Cryogenic Engineering

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ENGINEERING
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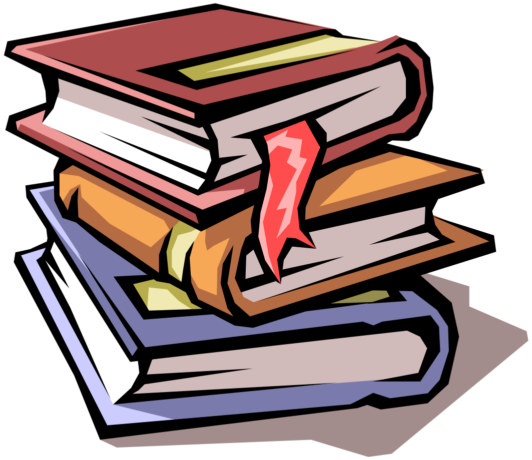
Chapter 1.

INTRODUCTION TO CRYOGENIC SYSTEMS

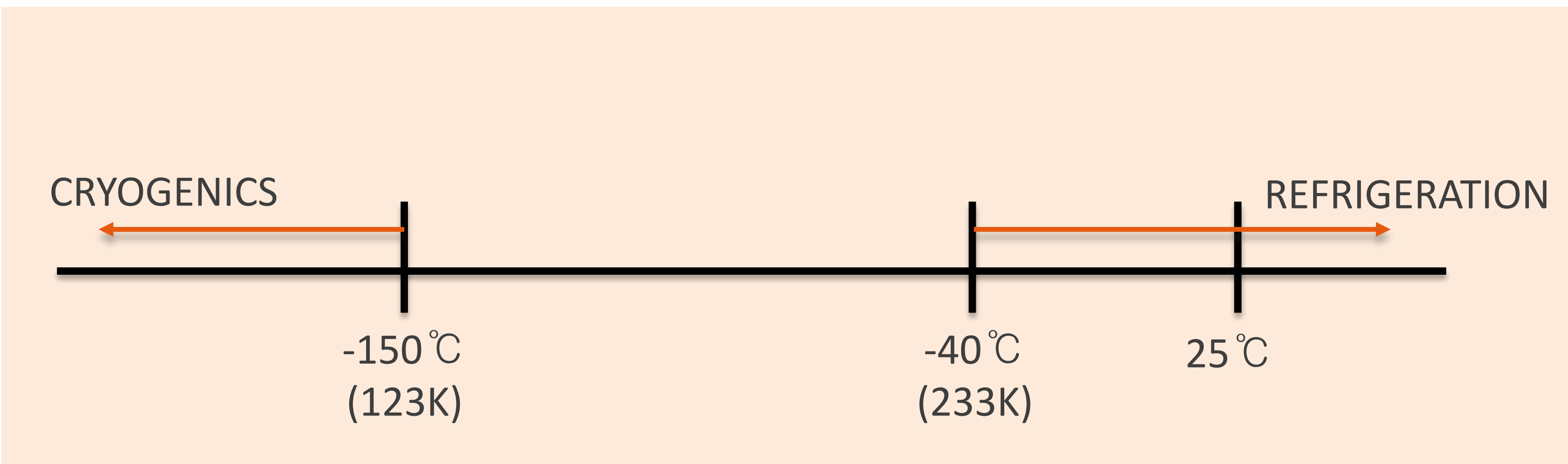


1.1 Introduction

CRYOGENIC=CRYO+GENE

CRYO → Ice

GENE → Generation



1.2 Historical background

- **Time of I. Newton**

I. Newton
1642 - 1727

- F. Bacon (1561 – 1621)

The third of the seven modes […] relates to […] **heat and cold**. And herein man's power is clearly **lame on one side**. For we have the heat of fire which is infinitely more potent and intense than the heat of the sun as it reaches us, or the warmth of animals.

But we have no cold save such as is to be got in wintertime, or in caverns, or by application of snow and ice, […]
And so too all natural condensations caused by cold should be investigated, in order that, their causes being known, **they may be imitated by art**.

