SAND2015-10823C

Techniques and Challenges of Helium Cryogenics

Chloé Bureau-Oxton
Université de Sherbrooke
Sandia National Laboratories

2015/01/06

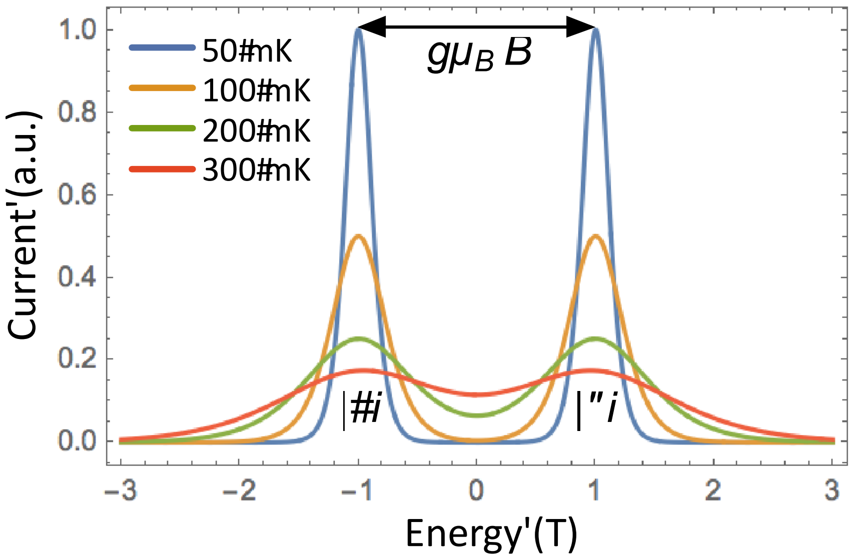
Outline

- Why are low temperatures needed?
- Why use helium?
- Helium cryogenic systems
  - Dippers
  - 1K pots
  - Dilution refrigerators
- Challenges

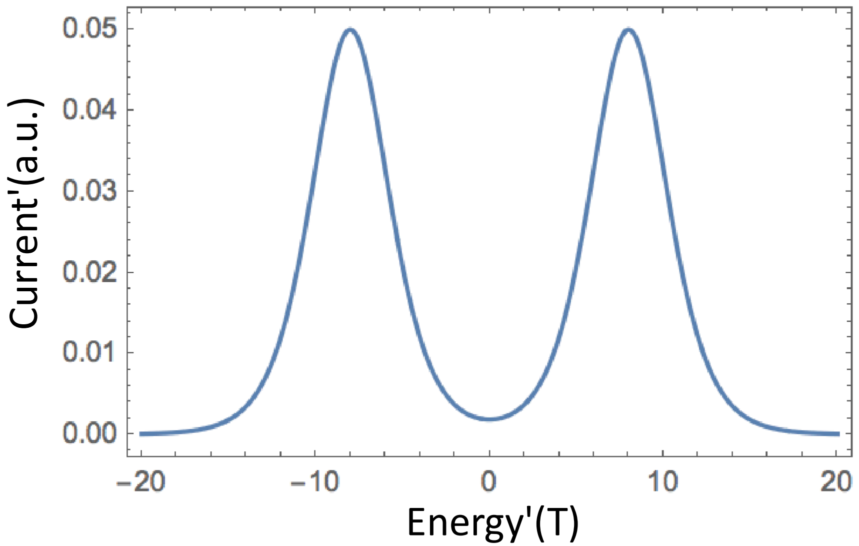
INTRODUCTION

Why are low temperatures needed?

Energy splitting for a single electron in a magnetic field of 1 T



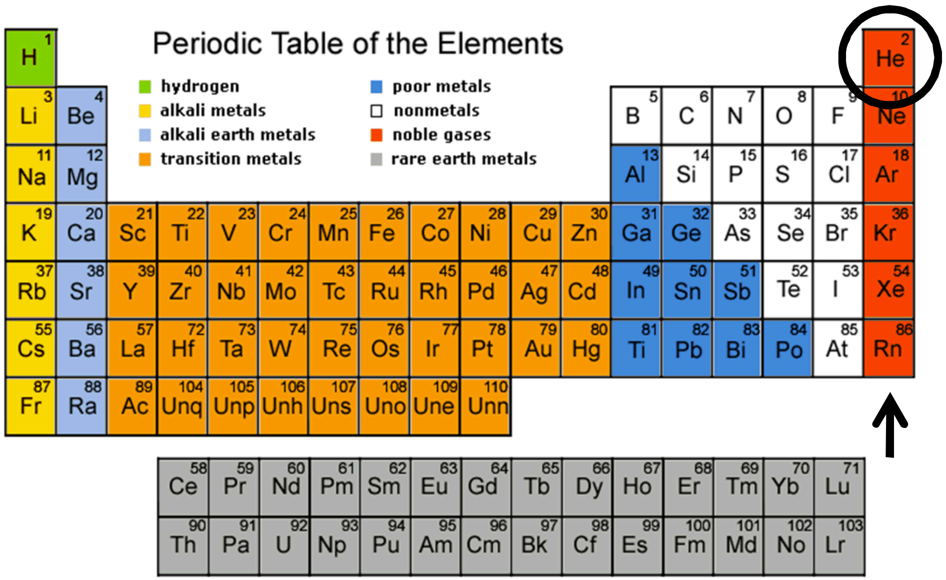
Energy splitting for a single electron at 1 K in a magnetic field of 8 T



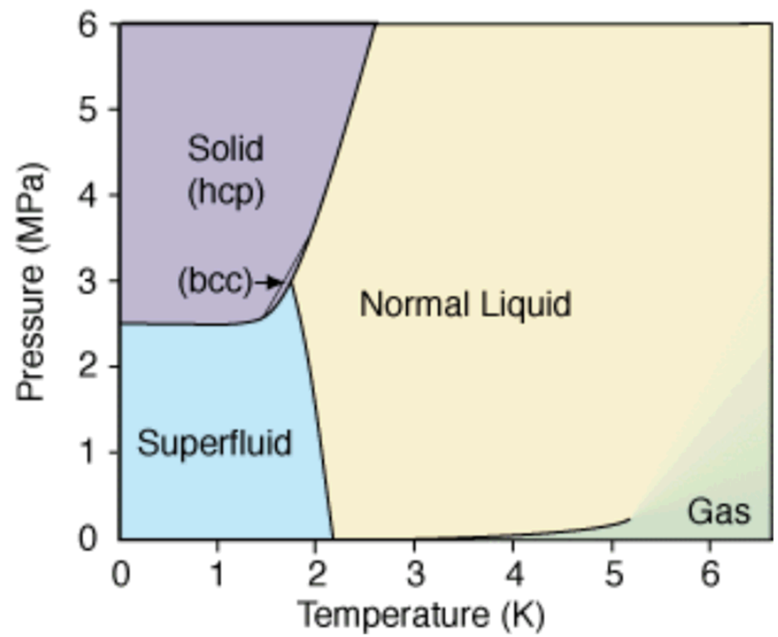
$$\frac{1}{T_1} \propto B^5$$

The relaxation rate in a field of 8T is 30000 faster than at 1 T

Why use helium?



