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Charge changing cross section and proton distribution radii of Be isotopes

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In this research, we tested a new idea to measure proton-distribution radii ($r_{\rm p}$) by heavy-ion secondary beam experiments. It is important for understanding the structures of nuclei to know the proton- and the neutron-distribution radii independently. From this point of view, we tried to develop a new method to deduce proton-distribution radii ($r_{\rm p}$) very efficiently using nuclear collisions .

Now, $r_{\rm p}$ can be measured by electron scattering and isotope shift measurements. They have high accuracy and precision, but applicable unstable nuclei are rather limited. On the other hand, the present new method could have the same degrees of accuracy and could measure a wide range of unstable nuclei.

The experiment was carried out at HIMAC, Heavy Ion Medical Accelerator in Chiba, in Japan. We measured charge changing cross sections ($\sigma_{\rm cc}$) for $^{7-12}$Be isotopes on proton, Be, C, and Al targets. Charge changing cross section ($\sigma_{\rm cc}$) is the cross section of changing the number of protons in the collision with the target nucleus. We can deduce charge changing cross sections ($\sigma_{\rm cc}$) from the number of incident particles N_1 and charge changed particles N_2:

\begin{equation}
\sigma_{\rm{cc}}=-\frac{1}{t}\rm{ln}\Bigl(1-\it{\frac{N_2}{N_1}}\Bigr)
\end{equation}

In the zeroth-order approximation, charge changing reaction can be attributed to the abrasion of protons in the incident nucleus by nucleons in the target nucleus. A schematic drawing of this process is shown in figure 1. Thus it is approximated by equation (2).

\begin{equation}
\sigma_{\rm{cc}}=\pi(r_{\rm{T}}+r_{\rm{p}})^2
\end{equation}

![charge changing][1]

From eq (2), we can derive proton radii if target's nucleon radius $r_{\rm T}$ and $\sigma_{\rm cc}$ are known. In practice, we need to use Glauber calculation with more realistic proton and neutron distributions both in the projectile and the target nuclei.

Thus, when trying to link the charge change cross-section and the proton distribution radius, the consideration of the proton evaporation process shown in fig. 2 is considered to be very important.
In this process, neutrons are firstly abraded, which excites prefragment and results in the evaporation of protons. If this process could be extracted independently, it would be very useful in deriving the proton-distribution radii from the charge change cross sections.

![proton evaporation][2]

In the experiment, we used proton, Be, C, and Al targets. Proton target is particularly sensitive to neutrons in the projectile reflecting the isospin asymmetry of the nucleon-nucleon total cross sections, which amplifies neutron abrasion. In short, the proton-evaporation effect has large portion of the charge changing cross section on proton target $\sigma^{\rm p}_{cc}$.

So, we assumed that $\sigma^{\rm p}_{cc}$ multiplied by some value x: $x\sigma^{\rm p}_{cc}$ is the cross section of proton evaporation for Be, C, and Al targets. Therefore, adding $x\sigma^{\rm p}_{cc}$ to eq (2) would reproduce the experimental results of charge changing cross sections.

In practice, we introduced x for each target and a constant parameter Y as the first and second approximation terms:

\begin{equation}
\sigma_{cc} = \sigma_{\rm{Glauber}} +
x\Bigl(\sigma^{\rm{p}}*{\rm{cc}}-[\sigma^{\rm{p}}*{\rm{Glauber}}+Y]\Bigr)
\end{equation}

As a result, we figured out that only 4 parameters, x(for 3 targets) and Y could reproduce 15 data of charge changing cross section for Be isotopes very well. It suggests a possibility of this new method for the deduction of proton-distribution radii with high accuracy and efficiency applicable to a wide range of unstable nuclei.

![proton distribution radii][3]

Experimental nuclear physics

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Theoretical nuclear physics

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