Lecture # 3

Refrigeration (Part II) & He II

I) Refrigeration

Collins Cycle

- **Used in most large He refrigerator / liquefiers**

- **Cycle consists of :**

  1) **Compression to ~ 20 Bar with cooling back to 300 K + oil removal**

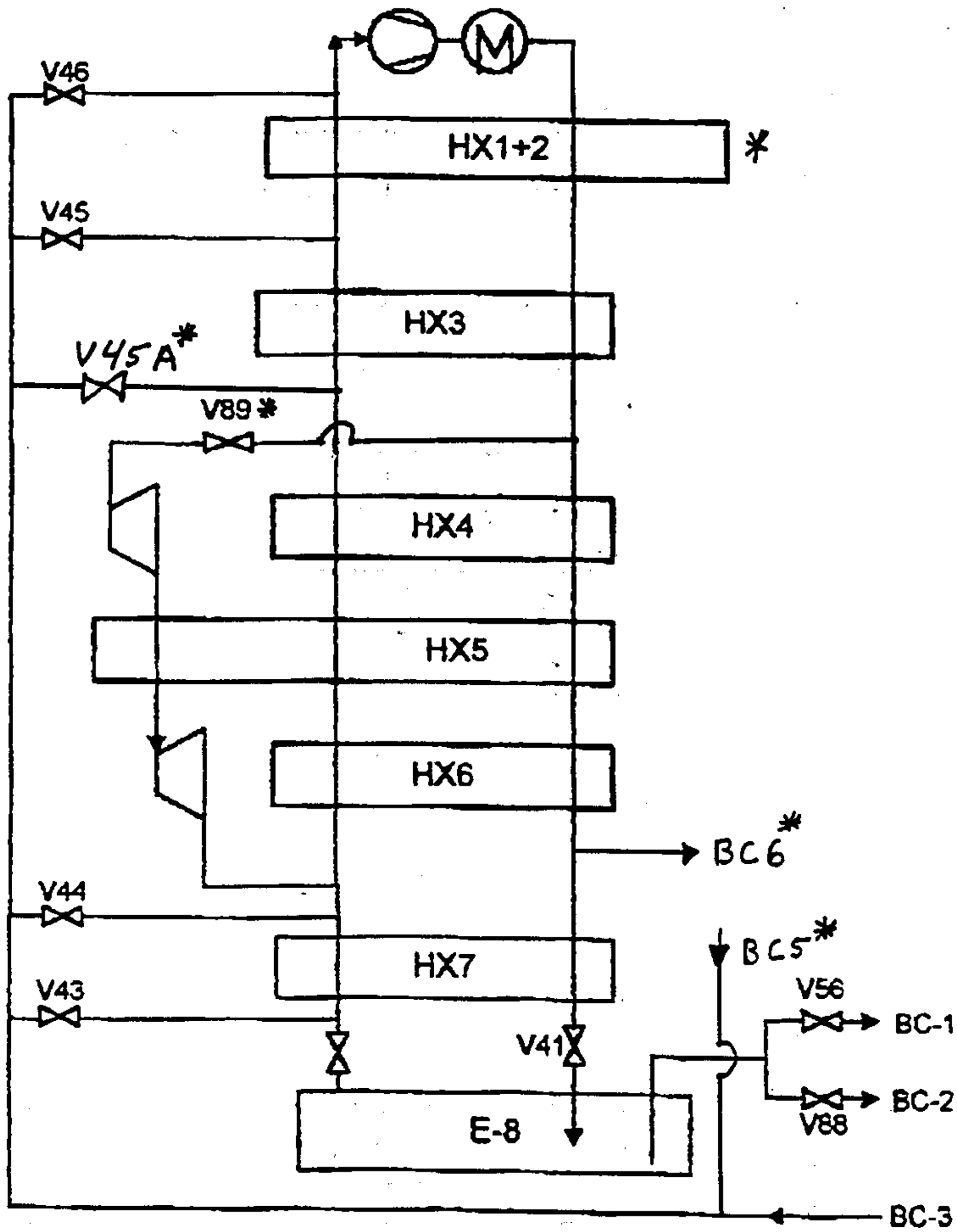
  2) **Cooling of HP gas with LN_2**

  3) **Isentropic expansion via 2 or more expansion engines**

  4) **Cooling of HP gas by cold returning LP stream**

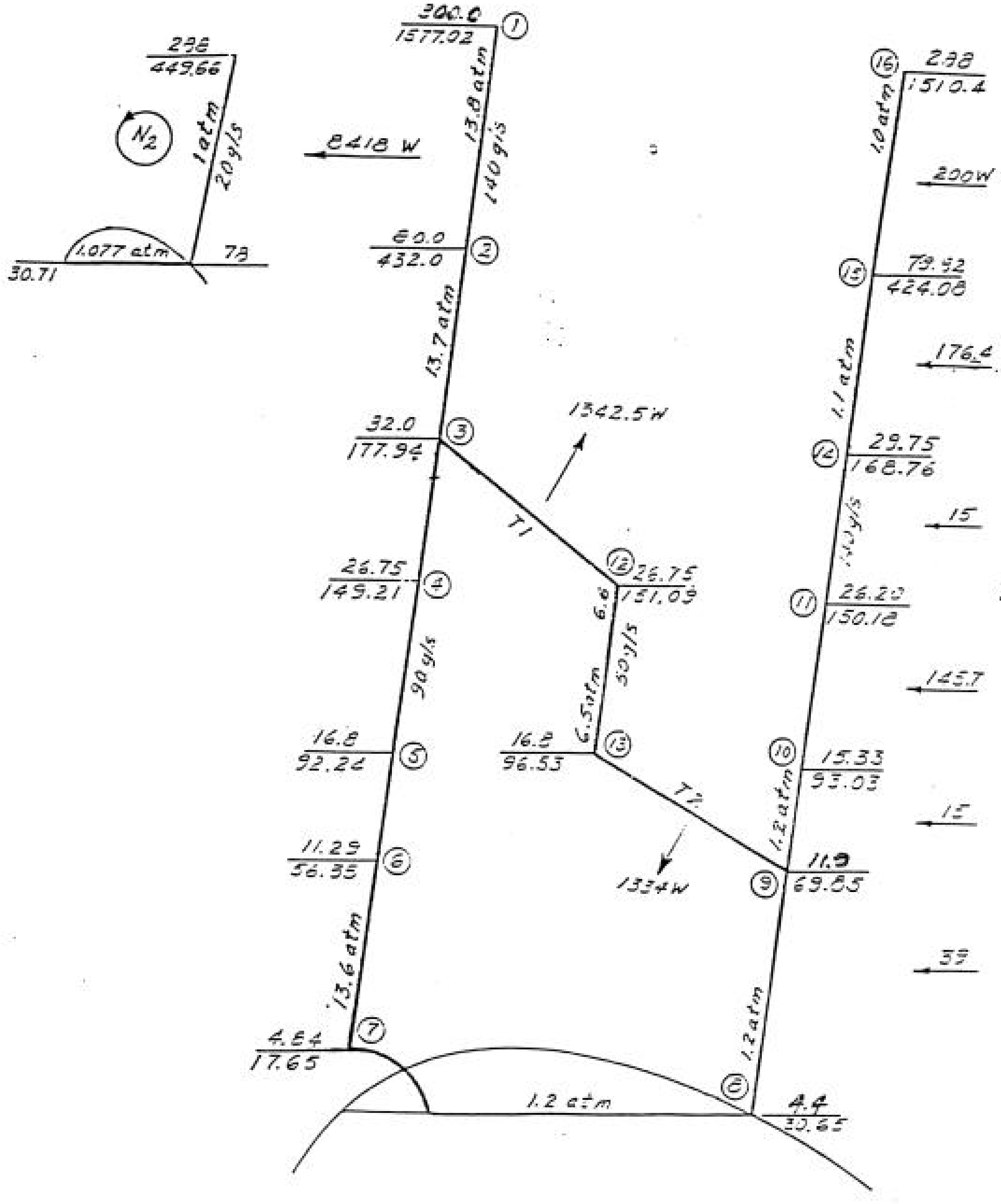
5) **Isenthalpic expansion through JT valve**