Helium is a noble gas and rarely reacts with other elements.



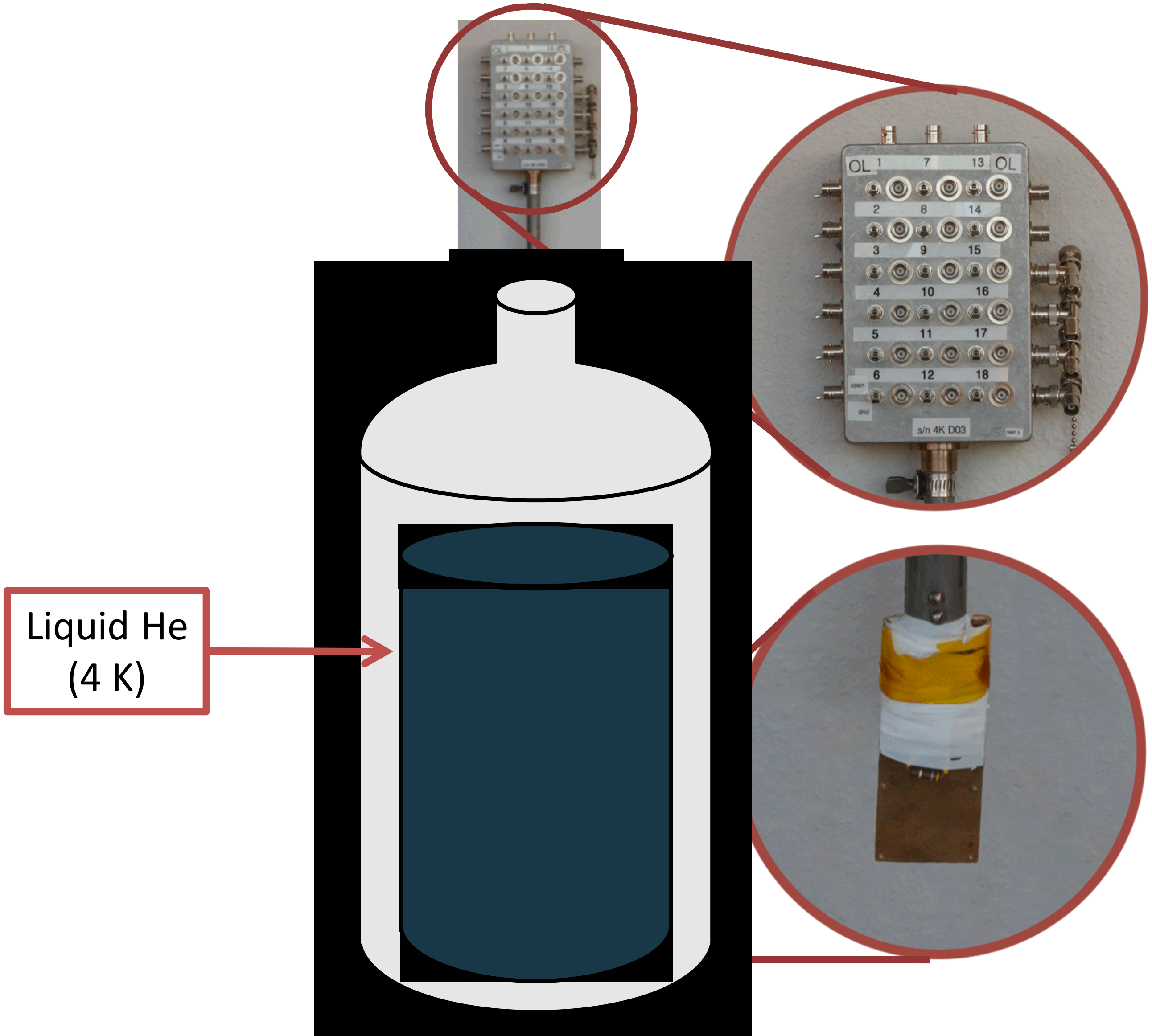
At low pressure, helium is never a solid.

$$\Delta x \Delta p \leq \frac{\hbar}{2}$$

$$K = \frac{\Delta p^2}{2m} = \frac{\hbar^2}{8m\Delta x^2}$$

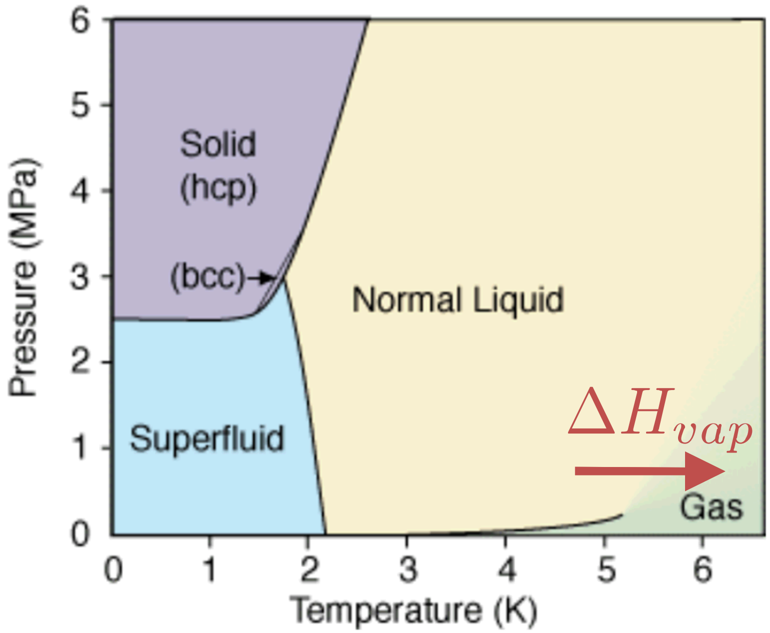
HELIUM CRYOGENIC SYSTEMS

Dippers (4 K)

