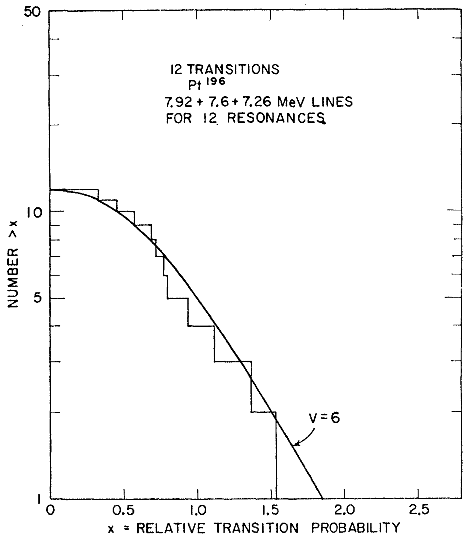

FIG. 11. The cumulative size distribution for the sum of the three high-energy transitions in Pt^{196}. The curve is for $\nu=6$.

of assigning $J=1$ to the level at 155 eV. The best value of ν in this case is lowered to 1.7. We conclude that the number of degrees of freedom describing the distribution in size of radiative transitions in Pt^{196} is quite small, lying between 1 and 2. The best fit to the observed distribution in strengths, however, is obtained with an exponential ($\nu=2$) rather than with a Porter-Thomas ($\nu=1$) distribution.

It is also of interest to examine the distribution of the sum of these three transitions. The narrowness of the distributions[3,8,12] of transitions to the unresolved low-lying states in U^{239} and W^{184} may be explained by postulating that the individual transitions are not independent. In Pt^{196} we find that the sum distribution has $\nu=6.2_{-2.5}^{+2.8}$ (this is decreased to $\nu\cong 5$ with the inclusion of $J=1$ for the 155-eV level). The fit to $\nu=6$ is shown in Fig. 11. For the combination of independent chi-squared distributions, the number of degrees of freedom is additive. We conclude, therefore, that in Pt^{196} we find no evidence for correlations between the transitions to the 0^+ ground state and the 2^+ excited states at 354 and 686 keV.

ACKNOWLEDGMENTS

The authors wish to acknowledge the valuable assistance of the technical staff of the Atomic Energy of Canada, Limited, Chalk River. We are indebted to A. J. Ferguson of Chalk River for allowing us to use his unfolding program.

PHYSICAL REVIEW VOLUME 127, NUMBER 5 SEPTEMBER 1, 1962

Direct Observation of Resonant p-Wave Neutron Capture*

H. E. JACKSON
Argonne National Laboratory, Argonne, Illinois

(Received March 5, 1962; revised manuscript received May 18, 1962)

The capture γ-ray spectra of resonances in Mo^{95} below 700 eV have been studied in an effort to make unambiguous identification of individual resonances resulting from capture of p-wave neutrons. A discussion is presented of the features of the experimental spectra which can be used to identify the parity of the compound state formed by neutron capture. In particular, a resonance in Mo^{95} at 107 eV with an anomalously strong ground-state transition is observed. The strength of this line is inconsistent with s-wave capture. The resonance must be due to capture of a p-wave neutron; the transition must be $E1$; and the capture state must be 1^-.

I. INTRODUCTION

THE study of the interactions of p-wave neutrons has received strong emphasis in neutron spectroscopy recently, particularly in the mass region around $A=90$ where the optical model predicts a giant resonance in the p-wave neutron strength function $\langle\Gamma_n^1\rangle/D$. The presence of p-wave neutron resonances in this region has been established by studying the distribution of reduced resonance widths $g\Gamma_n^0$ over some restricted range of energies below 1 keV,[1,2] and noting a number of levels, presumably p-wave resonances, with small $g\Gamma_n^0$ in excess of the amount predicted by a Porter-Thomas distribution. However, because of the character of the distribution, a unique separation of resonances of opposite parity is not possible. To date, no resonance below 20 keV has been specifically identified as being due to p-wave capture.

