Appendix A. Design and Fabrication of Cold Sleeve

A cold sleeve was designed and fabricated in order to conduct temperature-dependent studies on trapped ions in the ICR cell. Figure A.1 shows the machine diagrams for a custom-designed flange to be attached to the vacuum manifold at the point where the can enters the magnet. Two leads are provided to feed nitrogen through the system, one inlet and one outlet. Figure A.2 shows the body of the cold sleeve, which consists of stainless steel tubing around a copper blanket. Contractions due to cooling of the metal should separate the tubing from the blanket by only 0.003" at 80 K, so cooling ability should not be inordinately affected.

Both the double-sided flange and the cold sleeve have been fabricated. They still must be leak-tested and cleaned before any attempt is made to put them into the ICR. Longer bolts will be necessary to insert the double-sided flange between the arm of the can and the four-way cross where pulsed gas is introduced in the body of the instrument.

Following the figures is a treatment of the estimated heat conduction properties of the cold sleeve.

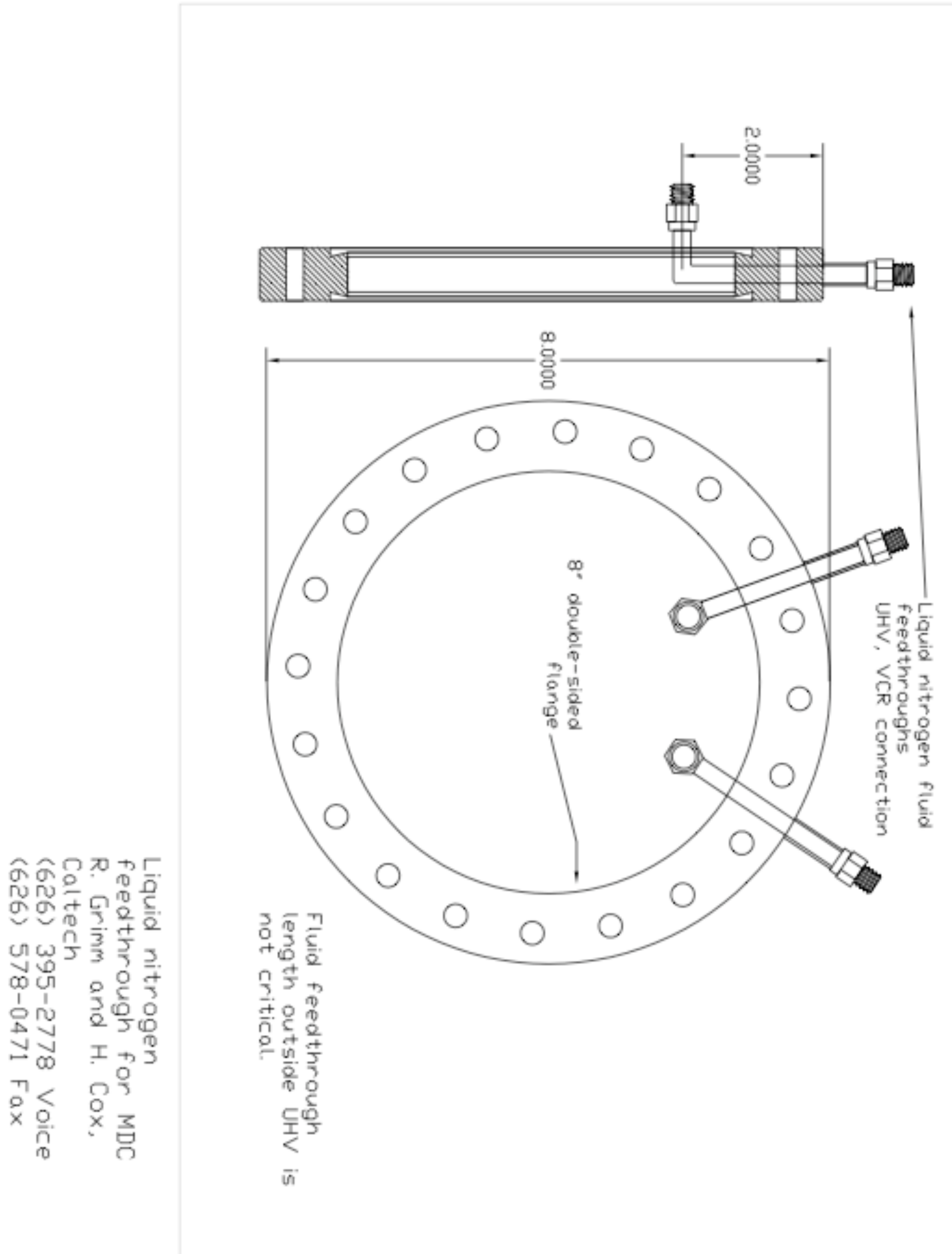

Figure A.1. Machine diagrams for construction of custom-built cooling flange.

