Effect of Reduced Pressure on the Polarization of ^{129}Xe in the Production of Hyperpolarized ^{129}Xe Gas: Development of a Simple Continuous Flow Mode Hyperpolarizing System Working at Pressures as Low as 0.15 atm

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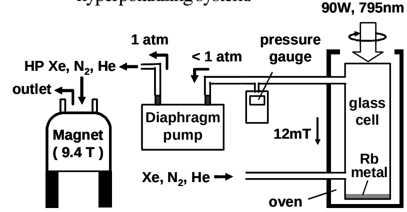
Introduction: Recent significant progress in MRI and MRS using hyperpolarized (HP) noble gases has stimulated great interest in the clinical applications of diagnostic tools for the lung and brain. One of the key features for HP noble gases to be established in wide routine applications is to develop a high-performance polarizer and easy access to HP gases for clinical as well as basic studies. Although ^{129}Xe polarization by using the optical pumping technique has been exploited mainly at a total gas pressures of 2-10 atm, several data reported previously promise a utility of ^{129}Xe polarization at a total gas pressures less than 1 atm [1-4]. In the present study, the effects of reduced pressure on ^{129}Xe polarization have been investigated, and capabilities of the continuous flow mode hyperpolarizing system have been analyzed at reduced pressures as low as 0.15 atm aiming at developing a simple and handy type hyperpolarizing system.

Apparatus: A schematic diagram of our hyperpolarizing system is shown in Fig. 1, which is a modified version of the system previously reported [3]. A cylindrical polarizing cell of 6 cm diameter and 10-100 cm length was made from Pyrex glass and placed in fringe field of 12 mT near a super-conducting NMR magnet at 9.4 T. About 0.5 g of rubidium was deposited into the polarizing cell. The cell was heated in an oven equipped with an air blower. The most important modification made in the present study was the use of a diaphragm pump, which was attached to the outlet of the polarizing cell to reduce the pressure down to 0.1 atm and supply polarized gas at 1 atm to a 10 Φ NMR tube placed in the NMR probe. Decrease in SNR was as low as 10 % when HP gas was passed through the pump, which was minor compared to the pressure effect.

Fig. 1 Schematic diagram of our hyperpolarizing system.



Experiments: NMR measurements were performed on a high-resolution NMR spectrometer, Varian Unity INOVA 400WB. ^{129}Xe NMR spectrum was measured at 110.6 MHz with a pulse width of 1 μs (flip angle = 8°) without accumulating multiple FID transients. To calculate the degree of polarization, SNR was compared with that measured for 50%Xe+50%O_2 gas mixture at thermal equilibrium. Dependence of ^{129}Xe polarization on several experimental conditions listed in Table 1 was investigated.

Table 1 Variable parameters tested in the experiment.

batch mode	continuous flow mode
total gas pressure	total gas pressure
Xe content	flow rate
N_2 content	cell temperature
	cell length
	use of ^{129}Xe-enriched gas

Results and Discussion: Figure 2 shows the total gas pressure dependence of polarization in the batch mode, where the binary mixture of Xe and N_2 was used. The polarization of ^{129}Xe was enhanced by reducing the pressure down to near 0.1 atm both low and high Xe content gas. Polarization measurements for Xe gas mixed with foreign gases in batch mode are listed in Table 2. The maximum polarization of 63.6 % was observed with a composition of 5%Xe+95%N_2. It is seen in Table 2 that maximum SNR is realized in the Xe+N_2 binary mixture at 60-70 % Xe when the HP gas was supplied for measurement without separating from the foreign gas. With the same Xe content, polarization at 0.15 atm was increased with increasing N_2 percentage. This indicates that He gas is not necessary as a buffer gas in sufficiently low pressures such as 0.15 atm because maximizing the N_2 content is suitable to maximize the quenching effect.

Fig. 2 Total gas pressure dependence.

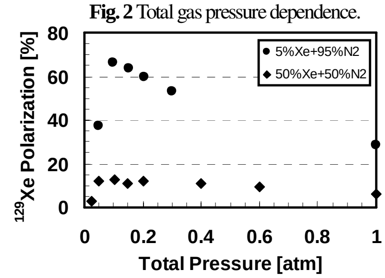
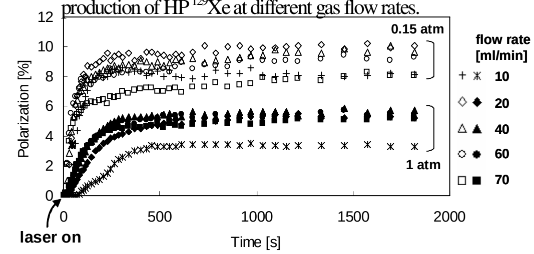


Table 2 ^{129}Xe polarization measured for Xe gas mixed with foreign gases in batch mode.

Foreign Gases	Pressure (atm)	Xe % in mixture: 5	10	20	30	40	50	60	70	80	90	100
N_2	0.15	63.6	34.9	20.0	11.7	8.7	11.1	11.1	10	7.6	5.7	4.4
	1	28.4	18.6		8.6		6	8.3	7.5	5.9		2.6
$N_2$70%+^4He	0.15	29.1	19.2	12.9								4.4
$N_2$50%+^4He	0.15	29.6	19.8		10.7							4.4
$N_2$30%+^4He	0.15	26.7	17.2		8.9		7.3	6.3				4.4
$N_2$10%+^4He	0.15	37.6	12.3	9.3	7.6		6.5	5.8	4.9			4.4
^4He	0.15	27.3	14.5		7.2		4.9		2.5		3.2	4.4

The build-up profile was measured in the time course study shown in Fig. 3. The build-up rate at 0.15 atm was 2.6 times faster than that at 1 atm. The stability of polarization in the continuous production of HP ^{129}Xe was sufficiently established after it reached a plateau in different flow rates (Fig. 3). Also, Isotopically enriched ^{129}Xe gas was tested in continuous flow mode. The low partial pressure Xe mixture with isotopically enriched ^{129}Xe will be suitable for medical use from the standpoint of preventing anesthetic side effects of Xe and reducing consumption of precious enriched gas while making use of enhanced polarization under the low pressure.

Fig. 3 Build-up and stability study of polarization in the continuous production of HP ^{129}Xe at different gas flow rates.



Conclusion: We have examined the experimental conditions for the polarization of ^{129}Xe to produce HP ^{129}Xe in a simple way, making use of the reduced pressure cells, and succeeded in attaining higher polarization in flow mode as well as batch mode. The technique developed in the present work is expected to provide a simple and handy type of ^{129}Xe hyperpolarizing system for use in MRI and MRS while the polarizer reported [4] seems useful for mass production of HP ^{129}Xe.

References: [1] Sato H, et al., Nucl Instr And Meth In Phys Res A 1998;402:241. [2] Ruth U, et al., Appl Phys B 1999;68:93. [3] Fukutomi J, et al, J Magn Reson 2003;160:26. [4] Ruset IC, et al., Phys Rev Lett 2006;96 :053002.