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A cryogenic target for direct reaction studies with exotic beams

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Abstract

A cryogenic system has been designed to make a thin target of solid hydrogen isotopes usable under vacuum, with a particle beam. In order to insure the homogeneity of the target, an equivalent pressure is maintained with helium on both sides of the target windows during the formation of the solid hydrogen. The system developed is described and the results obtained with 1 mm thick solid hydrogen and deuterium targets, in two different experiments using the radioactive beams from the SPIRAL facility, are presented. The flatness achieved was better than a few percent in both experiments.

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1. Introduction

With the development of secondary beams facilities, a new generation of experiments has become possible, in particular in the domain of direct reactions [1]. Indeed elastic and inelastic scattering, transfer and charge exchange reactions are powerful tools to obtain information on the low energy spectroscopic features of nuclei far from stability, for which the present knowledge is often very scarce. If we want to study the nature of nuclei far from stability, it is best to have interactions with simple particles, such as electrons, protons and other light particles of well understood structure. For example (p,d), (d,p), (d,3He) transfer reactions have been used extensively in the past to study single particle states of bound nuclei. The lifetime of the nuclei away from stability being too short to prepare targets in nearly all cases, it is necessary to inverse the role of target and projectile, and targets of hydrogen and deuterium are needed for the reactions mentioned above. Hydrogen and deuterium can be used as chemical compounds, and polyethylene, CH_2 and CD_2, is commonly used. Due to the carbon in this compound, for the same energy loss, the target contains three times less hydrogen than would be possible for a pure hydrogen target, and the energy and angular straggling are considerably increased. Furthermore, the carbon provokes a background that either must be determined by making a measurement with a pure carbon target or must be eliminated by coincidences.

It is therefore important to develop pure hydrogen and deuterium targets, which are gaseous at normal temperature and pressure. In these cases an entrance window is necessary. The thickness of this undesired window will be proportional to the pressure. Thus in order to increase the effective target thickness for a given window, the only way is to decrease the temperature. Standard coldheads for cryogenic pumps go down to about 15 K. At this temperature, the effective thickness has increased by a factor 20 with respect to room temperature. For hydrogen and deuterium, it is most convenient to work somewhat above the critical point for the coexistence of liquid–gas, at about 30 K. For a 1 cm thick target at 30 K and 5 atm, 5 mg/cm^2 of H_2 are obtained. At this pressure a

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havar window of at least 10 μm is needed for a diameter of 20 mm [2,3].

For thicker targets, either liquid or solid targets should be used. The filling of the target implies high pressures, in the case of H_2 at least 100 mbar are necessary to remain above the triple point (coexistence of vapor, liquid and solid at 14 K and 70 mbar). To avoid window deformations that will result in inhomogeneous targets, two methods have been used. The first one is to use a mold that confines the H_2 during solidification in a well defined volume [4,5]. At Ganil we opted for a transition to the liquid phase (16.2 K/230 mbar) before progressive solidification of the hydrogen ($T \leqslant 13.9$ K) [6], as described below. Liquid helium is used as a cold source at 4 K and the growth of the target is imposed by the temperature gradient in the metal frame supporting the target.

2. Description of the system

2.1. Principle

We used a target with a double window illustrated in Fig. 1. The target is made of a metal frame to which mylar windows are glued. A stack of frames forms an H_2 or D_2 target cell with a He cell on both sides of the target. During the target production phase, identical pressure is maintained on both sides of the target windows, in order to maintain the inner windows free from constraints. To do this, the pressure of a volume of helium gas matches the pressure variations of the hydrogen circuit during the phase transitions and up to the complete formation of the solid H_2 target. Once the solid is formed, the He can be taken out. The mechanical strength of the windows of the He circuit with respect to beam vacuum imposes the filling pressure, and hence the phase change temperature of the target gas. The total window thickness used in the first tests is four times 6 μm of mylar (3.3 mg/cm^2); a lower limit of about 1 mg/cm^2 is achievable.

