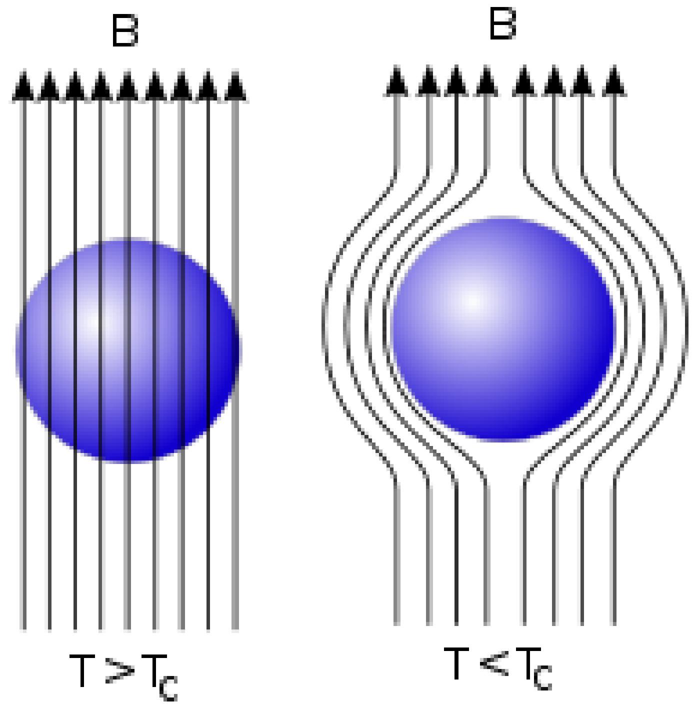
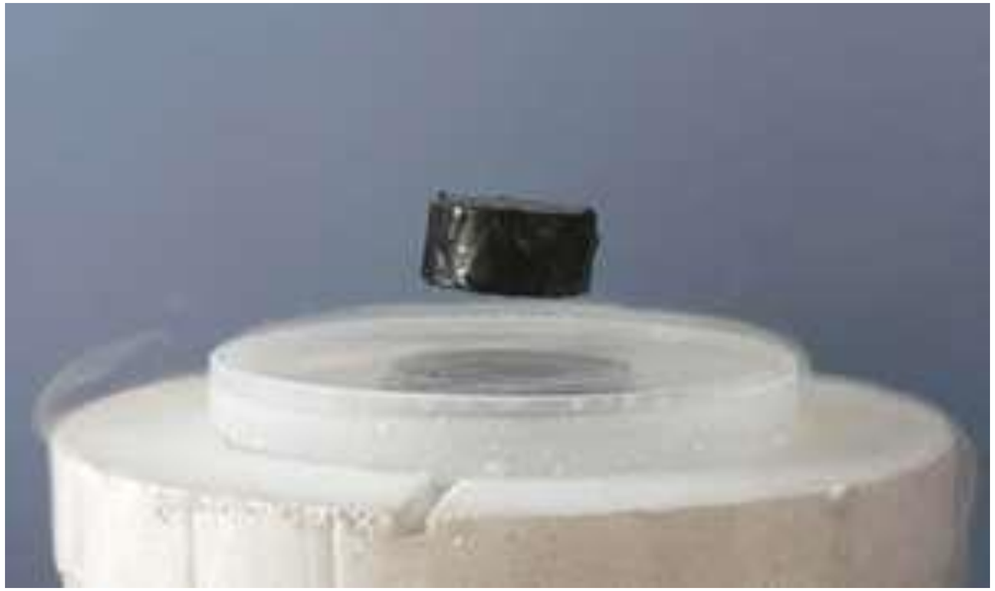
Superconductivity

Module 1

- The simultaneous disappearance of electrical resistance and appearance of perfect diamagnetism below a transition temperature.
- Destroyed by applied magnetic field (**critical field**).
  - Type 1: single value of critical field
  - Type 2: lower and upper critical field
- Similarly destroyed by a **critical current** which produces a magnetic field at the surface.
- Meissner effect: Expulsion of magnetic field by a super conducting material (frictionless bearing & Superconducting motor)

