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Independent–Particle Model for Fusion in Cluster Impact

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Abstract

Theory is presented in an independent–particle model for the fusion yields from impact of accelerated $(D_2O)_n^+$ clusters on TiD. It is assumed that deuterons from an incident cluster penetrate the medium independently of each other. Comparison is made with the recent experiment[1] of Beuhler, Friedlander, and Friedman. The measured yields (fusion events per incident cluster) are many orders of magnitude higher than the calculated ones (based on this theory). This shows that cooperative effects, involving the cluster, are crucial to interpretation of the reported results. The calculations illustrate the necessity of rigorously excluding low–mass deuterium–containing ions from the incident beam in such an experiment.

INTRODUCTION

Recently, Beuhler et al.[1] have reported the observation of fusion when accelerated charged clusters of D_2O molecules strike TiD targets. Novel methods of achieving nuclear fusion have been of great interest since the claimed discovery early this year of cold fusion,[2,3] and this latest report is certain to stimulate continued widespread interest in phenomena attending the penetration of charged particles in solids.

The purpose of this work is to calculate d–d fusion yields from an independent–particle model. It is assumed that clusters break up on impact with the TiD target, whereupon deuterons (and oxygen, too, which is not of interest) penetrate the solid and are transported in it independently of each other. No account is made for compression or heating of the medium. Incoming deuterons lose energy to electrons and phonons, and finally come to rest. In the process, a given projectile deuteron may, with small probability, enter into a fusion reaction with a deuteron belonging to the target.

It is clear, before beginning, that the model as outlined above is unlikely to explain the yields measured in the experiment. Beuhler et al. have argued that the rates might instead be due to compression and high energy density in the solid due to cluster impact, and it will be important to pursue those suggestions. Still, some insight might result from comparing the predictions of this model with the experiment, particularly as there is one significant aspect of the experimental results that argues for a simple explanation. No fusion was observed when the deuterium was replaced with hydrogen in either the beam or the target. This suggests that beam and target deuterons are not only both present where the reaction occurs, but also that they are still effectively distinguishable, as opposed to being randomly mixed.

Theory

Consider a $(D_2O)_n^+$ cluster of translational energy E, incident on a deuterium–loaded target. Suppose the 2n deuterons penetrate the target, each initially with the same velocity as the cluster. The probability dY that a d–d fusion reaction occurs (of the 2n fast deuterons) while one typical deuteron travels a distance dR (measured along its path) is given by

$$dY = 2nN\,\sigma(E_d)\,dR, \tag{1}$$

where N is the number of target deuterons in unit volume, and $\sigma(E_d)$ is the reaction cross section, which depends on the energy E_d of the deuteron. Now, if we make the approximation that the typical particle loses energy continuously in the solid, at a lineal rate dE_d/dR, we may replace dR in Eq. (1) by $(dE_d/dR)^{-1}dE_d$. The resulting equation is immediately integrable to give the following expression for the yield Y(E), or number of reactions per cluster:

$$Y(E) = 2nN \int_0^{E_{d0}} \sigma(E_d) \left[-\frac{dE_d}{dR}(E) \right]^{-1} dE_d \tag{2}$$

where $E_{d0} = (M_d/nM_{D_2O})E$ is the initial energy of the deuteron, given by the product of the mass ratio and the energy of the cluster. Note that quantity in the brackets in Eq. (2) above is just the deuteron stopping power of the solid.

The cross section of the D(d,p)T reaction is given[4,5] at the energies of interest by

$$\sigma(E_d) = 2\,\frac{S}{E_d}\,e^{-2\pi\eta}, \tag{3}$$

with

$$2\pi\eta = 2\pi\frac{e^2}{\hbar v} = 269.17\,(E_d\,a_0/e^2)^{-1/2},$$

where v is the velocity, e and a_0 are the charge of the electron and the Bohr radius, and S is the astrophysical constant extrapolated to zero energy, whose value[5] is 55.7 keV b = $7.31 \times 10^{-5}\ e^2a_0$. The prefactor of 2 in Eq. (3) is there because the energy E_d in the denominator is the projectile energy, instead of the relative energy.

The stopping power is the sum of the electronic nuclear stopping powers. For the electronic stopping power, values given by Andersen and Ziegler[6] for Ti metal were used. This should be a reasonable choice for the purpose, particularly since, as can be seen in Eq. (2), it is the ratio of the stopping power to the atomic density that is required. The nuclear stopping is calculated from LSS theory[7] for the Thomas–Fermi potential. The sum of the nuclear stopping by Ti and by D (assumed to be present in equal number) is used. At all the energies relevant to the present results (0.6 to 300 keV) it is found that the electronic stopping is greater than the nuclear stopping by Ti, which in turn is greater than the nuclear stopping by D.

Results and Discussion

The figure displays the results. The circles are the yields (number of D(d,p)T fusion reactions per cluster), computed as described above, for clusters composed of 1 to 50 D_2O molecules. The squares are yields of the same reaction, measured by Beuhler, et al. In each case, the clusters, which are singly charged, are accelerated to 300 keV energy. The experimental data extend to clusters of 1300 molecules.

