CLM - P 254

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TRAPPING OF keV DEUTERONS IN LITHIUM

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ABSTRACT

Measurements have been made of the trapping of 18 keV deuterons in solid and liquid lithium targets over the temperature range 320-730^{o}K. Trapping efficiencies of 97% were observed in the liquid for doses of more than 10^{19} ions cm^{-2} at temperatures up to 700^{o}K. At higher temperatures the dissociation of lithium deuteride prevented further trapping. In the solid lithium the trapping efficiencies were in the range 70-95% but were rather irreproducible.

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1. Introduction

The aim of a number of previous investigations (Borovik et al 1965, McCracken et al 1968, Erents and McCracken 1970) has been to discover the effectiveness of different metals as trapping media for high fluxes of hydrogen ions, such as might be found in ion injectors of large plasma physics experiments and ultimately in fusion reactors. Conclusions from these studies indicate that for metals which do not form an exothermic hydride, an equilibrium is set up between arrival and release rate of hydrogen and saturation quickly ensues. In metals such as titanium which undergo chemical reaction but in which the hydrogen forms a solid solution and diffusion is possible, it has been found that over a wide temperature range very large ion doses can be trapped. These latter results have been explained in terms of a model in which the relatively high diffusion coefficient allows the hydrogen to diffuse into the bulk of the metal, while the potential barrier due to the heat of solution prevents the diffusing hydrogen atoms from leaving the solid. Lithium was considered an interesting test of this model, since the ionic hydride bond (Libowitz 1965) should result in a low diffusion rate compared with the case of titanium. Lithium may also have some practical advantages since a liquid stream could act as a heat sink as well as a trap for hydrogen ions. Some measurements of the trapping efficiency of deuterium have therefore been undertaken in both solid and liquid lithium.

2. Experiment

The ion beam is accelerated to an energy of 18 keV, mass analysed and focussed as described previously (McCracken, Maple and Watson, 1966). The arrangement of the experiment is shown schematically in

figure 1. The beam is deflected electrostatically through 90° to allow horizontal mounting of the liquid lithium target. Three molybdenum buckets containing lithium and one solid molybdenum block are used as targets. These may be separately heated with tungsten wound ceramic heater tubes up to 1000°C. A turntable allows each target in turn to be moved to the bombardment position. During bombardment the ion current can be recorded, as can the lithium temperature using chromel-alumel thermocouples. By use of defining apertures where the ion current may also be monitored, it is possible to focus the beam to just cover the lithium surface. A good estimate of the beam area hitting the targets is thus obtained. A bellows mounted scraper, illuminated by a small lamp, is used to uncover a fresh lithium surface prior to each bombardment. Lithium was transferred, as a solid pellet, from a hexane bath to each bucket prior to pumpdown. This procedure reduced the oxide slag to a minimum - although a thin layer was visible after the vacuum system bakeout (200°C, for a few days). All slag was removed by scraping and a shiny lithium surface exposed before running the experiments.

The system was calibrated as described previously (McCracken and Maple, 1967). This was done basically by allowing the deuterium beam to strike a hot (600°K) molybdenum target, under which conditions it is known that all incident ions are released. The target chamber is dynamically pumped and so by relating all other mass spectrometer partial pressure measurements (P) to this 100% re-emission value, a direct measure of the fraction of ions trapped η is obtained, i.e.

$$\eta = 1 - \frac{P}{P_{Mo}}$$

All targets were held at a potential of +40 V with respect to earth to suppress secondary electrons. The lithium was heated to above its

melting point and stirred, then cooled again, several times before each bombardment to ensure uniformity and prevent deuterium accumulation. During bombardment masses $2(H_2)$, $3(HD)$ and $4(D_2)$ were all recorded. Other background gases were insignificant compared with these. The deuterium fraction in the re-emitted HD was included in calculation of η.

