Bull. Inst. Chem. Res., Kyoto Univ., Vol. 47, No. 2, 1969

A Scattering Chamber for Three Body Nuclear Reactions

Takuji YANABU*, Hirokazu FUJITA*, Masayuki GOTOH**, and Tatsuya IWASA**

Received March 20, 1969

To study the non-coplaner events in the three body nuclear reaction, a scattering chamber of three dimensional freedom was constructed, Three sets of radiation detectors could be mounted and could move to any position in the scattering chamber. Design of and some experimental results obtained with this chamber are described.

I. INTRODUCTION

In the Laboratory of Nuclear Reaction, Institute for Chemical Research, the scattering of alpha particles by nuclei and the emission of alpha particles from nuclei have been studied systematically for about eight years.[1] The merits of an alpha particle as a nuclear probe particle are:

1, the alpha particle is easily absorbed by the nucleus, so that one can survey the nature of nuclear surface with the scattering of alpha particles from the nucleus.

2, the alpha particle is a tightly bound particle and has no spin and isobaric spin, therefore the mechanism of the reaction induced by or emitting an alpha particle is simple relative to the proton or deuteron induced or producing reactions.

3, the alpha particle is a composite particle of nucleons, so that this particle is useful to investigate the composite structure of the nucleus. That means, the overlapping of alpha particle and the target nucleus is useful to see the alpha-like structure of the nucleus.

From these reasons, the collective motion of the nucleus and alpha cluster structure of the nucleus has been studied in the laboratory by the use of a 30 MeV alpha particle beam from the Kyoto University Cyclotron. In early stage of research works, two body reactions were the main subject of our investigations, but as the research developed, it was felt to be nescessary to construct a scattering chamber with which one can investigate the particle-particle or particle-gamma correlations in the final state. The reasons were as follows. We have become concious about the importance of the nucleon clustering into alpha clusters in the nucleus in the alpha particle emitting reactions such as

* 柳父 琢治, 冨士田 浩一: Laboratory of Nuclear Reaction, Institute for Chemical Research, Kyoto University, Kyoto.
** 後藤 正之, 岩佐 辰也: Central Research Laboratory, Mitsubishi Electric Corporation, Amagasaki.

(d, α) and (p, α) reactions. To investigate the existence of alpha clusters in the nucleus, quasi-free scattering experiment was programmed and the (α, 2α) reactions on Be^9, B^{10}, C^{12}, O^{16} and Ne^{20} have been studied.[2] In the course of these investigations, a scattering chamber equipped with two moving counters was nescessary and was constructed in 1964.[3] This scattering chamber had two co-axial rotating discs and co-planer particle-particle correlation experiment could be done when two counters were set on these discs. The Be^9 (p, pα) He^5 reaction was studied[4] with this chamber by the use of an FM cyclotron of the Institute for Nuclear Study, University of Tokyo. However, there still remained dissatisfaction with this chamber, because the non-coplaner particle-particle correlation could not be measured. We have experienced in the investigation of the Ne^{20} (α, 2α) O^{16} reaction, the coincidence spectrum of two alpha particles distributes discontinuously,[5] *i. e.*, the coincidence events on a kinematical line of two alpha particles leaving the residual O^{16} nucleus in its ground state, gather into several parts indicating the excited states of Ne^{20}. To confirm this phenomenon, the alpha decay from the excited states of Ne^{20} should be investigated and non-coplaner alpha-alpha coincidences around the recoil axis of the excited Ne^{20} should be measured. Moreover, in the experiment on the C^{12} (α, 2α) Be^8 reaction, it was found that two alpha particles from this reaction are emitted in coincidence mainly in the forward region.[6] An explanation of this phenomenon was that this phenomenon was caused by the final state interaction between two alpha particles. If this is true, the same phenomenon should be observed when the two alpha particle correlations were measured in the plane vertical to that defined by the beam direction and the recoil direction of Ne^{20}. To do this experiment, we needed a scattering chamber with which the three dimensional correlation could be measured.

In this report, the design, construction of a three dimensional scattering chamber and some of the nuclear physics experiment by the use of this chamber, are described.