1.2 Historical background

- **Time of I. Newton**

✓ Known refrigeration methods

- Refrigeration by a colder object(ex. Ice or snow)

- Refrigeration by evaporation

- Refrigeration by dissolving saltpeter in water
  (saltpeter = sodium nitrate $NaNo_3$ or potassium nitrate KNO_3)

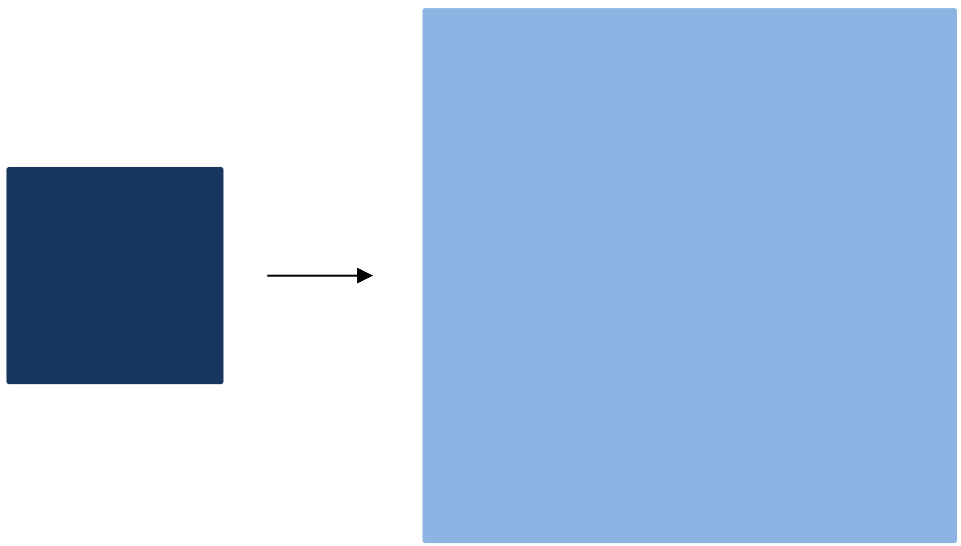
I. Newton
1642 - 1727

1.2 Historical background

- **Time of I. Newton**

I. Newton
1642 - 1727

- R. Boyle (1627 – 1691); E. Mariotte (1620 – 1684)

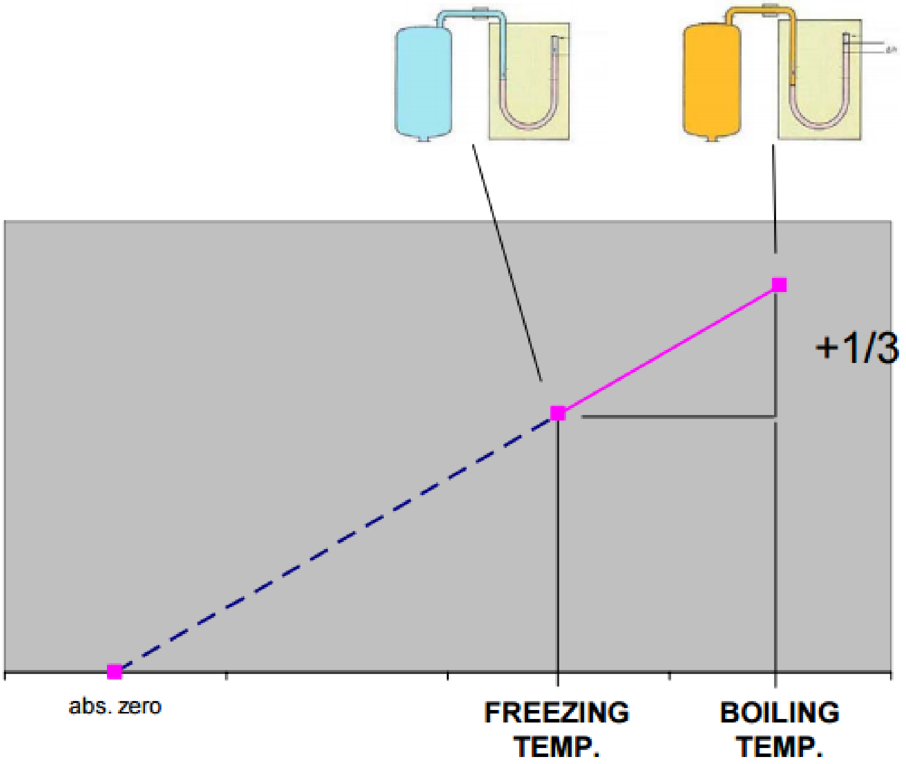


PV= constant

1.2 Historical background

- **Time of I. Newton**

  - G. Amontons (1663 – 1705)



