
CRYOGENIC ENGINEERING
Prof. Milind D. Atrey
Department of Mechanical Engineering,
IIT Bombay
Lecture No - 2

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

Year	Event
1877	Cailletet and Pictet liquefied Oxygen.
1879	Linde founded the Linde Eismaschinen AG.
1892	Dewar developed a vacuum insulated vessel for cryogenic fluid storage.
1895	Onnes established Leiden Laboratory.
1902	Claude established l'Air Liquide and developed air-liquefaction system.
1908	Onnes liquefied helium.
1911	Onnes discovered superconductivity.

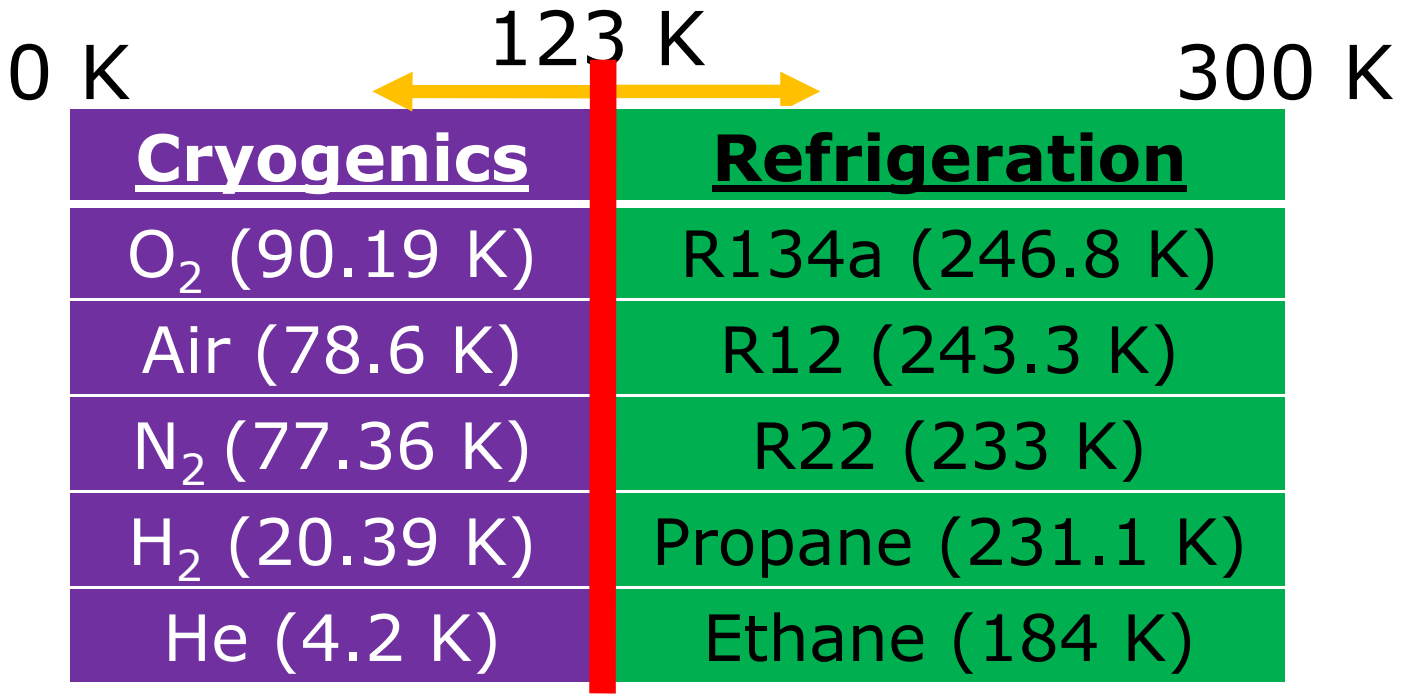
The Chronology

Year	Event
1926	Goddard test fired the first cryogenically propelled rocket.
1934	Kapitza designed the first expansion engine.
1952	National Institute of Standards & Technology (NIST), USA, Cryogenic Engineering Laboratory established.
1966	Development of Dilution refrigerator.
1975	Record high superconducting transition temperature (23 K) achieved.
1994	Matsubara developed a 4 K cryocooler

Introduction

What is Cryogenics?