6) **Return of gas to compressors at just above 1 Bar pressure**

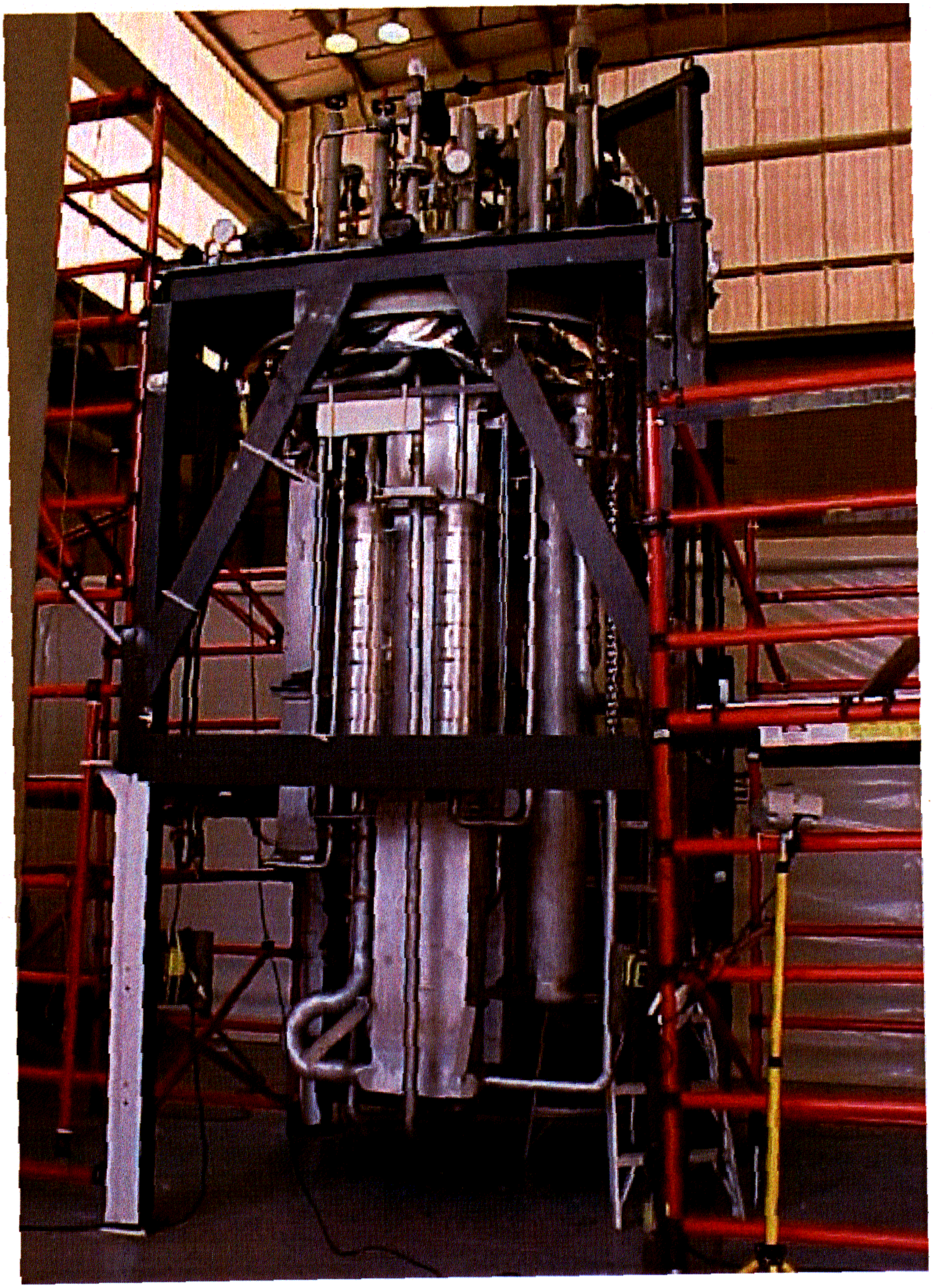


CTI 4000 Upgrade 12 / 2 / 99

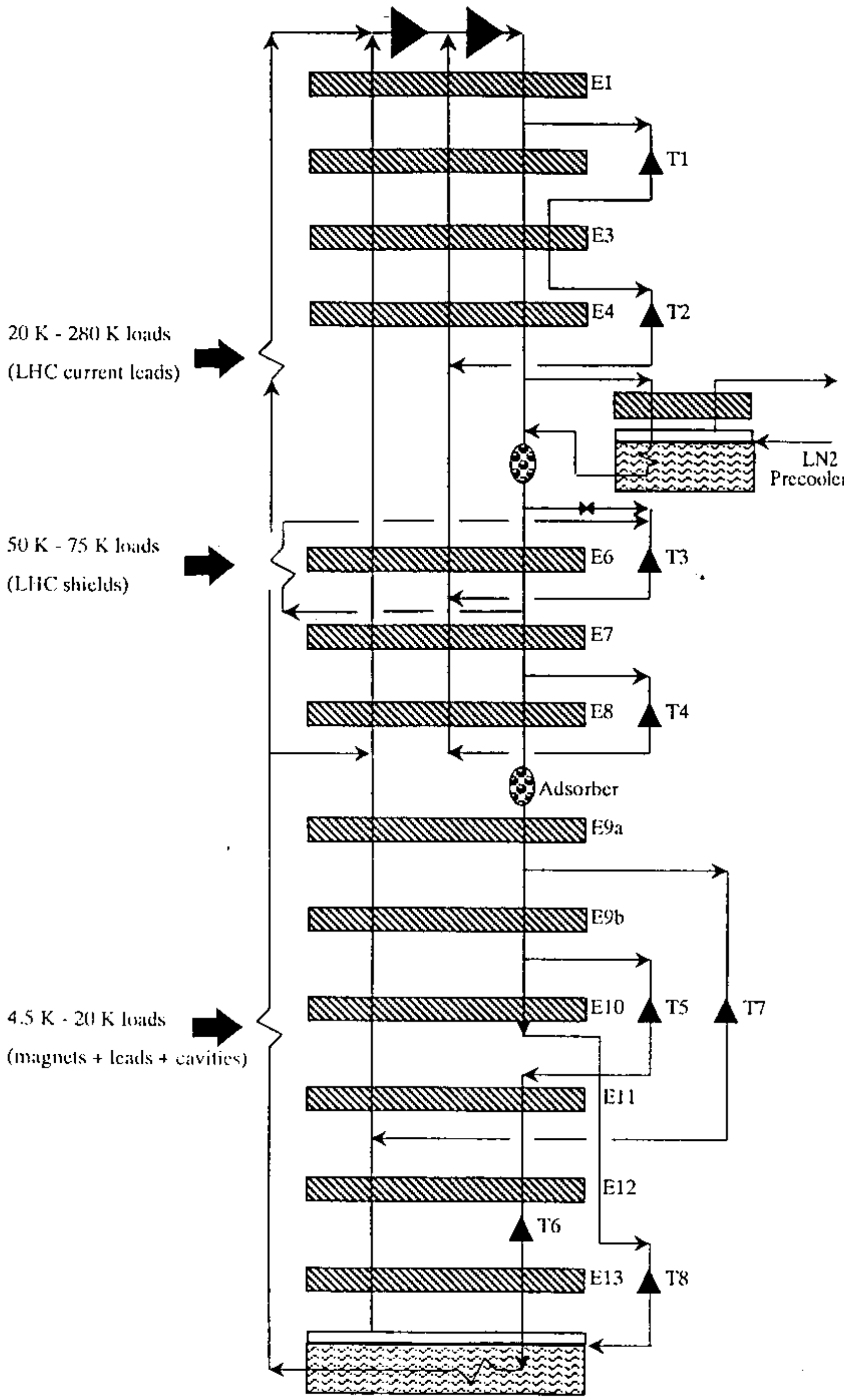
* Indicates new or changed component



298
449.66
N_2
1atm
20g/s
1.077 atm
30.71
78
8418 W
300.0
1577.02
13.8 atm
140 g/s
60.0
432.0
13.7 atm
32.0
177.94
1342.5 W
T1
26.75
149.21
90 g/s
26.75
151.09
6.6
50 g/s
6.5 atm
16.8
92.24
16.8
96.53
T2
11.29
56.35
1334 W
13.6 atm
4.84
17.65
1.2 atm
1.2 atm
4.4
30.65
11.9
69.85
1.2 atm
15.33
93.03
26.20
150.18
29.75
168.76
1.1 atm
79.92
424.08
298
1510.4
1.0 atm
200W
176.4
15
145.7
15
39




UpRight
MX 19



E1
T1
E3
E4
T2
20 K - 280 K loads
(LHC current leads)
LN2
Precooler
50 K - 75 K loads
(LHC shields)
E6
T3
E7
E8
T4
Adsorber
E9a
E9b
E10
T5
T7
4.5 K - 20 K loads
(magnets + leads + cavities)
E11
E12
T6
E13
T8

II) He II (Superfluid Helium)