I. Newton
1642 - 1727

1.2 Historical background

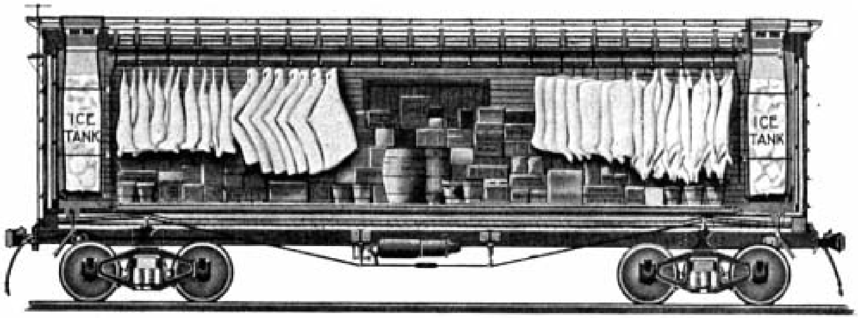
- **Further development of thermodynamics**

• J. Black (1728 – 1799)	latent heat
• A. Lavoisier (1743 – 1794)	caloric theory
• S. Carnot (1824)	work
• R. Clausius (1865)	entropy
• W. Gibbs (1867); R. Mollier (1923)	enthalpy

1.2 Historical background

- **Incentives for refrigeration and cryogenics**

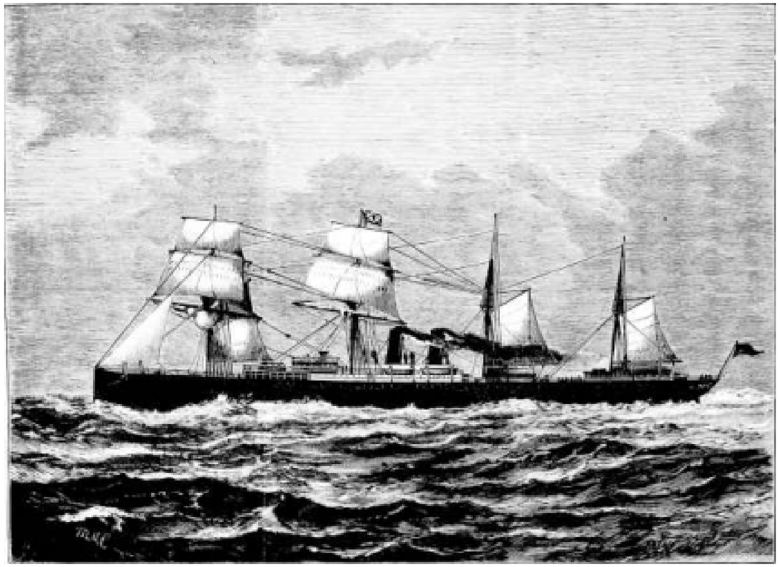
  - Early 19th century
  - Large scale refrigeration was only done by natural ice
  - Increasing demand for artificial refrigeration by
    - The butchers
    - The brewers and later on
    - The industrialists



1.2 Historical background

- **Incentives for refrigeration and cryogenics**

  - Examples of first commercial refrigeration applications

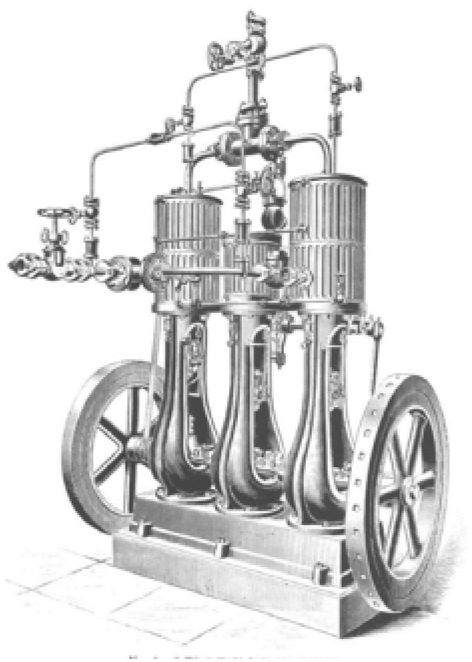


- S.S. Strathleven
  equipped with Bell&Coleman air-cycle refrigerator. First meat cargo transported from Australia to London 1879. 6. 12. – 1880. 2. 2

