CONTINUOUS REFRIGERATION BETWEEN 4.2 AND 1°K

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Introduction

Refrigeration between 4.2 and 1°K is commonly produced by the evaporation of liquid He⁴ from a thermally isolated bath maintained at the appropriate pressure by means of a vacuum pump. In the majority of experimental assemblies, a bath temperature of 1.25°K can be produced without difficulty at which temperature the saturation vapor pressure is slightly less than 1 mm Hg. When the liquid in the bath reaches a certain minimum volume, the experiment must be discontinued, at least temporarily, while the bath is returned to atmospheric pressure and a further supply of liquid at 4.2°K is added. Thereafter, there is an additional loss of liquid while the bath is again pumped down to the operating pressure.

With the recent development of devices, e.g., the maser, which may be required to operate without interruption below 4.2°K, a provision for continuous refrigeration in this temperature range becomes important. One method which we have developed for this purpose forms the subject of this report.

Flash Evaporation of Liquid He⁴

A simple approach to the problem is to assume the existence of a supply of liquid He⁴ at approximately 4°K and then to determine the feasibility, theoretically and experimentally, of continuously supplying this warm liquid at atmospheric pressure to the low-temperature volume in which the pressure is very much lower. As the liquid is delivered through an appropriate valve, partial flash vaporization will occur, which will cool the residue to the desired temperature. However, if this process is to form part of a larger thermodynamic system, it is desirable to have some reasonably accurate knowledge of its efficiency.

Since the enthalpies of the various components of the system are not known, it is not possible to apply the usual thermodynamic analysis. Instead, we postulate two models of the process, analysis of which should lead to the most optimistic and the most pessimistic of the results to be expected.

Assume that a unit mass at 4.2°K is cooled to temperature $T$ by evaporation of a portion $x$ so that the residual mass is now $(1-x)$. Evaporation of a further portion $dx$ leads to a change $dT$ in the temperature of the residue. Accordingly, if $C_p(T)$ and $L(T)$ are respectively the specific and latent heats of the liquid at $T$, then

$$C_p(T) \, (1-x) \, dT + L(T) \, dx = 0$$

$$\int_0^x \frac{dx}{1-x} = -\int_{4.2}^{T_f} \frac{C_p(T)}{L(T)} \, dT .$$

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Since it is not possible to express $C_p(T)$ or $L(T)$ in simple analytical forms, this equation must be solved arithmetically to obtain $x$ as a function of $T_f$.

This approach can be criticized on several grounds; in particular, it assumes a uniform temperature $T$ within the drop and thermodynamic equilibrium between the drop and its surroundings. Both assumptions are unrealistic. Nevertheless, if we refer to this as the "reversible" process, we can expect Eq. (2) to lead to the best efficiency (lowest values of $x$) which can be hoped for.

An alternative hypothesis is to assume that all the evaporation occurs at the temperature $T_f$, determined by the pressure surrounding the drop; therefore the entire unit mass of the original liquid is cooled to $T_f$ before it evaporates. This leads to the equation:

$$\int_{4.2}^{T_f} C_p(T) \,dT + xL(T_f) = 0 \quad (3)$$

from which $x(T_f)$ may be obtained, again arithmetically. For obvious reasons, we refer to this process as "irreversible."

**Experimental Investigation**

The apparatus used in obtaining experimental data is shown in Fig. 1. It consisted of a vacuum-jacketed container for liquid $\text{He}_4$ at atmospheric pressure mounted within an outer liquid-helium dewar and above the pumped, low-temperature helium bath. The flash-expansion valve, controlled by a rod running through an O-ring seal at room temperature, was mounted within a second vacuum space enclosing the storage volume. Liquid helium was conveyed from the

![Fig. 1. Schematic diagram of experimental apparatus.](image-url)