Nuclear Spin Polarization Induced By Ultrashort Laser Pulses

Takashi Nakajima

Institute of Advanced Energy, Kyoto University Gokasho, Uji, Kyoto 611-0011, Japan

How to prepare highly polarized nucleus is one of the important issues in nuclear physics. However, in most cases, the degree of nuclear spin polarization is very low. A few interesting methods have been developed in the last few decades, among which the use of lasers to induce nuclear spin polarization is an interesting application of optical physics to nuclear physics where photons play an essential role as a mediator. If the target atoms are alkali-metal atoms, their nuclear spin can be directly polarized through optical pumping, and if the target atoms are other than those, spin-exchange collisions are further introduced to polarize target atoms.

In this paper, we theoretically propose a novel scheme to polarize nuclear spin using ultrashort laser pulses, which is completely different from the above mentioned method based on the optical pumping. The laser we use is not a CW laser but ultrashort laser pulses. In other words, it is a transient method as we have recently demonstrated for spin-polarization of valence electrons of ions and photoelectrons [1,2]. We send a circularly polarized short laser pulse to the target atoms. If the pulse duration is shorter than the hyperfine coupling time, the photoabsorption process takes place without involving nuclear spin, i.e., nuclear spin is a spectator during photoabsorption After the first excitation pulse, the hyperfine interaction is turned on, and the angular momentum of photons are gradually transferred to nuclear spin. We wait until nuclear spin polarization reaches maximum through hyperfine interaction, and then "freeze" nuclear spin by removing the valence electrons through photoionization by the second short and intense laser pulses. In optical physics, this is generally called pump-probe technique. Our method works most effectively for two-valence-electron atoms such as Mg and Ca. To realize the above scenario, however, there is a big problem we have to overcome. Since the hyperfine interaction is very weak, nuclear spin polarization takes time. To accelerate the hyperfine coupling time, we apply the external electric field. Specifically we have carried our theoretical analysis for the isotopes of Mg and Ca with nuclear spin of I=1/2 and 3/2. Quite high (>70%) degree of nuclear spin polarization have been theoretically obtained for the doubly charged ions, Mg^{2+} and Ca^{2+} after removing the two valence electrons.

[1] Nakajima, "Control of the spin-polarization of photoelectrons/photoions using short laser pulses", Appl. Phys. Lett. **84**, 3786-3788 (2004).

[2] Nakajima, "Effects of laser intensity and applied electric field on coherent control of spin polarization by short laser pulses", Appl. Phys. Lett. **88**, 111105 (2006).