1.2 Historical background

- **Incentives for refrigeration and cryogenics**

  - Examples of first commercial refrigeration applications



- Standard ammonia cycle ice machine from York's 1892 catalogue

1.2 Historical background

- **Braking the cryo-barrier**

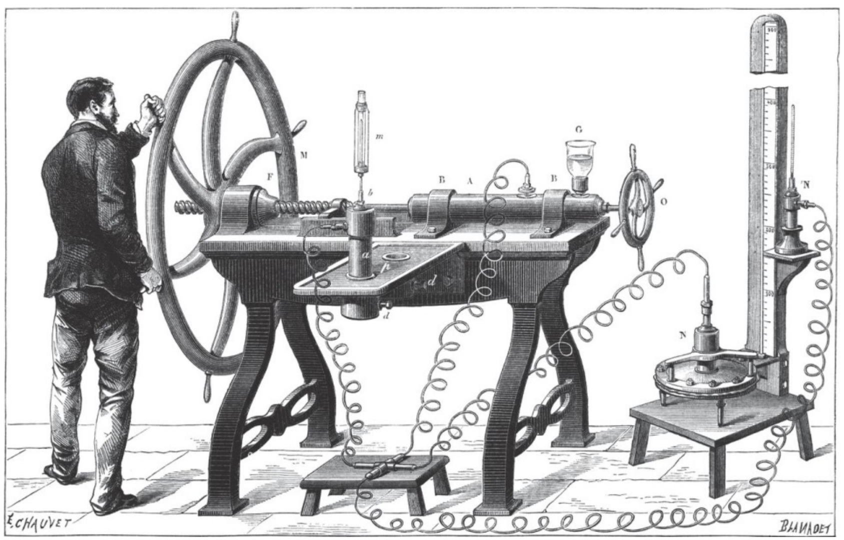
- The successful liquefaction of Oxygen was announced at the meeting of the Académie de Sciences in Paris on December 24th, 1877 independently by the physicist Louis Paul Cailletet from Paris and the professor Raoul Pictet from Geneva.

1.2 Historical background

- **Braking the cryo-barrier**

L.P. Cailletet
1832 - 1913

  - Cailletet's apparatus

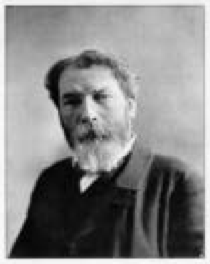


1.2 Historical background

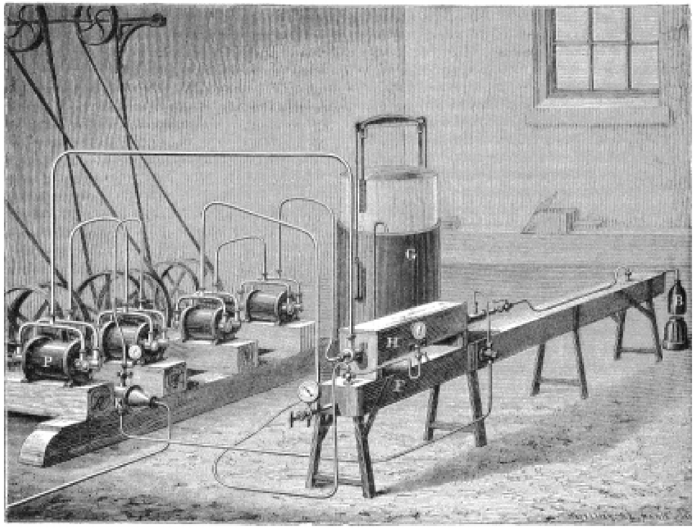
- **Braking the cryo-barrier**

  - Pictet't apparatus

    - Production of Oxygen under pressure in a retort
    - Two pre-cooling refrigeration cycle :
      first stage SO_2 (-10℃)
      second stage CO_2 (-78 ℃)
    - Oxygen flow is pre-cooled by the means of heat exchangers and expands to atmosphere via a hand valve