- Specific heat: increases abruptly.
- Thermoelectric effects: disappear.
- Thermal conductivity: decreases abruptly in the presence of a magnetic field for pure metals. Opposite for some alloys.
- Electric resistance: Abrupt decrease for type 1, spread over a temperature range for type 2.
- Magnetic permeability: (Meissner effect) abruptly for type 1 and gradual for type 2





Properties of Cryogenic Liquids

Module 1

LN_2

- Clear, colourless ……($\sim H_2O$)
- NBP = 77.36 K
- NFP = 63.2 K
- ρ = 807 kg/m^3 (1 atm, ~15 ^{0}C) ……(~80% of H_2O)
- h_{fg} = 200 kJ/kg ……(<10% of H_2O)
- Isotopes: N-14, N-15 ……(10,000:38)
- ~78% by volume & ~75 % by weight of air
- Produced by air distillation.

LO_2

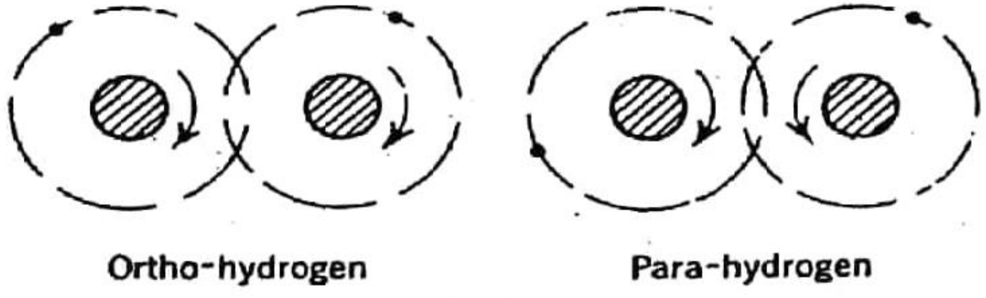
- Blue ……(long chain O_4 molecules)
- NBP = 90.18 K
- NFP = 54.4 K
- ρ = 1141 kg/m^3
- Hazardous
- Paramagnetic
- Isotopes: O-16, O-17, O-18 ……..(10,000: 4: 20)
- 20.95 % by volume & 23.2 % by weight
- Produced by air distillation.

LAr

- Clear, colourless, inert, non toxic
- NBP = 87.3 K
- NFP = 83.8 K
- ρ = 1394 kg/m^3
- Isotopes: Ar-36, Ar-38, Ar-40 …..(338: 63: 100,000)
- 0.934% by volume and 1.25% by weight of air
- Produced by air distillation.

LH_2

- Odourless, colourless, flammable in presence of Air/O_2
- NBP = 20.3 K
- NFP = 13.99 K
- $\rho = 1/14\ \rho_{H20}$
- Isotopes: H_2, D; exists as, H_2, HD(hydrogen deuteride) …….3200:1
- A 3rd isotope tritium exist but is very rare, radio active and have very short half life
- o-H_2 and p-H_2 (3:1 @ higher T → n-H_2, equilibrium mixture at any given T is called equilibrium H_2, e-H_2) concentration of p-H_2 increases as T is lowered (99.8% @ NBP)

