Experimental Techniques at the National High Magnetic Field Laboratory at Los Alamos National Lab

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Introduction

My summer at the National High Magnetic Field Laboratory at Los Alamos National Laboratory, with Dr. Alex Lacerda, began June 3, 2002 and ended July 26, 2002. My work revolved around my involvement with the 20 Tesla Superconducting Magnet. This report will include the mechanical work I performed during the summer and the concepts I have learned.

There are four aspects of my report that will be discussed: designing a copper sample holder, stripping and redesigning an existing probe, understanding and relating Maxwell's Equations, and basic concepts of magnetism and superconductivity.

I'd like to thank Dr. Alex Lacerda for his positive attitude towards Kathleen Leenerts, my partner, and myself. He made it possible to learn in a relaxed environment, but at the same time pushed us both beyond our limits of initial education and understanding. I'd also like to recognize Mr. Andrew Christianson, Mr. Michael Pacheco, Dr. Myung-hwa Jung, Dr. Charles Mielke, Ms. Lou Miller, Todd Barrick, and Kristin Mortensen for all their help.

I'd also like to thank Florida State University for allowing me too have this opportunity. Without their academic and financial support, I would not have been able to have this experience.

Section I : Designing the Sample Holder

Mr. Andrew Christianson began by describing and drawing the magnet and the He^3 system. Ohms Law was then discussed and how it is used to find resistivity.

$$V = IR$$

Where V = Voltage, I = Current, and R = Resistance

$$R = \frac{L\rho}{A}$$

Where L = Length of Sample, A = Area of cross - section of sample, and ρ = Resistivity

Solving for ρ we find

$$\rho = \frac{VA}{IL}$$

Mr. Christianson then had my partner and I design a copper sample holder for him. Together we decided on a two-sample holder that had a circular ledge on the bottom. This circular ledge allows a sample to be mounted perpendicular to the magnetic field, as opposed to gluing on a right angle copper piece. The design is included in Appendix I. After the copper piece was machiened it was then screwed onto the end of a long hollow stainless steel tube. With a triangular G-10 piece guiding the end of the probe, it will be placed into a He^3 system.

Section II : Resurrecting a Probe

Our next project was to mount a piece of $YbNi_2{}^{11}B_2C$ on an old probe and then test it in the magnet. Before we could mount the $YbNi_2{}^{11}B_2C$ on the probe, we had to pre-screen it using a "poor man's probe." A "poor man's probe" is a short probe that has a 25 pin connector on one end and a four pin connector on the other. The four pins received information from a connector that had the $YbNi_2{}^{11}B_2C$ glued onto it, and with the delicate platinum wires epoxyed onto four other pins on the connector (see Appendix 2). We then took this probe, placed it directly into a He^4 tank, and then used a Lakeshore LR-400 to test the resistance of the $YbNi_2{}^{11}B_2C$. The curve of Resistance vs. Temperature was normal, therefore we decided to move onto the large probe. Before we mounted the $YbNi_2{}^{11}B_2C$, we first inspected this probe and found there was a broken wire somewhere within the mess of the probe. This mess consisted of twisted wires and dental floss wrapped around the probe, tape, and dried GE Varnish. Kathleen and I took off all the wires, dental floss, tape, and GE Varnish. To begin the process all over again, we first found out how many wires we were going to need. It required eight wires for the two samples, four wires for the Cernox Resistor, and two wires for the heater: 14 wires total, 7 twisted pairs. The benefit of twisted wires is twofold: we were going to be putting these wires into a magnetic field. When a looped wire is put into a fluctuating magnetic field, a residual current is created inside the loop, thus skewing data. However, if we decrease the area of the loop as much as possible (by twisting) then there will be little to no induced current. We also twist the wires because if a current is induced, then the twisted wires create successively alternating signs; therefore one current is cancelled out by the other current. To avoid having to wrap the wires around the probe like before, Kathleen and I strung the twisted wires through a small Teflon tube. We then went to the 20T-experiment room, found the front panel plugs corresponding cable letters.

Front Panel	**VTI Cable "A"**	**VTI Cable "B"**
$^{-}I_{S1}$	F	
$^{+}I_{S1}$	E	
$^{-}V_{S1}$	K	
$^{+}V_{S1}$	J	
$^{-}I_{S2}$		D
$^{+}I_{S2}$		C
$^{-}V_{S2}$		A
$^{+}V_{S2}$		B
$^{-}I_{C}$		G
$^{+}I_{C}$		H
$^{-}V_{C}$		E
$^{+}V_{C}$		F
^{-}H	H	
^{+}H	G	

