Structure of β-emitting nuclei ^{29}P *

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Abstract The extoic structure of ^{29}P was investigated by measuring its magnetic moment in the ground state with β-NMR method. We got the experimental value of 1.2346 μ_N after diamagnetism correction. It is very close to the calculated value of 1.1009 μ_N computed with shell model. The shell model calculation also gave a proton density distribution of ^{29}P with a long tail. The present results show that $2s_{1/2}$ proton in the ^{29}P may lead to the proton-skin structure.

Key words ^{29}P, magnetic moment, β-NMR, proton density distribution, proton-skin

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1 Introduction

Because of the very small separation energy of the valance nucleons, a large nuclear radii and narrow momentum distribution, the nuclei far from β stability lines are expected to show some very interesting and exotic properties[1]. Since the discovery of neutron halo of ^{11}Li[2], scientists have observed some neutron halo nuclei (^{11}Be[3], ^{19}C[4], ^{6}He[5], etc.) and proton halo nuclei (^{8}B[6], ^{17}Ne[7], ^{20}Mg[8], etc.) theoretically and experimentally. Compared with the neutron halo, it is difficult to form the proton halo because of the Coulomb repulsion interaction. However, if the proton-rich unstable nucleus in the ground state has the structure that a valence proton of $s_{1/2}$ orbital coupled to the ground state of the core, it is easy to form proton halo structure[9]. The appropriate nuclei with such a configuration are those with $Z=15$ and $Z=16$.

$^{29}P(I^{\pi}=1/2^{+}, T_{1/2}=4.14$ s) is the β-emitting nuclei with the last proton in $2s_{1/2}$ orbit and its last proton separation energy is $S_p=2.748$ MeV. Therefore, ^{29}P may have exotic structure.Wei Yibin et al.[10] measured the parallel momentum distribution of the fragments from the break-up of ^{29}P on C target. They got the result that the proton-skin structure may exist in ^{29}P.

Among the approaches employed to study the halo structure, the measurement of nuclear moments plays an important role in nuclear structure study[1], it can yield related information on the wave function of the halo proton (or neutron) in combination with theoretical analysis[11]. For example, the quadrupole moment measurement of ^{11}Li[12] and the magnetic moment measurement of ^{11}Be[11] are of significant meaning in nuclear structure study.

Our motivation is to give new experimental data of magnetic moment with β-NMR method and to confirm whether the exotic structure exists in ^{29}P combined with shell model calculation.

2 Experiment details

The present experimental setup and procedure were similar to those used in previous magnetic moment measurements[13]. Fig. 1 is the β-NMR setup.

The ^{29}P nuclei were produced through the ^{28}Si(d, n) ^{29}P reaction with an incident deuteron beam of $E=3.0$ MeV from the 2×1.7 MV tandem accelerator. SiO_2 target with a thickness of 40 μg/cm^2 was used. The SiO_2 was evaporated in vacuum on the

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0.5 mm thick Ti backing. The target was attached on the target holder that was cooled by a water flow, which ensures the bombardment of a 5∼10 μA beam current. The glancing angle of the target was 5° to the incident beam. The ^{29}P nuclei were recoiled into the single crystal Si stopper at the recoil angle of $15° \sim 25°$ through a Cu collimator.

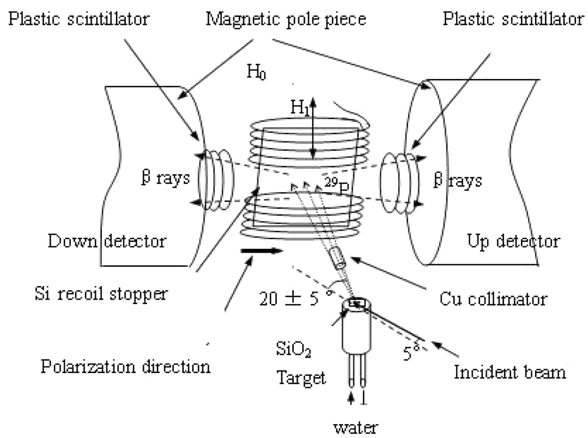

Fig. 1. β-NMR setup.

The spin-polarized ^{29}P nuclei emit β rays anisotropically. In order to control the change of polarization, a pulsed rf magnetic field H_1 was applied perpendicular to the externally applied magnetic field $H_0 = 0.4300$ T. When the applying rf field fulfils the resonance condition, the polarization is completely destroyed and the angular distribution of the emitted rays becomes isotropic. The asymmetry of the emitted β-rays was detected by a pair of counter telescopes placed at 0° and 180°, parallel and anti-parallel to the polarization direction, respectively.

