УДК 539.143 + 539.172.6

SEARCH FOR ^{28}O AND STUDY OF THE NEUTRON-RICH NUCLEI NEAR THE NEUTRON CLOSURE $N = 20$

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The results of a study of the properties of the extremely neutron-rich nuclei of light elements with $N = 20$ are presented. These nuclei were produced by projectile fragmentation of a ^{36}S (78*A* MeV) beam on a ^{181}Ta target. The reaction fragments were analyzed by the LISE spectrometer at GANIL on a base of measuring the magnetic rigidity, time-of-flight, energy loss and total kinetic energy. The evidence of particle unstability of ^{28}O was obtained. The study of beta-delayed decay of nuclei near neutron closure $N = 20$ was performed. The first measurement of $T_{1/2}$ values for ^{27,29}F, ^{30}Ne are presented.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

Поиск ^{28}O и исследование свойств нейтронно-избыточных ядер вблизи $N = 20$

Тарасов О. и др.

Представляются результаты исследований свойств ядер на границе стабильности в области замкнутой нейтронной оболочки $N = 20$. Исследования проводились на спектрометре LISE в GANIL с использованием первичного пучка ионов ^{36}S с энергией 78 МэВ/нуклон. Идентификация фрагментов взаимодействия пучка с танталовой мишенью осуществлялась на основе измерений магнитной жесткости, времени пролета, потерь и полной энергии. Впервые приводятся экспериментальные свидетельства нестабильности ядра ^{28}O. Приводятся также результаты исследования свойств распада ядер вблизи нейтронной оболочки $N = 20$. Впервые проведены измерения периодов распада ^{27,29}F, ^{30}Ne.

Работа выполнена в Лаборатории ядерных реакций им. Г.Н.Флерова ОИЯИ.

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1. Introduction

The study of the properties of extremely neutron-rich nuclei of light elements is considered an important and interesting modern research topic in nuclear physics. The interest in this field has been stimulated by the intriguing phenomena of nuclei near the neutron drip-line, such as «skin» or «halo» structures. Thus the synthesis and investigation of the properties of the extremely neutron rich isotopes of the lightest elements is of considerable interest both for locating the neutron drip-line and for testing various theories describing exotic nuclei.

One of the problems is which nuclear reaction can be used to reach the neutron drip-line. In the sense of the highest production rates of exotic nuclei, fragmentation reactions at energies above 30 MeV/A is one of the most effective methods. Moreover, the highest rates for neutron-rich products have been observed in the case of fragmentation of neutron-rich primary beam [1]. The merits of using of a ^{48}Ca-beam in this experiment have been shown when more than 10 neutron-rich nuclei had been synthesized for the first time. It was stressed that some of new neutron-rich isotopes produced had a neutron number larger than that of the projectile, the pick-up of some neutrons from target to fragments could be responsible for production of fragments with neutron number larger than 28.

The heaviest experimentally known oxygen isotope is ^{24}O, while ^{26}O has been found to be unbound [1]. Most of the theoretical models predict ^{26}O to be bound and ^{28}O unbound even though it is a double-magic nucleus. The last attempt [2] to synthesize ^{26}O by fragmentation of a 92 MeV/A ^{40}Ar has confirmed the nuclear instability of neutron-rich oxygen isotope.

The other interesting aspect of this range of nuclei is the deformation phenomenon observed close to $N=20$ in the Ne-Al region. The compact spherical shapes predicted to appear close to the magic numbers may be substituted by some other deformed equilibrium configurations. It was shown [3] that for ^{30}Na, which has one neutron hole with respect to the $N=20$ shell closure, the nuclear potential has two minima one at $\beta=0$ and another at $\beta=0.35$. As the neutron number increases the main equilibrium configuration for the Na isotopes becomes that at $\beta=0.35$. The deformation of this neutron number region could also result as the appearance of isomeric states of extremely neutron-rich oxygen, neon and sodium isotopes. Such effects may influence the decay properties of these nuclei, for example half-life, neutron emission probability, and as already observed in some cases, masses and mean square radii.

The aim of the present paper is the search for particle stable nuclei around the neutron shell closure $N=20$ (mainly, ^{28}O) and also the study of β-decay of the nuclei in this region. The fragmentation of an intense beam of a very neutron-rich ^{36}S has been chosen to produce these extremely neutron-rich nuclei.