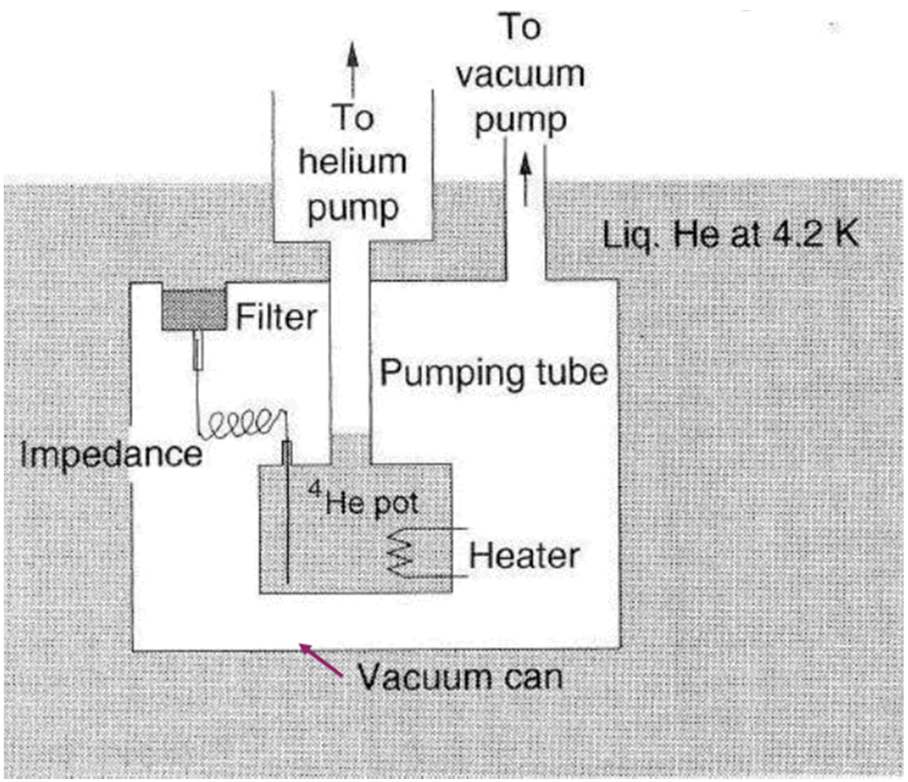


1K pots (> 1 K)

Evaporative cooling



The boiling point of a liquid is a function of its vapor pressure. **Just by pumping on a liquid, it is possible to cool it.**

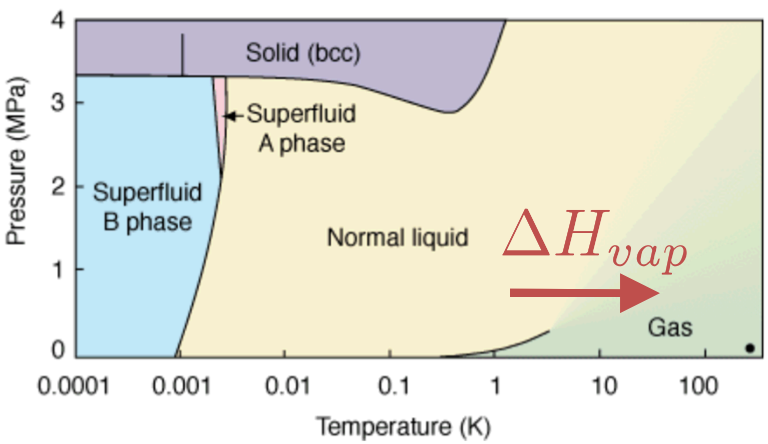


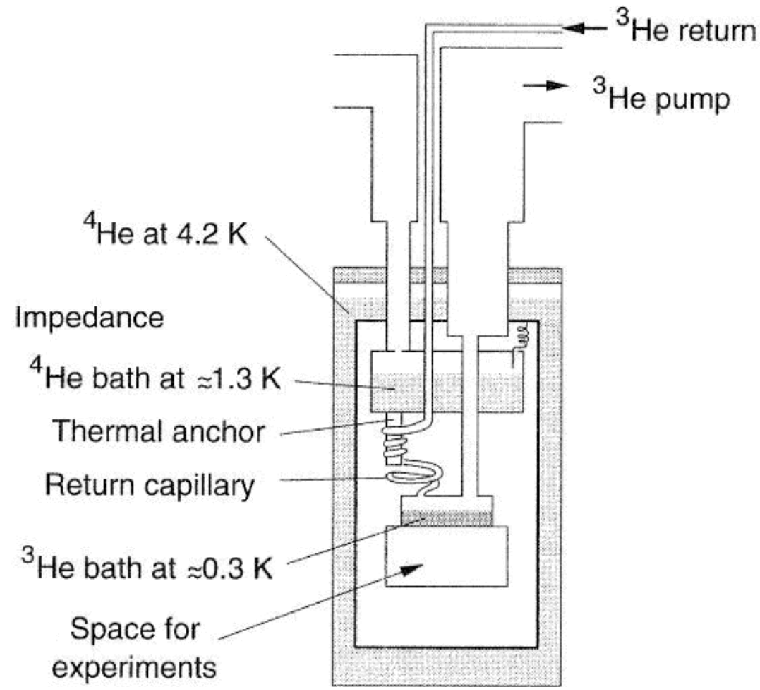
Simply by pumping on ^{4}He, temperatures of ~ 1 K can be reached.

The record low for a 1K pot is ~ 0.75 K.

^{3}He refrigerators (~ 300 mK)

Evaporative cooling (again)



