ENERGY LOSS OF RADIOACTIVE ION ^{22}Mg AND ^{4}He PARTICLE IN THE GAS TARGET $HeCO_2$(10%)

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Abstract: Energy loss of alphas in the energy region 4.788-5.795 MeV and radioactive ions ^{22}Mg at 25.894 MeV in active gas target $HeCO_2$ was measured. The experiment was performed directly in inverse kinematic for ^{22}Mg producing by CRIB spectrometer of the University of Tokyo located at RIKEN, Japan in 2011. The experimental results are compared with theoretical calculation in a good agreement. The obtained values are also confirmed by Bragg's law over the investigated energy range.

Keywords: *energy loss, radioactive ion ^{22}Mg, active gas $HeCO_2$.*

1. Introduction

The direct measurement of the ^{22}Mg + ^{4}He system plays an important role not only in studying ^{26}Si structure but also for reaction rate of the stellar reaction $^{22}Mg(\alpha, p)^{25}Al$ in the αp-process [1, 2]. The measurement needs to be performed in inverse kinematics by using the active gas target technique. Although the mixture gas $HeCO_2$ is one of crucial gas targets in astrophysical experiments, specially for (α, p) reactions, no experimental data of interaction with the particles obtained. The energy loss of the scattering alphas ^{4}He and the incident radioactive beam ^{22}Mg plays a crucial role in the direct measurement of the stellar reaction. In addition, the accuracy of energy loss is one of a factor for ion beam analysis [3] as well as industrial applications [4, 5]. In our work, we measured the energy loss of alpha particles at 4.788 MeV, 5.486 MeV and 5.795 MeV and radioactive ions ^{22}Mg at 25.894 MeV in mixture gas $HeCO_2$ (He-90%, CO_2-10%) with different thickness of the target. The experiment was carried out in the framework of the direct measurement of the ^{22}Mg + ^{4}He system at CRIB (CNS Radioactive Ion Beam separator) facility of the Center for Nuclear Study (CNS) [6], the University of Tokyo in October, 2011. The results were compared with other theoretical codes elaborated by Ziegler (SRIM 2008) [7], by Hans Geissel, et al. (ATIMA) [8] and database in ref. [9] with a good agreement.

2. Experiment

The ^{22}Mg beam production was performed by using the CRIB spectrometer located at RIKEN (fig. 1). The radioactive ion (RI) beam ^{22}Mg is produced via $^{3}He(^{20}Ne,^{22}Mg)n$ reaction by bombarding a Havar-windows 2.5 μm, cryogenic gas target [10] of ^{3}He at 90 K with the primary beam ^{20}Ne at 6.2 MeV/u from AVF cyclotron. The RI beam is more preferentially populated at achromatic focal plane F2 using dipole magnets and identified by beam monitors PPACs [11]. We separated and purified successfully on target at F3 plane after coming through a Wien filter, see table 1 for details of beam production.

The alphas used is from a thin triple alpha-source including ^{237}Np (4.788 MeV), ^{241}Am (5.486 MeV) and ^{244}Cm (5.795 MeV) with 350 Bq of intensity.

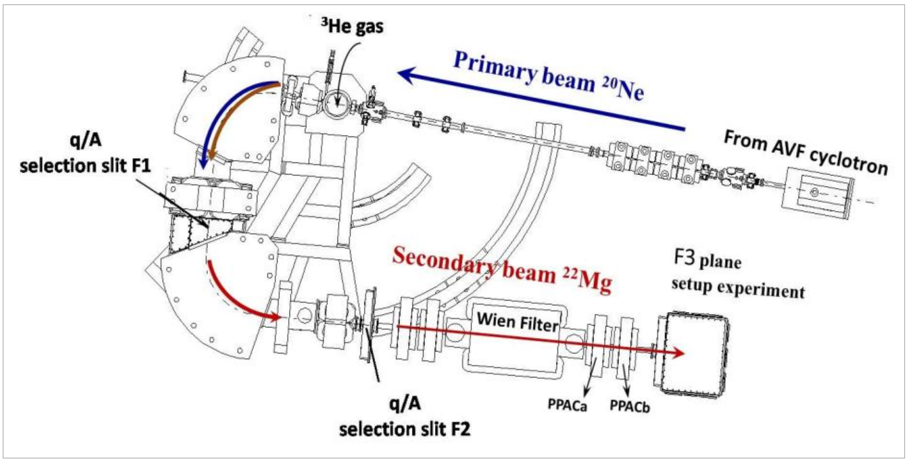

Fig 1. A plane view of CRIB spectrometer of the University of Tokyo at RIKEN, Japan.

The experiment was set up in a gas-target chamber at F3 filled $HeCO_2$ whose stable pressures were kept by a gas system including an automatic electronic valve between the chamber and outside. Homogeneous gas is one of the important element to estimate the thickness of gas target, and therefore, homogenizing is necessary to be done. We used a flow gas system with a rate of 20 sccm (standard cubic of a centimeter per minute) during the experiment. In addition, room temperature of the gas was also kept at approximately stable value having a negligible deviation compared with the estimated thickness. The incident particles come through mixture gas and reach to a silicon detector collimated by a narrow hole of 4 mm in diameter. The detector was located downstream of the beam with 400 mm of distance from beam spot or alpha source to the detector. Figure 2 shows the details of the experimental setup.

