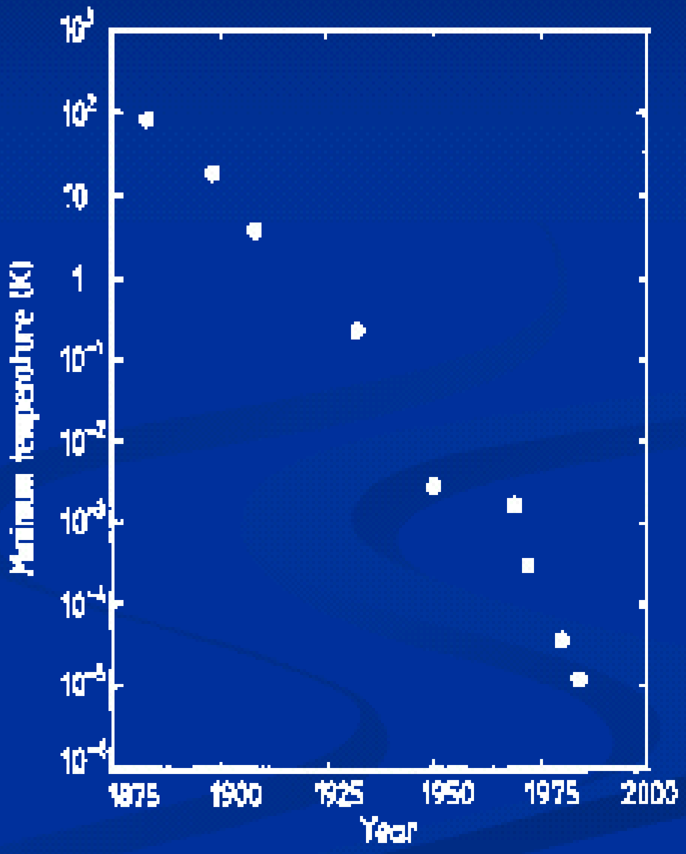
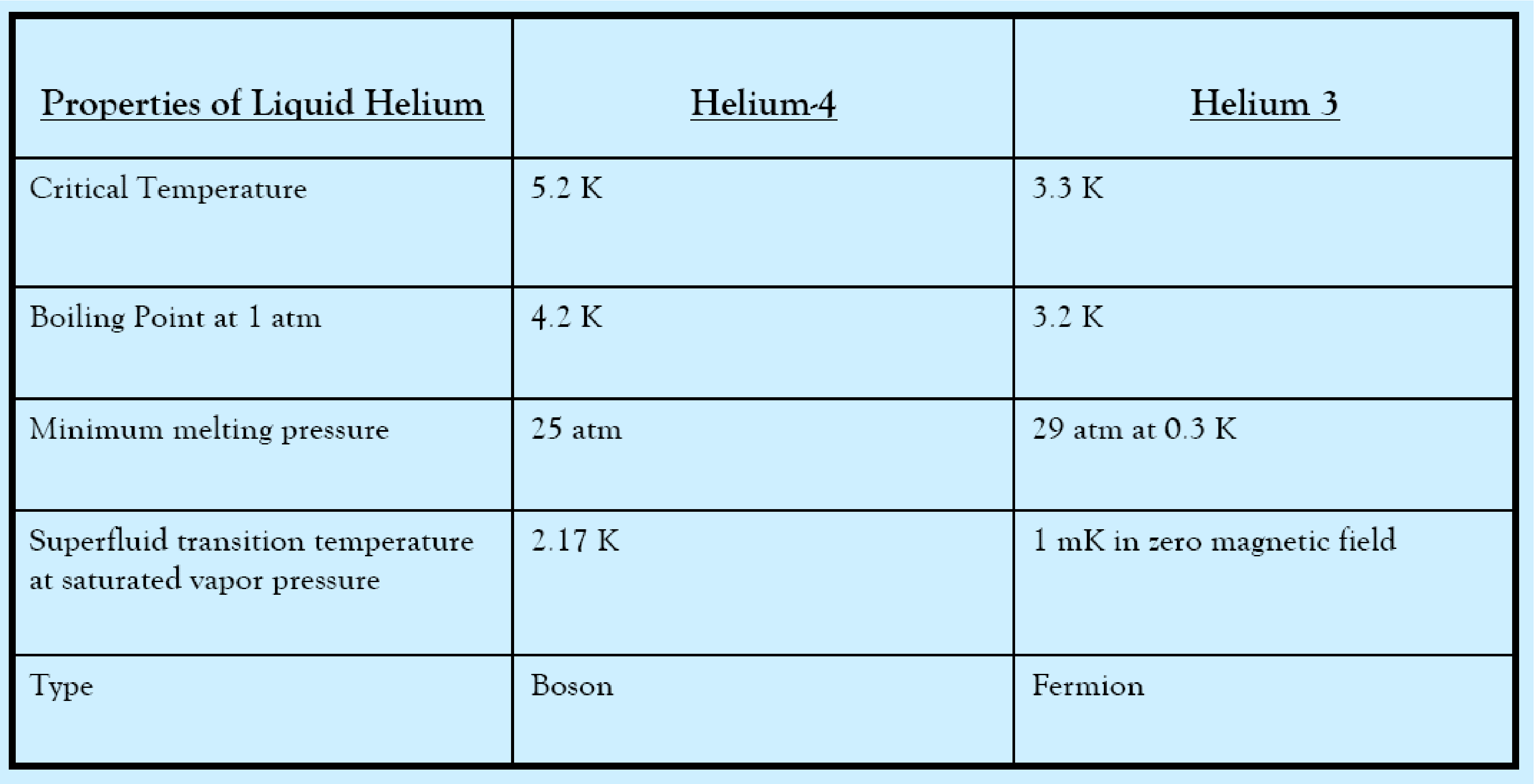
Historical Overview