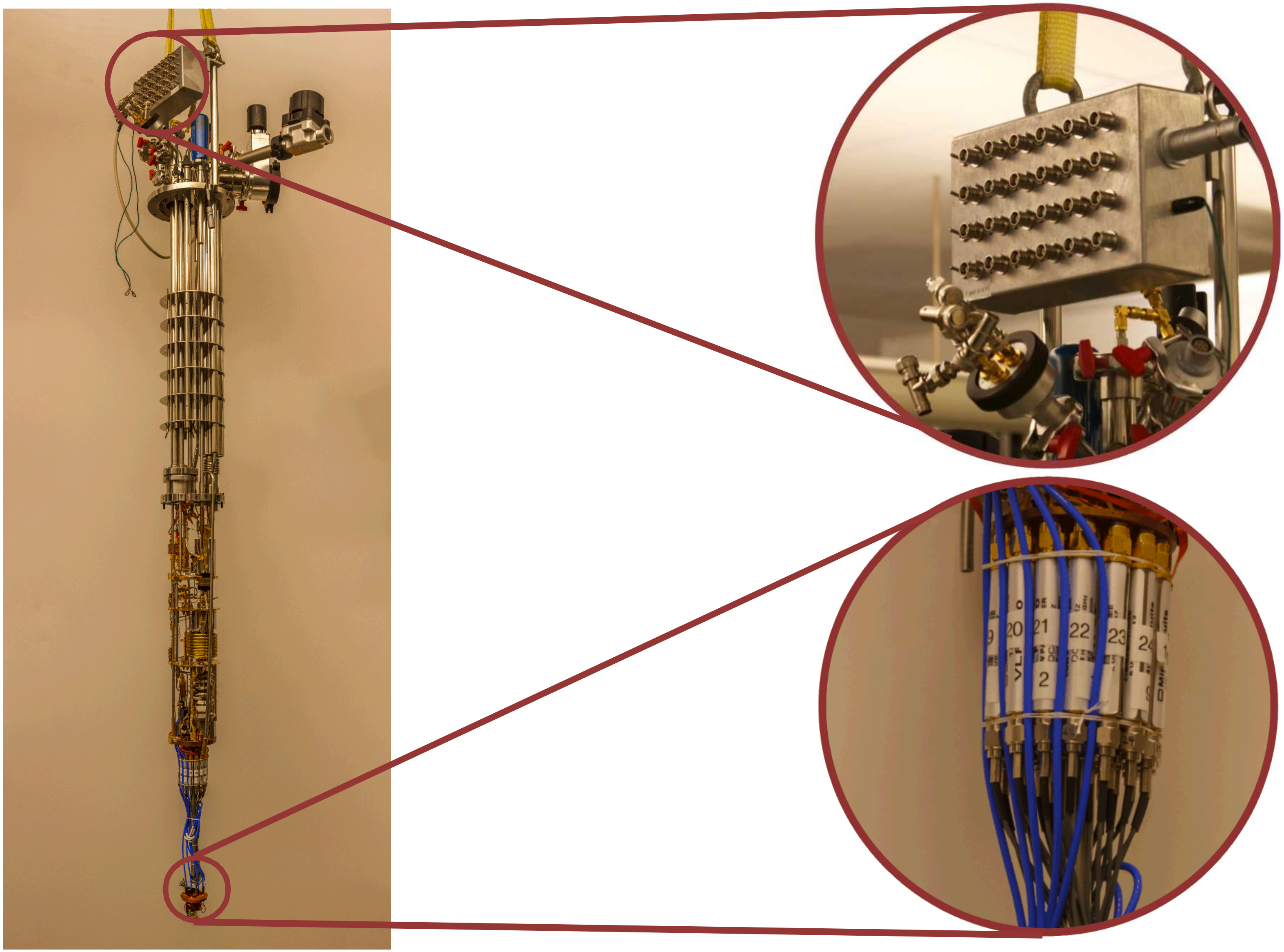


Natural occurrence of ^{3}He is 0.000137%.

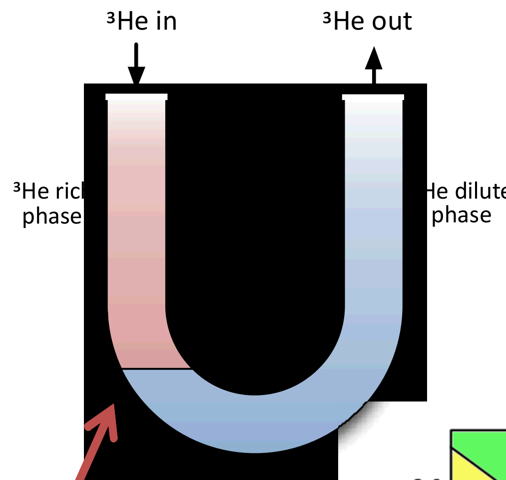
➔ 1 L of ^{3}He ≈ 100000$.

➔ The ^{3}He is reused.

Dilution refrigerators (~10 mK)

