Title
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Publication Date
1969

UCRL-18724

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LAWRENCE RADIATION LABORATORY
UNIVERSITY of CALIFORNIA BERKELEY

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UCRL-18724

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Submitted to Phys. Rev. Letters

UCRL-18724
Preprint

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California 94720

AEC Contract No. W-7405-eng-48

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THE NEW NUCLIDES ^{19}Na AND ^{23}Al OBSERVED VIA THE (p,^{6}He) REACTION*

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By employing the ^{24}Mg(p,^{6}He)^{19}Na and ^{28}Si(p,^{6}He)^{23}Al reactions [$d\sigma/d\Omega$ ~100 nb/sr], the mass excesses of ^{19}Na and ^{23}Al are found to be 12.974±0.070 MeV and 6.766±0.080 MeV, respectively [^{12}C = 0]. Since ^{19}Na is determined to be proton-unstable, ^{23}Al should be the lightest, nucleon-stable member of the A = 4n+3, T_Z = -3/2 mass series.

Although the masses and decay schemes of the A = 4n+1 series of T_Z = -3/2 nuclei in the light elements are fairly well established,[1] almost nothing is known about the comparable 4n+3 nuclei. Only the properties of ^{7}B in the latter series are known[2] and only ^{11}N can be additionally studied using existing nuclear reaction techniques and stable targets. We wish herein to report the successful utilization of a new nuclear reaction tool--the (p,^{6}He) reaction--capable of studying in general these 4n+3, T_Z = -3/2 nuclei. The masses of ^{19}Na and ^{23}Al have been measured via the ^{24}Mg(p,^{6}He)^{19}Na and ^{28}Si(p,^{6}He)^{23}Al reactions; these masses agree well with various mass predictions.

Preliminary measurements had shown that the $(p,{}^{6}He)$ reaction producing such 4n+3 nuclei ($Q \sim -37$ MeV) possessed a differential cross section of $\sim$100 nb/sr so that techniques capable of observing such small yields had to be employed. Our basic approach has been described previously[3] so that only the improvements to this system will be detailed here.

A 54.7 MeV proton beam from the Berkeley 88-inch cyclotron was used to bombard thin targets of adenine ($C_5H_5N_5$), ${}^{24}Mg$, and natural silicon. Reactions occurring on the first target provided calibration groups. Figure 1 presents a diagram of one of the two similar counter-telescope and electronic systems which were simultaneously employed; the counter telescopes were placed at 14.1 deg on opposite sides of the beam. Four silicon transmission detectors were used in each telescope. After a fast coincidence among the first three detectors restricted the origin of all allowed events to a single beam burst, two particle identifications (PI) were performed and compared using the signals from the two successive differential-energy-loss detectors--denoted $\Delta E2$ and $\Delta E1$, respectively--and the third "E" detector.[3] Any events traversing the first three counters were rejected by the fourth.

Even with the above electronics, pile-up between events coincident within a single beam burst creates a substantial background ($\sim$50 nb/sr at our typical counting rate) and interferes with or prevents studies of unusual nuclear reactions with cross sections below 100 nb/sr. As a result, time-of-flight (TOF) measurements over the 51 cm flight path between the target and the $\Delta E2$ counter have been added; a resulting mass calculation readily distinguishes true ${}^{6}He$ events from ones arising, for example, from ${}^{3}He$-d pile-up that also appear in the ${}^{6}He$ region of the PI spectrum.[3] In addition, a

sub-nanosecond pile-up-detection system (PUD) on the signal from the ΔE2 counter places a further requirement on each event. These improvements drastically reduce the chance coincidence background and would appear to make feasible the study of highly endothermic nuclear reactions with cross sections as low as 10 nb/sr.

