Summary of heat leaks into a cryostat

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Radiation

For two plane parallel surfaces with emissivities ε_1 and ε_2,

$$\dot{Q} = \sigma A \varepsilon_{eff} \left(T_1^4 - T_2^4\right)$$

where

$$\varepsilon_{eff} = \frac{\varepsilon_1 \varepsilon_2}{\varepsilon_1 + \varepsilon_2 - \varepsilon_1 \varepsilon_2}$$

Heat conduction through gas

For low pressures such that the mean free path is larger then the separation, the molecules will go from one side to the the other without colliding with each other. The conduction through the gas will proportional to the pressure (i.e. the number of molcules).

$$\dot{Q} = \text{const} \cdot a_0 \cdot P_{mm} \left(T_1 - T_2\right) \qquad \left[\frac{\text{W}}{\text{cm}^2}\right]$$

where const = 0.028 for He and

$$a_0 = \frac{a_1 a_2}{a_1 + (A_1/A_2)(1 - a_1) a_2}$$

a_1 and a_2 are the accommodation coefficients for the two surfaces and A_1 and A_2 are the corresponding areas.

Heat conduction through support and leads

The heat conduction can be calulated by using Fourier's law, $\dot{Q} = -\lambda \nabla T$. We consider a volume with cross-sectional area A and temperature dependence only in the x-direction.

$$\dot{Q} = -A \lambda(T) \frac{\partial T}{\partial x} = -\frac{A}{l} \int_{T_1}^{T_2} \lambda(T) dt = \frac{A}{l} \bar{\lambda} \left(T_1 - T_2\right)$$

$\bar{\lambda}$ is the mean value of the thermal conductivity between the two temperatures

$$\bar{\lambda} = \frac{1}{T_2 - T_1} \int_{T_1}^{T_2} \lambda(T) dt$$

and is tabulated for different materials and temperatures.

Experiment

Joule heating

$$\dot{Q} = RI^2$$

Summary

Type	77 to 4.2K	295 to 4.2K	4.2 to 1.2K
1. Radiation from warm to cold vessel	2	430	0.000018
2. Radiation in pumping tube	0.075[a] - 130[b]	0.075 - 130	0.075 - 130
3. Conduction through pumping (SS) tube	100	190[c]	0.2
4. Conduction through leads	38	31[d]	0.63
5. Conduction through vaccum space	3.4	13.5	0.14
6. Conduction through gas in pump tube	9.5	23[e]	0
7. Joule heating in thermometer	1[f]	1	1
Total heat [mW]	154 - 284	259 - 389	2 - 130
He boil off [l/h]	0.21 - 0.38	0.35 - 0.52	-

[a] Blackened tube
[b] Total reflection
[c] $l = 30$ cm
[d] $l = 36$ cm
[e] $l = 30$ cm
[f] $I = 1$ mA

Table 1: Contributions of heat leaks in units of mW.

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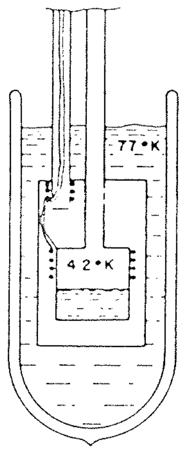
Low Temperature Physics: Calculations of Heat Leaks

The purpose of this exercise is to give you a feeling of the magnitudes of the heat leaks of a cryostat and to estimate which parameters that are the most important ones to consider in the design of low temperature apparatus. Hence, we will estimate the main contributions of the heat transport into the (simplified) cryostat which is specified below.



Inner part: polished Cu — surface 500 cm^2, volume 800 cm^3
$\varepsilon = 0{,}02$

Outer part: tarnished brass
$\varepsilon = 0.6$

Support: stainless steel tube with
diameter Ø=2.0 cm
thickness t=0.3 mm
length (77 to 4.2 K) l=6.0 cm

Pressure (He gas) in vacuum space:
$p = 10^{-5}$ mmHg

Electrical leads: 8 Cu wires, Ø=0.1 mm
4 constantan, Ø=0.2 mm

Total length of cryostat, about 50 cm

Rough scale of figure: 1:10

What are the different contributions to the heat transport into the inner part? You should find at least 6 ones. Estimate these heat leaks with the aid of the specifications above and the tables that are enclosed.

Investigate if the Joule heating in connecting leads and a Ge thermometer attached to the inner space will give any problems. (Try different values of the measuring current.) The thermometer has a resistance of about 1 kΩ in the temperature range in question.

In order to get a feeling of the effectiveness of the liquid nitrogen cooled shield, you should make the same calculations for an outer space temperature of 295 K, inner one 4.2 K.

Would the heat leaks change drastically if the outer container were at 4.2 K and the inner one at 1.2 K? (This would correspond to the case of a pumped ^{4}He bath surrounded by an unpumped one.) Any other issues to be considered in this case?

Starting from the calculated values (which can be presented in the form of a table to get an overview) we will discuss possible improvements of the cryostat construction (the elements of which are rather antiquated, but is treated for pedagogic reasons).