CRYOGENIC ENGINEERING

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Course Objectives

1	To provide the knowledge of evolution of low temperature science
2	To provide knowledge on the properties of materials at low temperature
3	To familiarize with various gas liquefaction and refrigeration systems and to provide design aspects of cryogenic storage and transfer lines

MODULE	SYLLABUS	HOURS
I	**Introduction to Cryogenic Systems:** Historical development, Applications of Cryogenics (Space, Food Processing, Super conductivity, Electrical Power, Biology, Medicine, Electronics and Cutting Tool Industry). **Low Temperature Properties:** Properties of Engineering Materials (Mechanical properties, Thermal properties, Electric and Magnetic properties), Properties of Cryogenic fluids.	8
II	**Introduction to Liquefaction Systems:** Ideal system, Joule Thomson expansion, Adiabatic expansion, Linde Hampson Cycle, Claude & Cascaded System. **Introduction to Cryogenic Refrigeration Systems:** Magnetic Cooling, Stirling Cycle Cryo Coolers.	7
III	**Gas Liquefaction Systems:** General liquefaction systems. Liquefaction systems for Neon, Hydrogen and Helium. Critical components of liquefaction systems.	6
IV	**Cryogenic Refrigeration Systems:** Ideal refrigeration systems, Refrigeration using liquids and gases as refrigerant, Refrigerators using solids as working media.	6
V	**Cryogenic Fluid Storage and Transfer Systems:** Cryogenic storage vessels and transportation. Thermal insulation and their performance at cryogenic temperatures, Super insulations, Vacuum insulation, Powder insulation. Cryogenic fluid transfer systems.	8
VI	**Cryogenic Instrumentation:** Pressure, flow-rate, liquid-level and temperature measurements. **Types of Heat Exchangers** used in cryogenic systems (only description with figure). **Cryo Pumping** Applications.	7

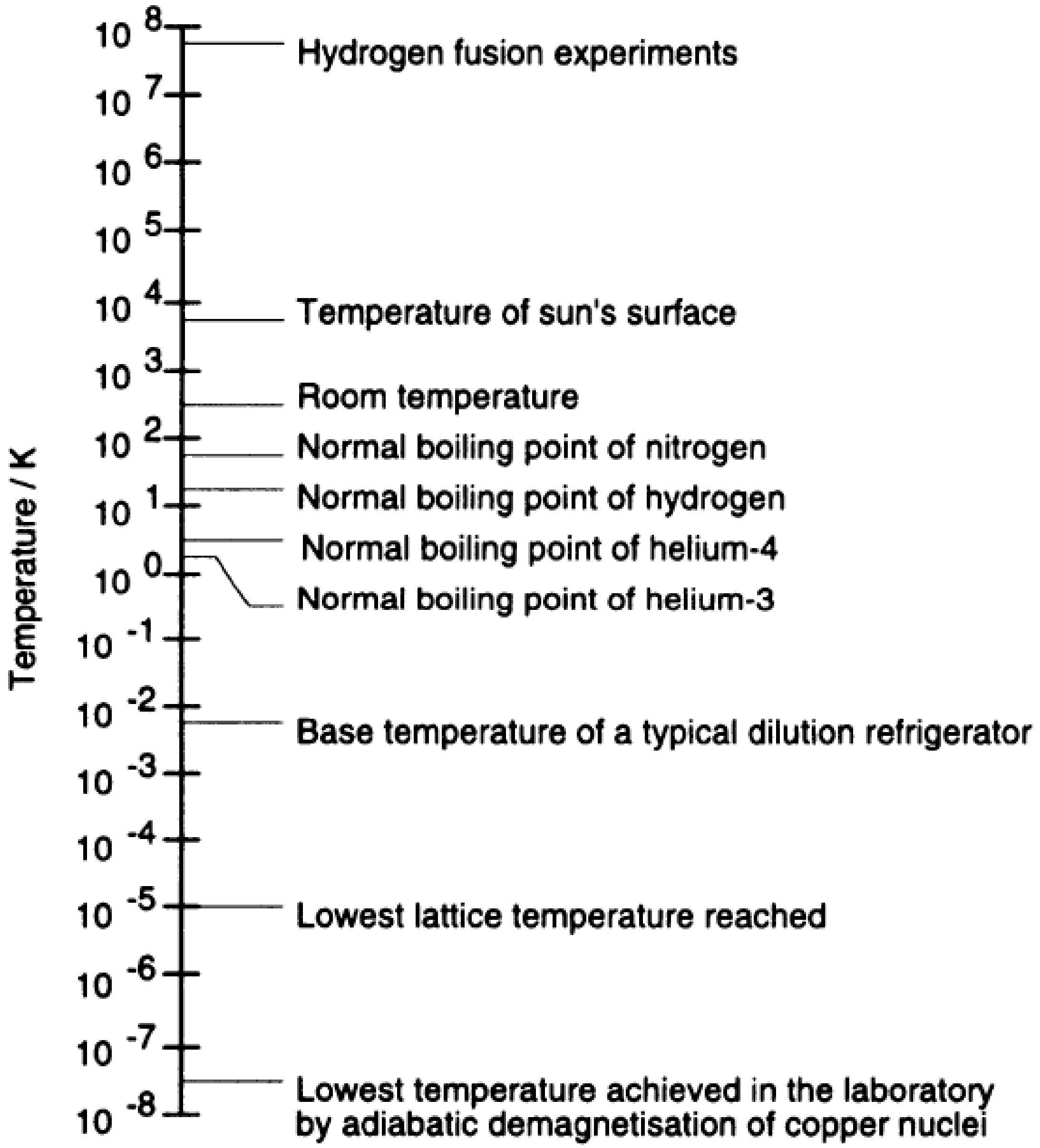
T/R	*BOOK TITLE/AUTHOR/PUBLICATION*
T1	J. H. Boll Jr, Cryogenic Engineering
T2	R. B. Scott, Cryogenic Engineering, Van Nostrand Co., 1959
T3	Randal F.Barron, Cryogenic systems, McGraw Hill, 1986
R1	Klaus D.Timmerhaus and Thomas M.Flynn, Cryogenic Process Engineering, Plenum Press, New York, 1989.

