Liquid H_2 Density in the G1C CLAS Cryotarget

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Abstract

The density of liquid H_2 in the CLAS cryotarget is calculated to be $.0711 \pm .0001 \frac{g}{cm^3}$ for the 2.4 GeV dataset, $.07078 \pm .00008 \frac{g}{cm^3}$ for the 2.9 GeV dataset, and $.0707 \pm .0002 \frac{g}{cm^3}$ for the 3.1 GeV dataset of the G1C run period. Target pressure and temperature data are available from the online database. A parameterization that uses this data to calculate the H_2 density is given. The average H_2 density over a group of runs is an acceptable approximation of the density for the runs considered. The standard deviation serves as the error estimate.

1 Introduction

Determination of the density of H_2 in the CLAS cryotarget is a necessary step in making cross section measurements. This document is designed to serve as a brief overview of the steps needed to calculate the H_2 density.

The cryotarget temperature and pressure are continuously fluctuating during data collection. One could calculate H_2 density as a function of time, but the benefits of such a strategy would be small in light of the work required to implement it. Figure 1 shows the distribution of H_2 density as a function of run number for all G1C runs. The three different datasets are shown in different colors and symbols, and the average values of H_2 densities for each dataset are plotted as black lines. The distribution for each dataset is extremely flat, so the calculation of an average density for each dataset is an appropriate strategy that will account for any systematic changes in this quantity.

This paper will be concerned with the calculation of a single value of hydrogen density for each group of runs. In particular, we will present values for H_2 density for the 2.4 GeV, 2.9 GeV, and 3.1 GeV datasets of the G1C run period, but similar steps may be used to calculate hydrogen density for other datasets. In what follows, Section 2 discusses obtaining target pressure and temperature information from the online database. Section 3 outlines out parameterization of tabulated thermodynamic data for H_2. Section 4 covers the calculation of a global H_2 density for a number of data runs and Section 5 presents the final results of the calculation.

2 Online Database

Temperature and pressure of the cryotarget are recorded in the CLAS online database on claspc10. The online database is an SQL database, so familiarity with SQL or *MySQL* is useful. A basic SQL primer and introduction to the CLAS database is given in Reference [1]. While information can be retrieved interactively from the database, the tidiest method is to use PERL in conjunction with the DBI module. Reference [1] gives examples of scripts that may be modified to retrieve database information; these examples are available pre-coded at */home/freyberg/PERL/EXAMPLE/* on the JLab network. The first modification to any of

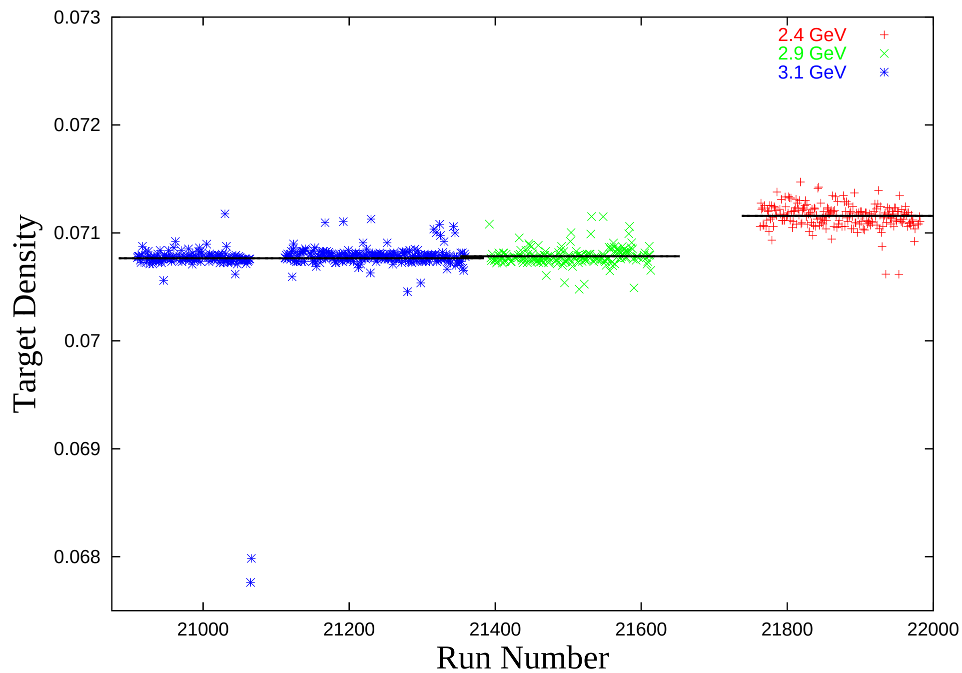

Figure 1: H_2 density for single runs as a function of run number. The 2.4 GeV, 2.9 GeV, and 3.1 GeV datasets have been plotted in different colors and symbols. The mean value of each dataset has been plotted as a black line.

these scripts should be to change the socket connection from “claspc10.cebaf.gov” to “claspc10”, because “claspc10.cebaf.gov” will result in connection errors.

The runs which we take to define each energy dataset of the G1C run period are listed in Table 1. The data returned from the database were minimally filtered to reject runs with uncharacteristic temperatures. Runs having temperatures around $83K$ or a temperature of “-9999.000000” were not considered in our calculation.

The online database returns one value of temperature and pressure for each run.

