Gamma Rays and Transition Multipolarities in the Decay of 15.8-h ^{186}Ir†

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Energies and intensities of 127 γ rays emitted in the decay of 15.8-h ^{186}Ir have been determined with high-resolution Ge(Li) detectors. When combined with conversion-electron intensities of previous workers, γ-ray intensities led to conversion coefficients and assignment of multipole orders to most transitions. Differences among existing level schemes of ^{186}Os were largely resolved. Previously established ground-state and $K=2$ γ-vibrational bands were strongly supported. A tentative suggestion of a $K=4$ band, which had been proposed earlier, was also supported. A number of new levels have been proposed to accommodate the observed high-energy transitions, some of which have $E0$ components.

I. INTRODUCTION

THE radiations emitted in the decay of 15.8-h ^{186}Ir are known to constitute a very complex spectrum. Most of the information about ^{186}Os levels has been obtained from high-resolution conversion-electron spectrometry by Emery *et al.*[1] at Brookhaven National Laboratory, and by Harmatz and Handley[2] at Oak Ridge National Laboratory.

Earlier work[3] with low-resolution NaI(Tl) detectors revealed clearly only the most intense transitions in the ground-state rotational band and a few other transitions. Until high-resolution Ge(Li) detectors became available, direct inspection of the complex γ-ray spectrum was not feasible. In this work we report a detailed analysis of the high resolution γ-ray spectrum of ^{186}Ir decay. Our primary goals were to supplement the electron results and to help resolve differences between the level schemes proposed for ^{186}Os by the two electron-spectrometry groups. In a number of instances transitions were proposed on the basis of observed electron lines originating in shells only indirectly identifiable; the search for the γ radiations corresponding to such electron lines is clearly useful.

If both electron intensities and γ-ray intensities are known, conversion coefficients can be calculated and multipole orders can be assigned to many of the transitions observed. This type of information should also be helpful in establishing a level scheme.

Levels in ^{186}Os have also been studied by observation of reaction γ rays in the ^{184}W$(\alpha, 2n)^{186}$Os and ^{186}W$(\alpha, 4n)^{186}$Os reactions.[4,5] These studies and the two electron studies show that the 2^+, 4^+, and 6^+ levels of the ground-state rotational band are at 137.15, 433.91, and 868.70 keV. We adopt the scheme of labeling levels in Ref. 1 and identify these as B, C, and D, respectively. The electron-spectrometry groups place the 8^+ member E at 1453.12 keV while the reaction studies suggest it to be at 1420 keV. In a recent semiempirical treatment of rotational levels,[6] 1420 keV was judged to be more consistent with that observed for other deformed nuclei.

The electron-spectrometry groups agree also in the placing of a 2^+ γ-vibrational band head (F) at 767.38 keV. The higher members of the band, the 3^+, 4^+, 5^+, 6^+, and 7^+ levels (identified as G, H, I, J, and K, respectively), are at 910.33, 1070.25, 1275.30, 1490.93, and 1752.28 keV. Other levels proposed in Refs. 1 and 2 are at 1461.09 (Q), 2056.38 (T), and 2081.21 (U) keV. Each group has proposed a number of other levels which do not coincide with the proposals of the other. This is summarized in Fig. 1, which has been adapted from the Nuclear Data Sheets.[3]

In this study, which was carried out in part at Brookhaven National Laboratory and in part at Clark University, it is found that most of the transitions reported in Ref. 1, and indirectly the levels there proposed, are confirmed by the γ-ray data. Many of the transitions

