Construction of a ^{3}He cryostat using a charcoal sorption pump

Yasuhisa Ushida [a], Hiroyuki Nakane [a], Kunihiro Kimura [a], Takashi Tsuzuki [a,1], Takashi Nishioka [a], Syoji Inoue [b], Koji Matsushita [b], Noriaki K. Sato [a]

[a] *Department of Physics, Graduate School of Science, Nagoya University, Nagoya 464-8602, Japan.*

[b] *Technical Division, School of Science, Nagoya University, Nagoya 464-8602, Japan.*

Abstract

For a typical heavy fermion superconductor, a superconducting transition temperature is lower than 1 K. Therefore it is needed to perform measurements at a low temperature below 1 K. For this purpose, we have constructed a highly simple ^{3}He cryostat using a charcoal sorption pump, instead of using a rotary vacuum pump. We have found that a sample cools down to 0.31 K within 30 minutes after transferring liquid ^{4}He into the cryostat.

Key words: charcoal sorption pump; ^{3}He cryostat; specific heat

There are fascinating intermetallic compounds called heavy fermion metals [1]. These contain a periodic lattice of certain lanthanide or actinide ions. Owing to both the strong Coulomb correlations within *f* shells and the mixing of the localized *f*-electron wave function with the itinerant conduction electron one, a new metallic state is formed at low temperatures, usually below 1 K. A typical example is the ferromagnet UGe_2; the Curie temperature of ∼52 K at ambient pressure decreases with increasing pressure, and vanishes around ∼16 kbar. Interestingly, in the pressure range between ∼10 and ∼16 kbar, superconductivity appears below ∼0.8 K [2]. In order to study such a novel material, we need a cryostat for low temperature experiments such as heat capacity. For this purpose, we may use a ^{3}He/^{4}He dilution refrigerator, which allows us to carry out low temperature experiments below 0.1 K. However, a commercial dilution refrigerator is expensive, and it is not easy for a "beginner" to construct it by himself. On the other hand, we can rather easily construct a laboratory-made ^{3}He cryostat, although the lowest accessible temperature ∼0.3 K is not so low compared to that for a dilution fridge. In this paper, we describe specifications of the ^{3}He cryostat using a charcoal pump that is constructed for the heat capacity measurement.

A schematic drawing of the cryostat is shown in Fig. 1. The charcoal is put in a copper cylindrical tube that has a lot of holes, which is referred to as charcoal pot hereafter, and it can be raised or lowered by hand. At first, we set the charcoal pot at the highest position, where temperature is almost room temperature, and then we introduce gaseous ^{3}He from a ^{3}He storage tank into a main line that leads to a ^{3}He pot. The gaseous ^{3}He is liquefied when it passes through a 1K pot that is kept at 1.3 K, and condenses in the ^{3}He pot. It takes only five minutes to finish the condensation process. This quick condensation is possibly due to large surface area of the boundary in the 1K pot between ^{4}He and ^{3}He. The temperature of the ^{3}He pot begins to decrease, as soon as the charcoal pot is set to the bottom position.

In order to test this apparatus, we examined the lowest temperature achieved under various conditions. The results are summarized in Table 1. Comparing runs of no. 1 and no. 2, we find that the charcoal pump yields lower $T_{\min}$ than the rotary pump. Here, one may notice the difference in a liquid ^{4}He level. However, comparison between no. 7 and no. 9 tells us that the

[1] Corresponding author. E-mail: f010237m@mbox.media.nagoya-u.ac.jp

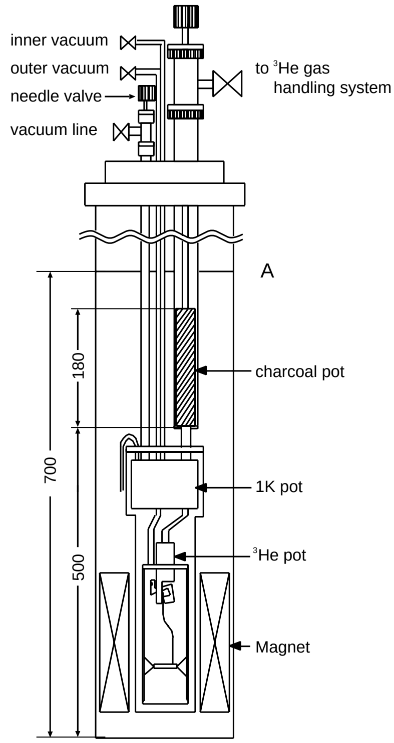

Fig. 1. Schematic drawing of a ^{3}He cryostat with a charcoal sorption pump constructed for heat capacity measurements. 'A' denotes the position of liquid ^{4}He when it is filled completely.