S1 = Sample One

S2 = Sample Two

C = Cernox Resistor

H = Heater

We had to strip the wires before soldering them. To do this, one can place a small amount of Strip-X on the wire, wait a few minutes, and then wipe it off, or one can take a razor and gently scrap off the insulation. We soldered the ends of the twisted wires into the cable connectors at the top of the probe corresponding to the chart shown above. After establishing the position of the wires, we then soldered the other ends of the wires to the heater, Cernox Resistor, and the eight pins (see Appendix II). We used Phosphor Bronze wire for two reasons: it is insulated and it is not thermal conductive, unlike copper. After soldering all the wires in place it was time to place the platinum contacts on the new sample, $CeRh_8Ir_2In_5$. We used a four-wire measurement system because the resistance of the sample can become so low at specific temperatures that if the two-wire measurement system were used, the resistance of the wires would interfere with the measurement of the sample's resistance. Therefore the current method is the four-wire method; the two outside contacts send a current through the sample and the two inside contacts measure the voltage across the sample. We were able to glue these contacts to the sample by using conductive silver epoxy. The epoxy comes in two parts and must be mixed in a 1:1 ratio. We would then slide the platinum wire through the epoxy mixture so a little was on the end. Then we would place the wire on the sample, bake it for 30-40 minutes in the oven at 100° C, and then repeat the process over again until all four contacts were placed on. We wanted the magnetic field perpendicular to the sample, so we had to glue the sample onto a right-angle copper piece. The sample could not be in contact with the copper piece because that would cause a short to ground. Therefore, we glued three small pieces of Kimwipes EX-L on all sides of the copper piece using GE Varnish. After this was completed, Kathleen and I glued the sample onto the covered copper piece with GE Varnish, and baked it in the oven for 10 minutes at 100° C. When the GE Varnish had dried we glued the copper piece onto the end of the probe's sample holder under "Sample 2." When we glued the copper piece down, we made sure that the sample was facing out ward so that the platinum wires were facing the pins. Because the probe cannot be baked, it was left alone overnight so that the GE Varnish could dry the copper piece in place. The platinum wires then had to be soldered to the pins. It is recommended to place a small drop of solder onto the pin first and allow it to cool. Then melt the solder with one hand and gently wrap the platinum wire around the pin when the solder is melted, then allow it to cool. Afterwards we tested both ends to make sure there was full continuity and no resistance between other wires. Kathleen and I went to see if the Lakeshore LR-700 and Lakeshore DRC-91CA Temperature Controller were working properly. We had to insert the resistance curve directly into the temperature controller. To do this, we used a Visual Basic program called "Curve Handler." The program and curve numbers (Appendix III) are included. The data collected (Appendix IV) indicates that the $CeRh_8Ir_2In_5$ is anti ferromagnetic, but that is inconclusive considering the sample was not prescreened.

Section III: Understanding and Relating Maxwell's Equations

Maxwell's Equations:

Gauss' Electric Law

$$\nabla \cdot E = \frac{\rho}{\varepsilon_\circ}$$

Where $\rho =$ charge density, $\varepsilon_\circ =$ permittivity of free space

Gauss' Magnetic Law

$$\nabla \cdot B = 0$$

Faraday's Law:

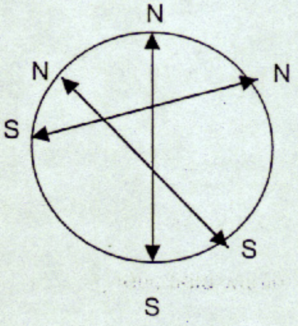
$$\nabla \times E = -\frac{\partial B}{\partial t}$$

Ampere's Law:

$$\nabla \times B = \frac{1}{c^2}\left(\frac{J}{\varepsilon_\circ} + \frac{\partial E}{\partial t}\right)$$

Both of Gauss' laws fall under electrostatics. Gauss' Electric Law states that if there is a charge within a closed loop and that charge is not changing, then the electric flux is a constant. The same came be said about Gauss' Magnetic Law. The net change of a magnetic field within a closed surface will always be zero because the two opposing "poles" will cancel each other's magnetic moments (Fig. 1).

Figure 1



Faraday's and Ampere's Laws are also related. Faraday's Law explains that if the electric field is changing, there must be a negative rate of change in the magnetic field. Ampere's Law states that if there is a magnetic field around a closed area, it is proportional to the electric current. For example, if one takes a piece of metal (let's say a nail), and wraps a wire around it, and then drops a current through the wire, a magnetic field will be created around the nail making it magnetized.

Section IV: Basic Concepts of Magnetism and Superconductivity

Superconductivity: The ability to conduct electricity without resistance. Each superconductor (element, inter-metallic alloy, or compound) must be below a certain temperature to be superconductive.

T_c (Curie Temperature or Critical Temperature): Temperature at which a material begins to superconduct. Each material has its own critical temperature. Above the Curie Temperature a ferromagnet loses its ferromagnetic properties.

Ferromagnetism: The state in which a material is completely magnetized in a magnetic field but retains its magnetism after the field has been removed. The residual magnetism stays because of the alignment of ions in the lattice.

Ferrimagnetism: The magnetic ordering of a material is created by two kinds of magnetic ions, therefore two kinds of magnetic moments. These moments can align parallel or anti-parallel to the magnetic field. The adjacent moments are not consecutively aanti-parallel.

Antiferrimagnetism: The state in which a material's magnetic moments align anti-parallel adjacent to each moment, creating a net magnetic moment of zero.

