NOTE: AMS-TRD GAS #2

Procedure of Xenon Transfer

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February 28, 2005

In this write up, we discuss the procedure on how to transfer xenon to a designed gas storage vessel that supplies xenon to the TRD for AMS-02. Our goal is the have the desired final gas density in the target vessel to be 13.4mole/L but not to exceed this value for safety reasons. In out setup, we used a 300ml vessel, which simulates a ten-day life cycle of the gas supply to the TRD. The purpose of this write up is to serve as a guide for future filling of the space qualified xenon vessel in Box S of the TRD.

1. General Description

The transition Radiation Detector (TRD) for the AMS-02 detector requires a detection medium containing a mixture of xenon and carbon dioxide gas at a ratio of 80:20 by volume[1]. About 48.4 kg (109lbs) of xenon and 5.8 kg (11 lbs) of CO_2[2] in carbon fiber over-wrapped lightweight stainless steel vessels of 27.5 L and 13.3 L, respectively are needed for a full mission of more than 3 years. These vessels will be filled on ground prior to launch.

Our gal at MIT is to perform ten-day life cycle simulations of the gas supply system with the Engineering Module, both manually and with the electronics developed at CERN and in Rome. Each ten-day cycle simulation will represent about 1% volume of xenon and CO_2. To this end, we have set up a xenon transfer system and have successfully filled two 300 ml bottles of xenon for our initial test. A detailed discussion of the gas transfer system and the transfer procedure is presented below.

2. Requirements

Transfer Xe from source bottle to a store bottle to the density of 13.4 mol/L.
Process should be controllable and safe.
Considering the safety issue, we should not overfill it.

3. Properties of Xenon

The main properties of Xe are

Molecular weight:	131.3 g/mol
Boiling point:	-108.1 °C (1.013 bar)
Melting point:	-111.8 °C
Critical temperature:	16.5 °C
Critical pressure:	847.02 psi
Liquid density:	3057 kg/m^3 (1.013 bar at boiling point)

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Following Fig.1 describe the isothermal property of Xenon[3]

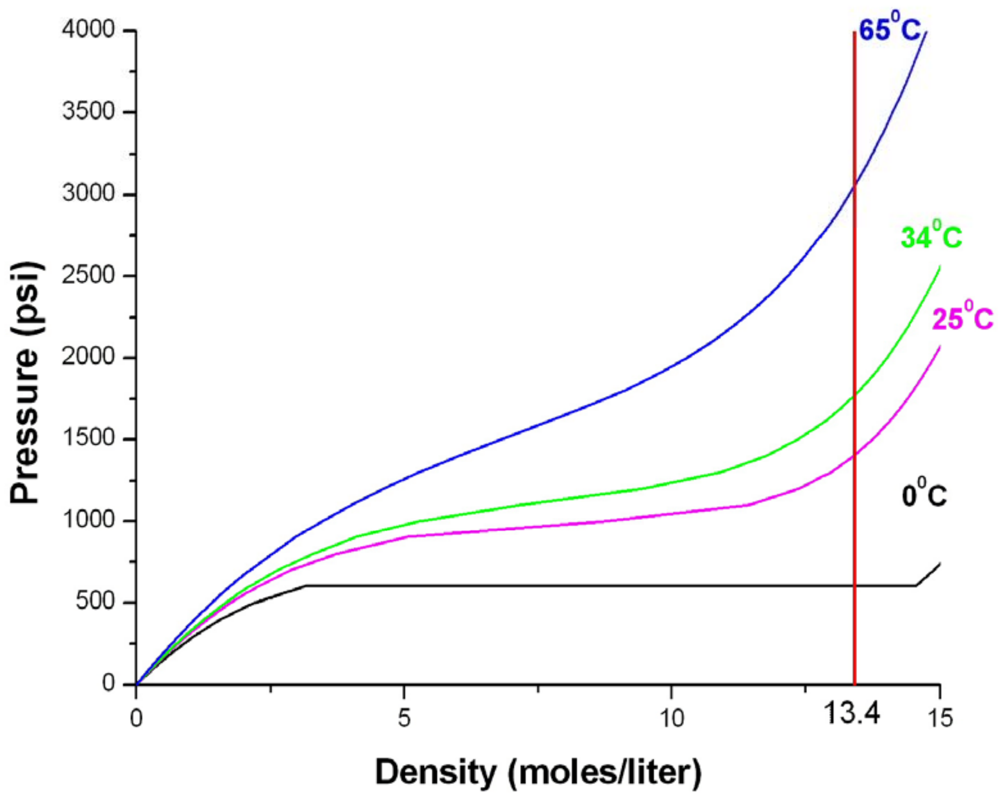

Fig. 1 Isothermal curves of Xenon

4. Transfer System

The Fig. 2 and Fig. 3 below show the scheme of the transfer system.

