Charge state distribution measurement of ^{86}Kr in H_2 and He gases at 2.7 MeV/nucleon

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We can obtain heavy ions with higher charge states in gases with small atomic numbers (low-Z gas) such as hydrogen (H_2) or helium (He) as compared to other standard gases (nitrogen (N_2) or argon).[1] Recently, a windowless He gas stripper utilizing a strong differential pumping system has been constructed for uranium (U) beams at the RIKEN RI Beam Factory (RIBF).[2] It has successfully functioned and has provided high intensity U beams stably.

The possibility of application of low-Z gas charge strippers to krypton (Kr) beam acceleration at the RIBF has been studied. The first stripper for ^{86}Kr acceleration is located downstream of the RILAC, where the exit energy becomes 2.7 MeV/nucleon. Carbon foils with thicknesses of 40–80 μg/cm^2 have been used as the first stripper to obtain ^{86}Kr^{26+} for acceleration by the subsequent cyclotron RRC.[3] A low-Z gas stripper can be one of the candidates for a long-lived stripper if a sufficient fraction of 26+ is obtained.

We have developed a prototype of a gas stripper and measured the charge state distributions of ^{86}Kr in H_2 and He with different thicknesses. The ^{86}Kr^{20+} beams at 2.7 MeV/nucleon were transported to the gas stripper. A schematic of the gas stripper with its differential pumping system is shown in Fig. 1. Gases were injected in the target region (stage 1) located at the center. The length of the target region was 100 cm. The other stages, U2, D2, U3, and D3, are also shown along with the pumping speeds of their respective attached pumps. A 10-cm-long tube with 4-mm inner diameter was installed between each stage. The charge state distributions of ^{86}Kr in H_2 and He are shown in Fig. 2. The fractions calculated for H_2, He, and N_2 are plotted in the figure. In Fig. 2 (a), the data for the H_2 gas with thicknesses of 10, 23, 46, 68, and 107 μg/cm^2 are denoted by asterisks, x-marks, open triangles, open squares, and open diamonds, respectively. In Fig. 2 (b), the data for the He gas with thicknesses of 16, 29, 59, 124, and 247 μg/cm^2 are denoted by asterisks, open triangles, open circles, open squares, and open diamonds, respectively. Finally, in Fig. 2 (c), The data for N_2 gas with thicknesses of 13, 36, 817, and 1221 μg/cm^2 are denoted by asterisks, open triangles, open circles, open squares, and open diamonds, respectively. The mean charge states of ^{86}Kr in H_2 and He gases attained equilibrium at 25.1 and 23.2, respectively. The fraction of ^{86}Kr^{26+} in H_2 is 32% at equilibrium. The mean charge state in N_2 at equilibrium was estimated to be lower than 20+. Since the maximum magnetic rigidity of the dipole magnet for selecting charge states was 0.97 T·m, the data are insufficient to reproduce charge distributions in N_2 gas.

It is found that the H_2 gas stripper can be used for ^{86}Kr acceleration. In addition, the charge states in He are sufficiently high for ^{78}Kr acceleration, since the lowest charge state of ^{78}Kr acceptable for RRC is 23+. Further development of a differential pumping system using orifices with a bore diameter larger than 10 mm is necessary for practical use.

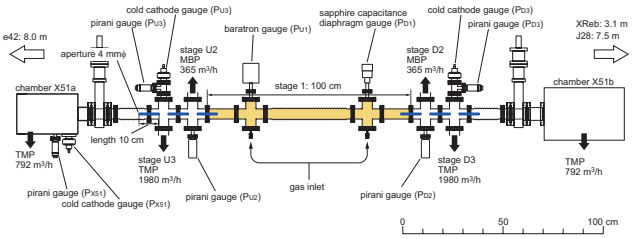

Fig. 1. Schematic of the gas charge stripper. Please see the text for details.

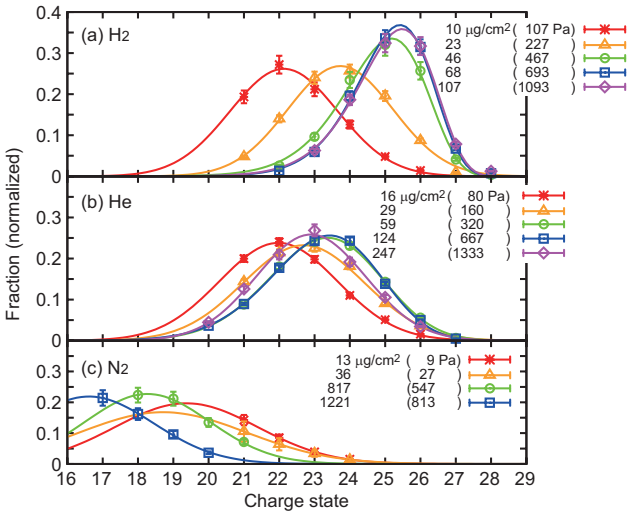

Fig. 2. Charge distributions of ^{86}Kr in (a) H_2, (b) He, and (c) N_2 gases. Please see the text for details.

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References
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