Antiferrimagnetic materials do not respond to a magnetic field at low temperatures, and present only a weak attraction at higher temperatures.

Magnetic Moment: A magnetic moment is created when a dipole is placed into a magnetic field where torque is exerted onto it. The magnetic moment is also the product of the strength of the pole and the distance between the poles.

Diamagnetism: The ability for a material to repel the magnetic field it is placed in. Superconductors are diamagnetic. The magnetic moments of a diamagnetic material align anti-parallel to the magnetic field exerted.

Paramagnet: A material that becomes proportionally magnetized to the strength of the magnetic field applied. Paramagnets are not as strong as ferromagnetic materials because they do not have residual magnetism after the magnetic field has been lifted.

Susceptibility: It is the unit of strength of the magnetization of a material that has been placed in a magnetic field. As the temperature decreases, a material's susceptibility increases.

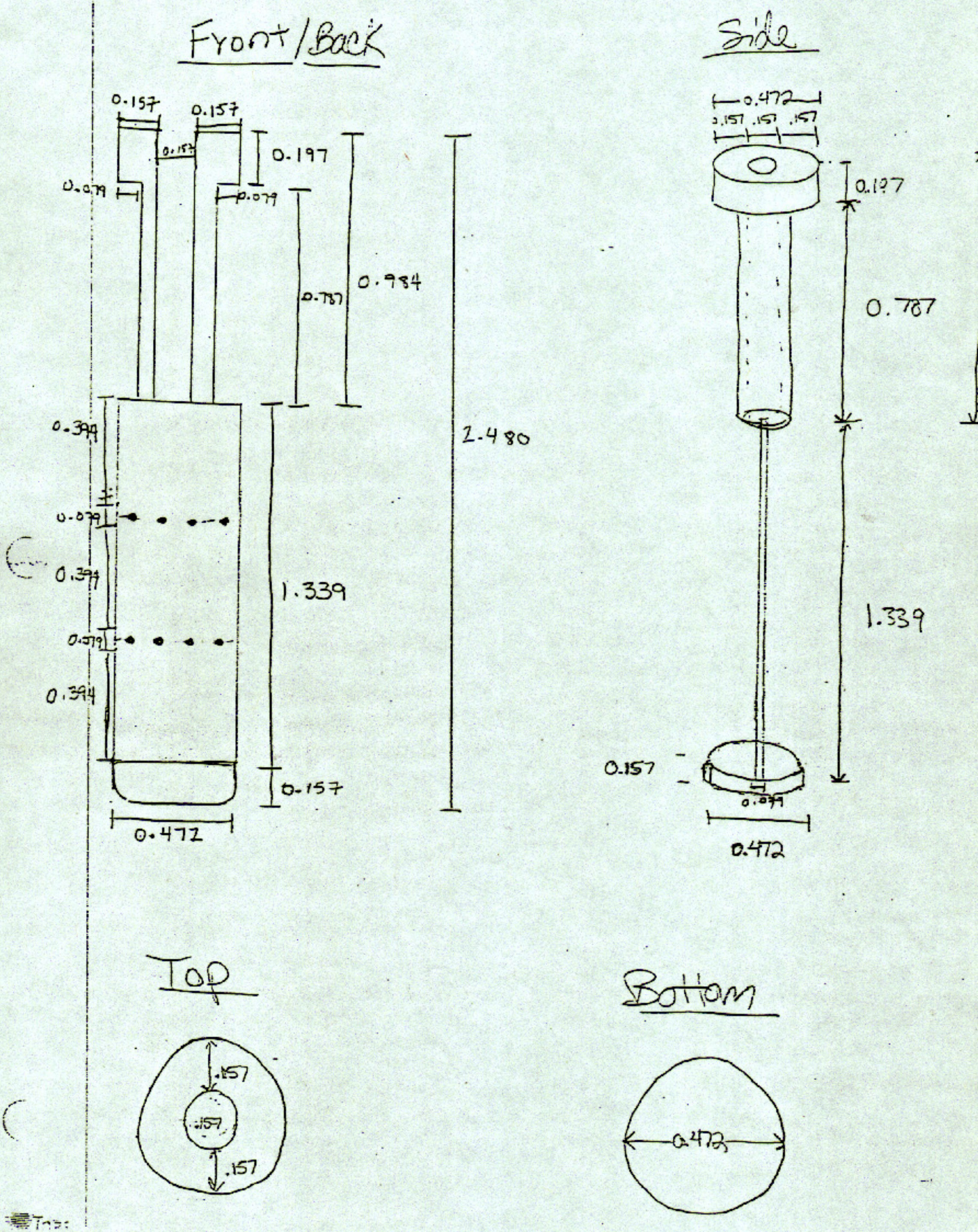
Anisotropic: An anisotropic material has different properties depending on the direction of the measurement.

Cooper Pair: Two electrons become paired, explained by the BCS theory, despite their negative charges. It is because of Cooper pairing a material become superconductive.

