

# Techniques and Challenges of Helium Cryogenics

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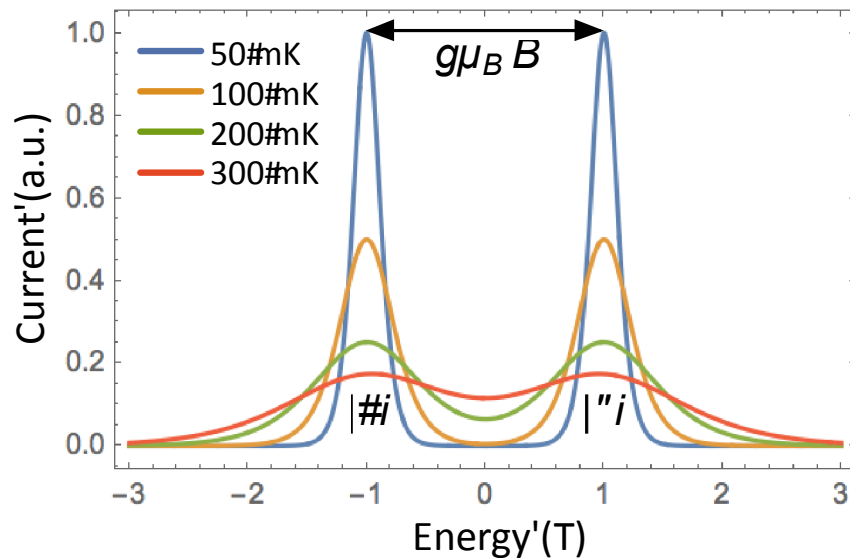
# Outline

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

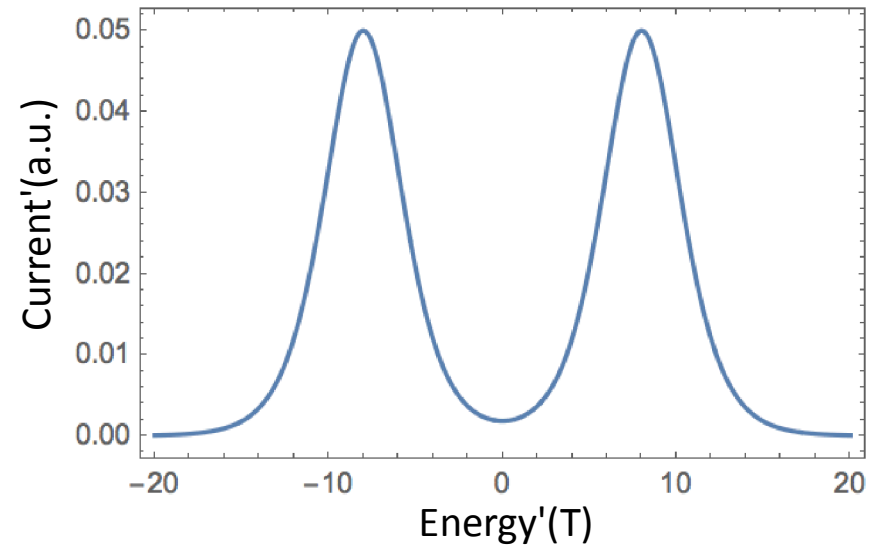
# **INTRODUCTION**

# 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?

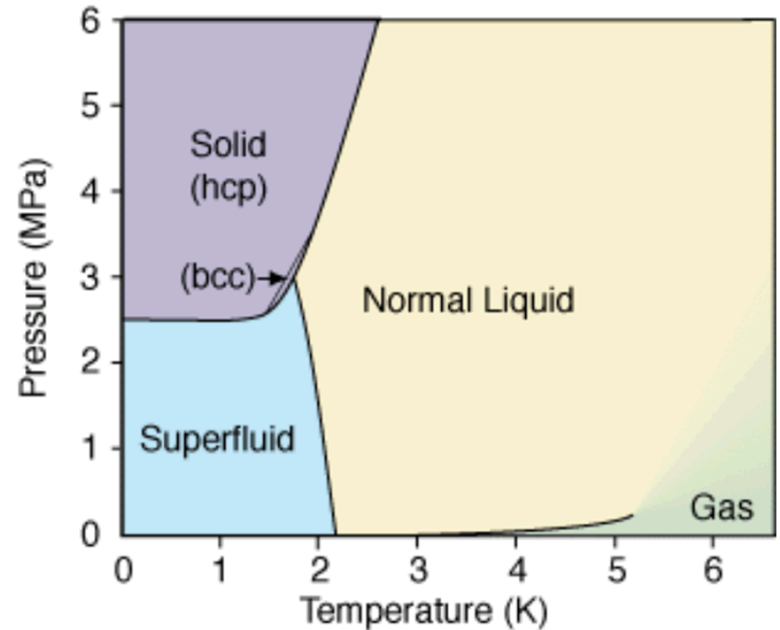
# Periodic Table of the Elements

**Legend:**

- hydrogen
- alkali metals
- alkali earth metals
- transition metals
- poor metals
- nonmetals
- noble gases
- rare earth metals

1 H																	2 He	
3 Li	4 Be																	10 Ne
11 Na	12 Mg																	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn	
87 Fr	88 Ra	89 Ac	104 Unq	105 Unp	106 Unh	107 Uns	108 Uno	109 Une	110 Unn									
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Helium is a noble gas and rarely reacts with other elements.