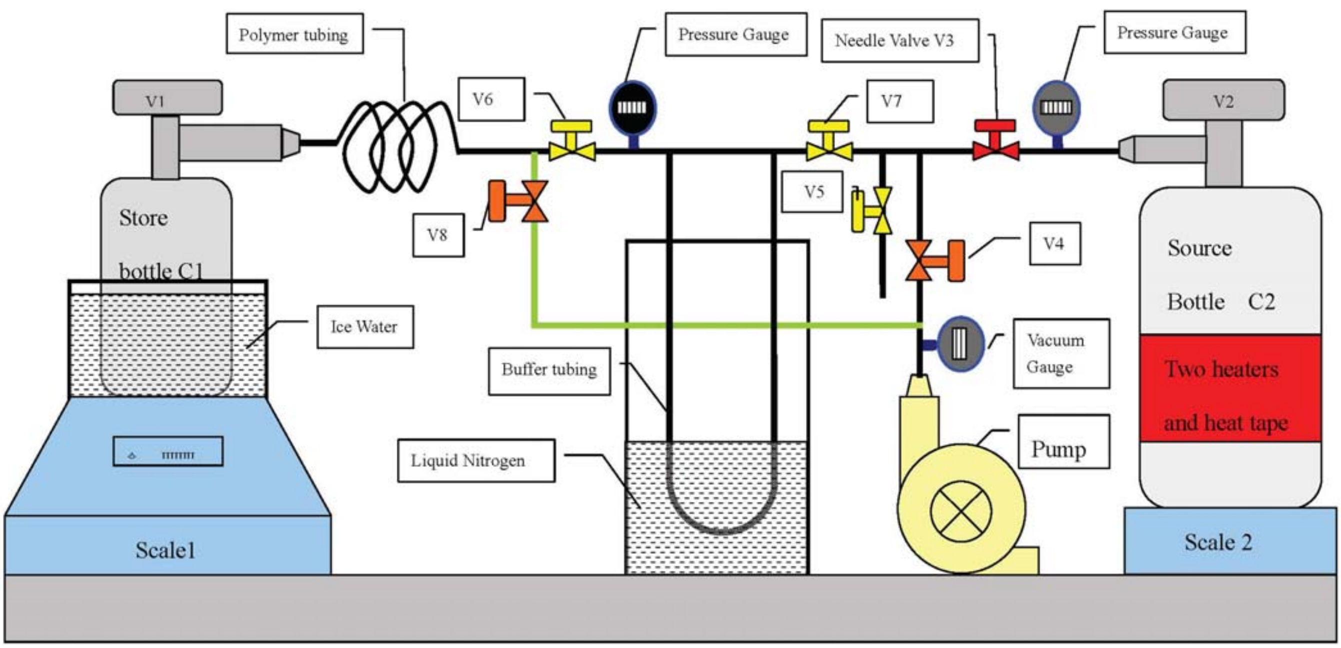

Fig. 2 Scheme of Xenon transfer

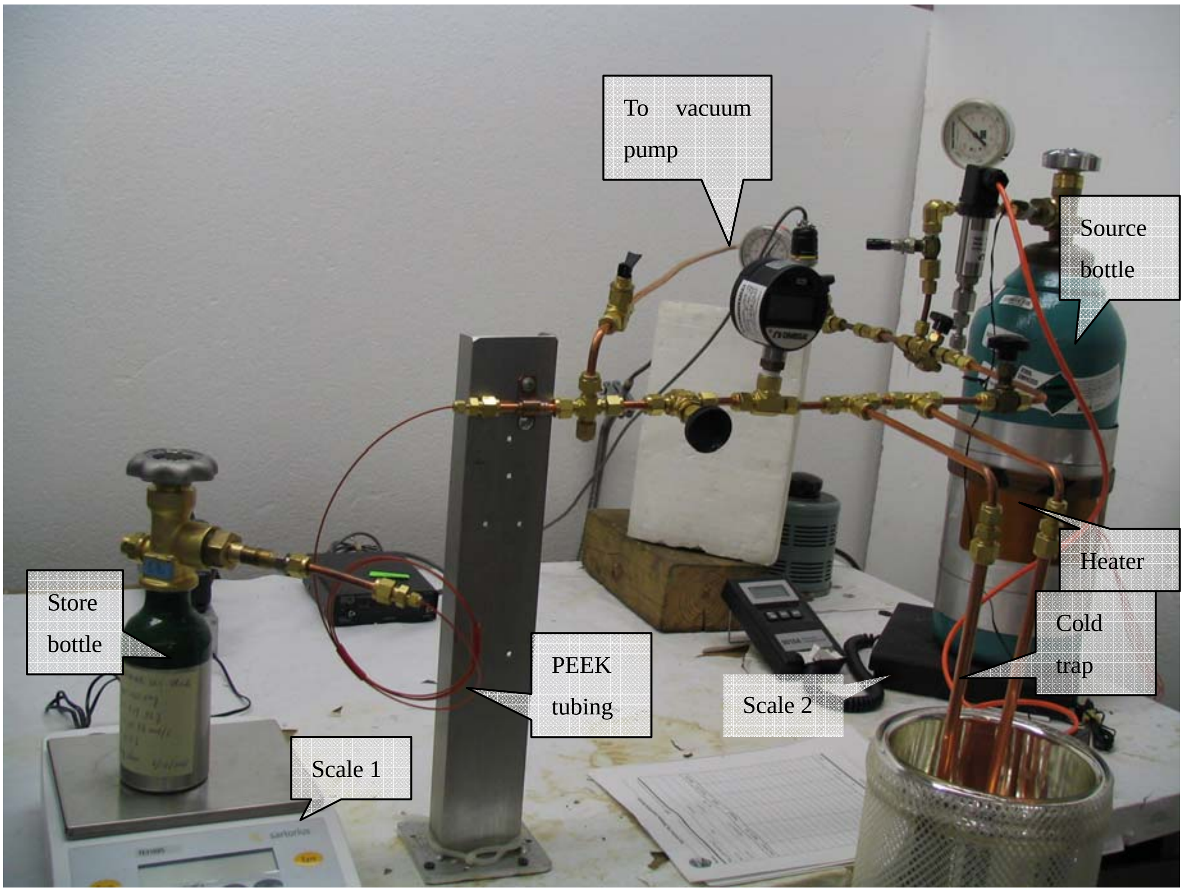

Fig. 3 Experimental setup for Xenon transfer

We use 1/4 inch copper tube as transmission line and the parameters of main parts are listed below.

Scale 1	Maximum: 3100 g	Accuracy: 0.01g	
Scale 2	Maximum: 20kg	Accuracy: 2g	
Heater	Used on AMS -01	U=120 V	W=20 Watt
Store bottle	V=300 ml	M_{net}=1135.72 g	
Source bottle	V=7.4 L	total 20.7 mole Xe	
Pressure Gauge 1	Mechanical	Maximum: 2000psi	
Pressure Gauge 2	Mechanical	Maximum: 3000psi	
Cold trap	3/8 out diameter	V~40 ml	
PEEK tubing	Can hold high pressure and flexible, greatly reduce the spring force		
Dewar and heat tape	commercial quality		

We need fill 527.8 g Xenon in this store bottle to reach the density up to 13.4 mol/L.

5. Procedure of Transfer by Heat

Since xenon is very expensive, we will not change the source bottle even if there is not enough gas for high pressure. I shall, of course, discuss the procedure for the case of low pressure. Now let me first assume there is much xenon in the source bottle and we separate the procedure into four steps.

1. Evacuate C1 and transmission lines

1) Measure the net mass of store bottle C1
2) Connect store bottle C1 with circuit to the supply bottle C2 and then dip it into ice water
3) Turn on heaters and heat tape on C2, Whenever the pressure reach as 1000 psi or the temperature reach 60°C, stop heating