3. Results

Deuterons of energy 18 keV and ion fluxes of between $2{\cdot}5 \times 10^{14}$ and $2{\cdot}5 \times 10^{15}$ ions cm^{-2} sec^{-1} were used for trapping measurements. The trapping efficiency is shown in figure 2, as a function of time, for various lithium temperatures.

In the liquid phase the results are consistent, with 97% of the incident ions being trapped up to the highest doses used in our experiment of 5×10^{19} ions cm^{-2}. Below the melting point the results are inconsistent as illustrated by thetwo separate results for $T = 423^{o}K$. This spread in results is shown more clearly in figure 3, where the trapping efficiency is plotted as a function of temperature for a total dose of 5×10^{17} ions cm^{-2}. The trapping efficiency varies between 70 and 95% and no clear trend has been observed with variation in target temperature or ion current density. It was found that if a thin layer of oxide was allowed to form on the lithium surface the trapping efficiency was considerably reduced. It is possible, therefore, that oxide on the surface was responsible for the scatter in the experimental results, although great care was taken before each experiment to scrape the lithium to produce a fresh surface and measurements were carried out in a pressure of 10^{-8} torr of background gas, mostly CO.

At the melting point (459^{o}K) there is a fairly sharp discontinuity and the trapping efficiency rises above this temperature, until at ~ 680^{o}K it begins to decrease again. Measurements above 650^{o}K were found difficult to make, because of the high lithium vapour pressure, and dissociation of the deuteride. The background pressure due to thermal release of previously trapped deuterium is a function of the bombardment history and this background was subtracted from the recorded pressure under "beam-on" conditions. Measurements could only be made for a short period of time (~ 10^{15} ions cm^{-2}) because of the lithium evaporation, but it is clear that the effective trapping efficiency very quickly falls towards zero above 700^{o}K.

To examine the variation in trapping efficiency during the transition from liquid to solid phase, the re-emission during bombardment was monitored continuously as the target cooled from 500^{o}K. These results are shown in figure 4. The total deuterium trapping efficiency, estimated from D_2 + ½ HD, is seen to fall from 97% to 85% on going from liquid to solid. It is notable that quite a large contribution is due to the increase in the HD from the solid phase. It was found that if the temperature was increased again while still bombarding the target there was a corresponding increase in trapping efficiency back to about 95% as the target went from the solid to the liquid phase.

The trapping efficiency calculated from the results in figure 4 has also been plotted in figure 3 as a dotted line in order to compare it with the results of the previous experiment. It must be noted, however, that the results shown in figure 4 are taken with a continuously changing dose, which was of the order of 5 × 10^{17} ions cm^{-2} at the melting point.

4. Discussion

Because of the ionic bond which exists in lithium hydride it is expected that very little diffusion of deuterium will take place in the solid. Nevertheless, the high trapping efficiency recorded in the liquid phase suggests that no build-up of deuterium close to the surface takes place. This may be due to the deuterium being soluble in the liquid and thus able to diffuse, or possibly that any deuteride formed is carried away by convection. Trapping at high temperatures must be limited by the dissociation pressure of the deuteride, which will depend on both temperature and deuteride concentration within the liquid. The apparent dissociation pressure which we observe is much lower than that calculated from the data for lithium deuteride (Heumann and Salmon, 1956) but this is presumably due to the very low concentration of deuterium in the lithium, which we estimate was never greater than 0·1 atomic %. For the current densities and doses considered here the dissociation of the hydride appears to be the dominating release process at temperatures > 700^{o}K.

The release mechanism from the solid is more difficult to explain. The effect of the dissociation pressure (10^{-8} torr at 440^{o}K) may be greater than in the liquid since, if diffusion does not take place, high deuteride concentration can build up at the surface. However, for a 20 μA beam this should give rise to a maximum of 5% re-emission at 440^{o}K. Therefore although this effect may contribute to the re-emission it cannot explain it fully.