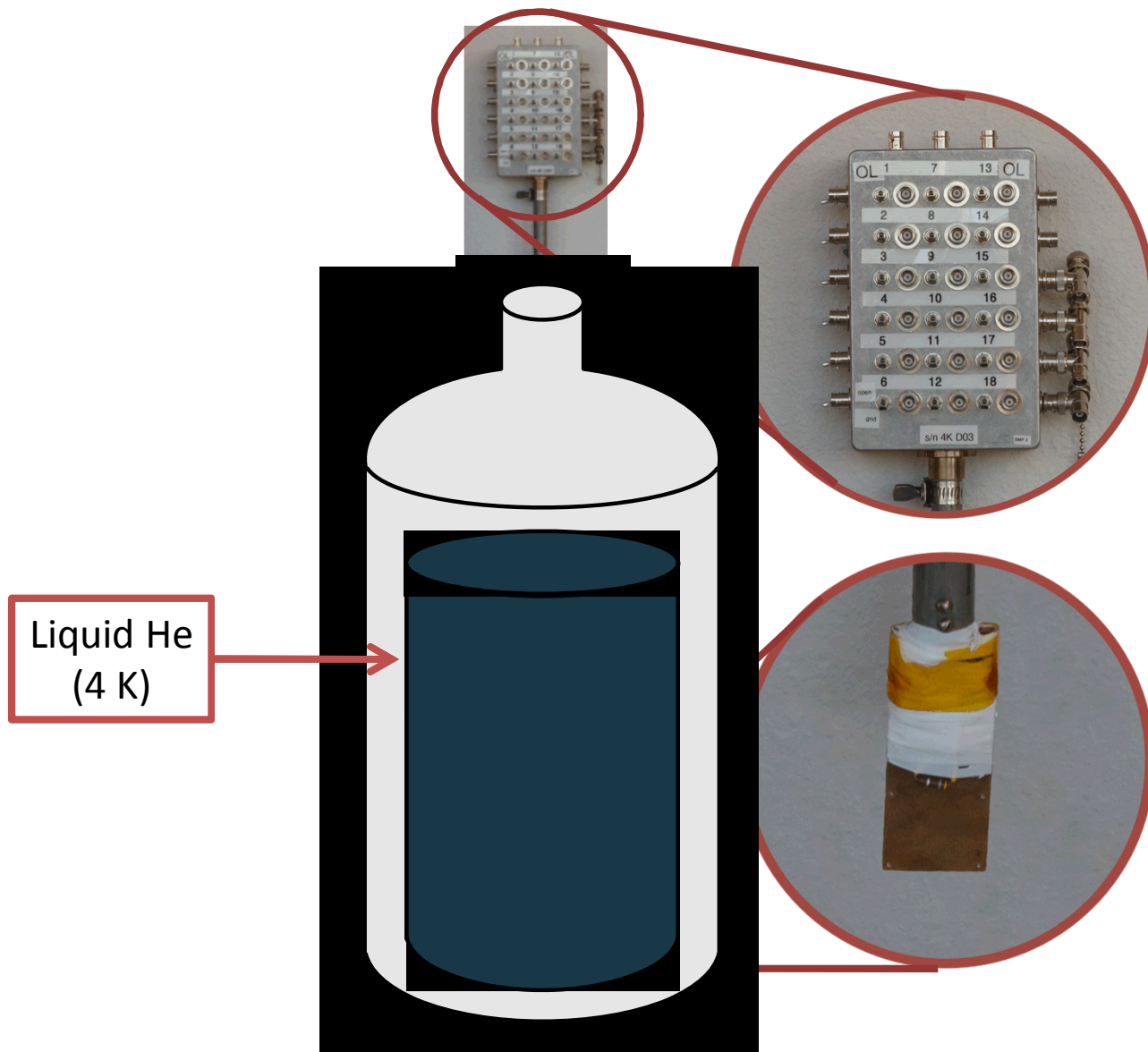
At low pressure, helium is never a solid.

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

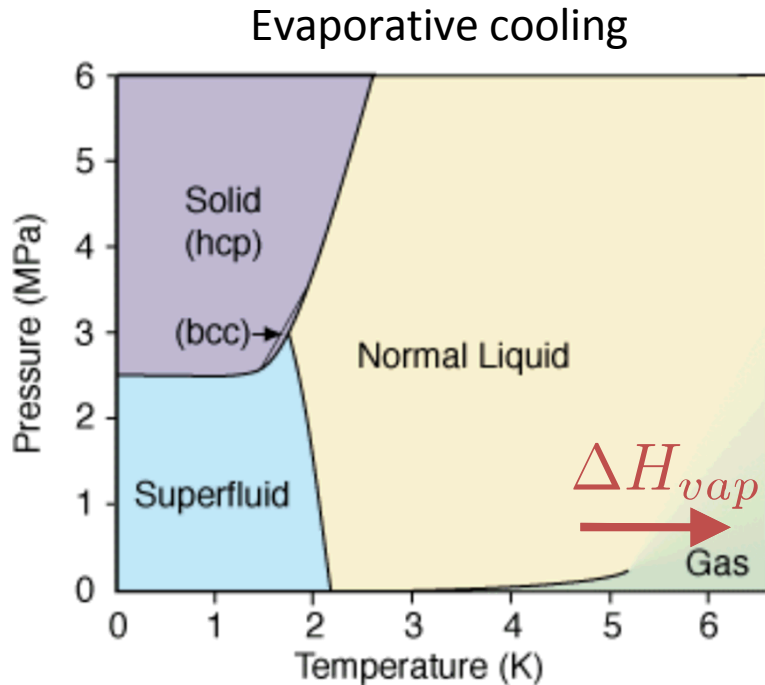
$$K = \frac{\Delta p^2}{2m} = \frac{\hbar^2}{8m\Delta x^2}$$

