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OCTUPOLE STATES IN N15 AND O16


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### Authors
Bussiere, Andre
Glendenning, Norman K.
Harvey, Bernard G.
et al.



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OCTUPOLE STATES IN $N^{15}$ AND $O^{16}$

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Andre Bussiere, Norman K. Glendenning, Bernard G. Harvey
Jeannette Mahoney, John R. Meriwether, and Daniel J. Horen

August 1964

# OCTUPOLE STATES IN $N^{15}$ AND $O^{16\dagger}$

Andre Bussiere,* Norman K. Glendenning, Bernard G. Harvey,
Jeannette Mahoney, and John R. Metiwether

Lawrence Radiation Laboratory
University of California
Berkeley, California

and

Daniel J. Horen

Naval Radiological Defense Laboratory
San Francisco, California

Many examples are known of nuclear energy levels whose properties can be described by a moderately weak coupling of an odd particle to a strongly collective vibrational 2+ level of an even-even nuclear core(1). For example, the first three excited states of $Cu^{63}$ are connected to the ground state by E2 transitions whose strengths are nearly equal to each other and to the strength of the transition in $Ni^{62}$ from its first 2+ excited state to the ground state(2).

The 6.134-MeV 3- level of $O^{16}$ has an enhanced E3 transition strength to the ground state(3). In inelastic helium ion scattering from $O^{16}$, the 6.134-MeV level is strongly excited(4), and the angular distribution of the scattered particles is characteristic of an $\ell = 3$ transition.

According to the weak coupling model, there should be two strong octupole levels in $N^{15}$ with spins 5/2+ and 7/2+, formed by coupling a $p_{1/2}$ proton hole to an octupole vibration of the nucleus which is related to the octupole level of $O^{16}$. These two levels should be found at excitations not far from 6.1 MeV. They should have octupole strengths equal to each other and equal to that of the 6.1-MeV level of $O^{16}$. The angular distributions for all three levels

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* NATO Fellow. On leave from Labroatoire de Physique Nucleaire, Orsay (S et O), France.

should have the same shape. $N^{15}$ has 5/2+ levels at 5.276 and 7.16 MeV and a 7/2+ level at 7.57 MeV[5].

The elastic and inelastic scattering by $N^{15}$ and $O^{16}$ of 40.6-MeV helium ions from the Berkeley 224 cm spiral ridge cyclotron was studied with equipment that has been previously described[4]. The target gases were confined in a cell with 0.00025 cm windows of Havar foil.† Pulses from a lithium-drifted silicon detector were recorded in a 1024-channel Nuclear Data analyzer. The energy resolution varied from 100 keV at small angles to about 250 keV at large angles. Spectra taken at an angle of 24° in the laboratory system are shown in fig. 1.

The levels of $N^{15}$ at 5.276 and 7.57 MeV were found to be strongly excited; excitation of the 7.16-MeV level was very weak at all angles. We assume that the 5.304-MeV level of $N^{15}$ (which would be unresolved) does not contribute significantly to the observed peak at 5.8 MeV, because its spin is 1/2 instead of 5/2 and because the $\ell = 1$ transitions in $O^{16}$ and $N^{14}$ are weaker than the $\ell = 3$ transitions. The 6.06-MeV 0+ level of $O^{16}$ is assumed not to contribute significantly to the observed peak at 6.1 MeV. The angular distributions for the 5.276-MeV and 7.57-MeV levels of $N^{15}$ and for the 6.134-MeV level of $O^{16}$ are shown in fig. 2. They are quite similar in shape.

Optical model fits to the elastic angular distributions were made for $N^{15}$ and $O^{16}$ with the computer program GULLEY[6]. The best parameter sets are shown in table 1. The notation in the table is conventional; $r_o$ is the parameter relating the nuclear radius to the mass number A. The helium ion is given a radius $r_\alpha$ so that the optical potential radius is $R = r_o A^{1/3} + r_\alpha$; the

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† Hamilton Watch Co., Lancaster, Pennsylvania.