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



Temperature

Kelvin (K)	Celsius (°C)	Rankine (°R)	Fahrenheit (°F)
0	-273.15	0	-459.67
273.15	0	491.67	32
373.15	100	671.67	212

Increment

- 1 K = 1°C = 1.8°R = 1.8°F

Temperature

The Kelvin Temperature Scale

- K = °C + 273 (Note it is Kelvin, but not degree Kelvin).

Room Temperature ~ 300 K

Cryogen	Temp (K)	Cost (Rs/Lit)
LN_2	77.36	25
LH_2	20.39	
LHe	4.2	1000

Cryogen

Cryogen

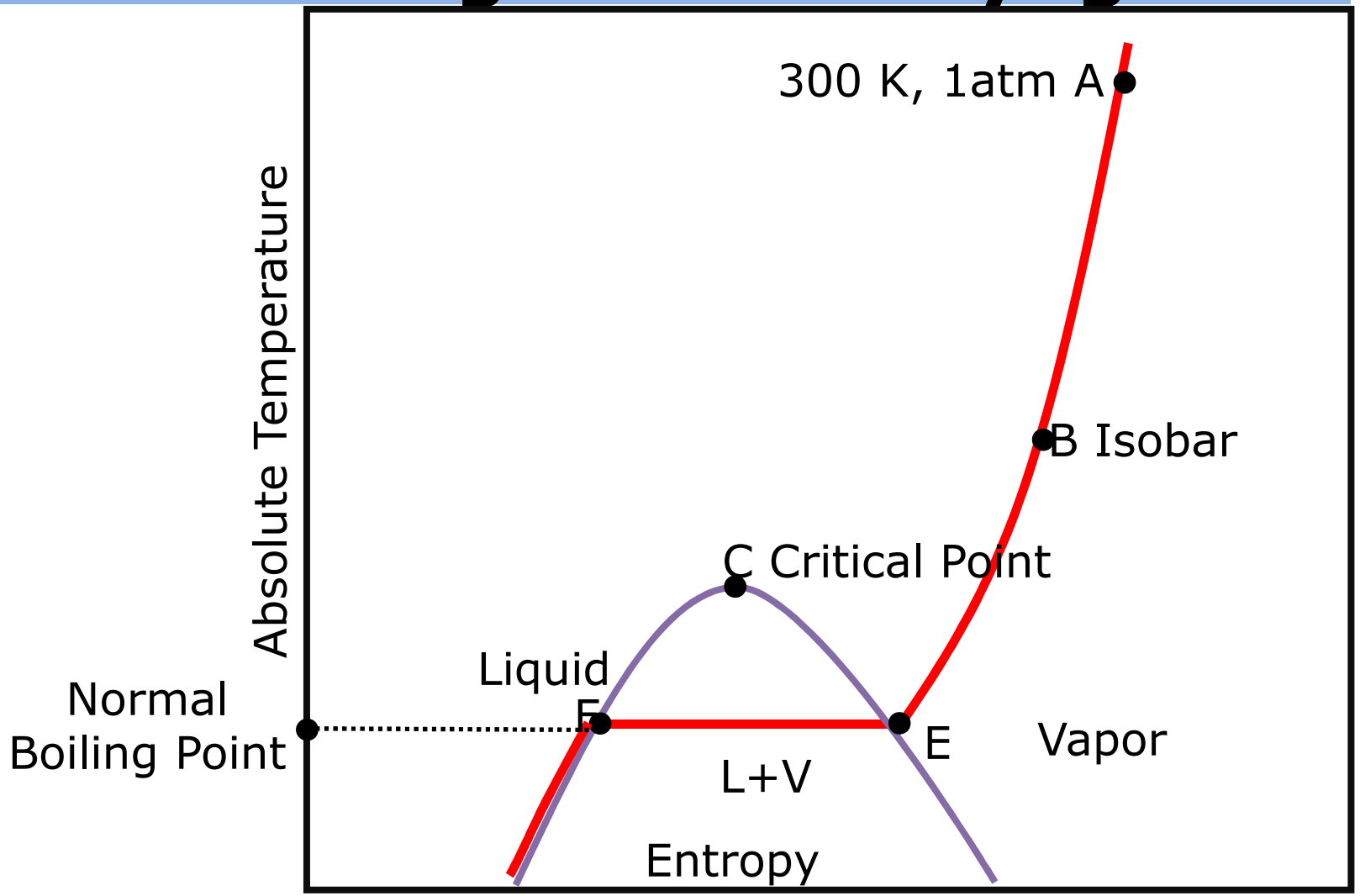
- Fluid with normal boiling point less than 123 K.