2. Experimental Set-Up

The search for nuclei near the neutron drip line which are expected to have a very low production yields was carried out at GANIL using the LISE spectrometer [4] collecting

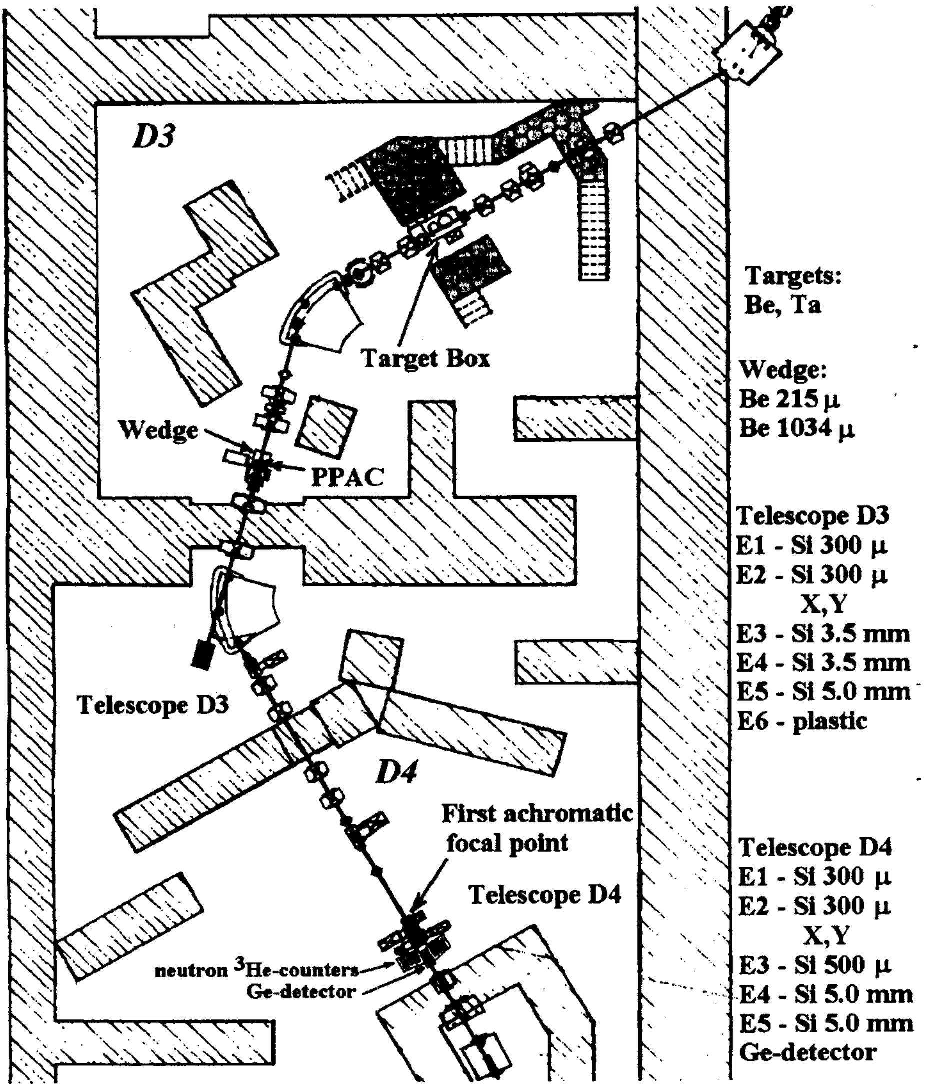

Fig.1

projectile-like fragments at 0 degree by a two-dipole system. The attempt to synthesize the ^{28}O nuclei was performed using fragmentation of a ^{36}S (78.1 MeV/A) at the highest available intensity. The use of ^{36}S should enable one to obtain the higher production rate of the neutron-rich isotopes near the drip-line with $N = 20$ than has been reached in former experiments [1,2]. Another advantage was obtained by the use of an increased magnetic rigidity (up to 4.3 Tm) available after the upgrading of the first dipole of the LISE