Table 1

Optical parameters for interaction of 40.6-MeV helium ions with $N^{15}$ and $O^{16}$

| | V (MeV) | W (MeV) | $r_o$(F) | $r_\alpha$(F) | $a_o$(F) | $b_o$(F) |
|---|---|---|---|---|---|---|
| $N^{15}$ | -45.1 | -15.1 | 1.30 | 1.20 | 0.586 | 0.500 |
| $O^{16}$ | -45.7 | -15.2 | 1.30 | 1.20 | 0.606 | 0.500 |

diffuseness parameter of the real potential, V, is $a_o$ and that of the imaginary potential, W, is $b_o$. The Woods-Saxon shape was used for the real and imaginary parts. The experimental and calculated angular distributions are shown in fig. 3.

The parameters of table 1 were used to calculate the inelastic angular distributions for the three $\ell = 3$ levels. The DWBA curves, shown in fig. 2 as dashed lines, were normalized to the experimental cross sections at the $40^o$ maximum. In this way it was found that the octupole deformation parameter $\beta_3$ was equal to 0.31 for each of the three levels. Thus the macroscopic model mentioned in the first paragraph yields a consistent interpretation of the experimental results.

The question that we have not yet examined in detail is whether the microsopic wave functions obtained from the shell model calculations mentioned below also yield a consistent interpretation. Qualitatively it appears that this would be possible. The 6.134-MeV level of $O^{16}$, according to the shell model calculations of Elliott and Flowers(3) has a large amplitude for the configuration $s^4p^{11}d_{5/2}$. The shell model calculations of Halbert and French(7) assign the configuration $s^4p^{10}d_{5/2}$ to the 5.27- and 7.57-MeV levels of $N^{15}$. Thus all three levels can be formed from their respective ground states by promotion of a $p_{1/2}$ nucleon to the $d_{5/2}$ shell. In the 5.27-MeV level it is a proton that is promoted; in the 7.57-MeV level it is a neutron[7]. We have observed similar angular distributions and octupole strengths for excitation of the 5.10-MeV 2- and 5.83-MeV 3- levels of $N^{14}$, both of which can be formed from the ground state by a $1p_{1/2}$ to $1d_{5/2}$ promotion. The form factor for these single particle transitions is

$$F(r) \propto r^3 \exp\left(-\frac{\nu\gamma}{\nu+\gamma} r^2\right)$$

where $\gamma^{-1/2}$ is the range of the nucleon-alpha potential, and $\nu(\sim A^{-1/3}F^{-2})$ is the nuclear size parameter[8]. This function has one maximum at

$$r = \left(\frac{3}{2}\ \frac{\gamma+\nu}{\gamma\nu}\right)^{1/2}$$

or about 3 F. It looks roughly like the form factor, $\partial V/\partial r$ used in the macroscopic description and therefore would yield similar angular distributions. The actual intensity we do not discuss here. In any case the similarity in inelastic helium ion angular distributions and octupole strengths for all these levels shows that their wave functions are very closely related to each other.

