Role of surface layer in cooling of superfluid ^{3}He in a demagnetization cryostat

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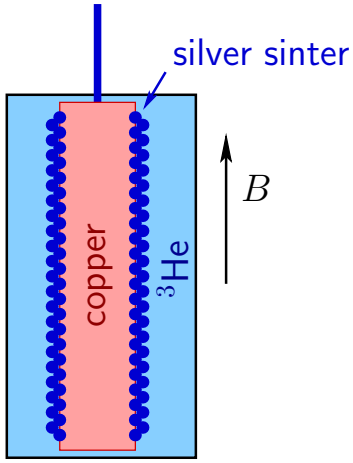


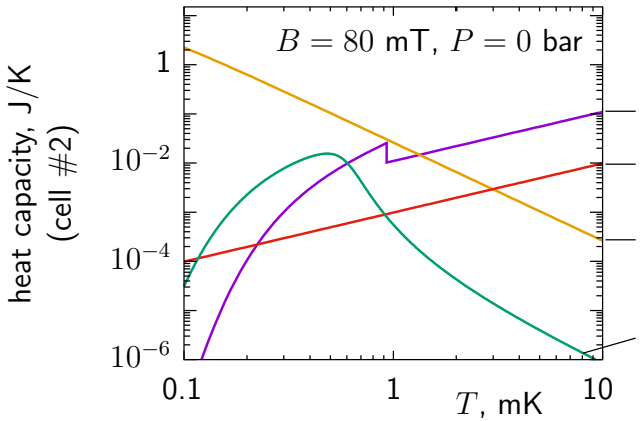
Demagnetization of copper – usual method of cooling ^{3}He to sub-millikelvin temperatures

Sinter with big area is used for better thermal link between copper and helium

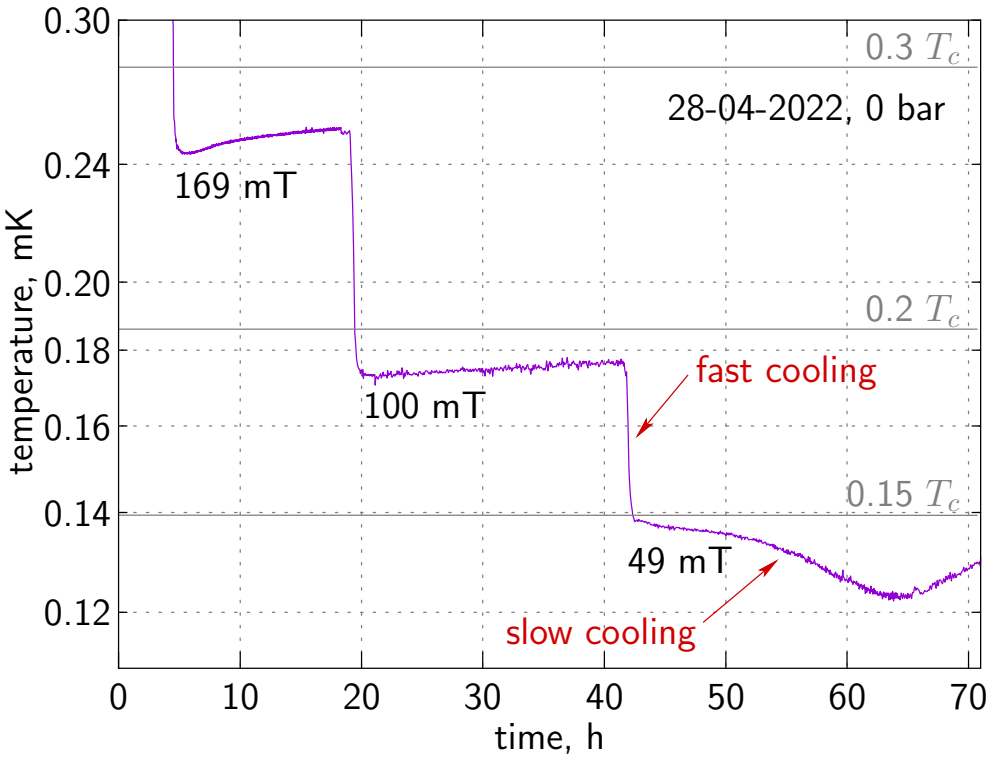
Cooling of ^{3}He stops at about 100 μK because of very high thermal resistance. Typical time constant: tens of hours.

