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Weight and volume measurement of the large COMPASS target

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Abstract

The ⁶LiD was weighed after unloading of the target. With the help of the measured cold volumes of the target cells the packing factor of the target material in each cell could be determined. From the known isotopic content in the target material a table of elements was produced for each cell.

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In the COMPASS experiment two oppositely polarized 60 cm long and 3 cm diameter target cells are used [1]. The cells are made of epoxy impregnated polyamide mesh reinforced with kevlar thread. The mesh is used to improve the flow of cold liquid helium inside the target cells. About 450 cm³ of the ⁶LiD target material for each cell has been produced at Bochum [2]. The material weight in each cell has to be known for accurate determination of the fraction of the polarized nuclei or the dilution factor [1]. The cold volumes of the two target cells need to

be measured to determine the packing factor of the ⁶LiD crystals in the ³He/⁴He mixture.

The ⁶LiD in each cell was weighed after unloading in 2003. The material was kept below 100 K above liquid nitrogen bath in cold gas. The system with cooled shield (see Fig. 1) is described in Ref. [3]. The thin nylon socks containing the target material were hung with a very light cotton thread from a balance (PJ4000, Mettler-Toledo (Schweiz) AG). The crystals become slowly dry of liquid nitrogen. This is seen as a drop in the measured weight. One measurement takes 6–12 h. After one hour of stable value the weight is recorded. The weight of the sock, copper wire, label tape and thermometer have to be subtracted from the gross weight to get the material weight.

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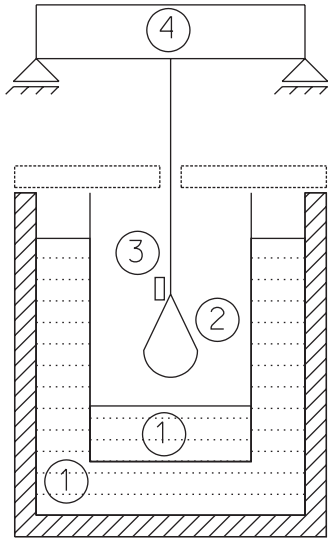


Fig. 1. The principle of material weighing in cold nitrogen gas above liquid nitrogen bath (1) using a digital balance (4). The material is in the sock (2) and the temperature is measured with a pt100 platinum thermometer (3).

Their contribution was estimated to be 4.5 ± 0.7 g. About 0.3 g of ice on the cotton thread was removed after a stable value had been reached. In addition a buoyancy of $0.3 \text{ g}/100 \text{ cm}^3$ due to the dense cold nitrogen gas was taken into account. The total material weight for the upstream cell is 172.1 ± 2.5 and 178.1 ± 2.5 g for the downstream cell. Thus the relative error in Table 1 is 1.5% in the total amount of H, D, ^6Li , and ^7Li , given for each cell.

The target cells were cooled inside a liquid nitrogen bath and filled with quartz grit with typical diameter of 3 mm and length 6 mm. This is close to the crystal size ~ 4 mm of the ^6LiD material [2]. The measured volumes were $413 \pm 5 \text{ cm}^3$ for upstream and $416 \pm 5 \text{ cm}^3$ for downstream. In 2002 these were 411 ± 5 and $413 \pm 5 \text{ cm}^3$. The target cells are the same for both years, but the embedded coil in the upstream cell was removed for 2003. The theoretical upstream volume of 424 cm^3 is 11 cm^3 more than the real measured cold volume. For the downstream the volume difference is 8 cm^3 .

The packing factor is defined as the ratio between the volume of the material loaded into

Table 1

Summary of the elements inside the upstream (up) and downstream (down) target cells for 2003 in the COMPASS experiment

	mass [amu]	up [mol]	down [mol]
H	1.00794	0.11	0.11
D	2.0140	21.23	21.97
^3He	3.0169	0.7 ± 0.2	0.7 ± 0.2
^4He	4.0026	6.8 ∓ 0.3	6.6 ∓ 0.3
^6Li	6.0151	20.44	21.15
^7Li	7.0160	0.90	0.93

the cell and the volume of the cell

$$PF = \frac{V}{V_{\text{cell}}} = \frac{m}{\rho V_{\text{cell}}}, \quad (1)$$

where m is the mass of the material in the cell, V is the volume of the material and V_{cell} is the volume of the cell. The density of the target material, $\rho = 0.82 \pm 0.02 \text{ g/cm}^3$ [2], is very close to the density of liquid nitrogen 0.81 g/cm^3 . The density can also be estimated from the known lattice constant $a = 0.406 \text{ nm}$ [2] and the isotopic content 0.5% of protons in deuterium and 4.2% of ^7Li in ^6Li [4]. Using the measured target cell volumes at liquid nitrogen temperature, we get the packing factor 0.508 ± 0.027 for upstream and 0.522 ± 0.027 for downstream. In 2002 these were 0.492 ± 0.026 and 0.535 ± 0.027 for downstream.

For the amount of H, D, ^6Li and ^7Li we get the following equations:

$$m = n_{^7\text{Li}} a_{^7\text{Li}} + n_{^6\text{Li}} a_{^6\text{Li}} + n_{\text{D}} a_{\text{D}} + n_{\text{H}} a_{\text{H}} \quad (2)$$

$$n_{^7\text{Li}} + n_{^6\text{Li}} = n_{\text{H}} + n_{\text{D}}. \quad (3)$$

Here n_{ele} is the amount of the element in mol, a_{ele} the atomic mass of the element and m the measured total mass. The ratio of isotopes $n_{^7\text{Li}}/n_{^6\text{Li}} = 0.044 \pm 0.001$ and $n_{\text{H}}/n_{\text{D}} = 0.0050 \pm 0.0004$ was determined from the integrated NMR lines [4]. The elements inside the target cells are shown in Table 1. The total amount of heavier elements C, Cu, F, or Ni due to a small NMR coil embedded into the material can be estimated to be less than 0.05 mol. From the theoretical upstream volume (424 cm^3) 214 cm^3 are filled with liquid helium. For the downstream cell the helium volume is 207 cm^3 .

We can assume either a perfect phase separation between the ^3He rich and the diluted phase or a perfect mixing of ^3He with ^4He . These two cases give the estimates of helium in [Table 1](#). The ^3He rich phase does not penetrate into the target cells due to the large amount of ^4He . The theoretical target cell volume corresponds to the geometrical cut used in the physics data analyzes of spin asymmetry.

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