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MEASUREMENT OF D-D AND D-6LI NUCLEAR REACTIONS AT VERY LOW ENERGIES

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ABSTRACT

The nuclear reactions of very low energy deuterons (down to center-of-mass energies of 2 keV) with deuterons and ^{6}Li have been measured. The measured D-D reactions are in good with agreement recent R-matrix calculations. The reaction ratios D(d,p)T/D(d,n)^{3}He and ^{6}Li(d,p)^{7}Li/^{6}Li(d,α)^{4}He in particular were examined for possible evidence of an Oppenheimer-Phillips type enhancement. No significant enhancement was found in either ratio or in the absolute yields of the reactions. The radiative capture reactions D(d,γ)^{4}He and ^{6}Li(d,γ)^{8}Be were likewise measured. The branching ratios of these radiative capture reactions to the nucleonic branches of the reactions appear roughly independent of energy. The role of these reactions in the production of heat in cold-fusion experiments is evaluated.

INTRODUCTION

The nuclear reactions between two deuterons and perhaps between a deuteron and a ^{6}Li nucleus are generally accepted as playing crucial roles in recently observed nuclear processes and significant heat production in condensed matter deuterium-metal systems. Independent measurements of the cross sections for these nuclear reactions at low energies will allow these assumed roles to be addressed. The ratio of the reactions D(d,n)^{3}He and D(d,p)T or the ratio of the reactions D(d,γ)^{4}He and D(d,p)T at very low energies will, for example, determine whether significant heat production is possible from D-D nuclear reactions in the absence of enormous quantities of escaping and potentially hazardous radiation. Similarly, the ratio of the reactions $^6Li(d,p)^7Li$ and $^6Li(d,\alpha)^4He$ and the ratio of the reactions $^6Li(d,\gamma)^8Be$ and $^6Li(d,\alpha)^4He$ will allow the analogous determination for the D-^{6}Li reaction to be addressed. In this work, we report on our recent measurements of these reactions. While some of these reactions have been studied at relatively low energies[1-5], the present work extends our knowledge of these reactions to significantly lower energies. On the other hand, our measurement of the reaction $^6Li(d,\gamma)^8Be$ is the first reported observation of this reaction.

EXPERIMENTAL RESULTS

The D-D and D-^{6}Li reactions were studied using magnetically analyzed deuteron beams from the Colorado School of Mines low energy charged particle accelerator[6]. The targets consisted of pressed sheets of CD_2 and rolled foils of metallic Li, isotopically enriched to 94% ^{6}Li. The charged reaction products were detected with silicon surface barrier detectors placed at 150° from the beam direction and protected from the Rutherford backscatterd beam deuterons by a thin Al foil. The gamma rays were detected with a NaI(Tl) scintillation spectrometer surrounded by an active Compton scattered gamma ray and cosmic ray shield. This gamma ray detector system has been described elsewhere[7]. The techniques used in the gamma ray to charged particle branching ratio measurements have likewise been described in some of our earlier studies[8].

Charged particle spectra measured during the bombardment of the CD_2 and ^{6}Li targets are shown in Figure 1.

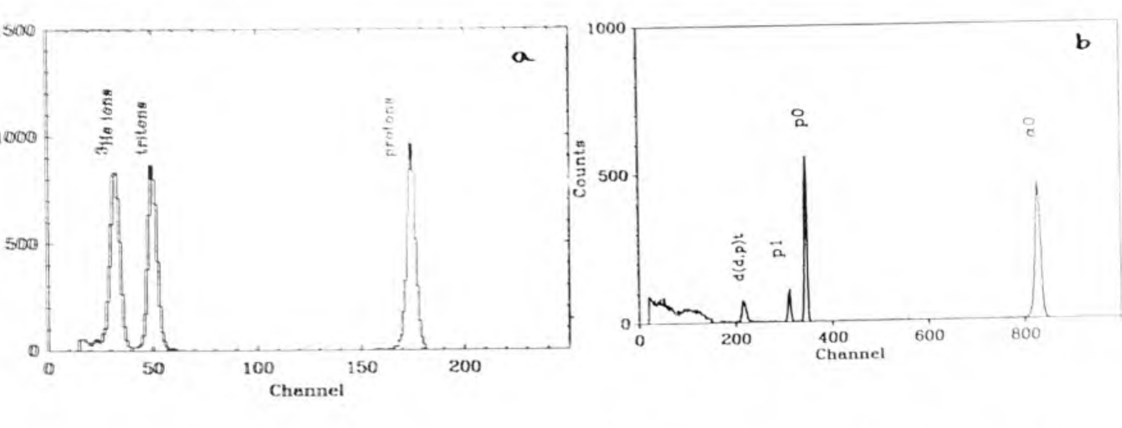

Figure 1. (a)Charged particle spectrum for D-D reaction at $E_{lab} = 10$ keV. (b) Charged particle spectrum for D-^{6}Li reaction at $E_{lab} = 150$ keV.