Target sputtering has also been considered. The range of 18 keV deuterons has been calculated from the theory of Schiott (1966) to be 7000 Å. The range straggling is such that 50% of ions should come to rest

within ± 700 Å of the most probable range. The sputtering yield of lithium by D^+ ions calculated from the theory due to Pease (1960) is 0·004 atoms/ion. Thus for 10^{18} ions cm^{-2} only about 10 Å of surface would be eroded, and target sputtering cannot be responsible for the low trapping efficiency, unless a substantial broadening of the range distribution is invoked.

Finally the "gas sputtering" mechanism as observed for hydrogen release in other metals at low temperatures (McCracken et al, 1968; Erents and McCracken, 1970) has been considered. However this mechanism should become more important as the density of trapped ions increases, resulting in an initial slow change in trapping efficiency followed by a more rapid change as the concentration of the trapped atoms approaches that of the lattice atoms. The results shown in figure 2 in fact show the opposite trend.

5. Conclusions

It has been shown that liquid lithium provides a good trapping surface for 18 keV deuterons over thetemperature range from 460°K (the melting point) up to 650°K. Fluxes of $2{\cdot}5 \times 10^{15}$ ions cm^{-2} sec^{-1} continue to trap with 97% efficiency up to total doses of at least 5×10^{19} ions cm^{-2}. Re-emission of deuterium from the metal has been observed to accelerate rapidly with temperature above 650°K and this is considered to be related to the dissociation pressure and the concentration of lithium deuteride within the lithium.

Trapping efficiencies in solid lithium were found to decrease with dose. The form of the decrease was, however, different to that previously observed in other metals, and no satisfactory explanation for the behaviour has been found.

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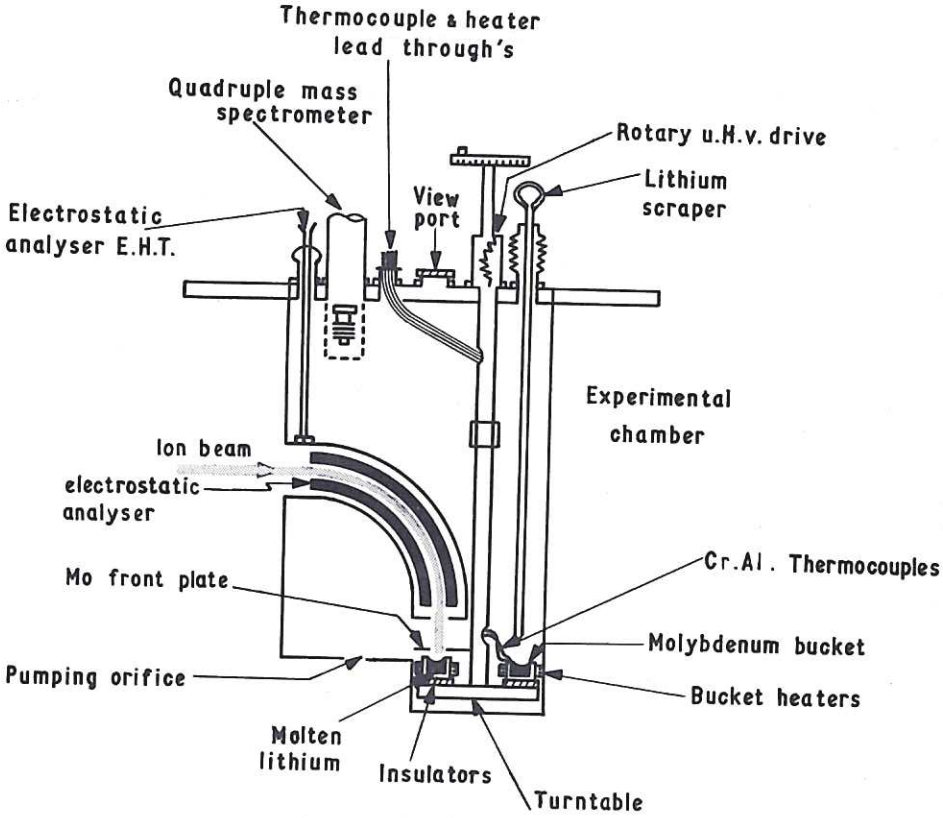