No.	^{3}He(cc)	^{4}He(cm)	Pump	T_{min}(K)	hole
1	6.7	20	charcoal	0.410	
2	6.7	5	rotary	0.502	$\phi 1 \times 10$
3	3.1	- 6	charcoal	0.361	
4	3.5	8	charcoal	0.318	
5	7.0	- 9	charcoal	0.398	$\phi 2 \times 102$
6	1.8	-11	charcoal	0.315	
7	1.8	18	charcoal	0.307	
8	1.3	8	charcoal	0.312	$\phi 3 \times 654$
9	1.6	4	charcoal	0.316	
10	0.8	0	charcoal	0.314	

Table 1
Table of the achieved lowest temperature and experimental conditions. 'No.' indicates run number. The column of '^{3}He(cc)' denotes the amount of liquefied ^{3}He condensed in the ^{3}He pot, which was evaluated using the density of ^{3}He at 0.5 K. '^{4}He (cm)' denotes the height of liquid ^{4}He level measured from the bottom of the charcoal pot. Negative value indicates liquid ^{4}He level is lower than the bottom of the charcoal pot. The full level of liquid ^{4}He (A in Fig. 1) is 20 cm above the bottom of the charcoal pot and the length of the pot is 18 cm, and thus the full level of liquid ^{4}He is only 2 cm above the top of the charcoal pot. The column of 'hole' means the diameter of each hole (in scale of mm) and number of the holes in the pot.

difference in the ^{4}He level does not play an important role for achieving low $T_{\rm min}$.

It is interesting to study the condition under which the charcoal pump works well. We note that the liquid ^{4}He level for no. 6 is much lower than the bottom of the charcoal pump (that is understood from minus sign), however the very low $T_{\rm min}$ was achieved, in spite of that we did nothing special for the heat contact between the charcoal and ^{3}He.

Comparing the data of no. 4 to 6, we find that the amount of ^{3}He is crucial; if there is too much ^{3}He, then we will not obtain low $T_{\rm min}$.

It may be readily understood that the total hole cross sections (diameter of each hole × number of holes) of the charcoal pot also affects $T_{\rm min}$. If we compare the results of no. 3 and no. 4, $T_{\rm min}$ is smaller for no. 4 than for no. 3. Further increasing the cross section from no. 6 to no. 7, however, gives little influence on $T_{\rm min}$. (We think that the slight decrease in $T_{\rm min}$ may be due to the position of liquid ^{4}He level rather than the increase in the cross section.)

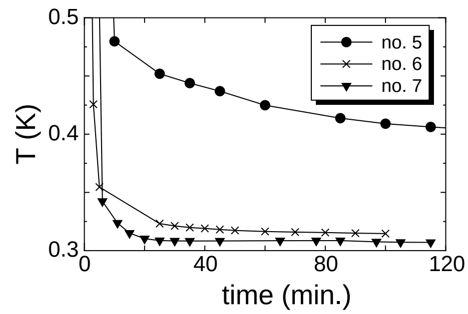

Fig. 2. Cooling speed for runs of no. 5, no. 6, and no. 7. Time is measured from that when the charcoal pot was set at the lowest position.

Another interesting specification is the cooling speed; how fast the ^{3}He pot reaches the lowest temperature. Figure 2 shows a plot of the ^{3}He pot temperature vs time; time was measured from that when the charcoal pump was set at the lowest position. For the case of no. 7, it takes only 20 minutes to attain the lowest temperature. This means that we need only 30 minutes totally to lower a sample down to ∼0.3 K.

In summary, we constructed a very simple ^{3}He cryostat with a charcoal sorption pump. This cryostat has the following characteristic: It is very easy to construct the cryostat and also to handle it. It takes only 30 min. to attain the lowest temperature of ∼0.31 K. It does not need a rotary pump, implying no noise due to vibration.

References

[1] N. Grewe and F. Steglich, "Handbook on the Physics and Chemistry on Rare Earths", Vol 14, edited by K. A. Gschneidner, Jr. and L. Eying (Elsevier Science Publishers B.V., 1991).

[2] S. S. Saxena *et al.*, Nature **406** (2000) 587.