Course Outcomes	
CME467.1	To gain ***knowledge*** and to ***understand*** the scope and history of cryogenics. To ***understand*** the properties of materials at low temperature ***applying*** fundamental ***knowledge***.
CME467.2	To ***apply*** the ***knowledge*** of low temperature production methods to ***understand*** and ***analyse*** different liquefaction systems. To gain ***knowledge*** about the critical components involved in liquefaction.
CME467.3	To ***apply*** the ***knowledge*** of ideal refrigeration techniques, to ***understand*** and ***analyse*** common cryogenic refrigeration systems. To ***understand*** some of the novel cryogenic refrigeration methods.
CME467.4	To gain ***knowledge*** and to ***understand*** various cryogenic fluid storage and transport systems and to ***evaluate*** their performance ***applying*** fundamental concepts
CME467.5	To gain ***knowledge*** about different cryogenic instrumentation and to ***understand*** cryo pumping.

Introduction

- Out of all properties Temperature affects processes and material properties the most.
- The ability to harness Temperature advanced our civilization.
- High T → forging, pottery, steam engine…
- Low T → A/c, treatment, food preservation…

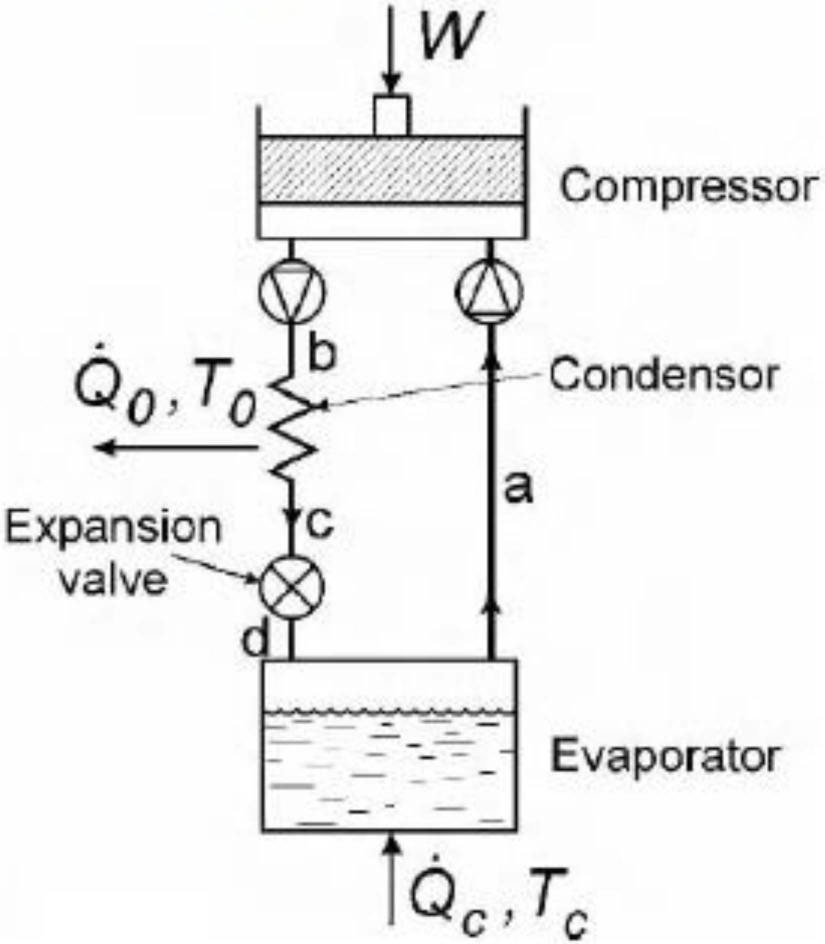
Range of temperatures achievable in the Laboratory



Until 1850

- In ancient times natural ice and evaporative cooling was mostly used.
- Later, precooled constant T compression followed by rapid expansion to atmospheric pressure was used to produce low Ts.
- 1823, Faraday used this method to liquify Cl (NBP – 239 K)
- Several other gases where similarly liquified subsequently, up to Ethylene (NBP – 169 K, the lowest yieldable T by this method)
- The gases which were known to be non-liquefiable even with a pressure of 40 MPa were called permanent gases. (CH_4, CO, O, N_2, H_2)
- In 1834, Perkins showed how to carry out this process continuously, beginning todays vapor compression refrigeration system.
- John Hague built one for caoutchoucine