# **HELIUM CRYOGENIC SYSTEMS**

# Dippers (4 K)

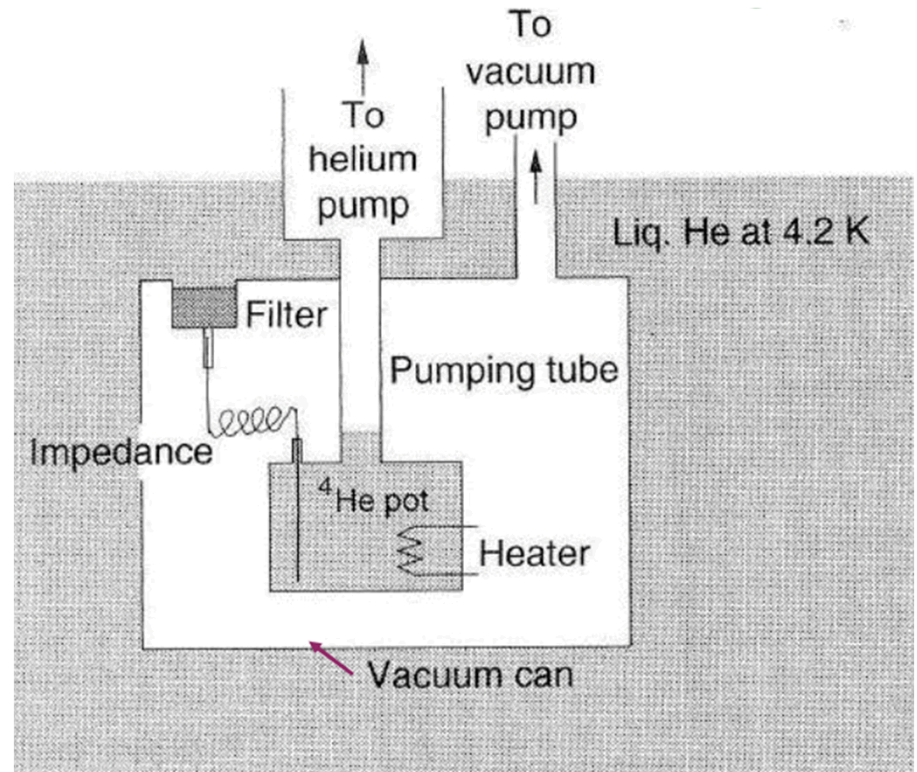


# 1K pots (> 1 K)



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.**



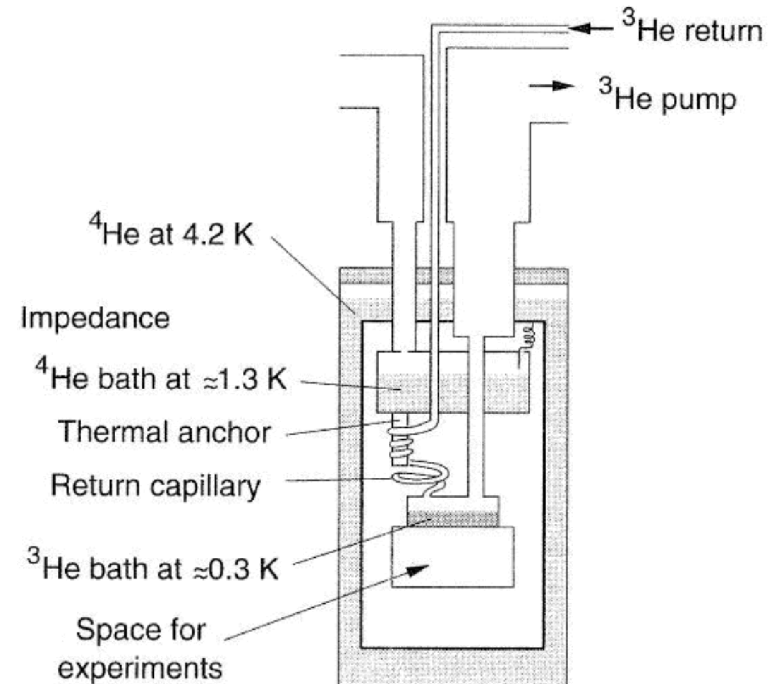
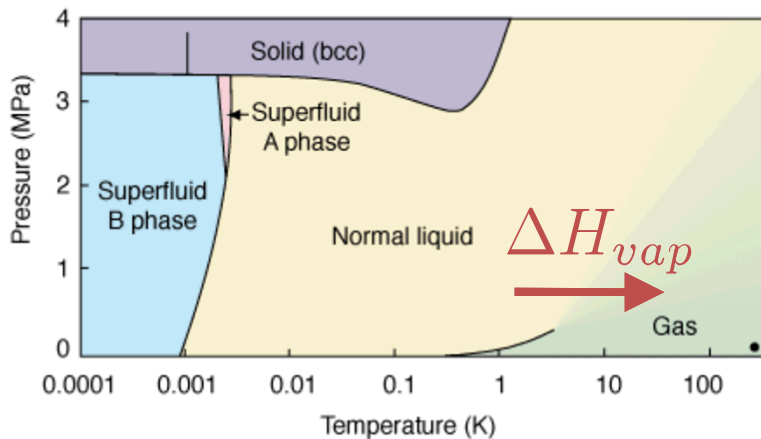
Simply by pumping on <sup>4</sup>He, temperatures of ~ 1 K can be reached.