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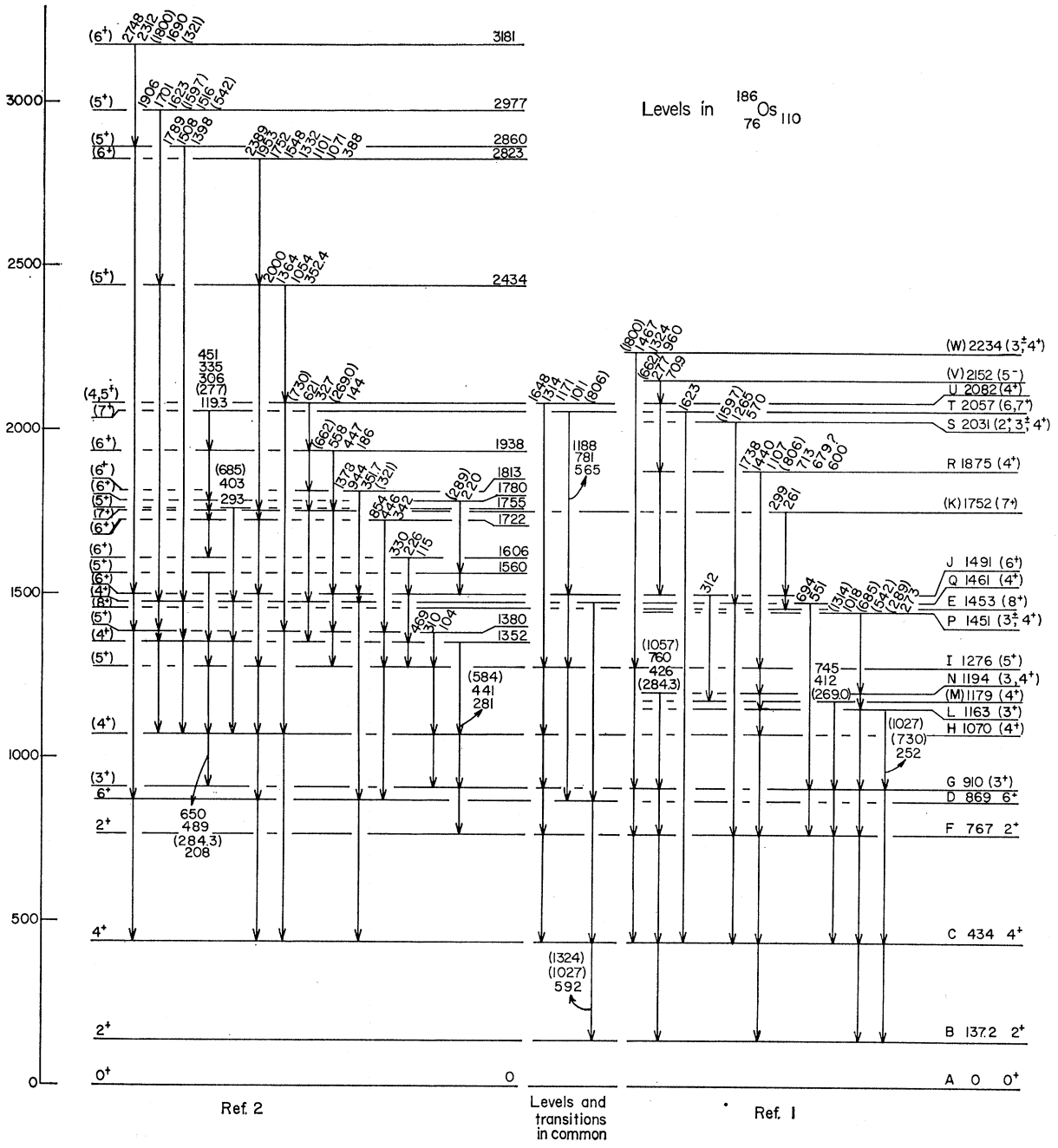