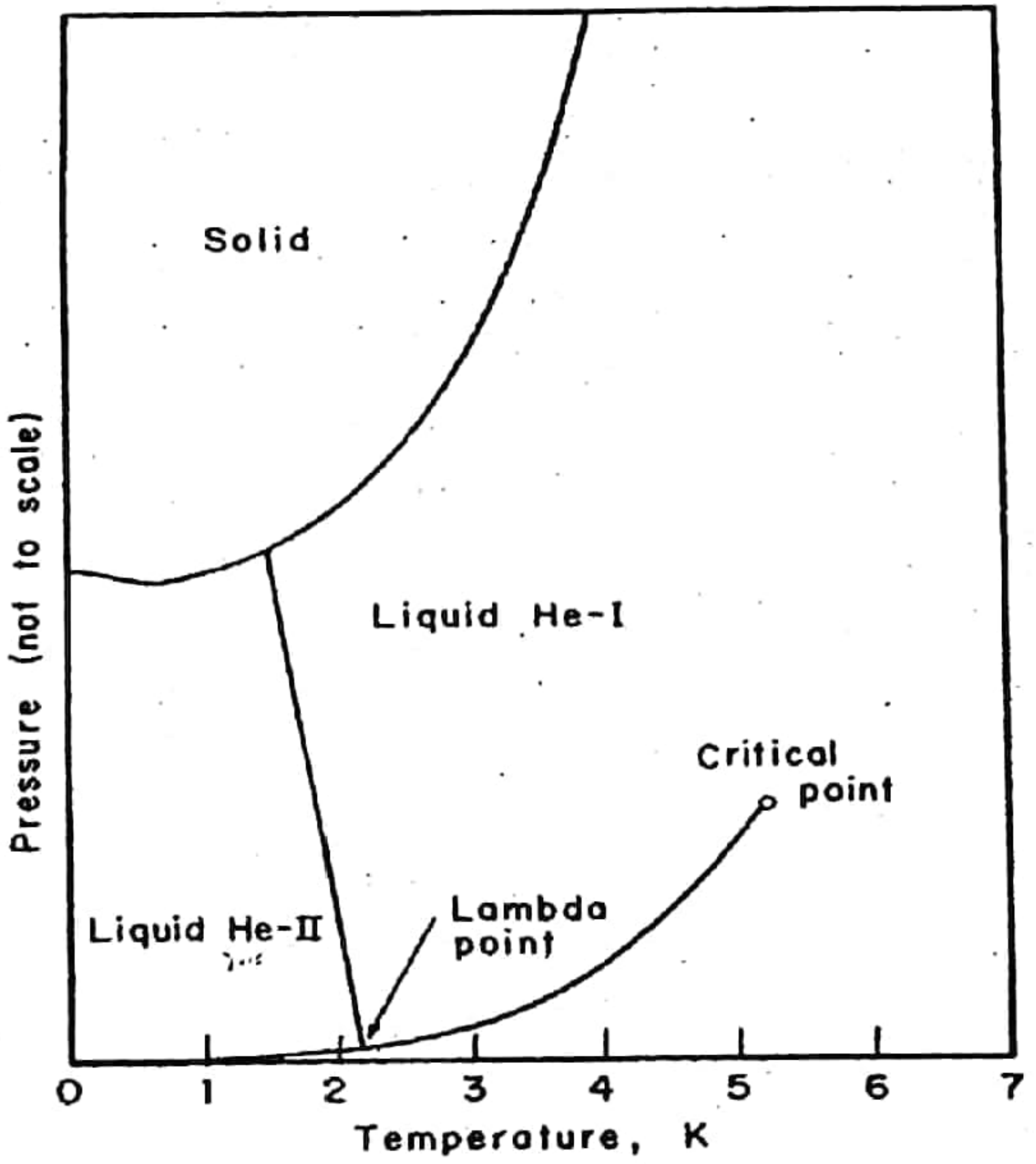


- Deuterium (2:1 ortho and para) para converted to ortho at low T
- Heat of conversion (H_2):
  - Exothermic
  - 730 kJ/kg compared to h_{fg} = 443 kJ/kg @NBP
  - Catalyst used to accelerate conversion during liquefaction