There are two reasons why the unambiguous identification of p-wave capture is of particular interest. First, although there has been conjecture as to the dependence of resonance parameters (particularly the total radiation width[3]) on the parity of the capture state, no experimental observations have been made for lack of known p-wave resonances. The second

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

[1] A. Saplakoglu, L. M. Bollinger, and R. E. Coté, Phys. Rev. **109**, 1258 (1958).

[2] J. S. Desjardin, J. L. Rosen, W. W. Havens, Jr., and J. Rainwater, Phys. Rev. **120**, 2214 (1960).

[3] A. G. W. Cameron, Can. J. Phys. **35**, 666 (1957).

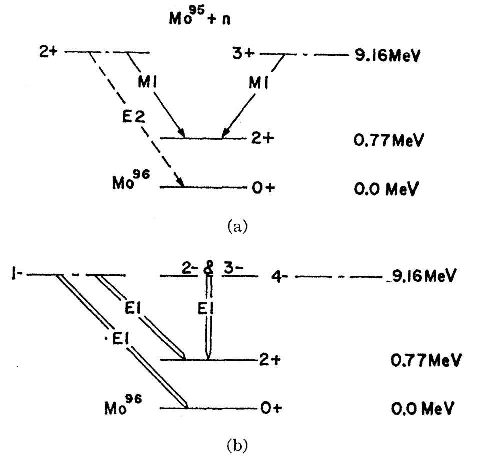

FIG. 1. Primary radiative transitions to the ground state and first excited state of Mo^{96} following *s*-wave capture (a) and *p*-wave capture (b) in Mo^{95}.

reason concerns the discrepancy which currently exists in the shape of the peak of the strength function as determined from average total cross sections[4] and from average capture cross sections.[5] The total cross-section results give a broad peak in the strength function. The observed width implies an amount of spin orbit coupling in the nuclear potential[6] which is twice the amount normally[6a] used in shell-model calculations. The capture data give a sharper peak. However, the analysis of capture data is based on the assumption that the total radiation width is independent of the parity as well as the spin of the capture state. One of the purposes of this experiment is to isolate resonances in which this assumption can be tested.

II. METHOD OF IDENTIFICATION

In an effort to make unambiguous identifications, capture gamma-ray spectra were examined for resonances below 700 eV in Mo^{95}. This nuclide was chosen because (1) it is located near the peak of the *p*-wave strength function; (2) its high neutron binding energy prevents severe background difficulties; (3) its spin and parity ($\frac{5}{2}^+$) give rise to capture states (for *s*-wave capture) which cannot reach the ground state of Mo^{96} by $E1$ or $M1$ radiation; and (4) Mo^{96} possesses a simple level scheme characteristic of even-even nuclides. A preliminary account of these data has already been reported.[7]

The spin and parity of the compound-nucleus states which can be formed by *s*-wave neutron capture are 2^+ and 3^+, while for *p*-wave capture they are 1^-, 2^-, 3^-, and 4^-. Figure 1 shows the spins and parities of the capture states together with the lowest order radiation to the ground state and the first excited state, which will occur following *s*-wave and *p*-wave capture. To date, there is no experimental evidence for collective enhancement of primary $E2$ transitions which could occur from 2^+ capture states to the ground state of Mo^{96}. Furthermore, results of a survey of strong resonances in Zr^{91}, Mo^{95}, Ru^{99}, and Pd^{105} made during the course of this experiment indicate that within the sensitivity of the present experiment they are not observable. Consequently, $E2$ radiation can be neglected in this analysis.

A transition to the ground state of Mo^{96} can have observable strength only if it goes from a 1^- state and, therefore, the presence of an observable ground-state transition in a resonance-capture gamma-ray spectrum indicates formation of a 1^- compound state by *p*-wave neutron capture. The strengths of primary transitions to the first excited state of Mo^{96} depend upon the parity of the capture state only to the extent that the strength of $M1$ radiation is less than $E1$ radiation. Although on the average $M1$ transitions are much weaker than $E1$ transitions, there will be large fluctuations in partial radiation widths[8] from resonance to resonance. In fact, because of these fluctuations, as indicated in the recent compilation of Bartholomew,[9] the strengths of measured $E1$ and $M1$ transitions show a considerable overlap in the region of atomic masses of interest here. Consequently, the presence of a primary transition to the first excited state is not conclusive evidence. Only transitions with strengths much too strong to be consistent with $M1$ radiation give an unambiguous indication of *p*-wave capture.

