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Production of a nuclear-spin–polarized ^{21}Ne sample

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Nuclear-spin-polarized samples of up to 200 Torr ^{21}Ne have been obtained through spin-exchange collisions with optically pumped Rb vapor. The exponential time constant associated with buildup and decay of this polarization along the quantization axis is in excess of 15 h in 3-cm-diam Pyrex cells. From the data and estimates given, samples of ^{21}Ne with densities greater than 1 STP and polarization in excess of 1% appear feasible.

The use of optically pumped Rb vapor to transfer angular momentum from an electron spin-polarized ensemble to an unpolarized noble-gas nucleus by spin-exchange collisions is well known and has been extensively studied.[1-3] I wish to report results obtained with ^{21}Ne samples polarized in this fashion. This work may be of immediate interest in the generation of nuclear-spin–polarized targets and plasmas, and magnetic-moment spectroscopy. It has been suggested[4] that ^{21}Ne samples described here would allow a sensitive test for the anisotropy of inertial mass.[5,6]

In a typical experimental arrangement, I have a 3-cm-diam Pyrex cell containing excess Rb metal, 15 Torr of N_2 which enhances the Rb polarization by quenching the reemission of Rb resonance radiation, and up to 200 Torr of 90% enriched ^{21}Ne. The maximum ^{21}Ne density used in this work was dictated only by the quantity available. The apparatus used to polarize the sample and the Rb magnetometer used to monitor the time development of ^{21}Ne polarization have been detailed previously.[1,7]

Since ^{21}Ne possesses a nuclear quadrupole moment, the transverse nuclear polarization decay in a free precessional decay experiment is expected to deviate from a simple exponential form and to depend on orientation of the resonance cell axis of symmetry relative to the external magnetic field axis. This behavior has been shown in the case of ^{83}Kr (Ref. 8) and ^{131}Xe (Ref. 9) to result from the interaction of the nuclear quadrupole moment with the electric field gradients present at the nucleus during collisions with the cell walls. There it was shown that nonexponential transverse decay could be explained as a spin dephasing through unequal level shifting which is first order in the quadrupole Hamiltonian. My ^{21}Ne data also show a strong dependence of transverse decay rate on cell orientation. Figure 1 illustrates the nonexponential behavior of this decay when the cell orientation is close to the "magic angle," i.e., the orientation which results in the longest decay time. Level transitions leading to a longitudinal relaxation rate are second order in the quadrupole Hamiltonian,[8] and for ^{83}Kr this rate was estimated to be smaller by several orders of magnitude than that for spin dephasing and characterized by a true exponential process. Since the ^{21}Ne relaxation rates I observed are several orders of magnitude less than for ^{83}Kr, I would expect this inequality to hold for ^{21}Ne as well.

If one assumes, then, exponential behavior for all relaxation processes, the time constant associated with the ^{21}Ne nuclear-spin–polarization lifetime T_p along the quantization axis is determined by the net relaxation rate, T_1^{-1}, due to all processes, and the ^{21}Ne spin-exchange rate, T_{ex}^{-1}, with the polarized Rb vapor,[7]

$$T_p^{-1} = T_{\text{ex}}^{-1} + T_1^{-1} \quad , \tag{1a}$$

$$T_{\text{ex}}^{-1} = \sigma_{\text{ex}} N v \quad , \tag{1b}$$

where σ_{ex} is the spin-exchange cross section, N is the Rb number density, and v is the Rb-atom–noble-gas-atom relative velocity. With $\langle I_L^0 \rangle$ and $\langle S_L^0 \rangle$ the expectation values for ^{21}Ne nuclear and Rb electronic polarization at steady state along the quantization axis, the pumping law is given by[7]

$$\langle I_L \rangle = \langle I_L^0 \rangle [1 - \exp(-t/T_p)] \quad . \tag{2}$$