An outline of the added time-of-flight and pile-up detection electronics is also shown in Fig. 1. A timing pulse was obtained from the first (ΔE2) detector via a fast charge-sensitive pre-amplifier (10%-90% rise time of 4 nsec for zero capacitance). For these purposes, signals from this pre-amplifier were used in two ways. First, utilizing the leading edge of the pulse, they provided a start signal for the PUD system time-to-amplitude converter (TAC). Second, by clipping this tail pulse to form a bi-polar pulse of 30 nsec total width, a timing signal was obtained from the zero-crossing point. This latter pulse provided the PUD stop pulse for the TAC (also see below). Any deviation between the normal leading-edge to cross-over time was indicative of pile-up. A resolution of 0.2 nsec for 10 MeV energy loss in the ΔE2 counter was obtainable with a maximum walk of 0.3 nsec for pulses between 1.5 and 10 MeV.

The zero-crossing discriminator output was also used to start another TAC which was stopped by a pulse derived from the arrival time of a beam burst in the fast Faraday cup shown in Fig. 1. Because of the fairly low frequency, sector-focused design of the Berkeley cyclotron--which normally provides a 45 deg phase width (full width at half maximum, FWHM) at 15.9 MHz for the 54.7 MeV proton beam--it was necessary to restrict the phase width to about 6 deg by the use of internal collimators. Even with these collimators, however, it was possible to obtain energy-analyzed beam (0.14%)

with intensities of 2.5 μA. An overall time resolution of 1.4 nsec FWHM was measured.

Events in each system with acceptable identifications were sent via an analogue-to-digital converter, multiplexer system to an on-line PDP-5 computer. Six parameters--ΔE2, ΔE1, E_T (total), PI, TOF, and PUD--were recorded for each event. The computer also stored twenty pulser-simulated ^{6}He events every hour to check both electronic systems and provide an accurate measure of drifts. A monitor counter independently measured the beam energy variation with time. Following the run, each ^{6}He event was analyzed in detail. The PUD was corrected for time walk of the leading edge trigger, and mass information was obtained by calculating $E_T(TOF)^2$; the latter yielded an overall FWHM of 0.6 amu for mass six. "Windows" were set on the PI, PUD, and mass data.

Figure 2 presents final energy spectra from the $^{12}C(p,^6He)^7B$, $^{14}N(p,^6He)^9C$, $^{24}Mg(p,^6He)^{19}Na$, and $^{28}Si(p,^6He)^{23}Al$ reactions. The $^{14}N(p,^6He)^9C$ data were used for calibration purposes. Runs of two to five hour duration on the adenine target were interspersed with longer runs on the other targets to minimize any effects due to beam instability. Only data from System 2 are shown for the adenine and ^{24}Mg targets; the cross-sections for production of ^9C and ^{19}Na are ∿160 nb/sr and ∿120 nb/sr, respectively. Results from both systems are combined for the ^{23}Al data because the target was thinner and the cross-section about a factor of three lower. The spectra appear quite clean after the mass and pile-up restrictions have been applied, with the slightly greater background at the higher energies in the silicon spectrum probably arising from reactions on ^{29}Si and ^{30}Si. If the

adenine data were considered without these mass and pile-up restrictions, for example, the energy region of interest would contain a continuous background of magnitude ∿1/3 the corrected ^{9}C ground-state peak extending from the ^{7}B ground state to ∿18 MeV as well as scattered counts at higher energies. The ground-state transitions for ^{9}C, ^{19}Na, and ^{23}Al all have widths consistent with the expected energy resolution.

The mass-excess of ^{19}Na is determined to be 12.974±0.070 MeV [$^{12}C = 0$]. Since the first excited state in the T = 3/2, $T_Z = \frac{N-Z}{2} = 3/2$ analogue nucleus ^{19}O lies at only 96 keV excitation[4] (the next state is at 1.47 MeV) and since the mechanism of the (p,^{6}He) reaction is uncertain, there is some ambiguity as to whether this mass-excess applies to the ground state and/or to the first excited state of ^{19}Na (the experimental resolution was ∿200 keV). We will take it to be the ground state noting that in either event ^{19}Na is proton unstable; with this assumption, ^{19}Na is unbound to ^{18}Ne+p by 366±70 keV.

