Outline of the Lecture

• What is Cryogenics?

• The Chronology of Cryogenic Technology

• Definitions and different temperature Scales

• T – s diagram of a Cryogenic Fluid

• Properties of the Cryogenic Fluids
What is Cryogenics?

- Kryo – Very cold (frost)
- Genics – to produce
- “Science and art of producing very cold”
# The Chronology

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1877</td>
<td>Cailletet and Pictet liquefied Oxygen.</td>
</tr>
<tr>
<td>1879</td>
<td>Linde founded the Linde Eismaschinen AG.</td>
</tr>
<tr>
<td>1892</td>
<td>Dewar developed a vacuum insulated vessel for cryogenic fluid storage.</td>
</tr>
<tr>
<td>1895</td>
<td>Onnes established Leiden Laboratory.</td>
</tr>
<tr>
<td>1902</td>
<td>Claude established l’Air Liquide and developed air-liquefaction system.</td>
</tr>
<tr>
<td>1908</td>
<td>Onnes liquefied helium.</td>
</tr>
<tr>
<td>1911</td>
<td>Onnes discovered superconductivity.</td>
</tr>
</tbody>
</table>
# The Chronology

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1926</td>
<td>Goddard test fired the first cryogenically propelled rocket.</td>
</tr>
<tr>
<td>1934</td>
<td>Kapitza designed the first turbo expansion engine.</td>
</tr>
<tr>
<td>1952</td>
<td>National Institute of Standards &amp; Technology (NIST), USA, Cryogenic Engineering Laboratory established.</td>
</tr>
<tr>
<td>1966</td>
<td>Development of Dilution refrigerator.</td>
</tr>
<tr>
<td>1975</td>
<td>Record high superconducting transition temperature (23 K) achieved.</td>
</tr>
<tr>
<td>1994</td>
<td>Matsubara developed a 4 K cryocooler</td>
</tr>
</tbody>
</table>
What is Cryogenics?

• Cryogenics is the science and technology associated with generation of low temperature below 123 K.
Temperature

<table>
<thead>
<tr>
<th>Kelvin (K)</th>
<th>Celsius (°C)</th>
<th>Rankine (°R)</th>
<th>Fahrenheit (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-273.15</td>
<td>0</td>
<td>-459.67</td>
</tr>
<tr>
<td>273.15</td>
<td>0</td>
<td>491.67</td>
<td>32</td>
</tr>
<tr>
<td>373.15</td>
<td>100</td>
<td>671.67</td>
<td>212</td>
</tr>
</tbody>
</table>

Increment

- $1\,\text{K} = 1\,\text{°C} = 1.8\,\text{°R} = 1.8\,\text{°F}$
Temperature

The Kelvin Temperature Scale
• $K = ^\circ C + 273$ (Note it is Kelvin, but not degree Kelvin).

Room Temperature $\sim 300$ K

<table>
<thead>
<tr>
<th>Cryogen</th>
<th>Temp (K)</th>
<th>Cost (Rs/Lit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LN$_2$</td>
<td>77.36</td>
<td>25</td>
</tr>
<tr>
<td>LH$_2$</td>
<td>20.39</td>
<td></td>
</tr>
<tr>
<td>LHe</td>
<td>4.2</td>
<td>1000</td>
</tr>
</tbody>
</table>
Cryogen

• Fluid with normal boiling point less than 123 K.

<table>
<thead>
<tr>
<th>Cryogen</th>
<th>Boiling Point (K)</th>
<th>Triple Point (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane, CH₄</td>
<td>111.67</td>
<td>90.69</td>
</tr>
<tr>
<td>Oxygen, O₂</td>
<td>90.19</td>
<td>54.36</td>
</tr>
<tr>
<td>Argon, Ar</td>
<td>87.30</td>
<td>83.81</td>
</tr>
<tr>
<td>Air(N₂+O₂+Ar)</td>
<td>78.6</td>
<td>59.75</td>
</tr>
</tbody>
</table>
### Cryogen (contd..)

<table>
<thead>
<tr>
<th>Cryogen</th>
<th>Boiling Point (K)</th>
<th>Triple Point (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen, N₂</td>
<td>77.36</td>
<td>63.15</td>
</tr>
<tr>
<td>Normal H₂</td>
<td>20.39</td>
<td>13.96</td>
</tr>
<tr>
<td>He⁴</td>
<td>4.230</td>
<td>-</td>
</tr>
<tr>
<td>He³</td>
<td>3.191</td>
<td>-</td>
</tr>
</tbody>
</table>
T – s diagram of a cryogen

- **C** Critical Point
- **E** Entropy
- **L+V** Liquid + Vapor
- **B** Isobar
- **300 K, 1 atm A**

