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A time projection chamber for the study of nuclear photodisintegration

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Abstract

A time projection chamber has been newly constructed for studying the nuclear photodisintegration reaction of a gas sample. All charged fragments from various channels of the reaction can be detected simultaneously by means of the time projection chamber with about 100% efficiency in the geometry of 4π. The assignment of these fragments to an individual reaction channel is unambiguously made using a path length, a pulse height, a track width and reaction kinematics of each of these fragments. The performance of the time projection chamber has been studied using the α-source of ^{241}Am and the photodisintegration reaction of ^{4}He induced by the pulsed laser-Compton backscattered photon beam.

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1. Introduction

The study of the photodisintegration reaction of a nucleus has been playing important roles in nuclear physics as well as nuclear astrophysics. In nuclear physics, since the photodisintegration reaction proceeds via well-known electromagnetic interactions, the reaction study provides us with important information on nucleon–nucleon (NN) interactions [1], meson exchange currents [2], charge symmetry of nuclear forces [3], and properties of the giant resonance states with various electromagnetic moments [4] and so on. In nuclear astrophysics, the accurate value of the reaction

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cross-section of a nucleus is necessary especially in a threshold energy region to estimate nucleosynthetic yields in the primordial nucleosynthesis [5] as well as stellar nucleosynthesis [6]. Note that these nucleosynthesis are considered to proceed in a stellar temperature range of between 10^8 and 10^9 K (10^{10} K$-$1 MeV), corresponding to the threshold energy regions of relevant reactions on the nucleosynthesis mentioned above. Recently a great interest has arisen in the photodisintegration reactions of few-body systems to investigate the properties of the giant electric dipole resonance (GDR) states from both nuclear physics [7] and nuclear astrophysics [8].

The experimental study of the photodisintegration reaction of a nucleus has been carried out by detecting a charged fragment emitted from the reaction by means of a cloud chamber [9], solid-state detectors [10], and/or scintillation detectors [11] using various photon beams such as bremsstrahlung photons, tagged photons and laser-Compton backscattered photons. Among these detectors, a cloud chamber has been used to detect simultaneously all charged fragments emitted from the reaction with a large solid angle of 4π being free from a dead layer of the detector and/or a window thickness of a sample container. We plan to study a nuclear photodisintegration of a gas sample in the GDR region and/or in the threshold energy region. In these studies various channels such as two-body (γ, p) and/or (γ, n) and three-body (γ, pn) channels open and the energy of a fragment could be as low as less than 100 keV. In addition, reaction yields are considered to be very low, since the amount of a gas sample is quite small. Therefore, it is crucial to use a detector system, which enables us to pick up a small true event from a huge amount of background with a large signal-to-noise ratio. We use a pulsed photon beam, which requires us to use a detector system having a capability to take data on a hard disk drive in a list mode. A cloud chamber has unique features, which meet various requirements necessary to perform our experimental studies mentioned above, but it does not have such a capability to take data in a list mode so as to utilize a characteristic feature of the pulsed photon beam.

In the present work we have newly constructed a time projection chamber (TPC), which meets all requirements necessary to study the nuclear photodisintegration of a gas sample using a pulsed photon beam. The TPC has the following features. Firstly, we can detect all charged fragments emitted from various channels of the photodisintegration reaction simultaneously with high detection efficiency of about 100% in the geometry of 4π. Secondly, we can unambiguously identify the reaction channel of each fragment using a path length, a pulse height, a track width and reaction kinematics of a fragment in the TPC. Thirdly, we can determine accurately the thickness of a gas sample by measuring its pressure and temperature in the TPC. Fourthly, we can easily discriminate a true event due to the photodisintegration of a sample from background by taking data in a list mode. Note that we use a quasi-monoenergetic pulsed laser-Compton backscattered (LCS) photon beam, and therefore a true event from the photodisintegration reaction of a nucleus is generated only for a short period of a pulsed beam at the LCS photon beam axis with a small diameter. Most background events do not originate from the LCS photon beam axis.

In the present paper, the TPC design is described in Chapter 2, its performance study using the α-source of ^{241}Am and the photodisintegration of ^{4}He is given in Chapter 3, and we conclude this work in Chapter 4.

2. Design of the time projection chamber (TPC)

2.1. Operation principle of the TPC

The TPC has been constructed for the study of a nuclear photodisintegration of a gas sample [12,13]. It is contained in a closed container filled with a mixed gas of a sample gas, 80% helium and 20% methane (CH_4) at a total pressure of 1.333 bar. The pressure was determined so as to obtain higher event rate of the photodisintegration by keeping a proper resolution of the path length of a charged fragment necessary to identify its reaction channel. Helium and methane are used as an operational gas and quenching gas of the TPC,