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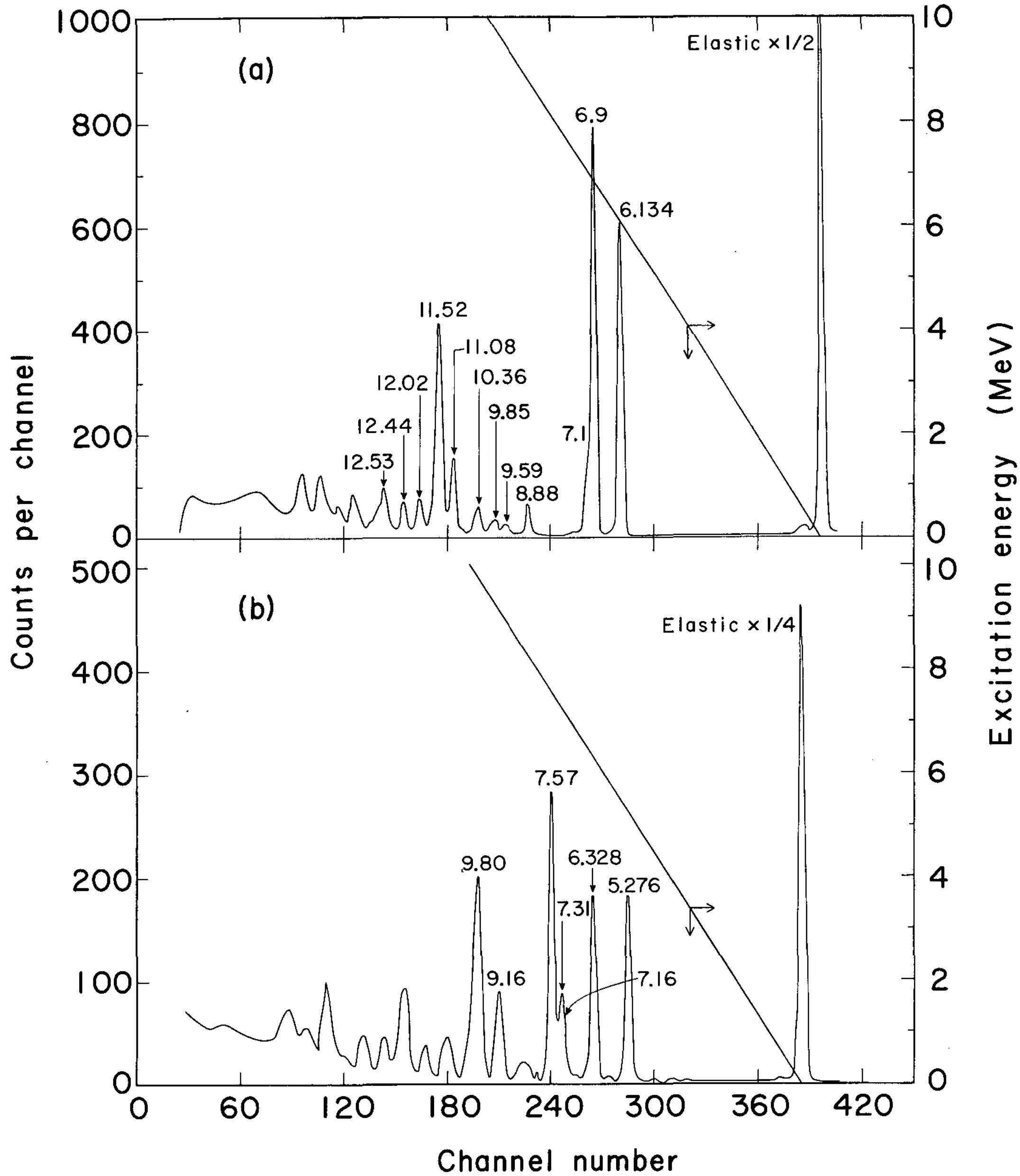
## Figure Captions

Fig. 1. Energy spectra of 40.6-MeV helium ions scattered from $O^{16}$ (upper) and $N^{15}$ (lower) at $24^{\circ}$ (lab).

Fig. 2. Experimental and calculated angular distributions for elastic scatterin of 40.6-MeV helium ions from $N^{15}$ and $O^{16}$. The solid line represents the theoretical curve.

Fig. 3. Angular distributions for 5.27- and 7.57-MeV levels of $N^{15}$ and the 6.134-MeV level of $O^{16}$. The dashed curves are DWBA calculations for $\ell = 3$, normalized to the experimental curves at the $40^{\circ}$ maximum.