The theoretical yields are seen to decrease rapidly with increase in the number n of molecules in the cluster. This is of course because the initial deuteron energy E_{d0} is inversely proportional to n, and the fusion cross section decreases rapidly with decreasing E_d. The theory falls below the experiment by a huge factor. At n = 50, the two differ by 18 orders of magnitude! More surprising, the experimental results do not decrease (within an order of magnitude) with increasing n until n exceeds about 1000. A successful explanation of the experiment will evidently have to show how a major fraction of the energy of a cluster comes to be concentrated on a small minority of the deuterons in or around the cluster.

The figure also illustrates the necessity of rigorously excluding low–mass deuterium–containing ions from the accelerated beam in such an experiment. (This point is also dealt with in detail by Beuhler, et al.) Thus, D_2O^+ or D_3O^+ must be kept to less than 1 % (by number of ions), or it will hide the desired signal. The yield from 300 keV D^+ ions, also calculated from the above model, is 1.7×10^{-7} D(d,p)T reactions per incident ion, which is 4 or 5 orders of magnitude larger than the experimental yields from clusters

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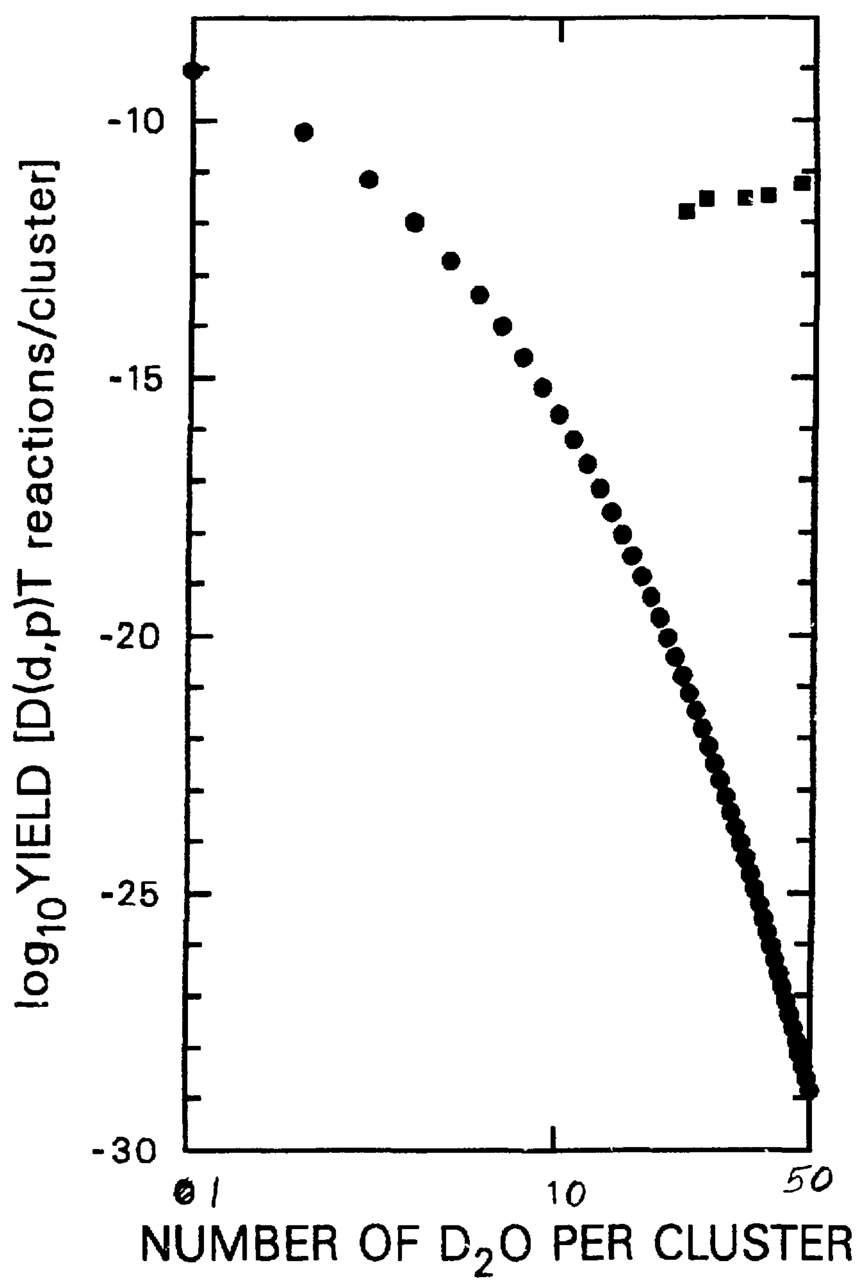
Figure Caption

Fusion yield, D(d,p)T reactions per 300–keV $(D_2O)_n^+$ cluster, versus n. The circles are the present calculation; the squares are experiment results from Beuhler et al.[1]



-10
-15
-20
-25
-30
log10 YIELD [D(d,p)T reactions/cluster]
Ø 1
10
50
NUMBER OF D2O PER CLUSTER