4) Open V1, V3, V4, V6 and V7
5) Turn on vacuum pump down to 1.81 Torr （99.999% purity）
6) Close V4 and V3, turn off pump

2. Preparation for transfer

1) Open V2
2) Turn on scales and zero both scales with the "tare" button.

3. Begin transfer

1) Open V3 partway (2.1 turn) to start transfer
2) When C1 has gained the desired mass* of gas, close V3 and V1
3) Turn off heaters and then close V2 and V6
4) Turn on vacuum pump and open V8 to vent the rest gas in connection to C1 and then turn off pump and close V8
5) Disconnect the store bottle and measure the mass increase

4. Correction

1) Connect store bottle C1 with circuit to the supply bottle C2 and then dip it into ice water
2) Open V8 and turn on vacuum pump down to 1.81 Torr
3) Close V8 and turn off pump
4) Open V6, V2 and V3 for 3 minutes
5) Zero scale 1 with the "tare" button
6) Open V1 till the mass increase reaches the desired value
7) Close all valves to prepare for the recovery step which we will mention soon

* Even the scale shows the right value of mass increase, it’s not the exact amount of Xenon in the store bottle. Because it’s affected by the residual gas in the connection part to C1 like the case in CO_2 and the dew condensed to the wall of store bottle due to low temperature. The exact value is always smaller than what we want, so we need the Correction step to redeem it.