Fig.1 Schematic diagram of target chamber

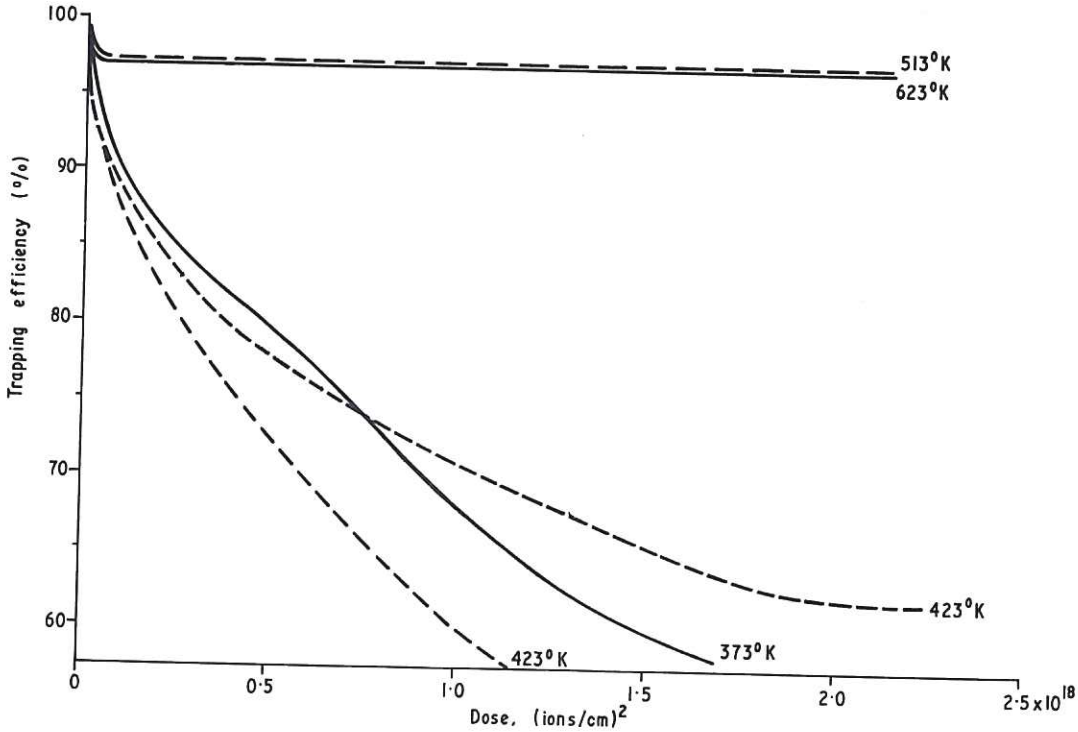

Fig.2 Trapping efficiency of 18 keV deuterons in lithium as a function of dose for various lithium target temperatures.