Another time constant: if liquid ^{3}He is overheated, it returns back to the equilibrium in $\approx$ 1s.

Autti et al., Phys. Rev. B 102, 064508 (2020)



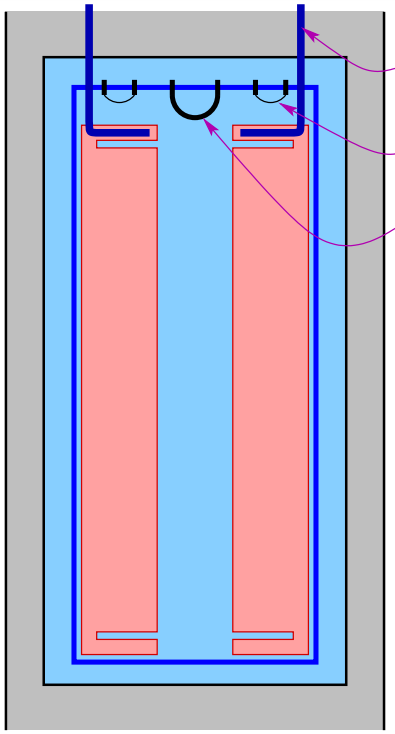
Collin et al., Phys.Rev.B 80, 094422 (2009)



Possible answer: solid ^{3}He on the sinter surface - at least one more system with noticeable heat capacity!

Surface layer is also involved in demagnetization cooling.

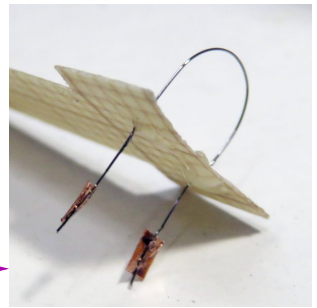
Experimental cell

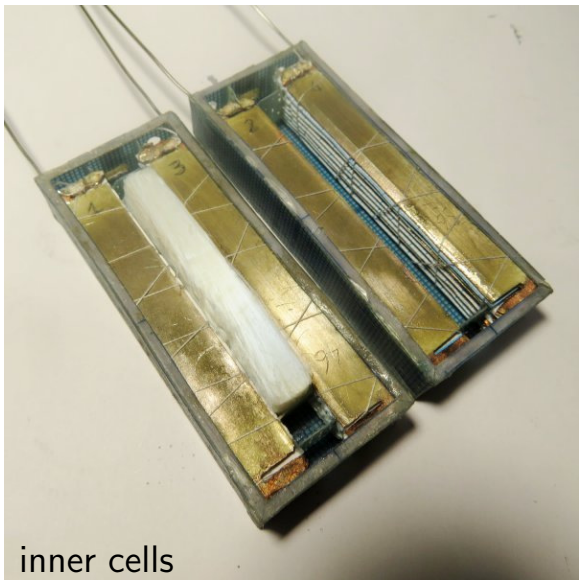


thermal link to dilution fridge (silver wire)

