# α knockout reaction as a new probe for α formation in α-decay nuclei

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The α decay, the emission of a $^4$He nucleus, was discovered by Rutherford and theoretically explained by Gamow in the 1920s. According to the theory, the preformed α particle at the nuclear surface is emitted with a certain half-life due to the quantum tunneling effect through the Coulomb potential barrier at the nuclear surface. See Fig. 1 for an illustration of the α decay process. However, it is still a challenge to understand how and how much of the α particle is produced at the surface of a nucleus.

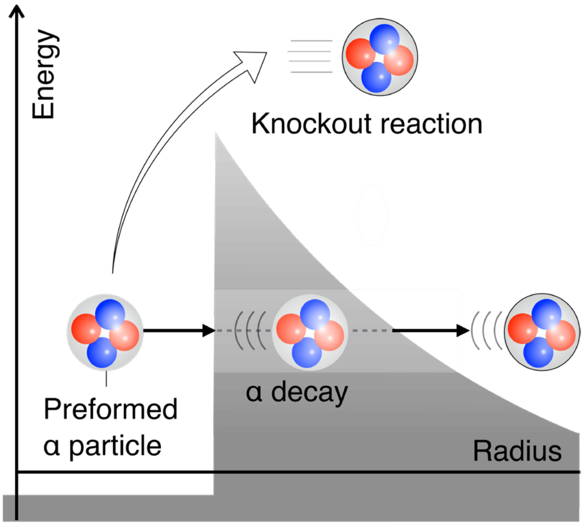


Fig. 1 Illustration of the α decay and the α knockout reaction.

The α-decay width $\Gamma_\alpha$ is given by a product of the Coulomb barrier penetrability $P$ and the reduced α width $\gamma^2$ [1]

$$\Gamma_\alpha = 2P\gamma^2.$$

$\gamma^2$ is known to be proportional to the α formation probability at the nuclear surface, $\gamma^2 \propto |RF(R)|^2$, where $R$ is a distance from the center of the nucleus, which is taken to be about a sum of the radii of the α particle and the daughter nucleus. Here, $F(R)$ represents the radial wave function of the α particle inside a nucleus and thus $|RF(R)|^2$ gives the probability density of the α particle.

In addition to the α decay studies, α formation in the medium mass nuclei, tin (Sn) isotopes, has been predicted by generalized relativistic mean field theory [2]. Note that these are not α decay nuclei, so the formation of α particles in these nuclei is not trivial. Recently, the prediction was experimentally confirmed by the proton-induced α knockout reaction, in which the Sn isotopes were bombarded with a 400 MeV proton beam and the α particles knocked out by the proton beam were measured [3]. The experiment was performed at the Research Center for Nuclear Physics, Osaka University. According to the theoretical study on the α knockout reaction from Sn nucleus [4], the α knockout reaction is sensitive to the α particle abundance on the nuclear surface. This is because the mean-free path of the α particle inside a nucleus is short and therefore only the α particle on the nuclear surface can be knockout out from a nucleus.

Based on this knowledge, we have theoretically studied the α knockout reaction of the α decay nuclei polonium 210 and 212 ($^{210}$Po, $^{212}$Po). The proton-induced α knockout reaction is described by the distorted wave impulse approximation framework, and the α knockout cross sections (knockout reaction probability) σ from $^{210}$Po and $^{212}$Po were obtained [5]. In this theoretical calculation we used the α formation probability determined by systematic analysis of the α decay half-lives [6]. Naively, we can expect that the knockout cross section is proportional to the probability of finding an α particle, i.e., the α formation probability.

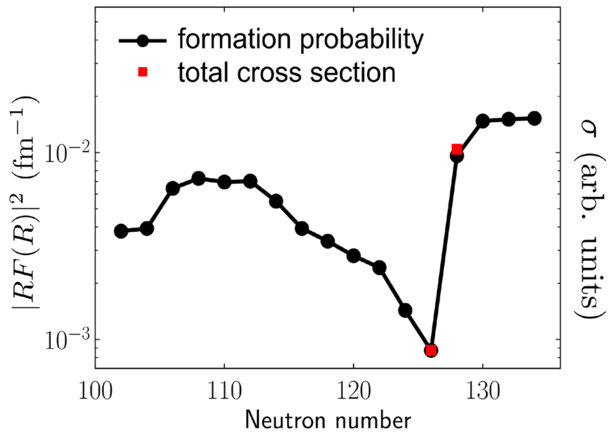


Fig. 2 Comparison between the systematics of the α formation probability and the α knockout cross section of the present work. The formation probability $|RF(R)|^2$ [7] (left axis) is shown in black circle and the total cross section σ (right axis) of the present work is shown in red square.

Figure 2 shows the comparison between the α knockout cross section of the present work and the systematics of the α formation probability determined by the α decay half-life measurement [7]. Since it is currently difficult to discuss quantitatively, the unit of the cross section is arbitrary, so that the α knockout cross section from $^{210}$Po coincides with the formation probability of $^{210}$Po. It can be seen in Fig. 2 that the α knockout cross sections follow the jump of the formation probability from $^{210}$Po to $^{212}$Po. This means that the α knockout reaction is an alternative probe for the α formation amplitude and will provide a clear link between the α formation probability and the experimental observable. It should be noted that the α knockout cross section is not related to the potential barrier penetrability and is therefore a more direct probe for the α formation probability. Both experimental and theoretical studies are needed to understand the mechanism of α formation. For more detail of this work, see Ref. [5].

**References**

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