In order to reduce un-wanted backgrounds the beam was pulsed by a beam chopper. The width and repetition periods of beam pulse were 5 s and 9 s, respectively. A beam pulse was followed by a 0.5 s rf pulse. The β-ray counting started at the end of the rf pulse and lasted to the next beam pulse.

3 Results and discussion

The typical β-NMR spectrum of ^{29}P in Si is shown in Fig. 2. From the resonant frequency $\nu_L = 8079.7 \pm 0.2$ kHz, the magnetic moment can be easily deduced to be $\mu(^{29}\mathrm{P}) = 1.2346(3)\mu_N$ after the diamagnetism correction[14].

We calculated the magnetic moment and the density distributions of protons and neutrons with OXBASH shell model code. An improved shell-model Hamiltonian with enhanced spin-flip proton-neutron interaction and modified single-particle energies was used and the interaction parameters were adjusted for the sd shells. With the one-body transition densities for isoscalars and isovectors obtained from the shell model wave functions, we calculated the magnetic moment and density distributions of protons, neutrons and matter. Our experimental value is in good agreement with the value of 1.2349 μ_N given by Sugimoto et al[15]. and it is very close to the calculated shell model value of 1.1009 μ_N. The shell model calculation shows that the magnetic moment of ^{29}P is resulted mainly from the $2s_{1/2}$ orbital. The density distributions of protons and neutrons and matter calculated with shell model is shown in Fig. 3. The density distribution of protons has a longer tail than that of neutrons, which is consistent with our Skyrme-Hartree-Fock calculation. Our shell model calculation plus high Coulomb and centrifugal barriers indicates the existent of proton skin in ^{29}P. This is in accordance with the proton-skin structure predicted by Wei Yibin et al.[10] who assumed a valence proton of $2s_{1/2}$ orbital in ^{29}P. The present results also shows the role of the $2s_{1/2}$ proton in proton-skin structure in ^{29}P.

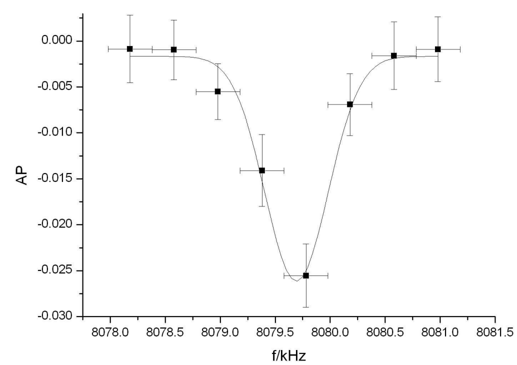

Fig. 2. Typical β-NMR spectrum of ^{29}P in Si.

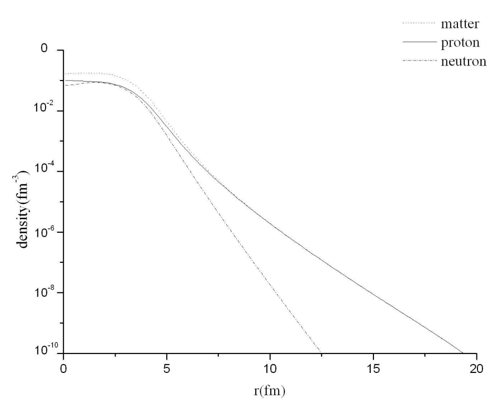

Fig. 3. Density distributions of protons, neutrons and matter in ^{29}P.

4 Summary

The exotic structure of ^{29}P in the ground state was investigated by measuring the magnetic moment of ^{29}P with β-NMR technique. The spin-polarized β-emitting nuclei ^{29}P nuclei were produced by ^{28}Si(d, n)^{29}P reaction. The magnetic moment obtained after diamagnetism correction is (^{29}P) 1.2346 μ_N. It is very close to the value of 1.1009 μ_N gived by shell model calculation. The shell model calculation also gave a long tail of the proton density distribution of ^{29}P. Considering the Coulomb and centrifugal barriers, the present result shows that proton skin exists in the ground state of ^{29}P and the role of $2s_{1/2}$ proton in ^{29}P may lead to proton-skin structure.

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