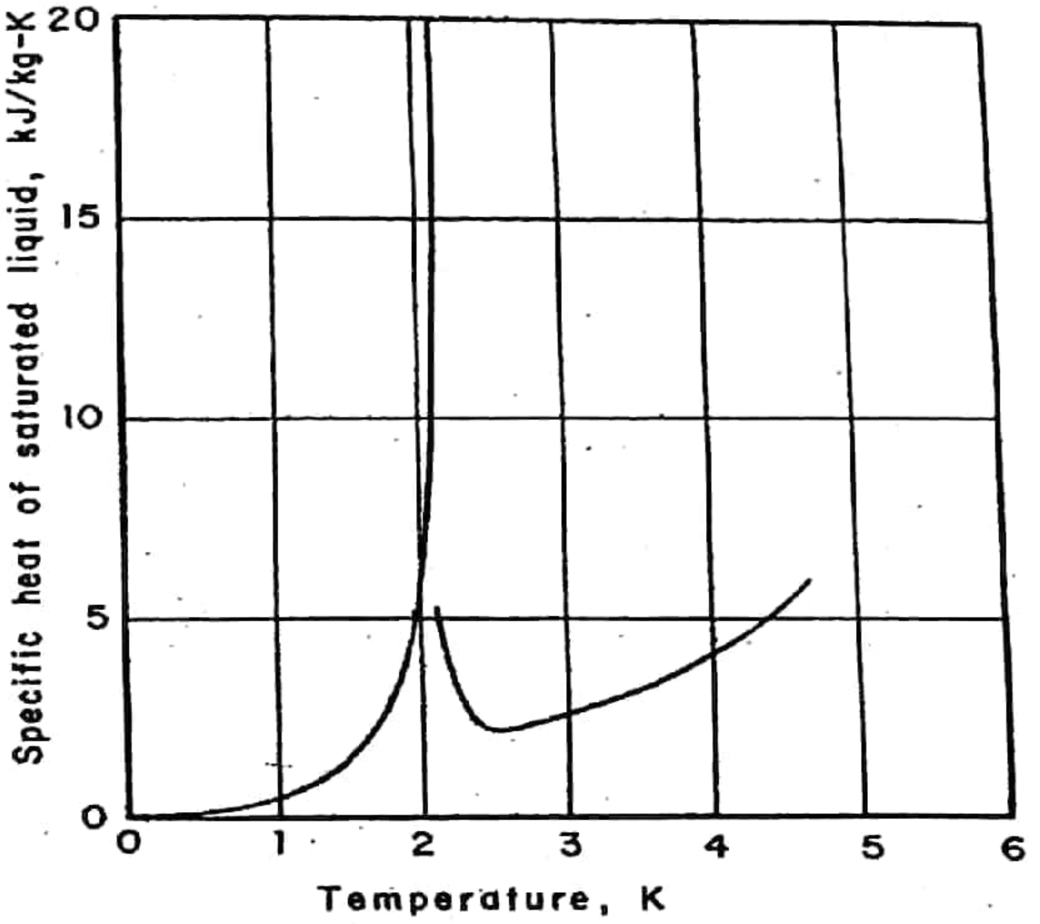
LHe (He^4)

- Colourless, odourless, index of refraction close to vapour He.
- Two isotopes: He^4, He^3 …….(He^3 → 1.3×10^{-4} %)
- NBP – 4.214 K
- No freezing point at P_{atm} …..not even at 0 K (only @ 2.5 MPa @ 0 K)
- $\rho = 124.8$ kg/m^3
- h_{fg} =20.9 kJ/kg

- No triple point
- 2 liquid phases:
- He-I (normal liquid)
- He-II (superfluid)
- The phase separation curve – Lambda line
- The point where Lambda line intersects vapor-pressure curve – Lambda point (2.171 K, 5.073 kPa)