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



# $^3\text{He}$ refrigerators ( $\sim 300\text{ mK}$ )

Evaporative cooling (again)

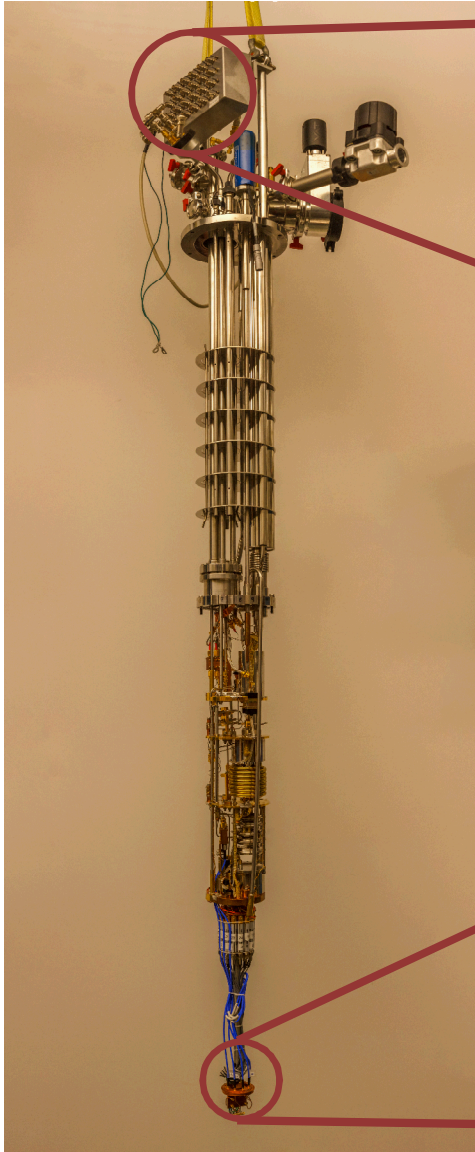


Natural occurrence of  $^3\text{He}$  is 0.000137%.

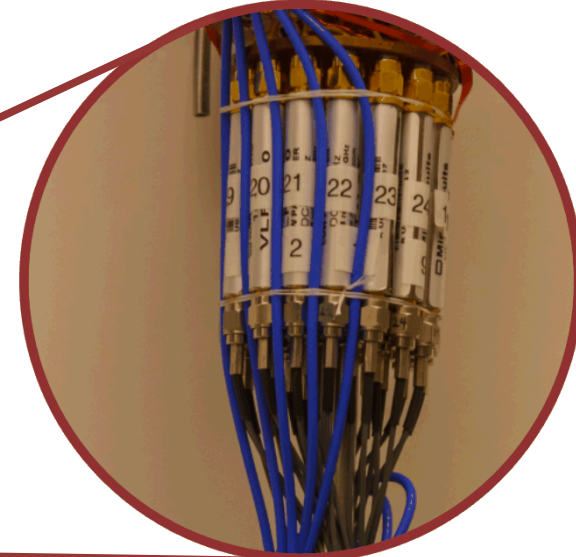
➔ 1 L of  $^3\text{He}$   $\approx$  100000\$.

➔ The  $^3\text{He}$  is reused.

# Dilution refrigerators ( $\sim 10$ mK)

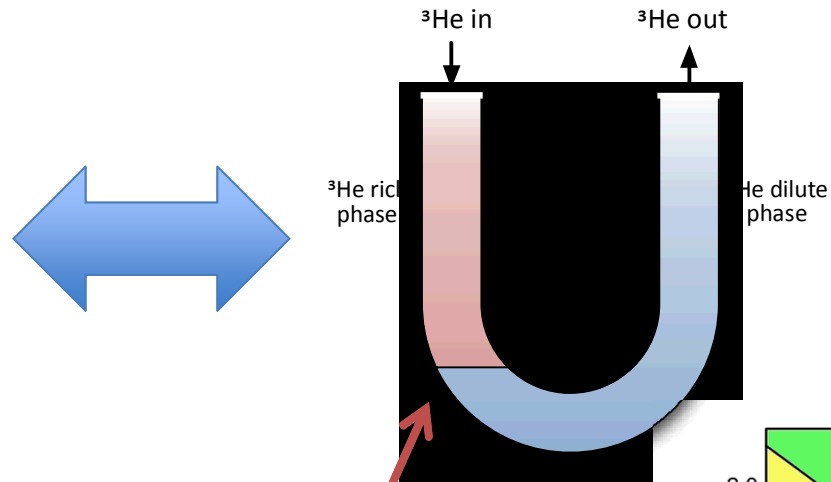
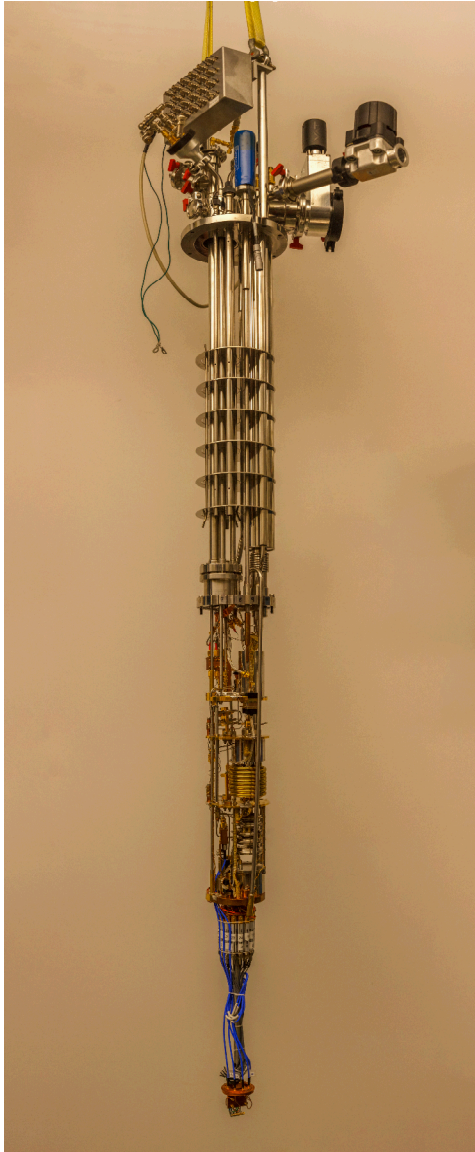


