第 18 卷 第 4 期
2001 年 12 月

原 子 核 物 理 评 论
Nuclear Physics Review

Vol. 18, No. 4
Dec., 2001

Article ID: 1007-4627(2001)04-0289-03

Explanation on New Magic Number $N=16$ in Light Neutron-rich Nuclei*

REN Zhong-zhou[1,2], S. Sugimoto[3,4], H. Toki[3]

(1 *Department of Physics, Nanjing University, Nanjing* 210008, *China*;
2 *Center of Theoretical Nuclear Physics, NLHIA of Lanzhou, Lanzhou* 730000, *China*;
3 *RCNP, Osaka University, Osaka* 567-0047, *Japan*;
4 *RIKEN, Hirosawa* 2-1, *Wako, Saitama* 351-0198, *Japan*)

Abstract: Based on the analysis of neutron-separation energies, Ozawa et al proposed a new magic number $N=16$ in light neutron-rich nuclei. The deformed and spherical relativistic mean-field (RMF) calculations have been carried out for $N=16$ isotones. The numerical relativistic mean-field results show there is a shape transition in $N=16$ isotones. This is the possible cause of the appearance of the new magic number in someneutron-rich nuclei.

Key words: deformation; relativistic mean field theory; new magic number

CLC number: O571.2 **Document code**: A

The experimental development of radioactive beams has produced many new exotic nuclei far from stability[1-3]. New phenomena such as neutron halos in light nuclei[1-3] have been observed and studied[4-6]. The existence of proton halos in proton-rich P and S isotopes is predicted in Ref. [7]. Brown et al[8] also agreed that ^{26}P and ^{27}S are the mostly interesting cases in this mass range[7,8]. Recently the proton halos in P isotopes have been observed experimentally[9,10]. The study of the properties of these nuclei brings a challenge to traditional nuclear structure models. At present mean-field models have been widely applied to these nuclei and received great success[11-16].

In this paper we will perform both the spherical and deformed calculations in the relativistic mean-field (RMF) model for some $N=16$ isotones. We input the force parameters TM2 which is the parameter set for light nuclei[13]. The values of the force parameter TM2 are: $M=938.0$ MeV; $m_\sigma=526.443$ MeV; $m_\omega=783.0$ MeV; $m_\rho=770.0$ MeV; $g_\sigma=11.4694$, $g_\omega=14.6377$; $g_\rho=4.6783$; $g_2=-4.4440$ fm^{-1}; $g_3=4.6076$; $c_3=84.5318$[16]. With the TM2 parameters, we treat the center-of-mass correction in the same way as Sugahara et al[13]: $E_{\rm cm}=-(1/2mA)\langle P_{\rm cm}^2\rangle$. The neutron pairing gaps are chosen as $\Delta_n=11.2/\sqrt{A}$ (MeV) and this is an old formula on pairing gaps and used in many studies. To test the code, we give the RMF results of the nucleus ^{23}O in Table 1. The Pauli blocking effect of an odd nucleon can be also treated in the code. The experimental binding energy of ^{23}O is taken from Ref. [14].

Received date: 11 Sep. 2001; **Crrected date**: 25 Sep. 2001

* **Foundation item**: The Support of a COE Professorship of Monboshu of Japan; the Major State Basic Research Development Program (G2000077400); NSFC

Biography: Ren Zhong-zhou (1962—), male (Han Nationality), Henan Nanyang, professor, Ph. D. super advisor, works on the field of theoretical nuclear physics and quantum chaos.

Table 1 The binding energies E_b, root-mean-square radii, and single particle levels of ^{23}O with and without blocking

Blocking orbit	E_b/MeV	r_m/fm	r_n/fm	r_p/fm	$1s_{1/2}$(n)	$1p_{3/2}$(n)	$1p_{1/2}$(n)	$1d_{5/2}$(n)	$2s_{1/2}$(n)	$1d_{3/2}$(n)
$1d_{5/2}$	162. 48	3. 08	3. 29	2. 62	−43. 27	−24. 11	−24. 11	−7. 35	−3. 60	−0. 24
$1d_{3/2}$	163. 5	3. 03	3. 23	2. 62	−43. 28	−24. 25	−24. 25	−7. 44	−3. 45	−0. 24
$2s_{1/2}$	166. 79	2. 99	3. 18	2. 61	−43. 82	−24. 46	−24. 46	−7. 45	−3. 42	−0. 08
No blocking	166. 57	3. 02	3. 21	2. 61	−43. 62	−24. 36	−24. 36	−7. 43	−3. 47	−0. 14

The experimental binding energy is 168. 48 MeV. r_m, r_n and r_p denotes radius of matter, neutron and proton.