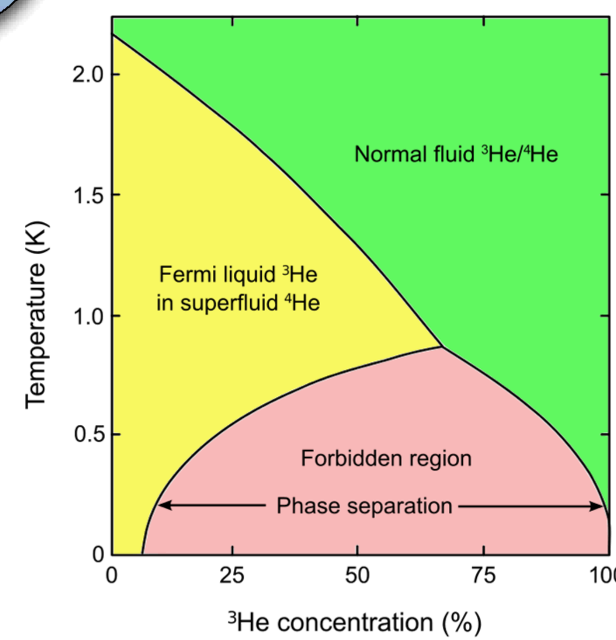


Dilution refrigerators

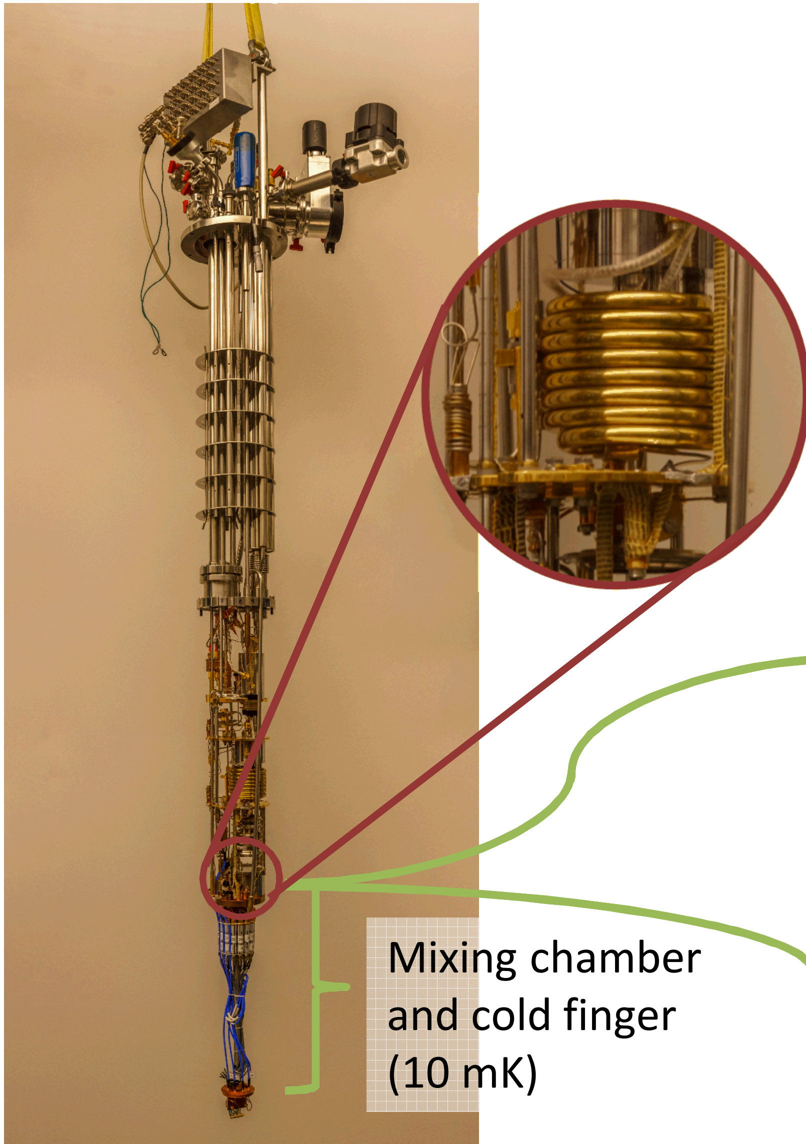


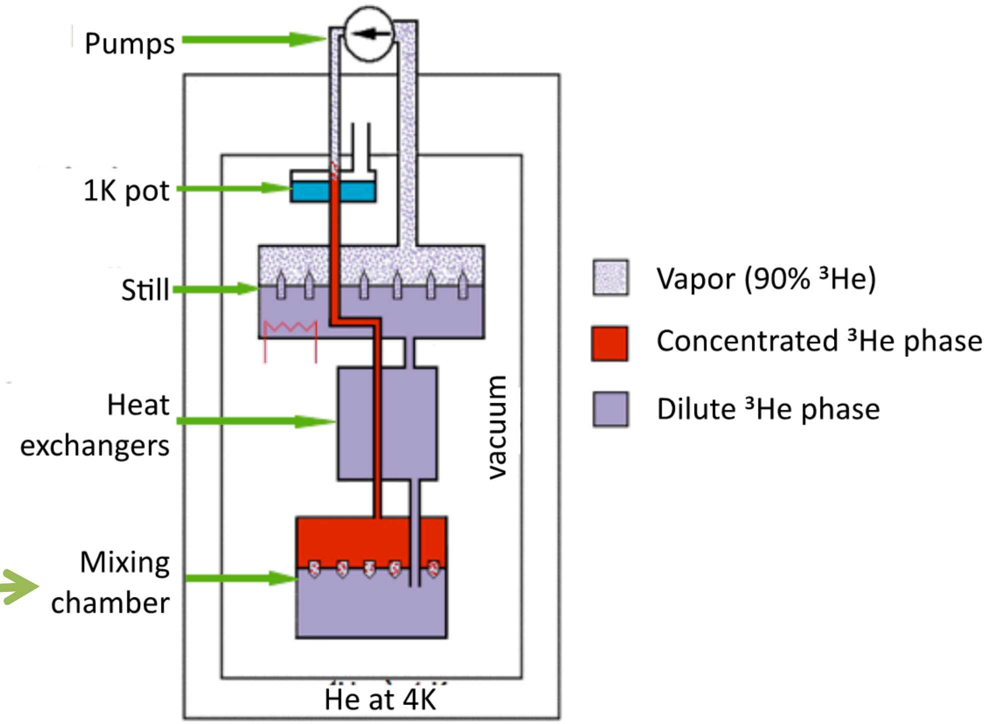
1st order approximation

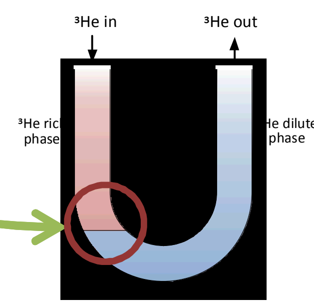
Coldest part of the refrigerator.
Place sample here.