The mass-excess of ^{23}Al is determined to be 6.766±0.080 MeV. (The data in Fig. 2 also show the presence of the ^{7}B g.s. from reactions on a ^{12}C target impurity.[5]) Therefore, ^{23}Al is bound to ^{22}Mg+p by 146±82 keV[6] and is nucleon stable. It should be the lightest such isotope in the $T_Z = -3/2$, 4n+3 mass series, is expected to have a half-life <600 msec, and should emit β-delayed protons of ∿200 keV. Only the ground-state of ^{23}Al is likely to be bound, since the first excited state of the analogue nucleus ^{23}Ne lies at 1.02 MeV.[7]

Both of these nuclei complete isobaric quartets;[8,9] their masses have already been predicted by the isobaric multiplet mass equation (IMME), as discussed in Ref. 1, and thus permit yet another check of its

validity. Mass predictions for these nuclei from the IMME,[1] from a systematic study of Coulomb energies in the $1d_{5/2}$ shell,[9] and from the Kelson-Garvey nuclidic mass relationship[10] are given in Table I. Good agreement is to be seen among the various theoretical predictions and between them and experiment for both ^{19}Na and ^{23}Al.

We would like to thank Dr. Jurgen Radeloff for developing the fast pre-amplifier used in these experiments, Dr. Francesco Resmini and Dr. David Clark for their efforts in preparing beams with suitable phase widths, Barbara Cerny for writing the off-line analysis program, and John Bowen and the cyclotron crew for maintaining the beam throughout a long, arduous run.

FOOTNOTES AND REFERENCES

*Work performed under the auspices of the U. S. Atomic Energy Commission.

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2. R. L. McGrath, J. Cerny, and E. Norbeck, Phys. Rev. Letters 19, 1442 (1967).

3. G. W. Butler, J. Cerny, S. W. Cosper, and R. L. McGrath, Phys. Rev. 166, 1096 (1968).

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5. Very tentative evidence for the $^{16}O(p,^{6}He)^{11}N$ reaction on oxygen target impurities was noted; however, this transition could not interfere with the ground-state measurements.

6. The ^{22}Mg mass is taken to be -377±16 keV as a weighted average of the values reported in J. Cerny, S. W. Cosper, G. W. Butler, R. H. Pehl, F. S. Goulding, D. A. Landis, and C. Détraz, Phys. Rev. Letters 16, 469 (1966); P. H. Barker, N. Drysdale, and W. R. Phillips, Proc. Phys. Soc. (London) 91, 587 (1967);
A. B. McDonald and E. G. Adelberger, Bull. Am. Phys. Soc. 12, 1145 (1967); and J. M. Adams, A. Adams, and J. M. Calvert, J. Phys. A (Proc. Phys. Soc.) [2], 1, 549 (1968).

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8. In fact, as is discussed in Refs. 1 and 9, the mass 19 isobaric multiplet for which three members are known comprises the first excited T = 3/2 states (J^{π} = 3/2+) in the T_z = 3/2, 1/2, and -1/2 nuclei.

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Table I. Experimental and predicted mass-excesses (in MeV ± keV).

Nuclide	Mass	Predictions		
		IMME[1]	$d_{5/2}$ shell Coulomb[9]	Kelson-Garvey[10]
^{19}Na	12.974±70	12.90 ±130	12.965±25	12.87
^{23}Al	6.766±80	6.684±98	6.743±25	6.71

FIGURE CAPTIONS

Fig. 1. An abbreviated diagram of the experimental layout and the electronic equipment for one of the two similar detection systems employed in these measurements.

Fig. 2. The energy spectra from the $(p,{}^{6}He)$ reaction on adenine (bottom), ^{24}Mg (middle), and natural silicon (top). Data from detection System 2 only are shown for the first two targets, while data from both systems are combined to produce the $^{28}Si(p,{}^{6}He)^{23}Al$ spectrum. Each block is one count and the block width is 80 keV. Transitions to the first excited state of ^{9}C might be present, distorting the spectrum of the ^{7}B g.s. in the data from the adenine target.

