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Muon spin rotation and relaxation study for energy materials[1]

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A muon spin rotation and relaxation (μ^+SR) technique is very popular for studying microscopic internal magnetic fields in condensed matters. Recently, μ^+SR measurements are also used to investigate the intrinsic nature of battery materials and hydrogen storage materials. Here, I wish to review the recent progress of the μ^+SR research on such materials. In 2009, it was found that Li^+-ion diffusion in solids is detectable with μ^+SR even in the materials containing magnetic ions [JS *et al.*, PRL **103**, 147601], while NMR is unable to do so due to the effect of localized magnetic moments on a spin-lattice relaxation rate. Such finding looks to open the door for the μ^+SR research on energy materials. Since then, many battery materials have been investigated with μ^+SR in order to determine their intrinsic diffusion coefficient (D) of Li^+ and Na^+ ions [M. Mansson & JS, Phys. Scr. **88**, 068509]. Furthermore, using such intrinsic D, the other important parameters are successfully derived, such as, the reactive surface area [JS *et al.*, Phys. Chem. Chem. Phys. B **15**, 10402], diffusion pathway [JS *et al.*, PRB **87**, 024409], and density of mobile ions [H. Nozaki *et al.*, Solid State Ionics **262**, 585]. In 2008, the internal magnetic field in a complex hydrogen storage material, $NaAlH_4$, was studied with μ^+SR [R. Kadono *et al.*, PRL **100**, 026401]. Despite the absence of magnetic ions, μ^+SR spectrum exhibited a clear oscillation, indicating the formation of a H-μ^+-H system in $NaAlH_4$. Moreover, it was proposed that the yield of the H-μ^+-H system depends on the hydrogen desorption temperature (T_d) through the diffusion of H in $NaAlH_4$. More systematic μ^+SR work on $M BH_4$(M =Li, Na, K, Mg, Ca, Sc) provided a clear relationship between the yield of the H-μ^+-H system and T_d [JS *et al.*, PRB **81**, 092103]. In addition, very recent *in-situ* μ^+SR measurements on MgH_2 during hydrogen desorption reaction revealed the importance of H-diffusion in solids for determining T_d [JS, J. Phys. Soc. Jpn, **85**, 091012].

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