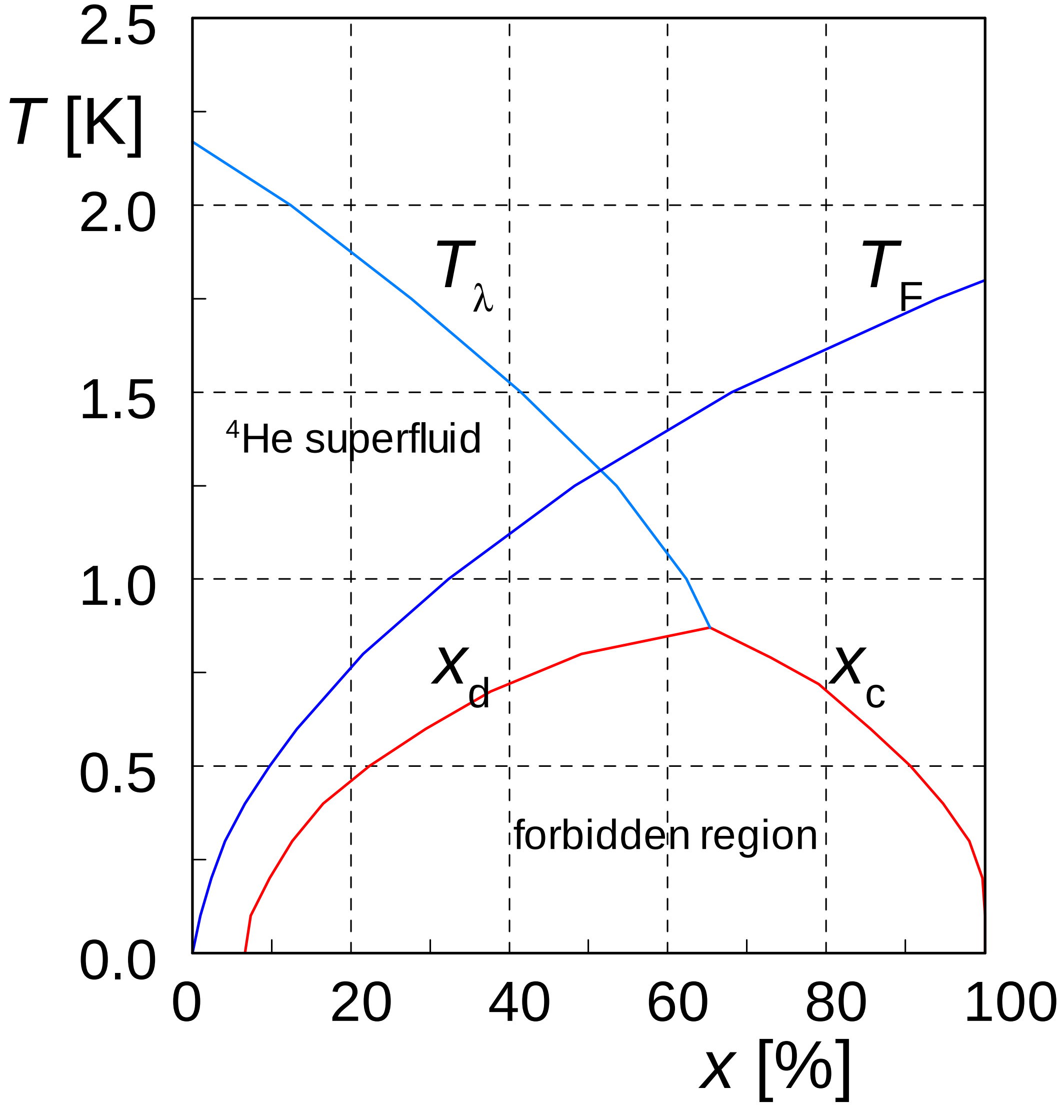