FIG. 1. Partial level schemes of ^{186}Os proposed in Refs. 1 and 2, as adapted from Ref. 3. References 1 and 2 agree on levels constituting the ground-state band (levels A–E) and the γ-vibrational band through the 6^+ state (levels F–J). They agree also on the expected intraband and interband transitions; these transitions have been omitted here (see Fig. 3). Other levels (Q, T, and U) and transitions common to the two level schemes are shown in the center region. Additional levels and transitions proposed in Ref. 1 are on the right; those in Ref. 2 are on the left. All energies are in keV. Transition energies in parentheses denote transitions placed more than once. Letters in parentheses indicate levels whose existence is less certain. The unconventional level-scheme representation used here, which has been taken from Ref. 3, is perhaps best explained by examples: References 1 and 2 agree that there is a level at 2057 keV (designated T in Ref. 1) and that deexciting transitions of energy 565, 781, and 1188 keV feed levels J, I, and D, respectively. Spin-parity assignments are 6, 7^+ in Ref. 1 and 7^+ in Ref. 2. In Ref. 1, the 1623-keV transition is placed between levels T and C while in Ref. 2 other transitions deexciting T are of energy 119.3, 277, 306, 335, and 451 keV. In the case of the 5^+ level at 2434 keV, reported in Ref. 2, deexciting transitions of 352.4, 1054, 1364, and 2000 keV are assigned, terminating at levels with energy 2082, 1380, 1070, and 434 keV, respectively.

observed by Harmatz and Handley could not be found in the γ-ray spectrum, thus weakening the case for some of the levels proposed by them. A partial level scheme combining the best features of the two proposed level scheme is presented.

The fitting of all transitions into a new and complete level scheme for ^{186}Os has proved to be beyond the scope of this work. Energy sums and multipolarities are inadequate to remove the many ambiguities which arise in combining nearly 130 transitions. High-resolution Ge(Li) coincidence spectrometry is necessary to resolve the problems. Such experiments are now in progress and will be reported in a subsequent communication.[7]

II. EXPERIMENTAL METHODS

A. Source Preparation and Chemical Separation

Targets were prepared from metallic rhenium powder, enriched to 96.7% in ^{185}Re, which was obtained from the Isotopes Development Center, Oak Ridge National Laboratory. A slurry of the metal powder in an acetone-water mixture was placed on 5-mil aluminum foil. The powder adhered firmly when the solvent mixture was evaporated. Targets were typically 10 mg/cm^2 in thickness. Aluminum foil (1 mil) was used to cover the target; aluminum absorbers were added when the beam energy was to be degraded.

After irradiation with ^{3}He or ^{4}He ions, the metal powder was washed into a centrifuge tube with water. The rhenium was dissolved in concentrated HNO_3, iridium carrier (2–5 mg) was added in the form of $IrCl_4$ in HCl solution, and the solution was taken to dryness. In this process, osmium activities were distilled off as OsO_4. The residue was taken up in water, 1 gm of sodium formate was added in solid form, and the solution was heated in a water bath. In about 20 min, iridium was reduced to the metal and precipitated.

The precipitate was centrifuged, washed, and usually mounted on a polyethylene foil. In some cases, the precipitate was left in the tip of a 10-ml centrifuge cone and the cone taped to a sample card.

B. Irradiations

The reactions used to produce ^{186}Ir sources were ^{185}Re(α, $3n$)^{186}Ir and ^{185}Re(^{3}He, $2n$)^{186}Ir. Excitation functions for the (α, xn) and (^{3}He, xn) reactions are sufficiently broad that inevitably ^{185}Ir and ^{187}Ir were also present in the sources. Further, ^{188}Ir was always produced by the (α, $3n$) or (^{3}He, $2n$) reaction on the ^{187}Re present in the target as well as by the ^{185}Re(α, n) reaction.

The similarity in half-life[3] among 14.0-h ^{185}Ir, 15.8-h ^{186}Ir, and 10.5-h ^{187}Ir made it difficult to identify impurity lines in the ^{186}Ir spectrum from decay alone. Lines from 41-h ^{188}Ir were easily distinguished, however. Irradiations were made at several bombarding energies to favor the production of one nuclide over another. With 30-MeV ^{4}He ions, ^{187}Ir and ^{186}Ir are the chief products; at about 36 MeV, ^{186}Ir is favored; at 40 MeV, the maximum ^{4}He energy available on the accelerators used, some ^{185}Ir is produced but not enough to distinguish its lines clearly from those of ^{186}Ir. With 21-MeV ^{3}He ions, ^{185}Ir and ^{186}Ir are produced in comparable yield. The discussion of impurity lines and their identification is continued in Sec. III D.