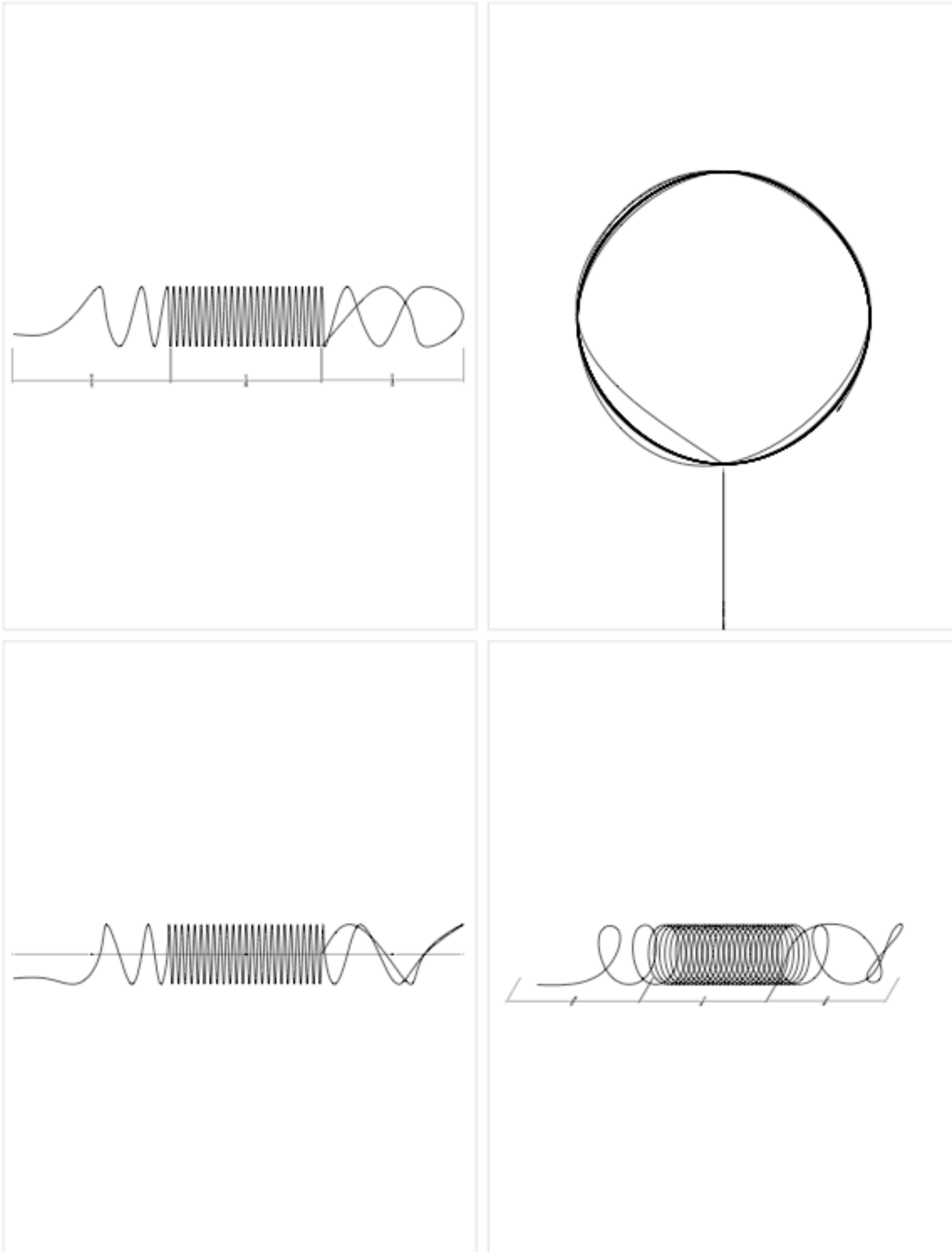

Figure A.2. Configuration of stainless steel cooling tubing around copper.

An analysis of temperature effects on a cold sleeve composed of copper tubing around a stainless steel cylinder. Key values and equations are from *Experimental Techniques in Low-Temperature Physics*, 2nd Edition, by Guy K. White, published in 1968.

There are three major contributors to heat transfer at low temperatures:

I. Conduction by solids

$$\dot{Q} = \frac{A}{l}\bar{\lambda}(T_2 - T_1)$$

where A is the cross-sectional area of a solid (in cm^2), l is the length of the solid, and T_2 and T_1 are the temperatures at either end of the solid. The mean values of thermal conductivity λ in W cm^{-1} K^{-1} for T_2 = 300 K and T_1 = 77 K, are 4.1 for copper (electrolytic tough pitch) and 0.123 for stainless steel types 303, 304, and 347.

II. Low-pressure gas conduction

For low temperature, low pressure, and parallel surfaces,

$$\dot{Q} = 0.243\frac{\gamma + 1}{\gamma - 1}a_0\frac{T_2 - T_1}{\sqrt{MT}}p$$

where γ is the ratio of specific heats, M is the molecular weight of the gas, a_0 is the accommodation coefficient, T is the temperature of the pressure gauge, and p is the pressure in torr. For T = 295 K,

$$\dot{Q} = Ka_0 p(T_2 - T_1)$$

The constant K is 0.028 for helium, 0.059 for hydrogen gas, and 0.016 for air. In our system, this is a negligible contribution to heat transfer (in nW) because the pressure of the ultra-high vacuum system is so low.