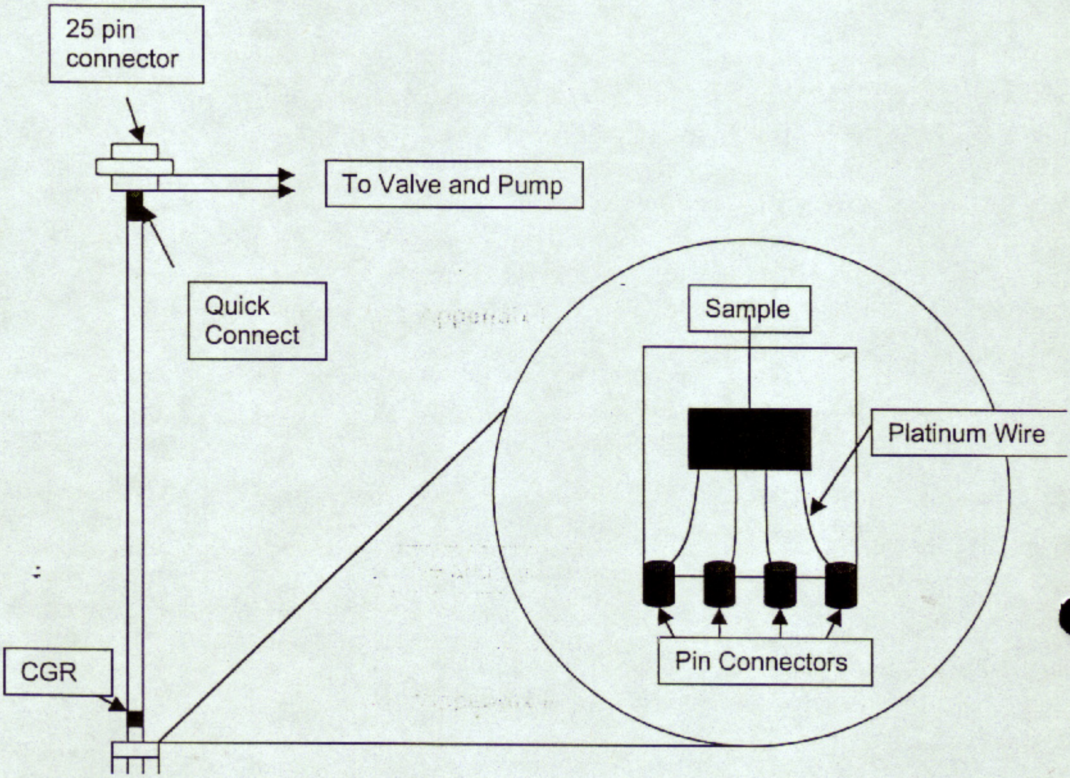
Resistivity: A material's opposition to the flow of current. When a superconductor reaches its critical temperature, resistivity drops to zero.