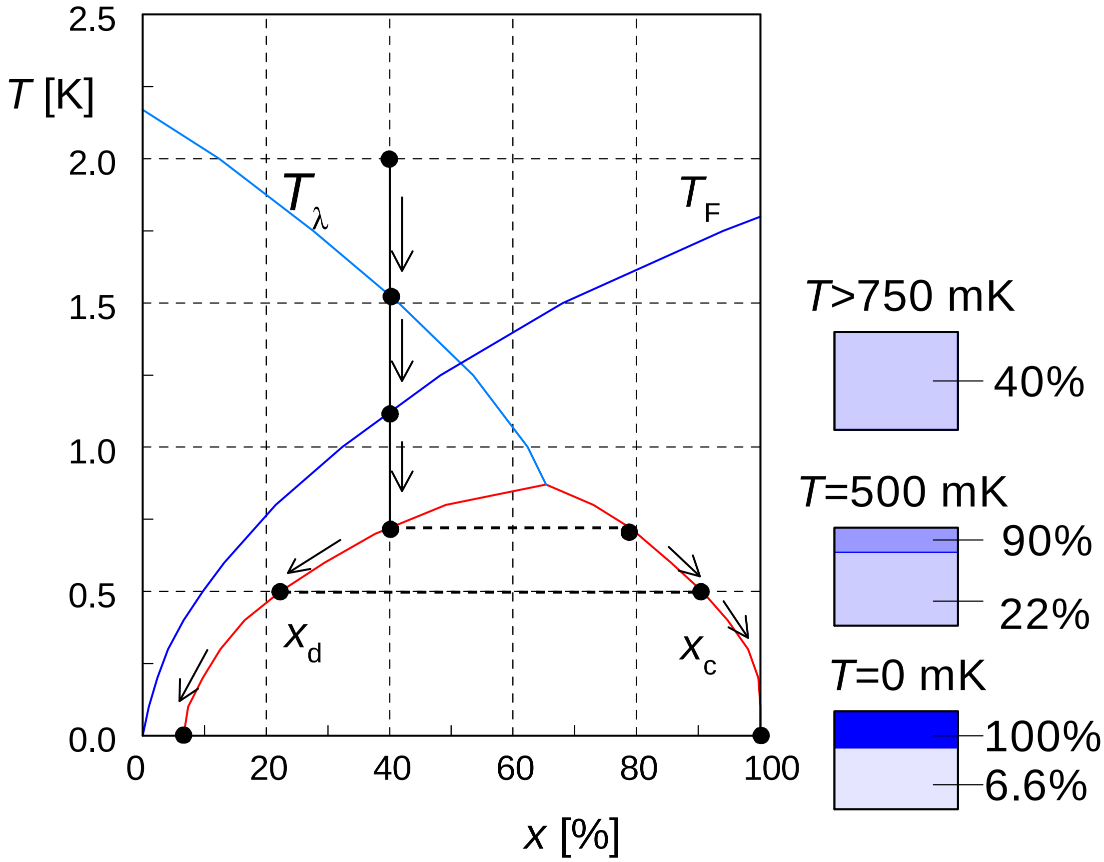