VAPOR-COMPRESSION CYCLE
(Steady Flow)



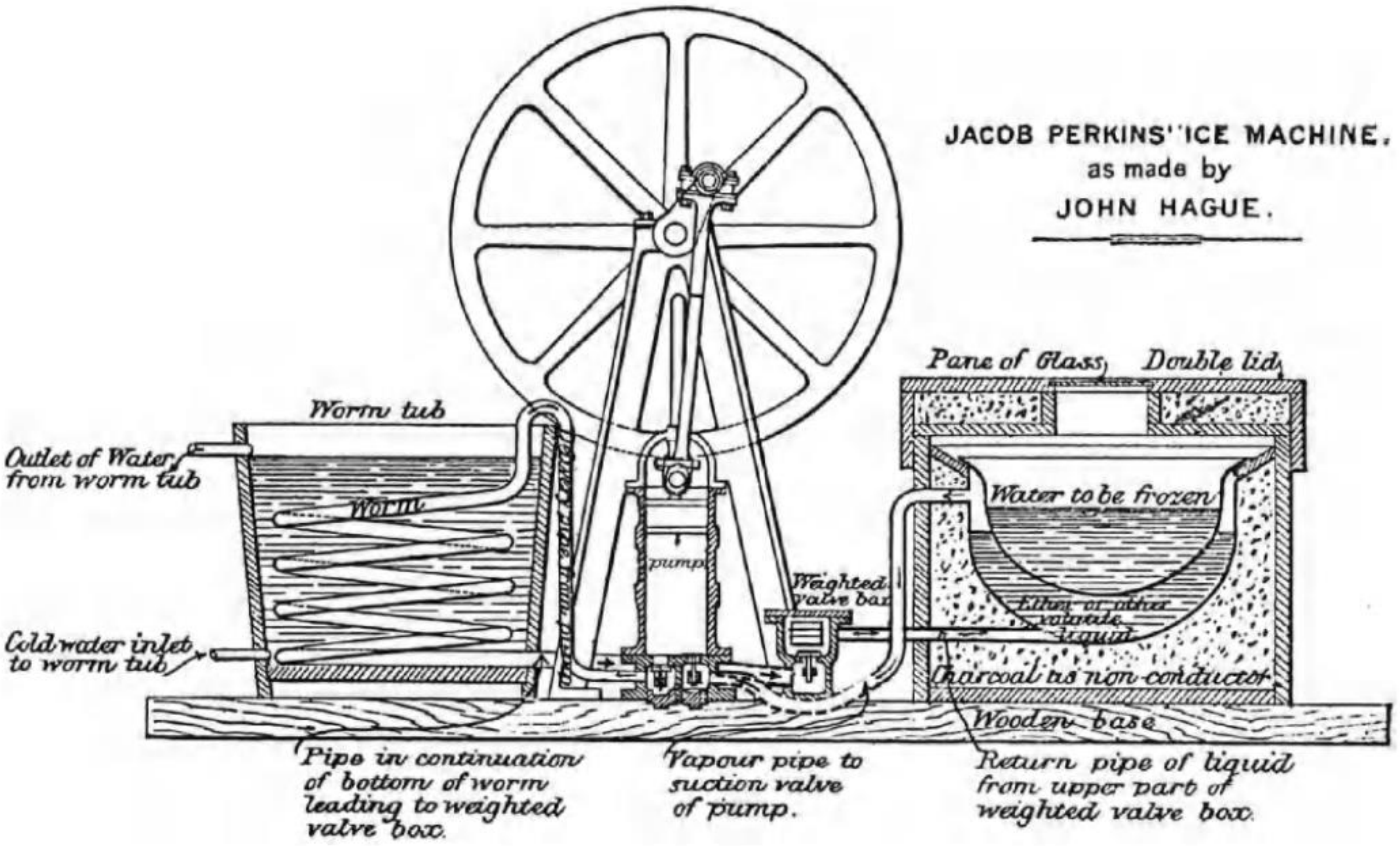
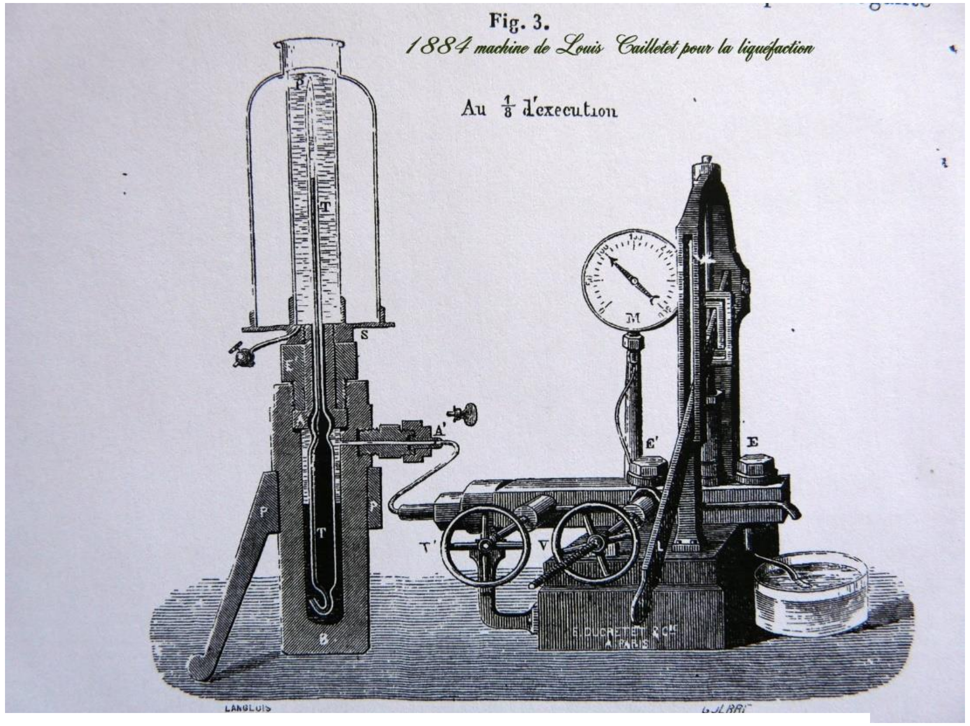
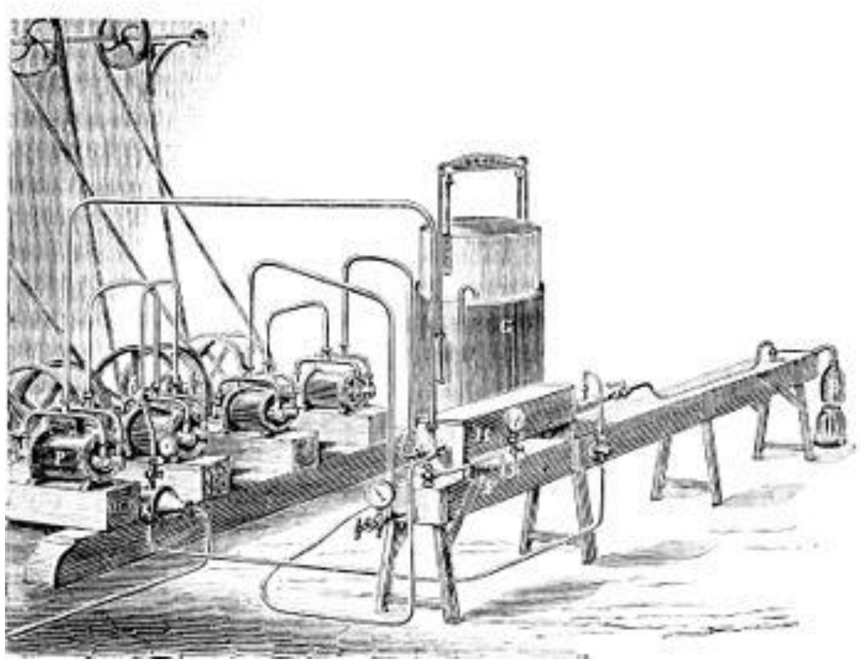


