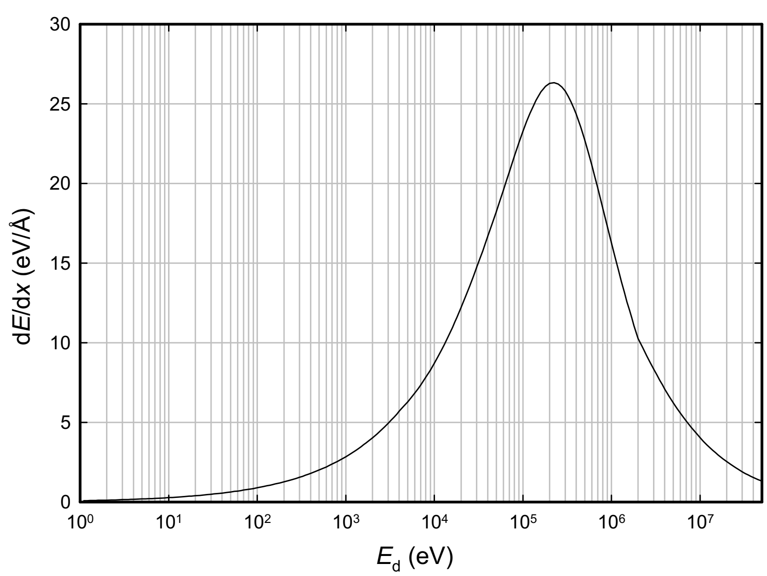

Figure 1. Stopping power for deuterons in PdD from SRIM2008.

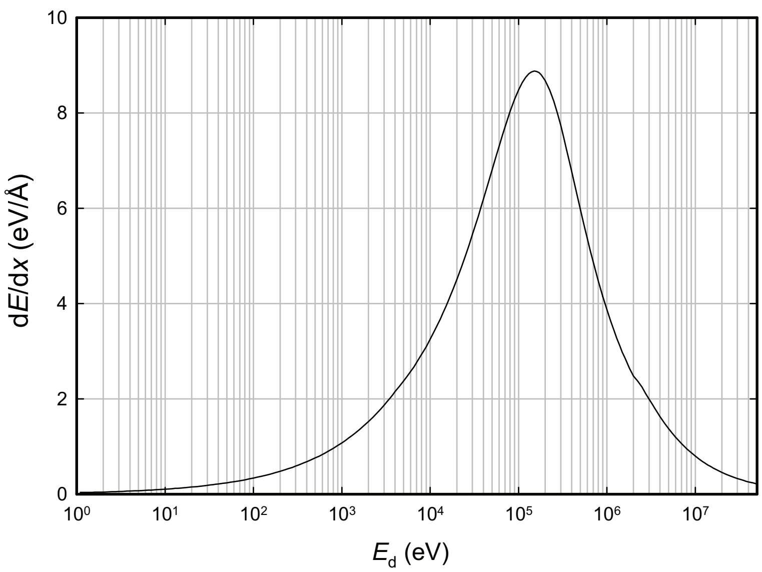

Figure 2. Stopping power for energetic deuterons in D_2O from SRIM2008.

would have to be shared with in order to be consistent with experiment.

2. Stopping power of deuterons in PdD and in D_2O

We have used the SRIM-2008 code of J. F. Ziegler, J. P. Biersack and U. Littmark to compute the stopping power of energetic deuterons in PdD and in D_2O. The stopping power for energetic deuterons in PdD is shown in Fig. 1, and the stopping power in D_2O is shown in Fig. 2. To construct these plots, we used a density of 10.921 g/cm^3 for PdD, and a density of 1.10 g/cm^3 for D_2O.

From a knowledge of the stopping power, one can compute the associated range using

$$R(E) = \int_0^E \left(\frac{\mathrm{d}E}{\mathrm{d}x}\right)^{-1} \mathrm{d}E. \tag{1}$$

Results for the range in the two cases are shown in Fig. 3.

3. Yield of neutrons from $^2H(^2H,n)^3He$ reactions

To compute the neutron yield from deuteron–deuteron fusion reactions, we need to integrate the product of the cross section and deuteron density over the deuteron trajectory as it slows down

$$Y(E) = \int_0^{R(E)} N_\mathrm{d}\sigma[E(x)]\mathrm{d}x. \tag{2}$$

Results of computations of the yield are shown in Fig. 4. For these calculations, we took the screening energy U_e to be 800 eV for PdD, and 25 eV for D_2O.