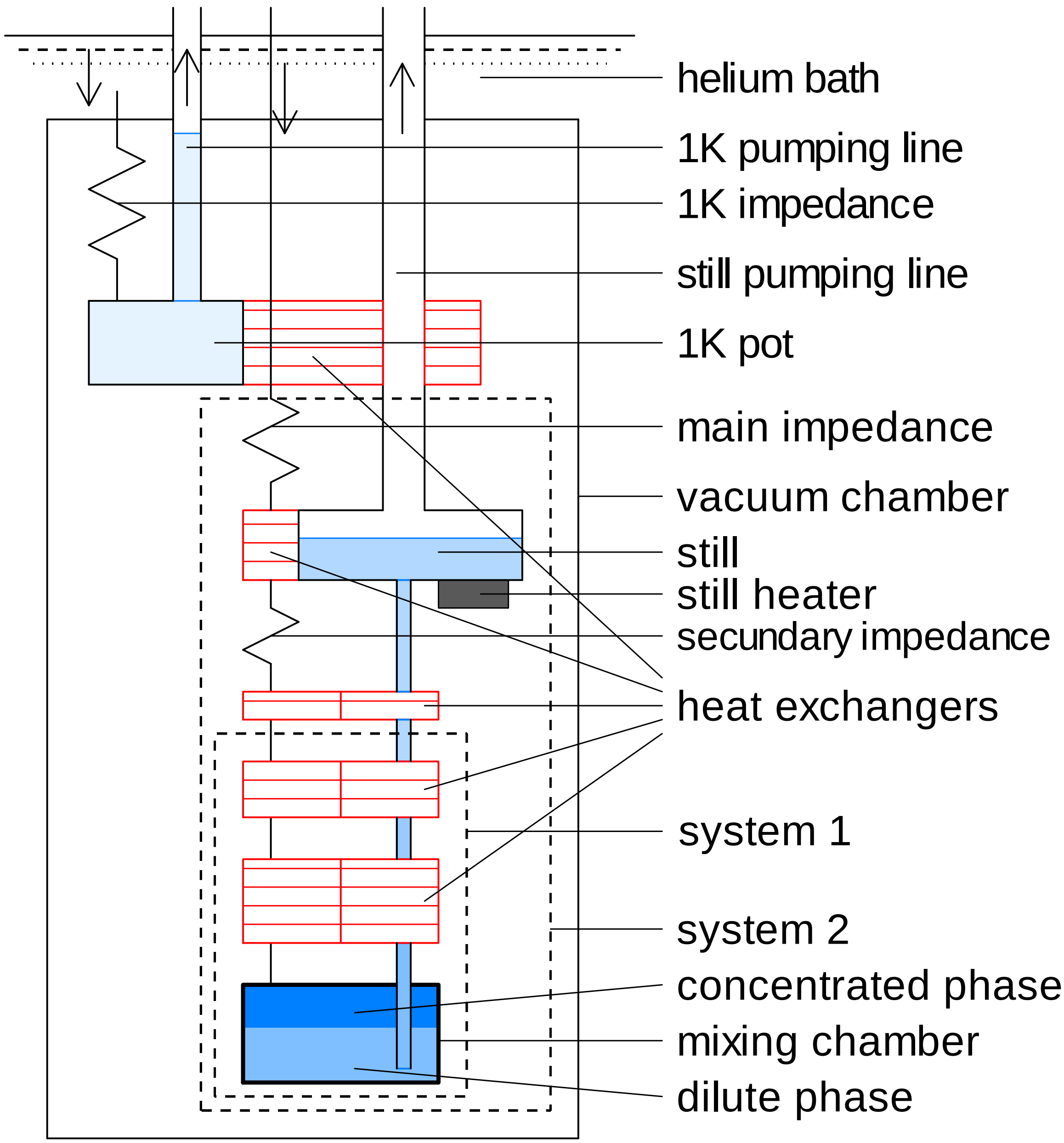
Dilution refrigerators