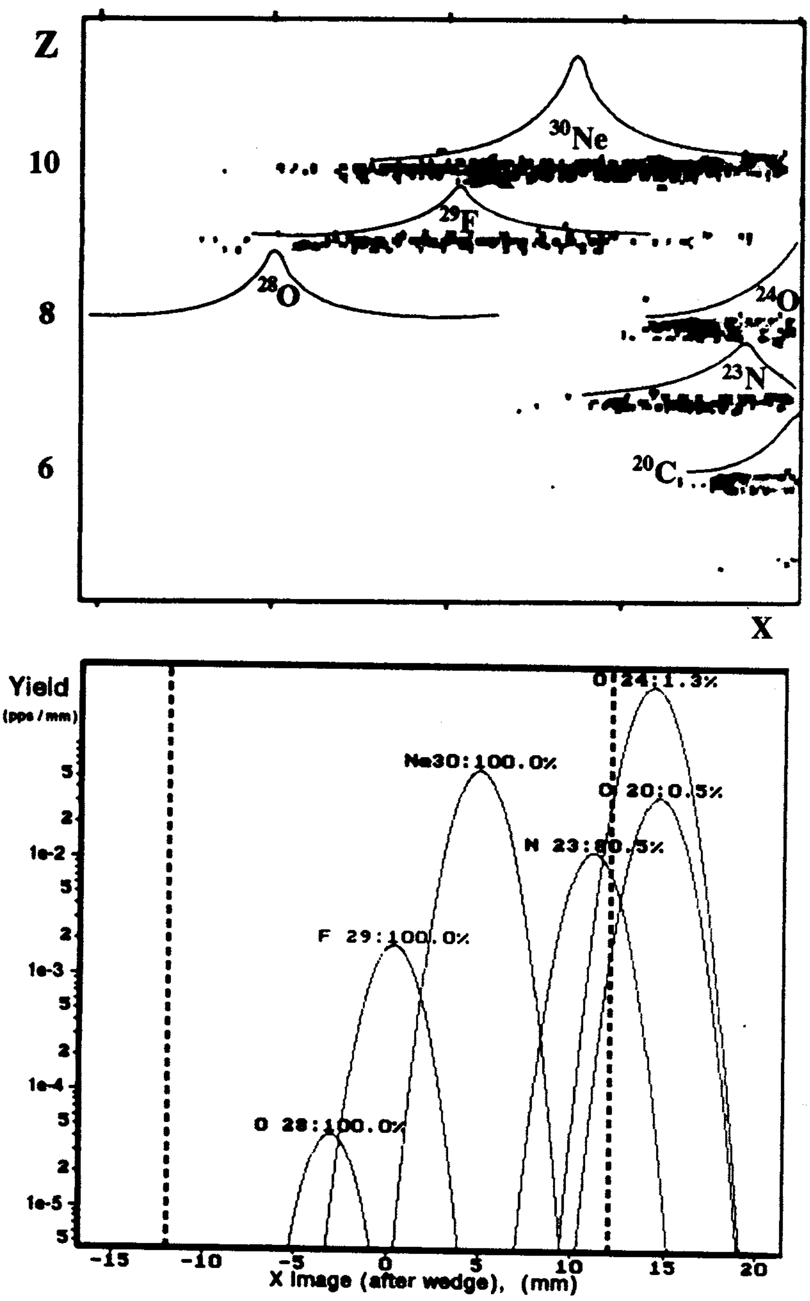
Z
10
8
6
X
^{30}Ne
^{29}F
^{28}O
^{24}O
^{23}N
^{20}C
Yield
(pps/mm)
5
2
1e-2
5
2
1e-3
5
2
1e-4
5
2
1e-5
5
O 24:1.3%
Ne30:100.0%
O 20:0.5%
N 23:80.5%
F 29:100.0%
O 28:100.0%
-15
-10
-5
0
5
10
15
20
X image (after wedge), (mm)

Fig.2

spectrometer. As a result, the production yield of the neutron-rich isotopes in the region of interest has been increased in comparison with that of a ^{48}Ca beam by a factor of 50 [1].

The lay-out of the spectrometer and detector system is given in Figure 1. To obtain the optimal setting of the LISE spectrometer, measurements of the momentum distribution of all isotopes in the region of interest were performed. The D3 telescope was used for analysis of the reaction products after the first dipole. The final analysis was performed using the five-stage semiconductor telescope D4 after the beam has been filtered with the second dipole magnet. The telescope was mounted in a vacuum chamber at the achromatic focal point of LISE and consisted of three planar surface barrier Si detectors with thicknesses 300 μm, 300 μm, 500 μm and two 5 mm thick Si(Li) detectors. Time of flight of the fragments was measured with respect to the radio frequency signal from the cyclotron.

The first detectors allowed independent Z determination, the masses were obtained either from the total energy and the time of flight, or from the magnetic rigidity and the time of flight. The thickness of the telescope was chosen so that fragments in the region of oxygen and neon should stop in the first 5 mm thick Si(Li) detector. A position sensitive Si detector was located in the telescope to perform the spatial analysis of the secondary beam.

The signal from each of the thick Si(Li) detectors was separated into two signals: one for residual energy measurements and another for β-particle detection after the decay of a stopped ion. The data acquisition was triggered by the third detector as well as by β-particle detectors. Each event was writted to tape with time of arriving.

