The beginning of dilution refrigeration in Leiden

Introduction

Thermodynamics (1959-'61) - 1965

London's Proposals for a Refrigerator to work below 1 °K 1951 - (1960-'62)

The ^3He circulating ^3He-^4He dilution refrigerator 1964

The ^4He circulating ^3He-^4He dilution refrigerator 1971

The cascade refrigerator 1967

H. London, 1951 LT2

Landau and Pomeranchuk (1948 - 1949)

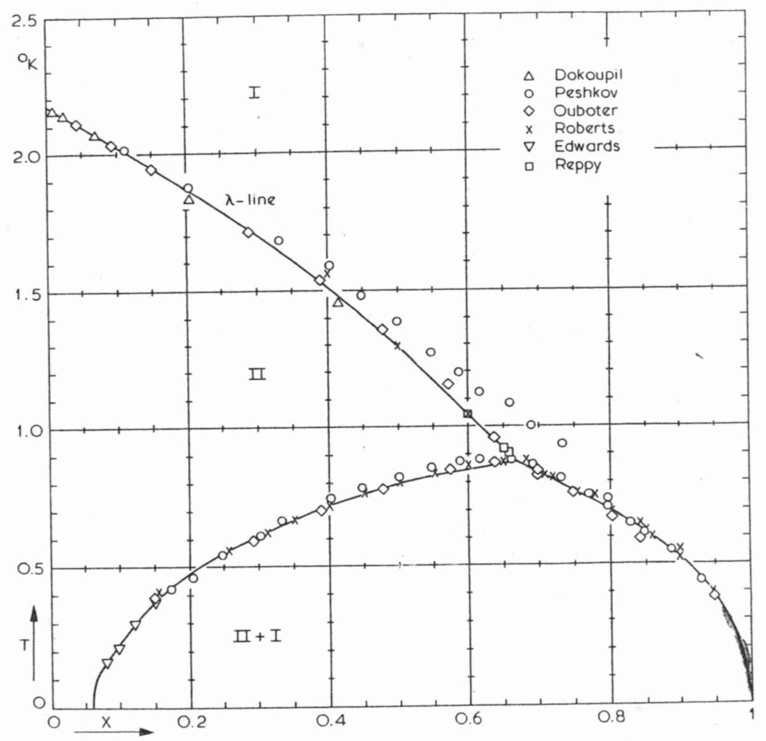
$$E = E_{03} + \frac{p^2}{2 m_3^*}$$

Walters and Fairbank (1956)

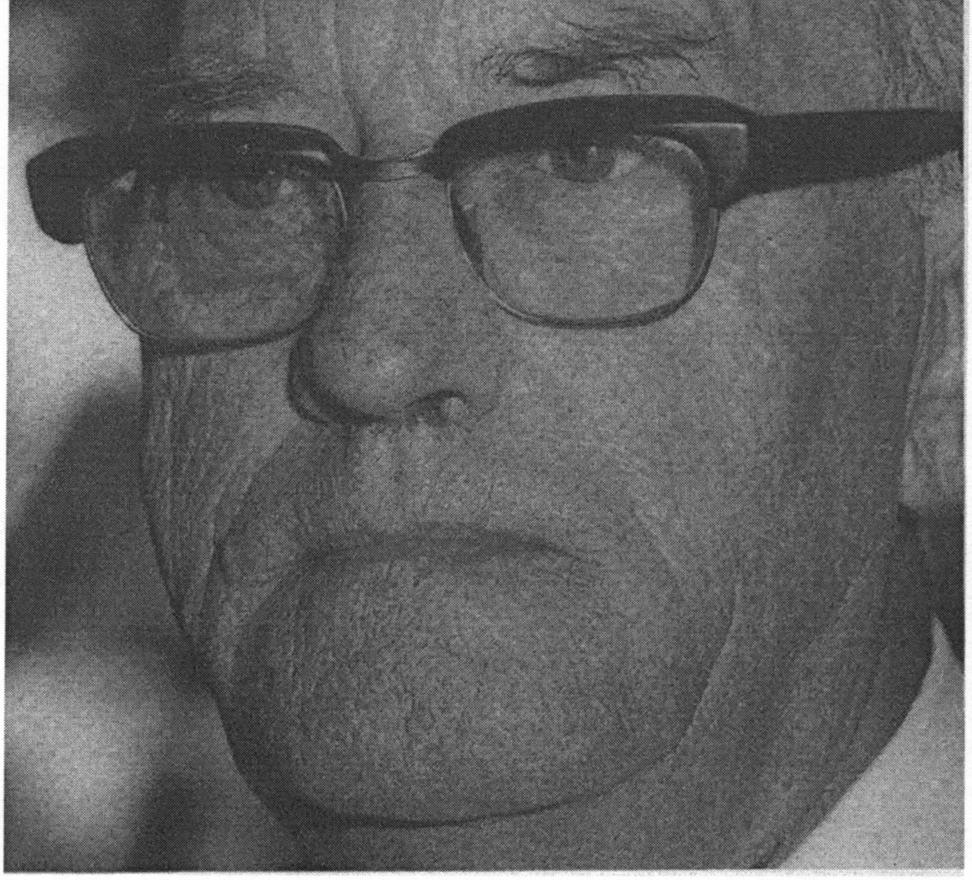
Phase separation
below 0.88 °K

H. London, Clarke, Mendoza
1960 - '62

③



2.5
°K
2.0
1.5
1.0
0.5
0
T
I
λ- line
II
II + I
Dokoupil
Peshkov
Ouboter
Roberts
Edwards
Reppy
0
X
0.2
0.4
0.6
0.8
1