6. Transfer by a Cold Trap

If the volume of Xenon is not enough to hold relative high pressure we need very long time to finish the step of 3.2. Thus cold trap is applied to accelerate the process of transfer.

1. Evacuate C1 and transmission lines

1) Measure the net mass of store bottle C1
2) Connect store bottle C1 with circuit to the supply bottle C2 and then dip it into ice water
3) Turn on heaters and heat tape on C2, Whenever the pressure reach as 1000 psi or the temperature reach 60°C, stop heating
4) Open V1, V3, V4, V6 and V7
5) Turn on vacuum pump down to 1.81 Torr （99.999% purity）
6) Close V4 and V3, turn off pump

2. Preparation for transfer

1) Open V2
2) Turn on scales and zero both scales with the "tare" button.

3. Begin transfer

1) Open V3 partway (2.1 turn) to start transfer
2) If the transfer velocity is very slow even the source bottle has approached 60°C, close V6 and heaters and then dip the bottom of buffer tubing into liquid nitrogen
3) Gradually add liquid nitrogen to cover the 1/5 of total length of tubing
4) If when you close V7, the pressure drop is very slow, that means the tubing is almost full of solid and liquid Xenon, then close V7.
5) Remove liquid nitrogen and heat the top of tubing by heat tape at least for 10 minutes and then gradually dip the tubing into warm water
6) When the pressure in tubing reaches 800 psi, open V6 and start to transfer
7) If the Xenon in tubing is almost depleted, close V6 and repeat sub-steps from (2) to (6) till the store bottle gains the desired the mass, close V1, V6, V7 and V2
8) dip the bottom of buffer tubing into liquid nitrogen, when the pressure in tubing almost falls to 0 psi, close V6 and remove liquid nitrogen
9) Disconnect the store bottle and measure the mass increase

4. Correction

1) Connect store bottle C1 with circuit to the supply bottle C2 and then dip it into ice water
2) Open V8 and turn on vacuum pump down to 1.81 Torr
3) Close V8 and turn off pump
4) Open V6, V2 and V3 for 3 minutes
5) Zero scale 1 with the "tare" button
6) Heat the buffer tubing

7) Open V1 till the mass increase reaches the desired value
8) Close all valves to prepare for recovery step

7. Recovery of Xenon

We don't want lose even the small amount of Xenon in gas line because it's so expensive. So we should apply the recovery step to save the residual Xenon.

1) Chill the source bottle by ice water
2) Dip the bottom of buffer tubing into liquid nitrogen and then open V6, V7 and V3
3) When the pressure drops to almost 0 psi close V6 and disconnect the store bottle C1.
4) Remove liquid nitrogen and heat the tubing like the steps in transfer process
5) Open V2 to start recovery
6) When the pressure in tubing keeps constant, close V2, V3 and V7 to store the main part of residual Xenon in tubing for future using

8. Sample of transfer procedure data

I will give one example of detail transfer data to demonstrate the procedure.
The initial status is

M_{C1net}=1135.72 g T_{room}=22.8℃ P_{C2}=380psi T_{C2}=22.8℃

Transfer	1	2	3	4	5	6	7	8	9
Method*	heat	buffer	buffer	buffer	buffer	buffer	buffer	buffer	recovery
Mass increase	67.82	65.58	73.77	72.44	64.38	63.35	61.86	60.48	10
Accumulated Mass	67.82	133.4	207.17	279.61	343.99	407.34	469.2	529.68	539.68

Table 1 Mass increase of every step

*Method means the way we use to transfer Xenon. "Heat" means transfer by heating the source bottle, see section 5. "Buffer" means transfer by a cooled buffer volume, see section 6.

The final status is
M_{Xe}=525.96 g Density=13.38 mol/L

9. Summary and future work

If there is enough Xenon in source bottle, the process is much like the one for CO_2 transfer. Since we can not heat the source bottle too much because of safety consideration and possibility of contamination, we should rely on buffer tubing to continue the process. The buffer is also used to recover and store the residual gas. The whole procedure is safe and controllable.
We will try to find the mixture of liquid nitrogen and methanol to replace pure liquid nitrogen. Because the former one can be liquid at relative higher temperature above the melting point of Xenon to prevent any plug in buffer tubing by solid Xenon.

Reference

[1] *"The construction of the Alpha Magnetic Spectrometer (AMS) for the International Space Station"*, AMS-02 Homepage.

[2] U. Becker, J. Burger and P. Fisher, *"TRD Gas system Summary and Specifications"*, AMS-02 Homepage.

[3] McCarty, R.D., "*Correlations for the Thermophysical Properties of Xenon*", National Institute of Standards and Technology, Boulder, CO, 1989, 00.