II. DESIGN AND CONSTRUCTION

This scattering chamber was expected to be mounted on the axis of the broad range magnetic spectrograph[7] in order to utilize the beam analyzed through the momentum analyzer magnet,[8] so the diameter of the chamber was limited by the entrance of the spectrograph. Moreover, the vacuum system of this chamber was the same of that of the spectrograph, so the depth of the chamber was also limited. Under these conditions, the outer dimensions of the chamber were designed as large as possible. To transport the radiation detector to any position in three dimensional space, a longitudinal rotation was coupled with a latitudinal translation. Longitudinal rotation was executed by a rotation around the vertical axis containing the target center. Latitudinal translation was performed by an arc of sphere and this arc-shaped arm was drived by a gear mechanism. Two sets of these arrangements were installed into the chamber so as to make the particle-particle space correlation measurement feasible. Be-

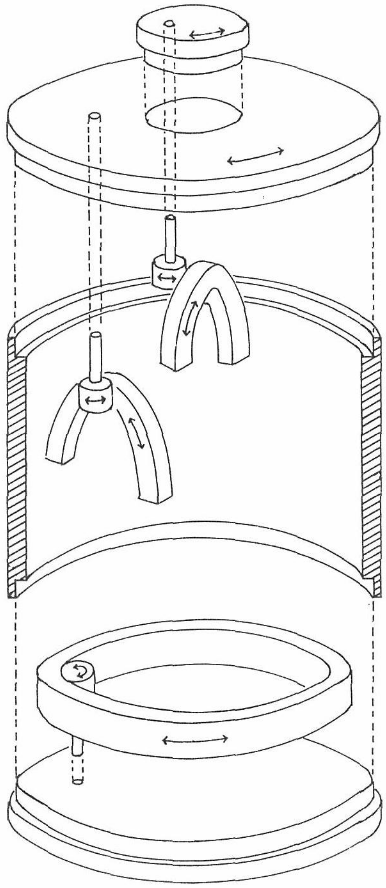

Fig. 1. Schematic drawing of the principle of three-dimensional freedom and three sets of moving arms.

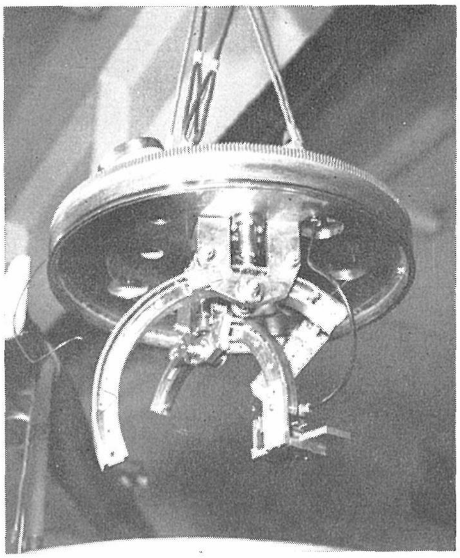

Fig. 2. Photo of the scattering chamber. Two moving arms are shown. These arms are attached to the upper lid of the chamber.

side these arrangements, a horizontal rotating disc was equipped to mount a monitor counter and to be capable of three body correlation experiment. A schematical drawing of these translation mechanism is shown in Fig. 1. Figure 2 shows the photographic view of the two rotating arms. These arms are attached to the lid of the chamber. The alignment of these arms and a rotating disc depends on the error of mechanical fabrication.

