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The study of nucleosynthesis by means of scandium45+p reaction

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Scandium45 is known as a "bottleneck" in silicon burning in stars. However, there are few experimental data on reaction rates with scandium45. The reaction flow in silicon burning is concentrated in the ^{42}Ca(α,p)^{45}Sc and ^{45}Sc(p,γ)^{46}Ti reactions. We focused on ^{42}Ca(α,p)^{45}Sc and have performed measurements of the cross section for the inverse reaction of ^{45}Sc(p,α)^{42}Ca (Q-value = 2.34 MeV). As a result, we could obtain new experimental data in the Gamow energy region.

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1. Introduction

Various elements lighter than iron are created in stars. In the initial stage of evolution of stars, p-p chain and triple-α reactions occur and elements up to ^{12}C are generated. Subsequently, in massive stars, carbon, oxygen, neon and silicon burning processes proceed and various elements up to iron are created. We took an interest in "silicon burning", which occurs in the final stage of evolution of stars. The silicon burning process starts from photodisintegration by high-energy γ-ray and α-capture by silicon. Various reactions e.g. (γ,α), (γ,p), (α,γ) and (p,γ) proceed under quasi-equilibrium conditions.

Figure.1 is a part of reaction flow in silicon burning reported by Woosely [1]. Reaction flow of quasi-equilibrium is complex and there are many reactions. We focus on ^{45}Sc, known to be a "bottleneck" in silicon burning where the reaction flow concentrates as shown in Fig.1. Especially, we investigate ^{42}Ca(α,p)^{45}Sc and ^{45}Sc(p,γ)^{46} Ti reactions. In order to evaluate reaction rate of ^{42} Ca(α,p)^{45}Sc, we have performed measurements of the cross section for the inverse reaction of ^{45}Sc(p,α)^{42}Ca (Q-value = 2.34 MeV). For both reactions, experimental data is quite limited [2] around the Gamow energy at 3 GK for silicon burning. The Gamow peak corresponds to 4.6 MeV for the ^{42}Ca(α,p)^{45}Sc reaction and 2 MeV for the the inverse reaction ^{45}Sc(p, α)^{42}Ca.

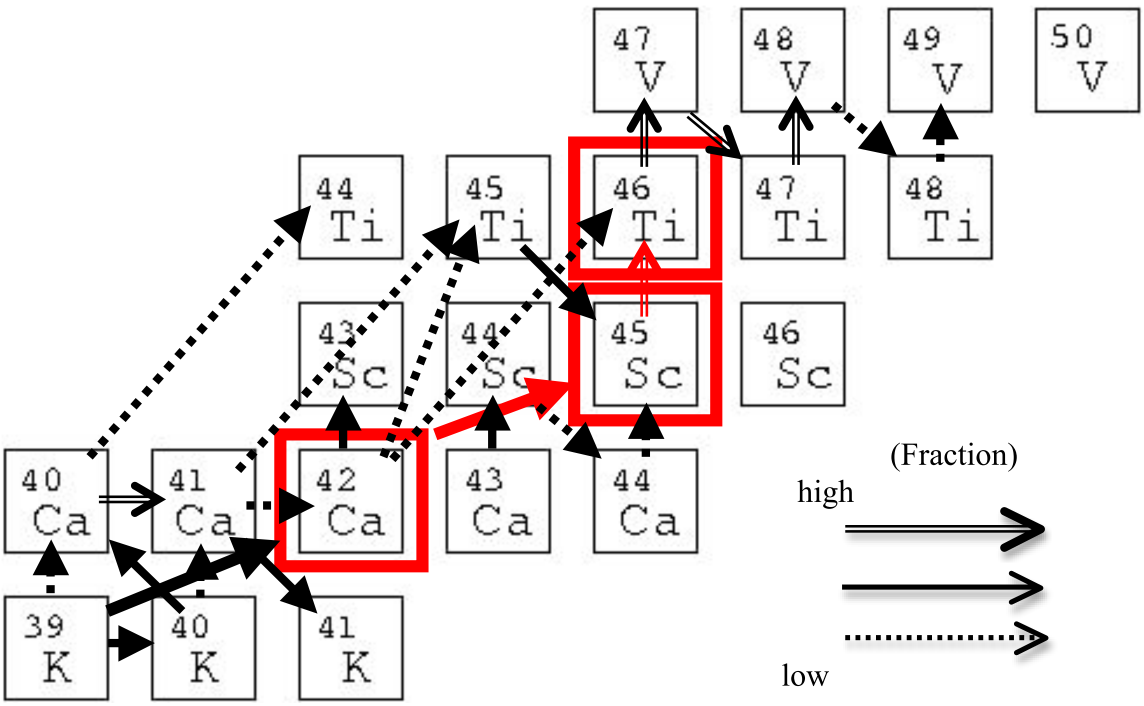

Fig. 1 This figure shows a part of reaction flow in silicon burning. The red symbols are the target of our study.

2. Experimental method

Our experiment were carried out with the 1 MV Tandetron at the University of Tsukuba Tandem Accelerator Complex (UTTAC), shown in Fig.2. Proton beam extracted from Cs sputtering ion source was accelerated to 2 MeV and irradiated on the Sc target, prepared by evaporation in vacuum on a 1.47 mg/cm^2 gold backing. The thickness of the Sc layer was 0.2 mg/cm^2.