Krijn Wijbren Taconis
20-7-1910 — 18-1-1992

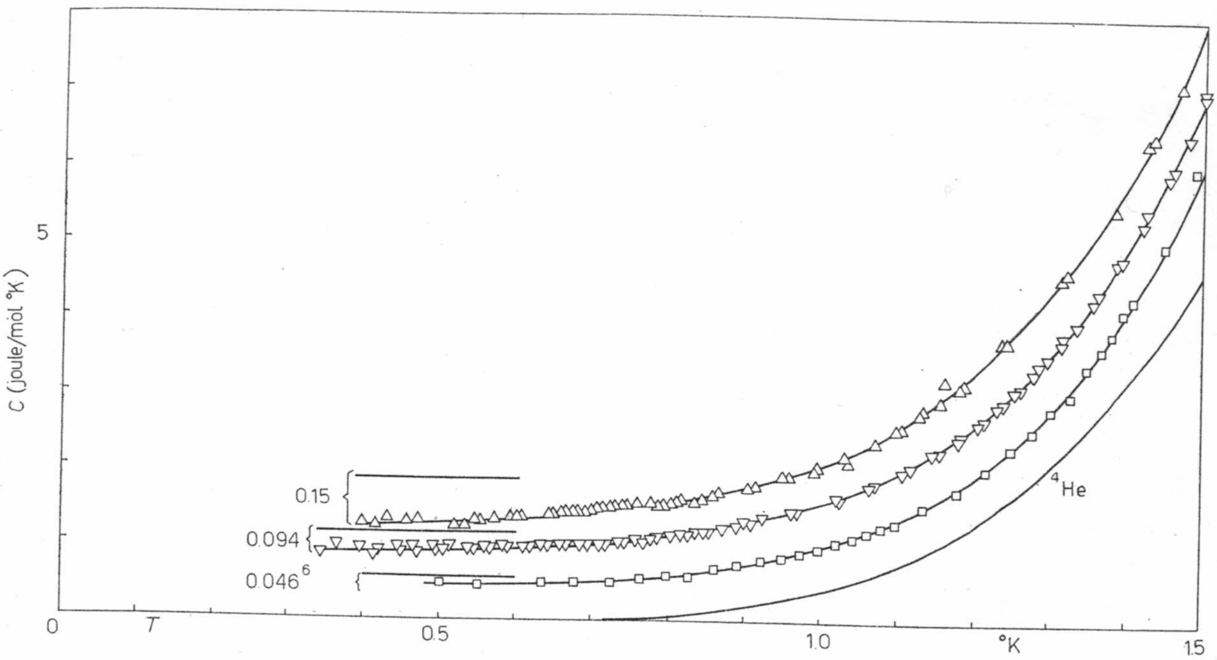
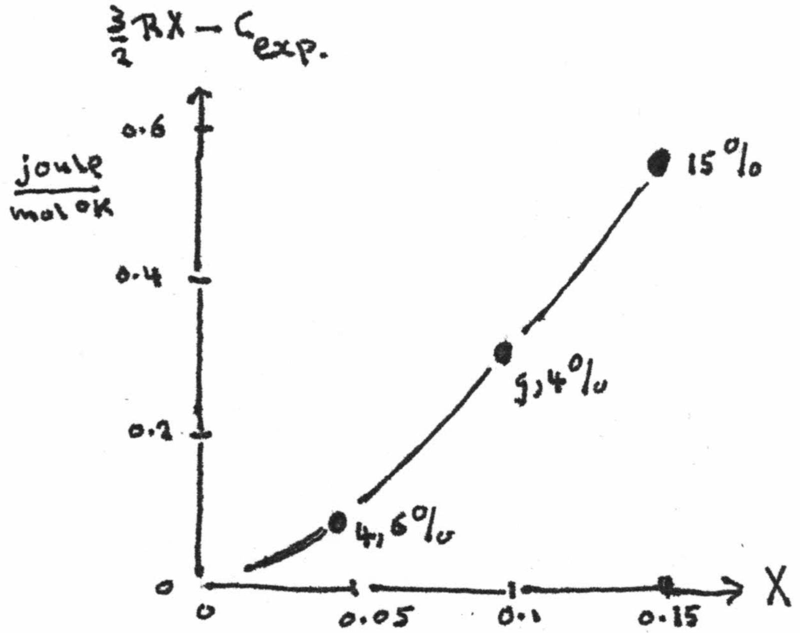


Fig. 1. – The specific heat of ³He-⁴He mixtures as a function of the temperature T at different concentrations: $X = 0.0466$, 0.094 and 0.15. The horizontal lines at low temperatures just above the curves are the theoretical values according to the theory of the ³He gaslike spectrum ($C_3 = \frac{3}{2}RX$).