The maximum ^{21}Ne nuclear polarization is related to the Rb

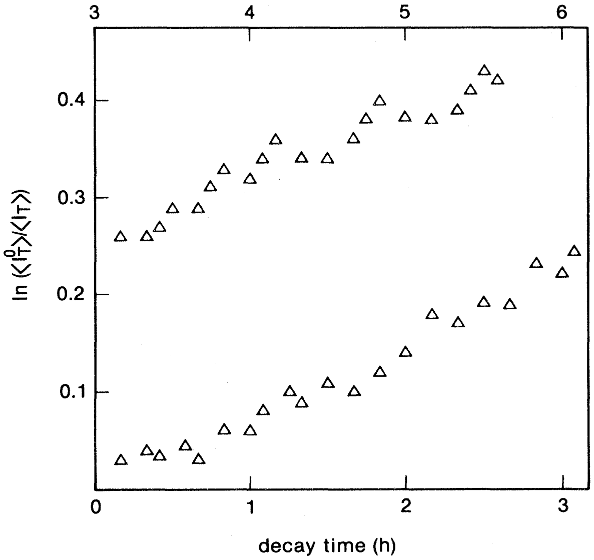

FIG. 1. Free precessional decay data of the transverse component of ^{21}Ne magnetization $\langle I_T \rangle$. The upper (lower) abscissa-axis labels apply to the upper (lower) data shown. Under the assumption of a pure exponential decay, the average slope gives an approximate time constant of 13 h. A modulation component with 40-min period is evident in the data and indicates the presence of spin dephasing (Ref. 7).

spin polarization through[7]

$$\langle I_L^0 \rangle = (T_p/T_{\text{ex}}) \langle S_L^0 \rangle \ . \tag{3}$$

A least-squares data fit to the pumping law of (2) has been made for a 200-Torr ^{21}Ne sample. Figure 2 shows the exponential fit to data taken at a sample temperature of 72 °C with time constant $T_p = 15.2$ h. Values of T_p obtained by this method show a reproducible temperature dependence over the 62 to 81 °C temperature range studied with maximum T_p located near 72 °C.

Estimates of ^{21}Ne polarization in these samples can be made on the basis of (3). Although an experimental value for the spin-exchange cross section between Rb and ^{21}Ne is not available at this time, an expression derived by Herman[10] gives

$$\sigma_{\text{ex}} = 10^{-23}\ \text{cm}^2 \ . \tag{4}$$

On the basis of a comparison between experimental values of Rb–noble-gas spin-exchange cross sections[3,11] and Herman's expression, (4) should be considered as a lower bound value to the Rb-^{21}Ne cross section. From (1b), T_{ex} at a cell temperature of 72 °C is then

$$T_{\text{ex}} = 4 \times 10^6\ \text{sec} \ , \tag{5}$$

and, with an estimated Rb polarization of 15% for our resonance cells, (3) gives 0.2% for ^{21}Ne polarization in my samples.

With dye laser optical pumping, Rb polarizations in excess of 60% have been reported in Rb-Xe samples.[3] Here a similar use of laser pumping combined with reductions in the spin-exchange time T_{ex}, by an increase in Rb vapor density at higher sample temperatures, will result in higher ^{21}Ne polarizations. I estimate that samples of ^{21}Ne with densities greater than 1 STP and nuclear polarizations greater than 1% may be obtained by this method.

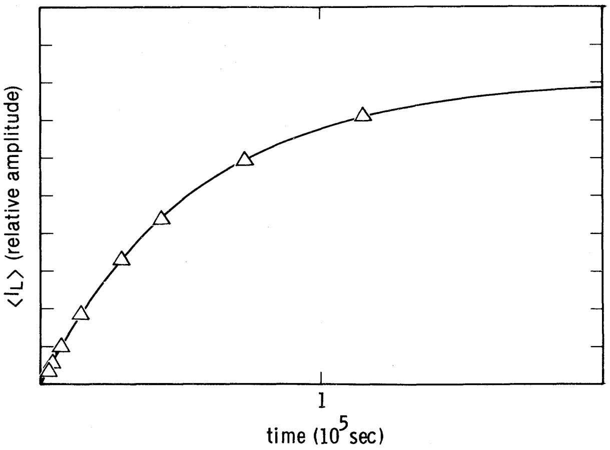

FIG. 2. Least-squares data fit of ^{21}Ne longitudinal magnetization buildup to the pumping law of (2). The time constant $T_p = 15.2$ h.

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