Since the angular distributions of the outgoing reaction products for the D-D and D-^{6}Li reactions have been shown to be nearly isotropic at low energies[1-3], the reaction ratios D(d,p)T/D(d,n)^{3}He and ^{6}Li(d,p)^{7}Li/^{6}Li(d,α)^{4}He are determined directly from the ratio of the yield of the peaks labelled "^{3}He ions" and "tritons" for the D-D reaction and "p0" and "α" for the D-^{6}Li reaction. The yield ratios so determined as a function of energy are given in Figure 2. The yield ratios for the D-D reaction presented in Figure 2 are compared to a recent R-matrix[9] calculation. Our measured yield ratios are consistent with the calculated ratio, indicating no enhancement of the (d,p) reaction as qualitatively suggested by Oppenheimer and Phillips[10]. While there have been no comparable calculations for the ratio of the reactions ^{6}Li(d,p)^{7}Li and ^{6}Li(d,α)^{4}He, Koonin[11] has calculated the (d,p)/(d,n) ratio for the D-^{6}Li reactions at low energies and has predicted no significant enhancement of the (d,p) reaction. Our results are consistent with these predictions since we would expect the (d,α) reaction to be unaffected by any Oppenheimer-Phillips type processes.

These spectra also allowed a determination of the absolute thick taget yield of the reactions. The measured yields are shown in Figure 3 and are compared, respectively, to yields based upon the R-matrix calculation noted above or calculated assuming a slowly varing astrophysical S-factor. There is good agreement between measured and calculated yields again indicating no anomolous behavior at very low energies.

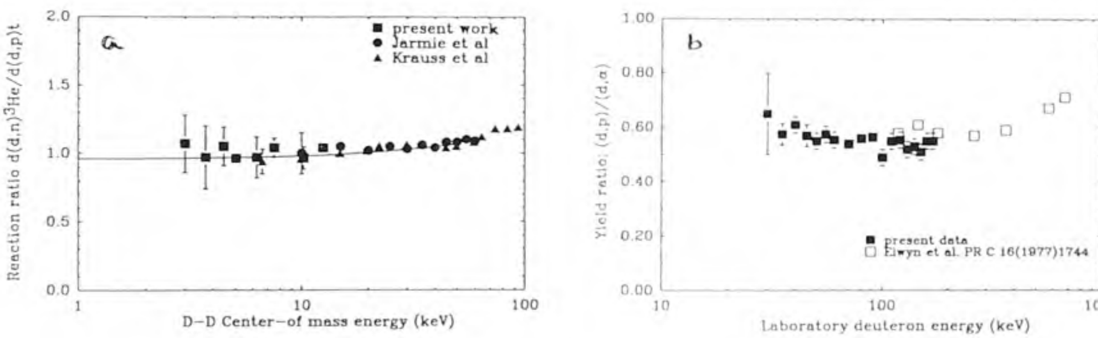

Figure 2. (a) Ratio of (d,p) to (d,n) branches for D-D reactions. (b) Ratio of (d,p) to (d,α) branches for D-^{6}Li reactions.

Gamma ray spectra were measured during the deuteron bombardment of the CD_2 and ^6Li targets between c.m. energies of 20 and 100 keV. The yield of the 23.8 MeV and 22.6 MeV gamma rays and the concurrent yield of the charged particles (see Figs 1) will determine the gamma ray to charged particle branching ratios for the D-D and D-^{6}Li reactions respectively after the yield ratios are corrected for the relative detector efficiencies. The branching ratios so determined are plotted in Figure 4. The D-D branching ratio is consistent at the higher energies with our earlier measurements. The fact that the measurements of the D-D gamma ray to charged particle branching ratio at c.m. energies of 20 and 40 keV are, to within errors, equal in value, suggest that the branching ratio is independent of energy. The energy dependence for the branching ratio for the D-^{6}Li reaction is somewhat inconclusive although energy independence is certainly not ruled out by virtue of the relatively large error bar on the lower energy data point for this reaction.