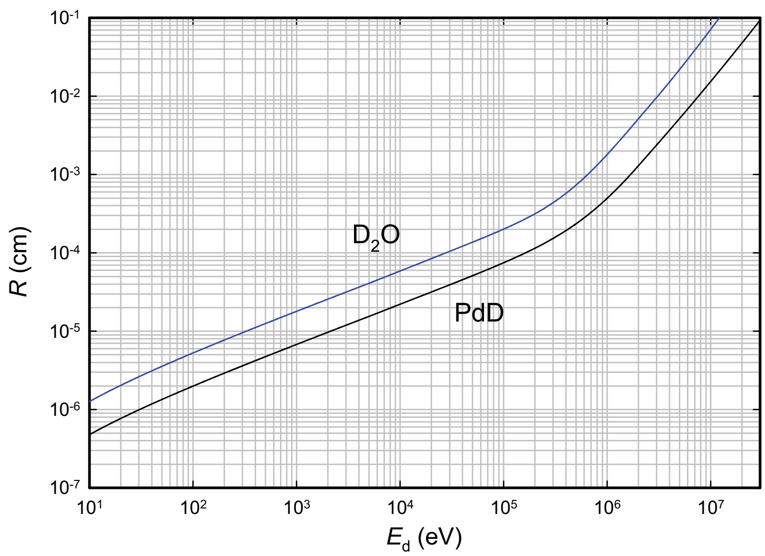

Figure 3. Range of energetic deuterons in PdD (lower curve) and in D_2O (upper curve).

4. Upper limits from experiment

The experimental data set associated with the Fleischmann–Pons experiment is often perplexing and not always consistent. With respect to the presence of low-level neutron emissions correlated with excess heat, one find mostly the absence of a correlation. In our view, there are different regimes where different effects are observed. For example in the case of a Fleischmann–Pons type rod cathode, excess heat is observed at higher current densities (several hundred mA/cm^2), while neutron emission is associated with lower current densities (tens of mA/cm^2).

If so, then of interest in the present discussion is the question of how many neutrons are seen when a system is running well, producing excess heat, and very little in the way of energetic emissions. This case presents the strictest constraints in regard to theoretical models.

Takahashi and coworkers reported on measurements of excess heat and neutron emission using Takahashi's high–low current protocol [4]. From our perspective, we would associate neutron emission with the low current part of the protocol, and excess heat with the high current part of the protocol. The data presented in this paper probably can be considered to support this notion weakly. In any event, there are numbers given both for excess power and for neutron emission above background from which we can extract a ratio. The source neutron emission rate is on the order of 1 n/s, largely uncorrelated with the presence of excess heat. The excess power is seen to reach about 100 W. Using these numbers leads to an estimate of 0.01 n/J.

Gozzi et al. reported positive measurements of excess heat run with neutron detection at ICCF4 [5]. In this case, excess power at levels on the order of 15 W, with no neutron emission above background. In the conference proceedings paper, the detector efficiency is not given. However, the detector was discussed in an earlier paper [6], and also in [7], and an efficiency of 22% is given. Using this efficiency, the background is about 35 neutrons counted in 10 min per segment, which corresponds to 12(0.265) = 3.2 source neutrons/s equivalent. We will assume that signals on the order of 10% of this number are detectable. The peak excess power in some of the bursts are in the range of 10-15 W. This leads to a limit on neutron production as low as 0.021 n/J.

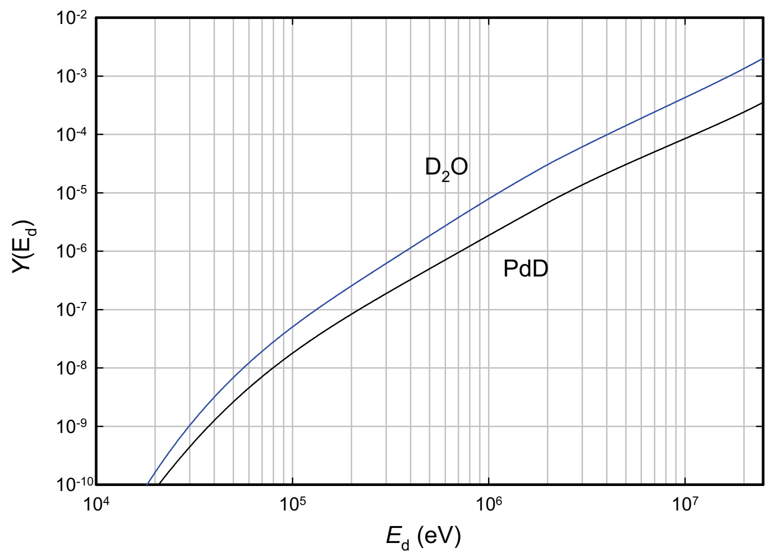

Figure 4. Yield of neutrons due to deuteron–deuteron fusion reactions in PdD (lower curve) and in D_2O (upper curve).

