β-delayed neutron decay of ^{21}N*

LOU Jian-Ling(楼建玲)[1] LI Zhi-Huan(李智焕)[1;1)] YE Yan-Lin(叶沿林)[1;2)] JIANG Dong-Xing(江栋兴)[1]
HUA Hui(华辉)[1] LI Xiang-Qing(李湘庆)[1] ZHANG Shuang-Quan(张双全)[1] ZHENG Tao(郑涛)[1]
GE Yu-Cheng(葛愉成)[1] KONG Zan(孔赞)[1] LÜ Lin-Hui(吕林辉)[1] LI Chen(李琛)[1] LU Fei(卢飞)[1]
FAN Feng-Ying(范凤英)[1] LI Zhong-Yu(李忠宇)[1] CAO Zhong-Xin(曹中鑫)[1] MA Li-Ying(马立英)[1]
Faisal[1] XU Hu-Shan(徐瑚珊)[2] HU Zheng-Guo(胡正国)[2] WANG Meng(王猛)[2] LEI Xiang-Guo(雷相国)[2]
DUAN Li-Min(段利敏)[2] XIAO Zhi-Gang(肖志刚)[2] HUANG Tian-Heng(黄天衡)[2] FU Fen(付芬)[2]
ZHANG Xue-Heng(章学恒)[2] ZHENG Chuan(郑川)[2] YU Yu-Hong(余玉洪)[2] TU Xiao-Lin(涂小林)[2]
ZHANG Ya-Peng(张亚鹏)[2] YANG Yan-Yun(杨彦云)[2] ZHANG Hong-Bin(张宏斌)[2] TANG Bin(唐彬)[2]
TIAN Yu-Lin(田育林)[2] OUYANG Zhen(欧阳珍)[2] HUANG Mei-Rong(黄美容)[2]
XU Zhi-Guo(徐治国)[2] YUE Ke(岳珂)[2] GAO Qi(高启)[2]

1 (School of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China)
2 (Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China)

Abstract The β-delayed neutron and γ spectra of neutron-rich nucleus ^{21}N using β-γ and β-n coincidence measurements were presented in this paper. Thirteen new neutron groups ranging from 0.28 MeV to 4.98 MeV and with a total branching ratio 88.7±4.2% were observed. One γ transition among the excited states of ^{21}O, and four γ transitions among the excited states of ^{20}O were identified in the β decay chain of ^{21}N. The ungated half-life of 83.8±2.1 ms was also determined for ^{21}N.

Key words β decay, β-delayed neutron emission, β-delayed γ emission

PACS 21.10.Pc, 23.40.-s, 27.30.+t

1 Introduction

β-delayed neutron emission is often the dominant decay mode for neutron-rich nuclei near the drip-line. The large decay energy (Q value) allows to populate the highly excited states of the daughter nucleus, which are of special importance to study the nuclear structure of the unstable nuclei. So far many experiments of this kind have been carried out for nuclei such as ^{17,18,19,20}N using neutron ball at MSU[1, 2], and for nuclei ^{18,21}N using a combined setup composed of neutron walls and neutron ball by Peking University group[3—5].

For neutron-rich nucleus ^{21}N, the β-decay energy is 17.189 MeV, which lies above the single neutron separation energy at S_n=3.806 MeV and the two neutron separation energy at S_{2n}=11.41 MeV, and delayed emissions of single or double neutron may occur. There exists little experimental information about the β decay of neutron-rich nucleus ^{21}N and its daughter nucleus ^{21}O, excepting the half-life, the total β-delayed neutron emission branching ratio of ^{21}N, and the level schemes lower than the single neutron separation energy of ^{21}O. A.C.Mueller et al. reported that the half-life and β-delayed neutron emission branching ratio of ^{21}N were 95+15-11ms and 84±9% in

Received 8 July 2008

* Supported by National Basic Research Program (973 Program) of China (2007CB815000, 2005CB724800) and National Natural Science Foundation of China (10775003, 10475004, 10405001, 10221003)

1) E-mail: zhli@hep.pku.edu.cn
2) E-mail: yeyl@hep.pku.edu.cn

1990[6], and P.L.Reeder et al measured the half-life for ^{21}N as 83.6±6.7 ms with total neutron emission probabilities as 78±7% in 1995[7]. Only M. Stanoiu et al. gave the bound states nuclear structure information of the daughter nucleus ^{21}O in 2004 using nuclear reaction method[8], but until now, level scheme on highly excited state is unavailable for ^{21}O. There are also no experimental data available for the neutron energies and their transition probabilities for the β decay of ^{21}N. For the first time, the β-delayed neutron and γ spectra of neutron-rich nucleus ^{21}N using β-γ and β-n coincidence measurements will be presented in this paper.