1755	artificial ice by evaporating (Cullen)
19th cent.	Liquification of various gases
1848	Discovery of absolute zero (Thompson)
1877	„DRP1250 Kälteerzeugungsmaschine“ (Linde)
1908	Liquid Helium (Kammerling-Ones)

Range		Refrigaration Technique	Since	T_{typ}	T_{rec}
I	K	He-4 evaporation	1908	1.3K	0.7K
		He-3 evaporation	1950	0.3K	0.25K
II	mK	Dilution	1965	10mK	2mK
		Pomeranchuk	1965	3mK	2mK
		Electronic magnetic	1934	3mK	1mK
III	µK	Nuclear magnetic	1956	50µK	2µK

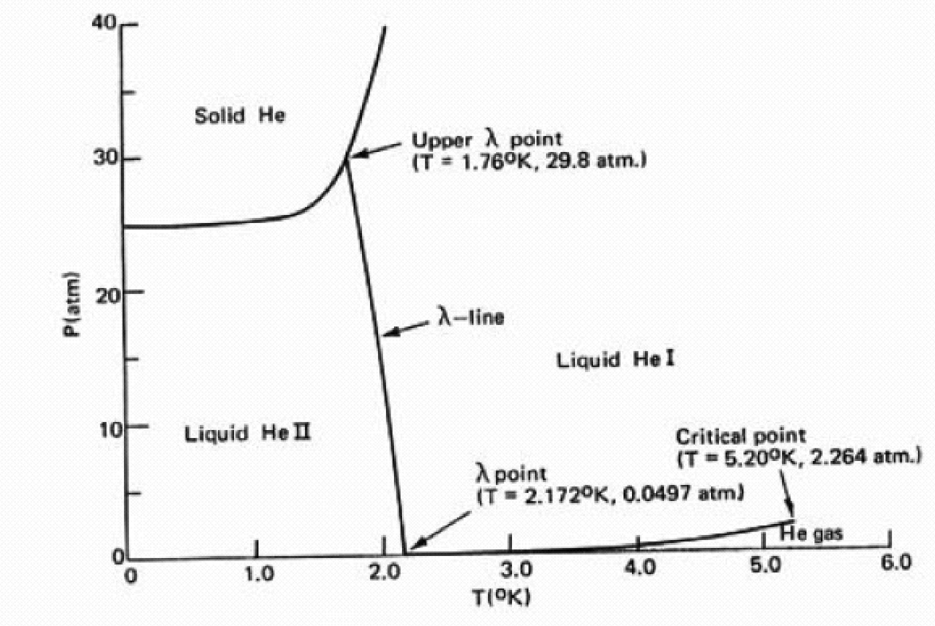


Relevant Low Temperature Techniques

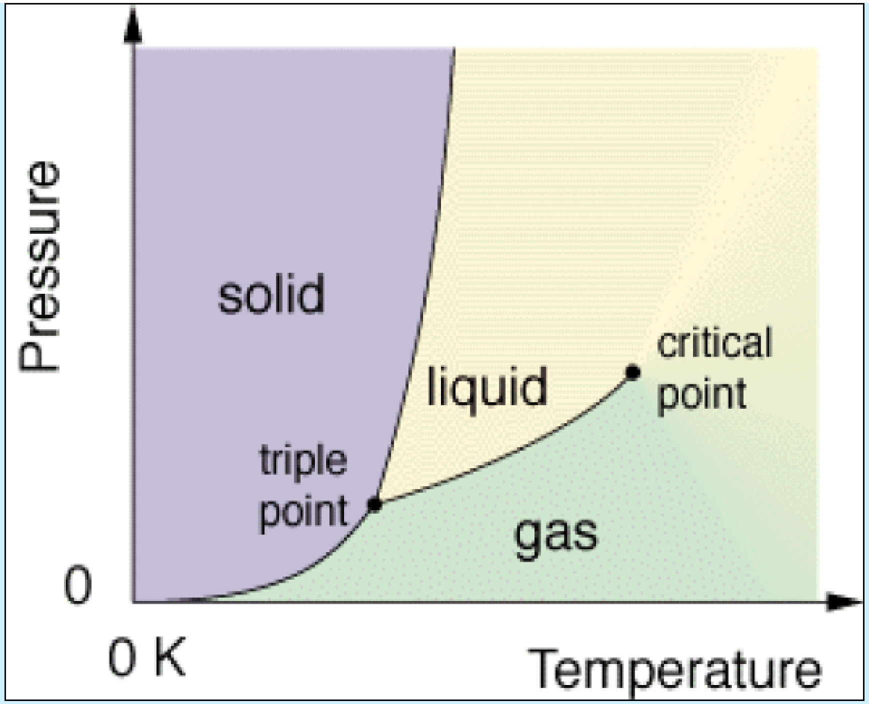


Properties of Liquid Helium	Helium-4	Helium 3
Critical Temperature	5.2 K	3.3 K
Boiling Point at 1 atm	4.2 K	3.2 K
Minimum melting pressure	25 atm	29 atm at 0.3 K
Superfluid transition temperature at saturated vapor pressure	2.17 K	1 mK in zero magnetic field
Type	Boson	Fermion

^{4}He Phase Diagram



The phase diagram of He^4.