III. EXPERIMENTAL PROCEDURE

The experimental arrangement is shown in Fig. 2. The Argonne fast chopper was used to select neutrons of known energy by measuring their time of flight. The time-of-flight resolution of the system was about 0.080

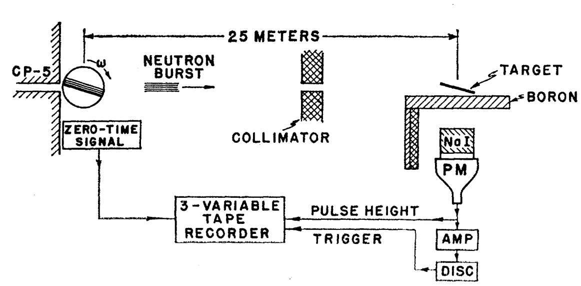

FIG. 2. Schematic diagram of the experimental arrangement.

[4] R. H. Tabony, K. K. Seth, E. G. Bilpuch, and H. W. Newson, Bull. Am. Phys. Soc. 7, 23 (1962).

[5] J. H. Gibbons, R. L. Macklin, P. D. Miller, and J. H. Neiler, Phys. Rev. 122, 182 (1961).

[6] T. K. Krueger and B. Margolis, Nuclear Phys. 28, 578 (1961).

[6a] *Note added in proof*. A more recent calculation of the *p*-wave strength function by Buck and Perey [see Phys. Rev. Letters 8, 444 (1962)] indicates that the total cross-section data is consistent with the normal amount of spin-orbit coupling if the effects of nuclear collective motion are included.

[7] H. E. Jackson, Bull. Am. Phys. Soc. 7, 289 (1962).

[8] L. M. Bollinger, R. E. Coté, and T. J. Kennett, Phys. Rev. Letters 3, 376 (1956).

[9] G. A. Bartholomew, Ann. Rev. Nuclear Sci. 11, 259 (1961).