Cryogen	Boiling Point (K)	Triple Point (K)
Methane, CH_4	111.67	90.69
Oxygen, O_2	90.19	54.36
Argon, Ar	87.30	83.81
Air(N_2+O_2+Ar)	78.6	59.75

Cryogen (contd..)

Cryogen	Boiling Point (K)	Triple Point (K)
Nitrogen, N_2	77.36	63.15
Normal H_2	20.39	13.96
He^4	4.230	-
He^3	3.191	-

T – s diagram of a cryogen



Properties of few Cryogens

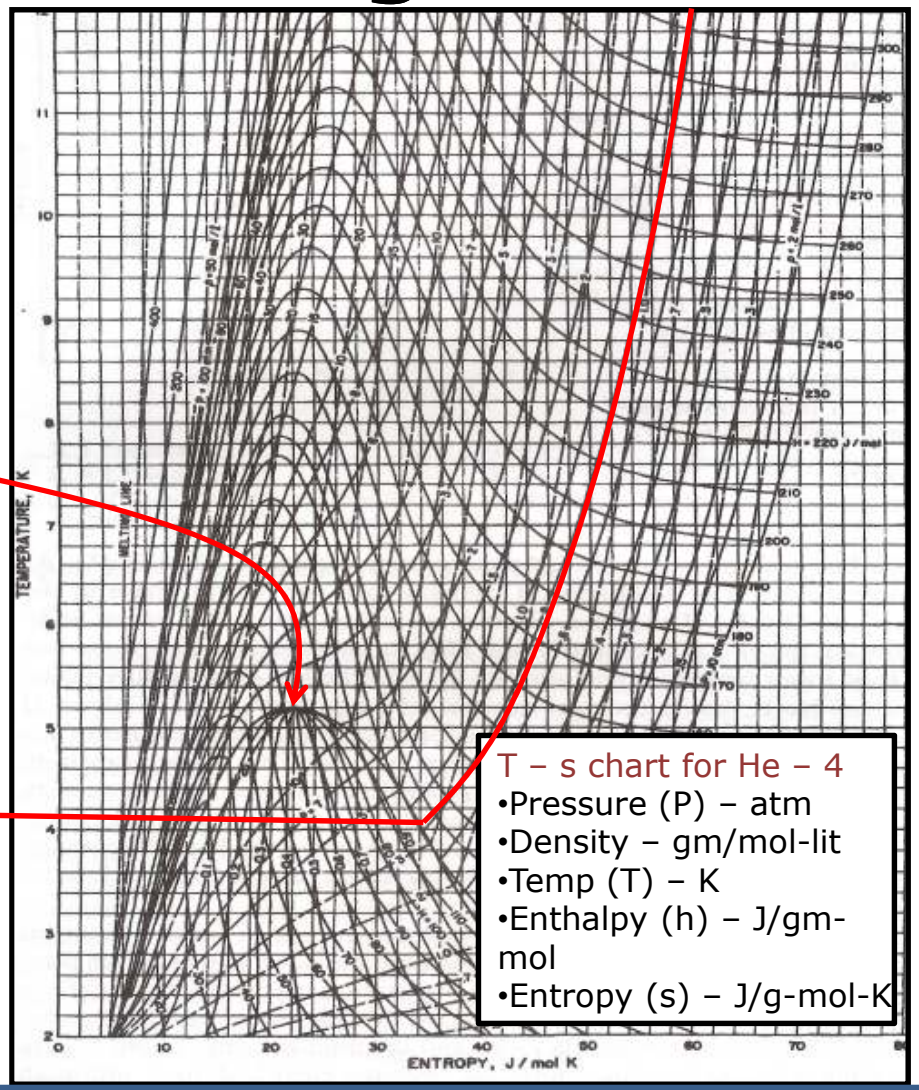
Sat. Liq. at 1atm		LHe 4	LH_2	LN_2	LAir	LOX
Normal Boiling Point	K	4.214	20.27	77.36	78.8	90.18
Critical Pressure	Mpa	0.229	1.315	3.39	3.92	5.08
Density	kg/m^3	124.8	70.79	807.3	874	1141
Latent Heat	kJ/kg	20.90	443	199.3	205	213