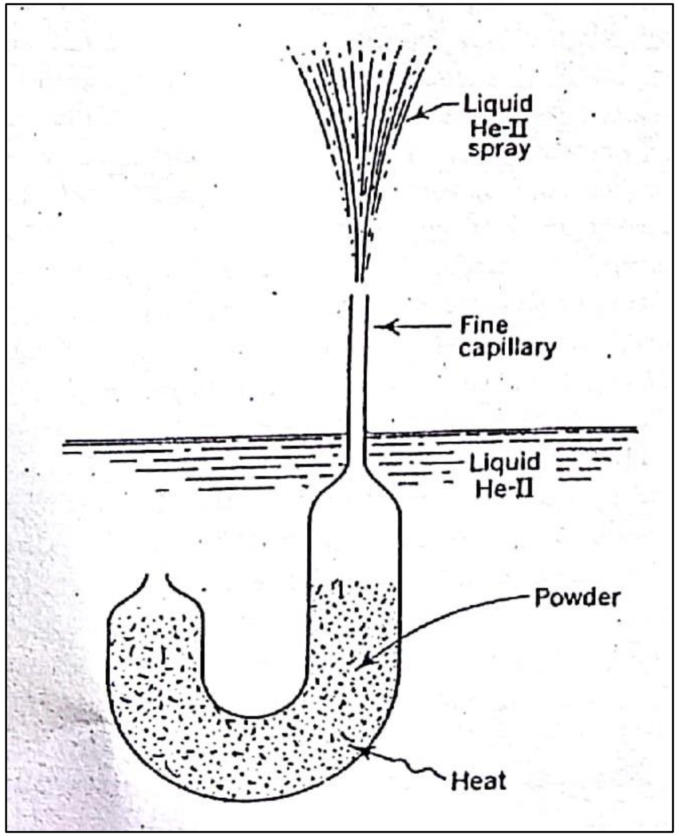


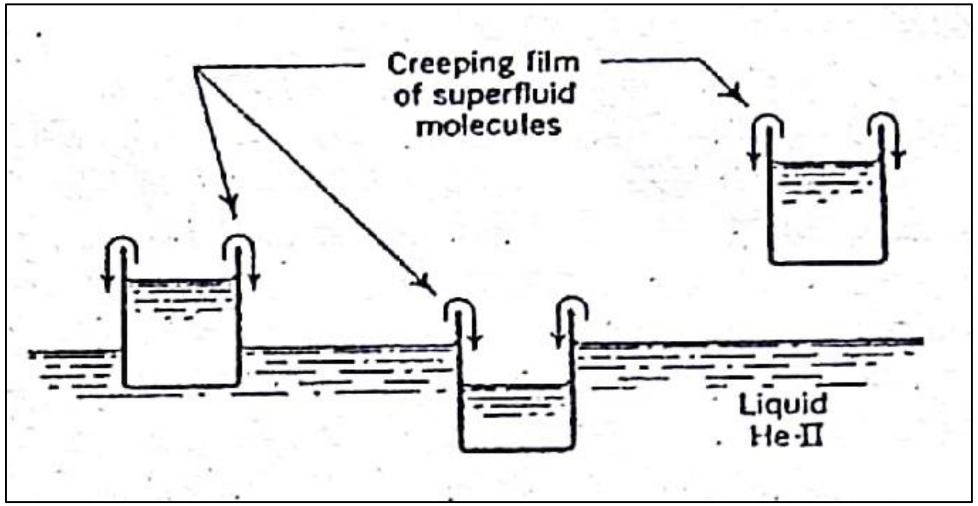
- Unusual variation of specific heat at Lambda point (increases to a very large value)
- Resembles lambda symbol
- For He-I, Thermal conductivity (k ~ 24 mW/m-K) reduces as T reduces (similar to gas not liquid)
- For He-II, the apparent thermal conductivity is very large (k ~ 85 kW/m-K, higher than Cu @ room Temperature)
- Boiling by pressure reduction is very vigorous in He-I until it reaches the lambda point. Where (He-II) boiling becomes quite and clear.
- The heat seems to be conducted very fast to the surface so that vapor bubbles do not have enough time to form.



Super Fluidity (He-II)