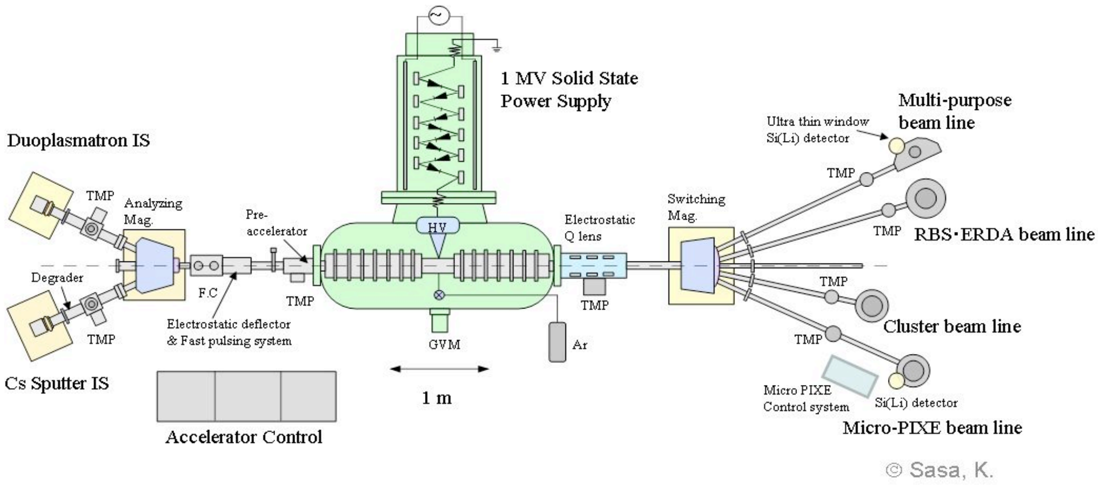

Fig.2 1MV Tandem accelerator at UTTAC

The ejected α-particle was detected with a E-ΔE counter (SSD) mounted 49.5±0.5 mm from the center of target at θ_{lab}=148°. The thickness of ΔE counter was 10 μm and that of E counter was 100 μm. The slit in front of SSD was square and included a circular hole(Φ7.0±0.1 mm). The solid angle for this measurement was 15.70±0.55 msr. For this experiment, we measured at only one energy and one angle.

3. Experimental results

Fig.3 shows the E-ΔE matrix. As shown in this figure, α-particles from ^{45}Sc(p,α)^{42}Ca reaction were well separated from strong elastic scattering (~10^7 counts) of protons mainly by the gold backing. In left side of Fig.3, there is no signal which corresponds to (p,α) for the case of only gold target. The yields of α-particles were corrected by dead time and evaluated to be 67 counts.

Using this value, we have calculated the differential cross section for the ^{45}Sc(p,α)^{42}Ca reaction. The relation of the yield and the cross section is represented as follows,

$$Y = n\frac{N}{S}\frac{d\sigma}{d\Omega}\Omega$$

where Y is yields, n is number of incident proton, N/S is the number of ^{45}Sc per unit area, dσ/dΩ is differential cross section and Ω is solid angle. We can calculate differential cross section from experimental data and obtain the following value.

$$\frac{d\sigma}{d\Omega} = 0.0066 \pm 0.0010 \ \ mb/sr$$

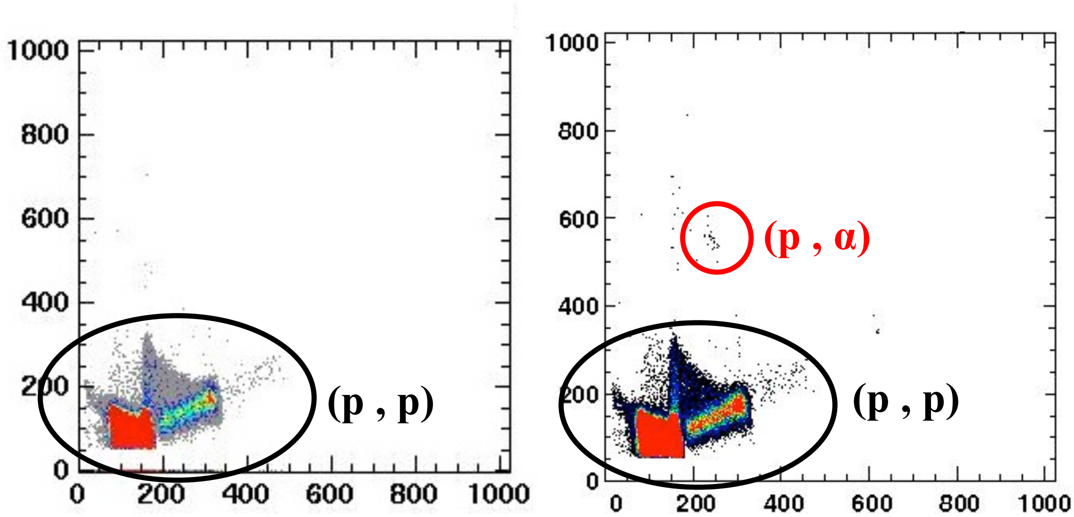

Fig.3 These figure show E-ΔE contour map. Left-hand side is the case of only gold target, Right-hand side is the case of Sc target on gold backing.

4. Conclusion

We could obtain a new data point in the low energy region for the $^{45}Sc(p,\alpha)^{42}Ca$ reaction. However, our experimental data is insufficient for detailed discussion. Since level density of ^{46}Ti, which is compound nucleus of this reaction, is high and many resonance structures can be expected, it is necessary to perform additional measurements of excitation function and angular distribution.

In this target, there is the problem that the rate of Rutherford scattering from the gold backing is too high. We are planning to perform measurements with another target with thinner and lower Z backing.

References

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[2] J.S. Schweitzer, *et al*, Nucl. Phys. A 287, 344-352 (1977)