The implantation detectors were surrounded by ^{3}He neutron counters and a 70% HPGe detector for measuring of β*n* and βγ coincidences from the decay and a search for microsecond isomeric states, for instance ^{32}Al^{m}.

To optimize the setting of the LISE spectrometer the momentum distributions of all isotopes in the region of $N = 20$ were carefully measured. The beam line tuning was controlled by the position-sensitive Si-detector. The spectrometer was set to center the ^{28}O in the Si-telescope. For this purpose the position-sensitive detector was inserted before the telescope. On the bi-dimensional spectrum (Figure 2) of the horizontal coordinate versus Z-value is shown. A horizontal projection of this spectra is in good agreement with computer simulation [5] of horizontal images in the focal point (one-dimensional spectra on this figure).

An optimization of the targets (Be, C, Ni, Ta) and measurements of momentum distribution of all fragments with $N = 20$ were undertaken for the best setting of the LISE spectrometer for ^{28}O. It was found that Ta target had produced the highest rates of the neutron-rich nuclei in agreement with earlier experiments.

3. Results

3.1. *Study of the stability of* ^{28}*O*. An example of measured Z versus A/Q matrix is given in Figure 3. A solid line is drawing through nuclei with $N = 20$. This spectrum was

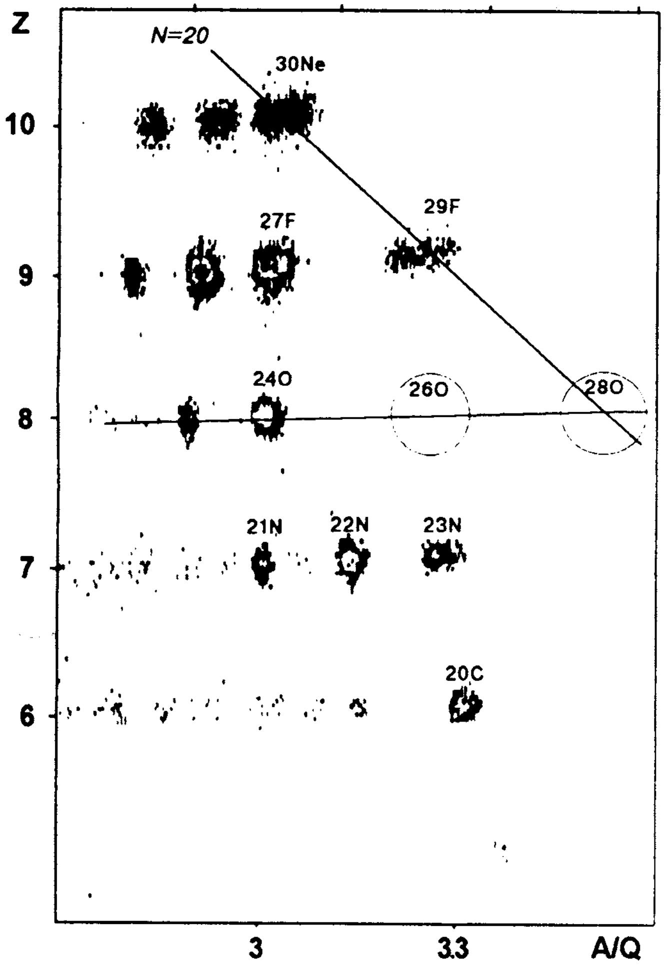

Fig.3

obtained in the 53-hours measurement with an average beam intensity of 800 enA. The heaviest known isotope of ^{29}F is clearly visible, finally it has accumulated 519 events of this nuclide. No events corresponding to ^{26}O and ^{28}O have been obtained.

Figure 4 shows the experimentally measured yields of light exotic nuclei with $N=20$ versus their Z-values. According to the estimation given by the modified formula of Summerer et al. [6] (solid curve) one could expect about 11 events corresponding to ^{28}O. The vertical arrow gives the counting rate for the observation of one event. The preliminary results of this investigation point to the particle instability of ^{28}O isotope as well as for ^{26}O. An upper limit for the cross section of the oxygen isotopes and some information about the stability and properties of nuclei near the closed shells $N=20$ (^{27,29}F, ^{24,26,28}O, ^{30}Ne) could be also extracted from the data.

Thus the present experiment gives first evidence on the particle instability of ^{28}O.

