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Summary of Polarimetry Analysis

Gordon Cates
Princeton University
cates@pupgg.princeton.edu

Steffen

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What follows is a summary of the various EPR calibrations that have been done. While much work remains, the summary presented here represents the first time all the calibrations have been gathered in one place, and analyzed in a consistent manner.

The goal in what follows is to produce a calibration constant (which I will call C) which is in units of milliVolts per Amagat per percent of polarization. (mV / Amg %). This quantity can be extracted from an EPR calibration involving any cell, and to the extent that one can assume that the cells are identical in geometry, it should always have the same value. The reproducibility of C from calibration to calibration is thus a measure of our understanding of the polarimetry.

Date	Nominal Temp.		Wait time	C x 10^2 (mV / Amg %)	C' = C x (.757/.7315)^2
Don't Worry					
9-27-98	100C		< 1 hour	2.88	3.08
9-27-98	125C		~ 1 hour	3.11	3.33
9-27-98	150C	**	~ 2 hours	3.06	3.28
9-28-98	120C	**	> 2 hours?	3.24	3.46
Blue					(.757/.719)^2
10-8-98	100C		short	2.77	3.07
Be Happy					(.757/.725)^2
10-14-98	120C		-	4.80	5.23
10-15-98	175C		-	3.34	3.64
Armegedon					(.757/.744)^2
10-20-98	170C		-	2.80	2.90
10-20-98	130C		< 1/2 hour	2.87	2.97
10-20-98	100C		~ 1/2 hour	3.01	3.12
10-20-98	100C	**	~ 2 hours	3.13	3.24
10-22-98	170C		-	3.04	3.15
9-25-98	Water I				3.00
10-19-98	Water II				3.17

Discussion of the Data

The largest systematic affecting our data is the so-called "polarization gradient" problem. This can be understood as follows. Since spin relaxation of He-3 occurs everywhere in the cell, but the polarization of He-3 spins occurs only in the pumping chamber, we can be certain that the polarization in the pumping chamber will in general be higher than in the target chamber. Furthermore, the only way we can know this gradient directly is to calculate it. The problem is further aggrevated by the fact that when we are taking beam, the spin relaxation rate in the target chamber is very much higher than anywhere else in the cell.

The affect of the polarization gradient is readily apparent in our data. The calibration constant C (called "cal" in the Mathematica notebook)

Figure 1:

is inversely proportional to the polarization in the target chamber. If the actual polarization in the target chamber is lower than what we assume when we compute C, the number we compute will be systematically smaller than what is actually the case. There are two sets of data in which several EPR calibrations were taken spanning a time during which the cell had been cooled, and the polarization gradient thus allowed to slowly equilibrate. These two sets of data are indicated by a vertical bar the right of the nominal temperatures at which the calibrations were performed. In both cases, C can be seen to drift upward by something like 6-12% as time progresses.

Another potential source of systematic error is our lack of knowledge of the temperature of the pumping cell. For the calibration constant C, this effect is suppressed because k_0, the constant that characterizes the size of the EPR shift, has a temperature dependence that in large part offsets the fact that at higher temperatures, the density in the pumping chamber is relatively lower. Still, if the pumping chamber temperature were misunderstood by something like 25 degrees, this would cause us to evaluate C about 2% higher than its real value. The protocol for EPR measurements outlined later in this report suggest a quick and easy means for limiting the size of this systematic.

There is one data point that I exclude from our analysis. This is the data point yielding C = 4.8. This calibration was taken immediately after we had been doing repairs on the target, and during the calibration, the NMR signal was seen to be crashing so quickly in prompted me to make the comment in the target logbook: "Where are these losses coming from?". At the time we had not yet realized that the time constants needed to allow polarization to equilibrate were as long as they are, so we were not on guard for the effect. Regretably, this is the calibration that was used for computing the version of k for a while.