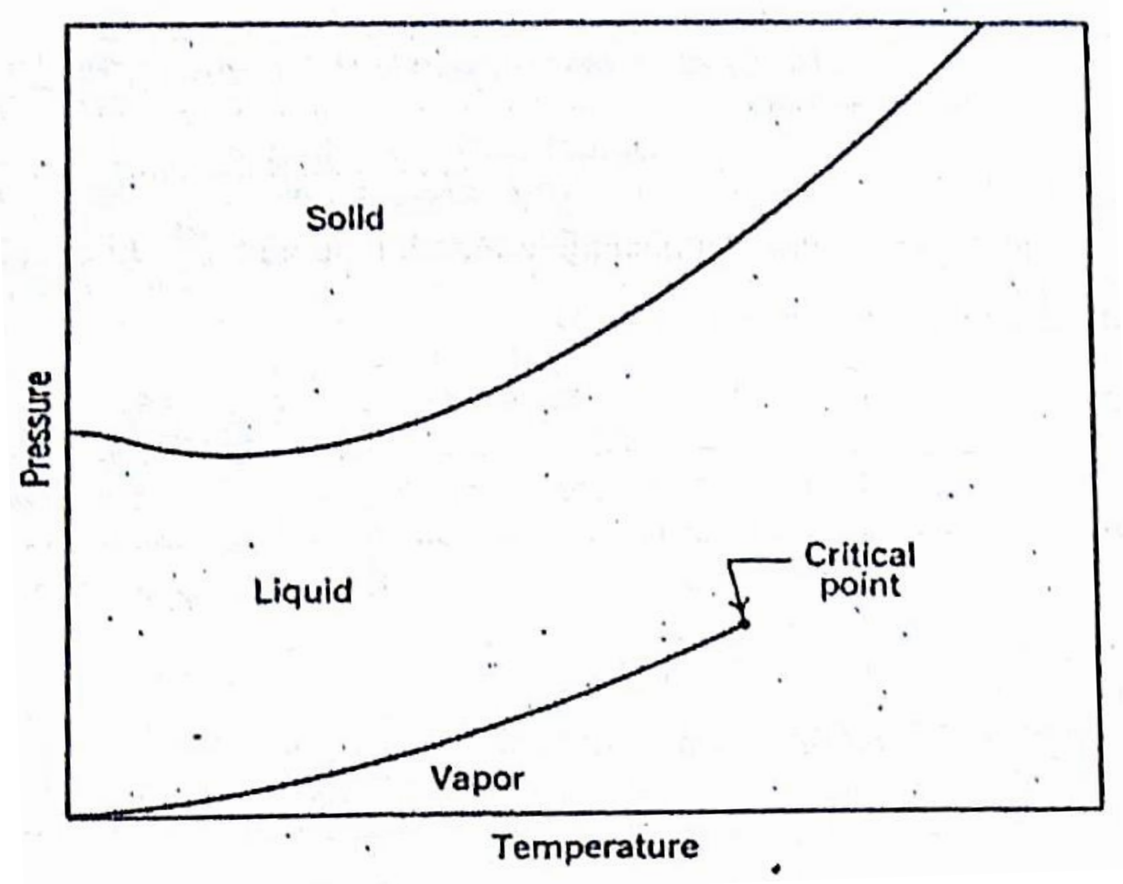
- Acts as it had zero viscosity
- Thought of as a mixture of two fluids (normal & super)
- @0K its 100% super fluid and @ lambda point 100% normal fluid.
- When heat is added normal fluid is formed. Super fluid moves rapidly to equalise the concentration
- Ie, the high apparent k is actually due to a fast convection process.
- The **Fountain Effect** can also be explained in a similar manner (25 to 30 cm have been observed)
- **Rollin film** (creeping liquid) and **Second Sound** (Temperature wave or local oscillations in T: velocity zero at lambda point to 239 m/s at 0 K)





LHe (He^3)