Break-out box  
(Room temp.  
 $\sim 300$  K)



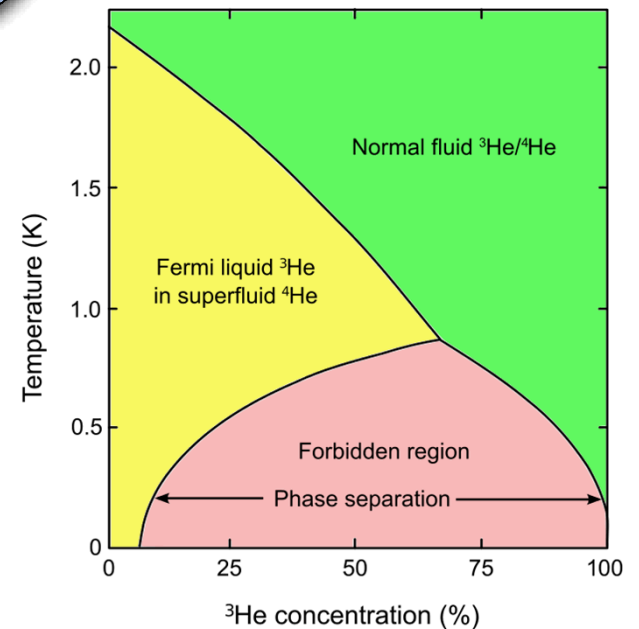
Cold finger  
(10 mK)

# Dilution refrigerators

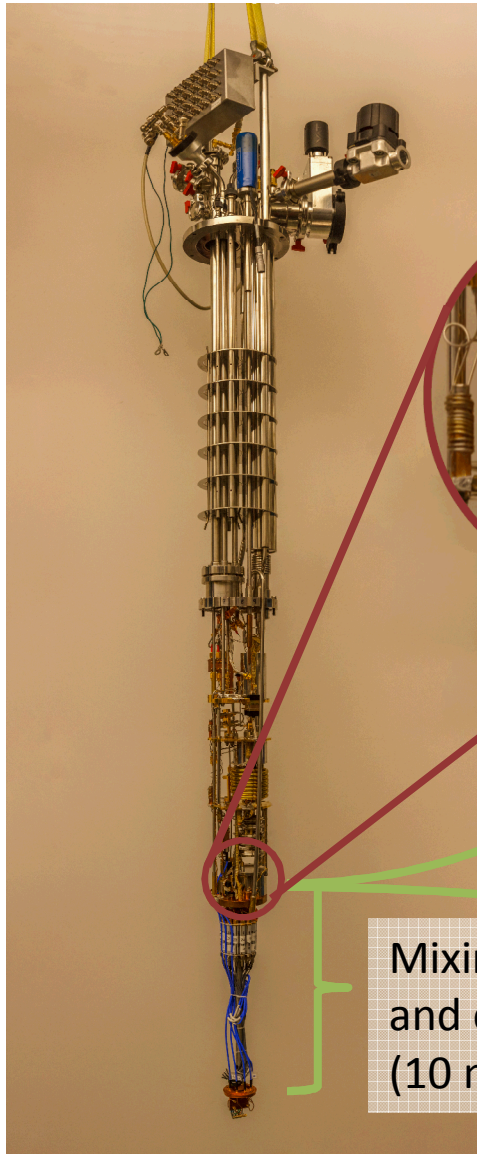


Coldest part of the refrigerator.  
Place sample here.