If we exclude the one bad data point, and do nothing but average the 11 remaining numbers, we find that C = 3.023 +/- 0.181 (5.99% sigma)
C'= 3.204 +/- 0.217 (6.76% sigma)

```
6 |
5 |   |***
4 |***|***
3 |***|***|
2 |***|***|***|
1 |***|***|***|
  ____________
  low  med high
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The fact that the systematic causes some of the values of C to be too low is visible in the histogram at left. Of course, other factors could influence this distribution (i.e. if we had done all our calibration after a wait of two two hours), but none-the-less, the fact that the distribution is as narrow as it is is reassuring.

Protocol for future EPR measurements

1) Print out RTD's
2) NMR measurement
3) EPR
4) NMR
5) Turn off lasers
6) Wait 5 minutes
7) Print out RTD's
8) NMR
9) Turn one laser back on.
10) Turn temperature down to 120 degrees (or value to be determined).

*This sequence, (4-8) permits the determination of extra heating in the pumping cell.

Figure 2:

	11) Wait for temperature to stabilize.
	12) Print out RTD's
*This pair yields a "pre-two-hour" calibration.	13) NMR 14) EPR
	15) NMR
	16) Turn off remaining laser
	17) Wait two or even three hours
	18) Print out RTD's
*Steps 19-23 will allow us to determine the extra heating in the cell due to one laser.	19) NMR 20) Turn on one laser. 21) Wait for temperatures to stabilize 22) Print out RTD's
*Steps 23-24: Primary calibration	23) NMR 24) EPR
	25) NMR

Computing "k" for the "Extract Polarization" program.

The final step in understanding our polarimetry is computing k, the percent per milliVolt that is entered into the "Extract Polarization" program. To do this, we need two additional pieces of data, the density in the target cell at the time of the measurment, and the relative dimensions of the target cell. For now, let me focus on the question of density.

In the accompanying Mathematica notebook, it is argued that the density in the target cell of Armegedon, while in operation, is 13 Amagats. Accordingly, the constant k, yielding percent per millivolts are as follows:

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Water: k = [(3.17 x 10^(-2)) mV/Amg % 1.02(.744/.757)^2 13 Amg]^-1 =2.46 %/mV
EPR    k = [(3.13 x 10^(-2)) mV/Amg % 13 Amg]^-1                    =2.46 %/mV
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In this argument, the temperature of the pumping cell is determined by looking at the NMR signal with lasers off, when presumably we know the temperatures fairly well, and then turning lasers on in order to see how much the NMR signal changes due to INTERNAL heating of the pumping cell. The suprising conclusion is that the average temperature of the pumping cell rises about 50C above what we might naively conclude from looking at the RTD's alone. This is from heat being deposited inside the cell. If we do nothing but look at the RTD's, we get a temperature more like 179C (here I assume tp = 1/3(oven set point + RTD 6 + RTD 7)). This would cause us to conclude that nt = 12.42 Amagats, yielding k(water) = 2.58 %/mV and k(EPR) = 2.57 %/mV. In summary:

Value for k

	Temp. of pumping chamber	
	179 C	229 C
Water	2.58 %/mV	2.46 %/mV
EPR	2.57 %/mV	24.46 %/mV

To be clear, I have used "Water II" and the post-two hour 100C

Figure 3:

EPR number from 10-20-98, which was excessively noisy. We should definitely be looking for an opportunity to repeat the EPR calibration using the above protocol to get a better number.

Remaining work on polarimetry

Of course there is a great deal that we should do. Here is a partial list of jobs.

1) First and foremost, we need to do another, and more accurate, EPR calibration. I suggest the above sequence. Since the opportunities to do EPR calibrations will be very few, I think we should discuss variations to the above plan BEFORE we do them. Let's make certain we get it right the first time.

2) Line-shape analysis of the water. We absolutely must learn to analyze our water lineshapes correctly. We ought to be able to look at the ratio of up to down peaks and extract from that a T_1 (and hence a T_2). We need to get this worked out. Right now we are applying an arbitrary 1.02 correction to account for relaxation effects, and that is certainly insufficient.

3) Further refine the inputs given in this report. As you will see looking at the notes accompanying each entry, the numbers could still be refined.

4) Learning to compute the polarization gradients. Once we do this, we can directly compare high temperature and low temperature calibrations.

5) Once we do another EPR calibration, and we know the degree to which one laser causes the average temperature of the pumping cell to be higher than what is indicated by the RTD's, we can further refine the temperature inputs used above. To do this before we also understand the polarization gradients, however, would probably not be useful.

In general, people interested in polarimetry should read, understand, and criticize this report. We need to refine things if we have any hope of reaching 4% errors on polarimetry.

Figure 4: