Enhancement of ^{129}Xe polarisation by off-resonant optical pumping

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Introduction: Hyperpolarised ^{129}Xe can be used as an inhaled contrast agent to study the lung [1]. In addition to imaging the gas phase in the lung, the chemical shift of dissolved ^{129}Xe strongly depends upon its environment, giving a unique tool to probe gas dissolution pathways in chemical and biological systems [2]. As gas phase MRI is inherently a low sensitivity technique, the success of these applications requires the production of gas with high polarisation in large volumes using spin exchange optical pumping (SEOP). To increase this polarisation, recent efforts have focused on utilising narrowed lasers. Recently a surprising result was found that the polarisation increased when the laser was detuned from the Rb absorption transition [3]. This investigation used a volume Bragg grating (VBG) laser where the power and wavelength are coupled. In the work presented here, a similar investigation is performed using a narrowed laser which can be independently tuned in power and/or wavelength.

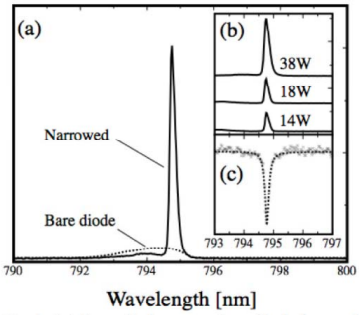

Fig 1: (a) Bare diode spectral profile before and after narrowing. (b) Spectral output of narrowed laser as a function of power (current), offset for clarity and (c) Rb absorption data.

Experimental Setup: The experimental work detailed here explores the use of an external cavity diode laser (ECDL) for ^{129}Xe polarisation using a design which has been shown to routinely achieve >99% Rb polarisation and ^{3}He polarisations >70% [4]. This device is the narrowest photon source at high power that has been used for Rb-Xe SEOP. Measurements of the Rb absorption, ^{129}Xe polarisation and laser emission spectra are presented in order to characterise the performance of these devices for ^{129}Xe SEOP. In addition to the laser, there are in-situ NMR diagnostics [5] and a large holding field. Central to the development of this system is the use of an ECDL, which allows better matching of the spectral output from the diode array to the rubidium absorption. The change in emission before and after narrowing is shown (fig 1a). The spectra in figure 1b show that the emission line width remains constant over a large range of powers. Using a white light source the Rb absorption line was also measured (fig 1c), centered at 794.77nm. Current investigations into the efficacy of this laser design are ongoing [6] and require tuning of the laser power and wavelength.

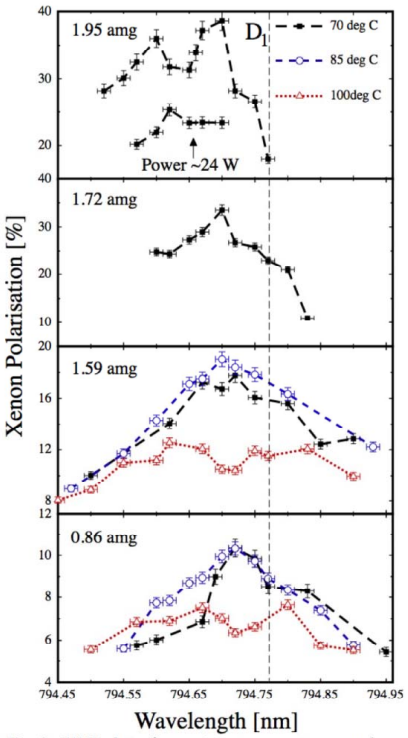

Fig 2: NMR data for various temperatures and gas densities as indicated in the figure. All measurements at 38W except where noted. The vertical dashed line (D_1) indicates the center of the Rb absorption.

Results: The optical pumping cell (Pyrex 5cm diameter 10cm long) was used containing a gas mixture of 3% Xe, 10% N_2 and 87% He. The Xe polarisation was measured by in-situ NMR. A range of total gas densities, cell temperatures and laser powers were investigated, the results of which are summarised in figure 2. A number of points are evident from these results; the first is that the optimum wavelength for maximum polarisation occurs at a lower wavelength than that of the Rb absorption, agreeing with earlier observations [6] when using a volume holographic grating laser. Direct comparison with the absorption measurement gives a detuning of -0.06nm at 1.59 amg. Secondly, when the cell temperature is raised to 100^{o}C (hence higher rubidium density ([Rb])) the polarisation starts to show a dip at the wavelength where the maximum polarisation was observed at lower temperatures. At 1.95amg and 70^{o}C, the polarisation has a dip at ~794.65nm, which disappears at lower power, albeit with a reduced total polarisation. The polarisation is observed to increase with gas density, the maximum gas density obtainable (1.95 amg) being limited by the cell design.

Discussion: The ECDL allows a better matching of the laser output to the Rb absorption (see figure 1) allowing high static polarisations to be achieved. When close to the Rb resonance, the light is absorbed predominantly at the front face of the cell whilst off-resonant light penetrates much further through the cell yielding a higher volume averaged rubidium polarisation than the on-resonant case. This type of behaviour would be expected to be symmetric around the measured absorption line assuming that the absorption line itself is symmetric. This is not the case in this work: the dip in polarisation at high absorption/[Rb] is observed but it is consistently shifted to lower wavelength. This is indicative of a new phenomenon the theory of which will require further study.

Summary: A narrow high power laser has been constructed and used to observe an off resonant behaviour previously reported [3]. The amount of detuning needed to achieve maximum polarisation was different to that reported earlier. This is attributed to the decoupling of the laser wavelength from the power, which is achievable using an ECDL. Further investigation of these effects will require a study of the alkali polarisation. Optimisation of this system will then need to be performed under typical flow conditions used to provide viable gas doses for lung imaging.

Acknowledgements: Funding through EPSRC grant no. EP/D070252/1.

References:

1. B.M.Goodson, Journal of Magnetic Resonance, **155**, 157 (2002)
2. S.Patz et al. European Journal of Radiology, **3**, 335 (2007)
3. P.Nikolaou et al, Journal of Magnetic Resonance **197**, 249 (2009)
4. S.R.Parnell et al., Nuclear Instruments and Methods A, **598**, 774 (2009)
5. S.R.Parnell, et al Measurement Science and Techn., **19**, 045601 (2008)
6. S.R.Parnell et al. Journal of Applied Physics, **108**, 064908 2010