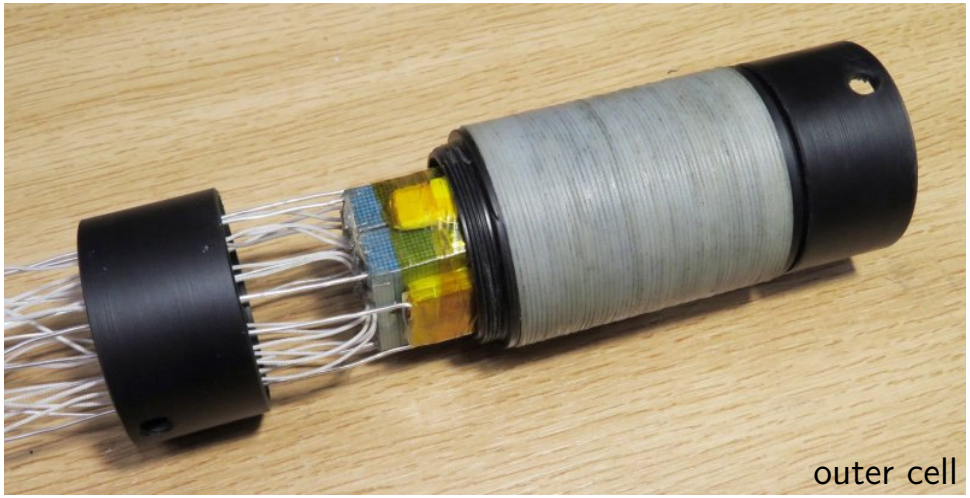
thermometer, NbTi wire, $D = 4.5\mu$m

heater, Ta wire, $D = 125\mu$m

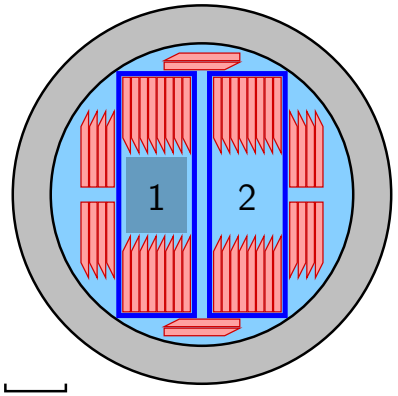




inner cells



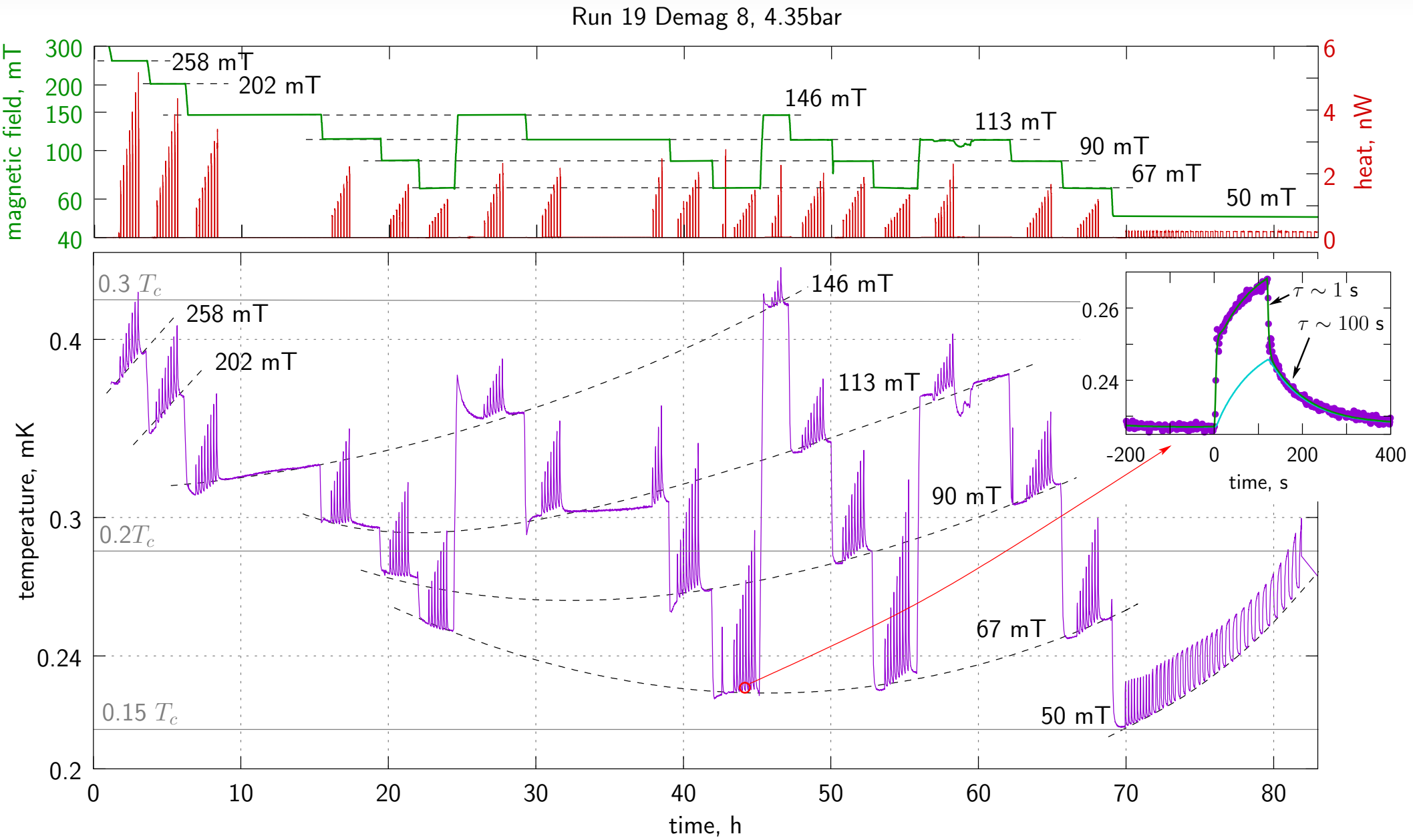
outer cell



- outer cell (glass-reinforced nylon)
- copper plates, covered with silver sinter
- inner cells (paper with Stycast-1266)
- ^{3}He
- aerogel sample in cell #1 (not used)

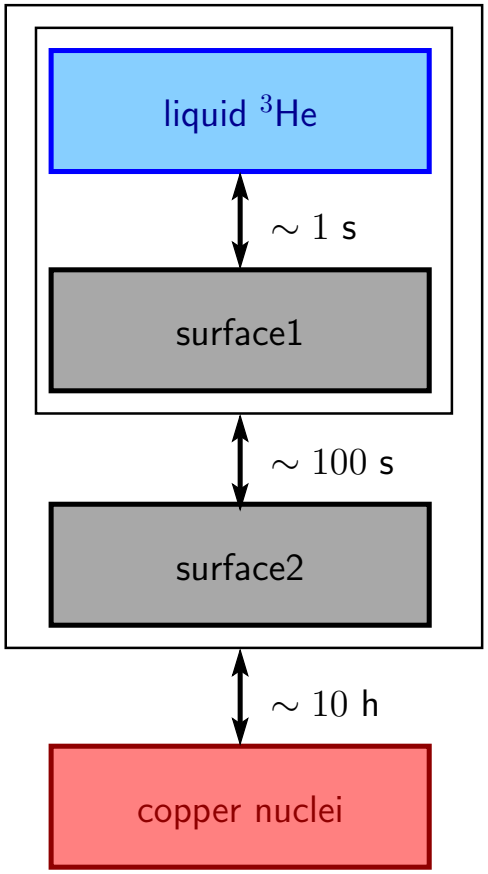
Inner cell #2:
- amount of copper: 86.0 g
- sinter area: 53.2 m^2
- ^{3}He volume: 17.8 cm^3

Experiment


Run 19 Demag 8, 4.35bar
magnetic field, mT
heat, nW
258 mT
202 mT
146 mT
113 mT
90 mT
67 mT
50 mT
temperature, mK
0.3 T_c
0.2T_c
0.15 T_c
time, h
$\tau \sim 1$ s
$\tau \sim 100$ s
time, s

Conclusions

Possible thermal model:



- We study simple system (copper + silver sinter + liquid ^{3}He) to find heat capacities and heat conductances of different parts vs T and B. Experiment is still in progress.
- We observe at least three different time constants in the thermalization processes, 1s, 100s, 10h. This means at least four thermal reservoirs (copper nuclei, liquid, two surface systems).
- Both surface systems have field-dependent heat capacity and provide cooling effect in demagnetization.
- Better understanding of this system can help in optimizing cooling of liquid ^{3}He. It's already clear that having heat exchanger in the center of demagnetization field gives better cooling. Precooling the surface system before demagnetization to the lowest temperature can help as well.
- Using aerogel as a source of large surface area very well connected to superfluid liquid can improve cooling even more. See Bradley et.al, Phys. Rev. Lett. 105, 125303 (2010)