The critical point

Tc = 5.20 K

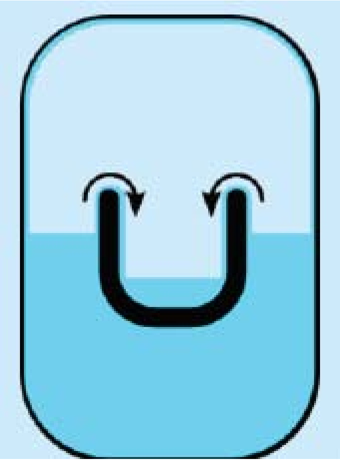
Pc = 2.264 atm

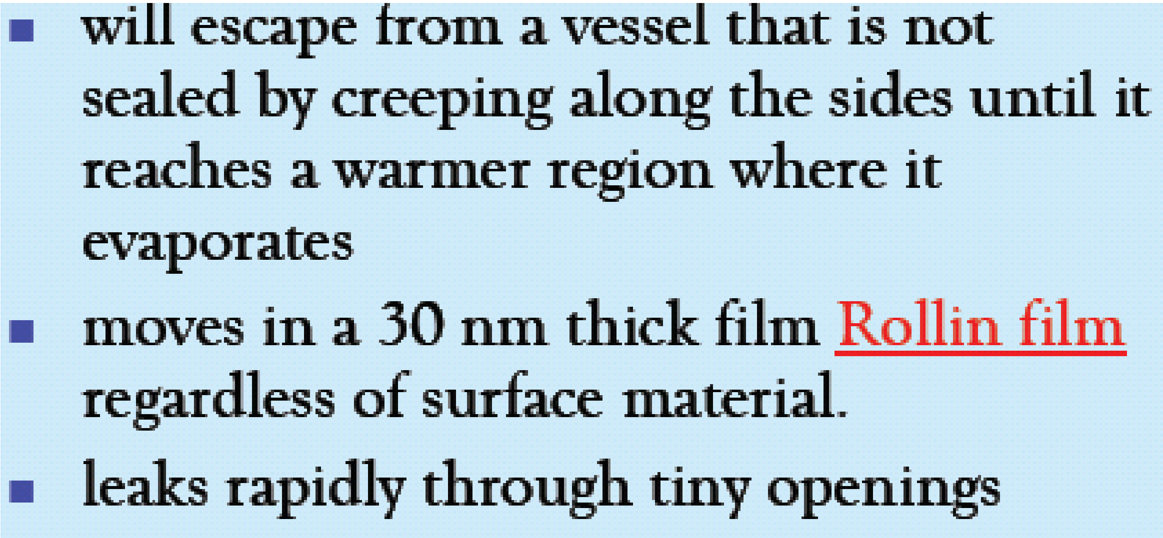
Typical phase diagram

He II: Superfluid

Bose-Einstein condensate

frictionless fluid

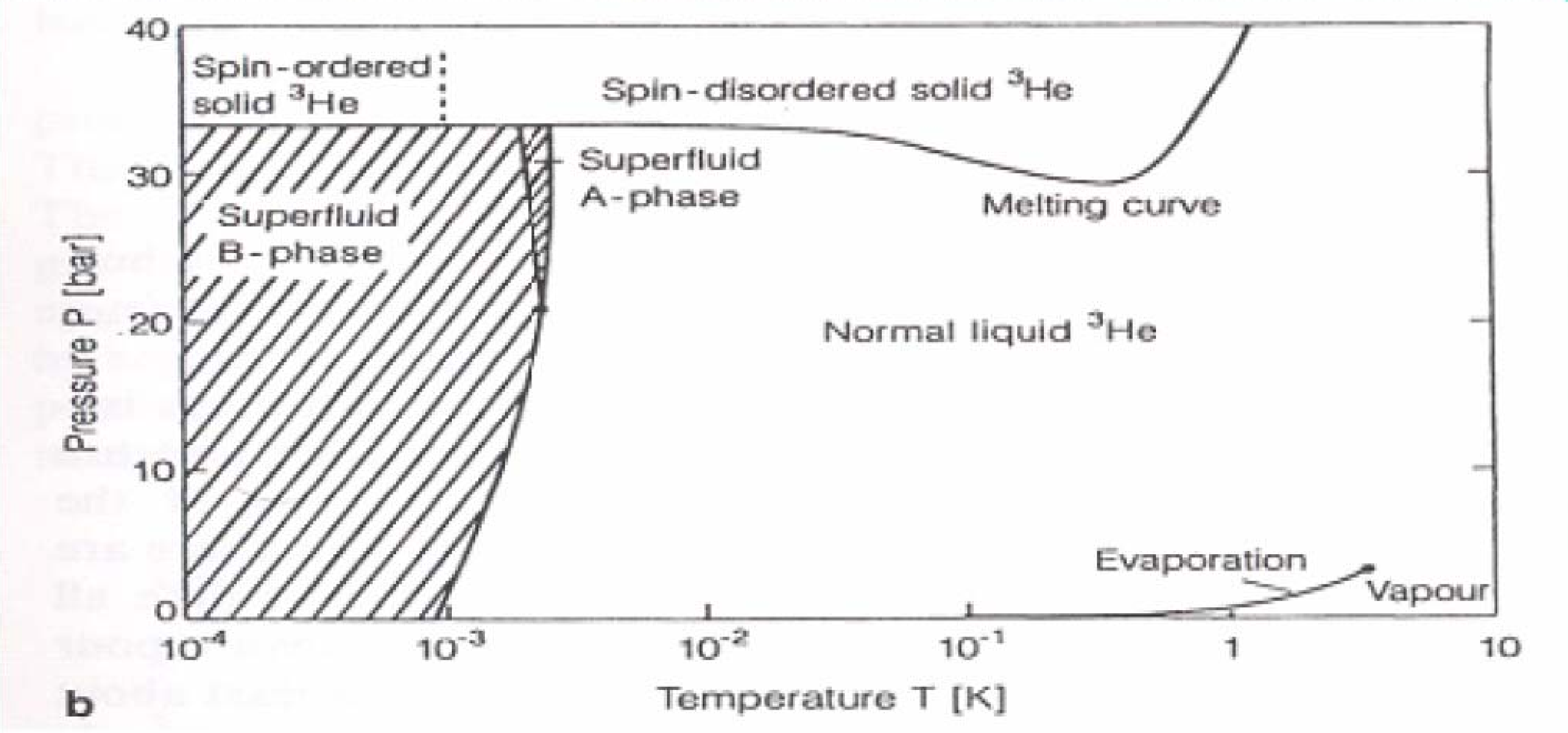




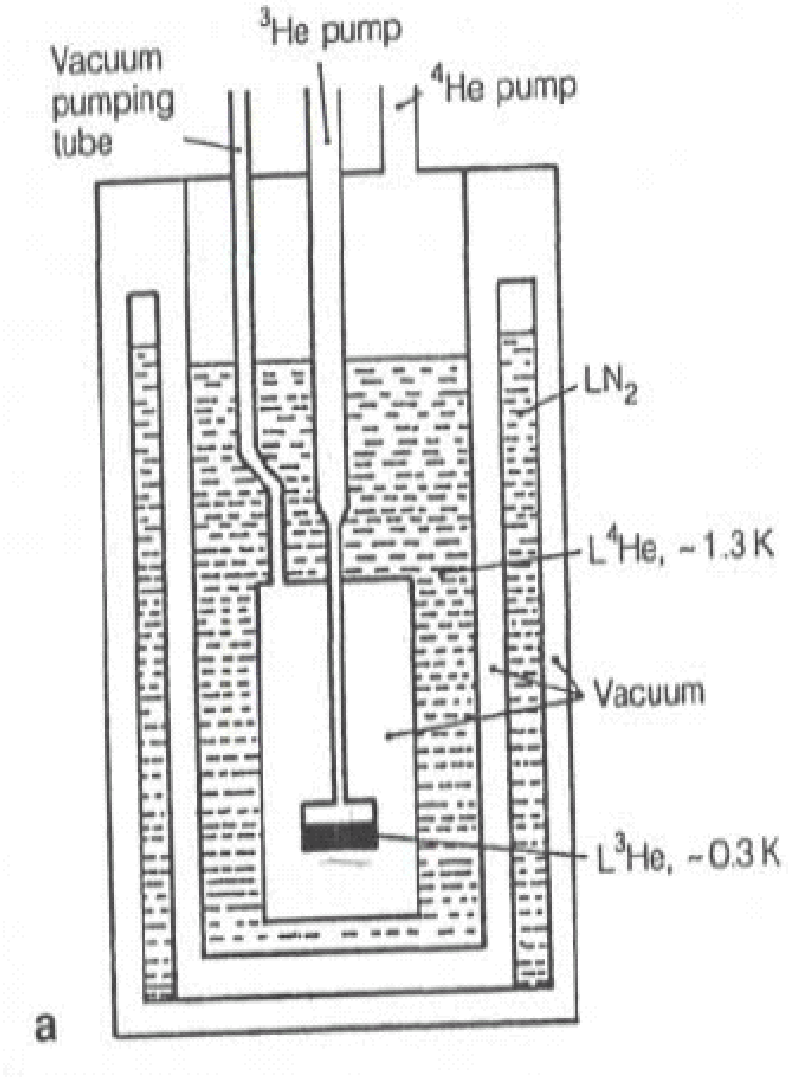
- will escape from a vessel that is not sealed by creeping along the sides until it reaches a warmer region where it evaporates
- moves in a 30 nm thick film Rollin film regardless of surface material.
- leaks rapidly through tiny openings