FIGURE 1.2. Perkin ice machine built by Hague.

1850-1900

- The ability to attain lower and lower temperatures were strengthened by,
  - Advancements in Thermodynamic principles.
  - Development of high pressure compressors.
- 1877, the cryogenic barrier was first broken.
  - **Louis Paul Cailletet**, a French mining engineer produced a fog of Liquid Oxygen droplets by earlier methods and using a cascade of precooling baths.
  - **Raul Pictet**, a Swiss Physicist, on the same day produced continuous mist of Liquid Oxygen by a cascaded vapour compression system.



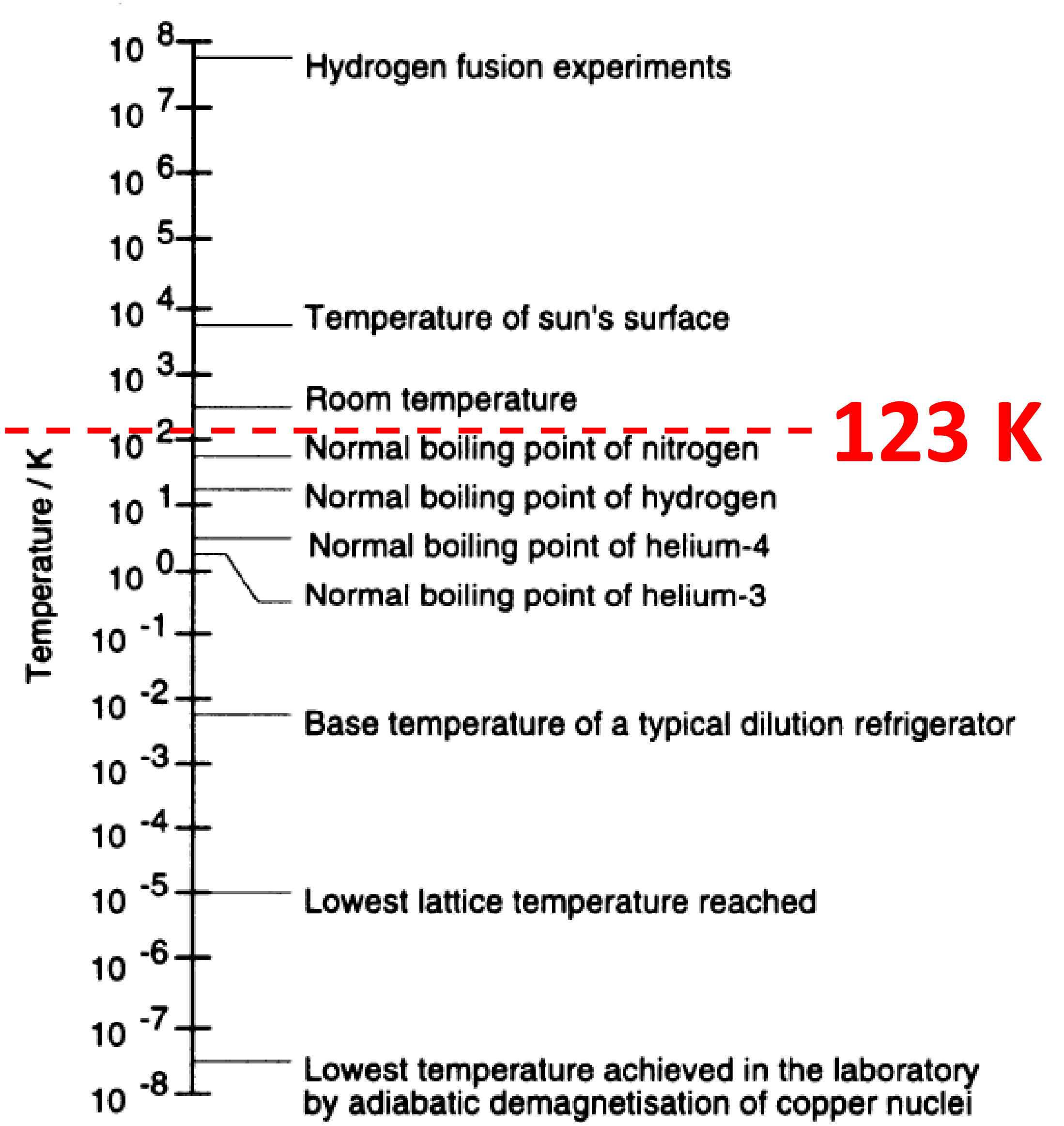


- Kamerlingh Onnes first coined the adjective 'CRYOGENIC' in 1894 in a paper titled " on cryogenic laboratory at Leiden and the production of very low temperatures".

- **Cryos** → icy cold
- **Genes** → generated from

(Greek)

- Below 123 K (as defined by National Bureau of Standards, US)
- Below which the so-called permanent gases are liquified



Cryogenic Engineering

Development and improving of low temperature techniques/ Processes/ Equipment.

Cryogenic System

An interacting group of components involving low temperature. Ex: Air Liquefaction Plant, He Refrigerator, Storage vessels etc.

1877 Cilletet & Pictet → LO2

1879 Linde → Linde Eismaschinen AG, Germany (1st Low temp phys lab)

1883 Wroblewski & Olszewski → good quantity of LO2, LN2
@ Cracow University Laboratory, Poland

1884 Wroblewski & Olszewski → A mist of LH2. Vapor shielding

1892 Dewar → vacuum-insulated vessel for cryogenic liquid storage

1895 Onnes → the Physical Laboratory, University of Leiden, Holland
Linde → patent for air liquefaction in Germany

1898 Dewar → LH2 in bulk

1902 Claude → l'Air Liquide. Air Liquefaction s/m using expansion engine

1908 Onnes → LHe

1910 Onnes → failed attempt to solidify He (1.04K)
Linde → Double column air separation system

1911 Onnes → Superconductivity (Nobel 1913)

1926 **Goddard → test fired first cryogenically propelled rocket**

Giauque & Debye →proposed Adiabatic demagnetization (<0.1 K)

1933 Giauque & MacDougall, Berkeley → 0.3 K (magnetic method)

Haas, kramers et. al., Leiden → 0.09K

1942 V-2 Weapons s/m test fired

1947 Collin’s Cryostat

‘56-’61 LH2 powered rocket engines, LO2 ICBMs, 1st space vehicle (LH2 + LO2)