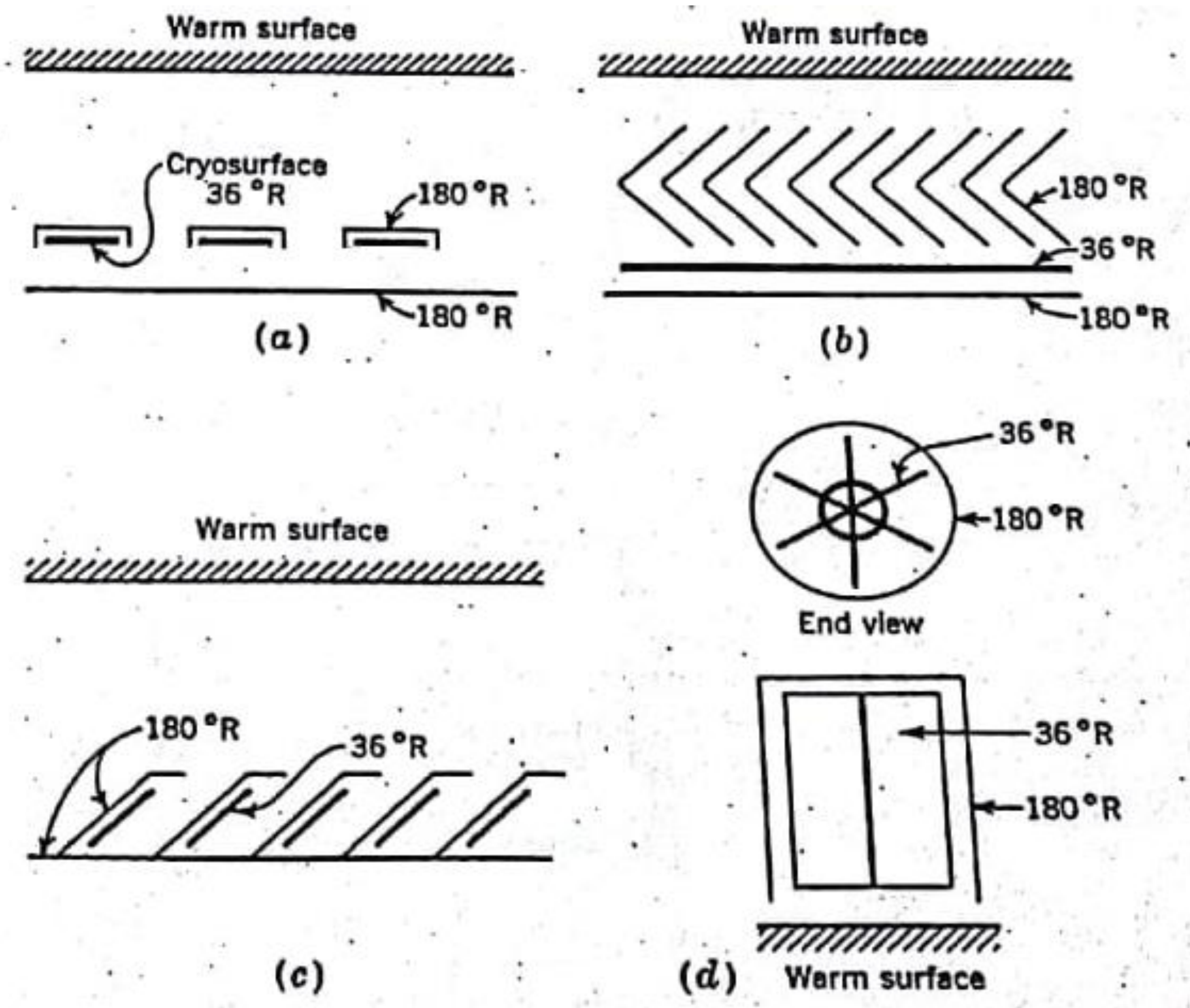
- Clear, colourless
- NBP = 3.19 K
- ρ = 58.9 kg/m^3
- h_{fg} = 8.49 kJ/kg @ NBP
- Must be compressed to 2.9 MPa @ 0 K to solidify
- Properties considerably different from He4
- Superfluid transition at 3.5 mK
- @ T below 0.827 K , He^3 - He^4 mixtures spontaneously separate into two phases (super fluid rich in He^4, normal rich in He^3)