- 2^{nd} liquid phase of helium

- Phase transition is 2^{nd} order (no latent heat) but discontinuity in specific heat hence lambda transition

- $T_{\lambda max} = 2.2$ K

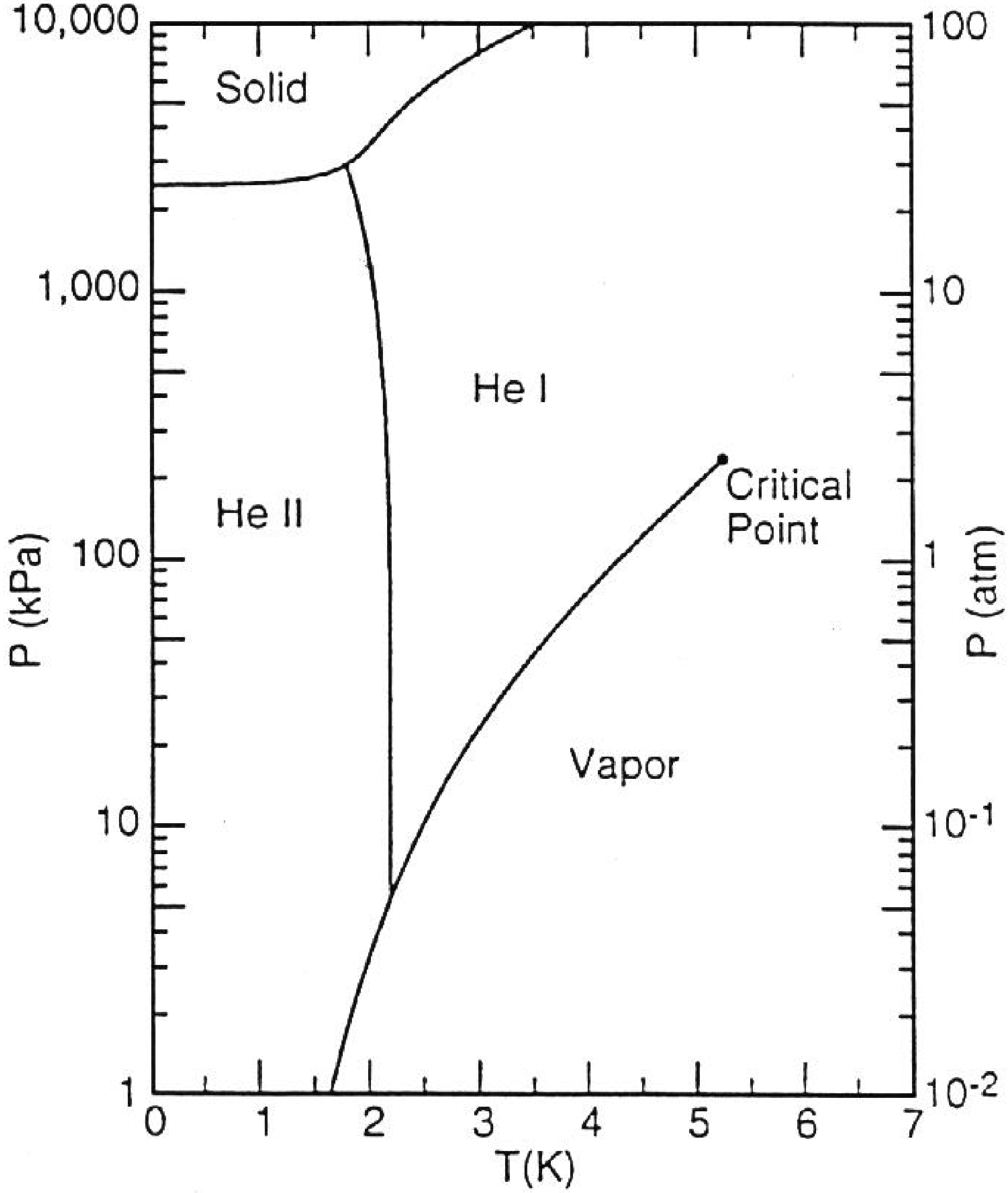
- Has unique thermal and fluid properties

- Lower temperature means:

  - Higher Field s/c magnets : LHC, Tore Supra

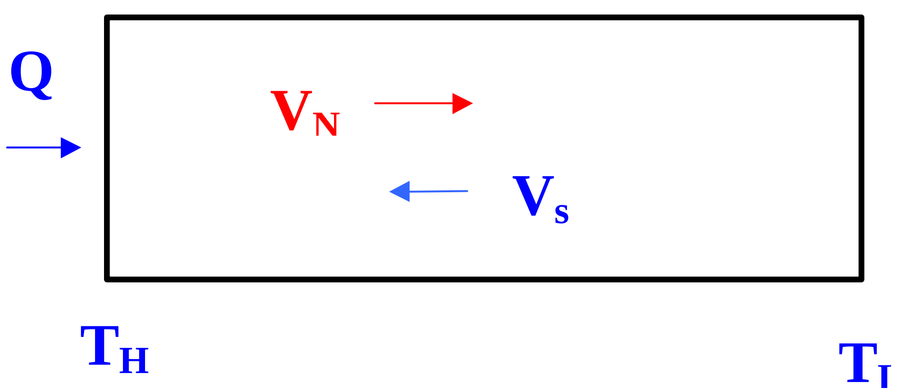
  - Lower BCS losses in RF s/c : TESLA, CEBAF

  - Lower background temperatures for IR observation : COBE, SIRTF



10,000
1,000
100
10
1
100
10
1
10-1
10-2
Solid
He I
He II
Critical
Point
Vapor
P (kPa)
P (atm)
0
1
2
3
4
5
6
7
T(K)