CLM-P 254

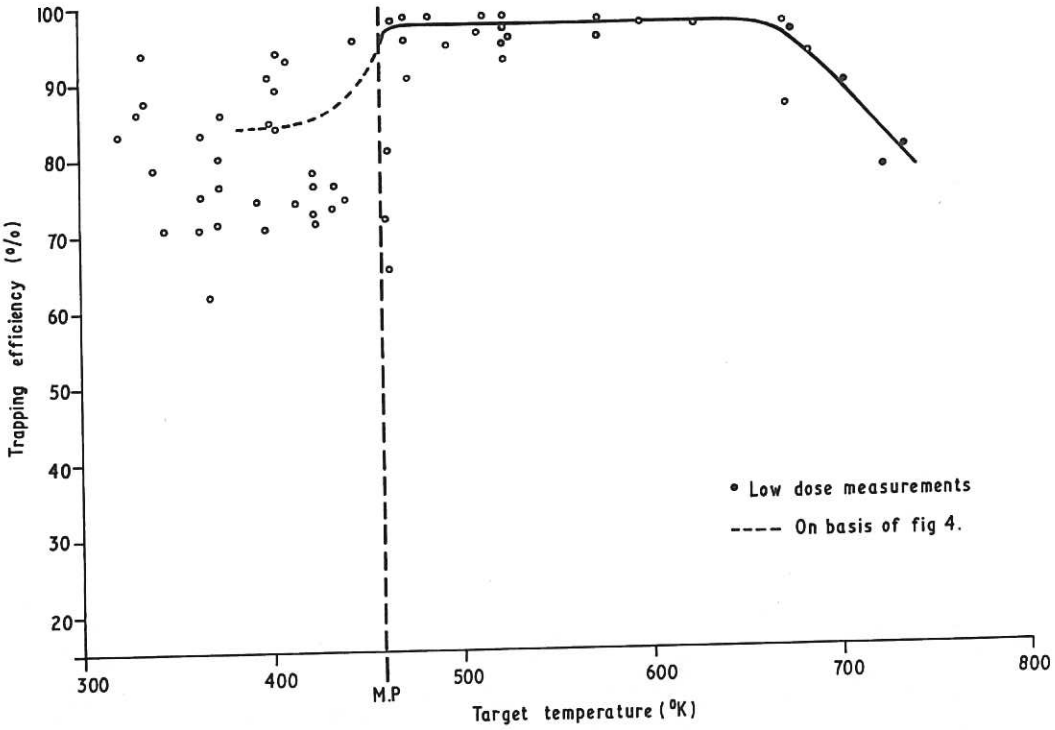

Fig.3 Trapping efficiency of lithium for 18 keV deuterons as a function of temperature for a constant dose of 5×10^{17} ions cm^{-2}.

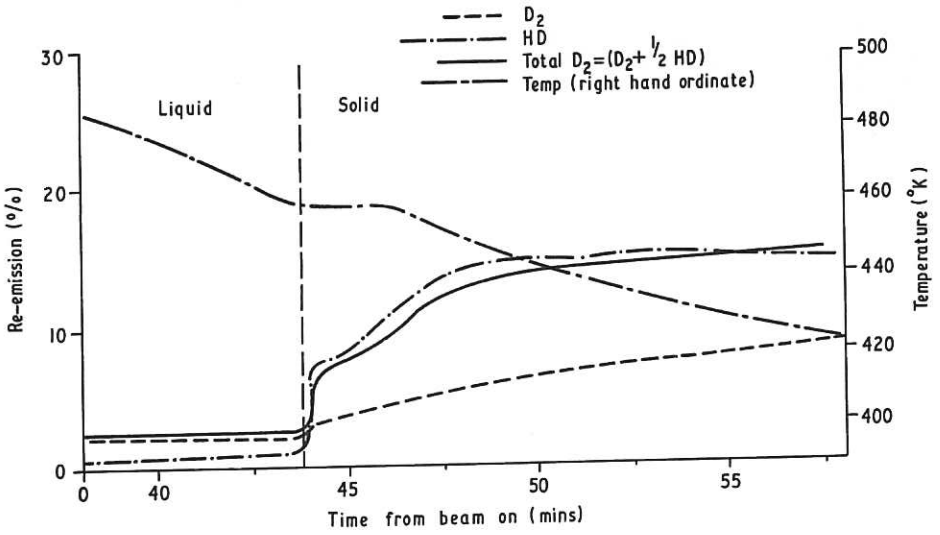

Fig.4 Deuterium re-emission during target cooling under continuous bombardment at $2{\cdot}5 \times 10^{14}$ cm^{-2} sec^{-1}

CLM-P 254