The thickness of the hydrogen is determined by the mechanics of the support of the inner windows. A minimum of 0.5 mm seems achievable, with very homogeneous thickness along the surface of the target. Here, results down to 1 mm, corresponding to 8.85 mg/cm^2, will be shown.

2.2. Cryogenic system

The cryogenic system consists of a cryostat with liquid helium circulation, where the cold thimble ($T = 4$ K) is mechanically coupled with the lower part of the target. This configuration helps to establish a temperature gradient, in such a way that the solid grows towards the upper portion of the target. The gases enter through stainless steel capillaries (Φ 1–2 mm) welded at the bottom of the target for He and at the top for H_2. A thermalization point is used from the cold thimble to reduce the power input by conduction of the capillaries at the top of the target. To prevent clogging, the H_2 circuits are kept at $T \geqslant 14$ K during the target filling phase. This condition is essential to prevent the formation of bubbles caused by a lack of hydrogen feed during the formation of the solid. The heat balance of the system gives a power received at the target of about 10 mW, 50% of it from thermal radiation via the beam axis aperture. The heat transfer analysis shows the possibility to obtain the desired growth of the solid, by using brass (intermediate thermal conductivity) and by adopting a suitable geometry for the target frame, such as shown in Figs. 2 and 3. The solid lines plotted in Fig. 3 in the center of the target holder represent the actual shape of the target with circular opening to the beam and open upper part towards the capillaries. This solution offers a compromise between the cooling of the target and the maintenance of the hydrogen in the capillaries in the gas phase.

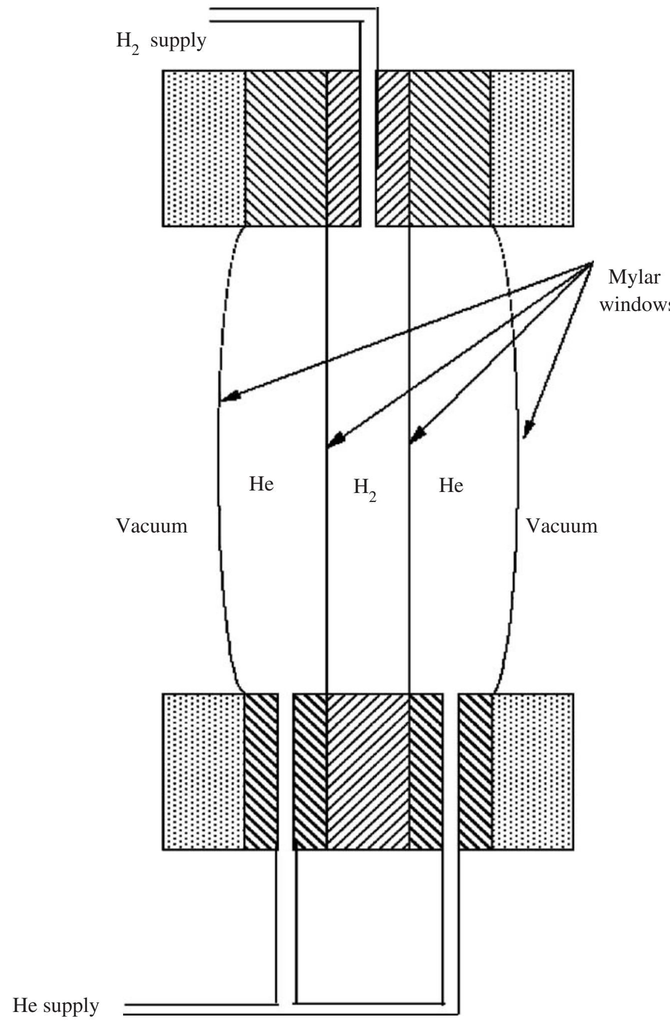

Fig. 1. Schematic view of the target that allows formation of homogeneous solid H_2 or D_2 without window deformation.