R. de Bruyn Ouboter, K. W. Taconis, C. le Pair, J. J. M. Beenakker (1960)



(6)

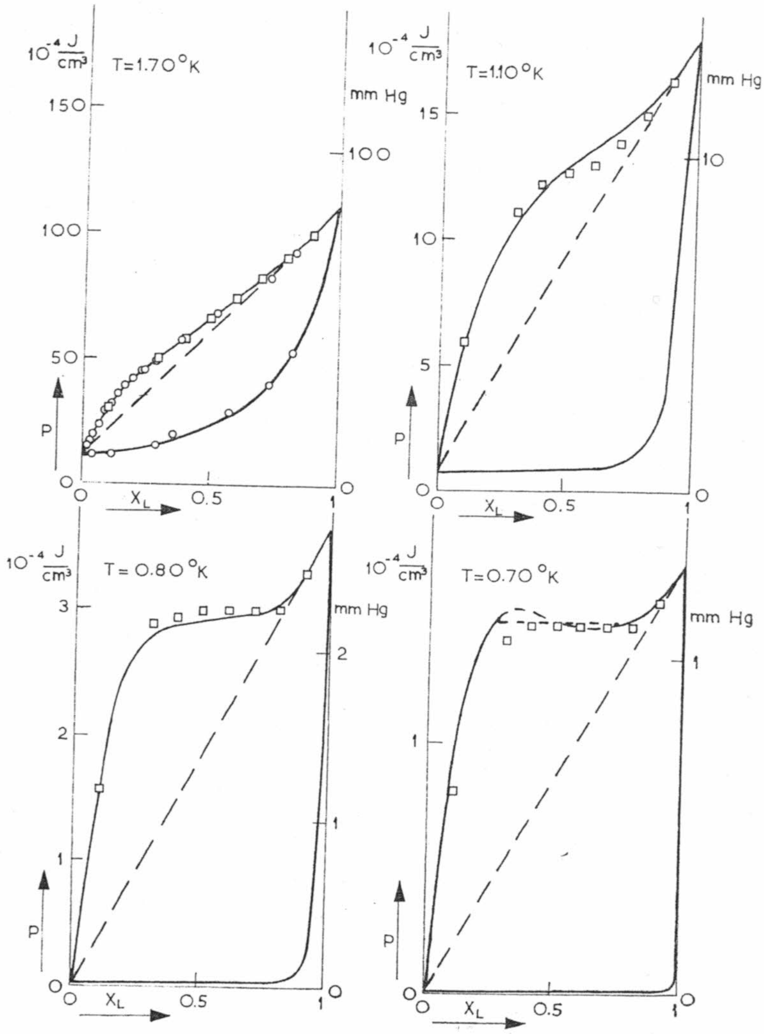


Fig. 8. Vapour liquid equilibrium diagrams at $T = 0.7°K$, $T = 0.8°K$, $T = 1.1°K$ and $T = 1.7°K$.

At $T = 0.7$, 0.8, 1.1°K the solid lines are calculated for a regular solution ($W/R = 1.54°K$).

⊙ Esel'son and Berezniak[2])

⊡ Roberts and Sydoriak[3])

R. de Bruyn Ouboter, J. J. M. Beenakker, K. W. Taconis (1959)

$$\mu_3 = NE_{03} + RT \ln\left[\frac{XN}{g_3 V_4{}^0}\left(\frac{2\pi\hbar^2}{m_3{}^* kT}\right)^{\frac{3}{2}}\right]. \tag{11}$$

$$NE_{03} = RT \ln\left[\frac{P_3}{X}\frac{V_4{}^0}{RT}\left(\frac{m_3{}^*}{m_3}\right)^{\frac{3}{2}}\right] \tag{13}$$

The potential energy NE_{03} (joule/mole) as a function of temperature T and concentration X.

X \ T(°K)	0.6	0.7	0.8	0.9	1.0
0.02	−21.5	−21.9	−22.1	−22.0	−21.6
0.04	−22.1	−22.6	−22.7	−22.7	−22.5
0.06	−22.6	−23.0	−23.1	−22.9	−22.9
0.08	−23.1	−23.3	−23.3	−23.3	−23.3
0.10	−23.5	−23.6	−23.6	−23.6	−23.5

