Cryocoolers for Space

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Abstract

Many of the detectors for space telescopes require cooling to increase sensitivity and reduce thermal noise. For space applications, such cooling requires reliable, long-life coolers that are relatively compact and light weight and have low vibration. We have developed or are developing coolers that meet these requirements over a wide range of temperatures. These include pulse tube coolers cooling from 300 K to below 10 K, a magnetic cooler cooling from 10 K to 2 K, a ^{3}He sorption cooler cooling from 2 K to 0.3 K and a helium dilution cooler cooling from 0.3 K to 0.05 K. Details of these coolers and their advantages are presented.

Pulse Tube Coolers

Figure 1 shows the basic components of a simple, single-stage pulse tube cooler. It is a closed system that uses an oscillating pressure at one end (typically produced by a compressor) to generate an oscillating gas flow in the rest of the system. This gas flow (usually helium gas) can carry heat away from a low temperature point (cold heat exchanger) if the conditions are right. An orifice controlling the flow at the other end of the cooler can provide the right condition for cooling to occur. A single cooler can cool from room temperature to 40 K and multi-stage systems can cool much lower. The amount of heat they can remove is only limited by their size and the power used to drive them. Their efficiency is comparable to other systems such as Stirling coolers. The primary advantage of pulse tube coolers over Stirling coolers is that they have no moving parts in the low-temperature region. This means that there is no friction, no wear and essentially no vibration, so the low-temperature sections have an infinite lifetime. The development status of these coolers is that single-stage coolers have been flown in space and we are developing multi-stage coolers to reach temperatures below 10 K[1-3].

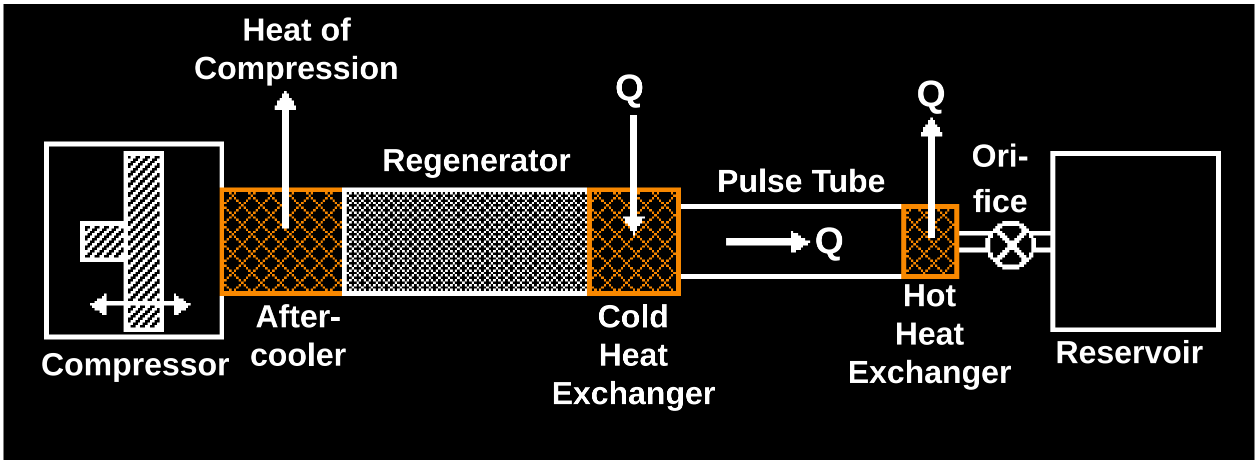

Fig. 1. A single-stage pulse tube cooler.

Magnetic Coolers

Figure 2 shows the features of an Adiabatic Demagnetization Refrigerator (ADR) we have developed[4,5] for cooling from 10 K to 2 K. The refrigerator consists of a Cu/GGG (copper/ Gadolinium Gallium Garnet) sandwich and two heat switches. Five slices of single crystal GGG are sandwiched together with four strips of high purity copper. Indium foil is used at interfaces between GGG and Cu to improve thermal conductance. The sandwich is held under compression by Kevlar strands which are tensioned by a SS draw-bar mechanism. The ADR is thermally anchored to the cold plate of a helium cryostat that is held at 10 K for testing. The copper strips allow heat transfer between the GGG and the heat switches. Two of the strips are connected to the 2 K heat switch, while the other two are connected to the 10 K heat switch. At both heat switches the strips are clamped down to one end of the heat switch with high purity indium foil placed at the interface. The magnet used in the tests is a superconducting magnet that is rated to 7 Tesla at 4 K. The field homogeneity is within 5 % over the entire length of the Cu/GGG sandwich.

