LD_2 Target Thickness Analysis for EG2

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Overview

The cell

- 2-cm LD_2 cell, 1.3 atm;
- Goal: thickness uncertainty $< 1\%$.

Error Sources

- Density $\rho = \rho(P, T)$;
- Absolute cell length measurement;
- Thermal contraction of cell wall (Kapton);
- Endcap bulging;
- Beam position drifting;

References

- R. Prydz, NBS report on *The Thermodynamic Properties of Deuterium*, (1967);
- R.F. Barron, *Cryogenic Systems*, (1985);
- Tests done at JLab: S. Christo, D. Kashy.

Density

- Pressure sensor: $\mathrm{dP} = 0.005\mathrm{P} + 50$ mbar= 56.6 mbar @ 1.3 atm;
- Temperature sensor: $\mathrm{dT} = 50$ mK (calibration);
- Subcooling:
  - From LD_2 test (with super insulation), observed no bubbling at 1.3 atm, 24.49 K (interpolated), this means no subcooling needed;
  - Plan: 1 K subcooled (to be confirmed), i.e., condenser set at 23.55 K, hence $\mathrm{dT} = 0.5$ K due to subcooling;
- From (P, T) to density (NBS report):
  - Two methods: equation of State, fit to data;

Method	ρ (g/cm^3)	$\partial\rho/\partial T$ (g/cm^3/K)	$\partial\rho/\partial P$ (g/cm^3/bar)
Eq. of State	0.1620 $\times(1\pm$ 0.80%)	-0.0026	0.213
Fit to NBS data	0.1621 $\times(1\pm$ 0.74%)	-0.0024	-0.285

  - Take the larger value 0.80% as a conservative estimation of uncertainty in deuterium density due to dP and dT;
  - Error in NBS data: 0.15% (typical).

Absolute cell length measurement

- $\mathrm{d}L = 80\mu$m, i.e., 0.4% to target thickness;

Kapton Thermal Contraction

- Kapton thermal contraction coefficient from 300 K to 78 K:
  - 31.13 ppm/K measured at JLab;
  - 21.4 ppm/K from Dupont;
- From 78 K to 22 K (non-linearity of thermal contraction)
  - Data on Kapton not available;
  - Using existing data of various plastic materials;
  - Estimate total shrinkage from 300 to 22 K
    $\approx (1.13 \pm 0.03)\times$ shrinkage from 300 to 78 K;
- Total:

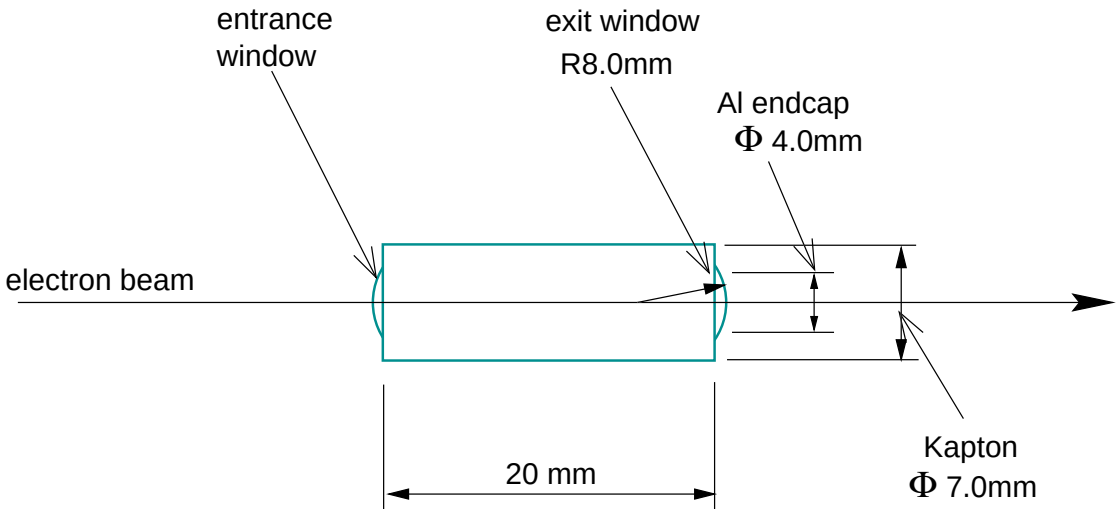
$$\begin{aligned} \frac{L(300K) - L(22K)}{L(300K)} &= (26.45 \pm 4.67)\ \mathrm{ppm} \times (300 - 78) \times (1.13 \pm 0.03) \\ &= (0.667 \pm 0.135\%) \end{aligned}$$

$\Rightarrow$ contribute 0.135% to target thickness.

Endcap bulging

- Cell length (body + exit window) measured from 0 to 1.5 atm;
- Exit window average 0.206 mm;
- Error of the measurement: 3 μm device, 5 μm fluctuation $\Rightarrow \approx$ 0.01 mm;
- Assuming the same deformation for the entrance window;
- Contribute 0.1 % to target thickness.

Beam position drifting



- Take $\mathrm{d}L/L = 0.4\%$, corresponding to 1.13 mm drift from center.

Summary

Source	Uncertainty in Thickness
dP and dT	0.823%
$\rho = \rho(P, T)$	0.15%
Absolute cell length	0.4%
Kapton contraction	0.135%
Endcap shape	0.10%
Beam position	0.40%
Local bubbling	0.00%
Total	1.005%