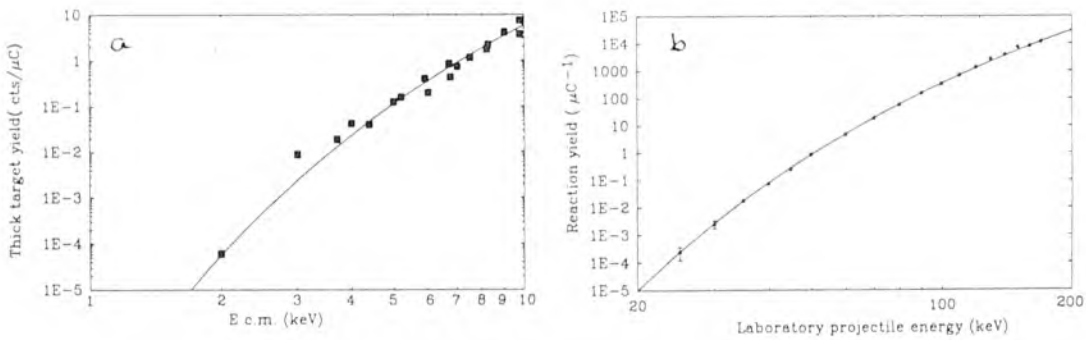

Figure 3. (a) Measured and calculated yields for D(d,p)T reaction. (b) Measured and calculated yields for $^6Li(d,\alpha)^4He$ reaction.

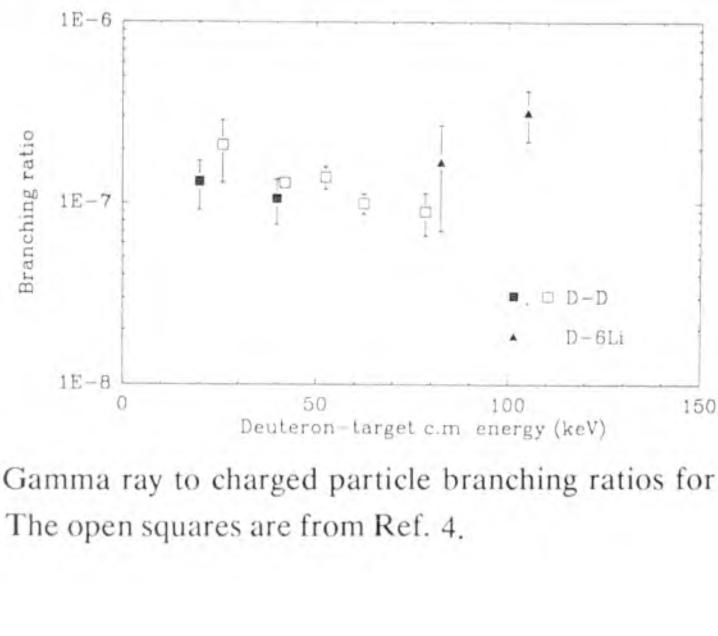

Figure 4. Gamma ray to charged particle branching ratios for the D-D and D-^{6}Li reactions. The open squares are from Ref. 4.

CONCLUSIONS

The results of our measurements have significant implications for any effort to associate the D-D or D-^{6}Li nuclear reactions with reports of heat production from cold fusion experiments. Specifically, if the particle-particle and gamma ray-particle branching ratios which we have measured at very low laboratory energies are characteristic of the branching ratios occuring in condensed matter fusion in deuterium-metal systems, then even low levels of heat production arising from these nuclear reactions will necessarily be associated with enormous quantities of escaping radiation. For example, based on the branching ratios given in Figures 2 and 4, if 1 Watt of power were produced by the D-D reaction, then there would be an accompanying production of about 10^{12} 2.5 MeV neutrons per second and about 10^5 24 MeV gamma rays per second. Comparable yields of neutrons and gamma rays will be associated will similar levels of power production by the D-^{6}Li reaction. If, therefore, the reported production of heat from condensed matter fusion in deuterium-metal systems is to be attributed to D-D or D-^{6}Li reactions, then the particle-particle and gamma ray-particle branching ratios at unmeasurably low energies must vary drastically from those measured at the low energies reported in this work.

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