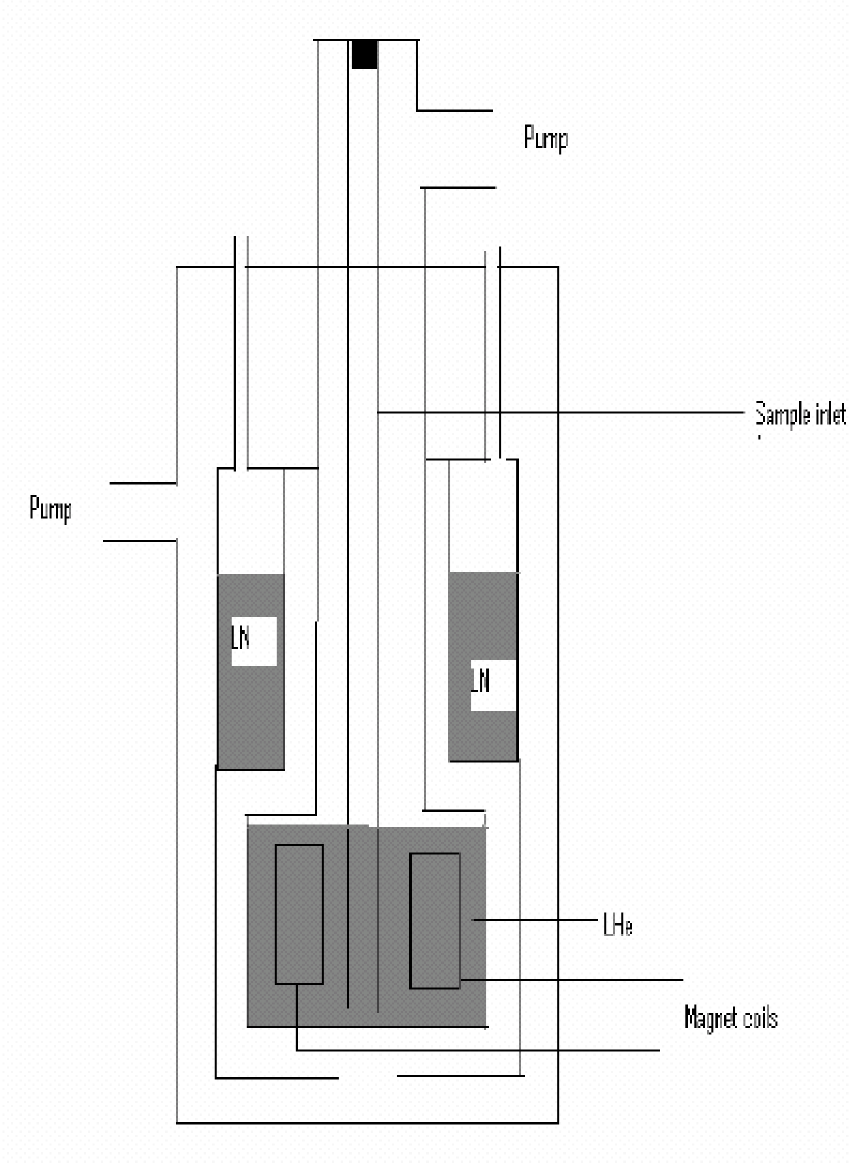
- **Production of He-3**
- Tritium Decay.
- D-D Fusion Reaction.
- The p+Li6 Reaction for Breeding He-3.

3He Phase Diagram



Cryostats


^{3}He pump
Vacuum pumping tube
^{4}He pump
LN_2
L^4He, ~1.3 K
Vacuum
L^3He, ~0.3 K
a


Pump
Sample inlet
Pump
LN
LN
LHe
Magnet coils

Evaporative Cooling

Clausius-Clapeyron-Equation

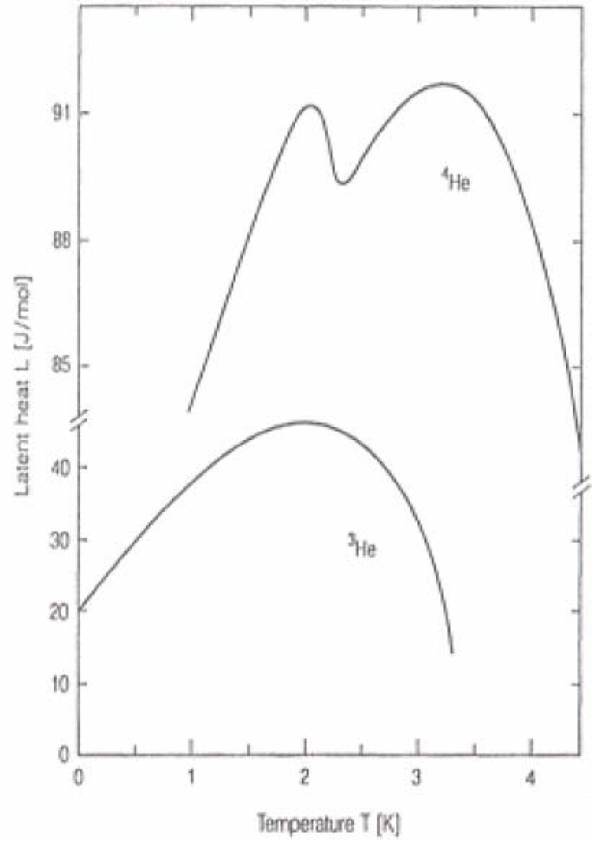
$$\left(\frac{\partial P}{\partial T}\right)_{vap} = \frac{S_{gas}-S_{liq}}{V_{mol,gas}-V_{mol,liq}}$$

with

$$\begin{aligned} &S_{gas} - S_{liq} = \frac{L}{T} \\ &V_{mol,gas} \gg V_{mol,liq} \\ &V_{gas}P = RT \\ &L \neq L(T) \end{aligned}$$