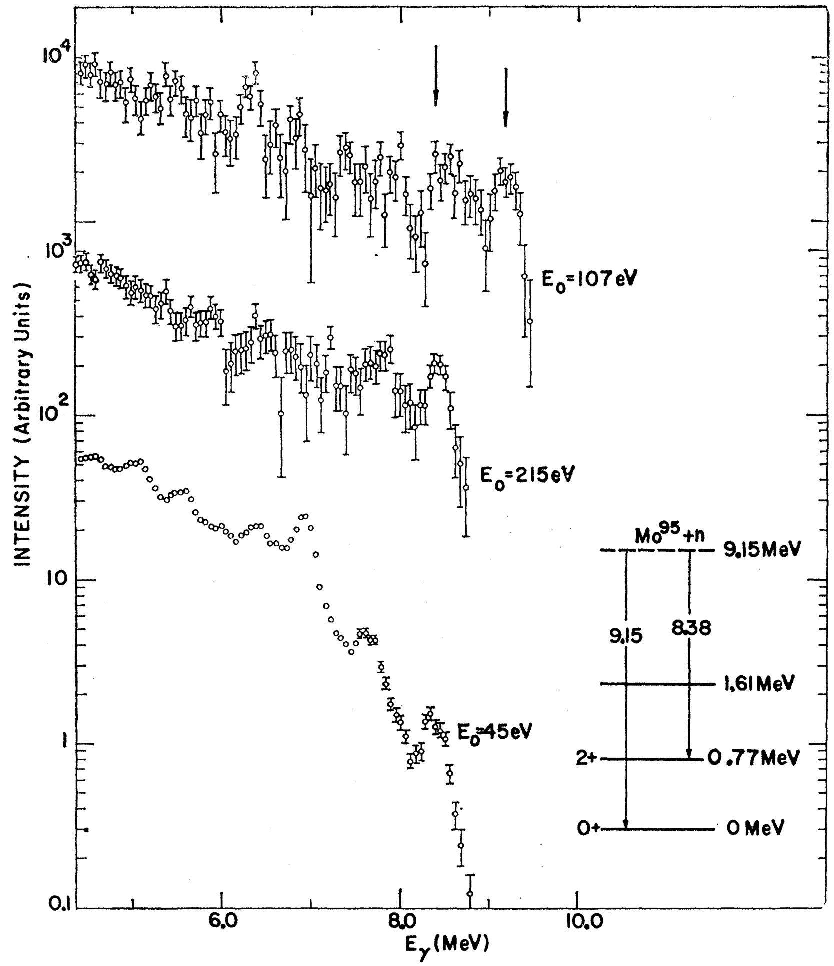

FIG. 3. Gamma-ray spectra from resonance capture in Mo^{95}. The arrows indicate the positions of the transitions which are shown in the level scheme for Mo^{96} (lower right).

μsec/m. Capture γ rays were observed in a NaI(Tl) crystal 8 in. diam and 6 in. deep. Each event, consisting of a pulse height and time of flight, was recorded and analyzed by means of the Argonne 3-variable magnetic-tape recording system.[10] Use of the 3-variable analyzer in a manner previously reported[10] allowed us to study resonances that were only partially resolved in the time-of-flight spectra, and recent Argonne transmission data were used to obtain precise resonance energies.

In order to make quantitative statements about the strengths of the observed lines, the absolute intensities of the 8.38- and 9.16-MeV lines in resonances at 45, 107, 160, and 215 eV were measured. The procedure was as follows: (1) All resonances were normalized to the same number of captures as observed for the 45-eV resonance by requiring that the total number of counts in the low-energy region of the capture spectra (below 3 MeV) be the same; (2) The published parameters for the resonance at 45 eV and the observed neutron flux were used to calculate the total number of captures in the 45-eV resonance; (3) The relative strengths of the transitions in the four resonances were determined by a least-squares fitting of the experimental spectra to the response function of the NaI(Tl) crystal; and (4) The efficiency of the system for detection of a high-energy γ ray was calibrated by observation of a standard line[11] at 7.92 MeV in the 11.8-eV resonance in Pt^{195}. The intensity of the line was taken to be 0.045 photon per capture. From these data the absolute intensities of the transitions of interest, in units of photons per capture, were calculated.

IV. RESULTS

The resonance-capture spectra for resonances at 45, 107, and 215 eV are shown in Fig. 3. The 45-eV resonance, because of its large $g\Gamma_n^0$, is assumed to be an s-wave resonance; and, as expected, the capture spectrum shows no ground-state transition and only a weak one to the 2^+ state. However, the resonance at 107 eV can be identified unambiguously as a p wave. The

[10] H. E. Jackson and L. M. Bollinger, Phys. Rev. **124**, 1142 (1961).

[11] R. T. Carpenter (private communication, 1961).

TABLE I. Parameters for resonances in Mo^{95}.

Resonance energy (eV)	Absolute intensity (photons per capture) $E_\gamma=8.38$ MeV	$E_\gamma=9.15$ MeV	k_{M1} (MeV^{-3}) $E_\gamma=8.38$ MeV	$g\Gamma_n^0$ (10^{-3} eV)
45	0.006 ± 0.001	0.0000 ± 0.0005	0.08×10^{-1}	$13.1\ \pm0.8$[a]
107	0.018 ± 0.004	$0.039\ \pm0.008$	...	0.010 ± 0.006[b]
160	0.013 ± 0.003	$0.000\ \pm0.001$	0.18×10^{-1}	$0.55\ \pm0.10$[a]
215	0.049 ± 0.010	$0.000\ \pm0.002$	0.69×10^{-1}	$0.08\ \pm0.04$[b]

[a] Brookhaven National Laboratory Report BNL-325 (U. S. Government Printing Office, Washington, D. C., 1955).
[b] J. P. Marion (private communication). These values were calculated by assuming s-wave capture.

strong ground-state transition in the capture spectrum indicates capture forming a 1^- compound state. The presence of a strong 8.38-MeV line in the spectrum of the 215-eV resonance suggests that it may also be a p-wave resonance.