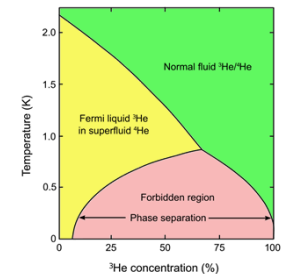
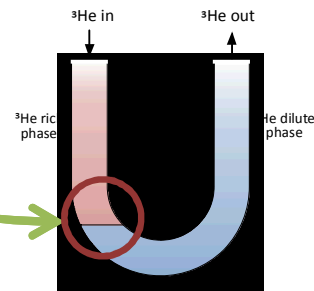
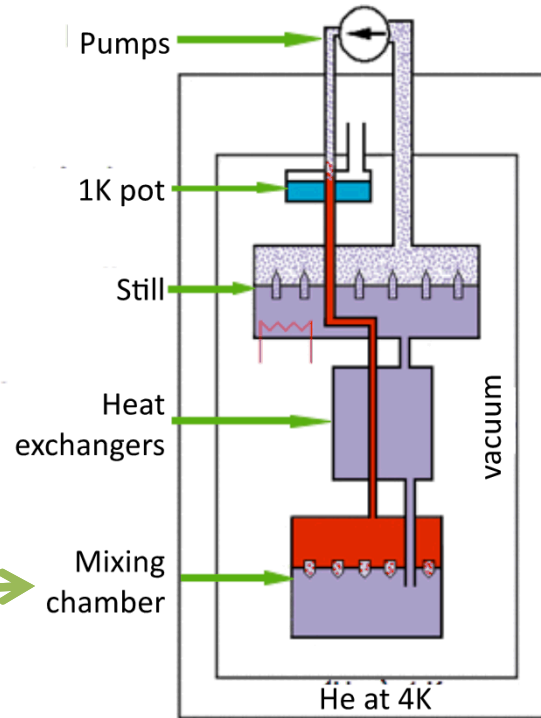
1<sup>st</sup> order  
approximation



# Dilution refrigerators



Mixing chamber and cold finger (10 mK)

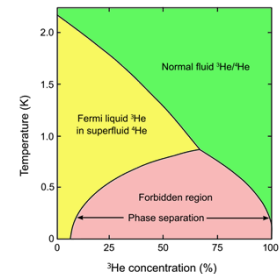
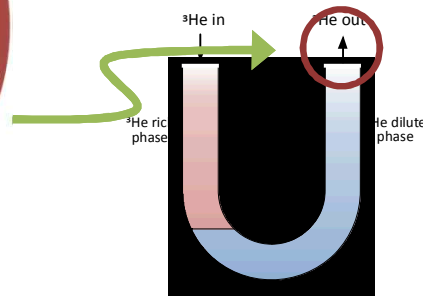
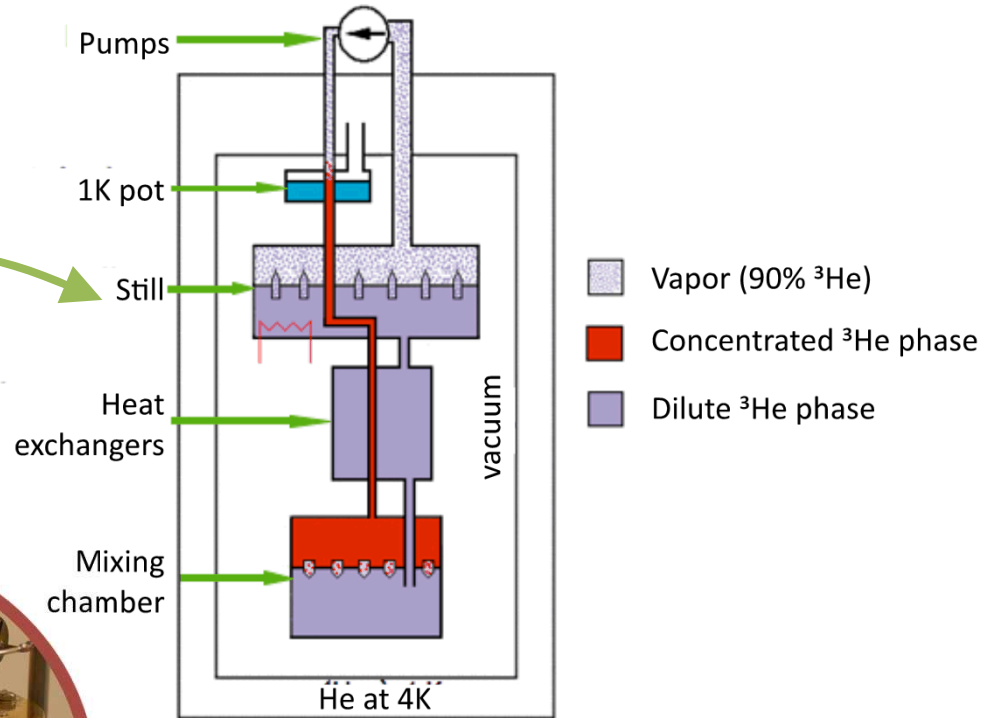
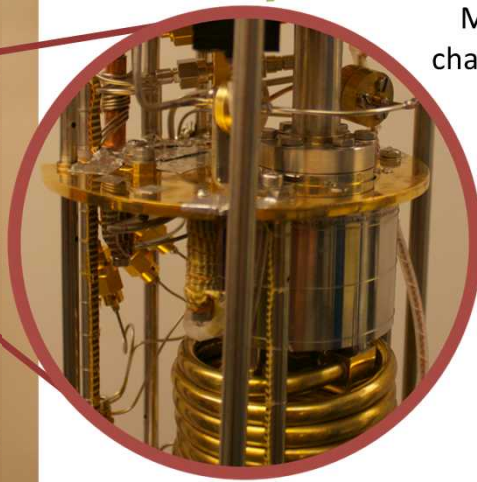




