Investigation of narrowed lasers and cell heating in 129Xe optical pumping

S. R. Parnell[1], M. H. Deppe[1], S. Boag[2], S. Ajraoui[1], J. Parra-Robles[1], and J. M. Wild[1]
[1]Unit of Academic Radiology, University of Sheffield, Sheffield, South Yorkshire, United Kingdom, [2]ISIS, Rutherford Appleton Laboratory, Didcot, Oxfordshire, United Kingdom

Introduction : The use of hyperpolarised gases in MRI has motivated improvements in both the polarisation and production rate of noble gases. The aim of this work was to evaluate the use of narrowed high power laser systems in the optical pumping of ^{129}Xe, these techniques have been applied to SEOP of ^{3}He to great success [1] and recent investigations have shown that high polarisations are not possible unless the laser is narrowed to linewidths significantly >1nm [2]. To date two approaches have been used in the design and construction of ^{129}Xe polarisers, these have been high pressure (~10Bar) [3] and low pressure (0.375Bar) [4]. The low pressure system has significant advantages in terms of production rate and polarisation. In this work we explore the intermediate pressure range (2.5Bar). One of the primary design criteria of polarisers has been to increase the efficacy of the lasers being used. For broadband lasers this is achieved using pressure broadening of the Rb absorption line with gas mixtures at high pressure. For ^{129}Xe however the dynamics of the optical pumping are complex, the high absorption of the pump laser and subsequent non-radiative quenching rotation modes give rise to heating of the nitrogen buffer gas. This laser heating gives rise to elevated temperatures of hundreds of degrees above ambient [5] and the formation of convection currents in the cell [6]. To date only one study has employed a narrowed laser for ^{129}Xe [7] at high pressure. This showed an increase in polarisation when pumping the Rb D_1 absorption line. For this work we have investigated the alkali metal polarisation and light absorption in order to assess the advantages of using a narrowed pumping source.

Materials and Methods : The use of EPR spectroscopy to measure the alkali metal polarisation has been performed by a number of groups [e.g 2]. The method used here is a simpler approach as it modulates the electronic levels of the Rb and measures the pump beam absorption using a photodiode, allowing the occupations of the various electron levels to be probed and the alkali polarisation determined. One disadvantage of this method is that it requires more power (hence causing greater depolarisation) to observe the signal and hence must be measured as a function of RF power and extracted back to zero RF power [8], however this method does not require Faraday rotation angle measurements as used in other studies. This work was performed on sealed Pyrex cells filled to 2.5Bar with a 3% Xe, 10% N_2 balance ^{4}He mix. The cells were optically pumped using a 100W external cavity diode laser (ECDL). A small (~8cm diameter) 3 turn coil was placed close to the cell and the RF frequency was swept though the various resonances of the alkali metal (sweep 13.9-16MHz in 0.8s). This was done at a relatively high field strength B_0=3.3mT (usually we pump at B_0 =1mT) in order to resolve the separate Rb resonances. The RF coil is operated away from any natural coil resonances, hence the power is not maximised, however this removes any strong Q dependence as the frequency is swept across the various resonances. In addition we measured the laser power transmitted through the cell as a function of temperature and hence rubidium density (Rb vapour pressure).

Results : Fig. 1 shows typical narrowed laser emission for the ECDL laser, with the inset showing the laser setup and the experimental layout. This measurement system was first tested with a sealed ^{3}He cell, the various resonances were identified and the procedure in ref. 2 was used to calculate the Rb polarisation (P_{Rb}) showing that the narrowed high power laser achieved P_{Rb} >99%. Following this P_{Rb} was determined as a function of temperature for the ^{129}Xe cell. Only the range 100°-130° was investigated, lower temperatures had little absorption and at higher temperatures the absorption was to high. In the temperature range investigated a distinct fall-off in alkali polarisation was observed. This is similar to earlier work using broadband sources [6]. Following this we investigated the amount of laser power which is transmitted through the cell. This data is also summarised in Fig. 2, again this shows a rapid decrease in the absorbed power, consistent with a runway process where excessive absorption causes heating of the Rb, creating higher Rb densities, which increases the absorption. Most importantly, shown in the upper trace of Fig. 2 is the NMR signal [9] of the ^{129}Xe, this has been corrected for the temperature changes in the coil. This was performed using a search coil outside the oven and measuring the coil (in the oven) pickup as a function of temperature, in addition the transmit pulse was generated from exterior coils outside the oven. This maximum polarisation observed by NMR at ~70° coincides with the sudden onset of increased laser absorption and decreasing Rb polarisation.

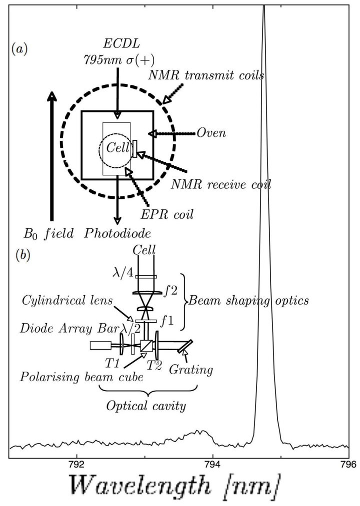

Fig. 1: Laser emission, (a) experimental setup used and (b) schematic of laser.

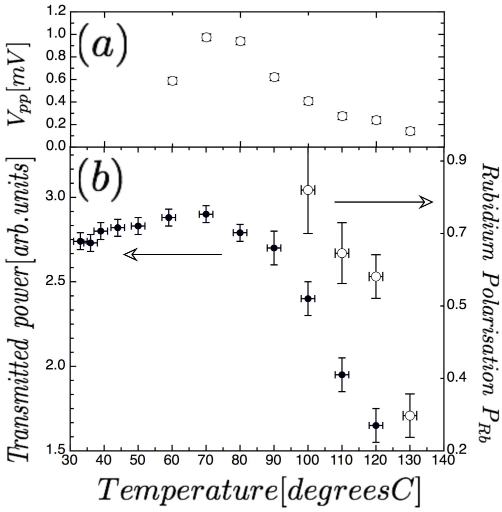

Fig. 2 (a) NMR signal for sealed cell, (b) power transmitted through cell (closed circles) and Rb polarisation (open circles) as a function of temperature.

Conclusions : These simple and inexpensive diagnostic measurements have allowed us to quickly optimise the optimum temperature for optical pumping at this cell pressure, as clearly evidenced by the NMR measurements presented in Fig. 2. Furthermore with these techniques we can further investigate different cell geometries and pressures in order to better minimise the Rb runaway.

References : [1]Phys. Rev. Lett. 96 (2006) 083003, [2]Phys. Rev. A 66 (2002) 032703, [3]Appl. Phys. Lett. 69 (1996) 1668, [4]Phys. Rev. Lett. 96 (2006) 053002, [5]Phys. Rev. Lett. 86 (2001) 3264, [6]Phys. Rev. A 72 (2005) 053411, [7]P.Nikolaou et al., ENC, Florida 2007, [8]Phys. Rev. Lett. 101 (2008) 083002, [9]Phys. Rev. A 49 (1994) 3854 **Acknowledgments :** Funding through EPSRC grant EP/D070252/1.