Table I contains a quantitative comparison of the absolute intensities of the 8.38- and 9.16-MeV lines corresponding to the resonances shown in Fig. 3 and also to the resonance at 160 eV. In addition, it shows the reduced width[12] k_{M1} for the 8.38-MeV line which was calculated by assuming $M1$ radiation. The resonance at 215 eV has an intensity of 0.05 photon per capture, which gives a reduced width of 0.069 MeV^{-3}, which is twice the largest value tabulated by Bartholomew[9] for nuclei with $A>75$. In the light of the possibility of fluctuations, only a probable assignment of negative parity can be made for this case; but the small value of $g\Gamma_n^0$ for the resonance is consistent with this conclusion.

These results indicate that capture spectra offer a promising means of identifying a large group of p-wave resonances, but it should be kept in mind that in this experiment no 4^- states formed in p-wave capture will be isolated by the methods outlined since spin considerations do not permit primary transitions to the region of interest. Nevertheless, in the light of the present interest in p-wave capture, a high-resolution measurement of the parameters of the resonances at 107 and 215 eV will be of considerable value in increasing our understanding of the importance of the parity of the compound state in neutron capture.

[12] The reduced width for $M1$ radiation is defined here as $k_{M1}=a\Gamma_\gamma/DE_\gamma^3$, where Γ_γ is the total radiation width of the resonance, a is the intensity of the transition, D is the spacing of states of the same spin and parity as the initial state, and E_γ is the γ-ray energy. This quantity, which is assumed to be independent of E_γ, facilitates comparison of the intensities of transitions in neighboring nuclei (see reference 9).

ACKNOWLEDGMENT

The author is indebted to Dr. L. M. Bollinger for discussions and encouragement concerning the experiment and valuable suggestions for preparing this report.

PHYSICAL REVIEW VOLUME 127, NUMBER 5 SEPTEMBER 1, 1962

A New Isotope, Pt^{201}

J. FACETTI, E. TRABAL, R. MCCLIN, AND S. TORRES
Puerto Rico Nuclear Center, Nuclear Science and Technology Division, Mayagüez, Puerto Rico*
(Received April 16, 1962)

A new Pt isotope was found by irradiation of mercury compounds with neutrons in the PRNC nuclear reactor. The Pt activities were separated from the mixture by precipitations as the K_2PtCl_6. In this fraction, a 2.3 ± 0.2 min activity could be attributed to Pt^{201}, produced by $Hg^{204}(n,\alpha)Pt^{201}$. The Pt^{201} decays to the well-known Au^{201}. The genetic relationship was established by chemical separations of the daughter nuclide. The Au^{201} was identified by its half-life and its gamma-ray energy. Further, the growth of the gamma ray of 0.55 MeV, corresponding to Au^{201}, was measured in the isolated Pt fraction, with a 4-in.$\times$4-in. NaI(Tl) scintillator coupled to a 512-channel pulse-height analyzer. The values of Butement and Shillito for Au^{201} were confirmed.

INTRODUCTION

When mercury is bombarded with neutrons, the formation of various isotopes of Pt can be expected; among them, the isotope with mass number 201 formed by the reaction $Hg^{204}(n,\alpha)Pt^{201}$.

To this isotope, Cameron[1] has assigned a β-disintegration energy of $\sim$1.7 MeV. Using a method published by Moszkowski,[2] the half-life has been estimated to be within the interval: 20 sec$\leqslant T_{1/2}\leqslant$20 min.

* Operated by the University of Puerto Rico for the Atomic Energy Commission.

[1] A. G. Cameron, Chalk River Laboratory Report CRP-690, 1957 (unpublished).
[2] S. A. Moszkowski, Phys. Rev. 82, 35 (1951).