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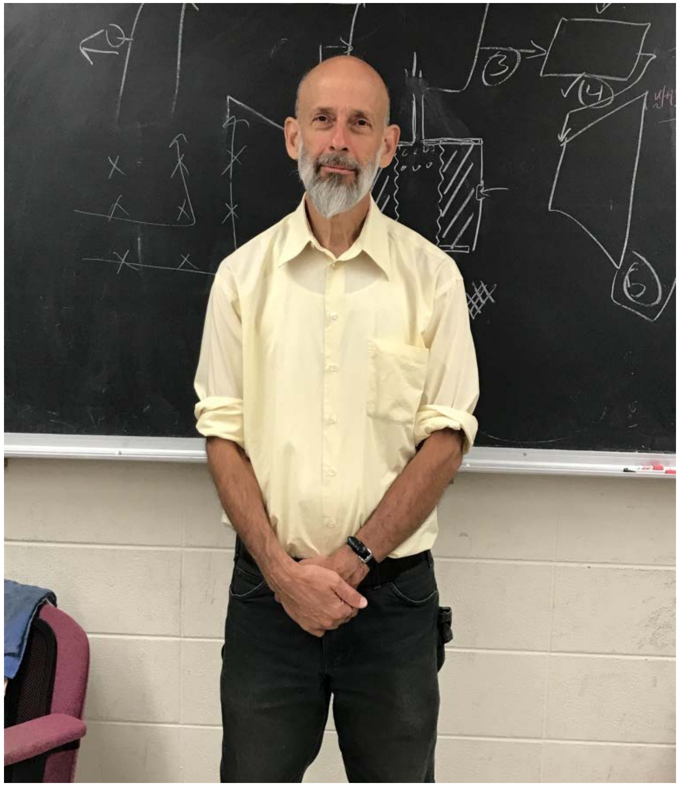


Thesis: A $^3He/^4He$ heat switch for the 1K to 2 K range

Background

^4He below the λ point (2.17 K) has high thermal conductivity, greater than that of copper at the same temperatures. But a small addition of ^3He greatly reduces this conductivity.

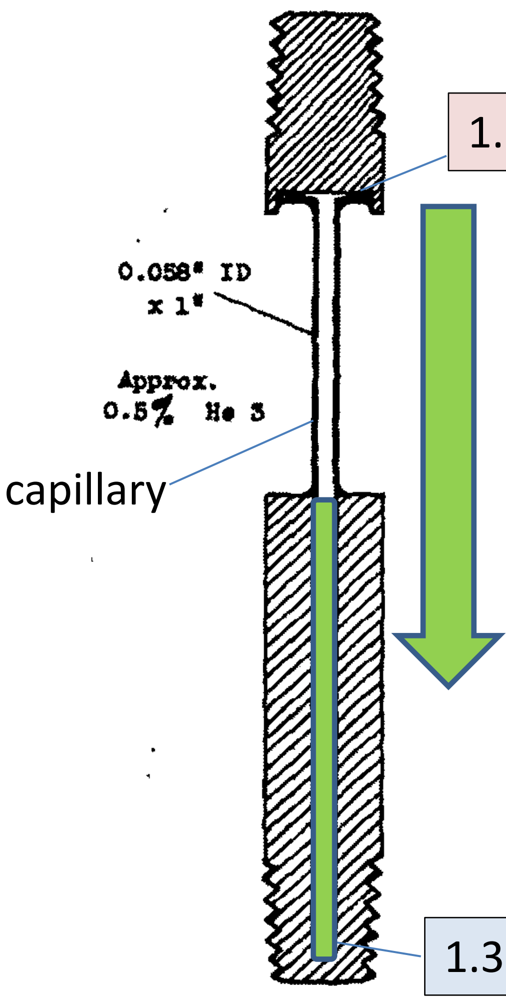
In a weak solution of $^3He/^4He$ (< 5% ^3He), when the solution flows from warm to cold the non-superfluid ^3He is swept along with the superfluid ^4He. This ^3He "*heat flush*" effect was discovered in the 1950's.

A heat switch was designed in the 1950's using this ^3He *heat flush* effect. A capillary connects one reservoir (smaller; fixed at a warmer temperature) to a second reservoir (larger; colder), all at T < 2.17 K.

In the **on state** the dissolved ^3He is flushed out of the smaller warm reservoir and the capillary into the larger reservoir, outside the heat path. ***Capillary thermal conductivity is high***.

