Overview of Earlier Lecture

- Hydrogen
- Helium
- Phase Diagram of Helium
- Super fluid Helium
Outline of the Lecture

• Uses of Helium – 4

• Thermomechanical, Mechanocaloric, Fountain, Rollin Film Effects.

• Sound Propagation in Super fluid

• Helium – 3 and Phase Diagram

• Summary
Helium – 4 Phase Diagram

- LHe – II, called as super fluid, exhibits properties like zero viscosity and large thermal conductivity.
- It flows through narrow slits and channels very rapidly.
Kapitza et al. stated that viscosity for flow through thin channels is independent of pressure drop and is only a function of temperature.
The NMR (Nuclear Magnetic Resonance) is used by the pharmaceutical industry to study the molecular structure.
It has a superconducting (SC) magnet (10 T ~ 25 T) cooled by Liquid Helium bath.

The accuracy of measurement increases with the field strength.
The MRI (Magnetic Resonance Imaging) machines are used for body scanning.

The SC magnets for both NMR and MRI machines are cooled by Liquid Helium.
Uses of Helium – 4

- The Super conducting magnet systems at CERN spanning over 27 km circumference are kept at 1.9 K using the Liquid Helium.

- The low viscosity and high thermal conductivity of Liquid Helium makes the system more efficient.

- Also, the engineering project ITER has Superconducting magnets maintained at low temperature by gaseous Helium.
Uses of Helium – 4

- Helium being a thin and inert gas, is used in leak detection systems.
- It is used as a shielding gas in arc welding to provide an inert atmosphere.
Liquid Helium - II

The peculiar properties of Liquid Helium – II give rise to interesting thermal and mechanical effects as listed below.

• Thermomechanical Effect
• Mechanocaloric Effect
• Fountain Effect
• Rollin Film Effect
Thermomechanical Effect

- This effect was discovered in the year 1938.

- Consider a flask filled with super fluid helium (LHe – II) and a heating coil placed inside a differential container as shown in the figure.

- When the heat is applied to the fluid in the inner container, the concentration of normal fluid increases.
Thermomechanical Effect

• The Super fluid component tends to move towards this region to equalize the concentration.

• Super fluid being less viscous, can flow rapidly through the narrow channel.

• Normal fluid being more viscous, its flow is impeded by the channel resistance.
Thermomechanical Effect

- As a result, due to the induced pressure difference, a pressure head called as Thermo Mechanical Pressure Head is developed.

- This head is proportionate to the temperature rise of $\Delta T$ in the fluid.
Mechano-caloric Effect

- It was discovered in the year 1939.

- The apparatus consists of a round flask filled with a fine powder and Super fluid Helium (LHe – II). The flask has an opening at the bottom.

- A resistance thermometer is mounted to detect the temperature changes, as shown in the figure.
Mechanocaloric Effect

- The Super fluid Helium (LHe - II) being less viscous flows through the fine powder easily.

- As a result, the concentration of normal fluid increases above the powder.

- Hence, the temperature increases inside the flask, which is sensed by resistance thermometer.
Consider an U-tube with a fine capillary as shown in the figure.

The U-tube is filled with a fine powder and is immersed in Super fluid Helium (LHe – II) bath.

When heat is added to the powder, the concentration of normal fluid increases due to rise in the temperature.
Fountain Effect

- As a result, the Super fluid rushes in, to equalize the concentration.

- Normal fluid, being more viscous cannot flow through the fine powder.

- The inflow of super fluid builds up with time and finally squirts out through the fine capillary opening at the top.
Rollin Effect

- This effect is named after Bernard V. Rollin in the year 1937.
- The Liquid Helium – II exhibits a property of clinging to the walls of the container called as Creeping effect.
- The thickness of the film is in the order of 30 nm.
- Consider a test tube filled with Liquid Helium – II as shown in the figure.
Rollin Effect

- When the test tube is lowered into the Liquid Helium - II bath, the Rollin film clings to the tube and gradually fills the tube.

- On the other hand, if the tube is raised above the bath level, it empties out slowly.

- The ability of the fluid to flow against gravity is called as Onnes effect.
Rollin Effect

- In these films, the capillary forces dominate the gravity and viscous forces.

- The rate of flow is independent of height of flow or barrier and difference in level. It increases with drop in temperature.

- It is zero at lambda point and becomes constant below 1.5 K.
Rollin Effect

- This creeping behaviour added to leaking ability of Helium – II, makes containment of LHe – II to an enclosure difficult.

- The enclosure or the container has to be designed properly otherwise otherwise Helium – II creeps to the warmer side through valves and openings and will evaporate.
Sound Propagation

- In LHe – II, at least three different mechanisms of sound can be propagated.
- For temperatures above and below lambda point, propagation of ordinary sound which is nothing but pressure and density oscillations occurs.
- This is called as First sound.
Sound Propagation

- Below the lambda point temperature, the Liquid Helium has LHe- I (normal fluid) and LHe – II (super fluid) components.

- Due to difference in concentrations of these fluids, there exists a temperature gradient. This gradient causes oscillations of Normal fluid and Super fluid which are called as Second sound.

- The velocity of Second sound varies from zero at lambda point to 239 m/s at near 0 K.
Sound Propagation

• In thin films, the LHe – I component clings to the walls due to the viscous effects.