2 Experimental setup

The β decay of ^{21}N using the neutron and γ detection array was carried-out in Lanzhou in January of 2007. The experimental setup was shown in Fig.1, and one unit of neutron ball was not shown in figure in order to make the implantation detection system seen clearly by reader. Along the beam line, the implantation detection system, which were used to identified second beam and serve as the start of time-of-flight, is composed of one upstream silicon surface-barrier detector, one aluminum energy degrader with adjustable thickness, one implantation detector and one downstream silicon surface-barrier detector, and their functions can be found in Refs. [3—4]. The beam intensity and purity of ^{21}N in this experiment is about 0.5 pps and 45.6%, respectively.

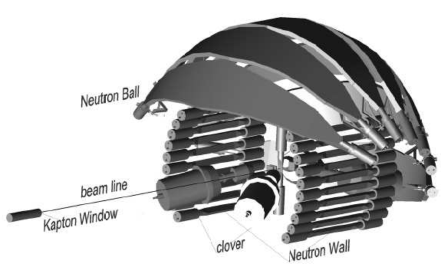

Fig. 1. The experimental setup in the experiment of ^{21}N.

The β-delayed neutrons were measured by two detection arrays: one called neutron ball, main for the measurement of the neutrons with the high energies, and the other called neutron wall, main for the observation of neutrons with low energies, and the detailed description can be found in Refs. [3—5]. The distance from the center of neutron wall's each bar to that of implantation detector is about 62 cm. Both ^{17}N and ^{16}C beams, whose β decay are accompanied by the delayed neutron emission with the well-known neutron energies and branching ratios, were used to calibrate neutron detection efficiency in this experiment, and the efficiency result can be seen in Ref. [9].

Four high-purity germanium 4-fold segmented clovers, which were produced by Eurisys, France, were used to detect γ-rays in this experiment. The distance between the center of each clover detector to that of the β detector is about 12 cm. Radioactive sources such as ^{60}Co, ^{207}Bi, ^{152}Eu as well as the radioactive beams of ^{17}N and ^{19}O (the impurities to ^{16}C beam) were used to calibrate the efficiency of the γ detectors. The absolute full-energy peak detection efficiency is about 1% for the γ-ray at the energy of 1.33 MeV.

3 Experimental result

The total number of decay events for ^{21}N detected throughout the beam-off period (300 ms) was extracted by fitting the decay curves. The ungated decay curve of ^{21}N was fitted by a single exponential decay function plus a constant background, and was shown in Fig. 2. The total number of β events was found to be 1.52×10^5 with a half-life of 83.8±2.1 ms, which is in agreement with the value from previous measurements made by Mueller[6] and Reeder[7].

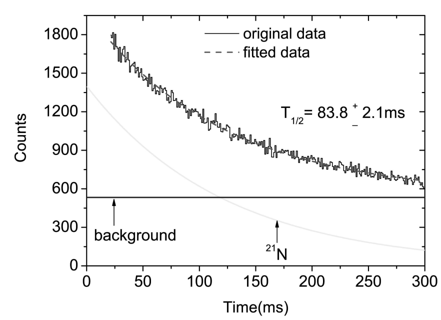

Fig. 2. The β-decay curve of ^{21}N.

The time-of-flight spectra of β-delayed neutrons from the β decay of ^{21}N were obtained from both neutron ball and neutron wall. The neutron wall's result was shown in Fig. 3. In order to compare expediently, the flight path of all neutron detectors were unified to 1 m. The spectrum was fitted with asymmetric Gaussian functions with a cubic background. The peak shapes, including an asymmetric factor based on energy, were taken from the neutron efficiency calibration beam ^{16}C and ^{17}N. Ten neutron groups are observed by neutron ball with energies from 0.62 MeV to 4.98 MeV, while thirteen neutron groups are measured by neutron wall and the corresponding energies are given in MeV in Fig. 3. Neutron ball, with large solid angle coverage, provides better statistics than neutron walls, but have higher neutron detection threshold, so the neutron peak lower than 0.62 MeV can not be clearly seen by the neutron ball, but by the neutron wall.