R. Pictet
1832 - 1913



1.2 Historical background

Milestones in the history of cryogenic technology

- 1892 Dewar – use of silvering and vacuum in double walled glass vessel
- 1895 Linde and Hampson build air liquefiers with recuperative heat exchangers
- 1898 Dewar – liquefies hydrogen
- 1902 Claude – use of piston expander
- 1908 Kamerlingh Onnes – liquefies helium
- 1908 Becquerel – freezes seeds and single cells
- 1910 Use of LOx in the production of steel
- 1911 Discovery of superconductivity

1.2 Historical background

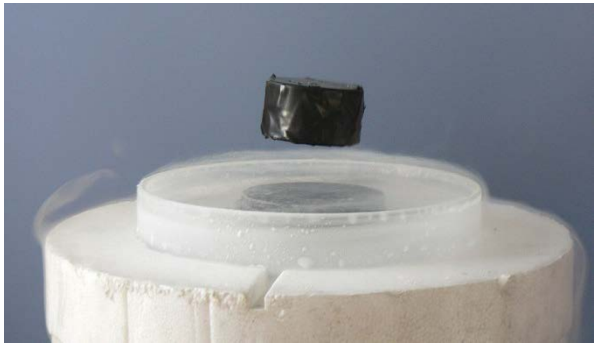
▪ Chronology of cryogenic technology

Table 1.1. Chronology of cryogenic technology

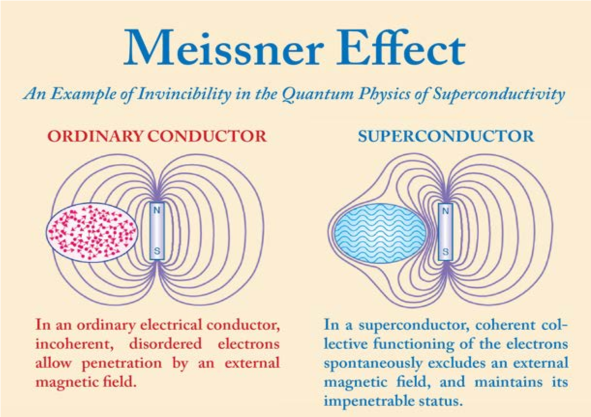
Year	Event
1877	Cailletet and Pictet liquefied oxygen (Pictet 1892).
1879	Linde founded the Linde Eismaschinen AG.
1883	Wroblewski and Olszewski completely liquefied nitrogen and oxygen at the Cracow University Laboratory (Olszewski 1895).
1884	Wroblewski produced a mist of liquid hydrogen.
1892	Dewar developed a vacuum-insulated vessel for cryogenic-fluid storage (Dewar 1927).
1895	Onnes established the Leiden Laboratory. Linde was granted a basic patent on air liquefaction in Germany.
1898	Dewar produced liquid hydrogen in bulk at the Royal Institute of London.
1902	Claude established l'Air Liquide and developed an air-liquefaction system using an expansion engine.
1907	Linde installed the first air-liquefaction plant in America. Claude produced neon as a by-product of an air plant.
1908	Onnes liquefied helium (Onnes 1908).
1910	Linde developed the double-column air-separation system.
1911	Onnes discovered superconductivity (Onnes 1913).
1912	First American-made air-liquefaction plant completed.
1916	First commercial production of argon in the United States.
1917	First natural-gas liquefaction plant to produce helium.
1922	First commercial production of neon in the United States.
1926	Goddard test-fired the first cryogenically propelled rocket. Cooling by adiabatic demagnetization independently suggested by Giauque and Debye.
1933	Magnetic cooling used to attain temperatures below 1 K.
1934	Kapitza designed and built the first expansion engine for helium.
1937	Evacuated-powder insulation first used on a commercial scale in cryogenic-fluid storage vessels.
1939	First vacuum-insulated railway tank car built for transport of liquid oxygen.
1942	The V-2 weapon system was test-fired (Dornberger 1954).
1947	The Collins cryostat developed.
1948	First 140 ton/day oxygen system built in America.
1949	First 300 ton/day on-site oxygen plant for chemical industry completed.
1952	National Bureau of Standards Cryogenic Engineering Laboratory established (Brickwedde 1960).
1957	LOX-RP-1 propelled Atlas ICBM test-fired. Fundamental theory (BCS theory) of superconductivity presented.
1958	High-efficiency multilayer cryogenic insulation developed (Black 1960).
1959	Large NASA liquid-hydrogen plant at Torrance, California, completed.
1960	Large-scale liquid-hydrogen plant completed at West Palm Beach, Florida.
1961	Saturn launch vehicle test-fired.
1963	60 ton/day liquid-hydrogen plant completed by Linde Co. at
1964	Two liquid-methane tanker ships designed by Conch Methane Services, Ltd., entered service.
1966	Dilution refrigerator using He^3-He^4 mixtures developed (Hall 1966; Neganov 1966).
1969	3250-hp dc superconducting motor constructed (Appleton 1971).
1970	Liquid oxygen plants with capacities between 60,000 m^3/h and 70,000 m^3/h developed.
1975	Record high superconducting transition temperature (23 K) achieved.