• If only the super fluid component in Second sound oscillates, then it is called as Third sound.

• This wave motion appears as an oscillation in the thickness of the film. The velocity of propagation of Third sound is around 0.5 m/s.

• Another form of sound called as Zero sound has been detected recently. The research is on to study its characteristics.
# Helium Nomenclature

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Temp</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Helium – 4</td>
<td>λ</td>
<td>LHe – I</td>
</tr>
<tr>
<td>Helium – 3</td>
<td></td>
<td>LHe – II</td>
</tr>
</tbody>
</table>
Helium – 3

• It is a non radioactive isotope with two protons and one neutron.

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Normal Boiling Point</td>
<td>K</td>
<td>3.19</td>
</tr>
<tr>
<td>Normal Freezing Point</td>
<td>K</td>
<td>-</td>
</tr>
<tr>
<td>Critical Pressure</td>
<td>MPa</td>
<td>0.117</td>
</tr>
<tr>
<td>Critical Temperature</td>
<td>K</td>
<td>3.32</td>
</tr>
<tr>
<td>Liquid He – 3 Density</td>
<td>kg/m³</td>
<td>58.9</td>
</tr>
<tr>
<td>Latent Heat</td>
<td>kJ/kg</td>
<td>8.49</td>
</tr>
</tbody>
</table>
Helium – 3

• In 1920, Aston discovered another isotope of Helium, He\textsuperscript{3}. First liquefaction of Helium – 3 was achieved by Sydoriak et. al. in the year 1948.

• This isotope He - 3 is very rare and is difficult to isolate from He – 4.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Relative %</th>
</tr>
</thead>
<tbody>
<tr>
<td>He – 4</td>
<td>~100</td>
</tr>
<tr>
<td>He – 3</td>
<td>1.3 x 10^{-4}</td>
</tr>
</tbody>
</table>
Helium – 3

From the adjacent figure, it is clear that for a given pressure, Liquid He - 3 is more colder than Liquid He – 4.
Helium – 3 phase diagram

- From the adjacent figure
- Saturated solid line.
- Saturated vapor line.
- Critical point.
Helium – 3 phase diagram

- LHe - 3 (like LHe - 4) remains liquid under its vapor pressure up to absolute zero.
- It must be compressed to 28.9 bar at 0.32 K to solidify.
Helium – 3 has no temperature and pressure at which solid - liquid – vapor can co-exist. It means that it has no triple point.

Liquid He - 3 undergoes a different type of super fluid transition at approximately 3.2 mK.
- The $\lambda$ line shown in the adjacent figure is a function of concentration of He – 3.

- The $\lambda$ point is depressed by addition of small amounts of He – 3.

- The mixture of He – 3 and He – 4 is not completely miscible at very low temperature.
The mixture of He – 3 and He – 4 separate below 1 K due to the differences in isotopic mass.

Separation occurs into Super fluid (rich in He - 4) and Normal fluid (rich in He - 3).
The point of intersection of Lambda line and phase separation region is called as Tricritical point (TCP).

The TCP at 0.872 K and with a concentration of 0.669 of He – 3.
This separation into two liquid phases and difference in vapor pressure forms the basis for Dilution Refrigerator.

### Diagram

- **Lambda Line**
- **Super fluid He – II**
- **He – I**
- **Phase Separation Region**

**Axes:**
- **Temperature, K**
- **Mole fraction He -3**
Uses of Helium – 3

• It is mostly used in Dilution refrigerators to achieve low temperatures.

• It is also used as working fluid in Cryocoolers. Temperature close to 1 K are reported with Pulse Tube Cryocooler.

• The properties are of interest in relation to the theories of quantum statistical mechanics.

• It is an important isotope in instrumentation for neutron detection.
Summary

• The summary of the topics covered are
  
• Introduction to Cryogenics

• Properties of Cryogens, T – s Diagram

• Hydrogen

• Helium

• Super fluid Helium

• Helium - 3
A self assessment exercise is given after this slide.

Kindly asses yourself for this lecture.
Self Assessment

1. The pressure head in Mechanocaloric effect is proportional to _________________.

2. In Thermomechanical effect, ______________ fluid flows out of fine powder.

3. The viscosity of Super fluid helium is ____________ than normal fluid.

4. At a given pressure, the temperature of LHe – 3 is ____________ than LHe – 4.
5. Boiling point of LHe – 3 is ________

6. Principle of Dilution Refrigerator is ____________

7. ____________ isotope of Helium is difficult to separate & also mention the temperature.

8. Second sound is due to the oscillations of ____________

9. The speed of Third sound in LHe – II is ____________
10. The thickness of Rollin film is in the order of ___________

11. The Tricritical point occurs at ____________ temperature.

12. Phase separation in He-3 and He-4 Mixture occurs below _______________ Temperature.
1. Rise in temperature
2. Super fluid helium (LHe –II).
3. Greater
4. Lower
5. 3.19 K
6. The separation that occurs below 0.8 K.
7. He – 3
8. Normal fluid and Super fluid Helium
9. 0.5 m/s
Answers

10. 30 nm
11. 0.872 K
12. 1 K
Thank You!