1966 **Hall, Ford, Thomson @ Manchester → Dilution Refrigeration (<0.1 K)**

Neganov, Borisov, Liburg @ Moscow

1972 Fawley Superconducting Motor

1975 Record high superconducting transition temperature (>23 K)

1994 **Matsubara (Japan) → 4 K Pulse tube cryocooler**

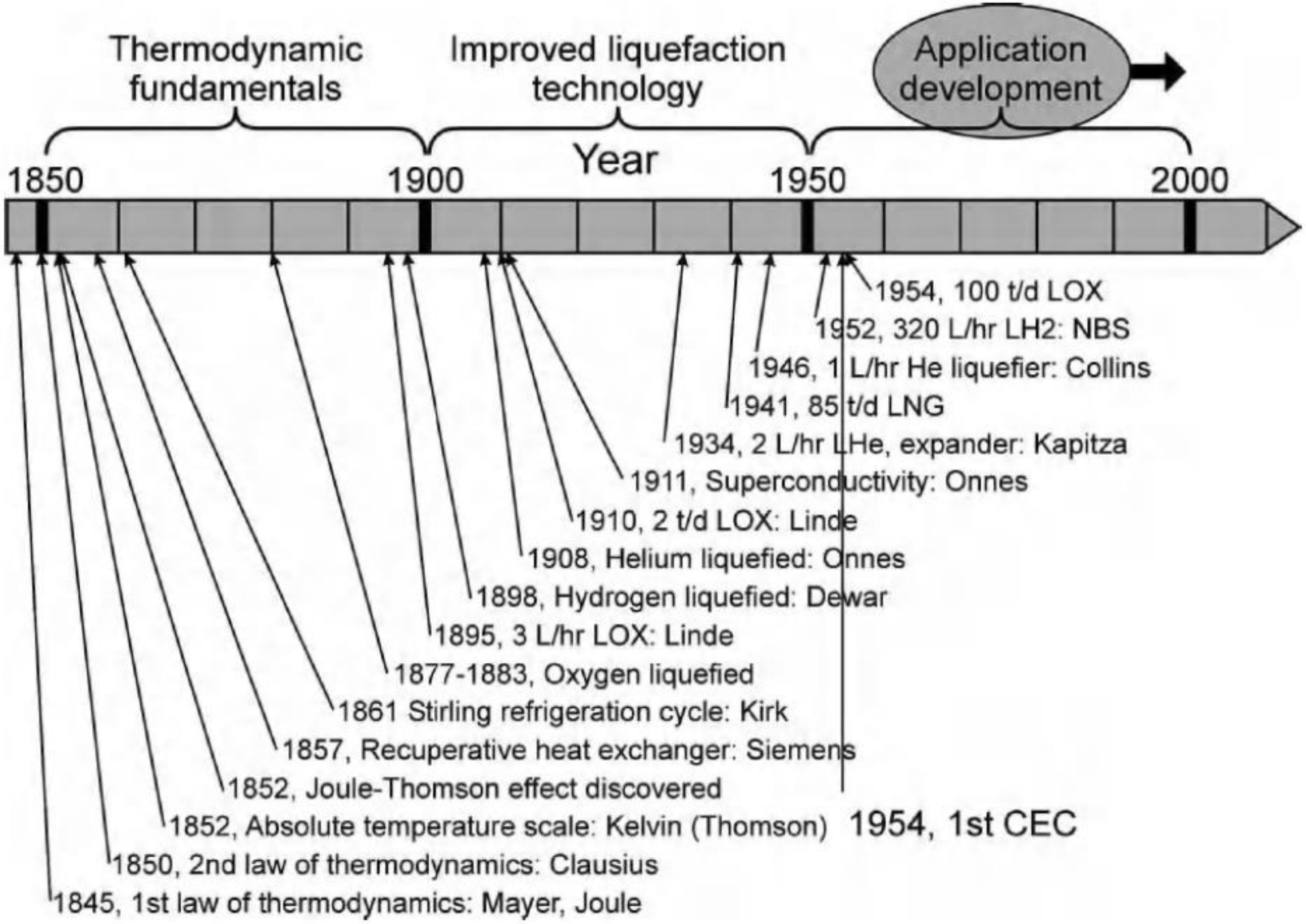