1.3 Present areas involving cryogenic engineering

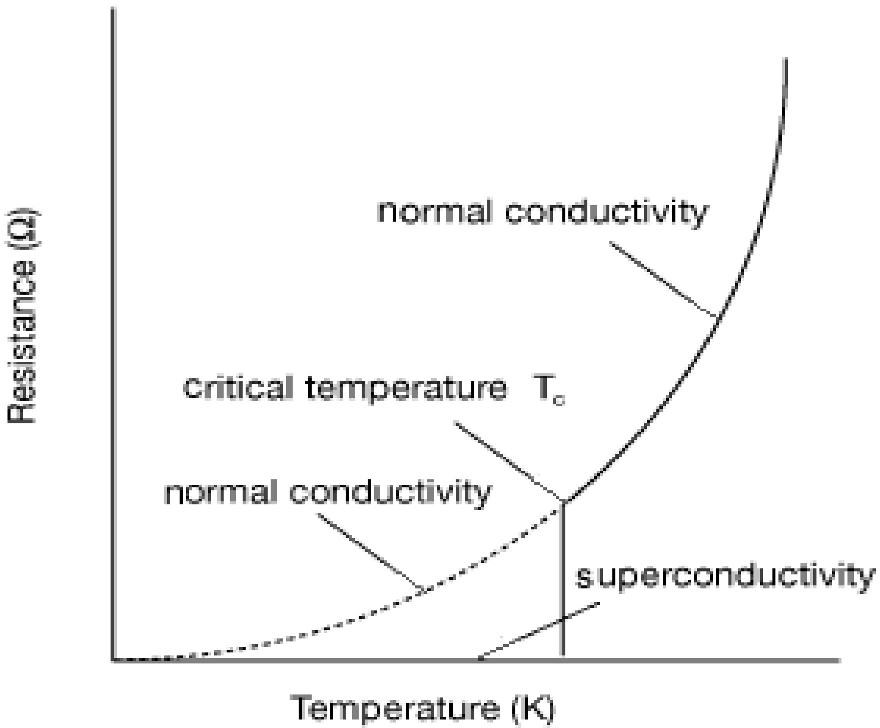
- **Superconductivity**



Superconductivit>



Meissner Effect



Critical temperature of a superconductor

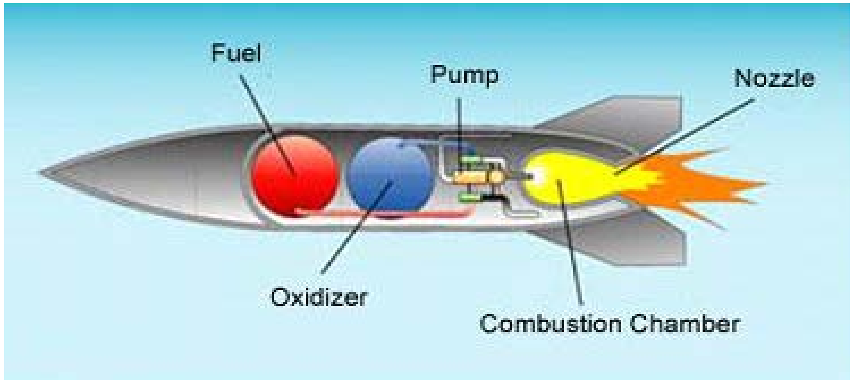
1.3 Present areas involving cryogenic engineering

