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α-Particle Transport Test of Korea Broad Acceptance Recoil Spectrometer and Apparatus at RAON

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Abstract. KoBRA of RAON has been prepared for various low energy nuclear physics studies such as nuclear structure, reactions, and astrophysics. An α-particle transport test was performed using a standard α-source of ^{241}Am so as to examine the design parameters. The position distribution of the α-particles was measured with a PPAC at the dispersive and achromatic focal planes, and compared with that of a LISE^{++} Monte Carlo calculation. The results are consistent with each other, confirming a few design parameters. We report on the preliminary results of the α-particle transport test for KoBRA.

1. Introduction to KoBRA

Korea Broad Acceptance Recoil spectrometer and Apparatus (KoBRA) is one of the low energy experimental facilities at Rare isotope Accelerator complex for ON-line experiments (RAON). KoBRA is a multi-purpose experimental instrument using stable or rare isotope beams in an energy range of $1 - 40$ MeV/nucleon for various low energy nuclear physics studies, such as nuclear structure, reactions, and astrophysics, at Rare Isotope Science Project of the Institute for Basic Science in Korea [1-8]. The installation of KoBRA was completed on June 2021 except for a Wien filter, and the first phase of RAON construction project was completed in December 2022 [9]. KoBRA will be utilized to produce rare isotope beams from a stable primary ion beam ^{40}Ar coming from the low-energy SuperConducting LINAC 3 (SCL3) for early phase experiments in the near future.

KoBRA, as illustrated in the Fig. 1, consists of a pair of swinger magnets used for bending the primary beam up to ±12 degrees onto the F0 target, a production target chamber at F0, two curved-edge bending magnets with two sextupole magnets to minimize high order aberrations up to 4$^{\text{th}}$ order, seven large quadrupole magnets with large apertures, eight small quadrupole magnets, and one Wien filter.

A particle identification for rare isotope beams can be done by employing the Bρ-TOF-ΔE technique with event-by-event coincidence measurements. The magnetic rigidity (Bρ) of the rare isotope beams is determined by measuring the position at the dispersive focus F1 with the

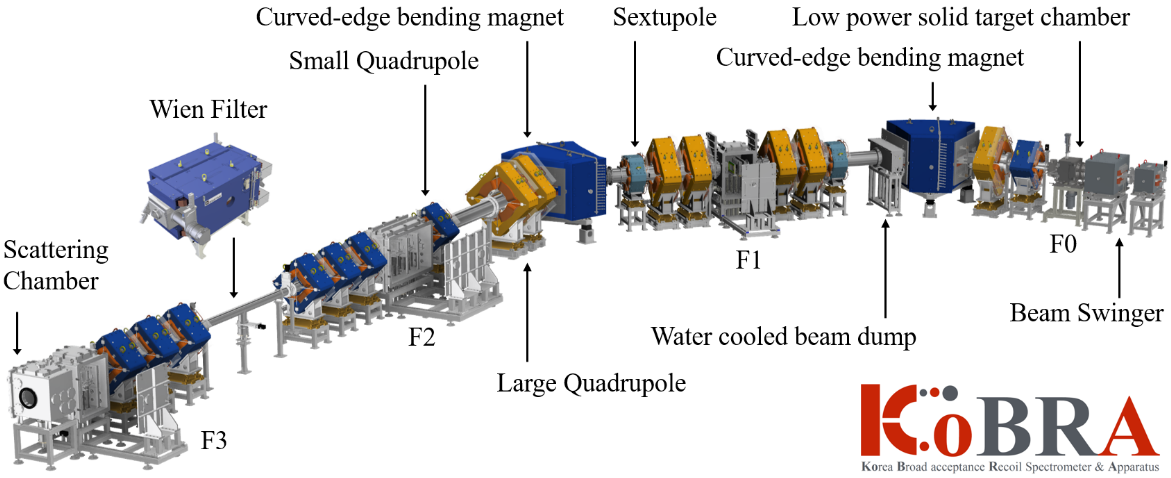

Figure 1. A schematic view of KoBRA.

Parallel Plate Avalanche Counter (PPAC) [10, 11]. The time-of-flight (TOF) is determined using thin plastic detectors placed at the double achromatic focuses F2 and F3. The energy loss (ΔE) is measured by a silicon detector located at F2 or F3. A homogeneous or curved degrader can be installed at F1 for the additional separation using the energy-loss achromat technique.

The Wien filter will be positioned between F2 and F3, and is utilized to purify the rare isotope beam with an energy range of less than a few MeV/nucleon. The Wien filter is being manufactured and will be constructed till the end of 2023. The basic design parameters of KoBRA are listed in Table 1.

The ion-optics of KoBRA was designed with a fifth order optics calculation [6] using the code COSY INFINITY [12]. The point-to-point focus conditions in both horizontal and vertical planes are satisfied at F1, F2 and F3. The momentum dispersion and the magnification at F1 are $(x|\delta) =$ 41 mm/% and $(x|x) = 0.96$ in the horizontal plane, respectively. Both momentum and angular dispersions at F2 and F3 are zero in order to satisfy the double achromatic condition. The higher-order aberrations are minimized by using the curved-edge bending magnets along with two sextupole magnets as reported by K. Tshoo *et al.* [6].

Table 1. Basic design parameters of KoBRA.

