Hyperpolarisation of Cs salts by optical pumping of Cs atoms in a random scattering medium

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Alkali-metal salts have been polarised by optical pumping of alkali-metal vapour with no cryogenic cooling and no microwave irradiation [1]. The procedure is similar to the hyperpolarisation of noble gases, which is achieved by the spin-exchange interaction between electron and nuclear spins. For alkali salts, optically polarized atoms transport angular momentum in the gas to the cell walls [2] where the nuclear spin polarisation of atoms is transferred to the nuclei of the salt. The spin transfer is dominated by the nuclear dipole interaction at the surface [3]. The transfer would be efficient if the large surface area of salt was on contact with the polarized vapour. To increase the surface area, we deposited the salt on the fibres of glass wool in a glass cell. The laser light pumped the alkali atoms moving in the voids within the glass wool. Since the glass wool scattered the pumping light extensively, the light polarization was also randomised. A component of the photon's angular momentum, nonetheless, was able to be efficiently transferred to the alkali atoms in a strong magnetic field of the NMR magnet [4]. This is because the electron Zeeman splitting was large enough to separate the optical transitions, and because the nuclei were optically polarized with the help of the hyperfine coupling to the valence electron in the atom.

To perform hyperpolarisation of salts, as described above, we have studied optical pumping of atoms in a random scattering medium (transferring of angular momentum from photons to atoms), the electron and nuclear spin currents in the gas phase, and the spin transfer from atoms to salts [1-4]. Next, we study the transport of spin polarization in the salts. Since the nuclear dipole interaction induces spin diffusion, most of nuclei are able to be polarised when salt films and crystallites are smaller than the spin diffusion length ($\leq$ 100 nm) [5]. Hyperpolarisation enables us to investigate the spin diffusion near the surface. The spin diffusion is, however, so slow that the mean nuclear polarization is low for macroscopic crystals. We need the different mechanism from the dipolar interaction for hyperpolarising bulk salts. Because the pumping light illuminated the glass wool as well as the atoms in our experiment, the salt on fibres can be heated by the laser. By focusing the laser beam, we are able to increase the temperature and the ion mobility in the salt. Since the polarized ions transport the angular momentum, the macroscopic crystals can be hyperpolarised [6].

Borosilicate glass cells were filled with a quartz-glass wool and ground powder of caesium halide (CsCl and CsI), and the cells were connected to a vacuum manifold. By baking at 350 ^{o}C for several days, the salt crystallites were deposited on the surface of the glass fibres. We added the Cs metal and the nitrogen gas at 2 kPa and then sealed the cells. Each glass cell was placed in the NMR magnet, and heated at 90 ^{o}C by an electric heater. The Cs vapour was polarised by a single mode laser of 1 W at the D1 and the D2 lines of Cs atoms. After hundreds of second for optical pumping to accumulate the angular momentum in the salt, we detected the Cs NMR signals for the Cs salt. Comparing to the signal amplitude at the thermal equilibrium, we calculated the enhancement of the nuclear spin polarization in the salt. When the laser beam was focused on the glass cell, the NMR signal was greatly enhanced and the linewidth was also narrowed. The observed narrowing was motional narrowing caused by the diffusion motion of ions in the hot salt, and the high-mobility ions transported the nuclear spin polarization through the crystals. The ion mobility was dramatically increased by heating even though the temperature of Cs salts was lower than the melting point approximately of 650 ^{o}C [7]. Since the spin polarization was transported by ion movement, the spin buildup time ($\leq$ 10 s) became shorter than the longitudinal spin relaxation time ($\approx$ a few hundreds seconds) of the bulk sample. As a result, the nuclear polarization was enhanced by more than three orders of magnitude over the thermal equilibrium at 90 ^{o}C and 0.56 T.

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