4+ Excited State in Osmium-188*

P. S. FISHER AND R. A. NAUMANN
Palmer Physical Laboratory and Frick Chemical Laboratory, Princeton University, Princeton, New Jersey
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Transitions in Os^{188} excited by the K capture from 41-hour Ir^{188} have been observed at 155, 324, 478, 633, 641, 827, 832, 1205, 1320, 1440, 1560, 1700, 1940, 2055, and 2190 kev. The new transition at 324 kev is in prompt coincidence with the 155-kev transition to the ground state, and an $E2$ assignment has been made from conversion electron and gamma-ray intensities. It is proposed that this is the transition between a 4+ rotational level in Os^{188} at 479 kev and the 2+ state at 155 kev.

THE low-lying nuclear excited states in the even isotopes of osmium have been attributed to collective motion of "rotational" and "vibrational" character.[1] The lowest lying excited states of osmium-188 populated from rhenium-188 beta decay occur 155 and 633 kev above the ground state; both these states are reported to have spin and parity 2+.[2] To search for evidence of the third 4+ member of a "rotational" level sequence in osmium-188 containing the ground state and the state at 155 kev, it appeared worth while to examine the osmium-188 gamma transitions accompanying the electron capture decay of 41-hour iridium-188. The pure sources of iridium-188 used in these investigations were obtained from the decay of 10.3-day platinum-188; the latter activity being prepared by 50-Mev proton bombardment of iridium in the Nevis synchrocyclotron.[3] Both equilibrium platinum 188—iridium 188 and pure iridium-188 sources have been examined with scintillation and conversion electron spectrometers.

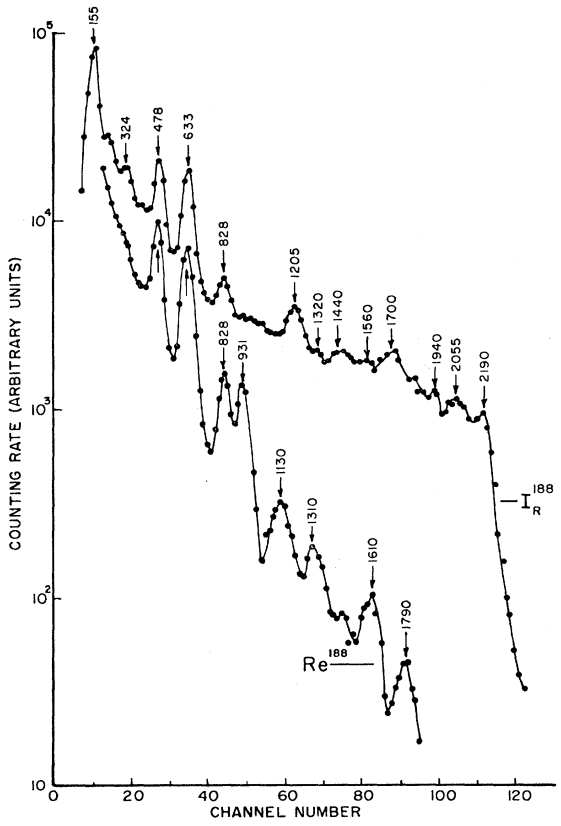

FIG. 1. Gamma-ray spectrum of iridium-188 (upper curve); gamma-ray spectrum of rhenium-188 (lower curve).

A scintillation spectrum of the gamma radiations from a source of pure iridium-188 taken with a $1\frac{1}{2}$-in. by 1-in. sodium iodide scintillation spectrometer is shown in Fig. 1, where it is compared with the gamma spectrum of a source of rhenium-188 taken with the same apparatus. It is evident that in the case of iridium-188 decay the majority of the transitions occur to excited states of osmium-188 and also that many of the transitions observed are different from those occurring in rhenium-188 decay. In particular, gamma rays were observed at 155, 324, 478, 633, 641, 827, 832, 1205, 1320, 1440, 1560, 1700, 1940, 2055, and 2190 kev. The majority of these gamma rays have been observed independently by Diamond and Hollander.[4] The gamma rays coincident with the 155-kev transition were examined with a coincidence circuit of

TABLE I. Measured relative intensities of the gamma-ray quanta and conversion electrons for transitions in osmium-188 following electron capture by iridium-188. The gamma-ray intensities are quoted relative to 100 155-kev quanta. The electron intensities are quoted relative to 100 K-conversion electrons for the 155-kev transition.

Gamma-ray energy	Intensity		
	Gamma rays	K electrons	L electrons
Os K	270		
155	100	100	$L_{II}=91$ $L_{III}=68$
324	8.0	1.3	0.6
478	55	5.7	1.5
633	93	3.8	1.0
641		0.18	0.21
827	19.2	0.32	0.20
832		0.25	
1205	40	0.95	0.20

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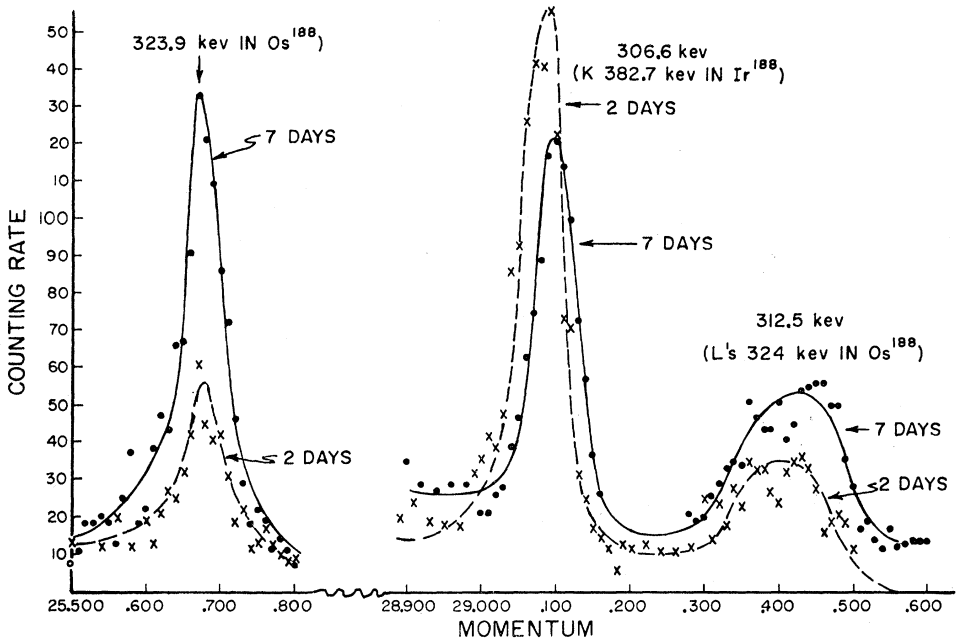

FIG. 2. K and L conversion lines of 324-kev transition in osmium-188; the K line of the 383-kev transition in iridium-188 is also shown.

resolving time $2\tau = 3\times10^{-8}$ sec. Both the new 324-kev transition and the 478-kev transition appeared in the coincident spectrum in the same intensity ratio as in the singles spectrum. Since the 478-kev transition occurs between the levels at 633 kev and 155 kev, the 324-kev transition must also feed the 155-kev level directly.

Successive conversion electron spectra from an initially pure source of platinum-188 were measured in a double-focusing electron spectrometer having a resolution of 0.25%. Conversion lines due to transitions in osmium-188 were identified by an initial increase in intensity due to the growth of iridium-188. The K and L conversion groups of the 324-kev transition are shown in Fig. 2 together with the K conversion line of a 380-kev transition in iridium-188.

The intensities of the gamma and electron lines relative to the 155-kev transition are shown in Table I. Conversion coefficients have been obtained from these relative intensities by assuming that the 155-kev transition has pure $E2$ character. Previous investigations of this transition excited by the beta decay of rhenium-188 indicate this assignment.[2] Normalization of the intensities was carried out to both the theoretical L_{II} and L_{III} conversion coefficients for the 155-kev $E2$ transition; this procedure being preferred to normalization to the single theoretical K conversion coefficient since it was felt that the measured L conversion electron intensity for the 155-kev transition was more reliable than the measured intensity of the lower energy K conversion electrons. The observed coefficients are compared in Table II with the theoretical K coefficients interpolated from the results of Sliv and Band[5] and the theoretical L coefficients of Rose[6]; multipole assignments deduced are shown in the last column.

The existence of an $E2$ 324-kev transition coincident with the 155-kev transition is attributed to the popu-

TABLE II. Conversion coefficients of transitions in osmium-188 following electron capture by iridium-188. Each value is to be multiplied by the power of 10 indicated in parentheses. The experimental conversion coefficients were computed from the intensities shown in Table I which were normalized to yield the theoretical L_{II} and L_{III} conversion coefficients for the 155-kev transition (values shown in curly braces). Had the normalization been carried out to yield the theoretical K conversion coefficients, the experimental values of the remaining coefficients would be increased by the factor $0.32/0.24=4/3$.