3 Parameterization of Tabulated H_2 Density

Thermodynamic properties of H_2 have been studied and are well-tabulated, as given in Reference [2]. H_2 comes in two varieties: para- and ortho-. Para-hydrogen is an angular momentum singlet state, while ortho-hydrogen is a triplet state. At normal ambient temperatures (around $300K$), the four accessible spin states are equally populated, yielding a gas that is 25% para-hydrogen and 75% ortho-hydrogen, otherwise known as “normal hydrogen”. At temperatures close to zero, the lower-energy singlet state is preferentially populated, so that any sample of H_2 is effectively all para-hydrogen. At the operating temperatures of the cryostat, the data listed for para-hydrogen and normal hydrogen in Reference [2] are identical.

Our parameterization considers normal hydrogen data for every tabulated isobar from .040 to .250 MPas-

Dataset	First Run	Last Run
2.4 GeV	21763	21982
2.9 GeV	21392	21613
3.1 GeV	20910	21359

Table 1: Runs considered in each dataset.

cal for every temperature from $13.804K$ up to the liquid-vapror equilibrium boundary, as given in Reference [2]. This parameterization, then, loses its validity for temperatures differing significantly from $20K$. Reference [2] claims that the tabulated data has an accuracy of .1%, so we used this to calculate error bars on the tabulated data for our fit. The final parameterization is given by

$$\rho = a_1 t^2 + a_2 p + a_3, \tag{1}$$

where t and p are the temperature and pressure read from the online database. a_1, a_2, and a_3 are the fit parameters; their values are given in Table 2.

Parameter	Value	Error
a_1	$-2.89 \times 10^{-5} \frac{g}{cm^3 K^2}$	$1 \times 10^{-7} \frac{g}{cm^3 K^2}$
a_2	$1.0 \times 10^{-7} \frac{g}{cm^3 mbar}$	$1 \times 10^{-8} \frac{g}{cm^3 mbar}$
a_3	$8.249 \times 10^{-2} \frac{g}{cm^3}$	$4 \times 10^{-5} \frac{g}{cm^3}$

Table 2: Fit parameters and errors

Errors on densities calculated with the above parameterization were calculated with the standard error propagation formula. In this case, we consider both errors on the fit parameters as well as errors in the measurement of the temperature and pressure. Errors on the fit parameters are given above. The covariance is given by Table 3.

Term	Value
σ_{12}	$-8.26 \times 10^{-16} \frac{g}{cm^3 K \sqrt{mbar}}$
σ_{13}	$-3.40 \times 10^{-12} \frac{g}{cm^3 K}$
σ_{23}	$-1.73 \times 10^{-13} \frac{g}{cm^3 \sqrt{mbar}}$

Table 3: Covariance terms for error propagation.

Errors in the temperature and pressure were taken to be the standard deviation of the appropriate quantity for the runs of interest. Because we had only one measurement of temperature and pressure per run, the error in these quantities was likely dominated by fluctuations over the time that the run was collected. A typical data run took two hours to record, and the temperature and pressure could not remain perfectly constant over that time. The standard deviation for each quantity over the entire dataset was then interpreted as a reasonable estimate of the error in temperature and pressure due to fluctuations. For all G1C datasets, the average temperature and pressure with their standard deviations are given in Table 4.

Dataset	Temperature	Pressure
2.4 GeV	$19.91 \pm .09K$	$1095 \pm 10mbar$
2.9 GeV	$20.23 \pm .07K$	$1103 \pm 16mbar$
3.1 GeV	$20.25 \pm .06K$	$1098 \pm 9mbar$

Table 4: Average temperature and pressure with standard deviation for 2.4 GeV, 2.9 GeV, and 3.1 GeV datasets from G1C run period.

The error propagation is then given by

$$\sigma_\rho^2 = \sum_{i=1}^{3} \left(\sigma_i \frac{\partial \rho}{\partial a_i}\right)^2 + \sum_{\substack{i=1 \\ j \neq i}}^{3} \sigma_{ij}^2 \left(\frac{\partial \rho}{\partial a_i}\right) \left(\frac{\partial \rho}{\partial a_j}\right) + \left(\sigma_t \frac{\partial \rho}{\partial t}\right)^2 + \left(\sigma_p \frac{\partial \rho}{\partial p}\right)^2, \tag{2}$$

where σ_t and σ_p are the standard deviation of the temperature and pressure, respectively, as listed in Table 4.

4 Density for Selection of Runs

With formulae (1) and (2), we calculatd a hydrogen density for each run having an entry in the online database. To arrive at the aforementioned global density for a group of runs, the simple average of the density over the runs for each dataset was determined. We interpret the standard deviation of the density over the runs in each dataset as the error on the density calculation. We considered using a weighted mean, where the density calculations were weighted by the inverse of the square of their errors, but the simple average and standard deviation gave a more conservative error estimate. In addition, the standard deviation was more representative of the scatter of the density calculations within a dataset.

5 Conclusion

The final results for the 2.4 GeV, 2.9 GeV, and 3.1 GeV datasets of the G1C run group are given in Table 5.

Dataset	Density $\left(\frac{g}{cm^3}\right)$	Error $\left(\frac{g}{cm^3}\right)$
2.4 GeV	7.11×10^{-2}	1×10^{-4}
2.9 GeV	7.078×10^{-2}	8×10^{-5}
3.1 GeV	7.07×10^{-2}	2×10^{-4}

Table 5: Results for G1C datasets.

References

[1] Arne Freyberger and Elliott Wolin, *Accessing the* CLAS *Online Database Tables.* Available online at *http://claspc10.jlab.org/CLASDB/online_db_tables.*

[2] R. D. McCartny, J. Hord, and H. M. Roder, *Selected Properties of Hydrogen (Engineering Design Data)* (Washington: U.S. Government Printing Office, 1981; National Bureau of Standards Monograph 168), ppg. 6-2, 6-134 to 6-149.