Scott et al. reported observations of excess heat at the same time that neutrons were detected [8]. In this case, excess heat was observed at the level of 4 W. Neutrons were monitored with an NE-213 detector with an efficiency of 0.00146, with a background of about 40 counts per day (about 0.32 n/s). If we assume that signals could be detected at the level of 10% of background, the associated upper limit is 0.008 n/J.

To compare with the calculations above, we have plotted the neutron yield divided by energy in comparable units (see Fig. 5). We see that in order to be consistent with the 0.008 n/J, that the upper limit on the deuteron energy is about 890 eV in the case of PdD. For low-energy deuterons in D_2O, the yield is less due to the weaker screening in this model.

5. Discussion

It has been suggested that the energy produced in the Fleischmann–Pons experiment is released as kinetic energy in a large number of low energy nuclei. Since most of the light nuclei in a Fleischmann–Pons experiment are deuterons, then one possibility is that the reaction energy is somehow distributed over a large number of deuterons, as has been discussed by Kim, and also by Storms. If so, then in order to be consistent with the experimental results discussed above, the average deuteron energy would have to be less than 900 eV if the deuterons remain in PdD. If the reaction energy is assumed to be 24 MeV, then this energy would need to be shared with at least 26,000 deuterons if all deuterons had the same energy. If the sharing process resulted in a thermal distribution, then probably more deuterons would be needed in order to reduce the contribution from the high energy tail of the thermal distribution. In Kim's paper [3], it is assumed that the energy is shared by on the order of 10^{10} deuterons.

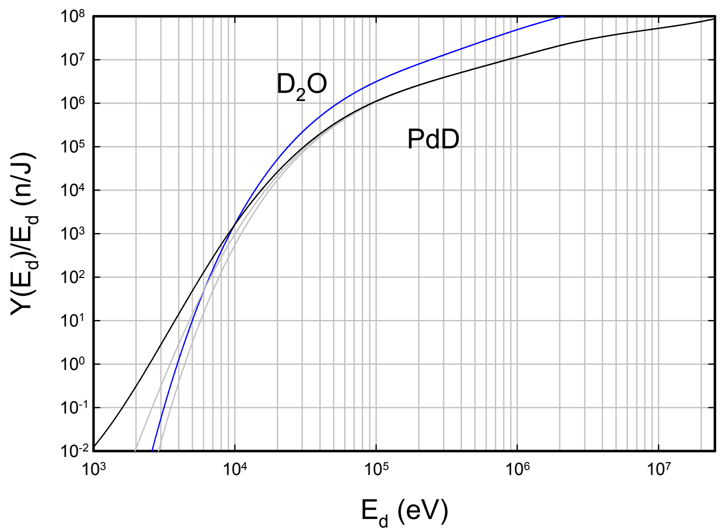

Figure 5. Yield of neutrons per unit energy due to deuteron–deuteron fusion reactions in PdD (black) and in D_2O (blue); also shown are results for PdD using 400 and 0 eV for the screening energy (gray).

References

[1] A. Takahashi, T. Inokuchi, Y. Chimi, T. Ikegawa, N. Kaji, Y. Nitta, K. Kobayashi, and M. Taniguchi, *Proc. ICCF5*, p. 69, 1995.

[2] X. Z. Li, B. Liu, S. Chen, Q. M. Wei, and H. Hora, *Laser and Particle Beams* **22** (2004) 469.

[3] Y. Kim, *Naturwissenschaften* **96** (2009) 803.

[4] A. Takahashi, A. Mega, T. Takeuchi, *Proc. ICCF3*, p.79, 1993.

[5] D. Gozzi, R. Caputo, P. L. Cignini, M. Tomellini, G. Gigli, G. Balducci, E. Cisbani, S. Frullani, F. Garibaldi, M. Jodice, G. M. Urciuoli, *Proc. ICCF4*, Vol. 1, p. 2-1, 1994.

[6] D. Gozzi, P. L. Cignini, R. Caputo, M. Tomellini, G. Balducci, G. Gigli, E. Cisbani, S. Frullani, F. Garibaldi, M. Jodice, G. M. Urciuoli, *Proc. ICCF3*, p. 155, 1993.

[7] E. Cisbani, G. M. Urciuoli, S. Frullani, F. Garibaldi, F. Giuliani, D. Gozzi, M. Gricia, M. Iodice, M. Lucentini, F. Santavenere, *Nucl. Instr. Meth.* **A 459** (2001) 247.

[8] C. D. Scott, J. E. Mrochek, T. C. Scott, G. E. Michaels, E. Newman, M. Petek M, *Fusion Technol.* **18** (1990) 103.