The vapour pressure is

$$P_{vap} \sim \mathrm{e}^{-\frac{L}{RT}}$$

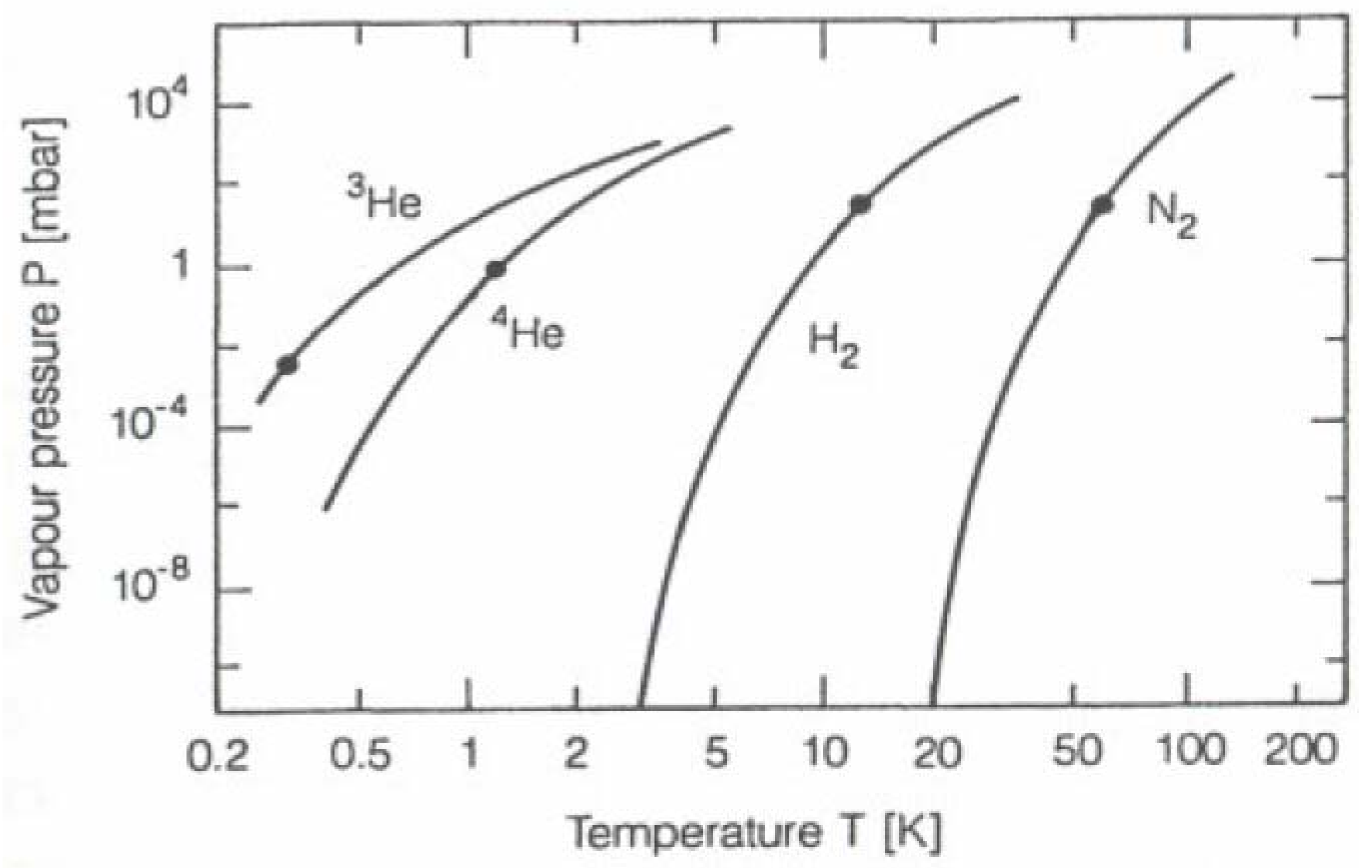


Resulting cooling power

$$\dot{Q} = \dot{n}L \sim LP_{vap} \sim \mathrm{e}^{-\frac{1}{T}}$$

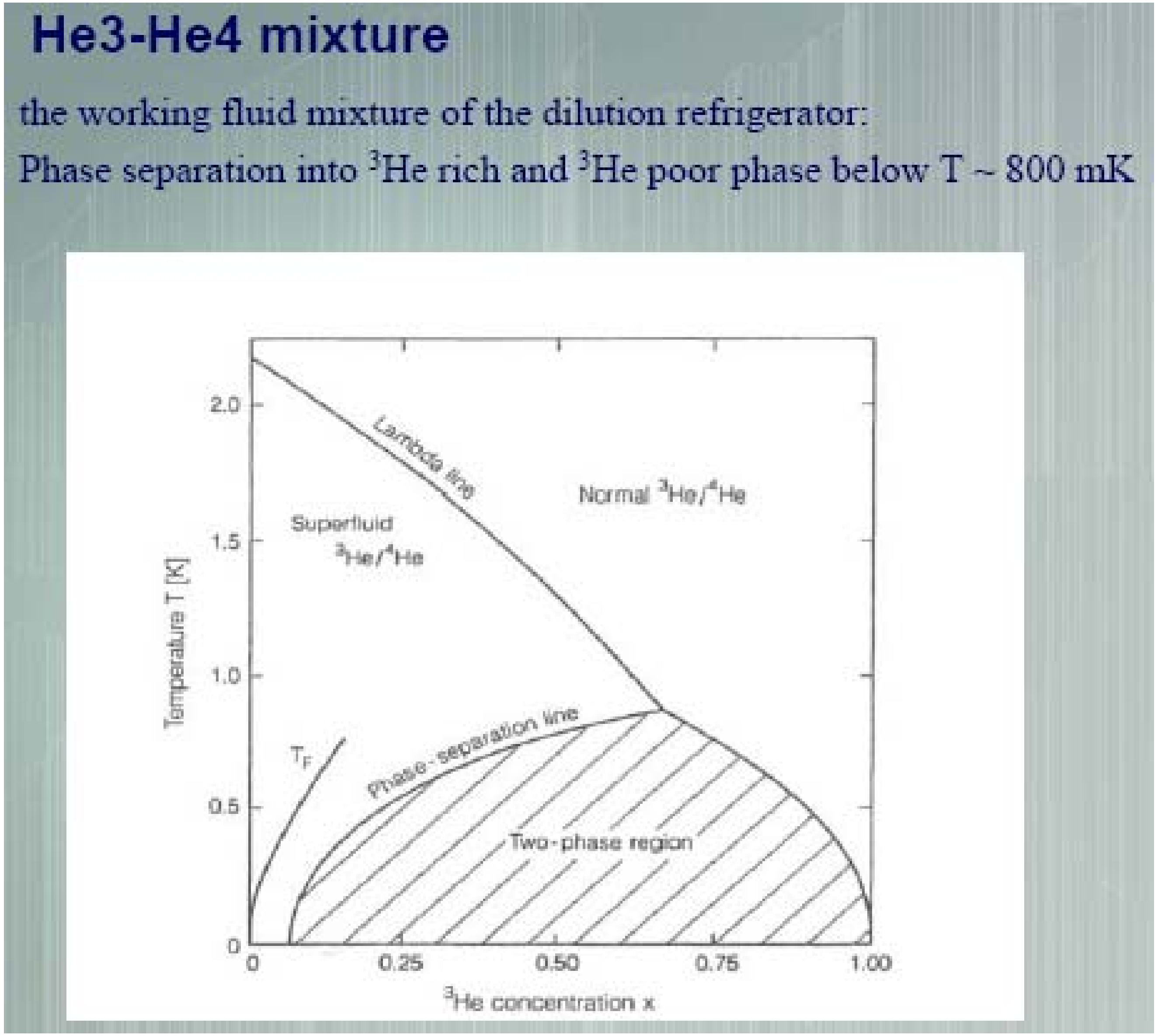
Cooling Power proportional to Vapour Pressure

