

# Impurities in alkali-metal coating for hyperpolarised noble gases

Kiyoshi Ishikawa<sup>a</sup> and Brian Patton<sup>b</sup>

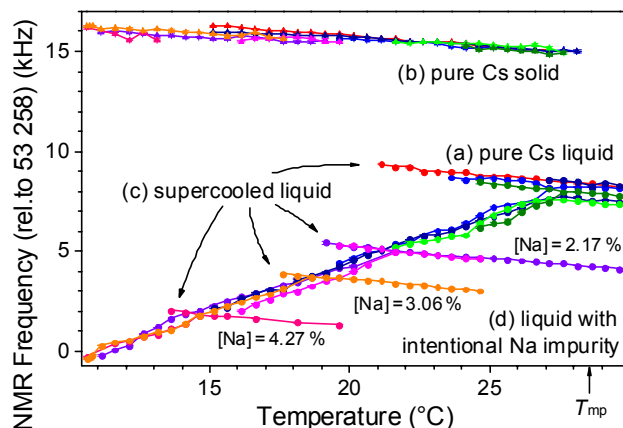
<sup>a</sup>Graduate School of Material Science, University of Hyogo, Hyogo 678-1297, Japan

<sup>b</sup>Department of Physics, University of California, Berkeley, CA 94720, USA

When the inner walls of glass cell are coated with the alkali metals, the conduction electrons generate a Van der Waals potential for noble gas atoms. The depth and the shape of the potential mainly depend on the density and the penetration length (or work function) of the electrons to vacuum. The low work function of Cs metal extends this potential away from the surface of the cell, isolating helium-3 atoms from the cell walls and extending their nuclear relaxation times. There exists tentative evidence that the spin relaxation of the He gas is more suppressed after the glass cells are used many times, i.e., the Cs metal coating is partially oxidized [1]. The potential shape might be modified by oxidization. Historically, alkali metals and their alloys have been thoroughly investigated with the NMR experiments. The Knight shift, from which we are able to study the electron density at the position of nuclei in the metal, depends on the temperature monotonically in a single phase of pure metals. When the metal is contaminated, the density of impurity depends on the temperature according to the phase diagram. By measuring the Knight shift, therefore, it is possible to detect the impurities which increase or decrease the density of conduction-band electrons in a metal. The impurity effect appears prominent near the melting point  $T_{mp}$ . Recently, we measured the Knight shift of the Cs suboxide, resulting in the *in-situ* determination of the electron density in the suboxide and the density of trace oxygen by using the Cs-O phase diagram [2]. Therefore, the NMR measurement of the Knight shift for the alkali metals should contribute to the suppression of the nuclear spin relaxation of hyperpolarized gases. There remains an unknown impurity which modifies the electron density in the Rb and the Cs metals. This impurity can appear in cells which we believe to be uncontaminated, and might be ubiquitous among alkali-vapour cells. In this work, we tried to identify the impurity before the extensive search of alkali-metal alloys optimized for the suppression of the spin relaxation.

<sup>133</sup>Cs NMR signals were measured with H, Si, C, and Rb added to the Cs metal. However, these elements never presented the Knight shift observed in the previous work. Next, we tried the intentional contamination of the Na metal. For this alloy, the borosilicate-glass cells connected to a vacuum manifold were baked at 350 °C for several days. Since the Cs and the Na metals were simultaneously chased into the glass cells, the Na molar ratio [Na] was unclear in advance of the NMR experiment. Figure 1 shows the NMR frequencies measured during cooling process for many cells. The pure Cs metal showed the signals for liquid above  $T_{mp}$  and for solid below  $T_{mp}$ . The frequency increased by cooling (negative slope) in both phases. The positive slope, which was also presented in most of cells below  $T_{mp}$ , was identical to the previous observation. Since [Na] increases along the liquidus curve, the Knight shift decreases by cooling, i.e., the Na metal takes the electrons from the Cs metal. The large freezing-point depression means that the Na contamination was on the order of percents based on the Cs-Na phase diagram [3]. Therefore, we found that the unknown impurity in the Cs metal was trace amounts of Na metal.

Fig. 1: Temperature dependence of the <sup>133</sup>Cs NMR frequency near the melting point. The resonances are, respectively, for (a) pure Cs liquid, (b) pure Cs solid, (c) supercooled liquid, and (d) liquid with intentional Na impurity.



- [1] A. Deninger, W. Heil, E.W. Otten, M. Wolf, R. K. Kremer, and A. Simon, Eur. Phys. J. D, Vol. 38 (2006), 439.
- [2] B. Patton, K. Ishikawa, Y.-Y. Jau, and W. Happer, Phys. Rev. Lett. Vol. 99 (2007), 027601.
- [3] J. B. Ott, J. R. Goates, and D. E. Oyler, Trans. Faraday Soc. Vol 67 (1971), 31.