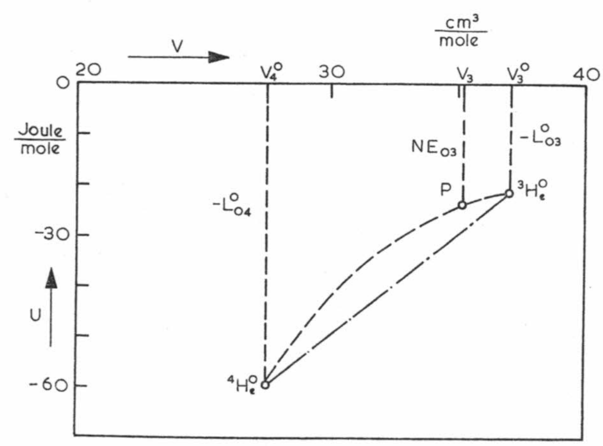
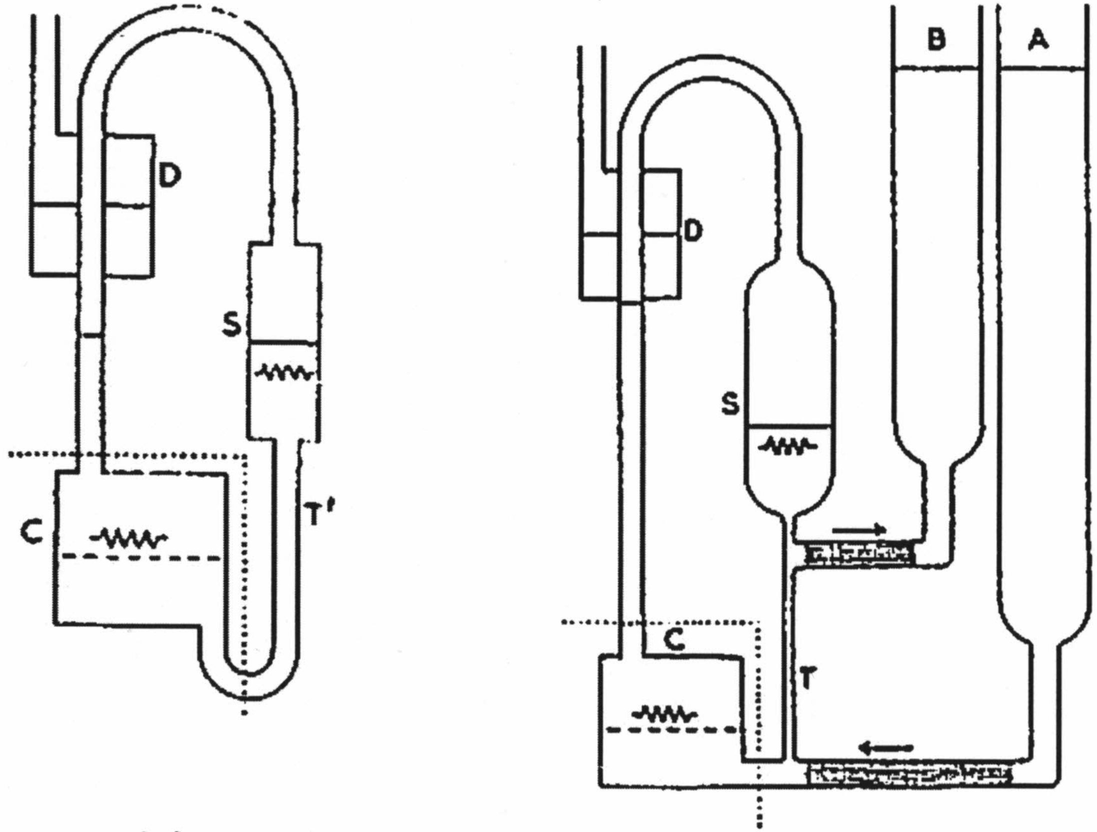


Fig. 18. $U^0{}_{03} = -L^0{}_{03}$, $U^0{}_{04} = -L^0{}_{04}$, NE_{03} as a function of the molar volume V. V_3=partial molar volume for a dilute mixture of ^{3}He in liquid ^{4}He derived from the molar volume experiments by Kerr [11]).