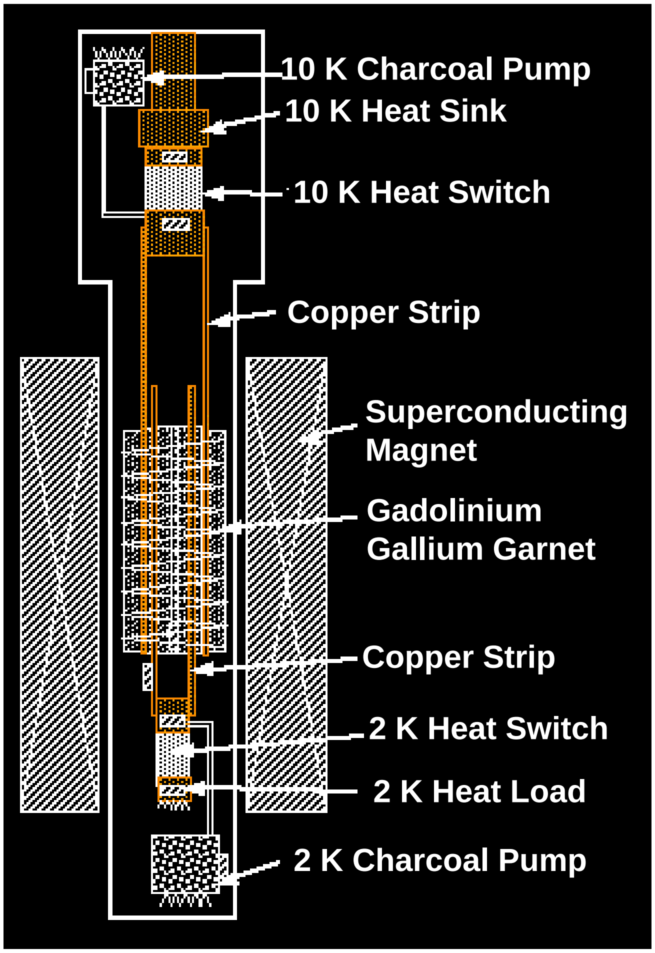

Fig. 2. An Adiabatic Demagnetization Refrigerator cooling from 10 K to 2 K.

This cooler has the advantages of no moving parts, no vibration and an indefinite lifetime. It has been successfully built and tested in our lab. We have found that, with 46 cm^3 of GGG, a cooling power of 0.030 W for 150 s can be achieved, and the total cycle time of the system can be as fast as 690 s.

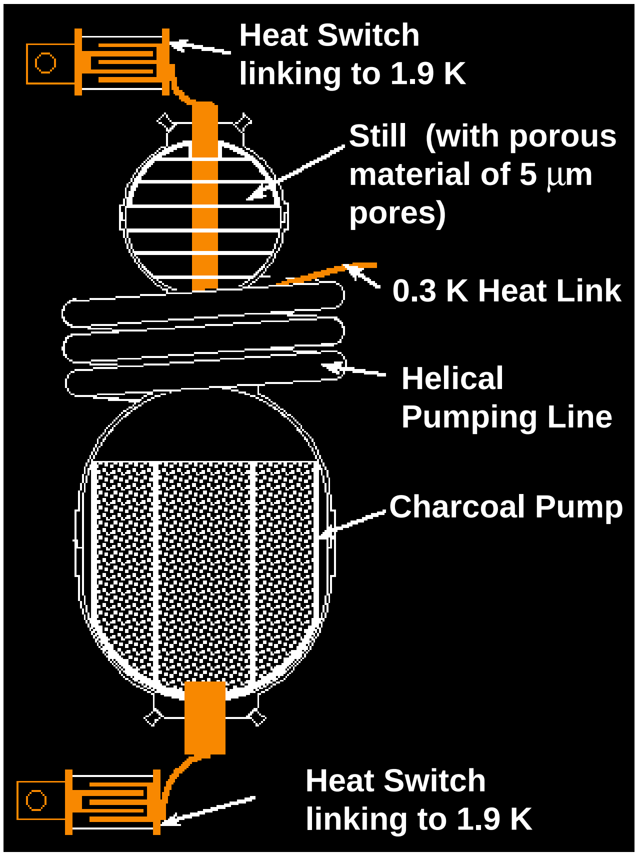

Fig. 3. A single-cycle flight ^{3}He cooler

^{3}He Sorption Coolers

The best way to achieve temperatures down to 0.3 K is to use a self-contained and compact ^{3}He cooler. Because of its lower boiling point, liquid ^{3}He can be condensed by a ^{4}He bath at 2 K and then pumped to a temperature of 0.3 K by adsorption onto charcoal. Cooling lasts until the ^{3}He runs out; the system is then recycled by heating the charcoal to provide another period of cooling. Figure 3 is a schematic of a sorption-pumped ^{3}He cooler that has flown in space[6]. This flight cooler produced 15 µW of cooling for 8 days at 0.3 K. It then recycled the ^{3}He in 15 hours, for a duty cycle of 93%. It had an average heat load on the 1.9 K heat sink of <2 mW and had a mass of less than 870 g. Such a cooler has the advantages of no moving parts, no vibration and an indefinite lifetime. We expect to be building a slightly larger version of this cooler to support a fundamental physics experiment on the International Space Station. We are also developing a continuously-operating version.