T – s diagram of Helium

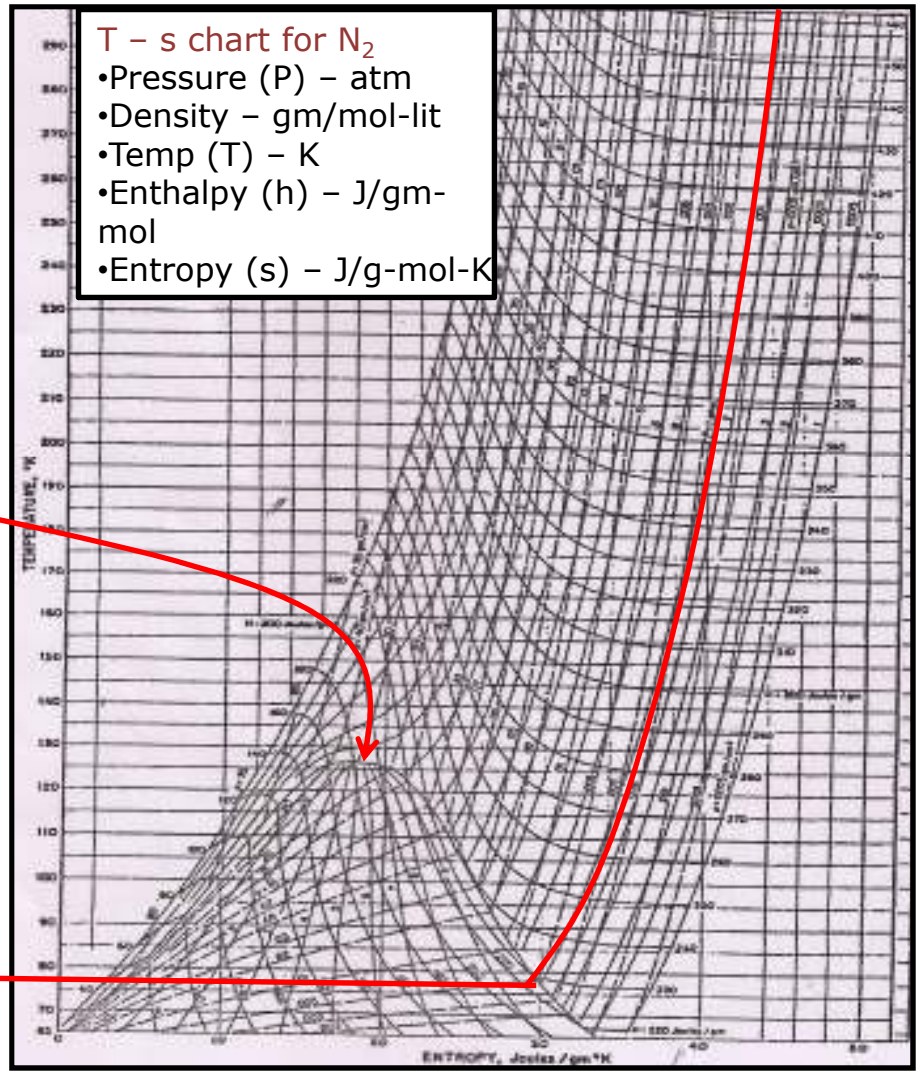
Critical Pt.

2.29 atm,
5.2 K

1 atm, 4.2 K



T – s diagram of Nitrogen



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.

Cryogenic Fluids

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).
- Exists in 2 stable isotopes - N14 & N15 in ratio of 10000 : 38.
- 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 1141kg/m^3 (water – 1000 kg/m^3).
- O_2 is slightly magnetic and exists in 3 stable isotopes - O16, O17, O18 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).
- Exists in 3 stable isotopes – Ar35, Ar38, Ar40 and in a ratio of (338 : 63 : 100000).

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% N_2 + 21% O_2 + 1% Ar + others.
- It has a boiling point of 78.9 K and 874 kg/m^3 as density (water density - 1000 kg/m^3).
- 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 LN_2 and LO_2 are _____ & _____ respectively.

Self Assessment

6. NIST stands for

_____

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

_____

8. Isotopes of oxygen are

_____

Answers

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. 87.30 K
8. O16, O17, O18

Thank You!