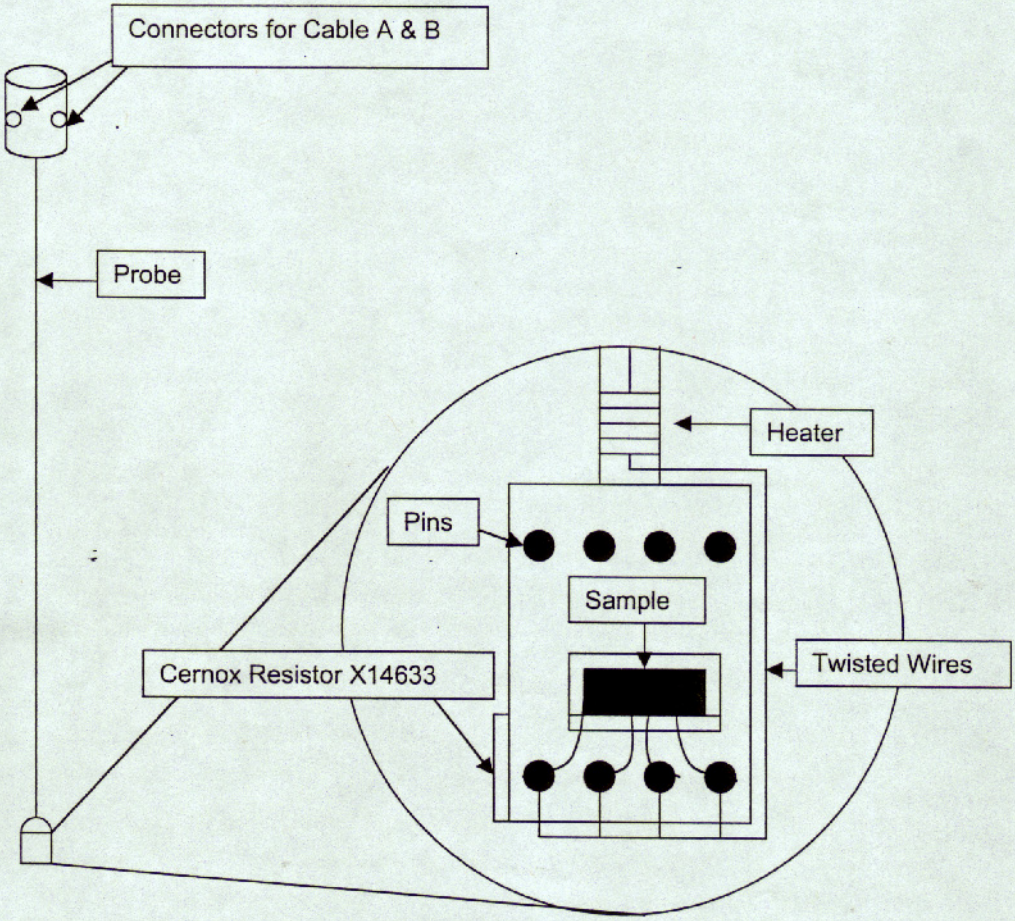
Eppen **Appendix I** 06/14/02

Note:
Every Unit in Inches



Appendix II


25 pin connector
To Valve and Pump
Quick Connect
Sample
Platinum Wire
Pin Connectors
CGR

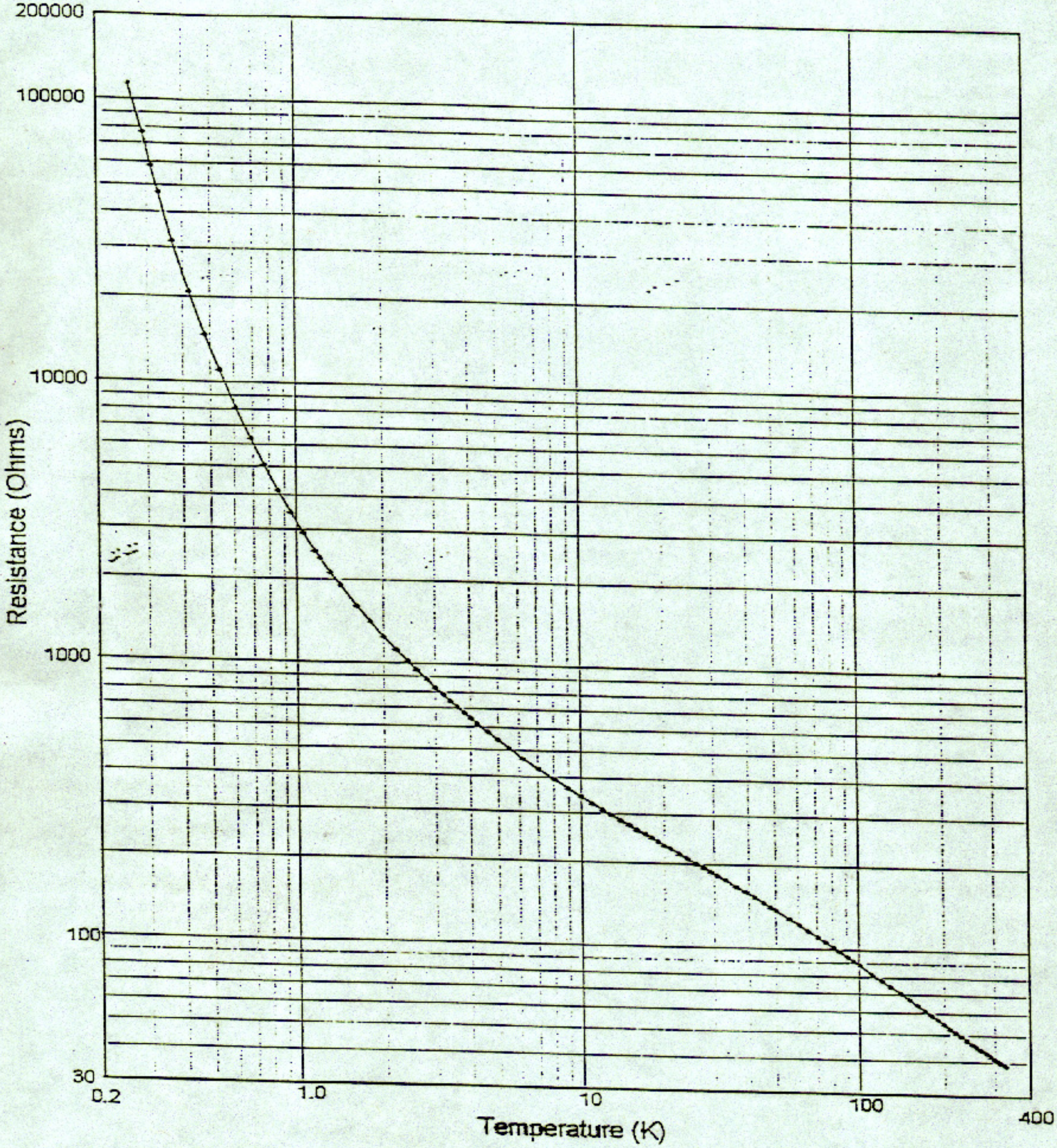

Connectors for Cable A & B
Probe
Heater
Pins
Sample
Twisted Wires
Cernox Resistor X14633

