Cleaning Electronegative Contamination from Gaseous Xenon Through Cryogenic Pumping

Ashton Rutkowski, Columbia University, REU Program, August 7, 2015
Dark Matter

Percentage of Observable Universe

- **Dark Matter**: 27%
- **Baryonic Matter**: 5%
- **Dark Energy**: 68%
XENON is a dark matter detection project that is based at the Laboratori Nazionali de Gran Sasso (LNGS) in Italy.

XENON1T uses liquid xenon as the detection medium.

This xenon needs to be clean of krypton down to parts per trillion.
WIMPs

Weakly Interacting Massive Particles

Likely dark matter candidate

Low reaction rate with baryonic matter

May be detected with very sensitive liquid xenon detector
Xenon as Detection Medium

- Detection happens when collisions produce low energy recoils
- Nuclear recoils come from WIMPs
- Xenon provides the best cross-section for detection
Scintillations in the TPC

- Time Projection Chamber

- Two scintillations:
  1. Light from initial collision ($S_1$)
  2. Charge from drifting electrons ($S_2$)

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It needs to be nearly 100% pure xenon to eliminate:

1. Background contamination from radioactive isotopes and
2. to extract drifting electrons from the interaction vertex from electronegative contaminates

neriX aids in research and development for XENON1T
Electronegative Contamination

- Electronegativity - tendency of an atom to attract electrons toward itself
- Nitrogen and oxygen highly electronegative
- S2 recording compromised from these elements

I'm falling for him!
He's so strong

ADAM'S ABILITY TO ATTRACT A BONDING PAIR OF ELECTRONS

ELECTRONEGATIVITY

Surfglippy.com
A getter is used to clean the xenon gas.

This device can only handle a few grams of nitrogen contamination.

Xenon gas must be pure to parts per million before getter is used.

Usually clean enough to use getter when xenon gas is received from factory.

It is then put into neriX to preform calibration measurements.
The neriX Problem

- Diaphragm pumps are used to circulate xenon gas through a purification loop
- One of these diaphragms ruptured
- Air got into the purified xenon gas
- Xenon gas unable to run through getter for purification
Objectives

- Measure the actual amount of air ($N_2$) contamination inside the rescue bottle
- Apply cryogenic pumping to clean the $N_2$ from the xenon
Outgassing System

- Outgassing system to leak in xenon gas
- Need high vacuum for analysis
- Xenon gas leaks in through pipette
- RGA analyzes relative pressures
Residual Gas Analyzer

- RGA used to measure xenon gas leaked in
- Works by detecting partial pressures
- Measures from 1 to 200 AMU
- Used RGA software to collect data
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Full RGA scan of a xenon leak on June 30, 2015

RGA scan highlighting the xenon peaks
Pipette

- Pipette used to transfer xenon gas from bottle to outgassing system
- Fine control leak valve to regulate pressure

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Attachment to Xenon

- Pipette attached to leak checker or a roughing pump
- Also attached to xenon bottle
- Regulator valve to check and reduce pressures

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Cryopumping

- Cool gas until frozen
- Wait a few hours for residue gas to surface
- Pump off residue gas with roughing pump
- Temperature is key!
<table>
<thead>
<tr>
<th>Element</th>
<th>Temperature</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (Boiling)</td>
<td>77 K (-196 °C)</td>
<td>1 bar</td>
</tr>
<tr>
<td>Argon (Liquid)</td>
<td>84 to 87 K (-189 to -186 °C)</td>
<td>1 bar</td>
</tr>
<tr>
<td>Xenon (Melting)</td>
<td>161 K (-112 °C)</td>
<td>1 bar</td>
</tr>
</tbody>
</table>
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Analysis of the data required several steps:

1. Collecting background and sample data
2. Plotting these data
3. Subtracting the background from the sample
4. Integrating the graph
5. Comparing percentages of the elements
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Xenon Leak After Third Clean (7/28/15)

- Background Data
- Raw Xenon Sample Data
- Background Subtracted Xenon Leak Data

Components detected:
- Water
- Argon
- Xenon
- Helium (H)
- Nitrogen (N₂)

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Xenon Leak After Third Clean (7/28/15)

![Graph showing pressure (Torr) vs. mass (AMU) with three curves: Background Data, Raw Xenon Sample Data, and Background Subtracted Xenon Leak Data.]
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# Final Results

<table>
<thead>
<tr>
<th>Date</th>
<th># of Cleanings</th>
<th>Percent of Xenon</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/30/15</td>
<td>Zero</td>
<td>88</td>
<td>No Hydrocarbons</td>
</tr>
<tr>
<td>7/1/15</td>
<td>Zero</td>
<td>86</td>
<td>No Hydrocarbons</td>
</tr>
<tr>
<td>7/20/15</td>
<td>One</td>
<td>80 (98)</td>
<td>HC Present</td>
</tr>
<tr>
<td>7/21/15</td>
<td>Two</td>
<td>90 (99)</td>
<td>HC Present</td>
</tr>
<tr>
<td>7/24/15</td>
<td>Two</td>
<td>96 (100)</td>
<td>HC Present</td>
</tr>
<tr>
<td>7/28/15</td>
<td>Three</td>
<td>89 (95)</td>
<td>HC Present</td>
</tr>
</tbody>
</table>

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Comments

Better assess the statistical uncertainty of the pressure gauge (possibly a few percent)

Analysis problems:

1. Hydrocarbons were manually subtracted
2. No explanation for why background subtraction didn’t work correctly
3. Xenon gas naturally has no hydrocarbons
Comments

- The precision of the method is only a few percent.
- 1% uncertainty corresponds to a nitrogen contamination of 5.3 g.
- Cannot be put in getter yet!
Next Steps

- Xenon needs to be cleaned to parts per million
- 99.9999% xenon and 0.0001% electronegative impurities
- Xenon can then be cleaned by getter
- The gas can be used for research and development by neriX after that
- Cleaning will have saved 1000’s of dollars
Acknowledgments

The REU Program at Nevis Laboratories – For choosing me for this amazing opportunity.

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Sources


http://www.nevis.columbia.edu/reu/xenon.html


https://www.astro.umd.edu/~ssm/darkmatter/WIMPexperiments.html

http://xenon.astro.columbia.edu/XENON100_Experiment/

Questions???