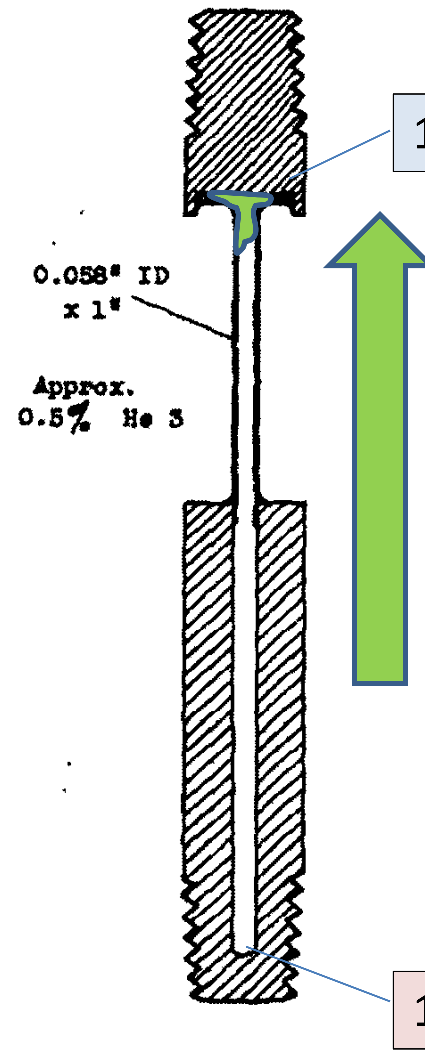
In the **off state** the heat current is reversed, ^3He is flushed into the capillary, concentrates at one end, and ***thermal conductivity through the capillary nears zero***.

ON STATE



^{3}He flushed out of heat path into colder reservoir – almost pure ^{4}He in capillary. ***High thermal conductivity in capillary.***

OFF STATE (predicted)



^{3}He flushed Into capillary, concentrates at one end. ***Low thermal conductivity in capillary.***

After Fulton, CD, Hwang, CF, Fairbank, WM, Vilas, JM, "Helium Heat Rectifiers and a Simple Magnetic Refrigerator", in *Proceedings of the 1956 Cryogenic Engineering Conference,* 220 – 224, 1956.

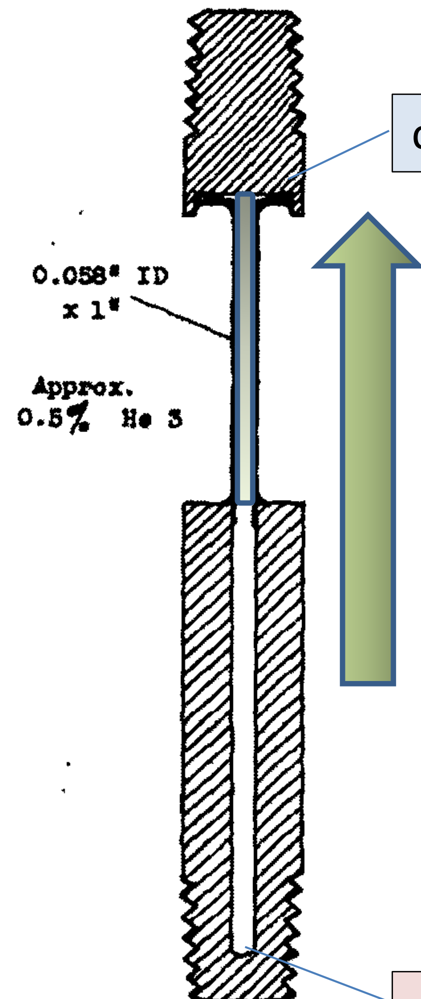
Motivation

Heat switches built on this principle failed when the difference in temperature between hot and cold ends was too large.

Off state heat fluxes were measured to be two to three orders of magnitude greater than predicted by models.

The hypothesized reason is that the $^3He/^4He$ solution becomes turbulent in the off state under actual operating conditions and the ^3He becomes uniformly distributed in the capillary. As ^3He is not concentrated in one area it no longer reduces thermal conductivity to near zero as predicted, and required, for the off state.

OFF STATE (observed)



Thermal conductivity in capillary < on state but >> zero. Hypothesis: ^3He is flushed into capillary but turbulence in capillary prevents predicted concentration of ^3He at colder end.

Objectives

The heat switch to be built attempts to solve this problem by adding a "*superleak*" adjacent to the capillary. A *superleak* is a filter with pore sizes so small (~ 10 microns) that superfluid ^4He (no viscosity) will pass through but normal fluid ^3He (has viscosity) will not. A capillary filled with jeweler's rouge (iron oxide particles) is frequently used.

Superfluid ^4He alone will flow through the superleak leaving non-turbulent $^3He/^4He$ solution in the capillary in the off state; ^3He can concentrate at one end.
The heat switch with superleak should yield near zero **off state** thermal conductivity as predicted by a resistance-network computer model.

OFF STATE (with superleak)