DATA PLOT

Appendix III

Calibration Report: 362906
Sensor Model: CX-1030-SD-0.3L
Sensor Type: Cernox Resistor
Temperature Range: 0.30K to 325K

Sales Order: 68796
Serial Number: X14633
Sensor Excitation: 2mV±50%



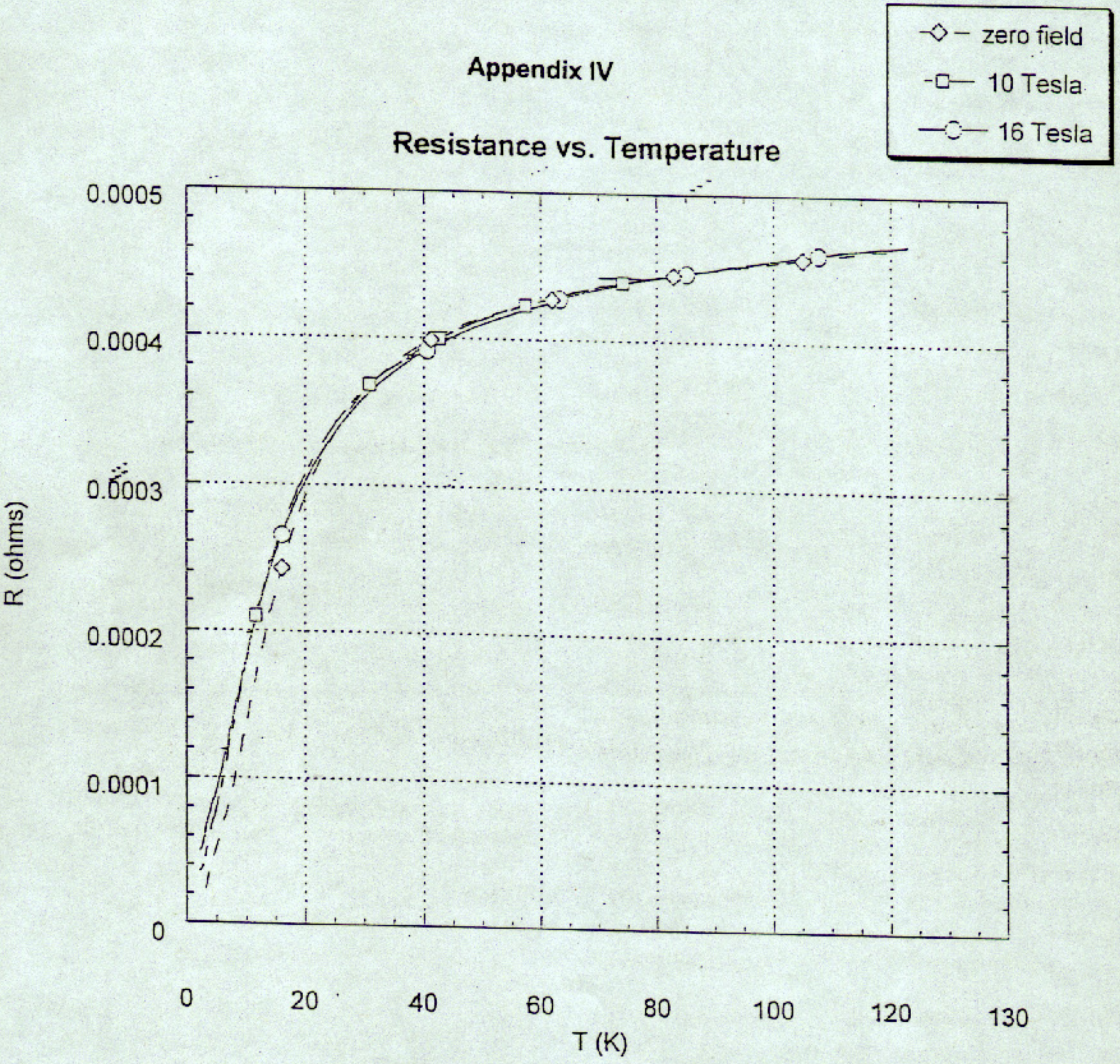
TEST DATA

Calibration Report: 362906
Sensor Model: CX-1030-SD-0.3L
Sensor Type: Cernox Resistor
Temperature Range: 0.30K to 325K