Design parameter	Specifications
Magnetic rigidity	0.25 − 3.0 Tm
Angular acceptance	±40 mrad (Horizontal), ±100 mrad (Vertical)
Momentum acceptance	±4%
Momentum resolving power at F1	2100 at 2-mm beam size
Maximum mass resolving power at F3	750 at 2-mm beam size
Beam Swinger	Up to ±12 degrees at 3 Tm
High order correction	Up to fourth order

2. α-Particle Transport Test

The α-particle transport test of KoBRA was performed using a ^{241}Am α-source as the first step after the installation without the Wien filter. We placed a ^{241}Am disk source with active dimension 5 mm (dia.) at the target position F0. The magnetic fields of all the magnets were scaled according to the magnetic rigidity of a 5.486-MeV α-particle (Bρ = 0.33741 Tm). We monitored the magnetic field strengths of the curved-edge bending magnets using NMR probes within an accuracy of about 10^{-6} T, and precisely tuned Bρ of KoBRA. The position distributions of the transported α-particles were measured at the dispersive focus F1 and the achromatic focus F3 with the PPAC.

The measured position distributions of the transported α-particles were compared with the results of a Monte Carlo calculation using LISE^{++} [13]. In this calculation, the α-particles were generated with an isotropic direction at F0, assuming that ^{241}Am materials deposited homogeneously in the active area at the substrate surface of ^{241}Am source. The transported particles were calculated with ion-optical transfer matrix elements up to fifth order, and the position distributions of the transported particles were acquired at F1 and F3. Fig. 2 (a) shows the measured two-dimensional position distributions (left) at F1 and F3, together with the results of the calculation (right). Three types of the transported α-particles with kinetic energies (branching ratio) of 5.486-MeV (84.45%), 5.443-MeV (13.23%), and 5.388-MeV (1.66%) were clearly separated in the horizontal direction at the dispersive focus F1. The transported α-particles were achromatically focused at F3.

Fig. 2 (b) shows the measured position distribution (open circle) in the horizontal plane, together with the result of the calculation (solid line). The transported α-particles were separately distributed with their kinetic energies, and each peak distribution had a gaussian-like shape. Second and third peak distributions for 5.443-MeV and 5.388-MeV α-particles from the center are consistent with the calculated distributions. However, the first peak distribution for 5.486-MeV α-particle had the left-side tail, which was speculated due to high order aberration of the transported particles with the angle near the maximum angular acceptance at F0. It can

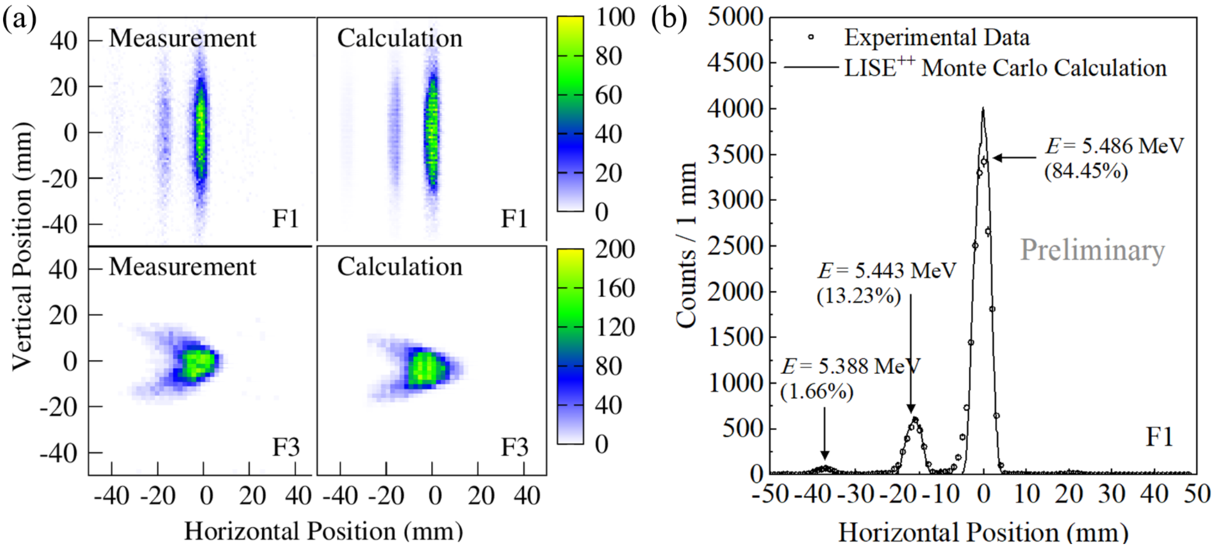

Figure 2. A comparison of measured and calculated (a) two-dimensional position distributions of the transported α-particles at the dispersive focus F1 and the achromatic focus F3. (b) horizontal position distributions at F1. All the calculations represent the results of normalized distribution to total counts of the measured distribution.

be expected to be resolved by further fine tune using the sextupole at the front of F1. Both measured and calculated horizontal distributions were fitted using Gaussian functions in order to obtain the peak positions and widths, from which the momentum dispersion was deduced to be 40.8 ± 0.3 mm/%. The magnification was also deduced to be 0.97 ± 0.04. The quoted errors come from the fitting uncertainty. These results are in good agreement with the optical design parameters within the errors, leading to the momentum resolving power of 2101.4 ± 2.1 at 2-mm beam size.

3. Summary

We completed the installation of KoBRA at the end of June 2021 except for the Wien filter, and performed an α-particle transport test with a ^{241}Am α-source. The position distributions at F1 and F3 are consistent with the calculated distributions. The momentum dispersion and horizontal magnification at F1 were measured to be 40.8 ± 0.3 mm/% and 0.97 ± 0.04, respectively, which corresponds to the momentum resolving power of 2100. These results are consistent with the design parameters within the errors. We plan to perform a beam commissioning with a ^{40}Ar beam in March 2023.

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