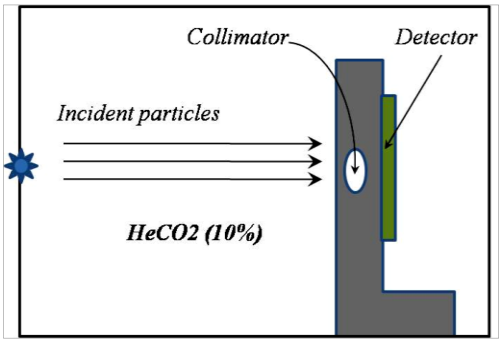

Fig 2. Schematic of the detection system at F3 was used for measuring energy loss of ^{4}He and ^{22}Mg in $HeCO_2$

Table 1. Condition of radioactive beam production.

^{20}Ne	*^{3}He Target*	*Purity*	*^{22}Mg at F3*
500 enA	0.72696 mg/cm^2	40%	700 cps

We kept the primary energy and measured energy loss of the particles through mixture gas step-by-step to estimate dependence on thickness of the target. The thickness of the target at 0.47916 mg/cm^2, 0.60752 mg/cm^2, 0.77008 mg/cm^2, 1.02676 mg/cm^2, 1.35192 mg/cm^2 and 1.71128 mg/cm^2 was changed by adjusting the gas pressure in the gas system.

The pulse-height spectra measured by silicon detector have been energy-calibrated using the triple-alpha source ^{237}Np, ^{241}Am and ^{244}Cm for alpha and ^{22}Mg measurement. In order to get more accurate data of heavy ion ^{22}Mg, a known energy ion beams of ^{20}Ne (different charge states: 10+, 9+, 8+, 7+ and 6+) from AVF cyclotron was used to calibrate the detector system. Experimental data of each thickness were recorded in a file by a computer and analyzed offline.

3. Results and discussion

We use ROOT program [12] for analyzing data. The resultant peaks are nearly of Gaussian distributions. Therefore, the experimental data have been extracted by fitting Gaussians from the foot of the low energy side to the foot of the high energy side of the peak centroids. The uncertainties of the results are estimated to be 6% for ^{4}He and 13% for ^{22}Mg ions including the errors in fitting the spectra, beam energy profile and system resolution. The calibration results show the work using charged ^{20}Ne beam is consistent with one using alpha source and with each other. Figure 3 and figure 4 show the spectra obtained with triple-alpha source, different charge states of ^{20}Ne beam and demonstrate the quality of the calibration.

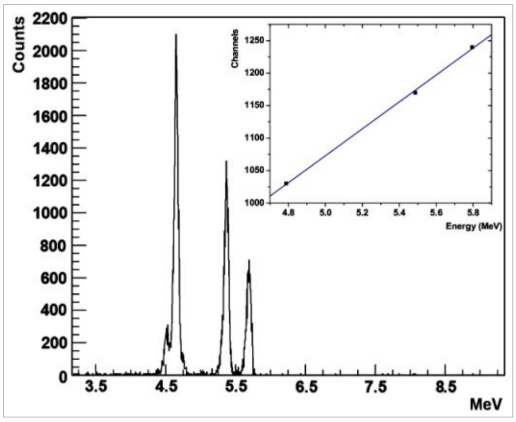

Fig 3. Energy spectrum was measured with triple-alpha source. The inset shows energy calibration for alpha energy loss measurement extracted from the spectrum

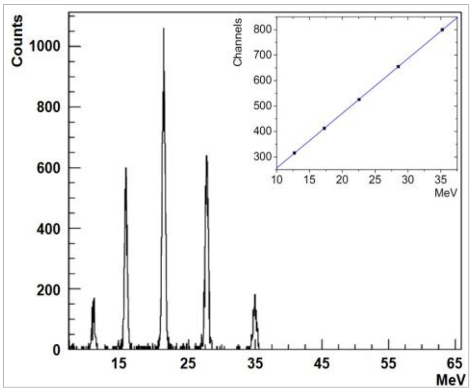

Fig 4. Energy spectrum was measured with different charge states of ^{20}Ne beam. The inset shows energy calibration for ^{22}Mg energy loss measurement extracted from the spectrum

Stopping power dE/dx for alpha and ^{22}Mg at the average particle energies (E_{av}) in the target have been determined by dividing the measured energy loss ΔE by the thickness of the target and $E_{av} = E_i - \Delta E/2$, where E_i is the incident particle energy. The results of the measurements for ^{4}He and ^{22}Mg in mixture gas $HeCO_2$ (10%) are shown in Figs. 5, 6 and table 2.

