Spring 4-23-2014

Understanding Thermometry at Low Temperature

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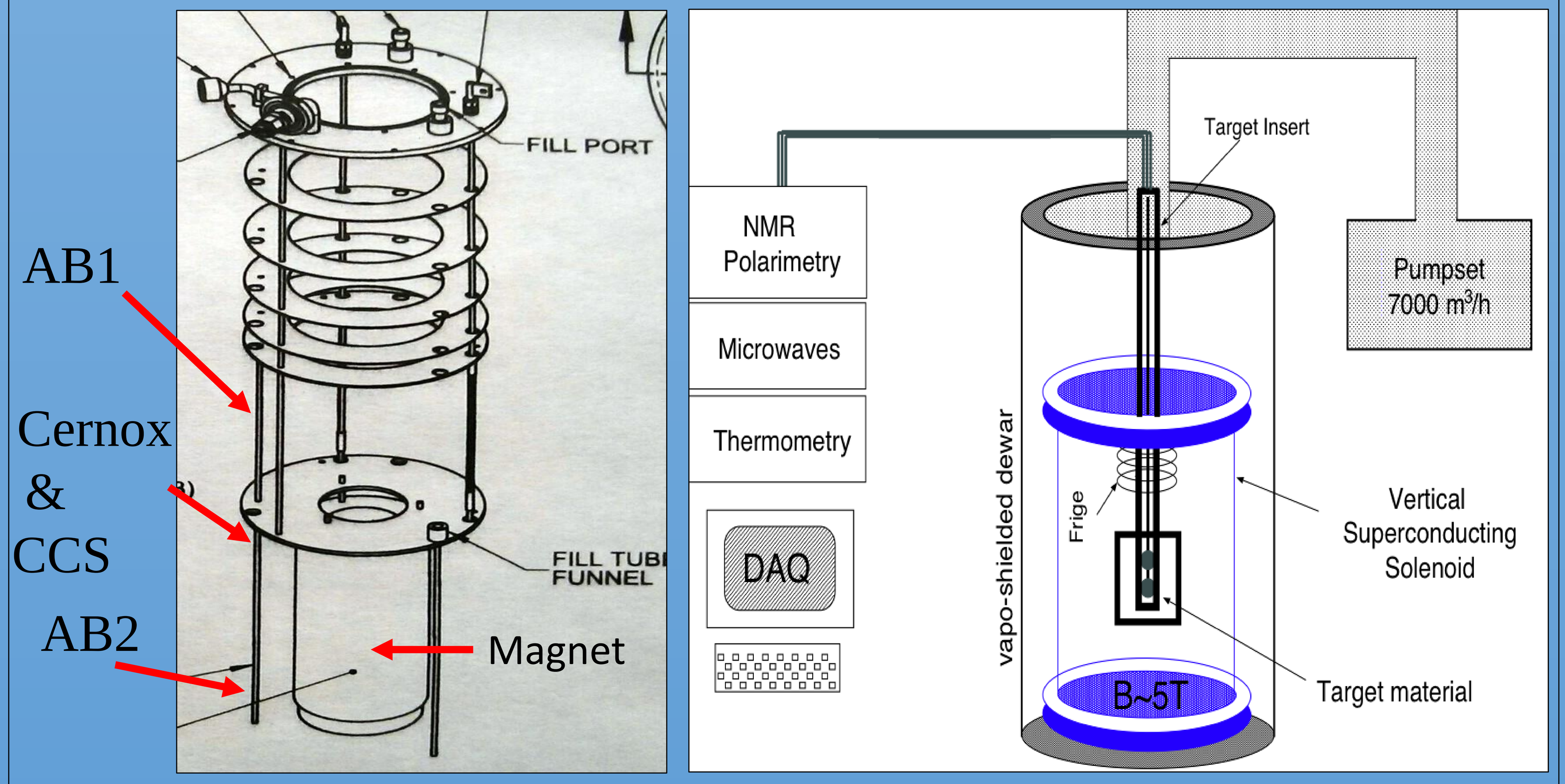
UNH-NPG

Abstract

Cryogenics play a vital role in building a Dynamic Nuclear Polarization (DNP) target for electron scattering experiments. The target material temperature was monitored using thermometry in order to evaluate their stability for use in the low temperature cryogenic bath of a DNP target. In this project, I investigated the resolutions and accuracies of carbon ceramic, Cernox, Allen-Bradley, and thermocouple sensors at five known temperatures.