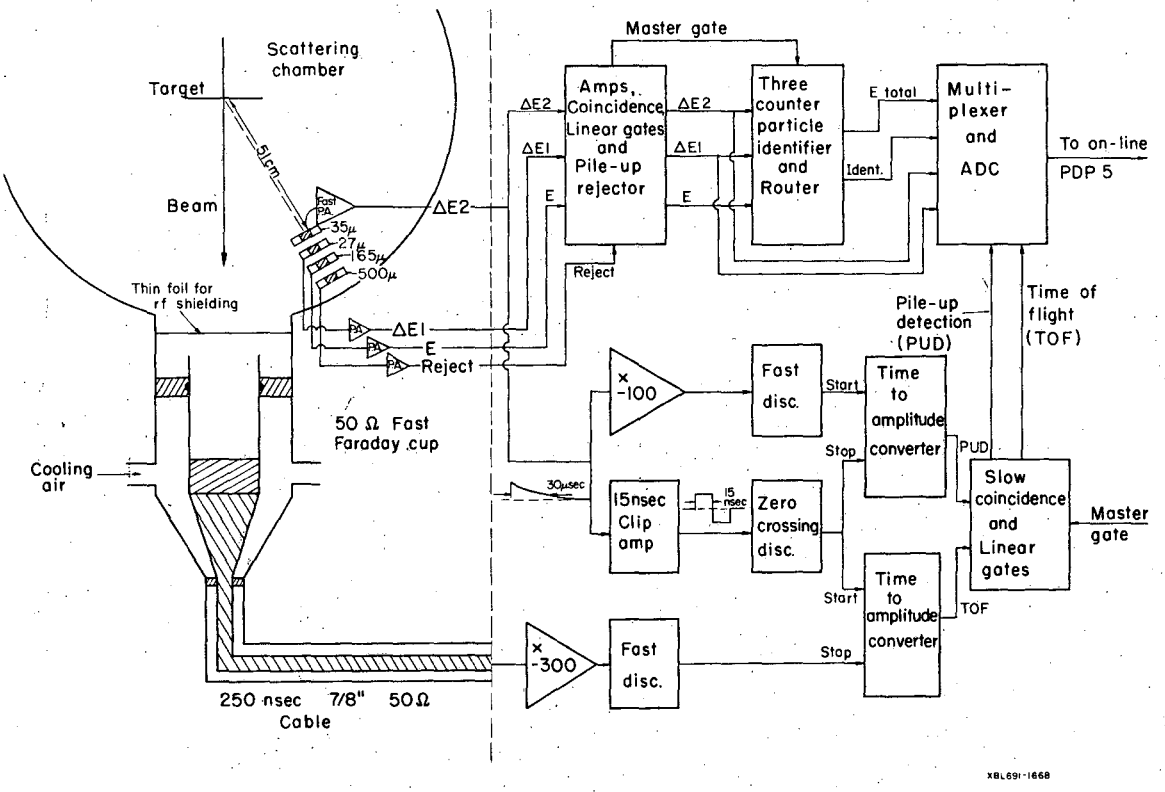
Scattering chamber
Target
5 cm
Beam
Thin foil for rf shielding
35μ
27μ
165μ
500μ
ΔE2
ΔE1
E
Reject
50 Ω Fast Faraday cup
Cooling air
250 nsec 7/8" 50Ω Cable
Master gate
Amps, Coincidence Linear gates and Pile-up rejector
Three counter particle identifier and Router
E total
Ident.
Multi-plexer and ADC
To on-line PDP 5
Time of flight (TOF)
Pile-up detection (PUD)
×-100
Fast disc.
Start
Time to amplitude converter
Stop
PUD
30μsec
15nsec Clip amp
15 nsec
Zero crossing disc.
Slow coincidence and Linear gates
Master gate
TOF
×-300
Fast disc.
Start
Time to amplitude converter
Stop
XBL691-1668