FIGURE 1.3. Cryogenic developments from 1850 to 1950.

Applications

Rocket Propulsion

- A cryogenic rocket engine is a rocket engine that uses a cryogenic fuel or oxidizer (or both).

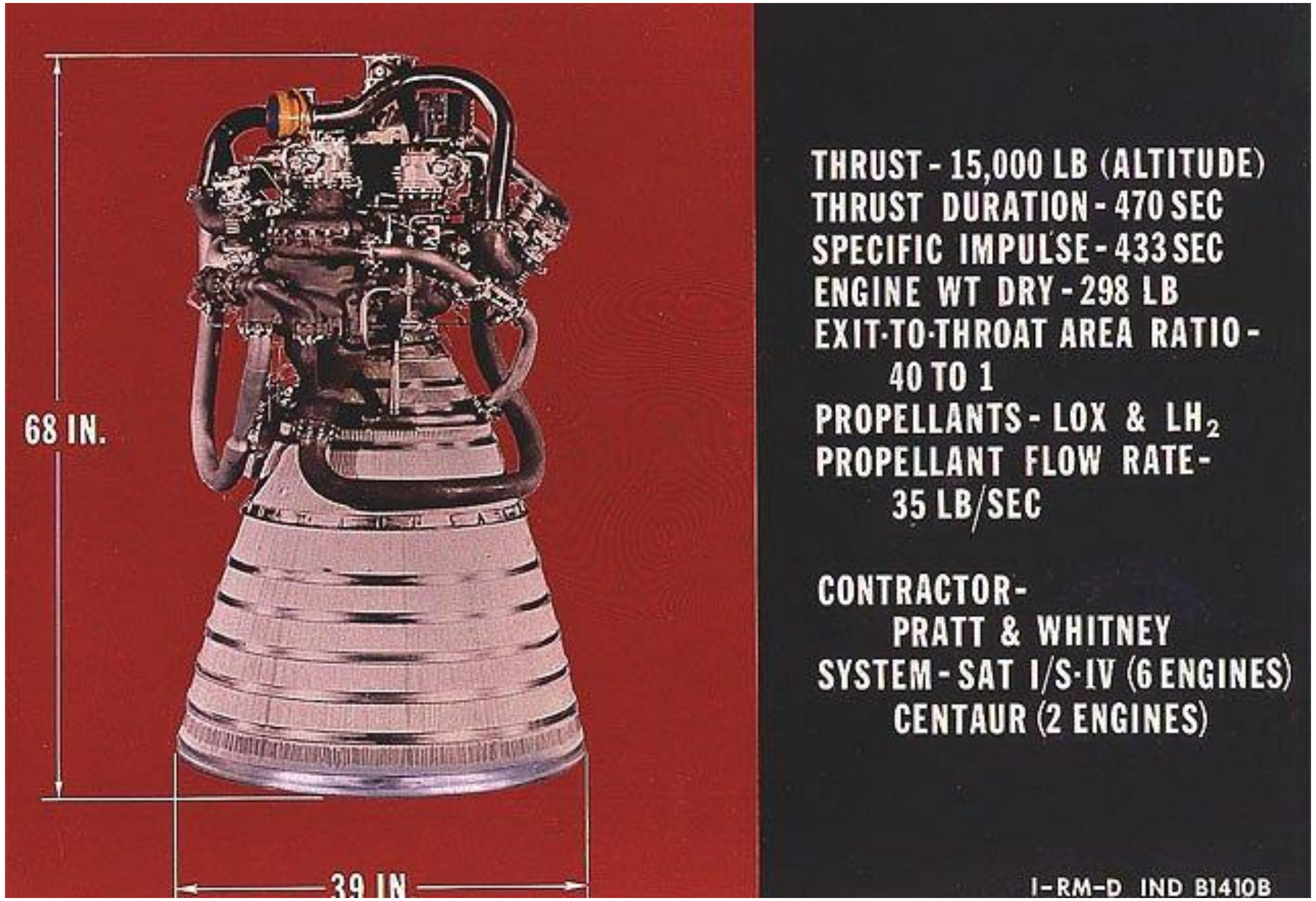
  i.e., they are liquefied and stored at