# Dilution refrigerators



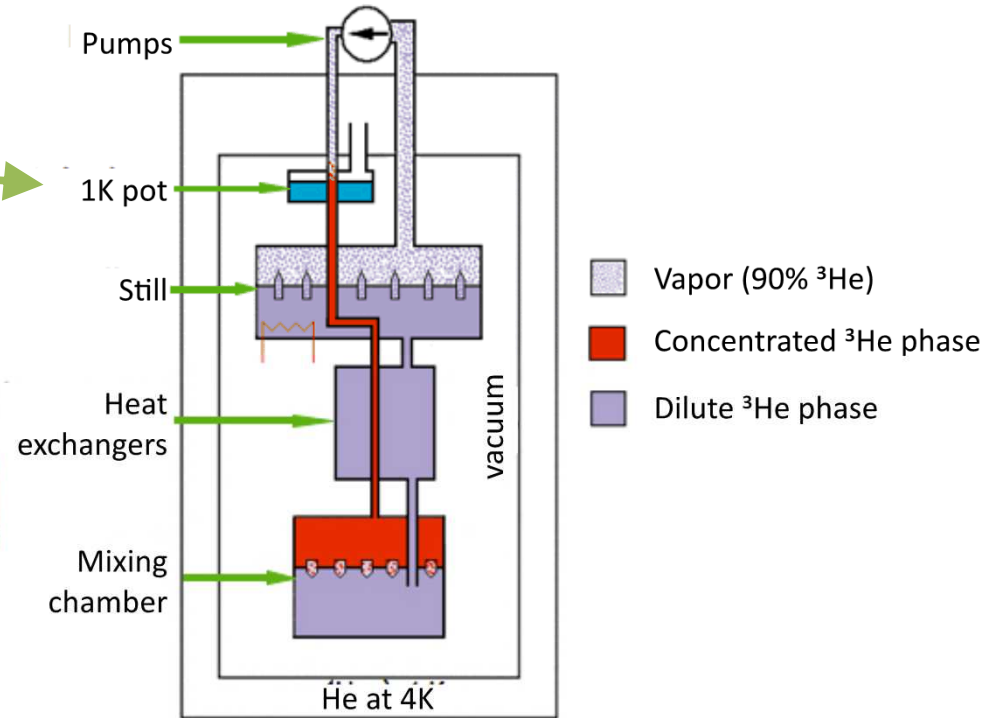
Still  
(~ 500 mK)



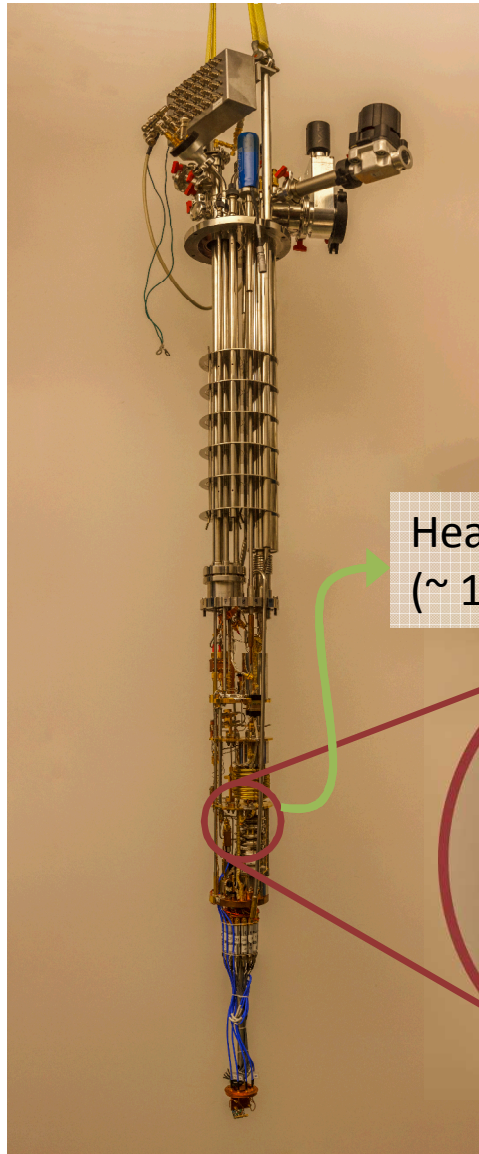
# Dilution refrigerators



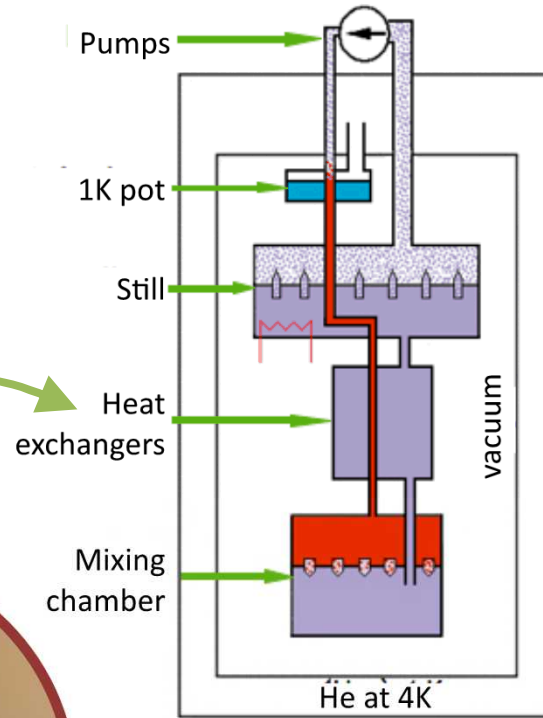
1K pot  
(~ 1.5 K)