- **Two Fluid Model**
  - **He II results from Bose-Einstein condensation**
  - **Model He II as two completely interpenetrating fluids**
  - **Some fluid in ground state: S=0, m= 0 (superfluid component)**
  - **Some fluid in excited : S and m finite (normal fluid component)**
- **Internal Convection**



- No net mass flow
- Extremely effective heat transfer mechanism

- Quantized Vortices
  - In the superfluid component:

$$C = \oint \mathbf{V}_s \cdot \mathbf{dl} = n \frac{h}{m}$$

  - Solves rotating bucket paradox

$\nabla^2 \mathbf{V}_s = 0$ in body of fluid

$\nabla^2 \mathbf{V}_s \neq 0$ at container wall

  - Have been experimentally observed

- **Heat Transfer in He II**

2 Regimes:

$V_s < V_{sc}$

$$q = \frac{(\rho s d)^2 T}{\beta \eta_n} \frac{dT}{dx}$$

$V_s > V_{sc}$

- **Mutual Friction regime**
- **As $V_{sc} \sim d^{1/4}$ (cgs units) this regime is most applicable in engineering applications of He II**

$$q = \left[f^{-1}(P,T) \frac{dT}{dx} \right]^{1/3}$$

Heat Transfer Limits

- In Pressurized He II $(T_h < T_\lambda)$

Thus the peak heat flux q* is:

$$q^* L^{1/3} = \left(\int_{T_b}^{T_\lambda} f^{-1}(T)\,dt \right)^{1/3}$$

At 1.9 K and 1 bar :

$$q^* L^{1/3} \sim 15 \text{ kW/m}^{5/3}$$

- In Saturated He II the limit is given by the local saturation temperature

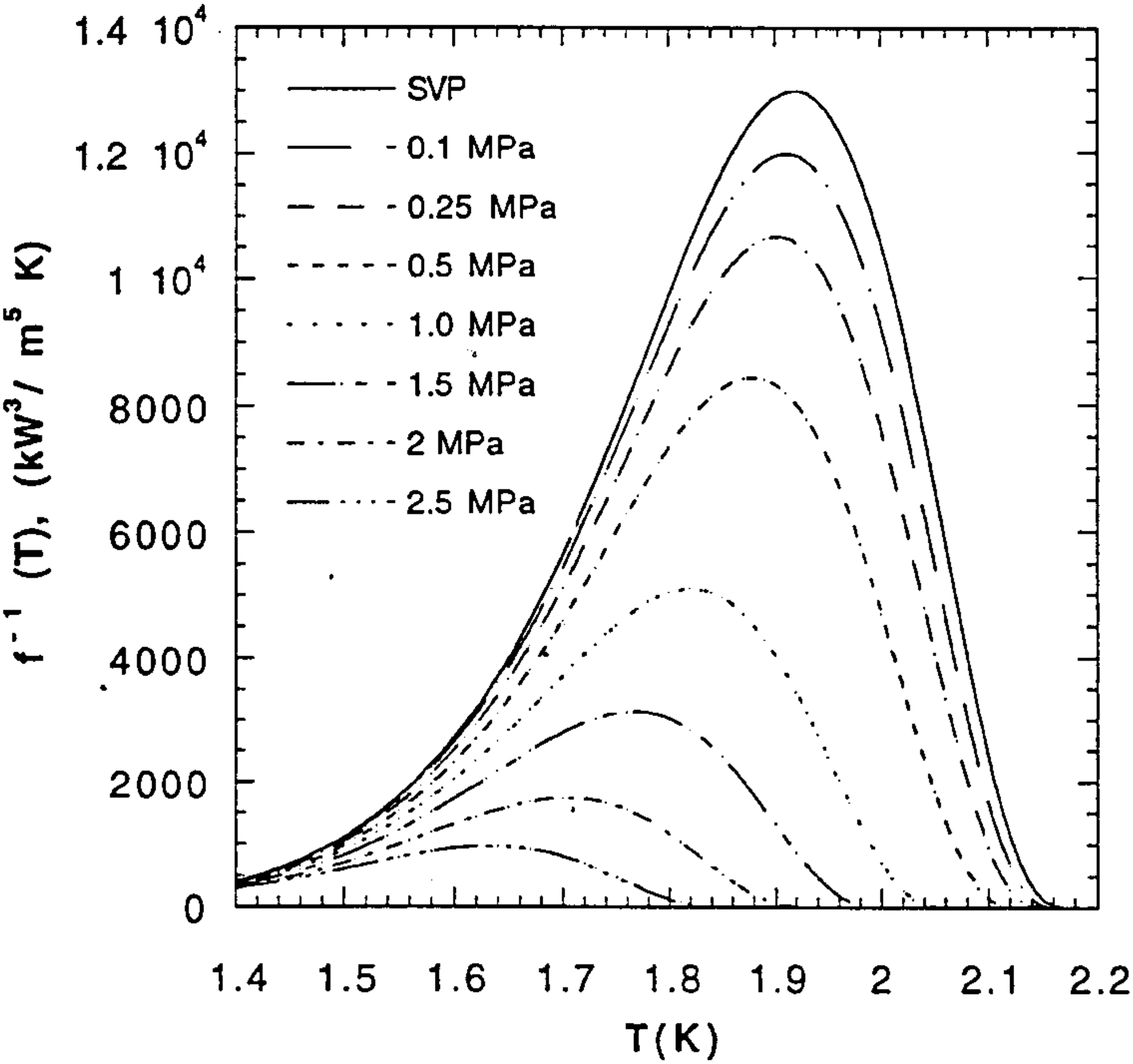
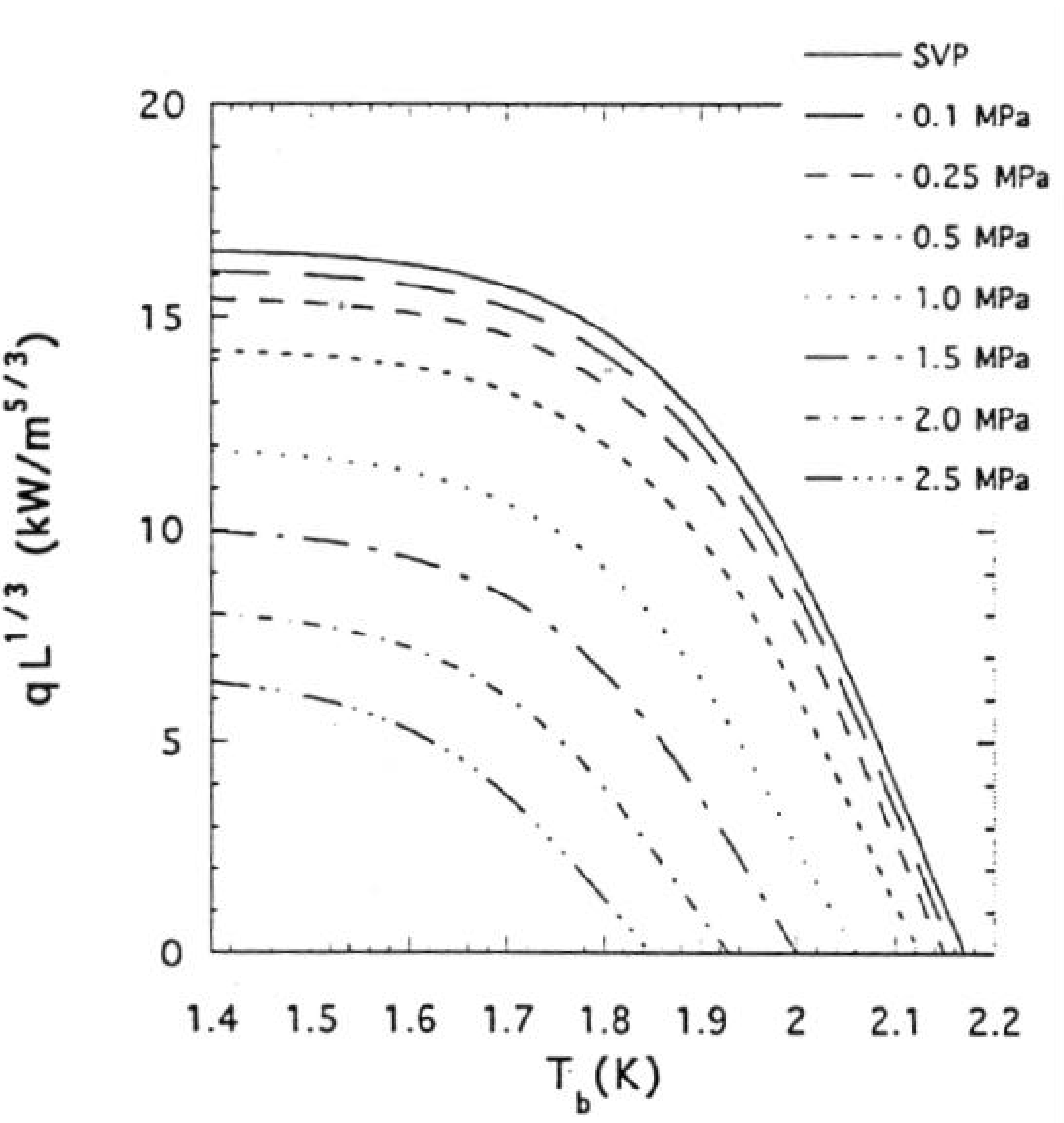