1000
800
600
400
200
0
500
400
300
200
100
0
10
8
6
4
2
0
(a)
Elastic ×1/2
6.9
6.134
11.52
11.08
12.02
10.36
12.44
9.85
12.53
7.1
9.59
8.88
(b)
Elastic ×1/4
7.57
9.80
6.328
5.276
7.31
9.16
7.16
0
60
120
180
240
300
360
420
Counts per channel
Excitation energy (MeV)
Channel number


Fig. 1

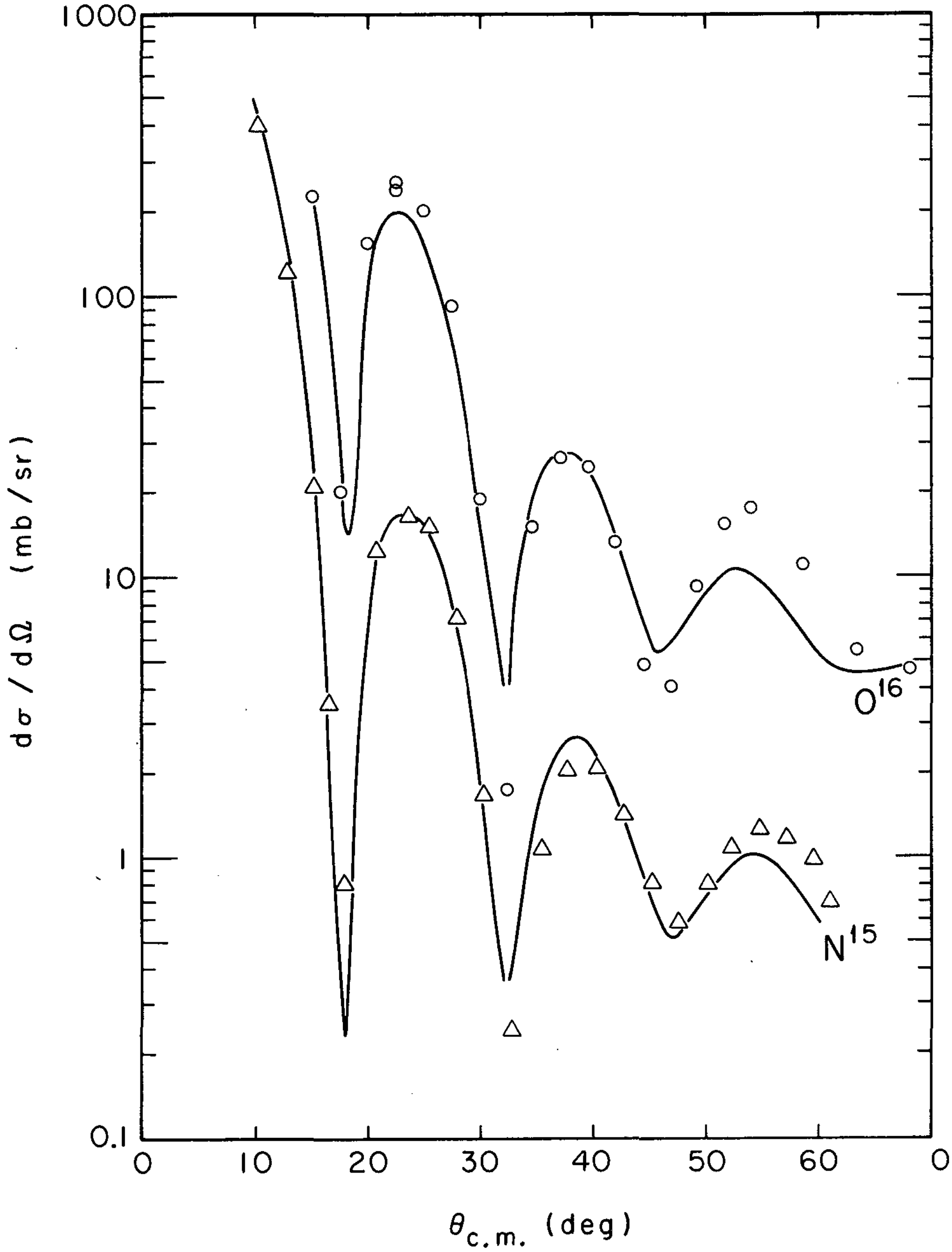