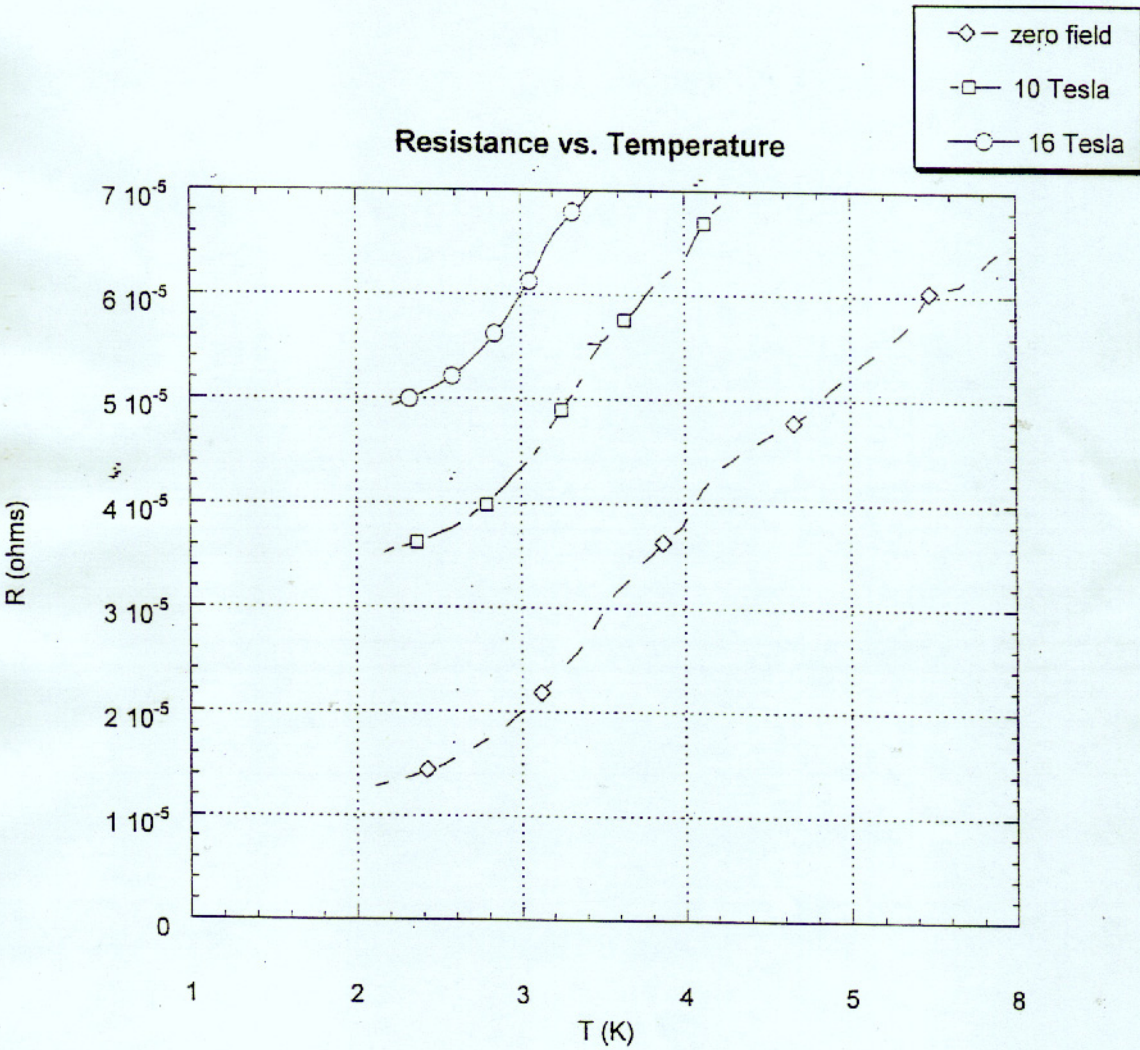
Sales Order: 68796
Serial Number: X14633
Sensor Excitation: 2mV±50%