Fig. 1

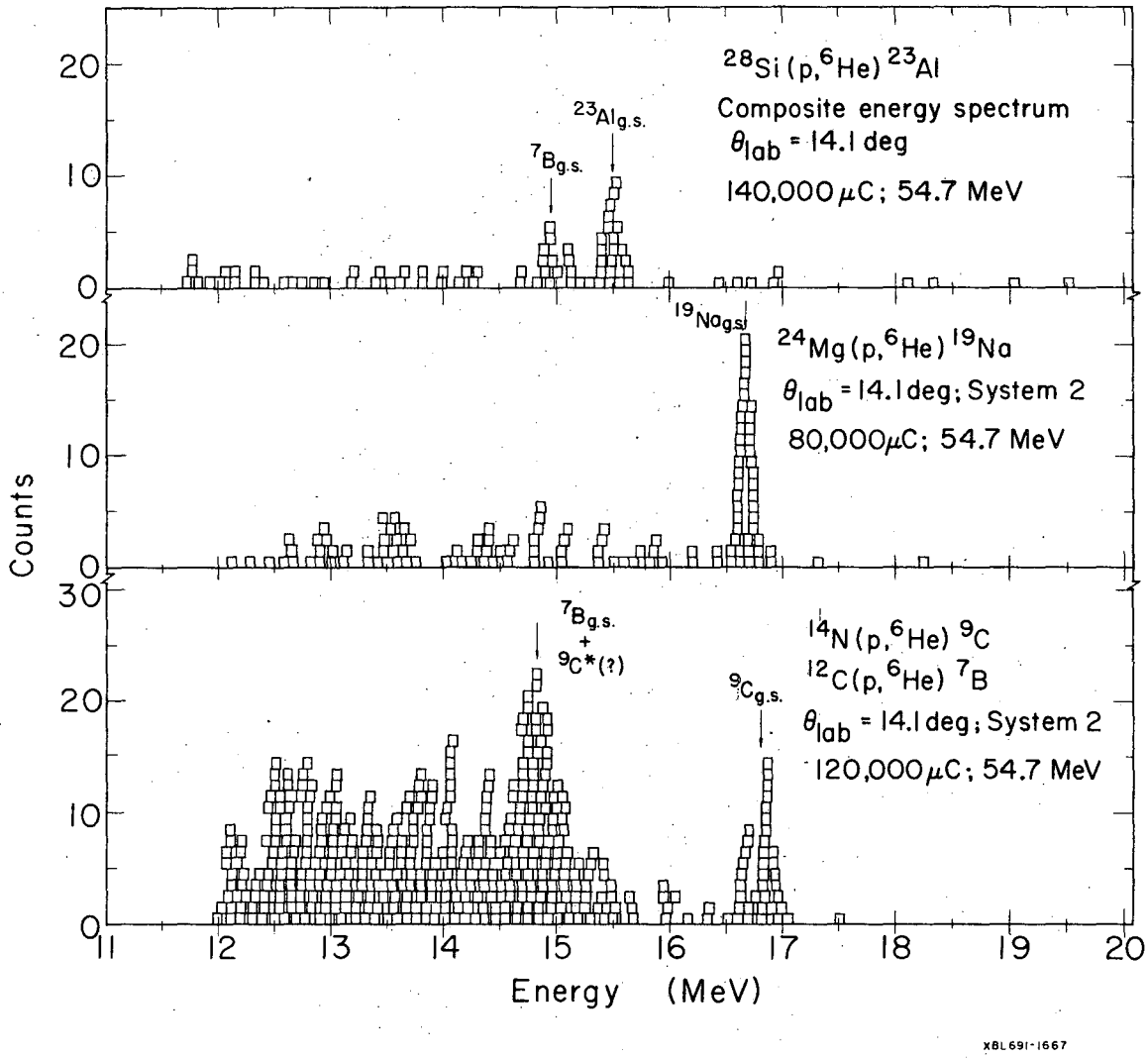
^{28}Si (p,^{6}He) ^{23}Al
Composite energy spectrum
θ_{lab} = 14.1 deg
140,000 μC; 54.7 MeV
^{23}Al$_{g.s.}$
^{7}B$_{g.s.}$
^{19}Na$_{g.s.}$
^{24}Mg (p,^{6}He) ^{19}Na
θ_{lab} = 14.1 deg; System 2
80,000 μC; 54.7 MeV
^{7}B$_{g.s.}$ + ^{9}C*(?)
^{9}C$_{g.s.}$
^{14}N (p,^{6}He) ^{9}C
^{12}C (p,^{6}He) ^{7}B
θ_{lab} = 14.1 deg; System 2
120,000 μC; 54.7 MeV
Counts
Energy (MeV)
X8L691-1667

Fig. 2

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