Gamma energy	Experimental		Theoretical								Mulitpole order
			K conversion				L conversion				
	K shell	L shell	α_1	α_2	α_3	β_1	α_1	α_2	α_3	β_1	
155	2.4(−1)	$\{L_{II}=2.2(-1)\}$ $\{L_{III}=1.6(-1)\}$	1.0(−1)	3.2(−1)	8.8(−1)	1.3(0)	L_{II} 3.0(−3) L_{III} 3.0(−3)	{2.2(−1)} {1.6(−1)}	4.5(0) 1.4(0)	2.2(−2) 2.0(−3)	$E2$
324	3.9(−2)	1.8(−2)	1.7(−2)	5.0(−2)	1.4(−1)	1.8(−1)	2.6(−3)	2.1(−2)	1.5(−1)	3.5(−2)	$E2$
478	2.5(−2)	6.5(−3)	1.2(−2)	3.3(−2)	8.5(−2)	1.2(−1)	1.0(−3)	4.9(−3)	2.4(−2)	9.0(−3)	$E2+M1$
633	9.8(−3)	2.6(−3)	4.1(−3)	1.0(−2)	2.5(−2)	3.2(−2)	5.6(−4)	2.1(−3)	8.1(−3)	4.3(−3)	$E2$
1205	5.7(−3)	1.2(−3)	1.2(−3)	2.9(−3)	6.3(−3)	6.3(−3)	1.6(−4)	4.5(−4)	1.0(−3)	8.5(−4)	$M1$?

[5] L. A. Sliv and I. M. Band, Leningrad Physico-Technical Institute Report, 1956 [translation: Report 57 ICCKl, issued by Physics Department, University of Illinois, Urbana, Illinois (unpublished)].
[6] M. E. Rose (privately circulated tables).

lation of a 4+ state in osmium-188 at 479 kev. The ratios of the energies of the 4+ and 2+ levels of the three osmium isotopes 186, 188, 190 then show consistent behavior with values 3.19, 3.10, 2.91, respectively.

Since the highest osmium-188 level populated by iridium-188 decay has energy equal to or greater than 2.19 Mev, this figure may be used as a minimum value of the electron capture energy. Assuming a partial half-life of 4 days for electron capture by iridium-188 to the 2+ state at 155 kev, a log *ft* value of 7.2 is computed consistent with a first-forbidden transition. The absence of a strong electron capture branch to the ground state of osmium-188 together with the excitation of a 4+ state suggests a spin of 2− or 3− for iridium-188.

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Coulomb Exchange Energy from Shell-Model Wave Functions*

N. V. V. J. SWAMY,† *The Florida State University, Tallahassee, Florida*

AND

A. E. S. GREEN,‡ *Los Alamos Scientific Laboratory, Los Alamos, New Mexico*

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The Coulomb direct and exchange energies of several light nuclei have been calculated by using harmonic-oscillator wave functions and approximate wave functions for a realistic diffuse-boundary potential. The Z dependence of the total exchange energy is expressed in terms of a convenient parameter c. Calculations show that for very low Z this parameter is appreciably smaller than a prior estimate by Bethe and Bacher based upon the statistical model, but that it rapidly reaches their value $5(3/16\pi)^{\frac{2}{3}}$ for $Z \gtrsim 10$.

1. INTRODUCTION

A NUMBER of studies[1–7] have been made which bear upon the differences of the Coulomb direct and exchange energies in mirror nuclei. These studies have been of particular interest in recent years in connection with Coulomb radii determinations. However, other than the original statistical calculations of von Weizsäcker[8] and Bethe and Bacher,[9] and a recent similar calculation by Cameron,[10] there has been little study of the total Coulomb exchange energy. Our interest in this quantity stems from difficulties[10,11] encountered with the mass formula at light nuclei. These difficulties arise when one attempts to improve the simple Bethe-Weizsäcker formula by inclusion of the Coulomb exchange energy as estimated using the statistical model. In view of the impressive successes of the independent-particle model of the nucleus, it was considered worthwhile to estimate the total Coulomb exchange-energy term on the basis of the independent-particle model of the nucleus.

2. CALCULATION WITH INDEPENDENT-PARTICLE MODEL WAVE FUNCTIONS

In the Hartree approximation, the Coulomb energy of a nucleus with Z protons is, after summing over spin coordinates,

$$E_c=\tfrac{1}{2}\sum_{j=1}^{Z}\sum_{i=1}^{Z}\int\int|\psi_i(\mathbf{r}_1)|^2\frac{e^2}{r_{12}}|\psi_j(\mathbf{r}_2)|^2d\mathbf{r}_1d\mathbf{r}_2$$
$$-\tfrac{1}{4}\sum_{i=1}^{Z}\sum_{j=1}^{Z}\int\int\psi_i^*(\mathbf{r}_1)\psi_j(\mathbf{r}_1)$$
$$\times\frac{e^2}{r_{12}}\psi_i(\mathbf{r}_2)\psi_j^*(\mathbf{r}_2)d\mathbf{r}_1d\mathbf{r}_2, \quad (1)$$

where

$$r_{12}=|\mathbf{r}_1-\mathbf{r}_2|.$$

The $\psi_i(\mathbf{r})$ are the central-field proton wave functions. The first term is the Coulomb direct energy and the second term is the "exchange energy" arising from the antisymmetrization of the ground-state wave functions needed to satisfy the exclusion principle. To obtain a result comparable with the statistical calculation of Bethe and Bacher, we have here followed their procedure of adding "self-energy" terms to the direct term and subtracting the corresponding terms from the ex-

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