Cryo Pumping

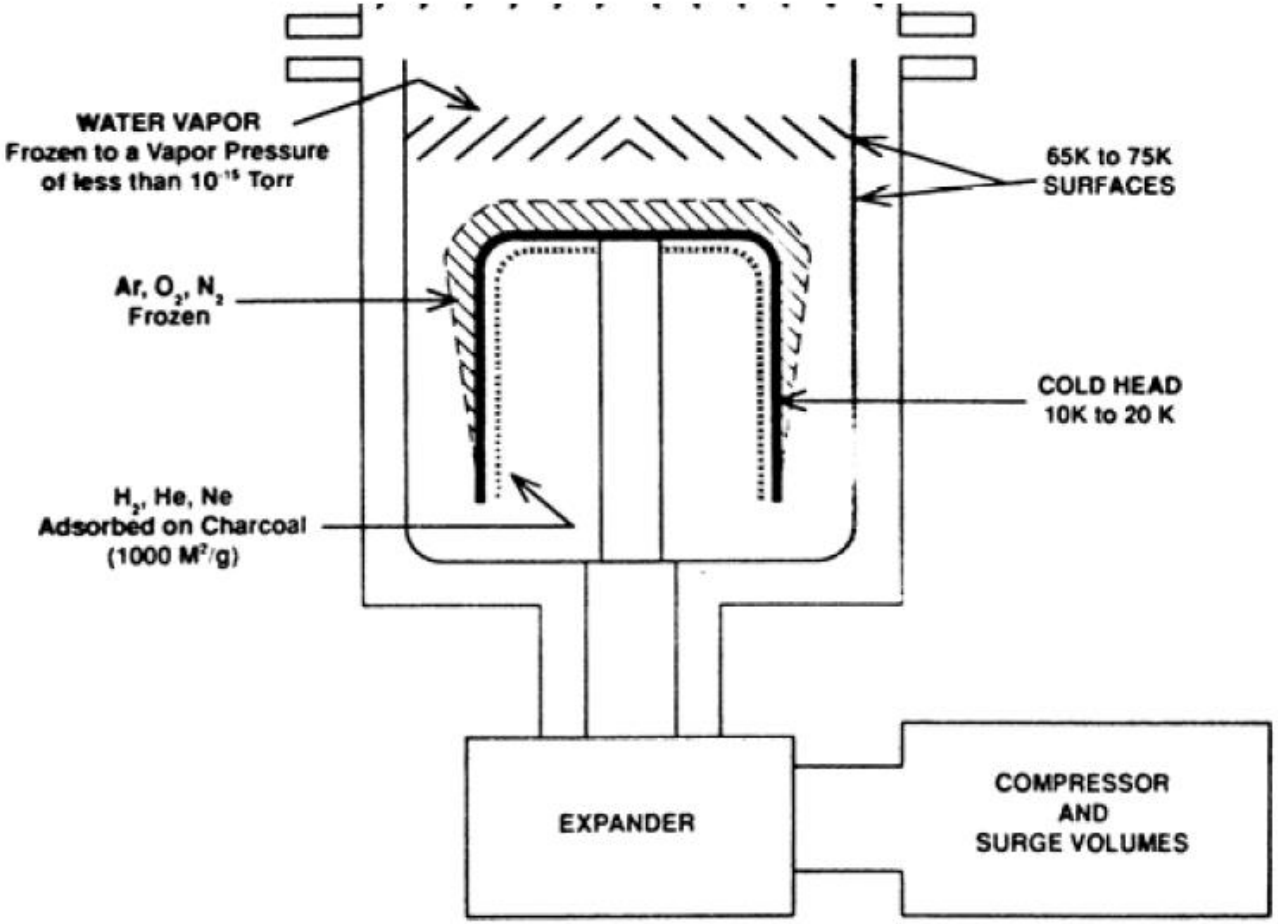
Module 6

- Condensation of gas on a cryogenically cooled surface to produce a vacuum.
- Gas to solid at the cold surface + Also adsorption of the gas molecules
- Extremely large pumping speeds can be attained.
- Resistance of interconnecting piping is eliminated
- Cryo panel is cooled internally to less than 20 K by cold He gas (liquid)
- Shielded by LN_2 cooled surfaces are used to shield the cryo panel in order to reduce the radiant heat load.
- Pumping speed for H_2 and He are low at these temperatures
- In such cases an adsorbent (typically charcoal) is coated on one side to adsorb those gases.


Warm surface
Cryosurface
36 °R
180 °R
180 °R
(a)
Warm surface
180 °R
36 °R
180 °R
(b)
Warm surface
180 °R
36 °R
(c)
36 °R
180 °R
End view
36 °R
180 °R
Warm surface
(d)


LEYBOLD
COOLVAC


CTI-CRYOGENICS
ON-BOARD
Cryopump
CTI-CRYOGENICS


WATER VAPOR
Frozen to a Vapor Pressure of less than 10^{-15} Torr
65K to 75K SURFACES
Ar, O_2, N_2 Frozen
COLD HEAD 10K to 20 K
H_2, He, Ne Adsorbed on Charcoal ($1000\ M^2/g$)
EXPANDER
COMPRESSOR AND SURGE VOLUMES