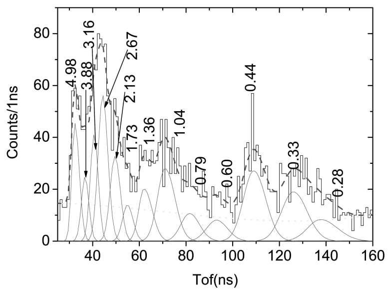

Fig. 3. The time-of-flight spectrum measured by neutron wall. The step vert solid line, the dash line, the dot line, and the solid line stand for original data, fitted data, background and fitted neutron peaks, respectively.

The neutron emission probability of each neutron group was calculated using the net neutron peak area, the neutron detection efficiency, and the total number of observed decay events. For neutron ball and neutron wall, not only the energies but also the probabilities are consistent with each other within the error. The total neutron emission probability was found to be 88.7±4.2% by adding all neutron branch probabilities seen by neutron wall. This is in agreement, within the errors, with previous values 84±9% and 78±7% measured by Mueller[6] and Reeder[7], respectively.

Figure 4 presents the result of γ spectra measured in coincidence with the β decay of ^{21}N during the beam-off intervals (300 ms) by all four clovers, with (a) showing the γ-rays with lower energies, whereas (b) giving the high energy part. The peaks are labelled with their parent nucleus and energy in keV. The 1222 keV transition is due to the β-decay of ^{21}N to the the first excited $1/2^+$ state in ^{21}O. The γ-rays at energies of 1674 keV, 2397 keV, 2780 keV, 3175 keV are obtained from β-delayed neutron decay of ^{21}N to the excited state in ^{20}O. Other features that are not labelled in Fig. 4, especially for the high energy part, are not considered as γ peaks, as they have unreasonably small FWHMs.

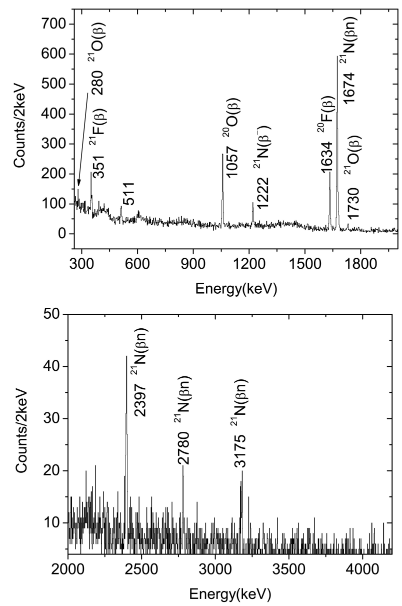

Fig. 4. β-γ coincidence spectra from the β-decay of ^{21}N, (a) is the low energy part and (b) is the high energy part, and all the energies are given in keV.

4 Conclusion

The β-delayed neutron and γ spectra of neutron-rich nucleus ^{21}N using β-γ and β-n coincidence measurements were presented in this paper. Thirteen new neutron groups ranging from 0.28 MeV to 4.98 MeV and with a total branching ratio 88.7±4.2% were observed. One γ transition among the excited states of ^{21}O, and four γ transitions among the excited states of ^{20}O were identified in the β decay of ^{21}N. The ungated half-life of 83.8±2.1 ms was also determined for ^{21}N.

We would like to acknowledge the staffs of HIRFL for providing the ^{26}Mg primary beam and the staffs of RIBLL for all kinds of assistance.

References

1 Sumithrarachchi C S et al. Phys. Rev. C, 2006, **74**: 024322
2 Scheller K W et al. Phys. Rev. C, 1994, **49**: 1
3 LI Z H et al. Phys. Rev. C, 2005, **72**: 064327
4 LOU J L et al. Phys. Rev. C, 2007, **75**: 057302
5 HU Q Y et al. IEEE on Nucl. Scie., 2005, **52**: 1
6 Mueller A C et al. Nucl. Phys. A, 1990, **513**: 1
7 Proc. Intern. Conf. on Exotic Nuclei and Atomic Masses, Arles, France, June 19-23, 1995, 587
8 Stanoiu M et al. Phys. Rev. C, 2004, **69**: 034312
9 KONG Zan et al. Chin. Phys. C (HEP & NP), 2008, **32**(Suppl. II): 187