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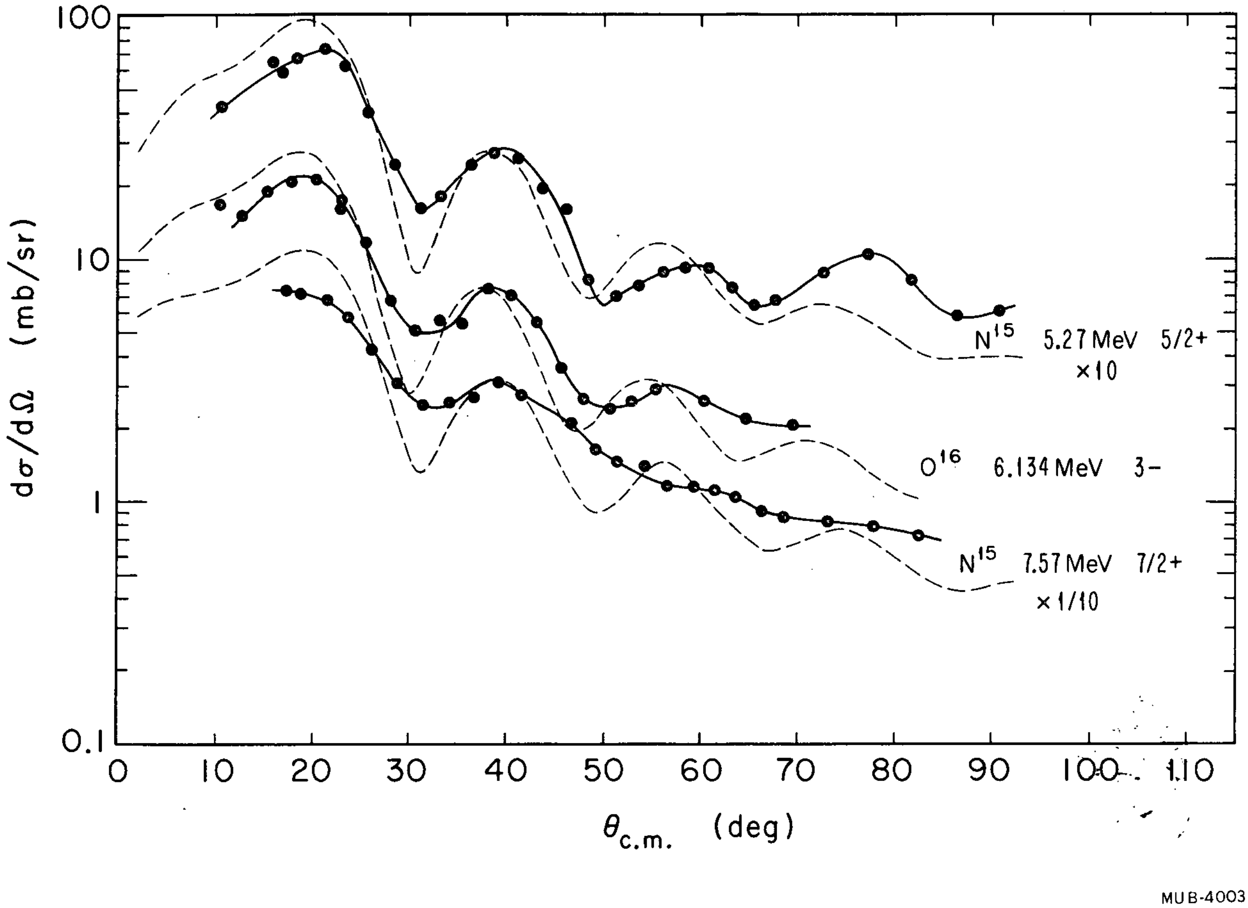
Fig. 2



100
10
1
0.1
dσ/dΩ (mb/sr)
0
10
20
30
40
50
60
70
80
90
100
110
θc.m. (deg)
N15 5.27 MeV 5/2+
×10
O16 6.134 MeV 3−
N15 7.57 MeV 7/2+
×1/10
MUB-4003


Fig. 3

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