Dilution Coolers

Figure 4 shows how a sorption-pumped, single-cycle dilution cooler operates. The lowest temperatures occur in the mixing chamber where there is a phase boundary between liquid ^{3}He and liquid ^{4}He. Cooling is produced when ^{3}He crosses this boundary into the ^{4}He. From the mixing chamber this dilute ^{3}He flows through the ^{4}He to a higher temperature chamber where it is fractionally distilled from the ^{4}He. The resulting ^{3}He gas is collected by the charcoal pump. The cooling cycle ends when all the ^{3}He is in the charcoal pump. Because the refrigerator uses adsorption onto charcoal for its pumping, all operations can be controlled by heaters and, as a consequence, there are no moving parts in the refrigerator.

Modification for Microgravity On the ground, the operation of a dilution refrigerator depends on gravity to keep the liquid ^{3}He and ^{4}He in their correct chambers. (The charcoal pump contains no liquid and is gravity independent.) Within the dilution refrigerator there are two liquid-vapor interfaces and one liquid-liquid interface. All of these interfaces must be stably located in the absence of gravitational forces in a way that allows the free flow of the evaporated gasses and of the ^{3}He within the liquid phases of the refrigerator. The modifications we have made[7,8] involve filling the liquid chambers of the dilution cooler with a sintered, porous metal matrix that confines the liquids to their correct positions by capillary forces. This configuration has been tested on the ground; it produced a cooling power of 5 µW at 0.10 K and it cooled below 0.06 K with no load. It has the advantages of no moving parts, no vibration and an indefinite lifetime. We are currently developing a continuously-operating version for use in space.

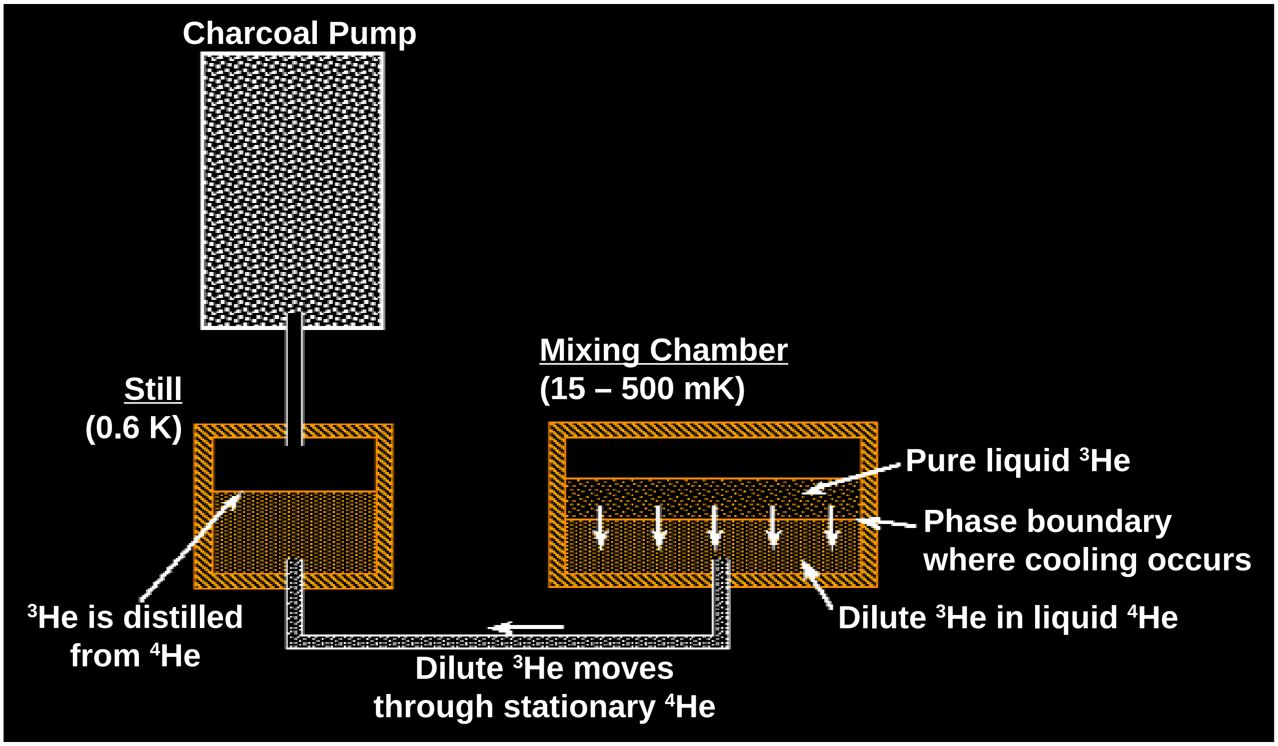

Fig. 4. Single-cycle dilution cooler.

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(For our latest publications and a summary of our current activities see our Web page at http://irtek.arc.nasa.gov/CryoDev.html)

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