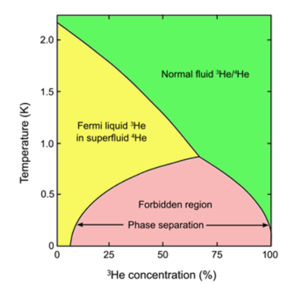


Dilution refrigerators

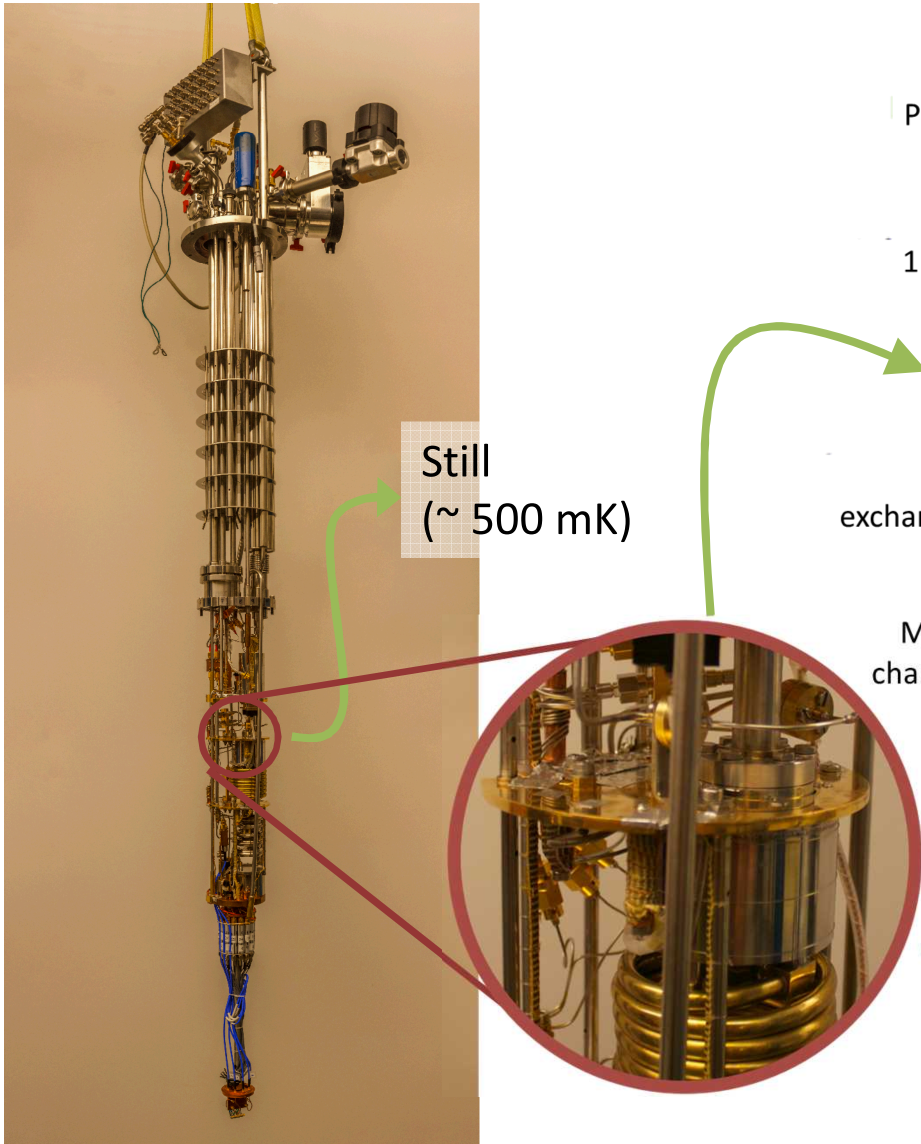


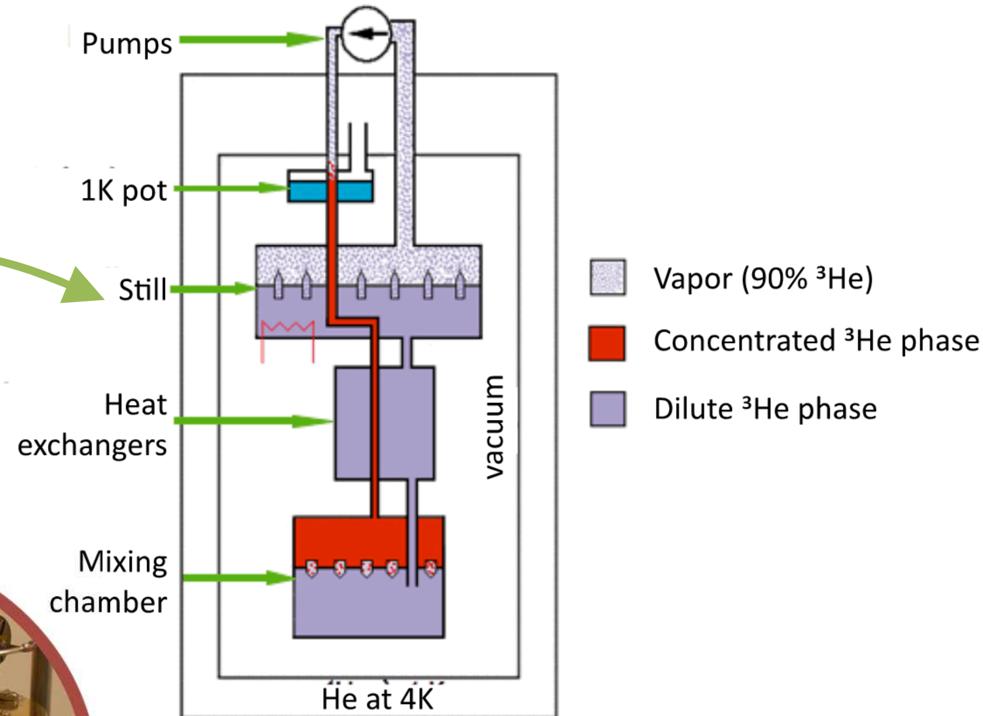


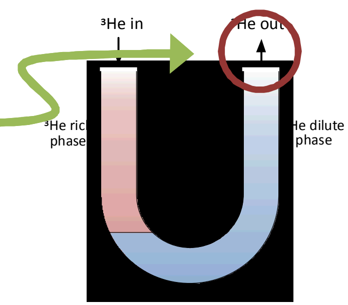


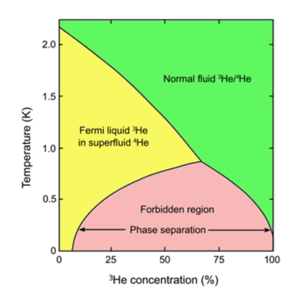


Dilution refrigerators

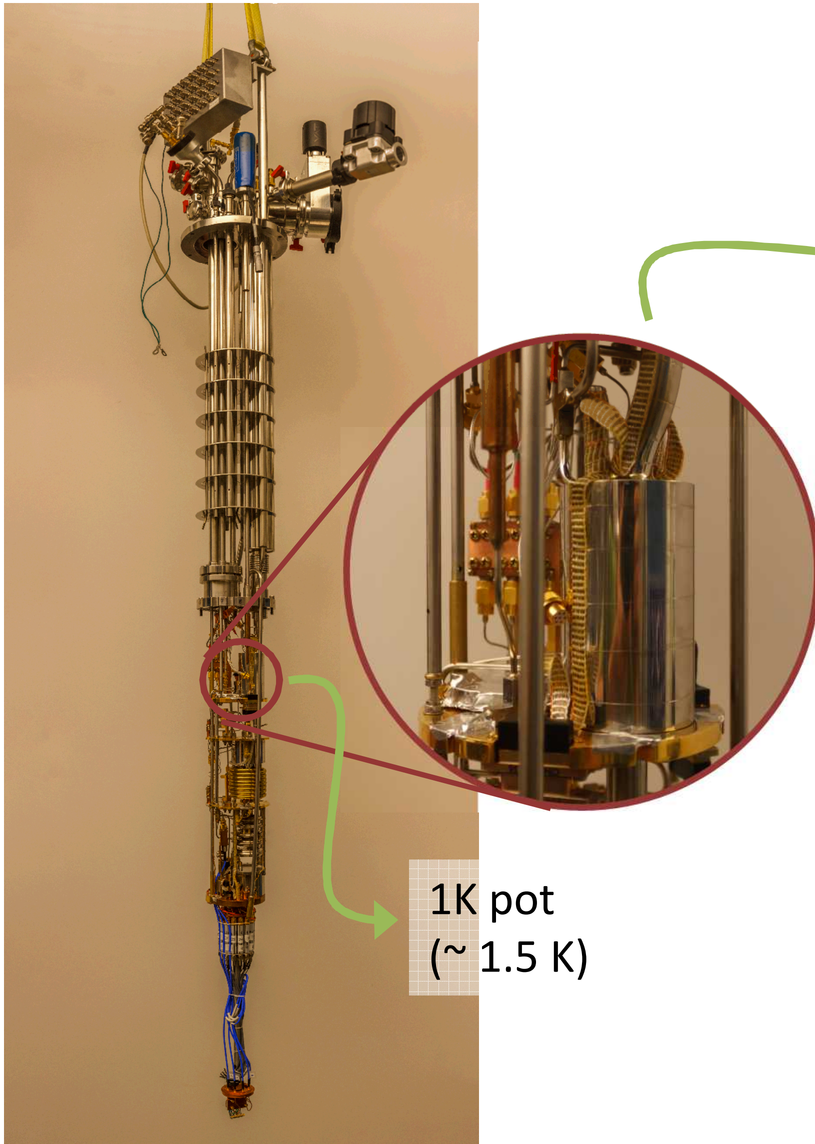


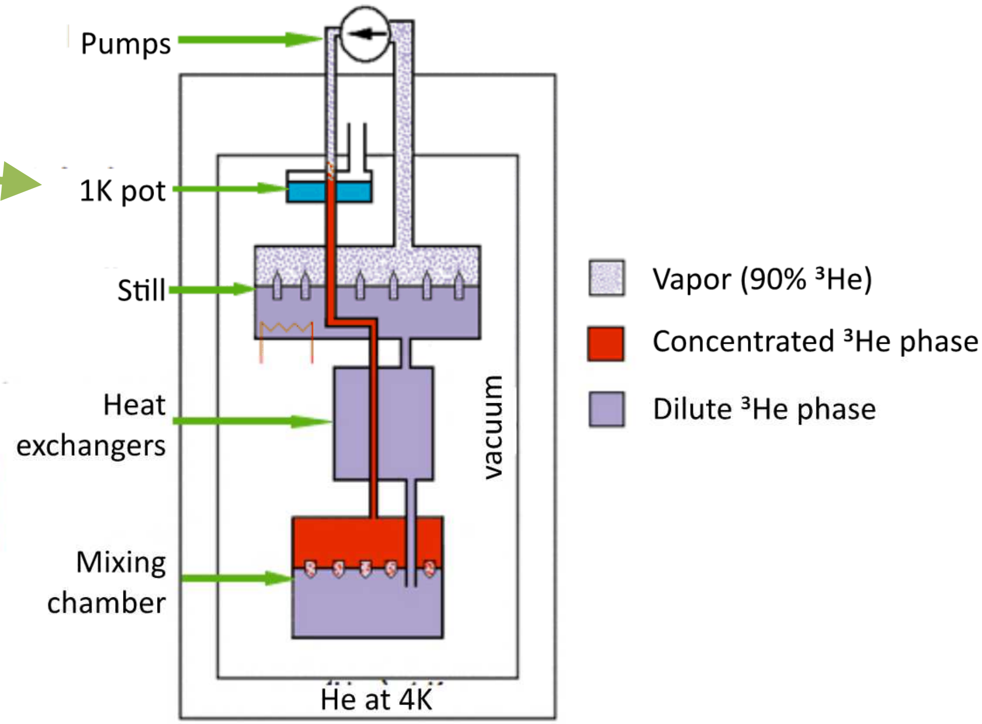




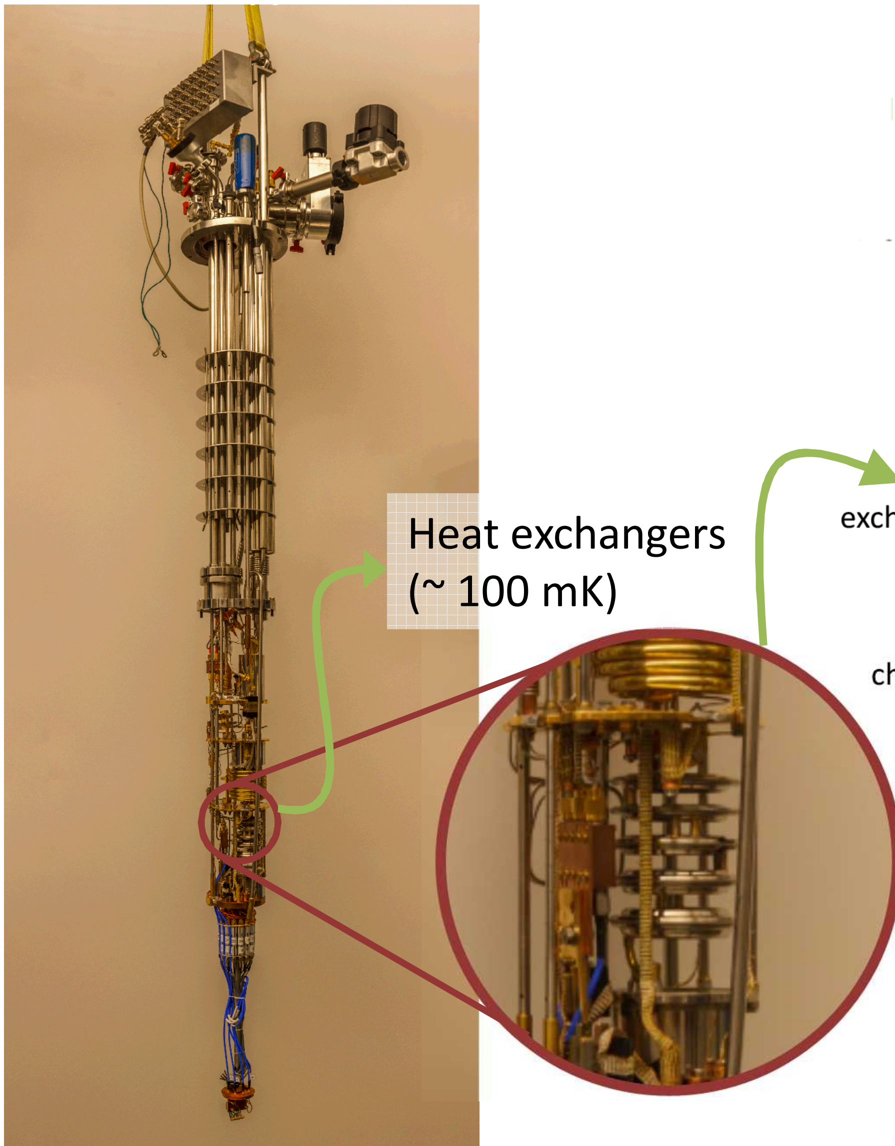


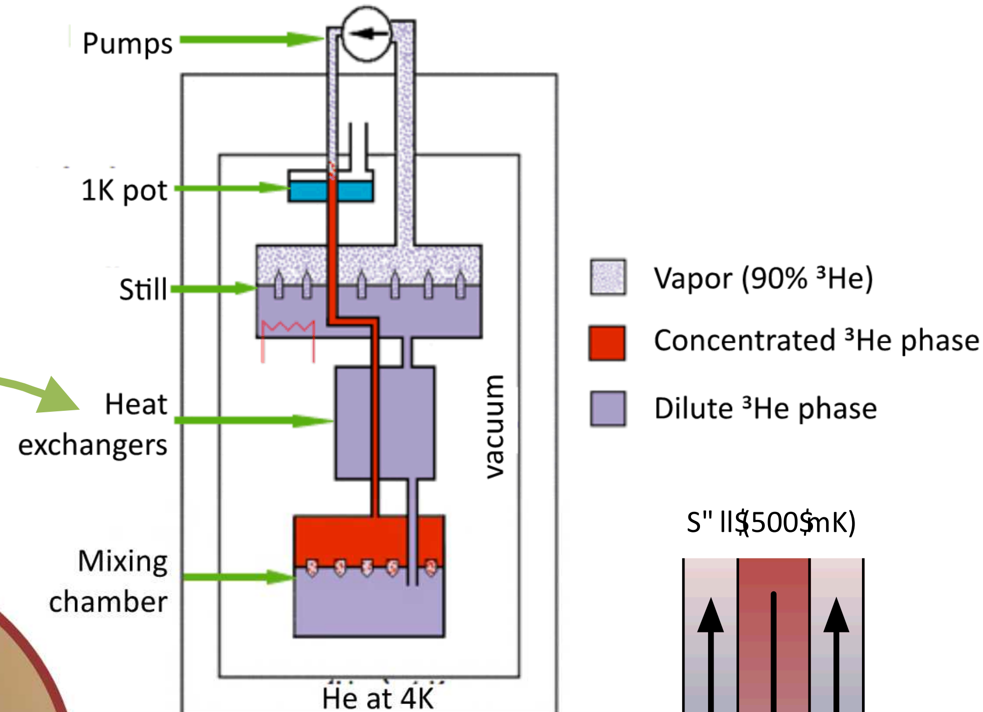
Dilution refrigerators

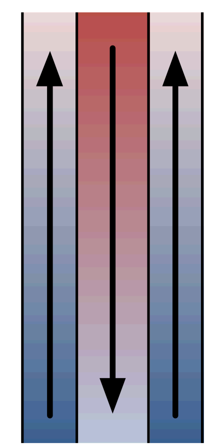




Dilution refrigerators







CHALLENGES

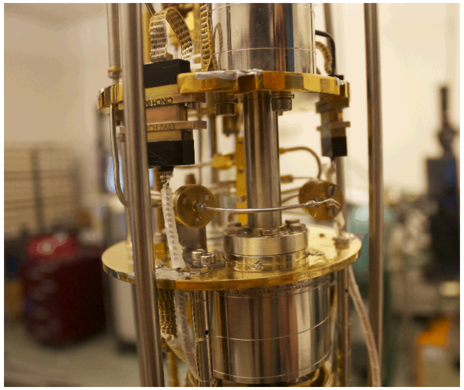
