Superconductivity Pre-lab Problems

1. Browse over "Working with Turbo Pump" in related material in the 122 website. The turbine-type blades in our HiCube pump typically spin at 1500 Hz and have a radius about 5 cm. Estimate the linear speed of the middle of the blades. Why is the physics department going to lose $8k if you accidentally vent the HiCube pump during its operation?

2. Read "CMP Variable Temp and Support Electronic Manual". Answer the following questions:
   a. Give an example of places where stainless steel is used and places that copper is used in the dewar. Why are different metals used at different parts in the cryostat?
   b. Convert 1 atm to hPa, mbar and mTorr. The target pressure of the vacuum chamber is 10^{-5} hPa. Estimate the mean free path of the molecules at this pressure.
   c. Estimate how much volume would 1-liter liquid nitrogen occupy when it evaporates. Comment on whether you may get suffocated during the experiment. [The liquid nitrogen density at 77 K is 0.808 kg/L, and the density of the ambient nitrogen gas is 1.25 g/L.]
   d. What detrimental consequence would occur if you vent the dewar when it's still cold? What would be the correct way to end the experiment before you leave the lab?

3. Read the Superconductivity Manual and its appendices. Answer the following questions:
   a. Fig. 2.1 shows the 4-wire method for measuring the resistance of a bar-shaped sample. The measurement assumed that the current flowing through the voltmeter is much smaller than that in the sample. The input impedance of a voltmeter is 10 MΩ. The sample is 2 mm thick, 3 mm wide, and 10 mm in length between points B and C. If the sample has a resistivity of 1 Ω m, is this assumption reasonable? What if the resistivity of the sample is 10^4 Ω m instead?
   b. The superconductive sample is a cylindrical tube, of inner-diameter 15 mm, wall thickness 1.5 mm, and length 15 mm. Suppose this sample were replaced by a cylindrical tube of the same size made of pure silver, what would be its room-temperature resistance, considered as a one-turn loop of conductor? What about at 77 K? What would be the approximate inductive time constant $\tau = L/R$ at these two temperatures? [The resistivity of silver is 1.6×10^{-8} Ω m at room temperature, and 3×10^{-9} Ωm at 77 K]
   c. Draw the magnetic field lines both inside and outside a long bar magnet. If the magnetization of the bar magnet made of NdFeB is $M = 10^6$ A/m, find the magnetic field inside the bar magnet. Then read over the calculation in Appendix C for the predicted 2.4 mT magnetic field created by the persistent current in the superconducting annulus. How would you change the geometry of the bar magnet, if you want to increase the value of this magnetic field?

4. Suppose you have a cylindrical tube made of a type-I superconducting material. The tube has inner radius a and outer radius b. Above T_c, you place the tube inside a uniform external magnetic field B_0

with the tube's axis along the direction of B_0. The magnetic field is not strong and does not kill the superconductivity. The tube is long, so you can treat it as a long solenoid and ignore the fringe effect.

a. You lower the temperature below T_c, and the tube becomes superconductive. The electric current must be zero inside the type-I superconductor (why?). So, the current can only flow at the surface. Find the surface current density at the inner surface and outer surface of the tube, respectively.

b. You then turn off the external magnetic field. Find the surface current density at the inner surface and outer surface, respectively. Find the magnetic field inside the hollow tube.

c. If the tube is made of a type-II superconductor such as BSCCO used in the experiment, the current can flow through the interior of the material (why?). If the wall is thin, we may treat the volume current to be uniform in the tube wall. If we repeat the thought experiment above for BSCCO, what would be the volume current density in the tube after the external magnetic field is turned off?