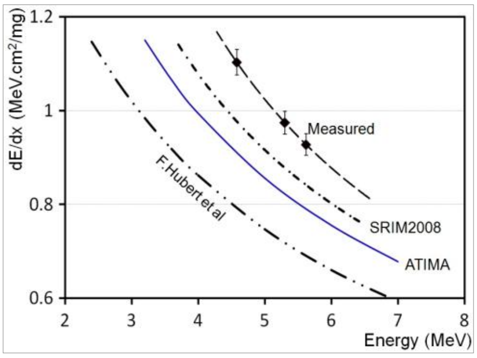

Fig 5. Stopping power of the alpha particles is as a function of average incident energy of thickness in $HeCO_2$. The experimental data are compared with the results calculated by codes in ref. [7, 8, 9].

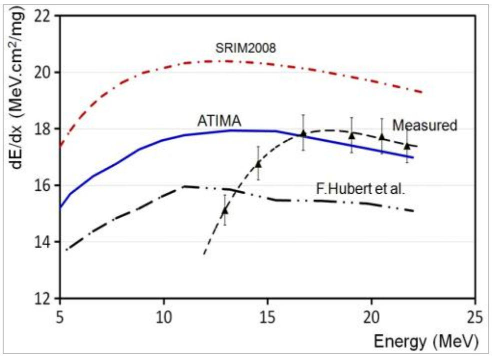

Fig 6. Stopping power of the radioactive ions ^{22}Mg is as a function of average incident energy of thickness in $HeCO_2$. The measured data are compared with the results calculated by codes in ref. [7, 8, 9].

As can be seen, in the low energy region of alpha particles, stopping power is more compatible with the semi-empirical curve predicted by SRIM2008 though the measured values are approximately 6% higher than the prediction. The result also points out that the energy loss of alphas is further than other calculations [8, 9]. Therefore, it is better to estimate energy loss of alpha by using SRIM2008 than using the others. For the radioactive ion ^{22}Mg, it is closer ATIMA [8] values than others in the energy range E > 17.5 MeV, whereas, it has a large difference in the region E < 17.5 MeV compared with codes [8, 9]. In this region, the experimental data are generally 11% lower than prediction of SRIM2008. The code can optimize exactly energy loss if it is modified by a factor of 11% higher. The compatibility of the codes [7, 8, 9] points out that a good applicability of Bragg's law for stopping measurement in the mentioned energy regions of the ions. The lower or higher results compared with calculation may be caused by the homogeneity, which influences the density of the absorber, of target consisting of various mass amounts of He and CO_2. In addition, difference of interaction of light particles and heavy radioactive ions in the gas also effects on the results. The mentioned reasons are predicted based on a comparison of this work with others investigating stopping power of alpha and ^{24}Mg in pure Helium gas [13] since no experimental data on ^{22}Mg and alpha in $HeCO_2$ have been obtained. The deviation of the results in this experiment collated with theory demonstrated that it is necessary to get much more data to modify energy loss calculation, such as Bethe-Bloch formula [14], for the real values.

Table 2. Average incident energies E_{av} inside thickness of target $HeCO_2$ and relative energy loss $\Delta E/E$ of ions in the target

Ion ^{4}He		Ion ^{22}Mg	
$E_{av}(MeV)$	$\Delta E/E$ (%)	$E_{av}(MeV)$	$\Delta E/E$ (%)
4.580	8.675	14.553	77.933
5.300	6.754	16.721	54.859
5.620	6.027	19.050	35.928
		20.506	26.275
		21.722	19.206

4. Conclusion

Since the $HeCO_2$ gas plays an important role in astrophysical experiments using active target, it is essential to investigate the energy loss of particles in the gas. In this study, energy loss of radioactive ions ^{22}Mg and alpha particles in mixed gas $HeCO_2$ is measured with a good agreement compared to theoretical calculations. The experiment results demonstrated that SRIM2008 and ATIMA are dominants for estimation of stopping power of the particles in the mentioned energy regions. However, there still need more energy loss measurements for particles covering a wide range of mass and energy for further estimation in the mixed gas.

Acknowledgement

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SỰ MẤT NĂNG LƯỢNG CỦA HẠT NHÂN KHÔNG BỀN ^{22}Mg VÀ ^{4}He TRONG HỖN HỢP KHÍ $HeCO_2$ (10%)

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Tóm tắt: Sự mất năng lượng của hạt alpha trong vùng năng lượng 4.788-5.795 MeV và hạt nhân không bền ^{22}Mg mang năng lượng 25.894 MeV trong hỗn hợp khí $HeCO_2$ đã được khảo sát. Chúng tôi tiến hành tạo chùm hạt không bền ^{22}Mg bằng hệ phổ kế từ CRIB của Đại học Tổng hợp Tokyo, đặt tại RIKEN, Nhật Bản vào năm 2011. Kết quả của phép đo được so sánh với kết quả tính toán theo lý thuyết cho thấy sự tương đồng trong vùng năng lượng xem xét. Điều đó, chứng tỏ sự mất năng lượng của các hạt vẫn tuân theo quy luật Bragg trong trường hợp này, tuy nhiên có một chút khác biệt cần hiệu chỉnh.

Từ khóa: *energy loss, radioactive ion ^{22}Mg, active gas $HeCO_2$.*