Figure 3-7

He II Heat Conductivity Function

He II (Superfluid Helium) S. W. Van Sciver, in Handbook of Cryogenic Engineering, J. G. Weisend II Ed.,Taylor & Francis (1998)



He II Peak Heat Flux

He II (Superfluid Helium) S. W. Van Sciver, in Handbook of Cryogenic Engineering, J. G. Weisend II Ed.,Taylor & Francis (1998)

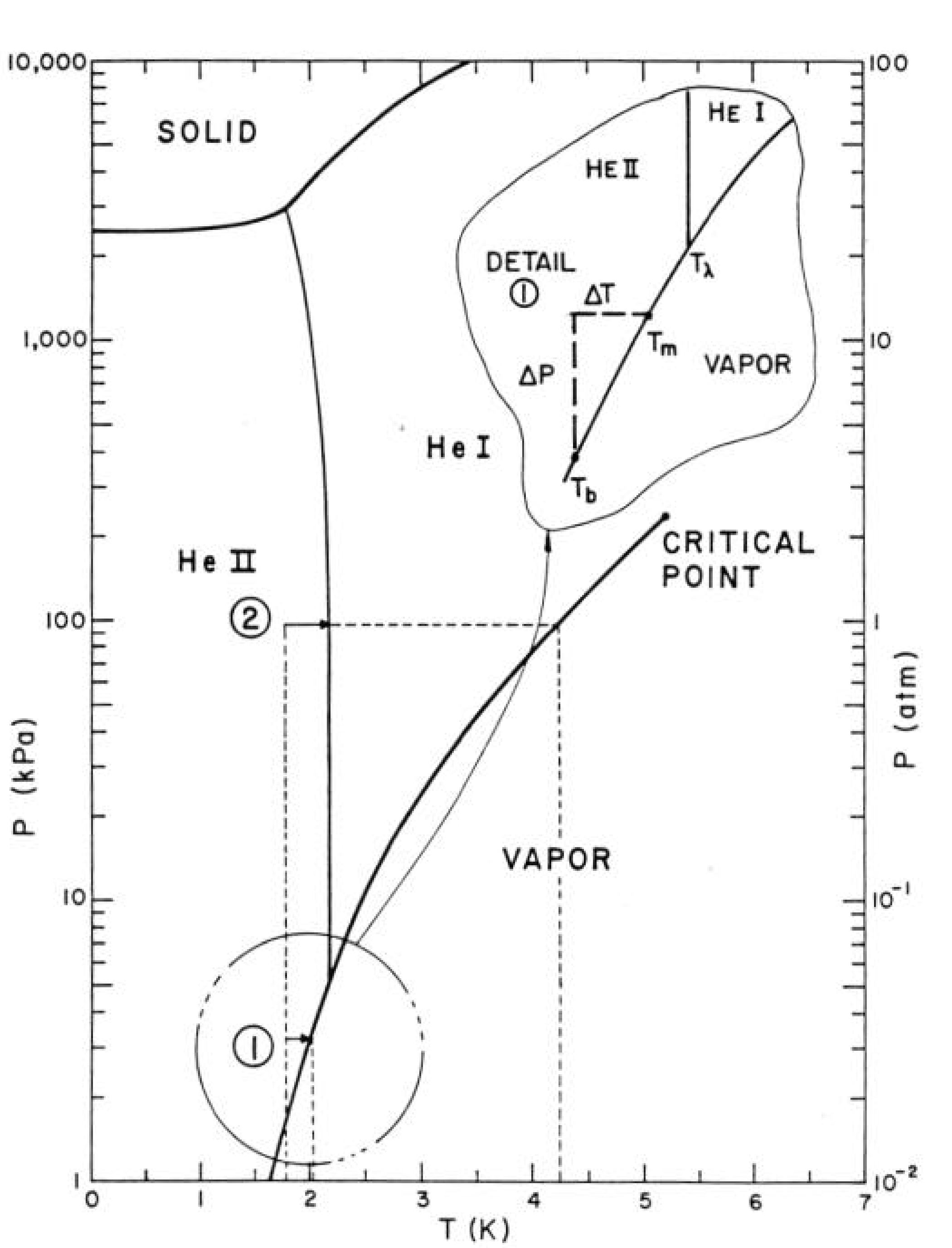


Figure3-9 Illustration of Saturated He II heat Transfer Limit

Helium Cryogenics ,S. W. Van Sciver, Plenum Press, (1986)

Surface Heat Transfer

- Dominated by Kapitza conductance

- For $q < 1\ kW/m^2$

$$q = h_k \Delta T_s$$

- For $q > 1\ kW/m^2$

$$q = a\left(T_s^m - T_b^m\right)$$

- h_k a and m are empirical and dependent on material, temperature and surface condition