III. Radiation

For two plane parallel surfaces each of area A, with emissivities ε_1 and ε_2, and at temperatures T_1 and T_2,

$$\dot{Q} = \sigma A (T_1^4 - T_2^4) \frac{\varepsilon_1 \varepsilon_2}{\varepsilon_1 + \varepsilon_2 - \varepsilon_1 \varepsilon_2}$$

where $\sigma = 5.67 \times 10^{-12}$ W cm^{-2} K^{-4}. For clean polished copper, $\varepsilon = 0.015 - 0.019$. For stainless steel, $\varepsilon = 0.074$ at room temperature.

Now we can determine the factors influencing heat transfer in our cold sleeve:

A. Conduction by solids

copper leads approximately 1 mm in diameter from cell

$A = 7.85 \times 10^{-3}$ cm^2

$l = 75$ cm

For one copper lead,

$$\dot{Q} = \frac{7.85 \times 10^{-3}\,\text{cm}^2}{75\,\text{cm}} \frac{4.1\,\text{W}}{\text{cm K}} (300\,\text{K} - 77\,\text{K}) = 9.5 \times 10^{-2}\,\text{W}$$

For six leads, $\dot{Q}_{\text{conduct}} = 0.57$ W to cool from 300 K to 77 K.

B. Gas Conduction

As noted in II, losses from gas conduction are on the order of nanowatts, and so not important.

C. Radiation

For a 4.5" diameter cylinder 10" in length, the surface area of the stainless steel cylinder is 912.1 cm^2. Then

$$\dot{Q} = (6.53 \times 10^{-11} \text{W K}^{-4})(T_1^4 - T_2^4)$$

For T_1 = 300 K and T_2 = 77 K, $\dot{Q}_{\text{rad}} = 0.49$ W.