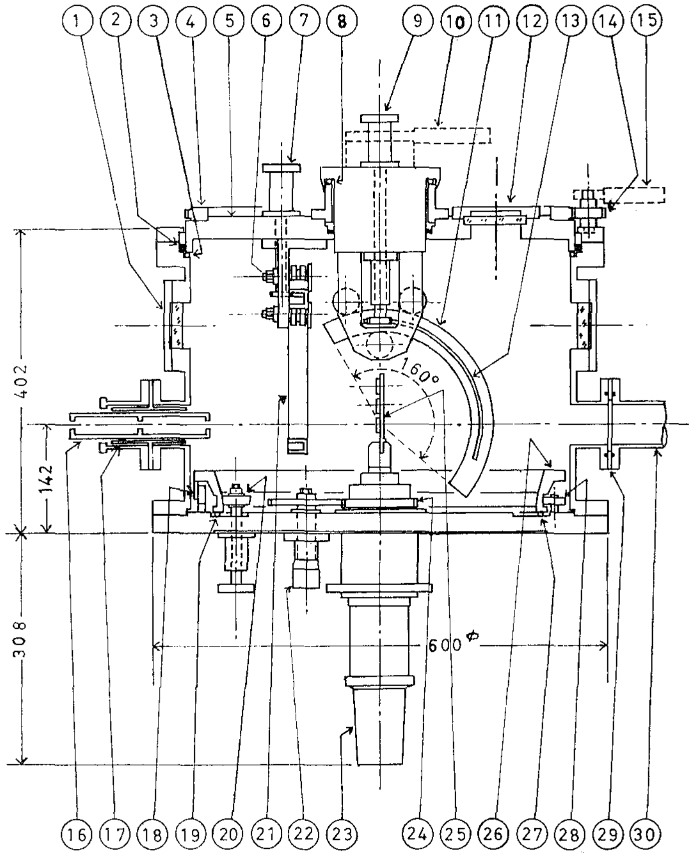

Fig. 3. Cross section of the scattering chamber. The parts of the chamber are: 1, viewing window. 2, O-ring seal of the upper lid. 3, ball bearings supporting the upper lid. 4, gears attached to the upper lid. 5, upper lid. 6, rollers defining the motion of the arm. 7, driving handle of the arm 21. 8, ball bearings supporting the central jig of the arm 11. 9, driving handle of the arm 11. 10, driving handle to rotate the central jig together with the arm 11. 11, moving arm. 12, viewing window. 13, gear attached to the arm 11. 14, driving gear of the gear 4. 15, driving handle of the gear 14. 16, collimator. 17, collimator support. 18, index of rotation angle of the disc 26. 19, ball bearings of the disc 26. 20, frictional wheel to rotate the disc 26. 21, moving arm. 22, driving handle to rotate the target holder. 23, tapered axis to fix the scattering chamber to the platform of reaction analyzer magnet. 24, gear attached to the target holder. 25, target frame. 26, rotating disc. 27, ball bearings. 28, rollers defining the motion of the disc 26. 29, insulator. 30, Faraday cup.

Figure 3 shows the dimensions of this chamber. The centering of the rotating disc is held by three segments attached to the bottom of the chamber and has no rotating axis. This mechanism comes from the need to leave room for target holder in the center of this chamber. The target holder could mount a rectangular frame to which three pieces of thin metalic foil are fixed or a gas target chamber. The height of the target holder is adjustable relative to the beam axis. Explanations of a beam collimater, a Faraday cup and a beam monitering port are omitted.

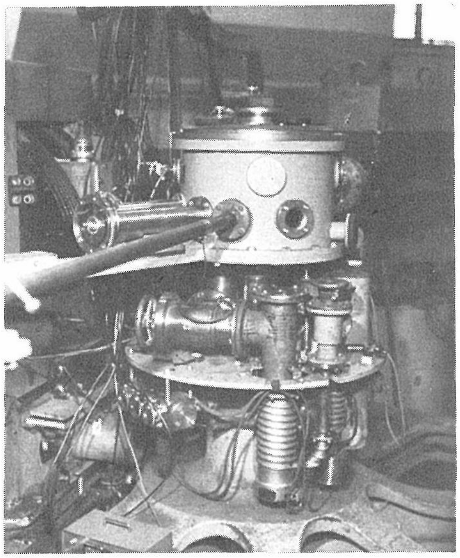

Fig. 4. Photo of the scattering chamber mounted on the platform of the reaction analyzer magnet.

The radiation detectors are mounted on the above mentioned arms and a disc by means of relevant jigs so as to point at the target center. To drive these arms geared mechanism is used. Driving of the rotating disc is done with a frictional wheel contact to the disc. Figure 4 shows the chamber set on the rack of the magnetic spectrograph. The rotation angle is read out from outside the chamber through viewing window. In assembling this chamber, two telescopes were set to fix the center of the chamber and errors of the machining were estimated by measuring the dimensions from this center.

III. PERFORMANCE

The scattering chamber was constructed in the beginning of 1966 and has been used since then. The accuracy of angular measurement is less than 0.2°, sufficient to investigate the particle-particle correlation experiment. Figure 5 shows the proton-alpha correlation spectra[9] as a function of azimuthal angle. The experiment is on the reaction $d+\alpha \rightarrow p+\alpha+n$. The proton counter was set at 45° with respect to the beam direction and was moved around the beam direc-

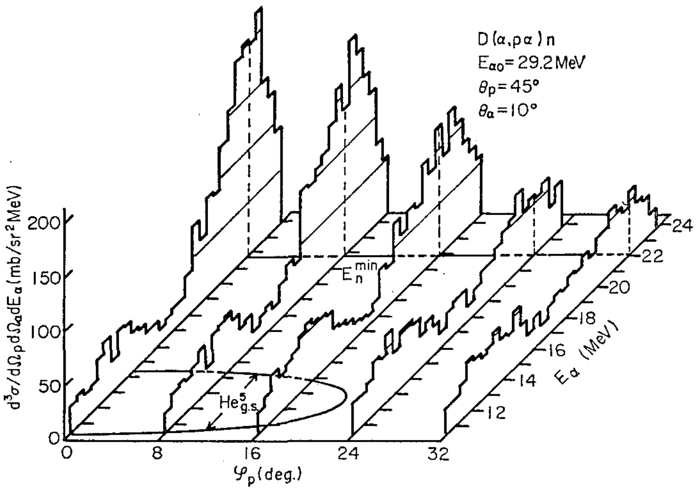

Fig. 5. Three dimensional representation of the energy spectra of alpha particles. See text. Figure from ref. 9)

tion varying azimuthal angles. The alpha particle counter was fixed at 10° with respect to the beam. In this system, the coincidence spectrum of alpha particles at $\phi_p = 0°$ gives the co-planer coincidence events. If the proton or neutron has no momentum inside the deuteron, it should give no coincidences when $\phi \neq 0$ against the experimental results. Figure 6 shows the momentum distribution of neutrons in the deuteron thus obtained.[9]