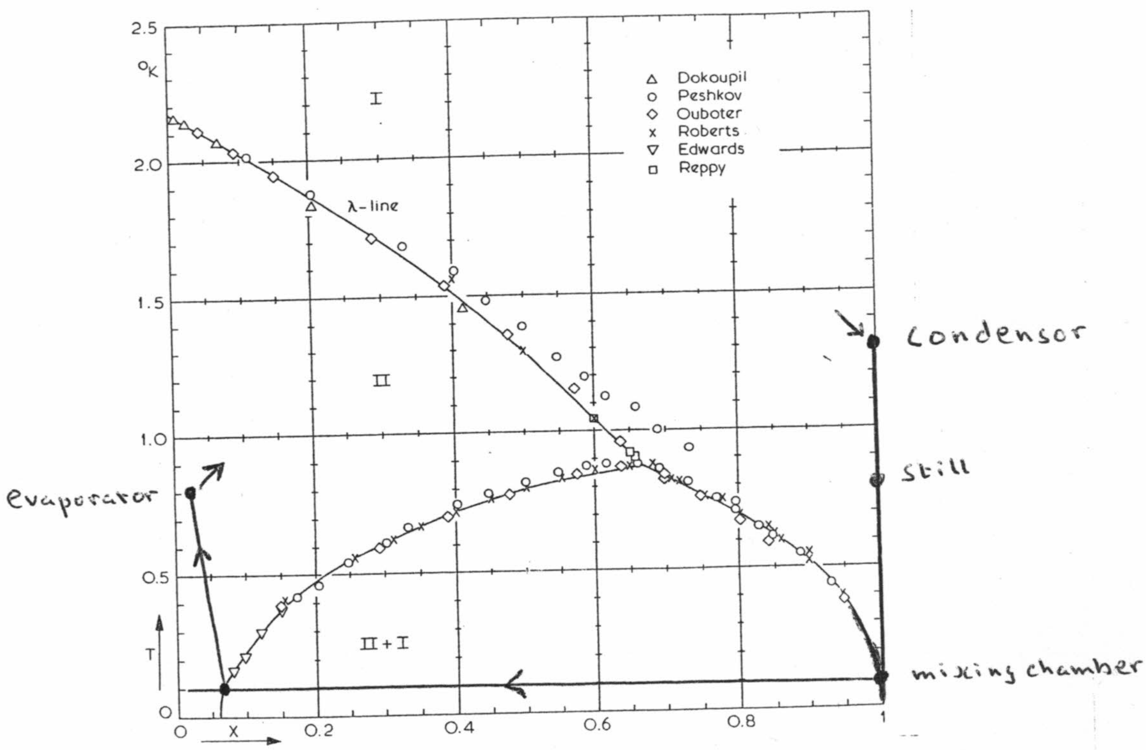


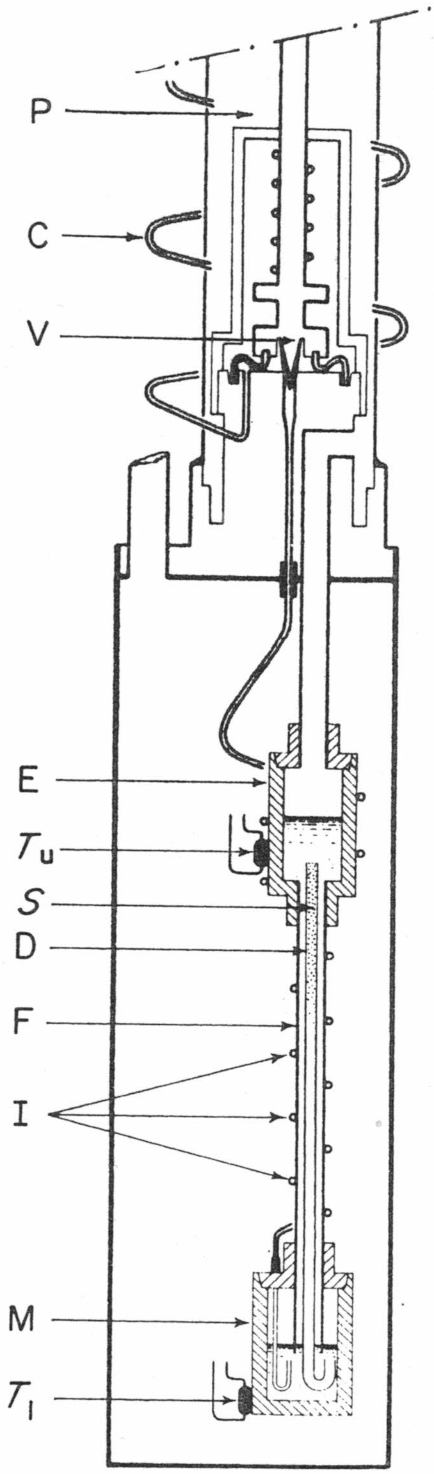
(a) (b)

Fig. 1. (a) Proposed scheme by London et al.: C mixing chamber with phase separation level; S evaporation and D condensor surrounded by ^{3}He bath. (b) Circulation increased by a superfluid vortexpump.

(1962)

H. London, G.R. Clarke, E. Mendoza


2.5
°K
2.0
1.5
1.0
0.5
T
0
0
X
0.2
0.4
0.6
0.8
1
I
II
II + I
λ- line
Dokoupil
Peshkov
Ouboter
Roberts
Edwards
Reppy
Condensor
still
evaporator
mixing chamber



The first dilution refrigerator

Das, de Bruyn Ouboter, Taconis (1964)