3.2. *β-Decay of Nuclei near Neutron Closure* $N=20$. Our experiment also gives an opportunity to study the β-decay of neutron-rich nuclei with magic neutron number $N=20$. The first measurements of $T_{1/2}$ values for ^{27,29}F, ^{30}Ne are presented. Additionally, the cases of ^{28,29}Ne, ^{30,31}Na are reexamined. The experimental curves of half-life measurement for ^{30}Ne and ^{31}Na are shown in Figure 5. Further data analysis and comparisons of presented data with various theories such as the gross theory [7] or QRPA [8] are in progress. The result of the study of ^{32}Al^{m} isomeric state is given elsewhere [11].

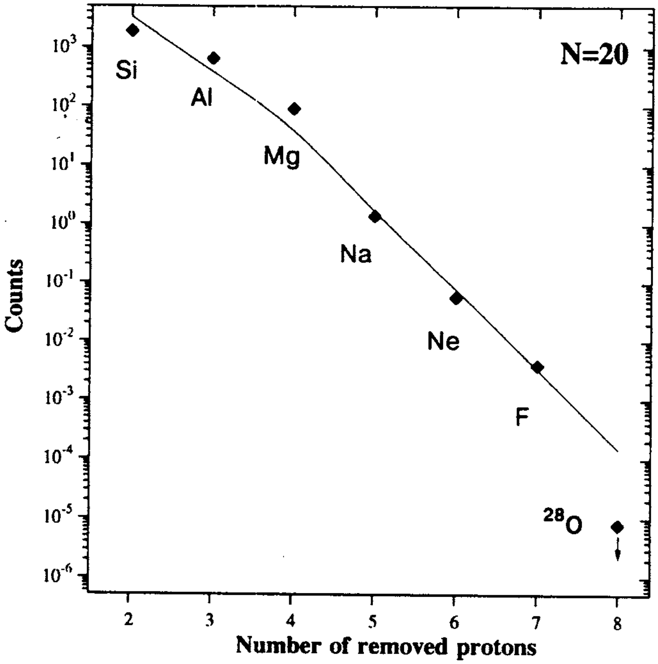
N=20
Si
Al
Mg
Na
Ne
F
^{28}O
Counts
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
2
3
4
5
6
7
8
Number of removed protons

Fig.4

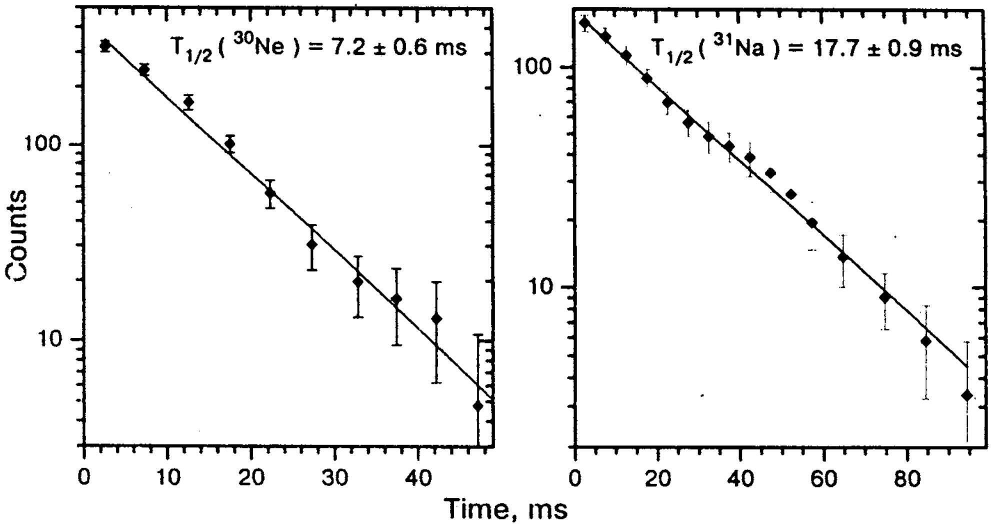
$T_{1/2}$ (^{30}Ne) = 7.2 ± 0.6 ms
$T_{1/2}$ (^{31}Na) = 17.7 ± 0.9 ms
Counts
100
10
0
10
20
30
40
100
10
0
20
40
60
80
Time, ms

Fig.5

Table

A, Z	This work		Reference	
	$T_{1/2}$ [ms]	$\Delta T_{1/2}$	$T_{1/2}$ [ms]	$\Delta T_{1/2}$
^{27}F	5.3	0.9	—	
^{29}F	2.4	0.8	—	
^{28}Ne	21	5	17[9]	4
^{29}Ne	15	3	200[9]	100
^{30}Ne	7	2	—	
^{30}Na	48	5	50[10]	3
^{31}Na	18	2	17[10]	0.4

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Received on July 24, 1996.