Radiation damping as a diagnostic tool for 3He polarimetry in optical pumping cells

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Introduction : For hyperpolarised ^{3}He accurate measurement of the polarisation is necessary in order for calibration of the initial polarisation for imaging studies [1] where polarisation is monitored to account for losses during storage and dispensing and studies into polarisation limits [2] where the x-factor determination requires accurate knowledge of the spin up and relaxation time constants. In-situ polarimetry of gas in the cell typically relies on small tip angle NMR from a coil close to the cell. In this work we investigate the effects of the high magnetisation on the observed FID from the optical pumping cell in both the high and low energy states and the effect of radiation damping on the observed total magnetisation.

Theory : Radiation damping [3] changes the shape of the FID by addition of a term $sech(t/\tau_{rd})$ to the original T_2* decay where τ_{rd} is the radiation damping time constant given in SI units by $\tau_{rd}^{-1}=Q\gamma m_o \eta\mu_0/2$ (Eq.1) and Q, γ, m_o, η are the coil quality factor, gyromagnetic ratio, magnetisation density and filling factor. Therefore for two coils with different Q we expect the observed linewidth to be different if radiation damping is occurring.

Experimental details : ^{3}He was polarised using spin exchange optical pumping (SEOP), with a 2Bar cell containing < 1g of Rb. The cell was polarised using an external cavity diode laser (40W), the system polarises cells to high magnetisation, typically 70%. We have constructed a home built digital NMR spectrometer using National Instruments Labview software and m-series acquisition card (1.25MSsec) with home built duplexer. Orthogonal coils of different Q were mounted in-situ on the optical pumping cell in a direction mutually orthogonal to the B_0 allowing the dual recording of the spin up using small tip angle pulse–acquire NMR at 32 kHz from the respective coils. The different Q's were obtained by winding different number of turns (100 Q=35 and 300 Q=3), in addition the 300 turn coil had a 10Ω resistor in series in order to artificially dampen the Q. Q was measured using a function generator and search coil to transmit and the pickup was measured using an oscilloscope connected to the coil. All experiments were carried out in a B_0 field of ~10G using a Helmholtz pair (diameter 0.8m). Checks for field uniformity were performed using a Lakeshore 3-axis probe mounted on a single axis translation stage. In addition we also measured gas lifetimes in sealed cells (~0.8Bar) >500 hours indicating the uniformity of the field environment is high. Pulses were 0.7V with a duration of 1.2ms and in each case the coils were pulsed sequentially with a delay of ~1s between them, therefore over the course of a spin up (~12 hours) they are measuring the same magnetisation (within error).

Results : The magnetisation build-up was monitored over time from the cell using the two coils. Figure 1 shows a plot of the peak to peak voltage vs T_{2obs}, showing a linear increase with magnetisation, consistent with an expected change from radiation damping (Eq.1). A typical FID is shown inset in Figure 1 showing good SNR. Figure 2 shows the change in linewidth with increasing polarisation (spin-up time) for the two coils. The low Q coil has a smaller change, during the start of the measurement at low m_o both coils have a similar observed T_2 and converge to a value > 200 ms representing the background T_2^*, however with increasing magnetisation the higher Q coil has an observed T_{2obs} which changes more significantly. Analysis of spin up time gives two different times (Q=35) 849±9min and (Q=3) 722±26min. This is consistent with the high Q coil having a lower effective tip angle as expected due to the radiation damping and shows that any magnetisation measurements inferred from NMR with this coil are more sensitive to error. Shown in Figure 3 are a series of FID's when pumping in the high energy state, this was done by adjusting the circular polarisation of the pump beam (relative direction of the B_0 and λ/4 polarising plate). The data is labelled *i,ii* and *iii* in increasing polarisation. The form of the decay is non-exponential obeying a simple *sech* relationship [3] and can be used to determine when pumping in the high energy state.

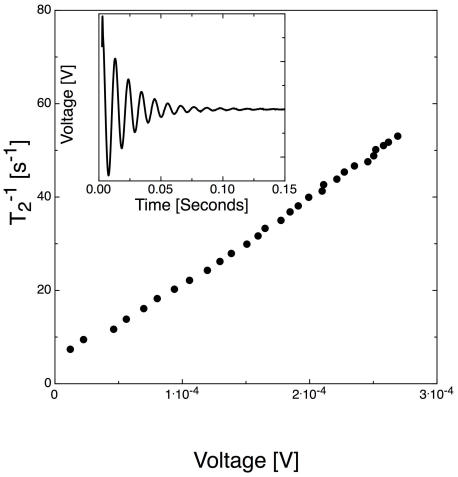

Figure 1 : Plot of peak to peak voltage from low Q coil vs : T_2^{-1} high Q coil. Inset FID from ^{3}He cell when optically pumped to the low energy state

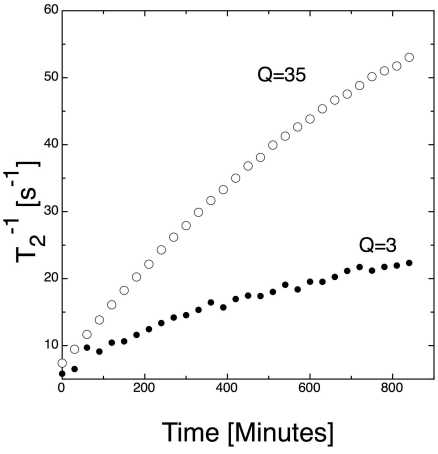

Figure 2 : T_2^{-1} for the two different coils

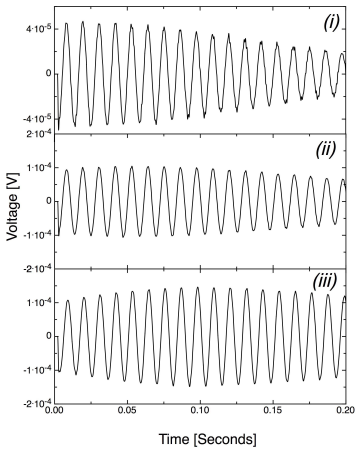

Figure 3 : Typical FID's obtained from ^{3}He pumped into the high energy state. Magnetisation increasing with number.

Conclusions : In this work we show how radiation damping can affect the measured time constants and the predicted polarisation in hyperpolarised gas optical pumping cells. In addition we also show how a high Q coil can be easily used to determine the energy state into which the ^{3}He has been pumped. With a twin coil NMR detection system like this where both Q's are known, then the filling factor can be eliminated from Eq. 1 allowing a direct calculation of the magnetisation density m_o in the cell to be made during the spin up process thus allowing direct calculation of the ^{3}He polarisation from the radiation damped FID line shapes alone. This is verified by the linearity in the plot of Figure 1. Such an approach could potentially dispense with the need for a calibration reference for the polarimeter.

References 1. K Teh et al. Journal of Magnetic Resonance 183 (2006) 13–24 2. E.Babcock et al. Phys. Rev. Lett. 96, 083003 (2006)3. M.P.Augustine Progress in Nuclear Magnetic Resonance Spectroscopy 40 (2002) 111-150. **Acknowledgments :** Funding through EPSRC grant EP/D070252/1.