Background

The UNH Nuclear Physics Group is building a dynamic nuclear polarization (DNP) target to spin-polarize protons in solid NH_3 at cryogenic temperatures. DNP is capable of producing nearly 100% proton polarization, but its accuracy is dependent on that of the temperature. The temperature of the DNP, shown below, is measured near the 5T magnet where the NH_3 will be located.



At thermal equilibrium the spin polarization of protons in NH3 have a known dependence on temperature and magnetic field:

$$P_{TE} = \tanh\left(\frac{\mu B}{kT}\right)$$

To keep the uncertainty of the polarization under 1%, we can solve for the required uncertainty in the thermometry.

$$\delta P = \sqrt{\left(\frac{\delta P}{\delta T}.\delta T\right)^2}$$

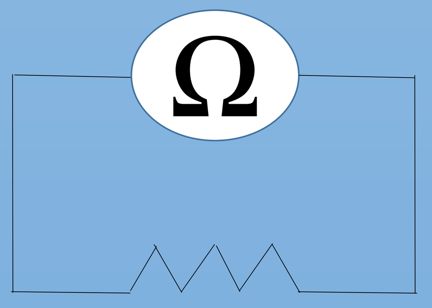
$$\delta P = \sqrt{\left(\frac{-\mu B sech^2\left(\frac{B\mu}{kT}\right)}{kT^2}\delta T\right)^2}$$

where $\delta P = 0.01$, $\mu = -9.2x10^{-24}$J/K, k = 1.38x10^{-23}J/K, T = 1K, B = 5T. Solving for δT gives us $\delta T = 0.62K$. It shows that uncertainty in temperature must be less than 0.62K to achieve less than 1% relative uncertainty in polarization.

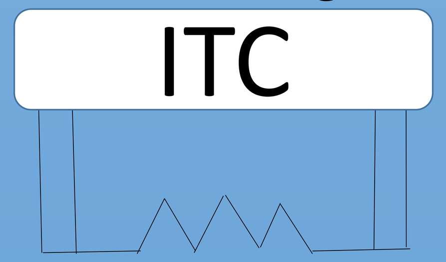
Method

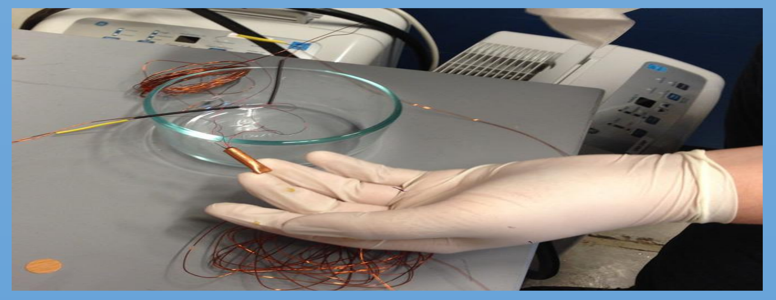
The Cernox was connected to the Mercury ITC which is capable of automatic data logging.

Carbon Ceramic Resistors (CCS):
The two terminals of the sensor were soldered with magnetic wire.
The output terminals were connected to ohmmeter.

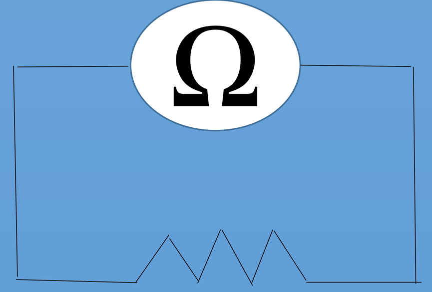


Cernox:
The two terminals of the Cernox were soldered with four magnetic copper wires. The inner two measures the voltage and outer two provides the current.
The current and voltage was measured through ITC.

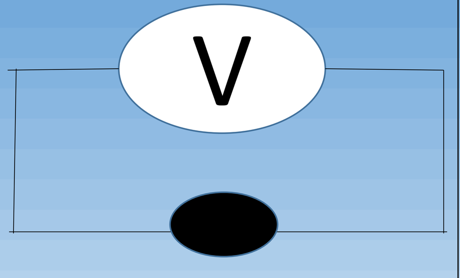




Allen Bradley Resistors:
The two terminals of Allen Bradley resistors were soldered with magnetic copper wire.
The resistance was measured using ohmmeter.



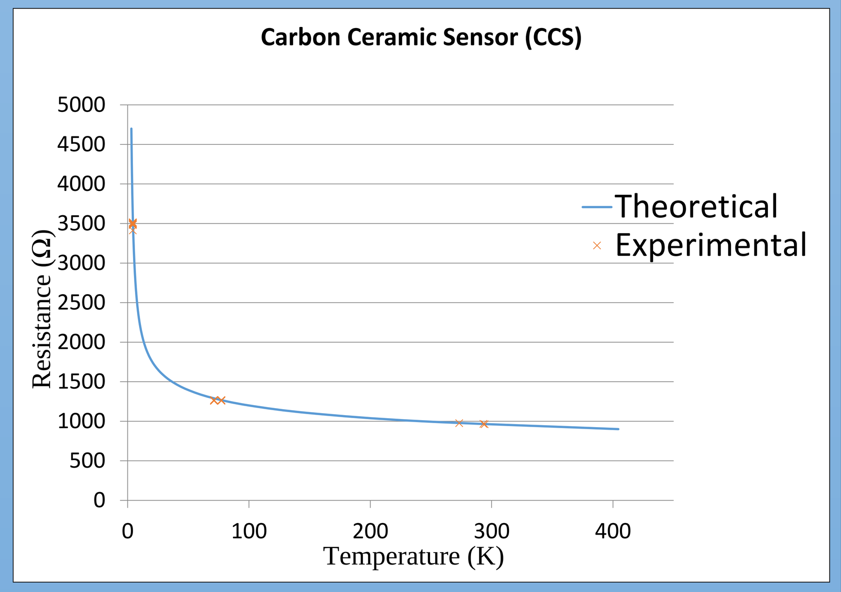
Thermocouple (Type K):
The positive nickel-chromium and negative nickel-aluminum were connected to the multimeter.



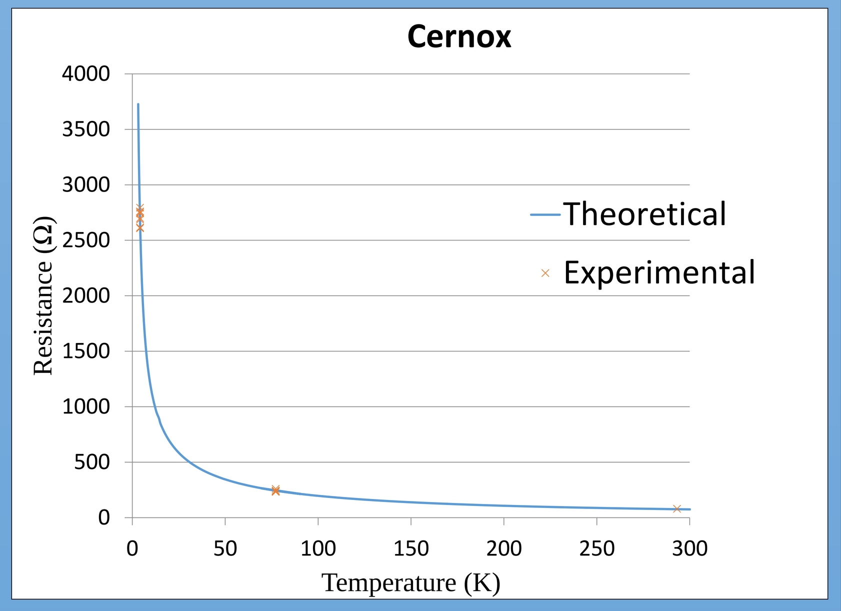
All the sensors were placed in liquid nitrogen, liquid helium, room temperature and ice water.

All the sensors except thermocouple are Negative Temperature Co-efficient (NTC). NTC sensors are made from pure metal oxides. They are inversely proportional to temperature changes.