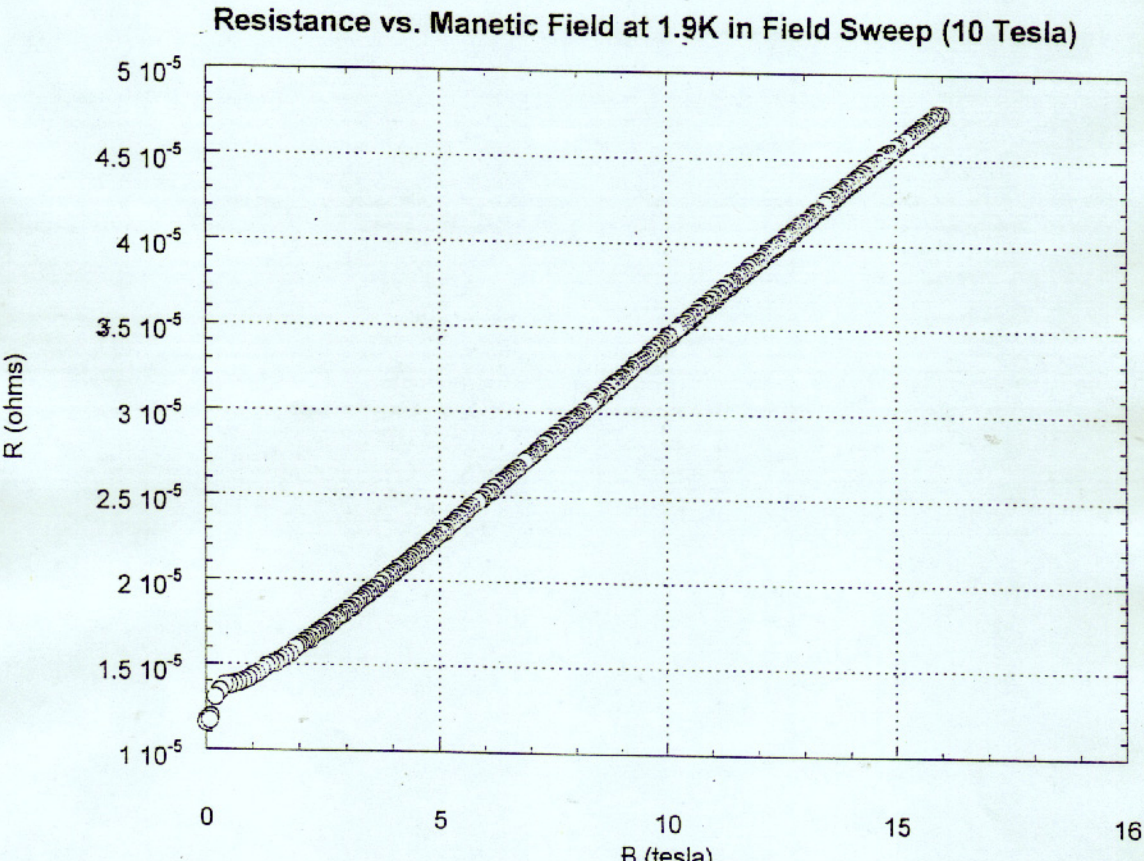
Index	Temperature (K)	Resistance (Ω)	Index	Temperature (K)	Resistance (Ω)
1	0.259782	114093.	51	21.1048	226.182
2	0.289978	76568.0	52	22.7024	217.294
3	0.309808	58463.0	53	24.2970	209.339
4	0.329790	46974.1	54	26.1859	200.796
5	0.367879	31701.3	55	27.7522	194.321
6	0.418079	20959.9	56	29.3476	188.306
7	0.476058	14698.4	57	30.9058	182.809
8	0.534747	10999.1	58	32.9998	176.043
9	0.609914	8086.00	59	36.1213	167.054
10	0.685040	6312.40	60	39.0769	159.495
11	0.764805	5064.79	61	42.0593	152.682
12	0.855060	4118.27	62	45.1690	146.272
13	0.950719	3433.40	63	48.0261	140.926
14	1.04977	2916.68	64	50.0229	137.468
15	1.15339	2515.01	65	55.8008	128.500
16	1.20323	2371.13	66	60.4406	122.257
17	1.30576	2112.09	67	65.3823	116.360
18	1.40799	1905.24	68	70.5157	110.900
19	1.61231	1599.51	69	75.4685	106.157
20	1.79671	1403.57	70	80.4551	101.858
21	1.99792	1243.25	71	85.3704	97.9877
22	2.19753	1121.31	72	90.4150	94.3651
23	2.40331	1021.29	73	95.3622	91.0971
24	2.59456	946.365	74	100.303	88.0794
25	2.80377	878.135	75	111.176	82.1788
26	3.00407	823.558	76	120.546	77.7689
27	3.20697	776.413	77	130.016	73.8232
28	3.41037	735.521	78	140.025	70.1166
29	3.59655	702.971	79	150.035	66.8072
30	3.80949	669.886	80	160.032	63.8352
31	4.00435	642.968	81	170.036	61.1541
32	4.21771	616.806	82	180.038	58.7259
33	4.61131	575.711	83	190.035	56.5118
34	4.99753	541.694	84	200.033	54.4970
35	5.48997	506.251	85	210.042	52.6369
36	6.19938	464.931	86	220.076	50.9263
37	7.01269	428.250	87	230.071	49.3566
38	8.01176	393.170	88	240.059	47.9054
39	9.01545	365.594	89	250.066	46.5609
40	10.0193	343.166	90	260.060	45.3175
41	11.0227	324.617	91	270.066	44.1559
42	12.0216	308.810	92	280.059	43.0750
43	13.0225	295.176	93	290.059	42.0671
44	14.0219	283.137	94	300.057	41.1228
45	15.0237	272.545	95	310.043	40.2450
46	16.0211	263.061	96	315.046	39.8233
47	17.0196	254.498	97	320.052	39.4196
48	18.0114	246.663	98	325.735	38.9709
49	19.0091	239.565	99	328.417	38.7650
50	20.0063	232.909			

Appendix IV



Resistance vs. Temperature
zero field
10 Tesla
16 Tesla
R (ohms)
0.0005
0.0004
0.0003
0.0002
0.0001
0
T (K)
0
20
40
60
80
100
120
130


Resistance vs. Temperature
zero field
10 Tesla
16 Tesla
7 10-5
6 10-5
5 10-5
4 10-5
3 10-5
2 10-5
1 10-5
0
R (ohms)
1
2
3
4
5
8
T (K)



Resistance vs. Manetic Field at 1.9K in Field Sweep (10 Tesla)
5 10-5
4.5 10-5
4 10-5
3.5 10-5
3 10-5
2.5 10-5
2 10-5
1.5 10-5
1 10-5
R (ohms)
0
5
10
15
16
B (tesla)