- $m \sim 3$

- Kapitza conductance is <u>not</u> dependent on helium flow rate

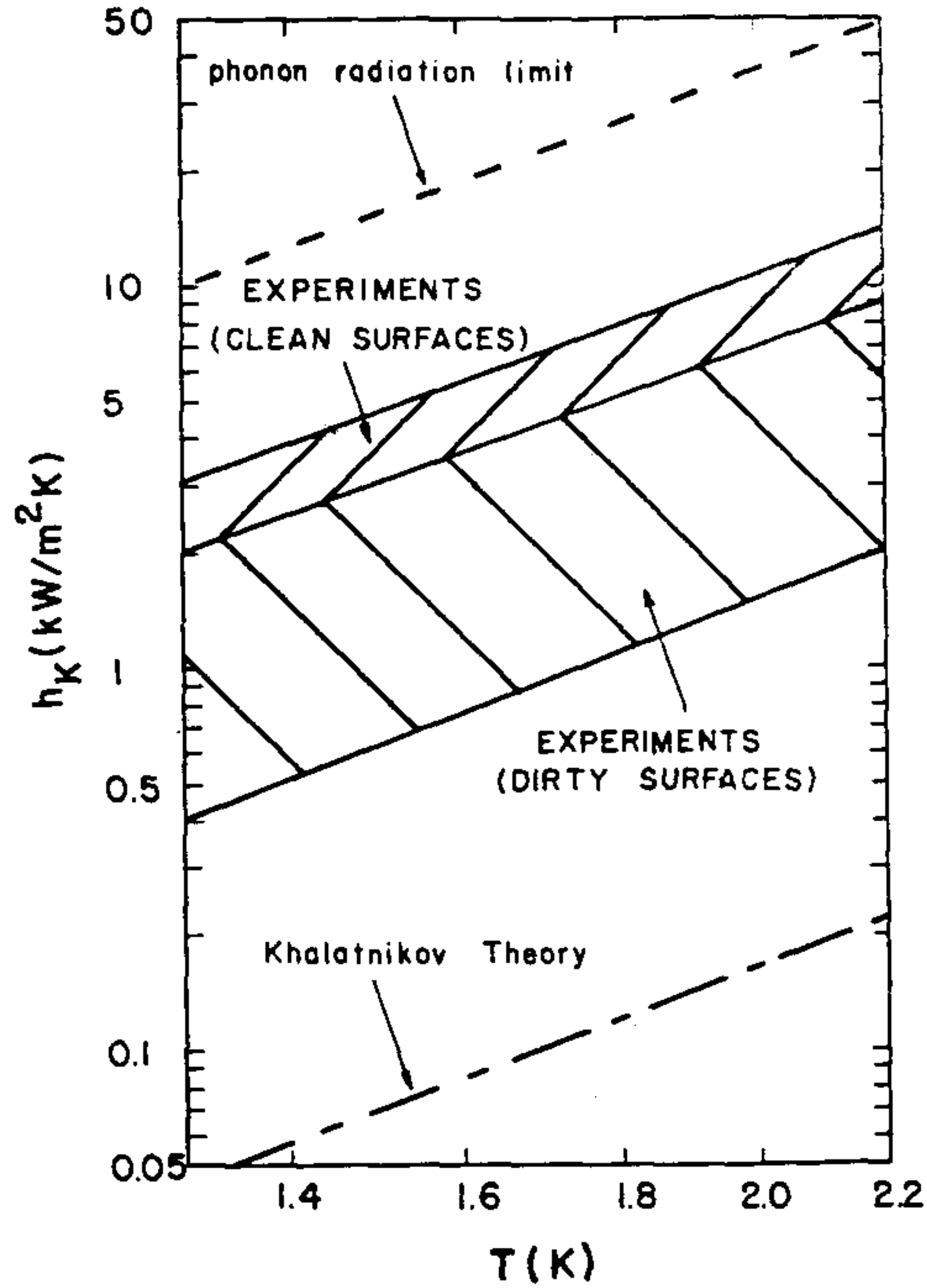


Figure 3-10
Kapitza Conductance for Copper
Helium Cryogenics ,S. W. Van Sciver, Plenum Press, (1986)

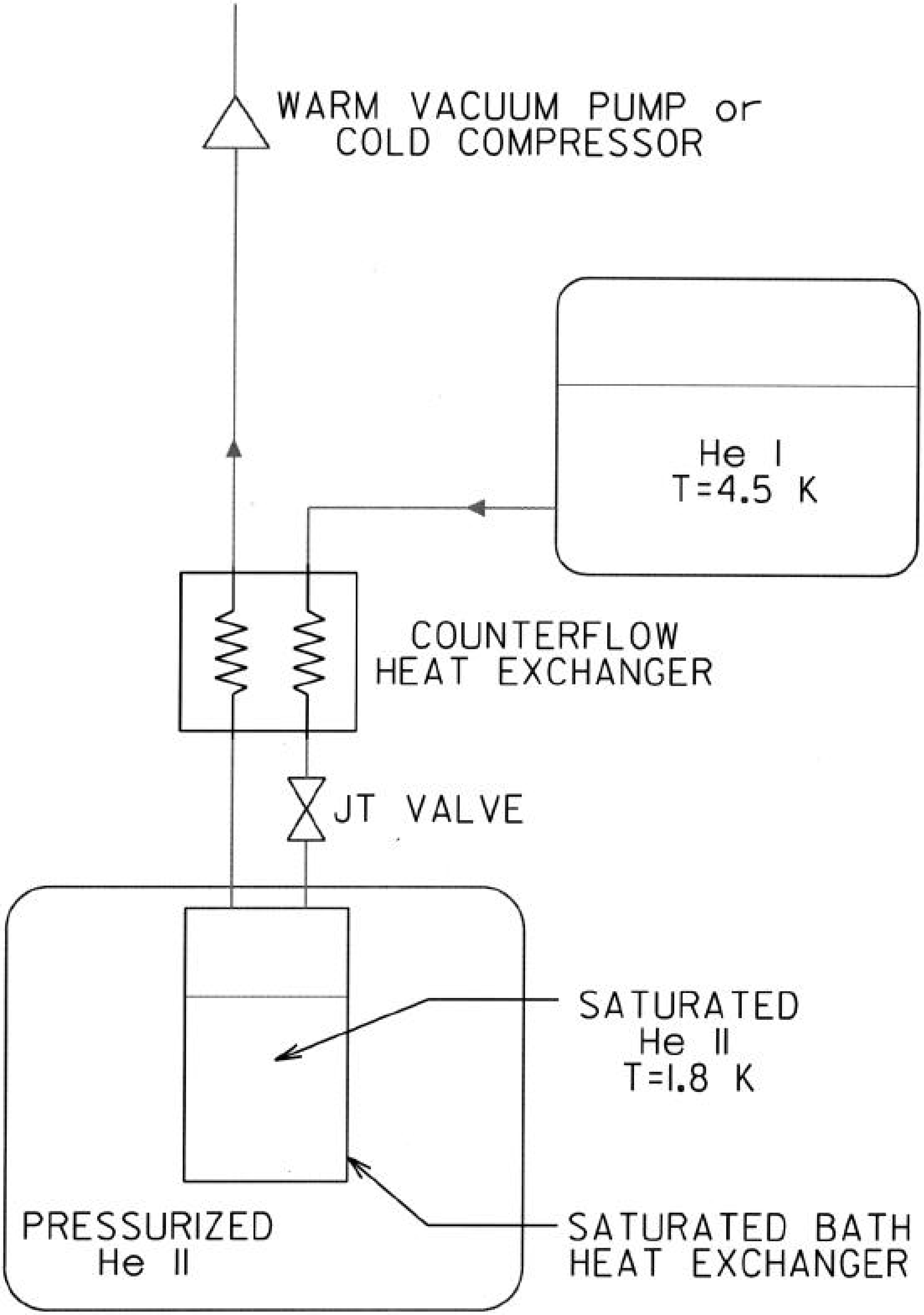
- **Fluid dynamics**
  - **Despite the presence of the superfluid component, in almost all engineering applications He II behaves as a classical fluid. This includes :**
    - ♦ **Pump performance**
    - ♦ **Pressure drop in tubes, valves, bellows and fitting**
    - ♦ **Flowmetering techniques**
  - **Not true for**
    - ♦ **Film flow**
    - ♦ **Porous plugs**
    - ♦ **Hot wire anemometers**

- **He II Heat Exchangers**

    - **Must take into account unique He II heat transfer properties**

    - **Must allow for rapidly changing specific heat with temperature**

    - **Handbook methods e.g.** e - **NTU are not suitable**


WARM VACUUM PUMP or
COLD COMPRESSOR
He I
T=4.5 K
COUNTERFLOW
HEAT EXCHANGER
JT VALVE
SATURATED
He II
T=1.8 K
PRESSURIZED
He II
SATURATED BATH
HEAT EXCHANGER