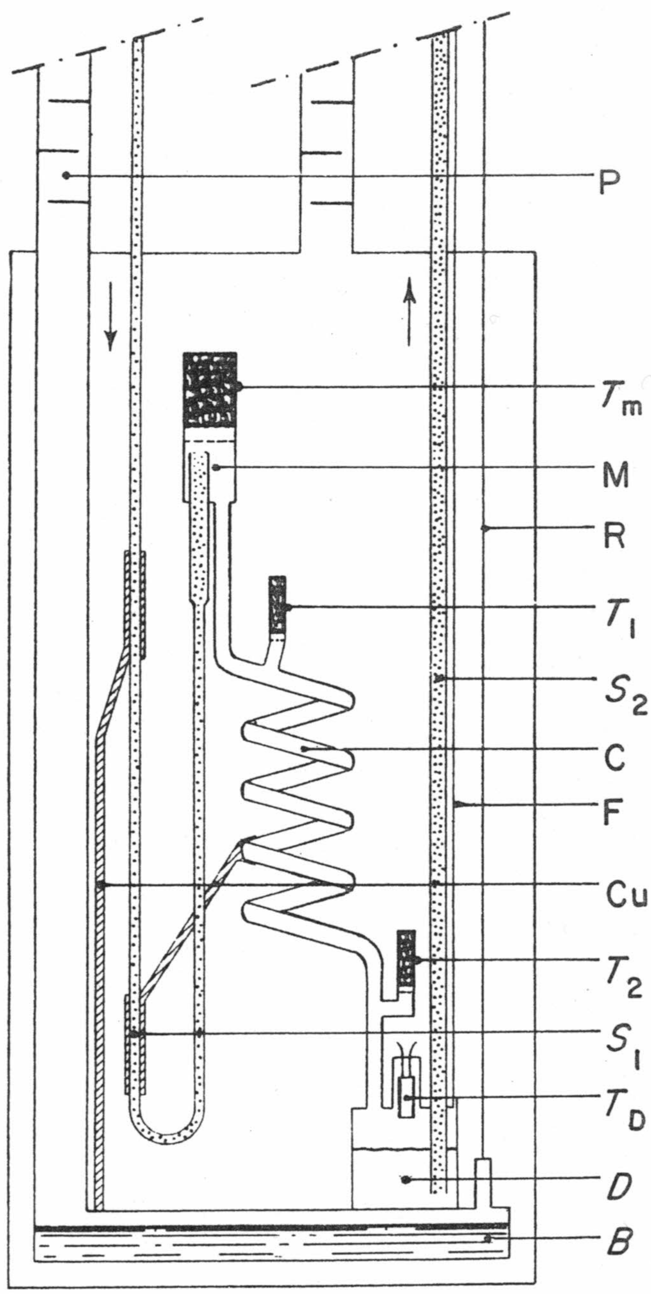
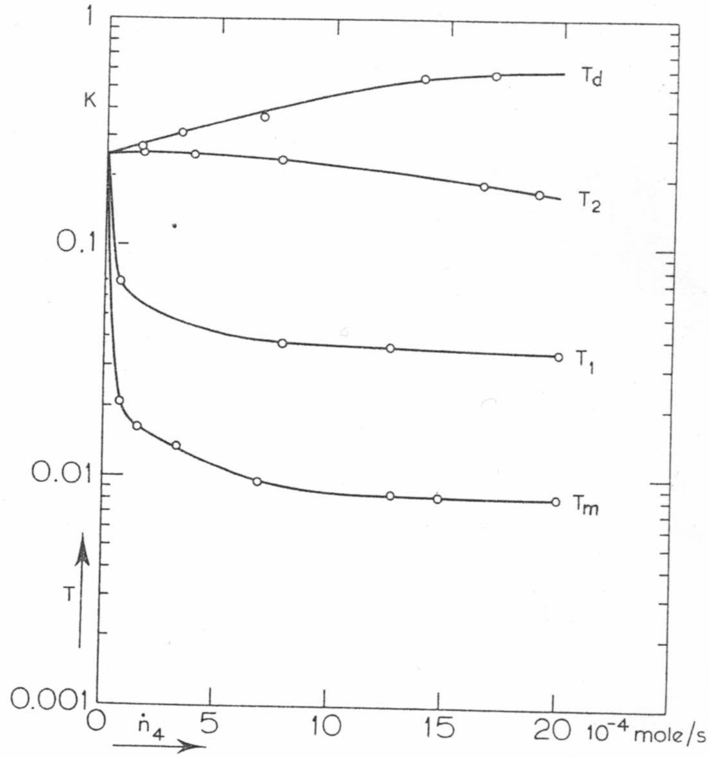
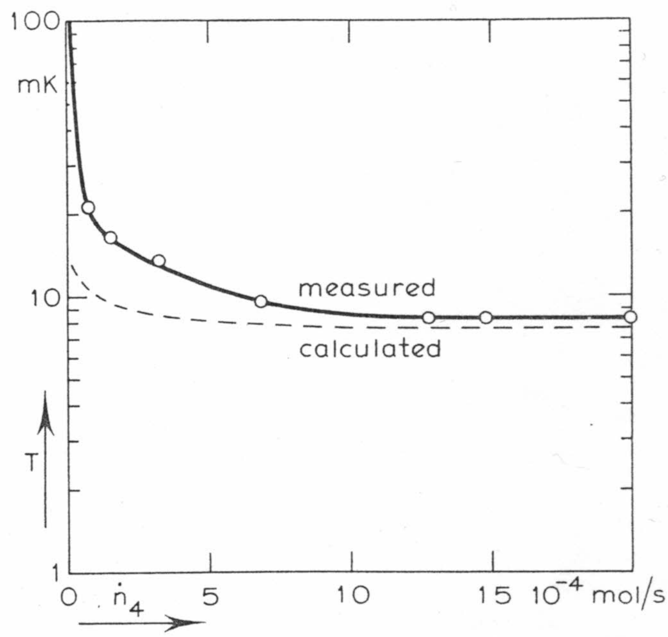
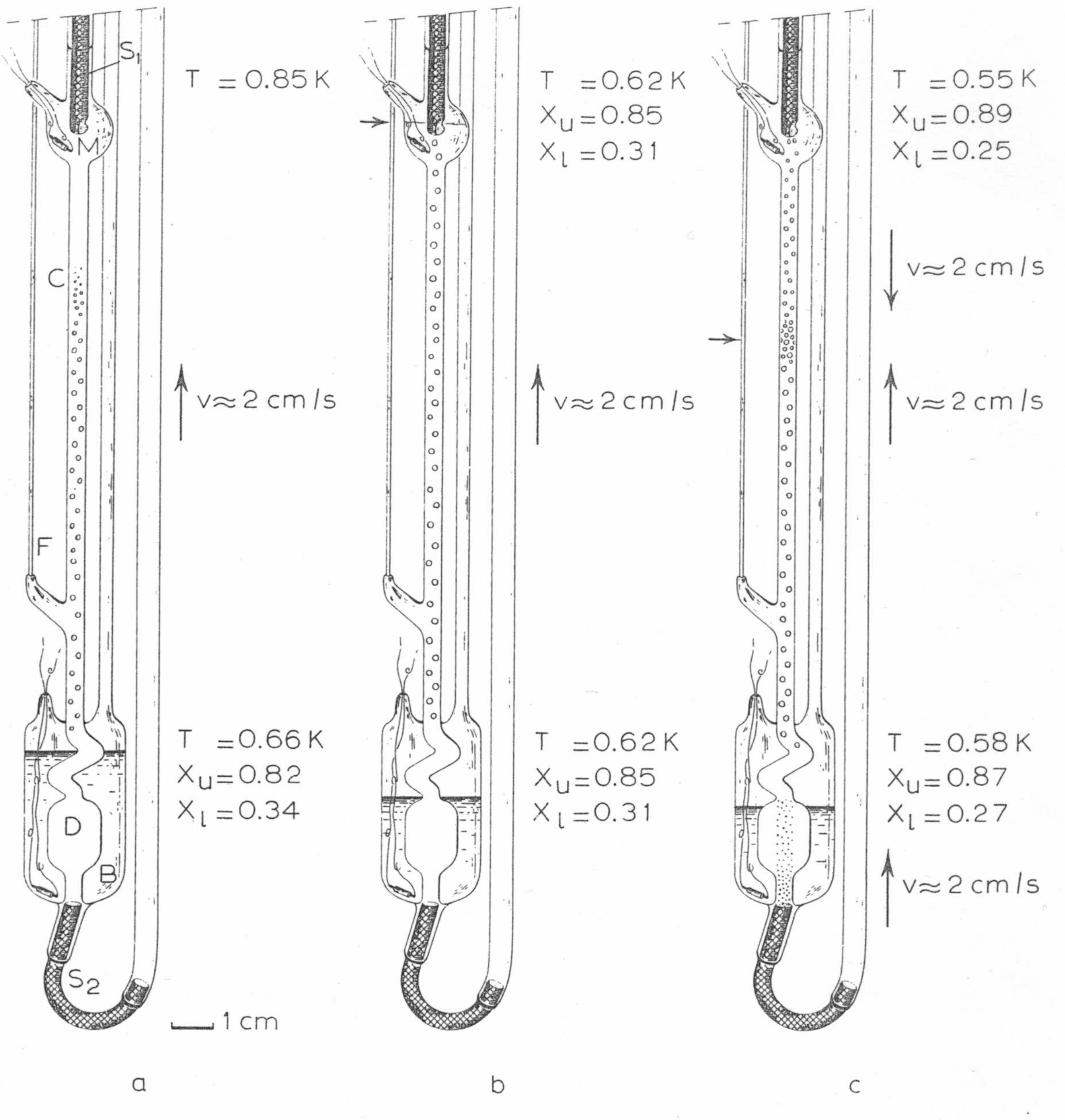