**Prof. M D Atrey, Department of Mechanical Engineering, IIT Bombay**
## Properties of few Cryogens

<table>
<thead>
<tr>
<th>Sat. Liq. at 1atm</th>
<th>LHe 4</th>
<th>LH(_2)</th>
<th>LN(_2)</th>
<th>LAir</th>
<th>LOX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Boiling Point</td>
<td>K</td>
<td>4.214</td>
<td>20.27</td>
<td>77.36</td>
<td>78.8</td>
</tr>
<tr>
<td>Critical Pressure</td>
<td>Mpa</td>
<td>0.229</td>
<td>1.315</td>
<td>3.39</td>
<td>3.92</td>
</tr>
<tr>
<td>Density</td>
<td>kg/m(^3)</td>
<td>124.8</td>
<td>70.79</td>
<td>807.3</td>
<td>874</td>
</tr>
<tr>
<td>Latent Heat</td>
<td>kJ/kg</td>
<td>20.90</td>
<td>443</td>
<td>199.3</td>
<td>205</td>
</tr>
</tbody>
</table>
T – s diagram of Helium

Critical Pt.
2.29 atm, 5.2 K

1 atm, 4.2 K

T – s chart for He – 4
• Pressure (P) – atm
• Density – gm/mol-lit
• Temp (T) – K
• Enthalpy (h) – J/gm-mol
• Entropy (s) – J/g-mol-K
T – s diagram of Nitrogen

T – s chart for N₂
• Pressure (P) – atm
• Density – gm/mol-lit
• Temp (T) – K
• Enthalpy (h) – J/gm-mol
• Entropy (s) – J/g-mol-K

Critical Pt.
33.9 atm, 126 K

1 atm, 77.36 K
Cryogenic Fluids

Hydrogen, Helium
• They fall in special class. These gases are dealt in next lecture.

Liquid Methane
• It boils at 111.7 K.
• It can be used as rocket fuel.
• In the form of Compressed natural gas (CNG).
Cryogenic Fluids

Liquid Neon

• It is a clear, colorless liquid with boiling point at 27.1 K.

• Neon is commonly used in neon advertising.

• Liquid neon is commercially used as cryogenic refrigerant.

• It is compact, inert and less expensive as compared to liquid helium.
Liquid Nitrogen (LN$_2$)

- Boils at 77.36 K and freezes at 63.2 K.

- Resembles water in appearance - 807 kg/m$^3$ (water – 1000 kg/m$^3$).


- Heat of vaporization is 199.3kJ (water - 2257kJ/kg) and it is produced by distillation of liquid air.
Cryogenic Fluids

Liquid Nitrogen (LN$_2$)

• Nitrogen is primarily used to provide an inert atmosphere in chemical and metallurgical industries.

• It is also used as a liquid to provide refrigeration.

• Food preservation, blood, cells preservation.

• High temperature superconductivity.
Cryogenic Fluids

Liquid Oxygen (LOX)

• Blue in color – due to long chains of $O_4$.

• Boils at 90.18 K and freezes at 54.4 K.

• Has a density of 1141 kg/m$^3$ (water – 1000 kg/m$^3$).

• $O_2$ is slightly magnetic and exists in 3 stable isotopes - $O_{16}$, $O_{17}$, $O_{18}$ in ratio of (10000 : 4 : 20).
Cryogenic Fluids

Liquid Oxygen (LOX)

- Because of the unique properties of oxygen, there is no substitute for oxygen in any of its uses – widely used in industries and for medical purpose.

- It is largely used in iron and steel manufacturing industry.

- Oxidizer propellant for spacecraft rocket applications.
Cryogenic Fluids

Liquid Argon

- It is a colorless, inert and non toxic gas.
- It boils at 87.3 K and freezes at 83.8 K.
- It has a density of 1394 kg/m$^3$ (water – 1000 kg/m$^3$).
Cryogenic Fluids

Liquid Argon

• The property of inertness of argon is used to purge moulds in casting industry.

• It is used in Argon-oxygen decarburization (AOD) process in stainless steel industry.

• It offers inert atmosphere for welding stainless steel, aluminum, titanium etc.
Cryogenic Fluids

Liquid Air

• For practical purpose, it is considered as a mixture of 78% N₂ + 21% O₂ + 1% Ar + others.

• It has a boiling point of 78.9 K and 874 kg/m³ as density (water density - 1000 kg/m³).

• Liquid air was earlier used as precoolant for low temperature applications.

• Liquid air is primarily used in production of pure nitrogen, oxygen, and rare gases.
• A self assessment exercise is given after this slide.

• Kindly asses yourself for this lecture.
Self Assessment

1. _____ is the temperature below which the cryogenic range begins.
2. Convert 400 K into Celsius scale - __________
3. Area enclosed by the dome in T – s diagram is in __________ phase.
4. Vertical lines in T – s diagram represent __________ lines.
5. Boiling point of LN₂ and LO₂ are _____ & _______ respectively.
6. NIST stands for ____________________________

7. An inert gas with boiling point of 87.3 K is ________________

8. Isotopes of oxygen are ________________________________
1. 123 K
2. 127 deg C
3. Liquid + Vapor
4. Entropy
5. 77.36 K, 90.19 K
6. National Institute of Standards & Technology
7. Argon
8. O16, O17, O18
Thank You!