Calcium isotope separation by DC18C6 crown-ether for neutrinoless double beta decay

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This study aimed to investigate the isotope separation and enrichment of calcium via liquid-liquid extraction (LLE) using DC18C6 crown-ether. This experiment aims to find a cost-effective way to enrich calcium-48 (^{48}Ca). The liquid-liquid extraction was carried out to find an appropriate isotope separation and enrichment condition. The measurement of calcium isotope composition was performed by reaction-cell ICP-MS. The maximum separation factor of ^{48}Ca/^{40}Ca was 1.007±0.004 in the aqueous phase under the presence of 12M HCl at the six[th] iteration stage. The advantage of LLE was that the feed concentration is higher than other methods, resulting in the appropriate condition for mass production.

Keywords: Isotope Separation, Calcium, Crown-ether, Enrichment

1. Introduction

Neutrinoless double-beta decay (0νββ) has been studied to demonstrate lepton number non-conservation [1]. The CANDLES (Calcium Fluoride for Neutrino and Dark Matter Studies by Low Energy Spectrometer) project employs calcium-48 (^{48}Ca), one of the natural double beta decay nuclides with the highest Q-value (4.27 MeV) for 0νββ study [2]. Nevertheless, ^{48}Ca has a natural abundance of 0.187%. The enrichment of ^{48}Ca is possible only by the magnetic separator, becoming a costly material. This research aims to improve the calcium isotope separation by crown-ether through liquid-liquid extraction system for cost-effective enrichment and mass production.

2. Methodology

0.07M of DC18C6 crown-ether in 100 mL chloroform prepared as an organic phase solution. The aqueous phase solutions were 5mL (30% w/w) $CaCl_2$, (aq) and $CaCl_2$, (HCl). Organic and aqueous solutions with the volume ratio of 10/1 were mixed in an Erlenmeyer flask using a magnetic stirrer for 1 minute and allowed for 10 minutes before the separation. The loaded solvent in the organic phase was back-extracted with the 10 mL pure water. The same procedure was performed using the aqueous solution from the previous extraction for the six[th] multistage iteration. All extraction processes were performed at room temperature. The aqueous phase concentration was measured by AAS (Shimadzu AA-6800) and isotopic analysis by reaction-cell ICP-MS (Agilent 7900) with an additional H_2 gas as a reaction gas. Careful correction for the calculation of separation factor was employed to avoid the mass bias from the measurement using the bracketing technique.

3. Results

The results of multistage iteration under the presence of HCl acid found that the distribution coefficient and separation factor was increased in the aqueous phase. The distribution coefficient of the HCl system was ranged from 0.1579±0.0007 to 0.0079±0.0002 at the first and the sixth iteration. The maximum separation factor of the aqueous phase ($^{48/40}\alpha_{aq}$) was 1.007±0.004 (ε = 0.007) at the 6th stage (Figure 1). This finding indicated the enrichment feasibility of the heavier isotopes of calcium via liquid-liquid extraction. The aqueous solvent on multistage iteration is in progress.

4. Conclusion

The advantage of LLE compared to other chemical enrichment methods was that the high concentration of calcium (3 – 4M) could be engaged. Moreover, the enrichment coefficient (ε) was higher than the resin chromatographic method (ε = 0.02 – 0.03) [3], resulting in the appropriate method for isotope enrichment and mass production. Regardless of the calcium recovery, the iteration stage required to achieve ten times ^{48}Ca enrichment was approximately 2122. Further research on the designed cascade for mass production is required.

References
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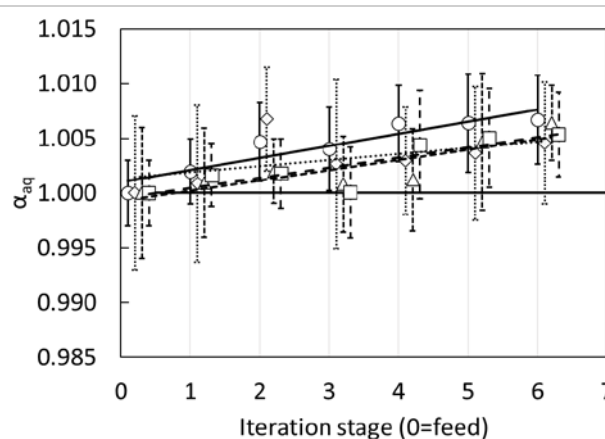[3] S. Umehara et al. (2018), *Journal of Nuclear Science and Technology*, 55(12), 1473-1480.

Figure 1. The separation factor of calcium isotopes in the aqueous phase (α_{aq}) to the iteration stage.
◯ = ^{48}Ca/^{40}Ca (——), ◇ = ^{48}Ca/^{42}Ca (········),
△ = ^{48}Ca/^{43}Ca (----), □ = ^{48}Ca/^{44}Ca (– – ·)