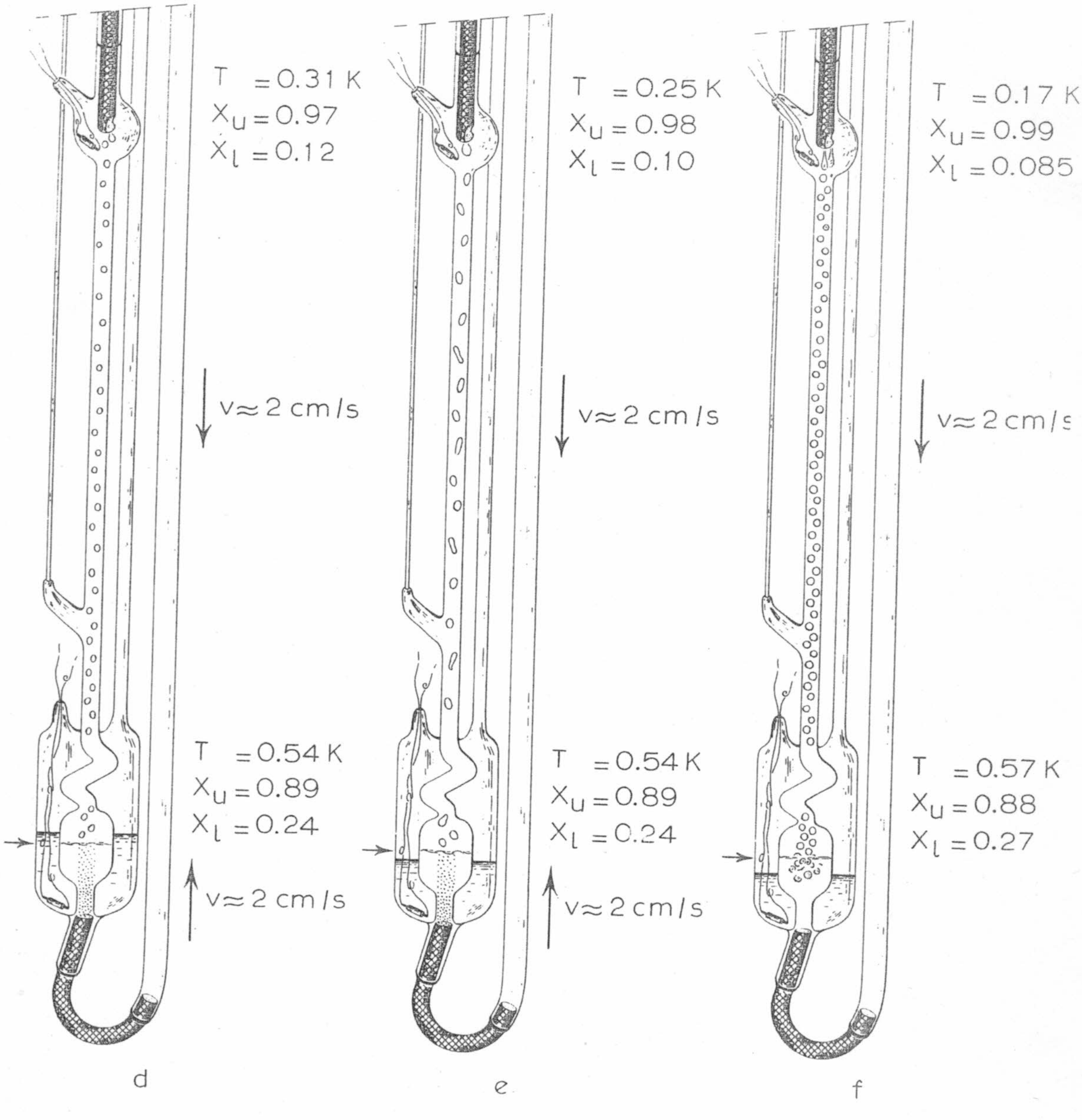
Fig. 3 Dilution refrigerator with flow of He^4 regulated at room temperature