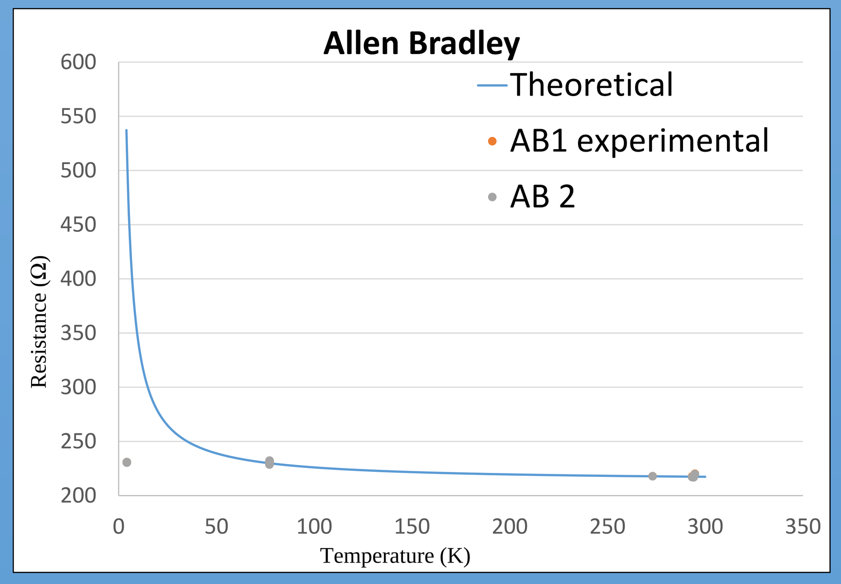
Carbon Ceramic Resistors:
- The temperature range is 1.5 - 300K
- Resistant to magnetic fields



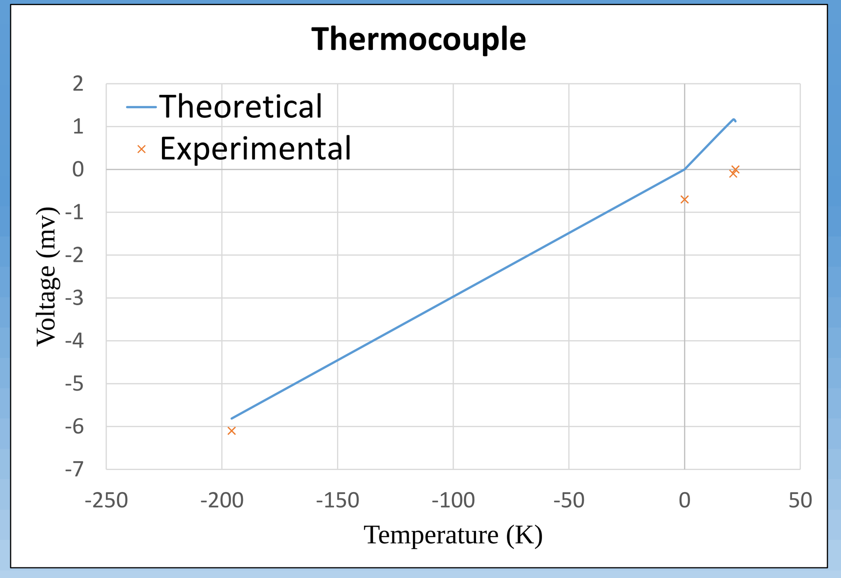
Cernox:
- Cernox temperature ranges from 100 mk to 420 K.
- They are high sensitive at low temperature and good sensitivity over a broad range.



Allen Bradley:
- They are also known as carbon resistors.
- There temperature ranges is below 1K-100K.
- Insensitive to nuclear radiations.



Thermocouple (type K):
- This thermocouple is made of nickel-chromium and nickel-aluminum.
- The temperature range is 73.15 K to 1533 K.
- They have good corrosion resistance.



Conclusions and future plans:

This project will establish an accurate thermometry system to be used in the polarized target lab. The calibration data indicates that CCS and Cernox perform with sufficient accuracy and precision in LHe in given temperatures, however AB responds poorly in LHe and does not match our calibration curve, thus we can't use it. For future measurements all of the thermometry data will go through the Mercury ITC and will be operated by Labview.