$$P \propto \exp\left(-\frac{L}{RT}\right)$$



pumping on ^4He: ~ 1 K
pumping on ^3He: ~ 0.25 K

Dilution Refrigeration

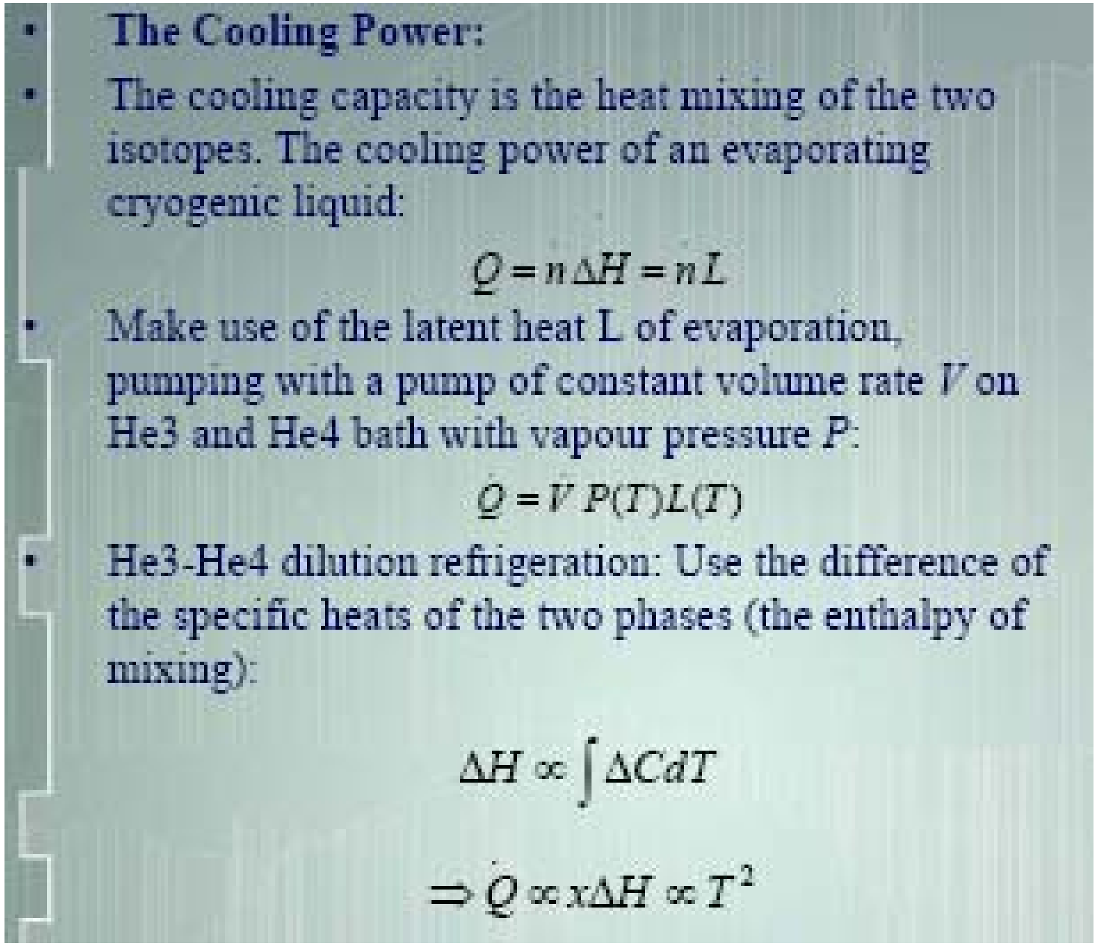


He3-He4 mixture

the working fluid mixture of the dilution refrigerator:

Phase separation into ^{3}He rich and ^{3}He poor phase below T ~ 800 mK

Dilution Refrigeration



- **The Cooling Power:**
- The cooling capacity is the heat mixing of the two isotopes. The cooling power of an evaporating cryogenic liquid:

$$\dot{Q} = \dot{n}\,\Delta H = \dot{n}\,L$$

- Make use of the latent heat L of evaporation, pumping with a pump of constant volume rate $\dot{V}$ on He3 and He4 bath with vapour pressure P:

$$\dot{Q} = \dot{V}\,P(T)L(T)$$

- He3-He4 dilution refrigeration: Use the difference of the specific heats of the two phases (the enthalpy of mixing):

$$\Delta H \propto \int \Delta C\,dT$$

$$\Rightarrow \dot{Q} \propto x\Delta H \propto T^2$$

dilution refrigerator:
cooling power: ~ T^2

reaches temperature ~ few mK

Dilution Refrigeration: Working Principle

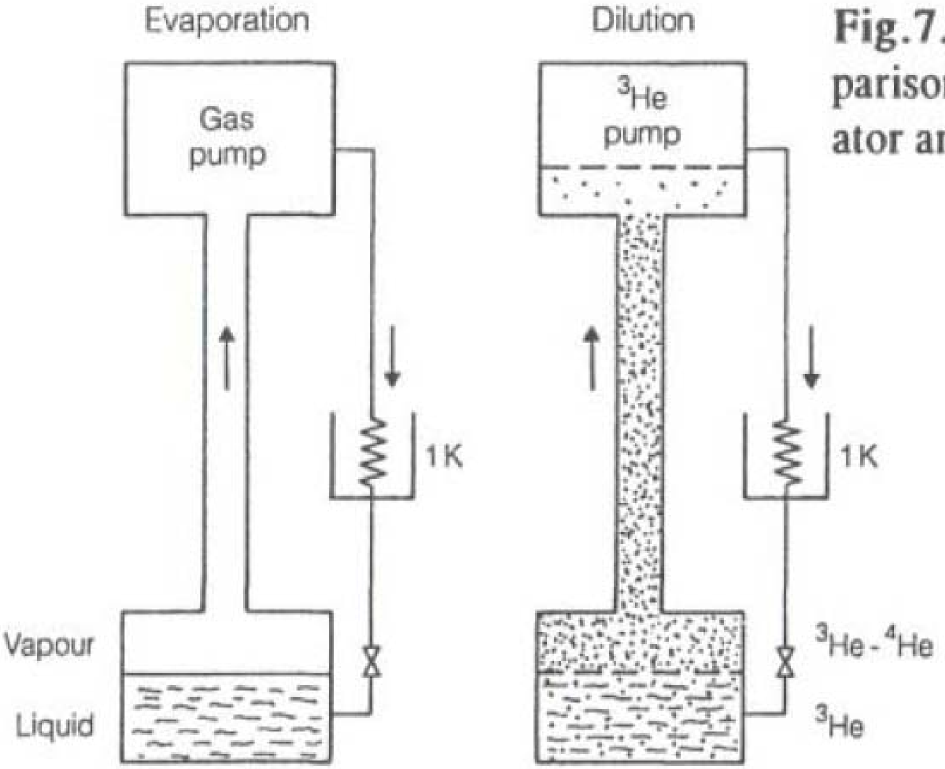


Fig.7.8
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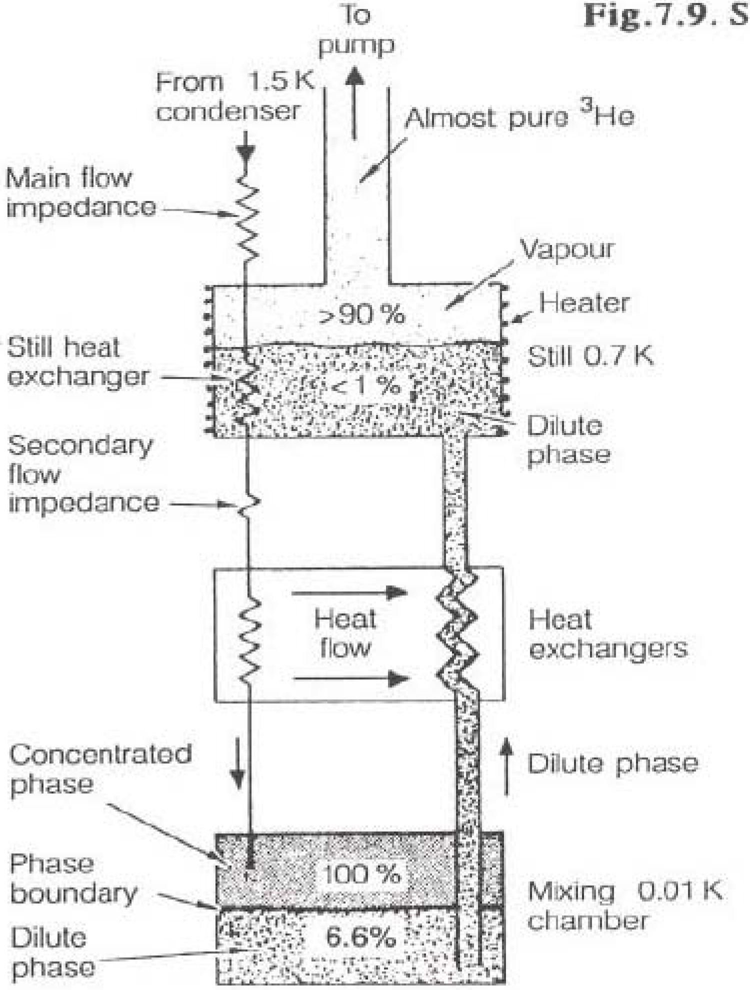

Fig.7.9. Sc

A Dilution Refridgerator

MNK 126-700