- Magnet levitation Train

1.3 Present areas involving cryogenic engineering

- **Rocket propulsion**

<Rocket propulsion>



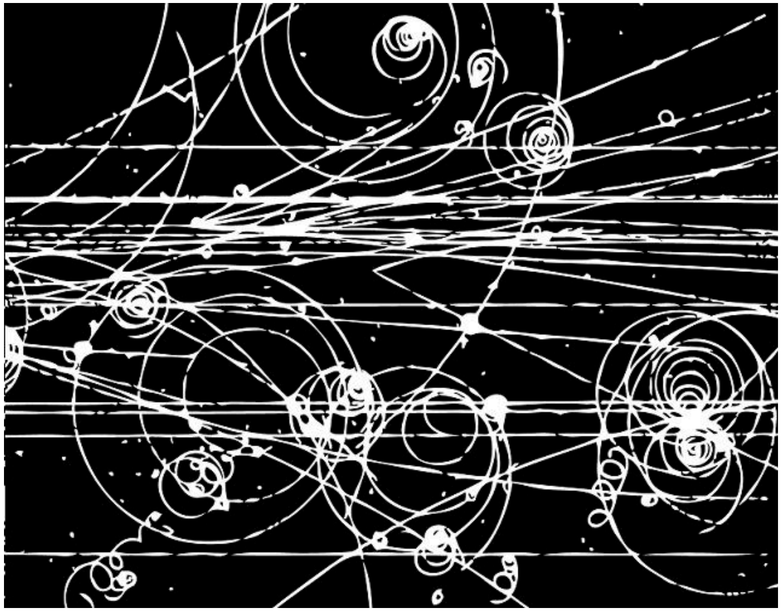
<Diagram of a liquid fuel rocket>

<Carbon composite cryogenic fuel tank>

1.3 Present areas involving cryogenic engineering

- **Studies in high-energy physics**

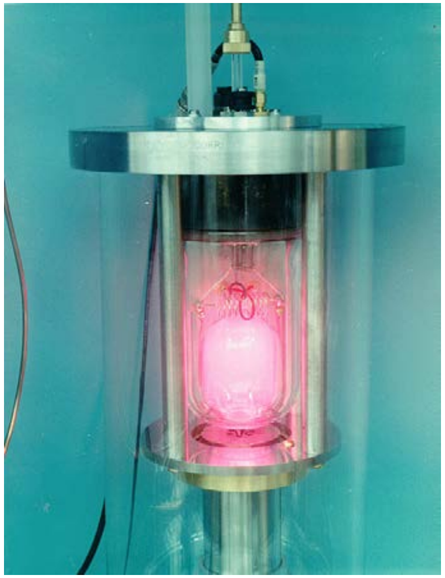
  - The hydrogen bubble chamber uses liquid hydrogen in large particle accelerators.
  - The hydrogen bubble chamber is used to detect high-energy particle



1.3 Present areas involving cryogenic engineering

- **Electronics**

  - Electronic device likes masers(sensitive microwave amplifiers), SQUIDs(superconducting quantum interference devices) are cooled to liquid nitrogen or liquid helium so that thermal vibrations of the atoms do not interfere devices operation.

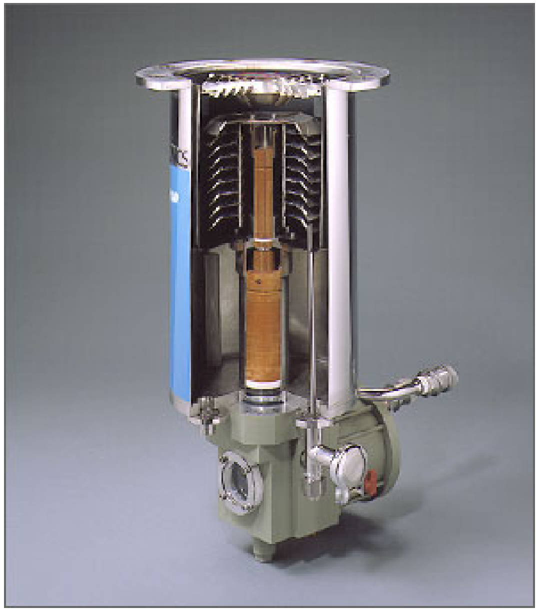


Maser

1.3 Present areas involving cryogenic engineering

- **Space simulation and high-vacuum technology**

  - To produce a vacuum, one of the more effective methods involves low temperature : **Cryopumping**
  - Cryopump traps gases and vapours by condensing them on a cold surface.



1.3 Present areas involving cryogenic engineering

- **Biological and medical application**

  - To preserve biological material, the use of cryogenics, **cryobiology** has aroused much interest.
  - Cryogenic surgery has been used for many disease.