  very low temperatures.

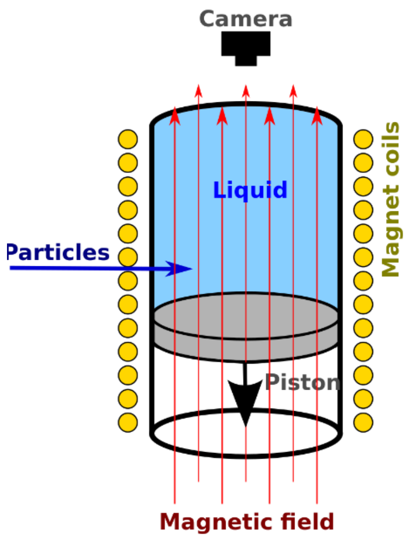
- Reduces the Size and Mass of the carrying tanks while keeping mass flow rate high.

  -as compared to compressed gas

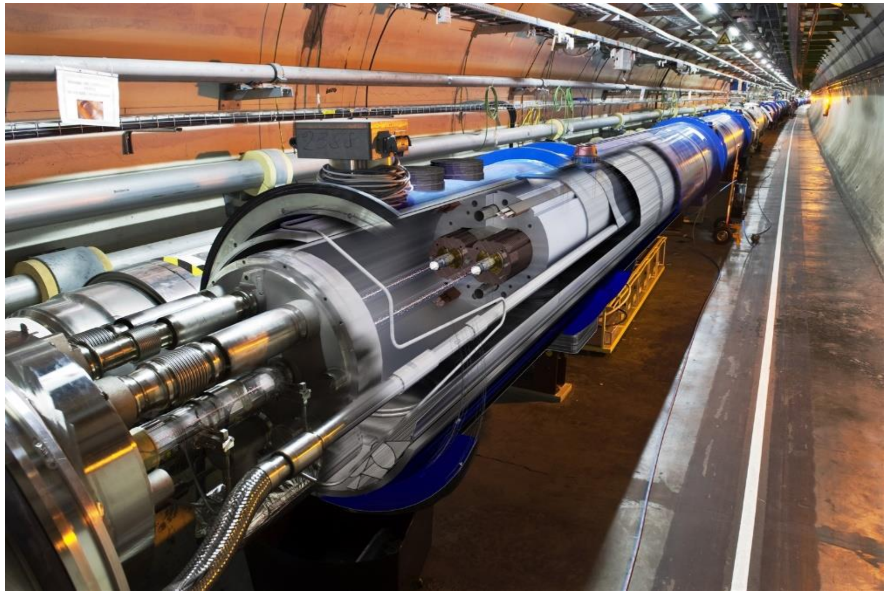
- The combination of liquid hydrogen (LH2) fuel and the liquid oxygen (LOX) oxidizer is one of the most widely used.



Studies in High Energy Physics

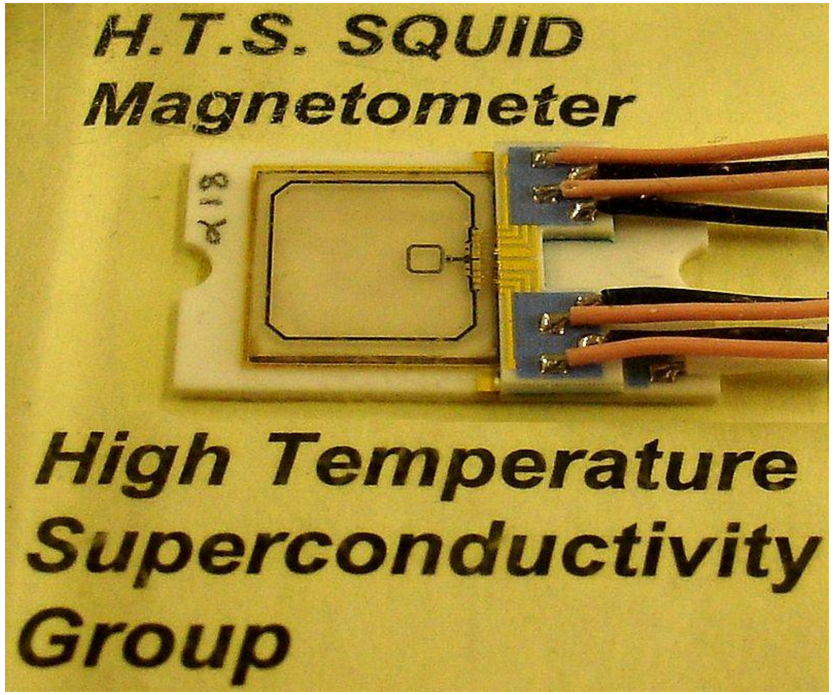


- Hydrogen bubble chamber uses LH2 in detection and study of high energy particles produced in large particle accelerators.
- Superconducting magnets are used in guiding particles in the same



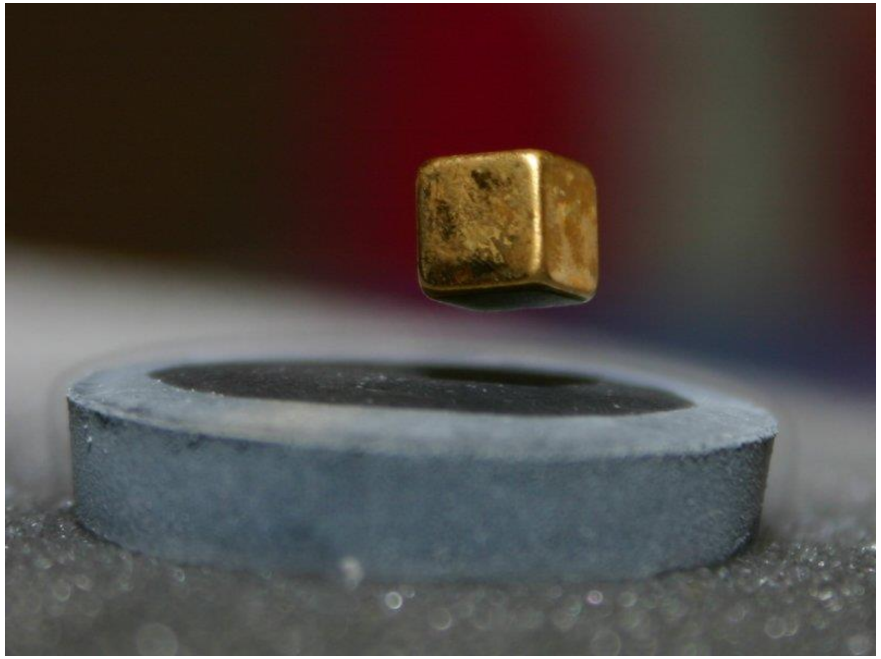
Electronics

- MASERs (microwave amplification by stimulated emission of radiation) – sensitive microwave/radio/infrared amplifiers cooled to cryogenic temperatures to reduce noise.
  - Missile detectors, radio astronomy, space communication systems
- SQUIDs (superconducting quantum interference devices) – used as extremely sensitive digital magnetometers and voltmeters.
  - Josephson effect



Mechanical Design

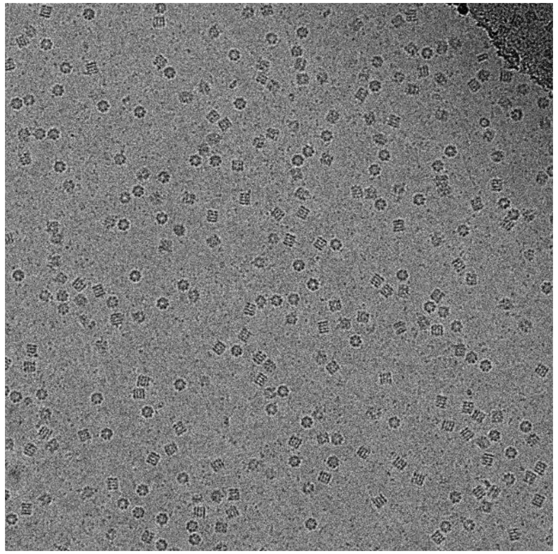
- Zero-friction bearings using magnetic field as lubricant.
  - Meisner effect
- Superconducting motors with zero electrical losses
  - Ship propulsion systems



Space Simulation & High Vacuum technology

- 10^{-12} to 10^{-14} torr. → Cryopumping
- Cold of free space is simulated by LN2

Biological/Medical Applications



- Cryobiology – Electron cryomicroscopy (CryoEM)
- Preservation – Blood, Tissue, Bone Marrow etc.
- Cryo surgery – Parkinson’s, Eye, lesions

Others

- Food processing/preservation
- Manufacturing – Heat treatment
- Recycling - Tyre