Hyperpolarized ^{129}Xe from the lab to the clinic: mitigating Rb cluster formation to boost polarization

Imaging with hyperpolarized (HP) ^{129}Xe MRI has seen much development in recent years, such that it now competes with the increasingly-scarce polarizable isotope ^{3}He in terms of image quality (see **Fig. 1**). Additionally, HP ^{129}Xe MRI has useful properties that ^{3}He does not, namely, ^{129}Xe is soluble in parenchymal tissue, plasma and red blood cells, where it exhibits chemical shifts exceeding 200 ppm, that enable the separate characterization of those compartments in vivo for the purposes of quantifying lung function. The challenges, however, in utilizing ^{129}Xe MRI for these purposes is that only about 1% of the magnetization transfers from the airspaces to the bloodstream, and the NMR signal has an intrinsically short T_2^* (decay time). We have mitigated these limitations through pulse sequence optimization, as well as reconstruction techniques, but fundamentally, the field is signal starved in terms of polarization.

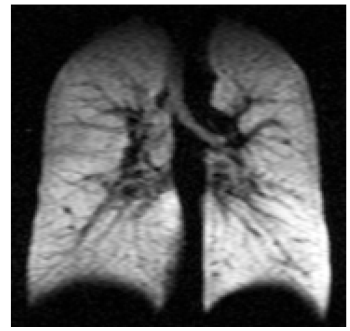

Figure 1: Typical ^{129}Xe MRI of the human lung.

For nearly all polarizers built to date, both peak ^{129}Xe polarization and the rate at which it is produced fall far below those predicted by the standard model of Rb metal vapor, spin-exchange optical pumping (SEOP). Through the comprehensive characterization of a high-volume, flow-through ^{129}Xe polarizer, measuring ^{129}Xe peak polarization and production as a function of gas flow rate, SEOP cell size, laser power and linewidth, and SEOP temperature, we have identified a mechanism that limits peak polarization for all cells to a factor of 2-3 times lower than predicted at all absorption levels. These systematic deviations from theory can be explained by invoking the presence of paramagnetic Rb clusters within the vapor.

The fundamental basis of SEOP theory is that optical pumping, and spin-exchange, occur only with free atomic Rb vapor. However, Rb cluster, $\left[Rb_n\right]$, formation within saturated alkali vapors is well established in the literature, and their interaction with resonant laser light was recently shown to create plasma-like conditions (see **Fig. 2**). Such cluster systems cause both Rb and ^{129}Xe depolarization, as well as excess photon scattering. These effects were incorporated into the SEOP model by assuming that clusters are activated in proportion to excited-state Rb number density and by further estimating physically reasonable values for the nanocluster-induced, velocity-averaged spin-destruction cross-section for Rb ($\langle\sigma_{\text{cluster-Rb}}v\rangle \approx 4\times10^{-7}$ cm^{3}s^{-1}), ^{129}Xe relaxation cross-section ($\langle\sigma_{\text{cluster-Xe}}v\rangle \approx 4\times10^{-13}$ cm^{3}s^{-1}), and a non-wavelength-specific, photon-scattering cross-section ($\sigma_{\text{cluster}} \approx 1\times10^{-12}$ cm^2). The resulting modified SEOP model now closely matches experimental observations.

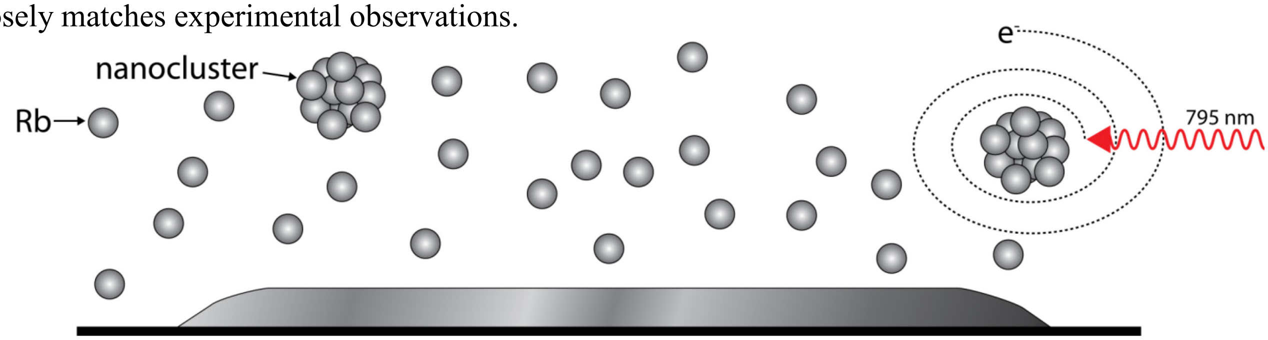

Figure 2: A simplified representation of the Rb vapor inside an SEOP cell, with the addition of postulated clusters.