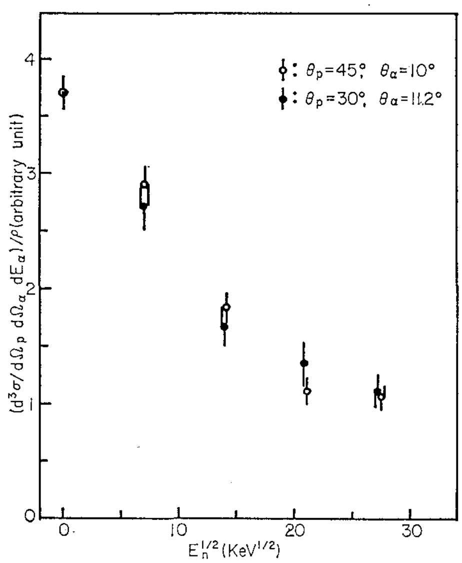

Fig. 6. Momentum distribution of a neutron in a deuteron. See text. Figure from ref. 9).

Figure 7 shows a result of other experiment.[10] This figure shows the azimuthal angular correlation distribution between alpha-particles and tritons from the reaction

$$Li^7 + \alpha \rightarrow Li^{7*}(4.63\,\text{MeV}) + \alpha'$$
$$\quad\quad\quad\quad \lfloor\!\rightarrow \alpha + t$$

Inelastically scattered alpha particles (α' in the equation) were detected at 60° with respect to the beam direction and the decay product tritons from the excited state of Li^7 were detected by moving a counter with 30° or 90° fixed polar angle and around the recoil axis of the excited Li^7. In the figure, it is seen that tritons are preferentially emitted in the reaction plane defined by the beam direction and by the alpha detector direction ; $\theta_{RCM}=0°$ or 180° in the figure. From these figures, it is seen that non-coplaner correlation measurements give more precise and abundant informations than the correlation measurements in the reaction plane.

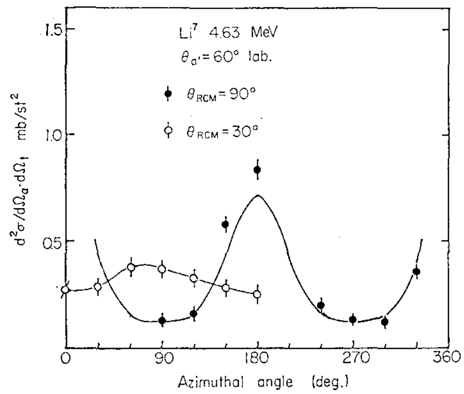

Fig. 7. Angular correlations between alpha particles and tritons. See text. Figure from ref. 10).

This three dimensional scattering chamber is now fully utilized in the laboratory to investigate final three body nuclear reaction and can be used in final four body nuclear reaction. Molecular structure of the nucleus can be clarified with this chamber and we hope to do a variety of experiments with this chamber.

ACKNOWLEDGMENT

The authors would like to acknowledge Prof. Y. Uemura, Dr. K. Fukunaga and other members of the Laboratory of Nuclear Science, Institute for Chemical Research, for their stimulating discussions in the course of designing.

REFERENCES

(1) K. Kimura, *Bull. Inst. Chem. Res. Kyoto Univ.*, 43, 499 (1965).
(2) T. Yanabu, S. Yamashita, K. Takimoto and K. Ogino, *J. Phys. Soc. Japan*, 20, 425 (1960).
K. Takimoto, *Mem. Coll. Sci., Univ. Kyoto, Ser. A*, Vol. 31, No. 2, Article 12 (1967).

T. Yanabu, S. Yamashita, K. Hosono, S. Matsuki, T. Tanabe, K. Takimoto, Y. Ôkuma, K. Ogino, S. Okumura and R. Ishiwari, *J. Phys. Soc. Japan*, 24, 667 (1968).
(3) T. Yanabu, to be published.
(4) S. Yamashita *et al*, *J. Phys. Soc. Japan*. **26**, 1078 (1969).
(5) T. Yanabu *et al*, Contribution No. 8-33, *International Conference on Nuclear Structure*, Sept. 1967, Tokyo, Japan.
(6) T. Yanabu *et al*, third paper of ref. 2)
(7) Y. Uemura *et al*, this Bulletin, preceding paper.
(8) T. Yanabu *et al*. this Bulletin, preceding paper.
(9) T. Tanabe, *J. Phys. Soc. Japan*, 25, 21 (1968).
(10) S. Matsuki, *J. Phys. Soc. Japan*, 24, 1203 (1968).