# Dilution refrigerators

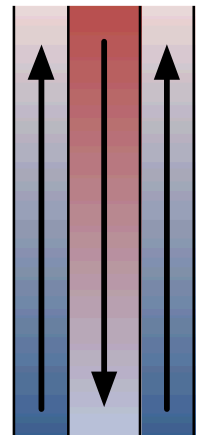


Heat exchangers  
(~ 100 mK)



- Vapor (90%  $^3\text{He}$ )
- Concentrated  $^3\text{He}$  phase
- Dilute  $^3\text{He}$  phase

500 mK



Mixing chamber  
(10 mK)

**CHALLENGES**



# What can go wrong?

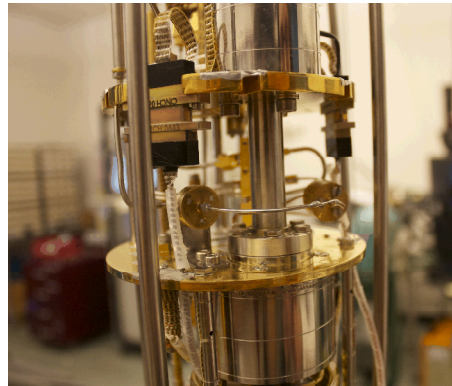
## Touches

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



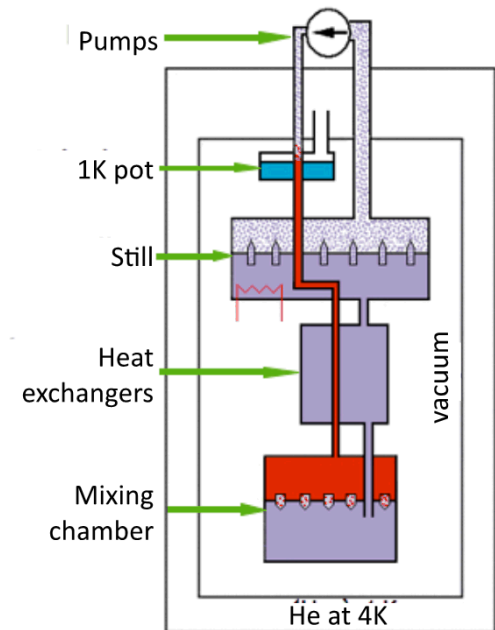
## Plugs

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



## Mixture imbalance

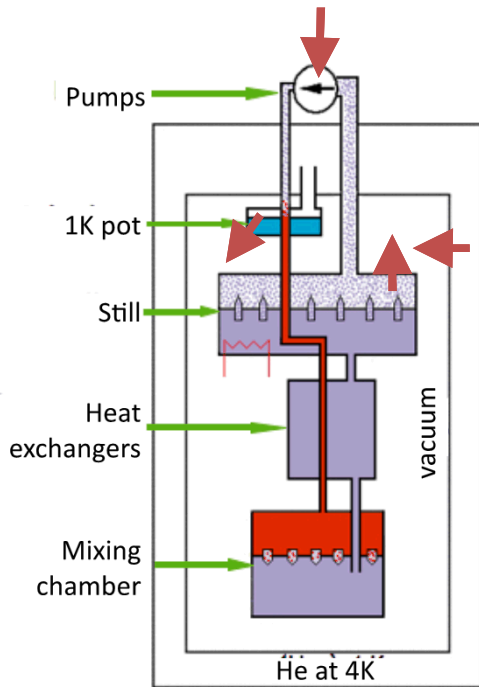
- There is too much/too little mixture causing the liquid level to be in the wrong place.
- The ratio of  $^3\text{He}$  is off, causing the phase separation to occur in the wrong place.



# Leaks

## Gas leaks

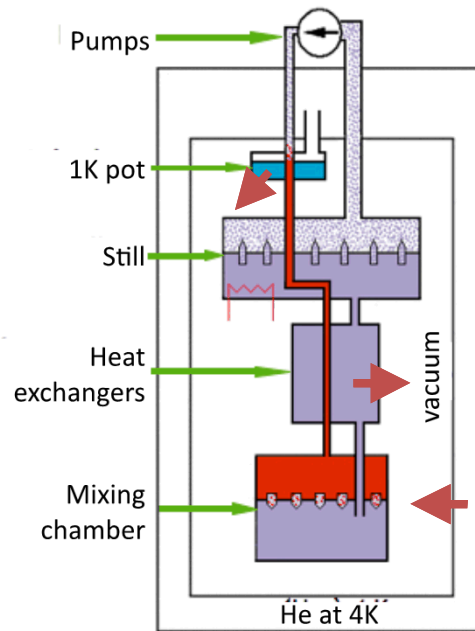
Detected at RT



- 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



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 ( $\sim 1$  K)
  - $^3\text{He}$  refrigerators ( $\sim 300$  mK)
  - Dilution refrigerators ( $\sim 10$  mK)
- All of these systems rely on evaporative cooling and the fact that He remains a liquid at low temperature.