What can go wrong?

Touches

A cold component of the fridge touches a warmer component and causes a large heat load.

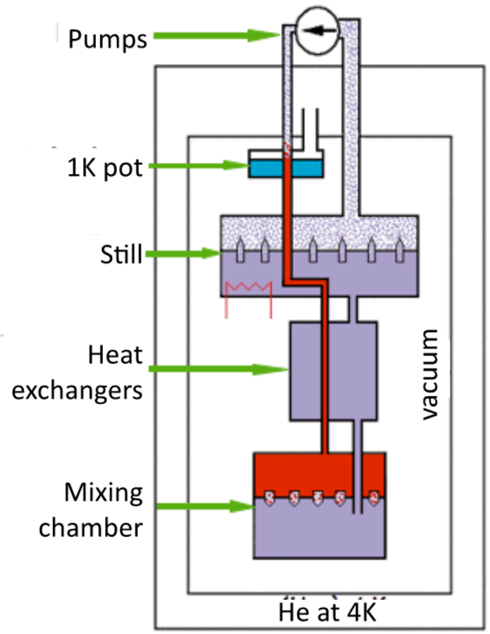
Plugs

Air or another contaminant gets into the fridge or the 1K pot, freezes and prevents circulation.



Mixture imbalance

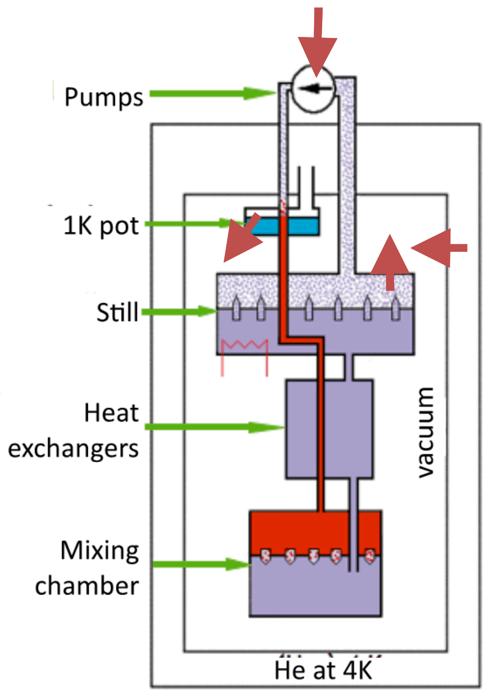
• There is too much/too little mixture causing the liquid level to be in the wrong place.
• The ratio of ^{3}He is off, causing the phase separation to occur in the wrong place.



Leaks

Gas leaks

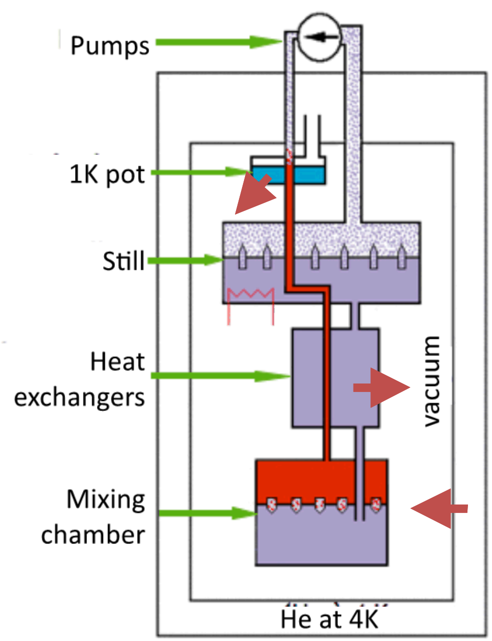
Detected at RT



- Air gets in and causes a plug.
- He gets in and destroys the vacuum.

Cold leaks

Detected at 4 K



The leak is small enough that He gas cannot get through, but liquid He can.

Super leaks

Detected at < 2 K

idem

The leak is so small that even liquid He can't get through, but superfluid He can because it has no viscosity.

CONCLUSION

Summary

- Different systems using He exist
  - Dippers (4 K)
  - 1K pots (~ 1 K)
  - ^{3}He refrigerators (~ 300 mK)
  - Dilution refrigerators (~ 10 mK)
- All of these systems rely on evaporative cooling and the fact that He remains a liquid at low temperature.