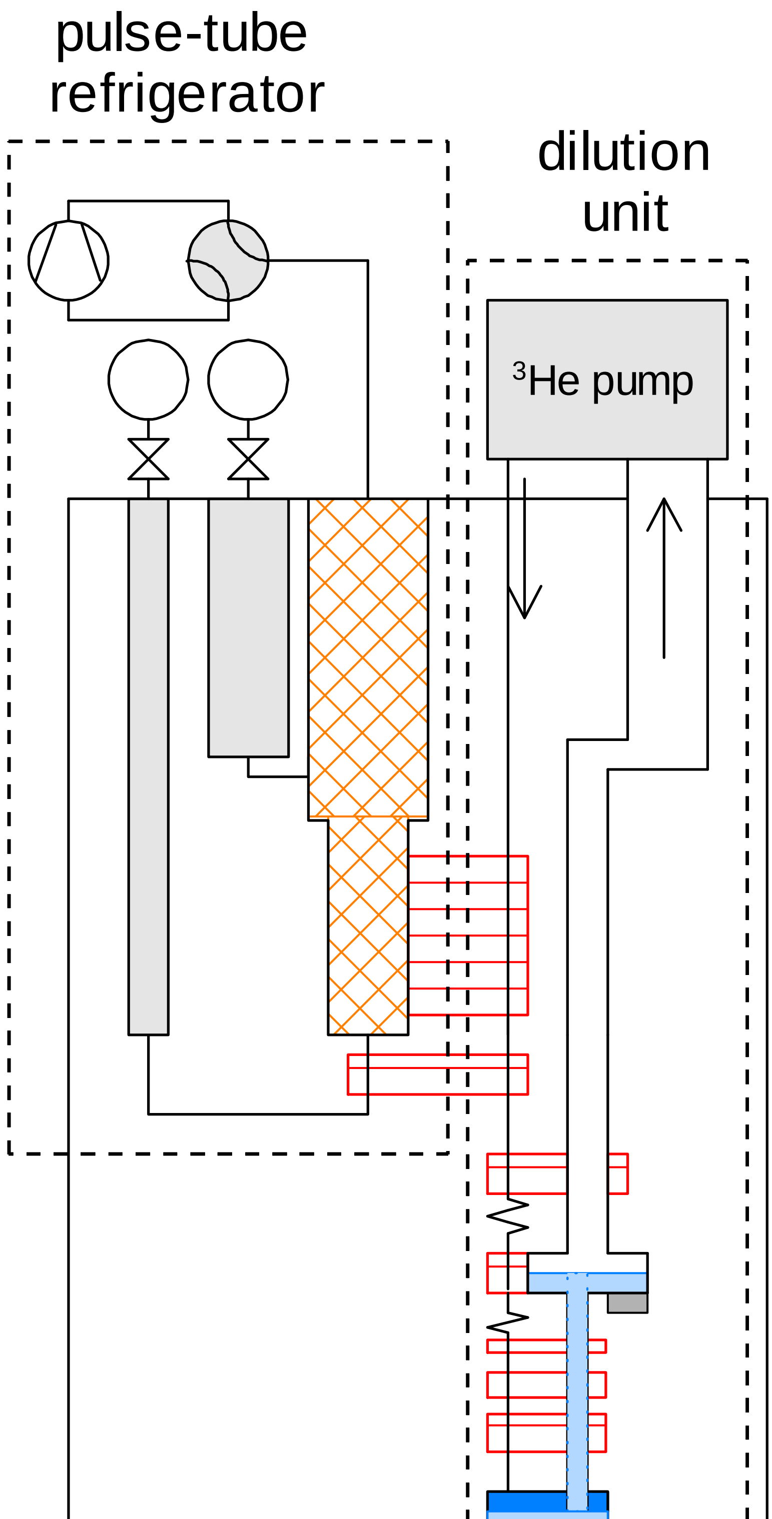
3He-4He phase diagram

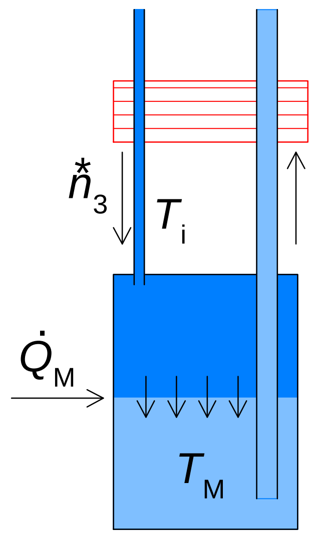




HePhaseDib.tc


helium bath
1K pumping line
1K impedance
still pumping line
1K pot
main impedance
vacuum chamber
still
still heater
secundary impedance
heat exchangers
system 1
system 2
concentrated phase
mixing chamber
dilute phase


pulse-tube
refrigerator
dilution
unit
³He pump



if $T_\mathsf{i} = T_\mathsf{M}$ then from second law

$$\dot{Q}_\mathsf{M} = \overset{*}{n}_3 T_\mathsf{M} \left(S_\mathsf{md} - S_\mathsf{mc}\right)$$

with ideal Fermi gas

$$S_\mathsf{m} \sim T_\mathsf{M} V_\mathsf{m}^{2/3}$$

so

$$\dot{Q}_\mathsf{M} \sim \overset{*}{n}_3 T_\mathsf{M}^2 \left(V_\mathsf{md}^{2/3} - V_\mathsf{mc}^{2/3}\right)$$

with $V_\mathsf{md} = 426$ and $V_\mathsf{mc} = 37$ cm^3/mol
so $\dot{Q}_\mathsf{M}$ is due to the expansion of the ^{3}He

in general ($T_i \neq T_M$) at low temperatures

$$\dot{Q}_M \approx \overset{*}{n}_3 \left(96T_M^2 - 12T_i^2\right)$$

if $\dot{Q}_M = 0$ (base temperature)

$$96T_M^2 = 12T_i^2$$

or

$$T_M = \frac{1}{\sqrt{8}} T_i \approx \frac{T_i}{2.8}$$

Kapitza resistance in the heat exchangers

$$\dot{Q}_X \sim A_H \left(T_H^4 - T_L^4\right) \approx A_H T_H^4$$

while

$$\dot{Q}_X \sim \overset{*}{n}_3 T_H^2$$

so

$$A_H \sim \frac{1}{T_H^2}$$

use very fine (silver) powder to get large A_H
at low temperatures the heat exchanger become very big