Taconis, Pennings, Das and de Bruyn Ouboter (1971)


1
K
0.1
0.01
0.001
T
Td
T2
T1
Tm
0
5
10
15
20
10^-4 mole/s
ṅ4


100
mK
10
1
T
measured
calculated
0
5
10
15
10^-4 mol/s
ṅ4


S1
M
C
F
D
B
S2
T = 0.85 K
v ≈ 2 cm/s
T = 0.66 K
Xu = 0.82
Xl = 0.34
1 cm
a
T = 0.62 K
Xu = 0.85
Xl = 0.31
v ≈ 2 cm/s
T = 0.62 K
Xu = 0.85
Xl = 0.31
b
T = 0.55 K
Xu = 0.89
Xl = 0.25
v ≈ 2 cm/s
v ≈ 2 cm/s
T = 0.58 K
Xu = 0.87
Xl = 0.27
v ≈ 2 cm/s
c



van den Brandt, Tierolf, Griffioen, de Bruyn Ouboter

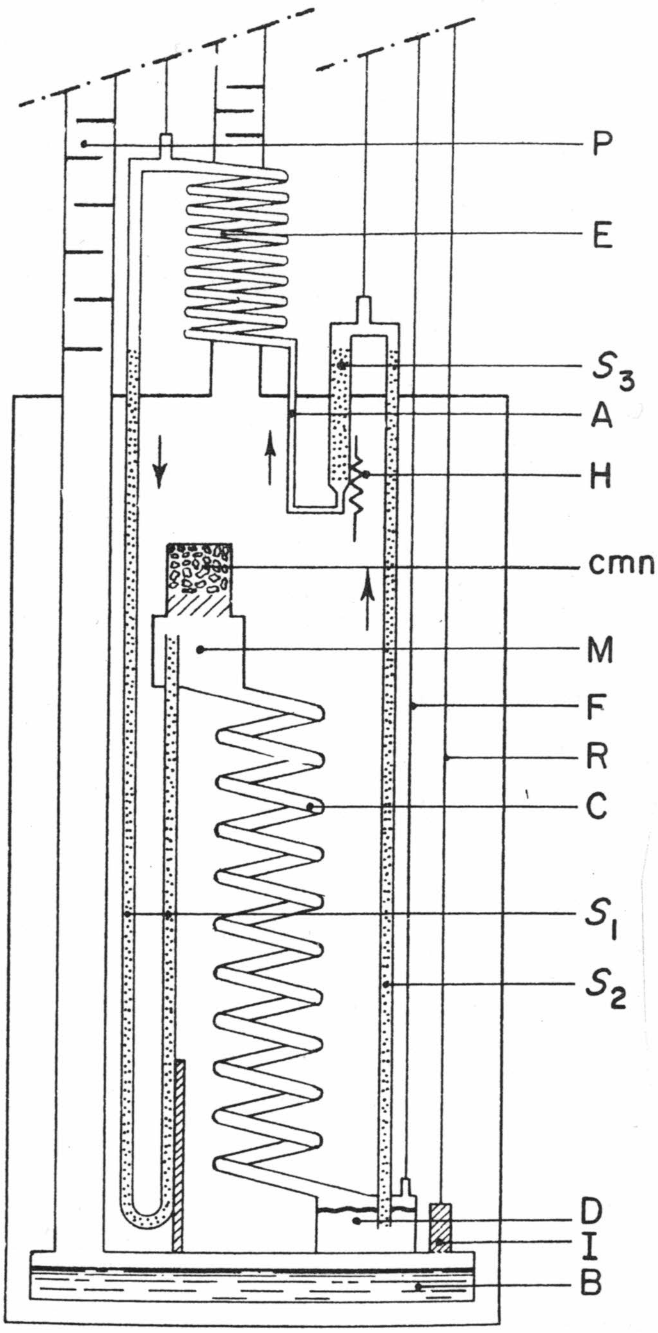


Fig. 4 Dilution refrigerator with a fountain pump

(16)

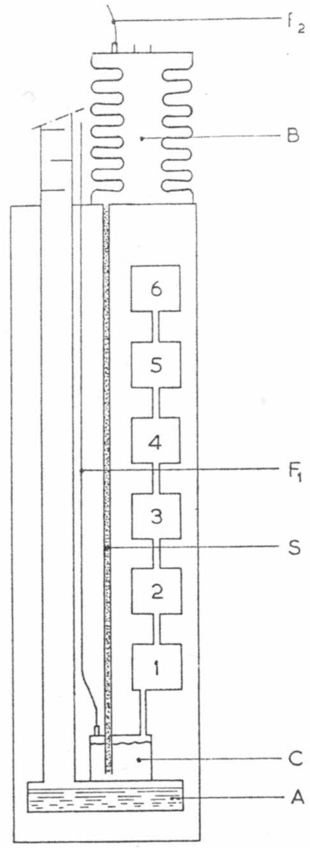


Fig. 1. F_1, F_2 – capillaries; B – bellows; S – superleak; C – vessel; A – ^{3}He bath; 1–6 – vessels.

Pennings, Taconis, Das, de Bruyn Ouboter (1967)