Very recently Ozawa et al[17] analysed the data of the neutron separation energy of odd-A nuclei and odd-odd nuclei and concluded that a new magic number $N=16$ appears for neutron-rich nuclei with the third component of isospin $T_z \geq 3$[18]. The experimental interaction cross section of nucleus-nucleus collisions also supports this conclusion[18]. Up to now, there is no theoretical study on this. We carried out the deformed RMF calculation for $N=16$ isotones and found that there existed shape transitions from deformed ground state to the spherical ground state with the increase of neutron excess in this isotones. The variation of the quadrupole deformation parameters with T_z of for $N=16$ isotones is given in Fig. 1. It is seen from Fig. 1 that the nuclei with $T_z \geq 3$ are approximately spherical (from ^{26}Ne to ^{22}C). The nuclei with $T_z < 3$ are deformed(from ^{32}S to ^{27}Na). For ^{22}C, we notice that an oblate solution is almost degenerate with the spherical solution in energy. This corresponds a shape coexistence. In order to analyse why there is a new magic number for nuclei with $T_z \geq 3$, we performed further the spherical RMF calculation for $N=16$ isotones and draw the spherical single particle levels in Fig. 2. In Fig. 2, the spherical single particle levels of nuclei with $T_z < 3$ are only used for explanation because they are well deformed nuclei. It is seen that the level space between $1d_{3/2}$ and $2s_{1/2}$ increases with T_z. The level $2s_{1/2}$ approaches to the level $1d_{5/2}$ and a gap appears between $2s_{1/2}$ and $1d_{3/2}$ when $T_z > 3$. This is why there is a new magic number for light nuclei with $T_z > 3$. The RMF calculation shows that this magic number $N=16$ is caused by the spherical shell closure in these nuclei with $T_z > 3$.

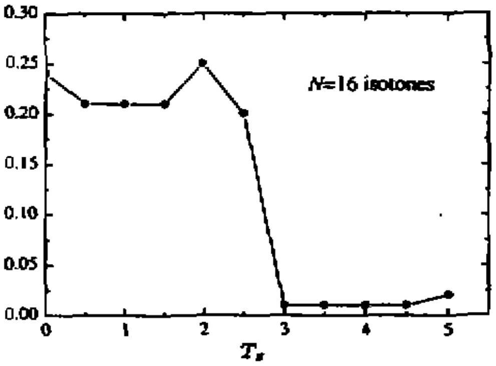

Fig. 1 The variation of the quadrupole deformation (β) of the $N=16$ isotones as a function of the third component of the isospin in the RMF model.

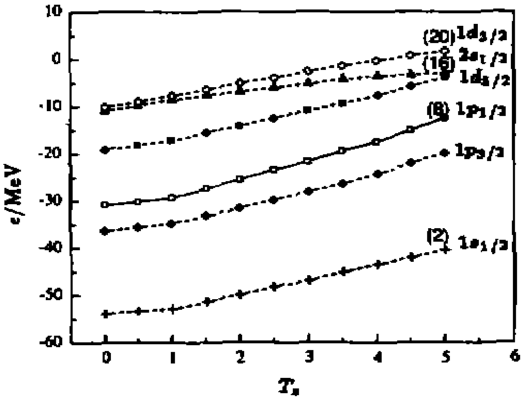

Fig. 2 The variation of the spherical single particle energies of $N=16$ isotones with the third component of the isospin.

We have investigated the deformation and single particle levels in $N=16$ isotones with both the deformed and spherical relativistic mean-field model. With the standard forces we show that there is a shape transition in $N=16$ isotones. The nuclei near the stable line are deformed and then become spherical with incrensing neutrons. A gap between the spherical level $2s_{1/2}$ and $1d_{3/2}$ increases with the increase of the neutron number. This is the cause of the appearance of new magic number $N=16$.

Therefore the new magic number $N=16$ of light neutron-rich nuclei with $T_z>3$ found by Ozawa et al[18] can be explained in the RMF model with the spherical shell closure $N=16$ of these nuclei .

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丰中子轻核新幻数 $N=16$ 的解释*

任中洲[1,2], S. Sugimoto[3,4], H. Toki[3]

(1 南京大学物理系, 江苏 南京 210093;
2 兰州重离子加速器国家实验室原子核理论中心, 甘肃 兰州 730000;
3 日本大阪大学核物理研究中心, 大阪 567-0047;
4 日本理化学研究所, 和光市 351-0198)

摘　要: 基于中子分离能的分析, Ozawa 等提出丰中子轻核存在新幻数 $N=16$. 对 $N=16$ 同中子素进行了形变和球形的相对论平均场计算. 相对论平均场的数值结果表明 $N=16$ 同中子素有形状相变. 这是一些丰中子核新幻数出现的可能原因.

关键词: 形变; 相对论平均场; 新幻数

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* **基金项目**: 日本 Monboshu COE 教授(职位)资助项目; 国家重点基金研究发展规划资助项目(G2000077400); 国家自然科学基金资助项目