At Brookhaven ^{4}He irradiations were carried out at 28, 34, and 40 MeV on the 60-in. cyclotron. Beam currents were typically 1 μA and irradiation times 2 h. For the experiments based at Clark University, irradiations were made on the Yale University heavy-ion accelerator with 21-MeV ^{3}He ions and 40-MeV ^{4}He ions. Beam currents were about 0.3 μA and irradiation times 3–8 h.

C. Detector and Electronics

Planar-drifted Ge(Li) detectors were used at both Brookhaven and Clark. The BNL detector had a surface area of 6 cm^2 and a drifted depth of 6 mm while the Clark detector was 5.5 cm^2×9 mm. At Brookhaven, a low-noise vacuum-tube preamplifier was used; the Clark equipment included a field-effect transistor preamplifier. Conventional pulse-shaping amplifiers and biased amplifiers were used with 512- or 1024-channel analyzers.

The energy resolution at low counting rates, expressed as full-width at half-maximum, was 2.1 and 5.0 keV for a pulser and at 1332 keV, respectively, for the BNL detector. At Clark, the corresponding values were 2.2 and 3.6 keV. Counting rates were kept low ($<10^3$ counts/sec) to maintain good resolution. Source geometry was changed from time to time during a measurement to compensate for intensity loss from radioactive decay. For several spectra of the high-energy region, the use of a lead absorber (2 gm/cm^2), which attenuated Os x rays and low-energy γ rays, permitted relatively close geometry without high total counting rates.

Counting times ranged from 24 to 90 h. Experimental linewidths in such spectra were never more than 0.3 keV broader than that of a standard line at the same energy which had been counted for an hour or less.

The energy calibration was made in part with standard sources obtained from the International Atomic Energy Agency (IAEA) and with ^{56}Co and ^{228}Th. The IAEA sources included ^{241}Am, ^{57}Co, ^{203}Hg, ^{22}Na, ^{137}Cs, ^{54}Mn, ^{88}Y, and ^{60}Co. Because the energies of many of the ^{186}Ir radiations are very well known from high-resolution conversion-electron spectrometry,[1] the strong ^{186}Ir lines were used in general as internal energy stand-

[7] Preliminary coincidence results have recently been reported by K. J. Hofstetter and T. T. Sugihara, Bull. Am. Phys. Soc. **13**, 1468 (1968).

TABLE I. Gamma-ray energies, intensities, and multipolarities in the decay of ^{186}Ir. Column 1 gives transition energies from the conversion-electron data of Ref. 1 if an error is quoted in column 2; the remaining entries are from Ref. 2. Gamma-ray energies in column 3 are marked with an asterisk if that transition has been used as an internal-energy standard. Energies in parentheses [e.g., (102)] denote γ rays which appeared to be present but which could not be clearly resolved. The estimated error in γ-ray energy is in column 4. The intensities in column 5 are on an arbitrary scale described in the text. In columns 5–9, an entry such as $94\pm10-1$ is to be read $(94\pm10)\times10^{-1}$. The experimental conversion coefficients in column 6 are for K conversion unless otherwise indicated in column 11 as L_1, L_2, etc., in which case such a conversion coefficient is recorded. Calculated conversion coefficients in columns 7–9 are from Ref. 10. Most probable multipole orders are assigned in column 10; see text for further details. The entries in column 11 such as 185, 187, 188, ^{185}Os, or $D2364$ mean that the contribution from ^{185}Ir, ^{187}Ir, ^{188}Ir, ^{185}Os, or the double-escape peak from the 2364-keV line has been subtracted.

Transition energy (keV) E_e	ΔE_e	E_γ	ΔE_γ	γ-ray intensity	Conversion coefficient Expt	$E1$	$E2$	$M1$	Order	Remarks
70.88	0.20								$E1$	L_1
87.19	0.20			$<3-2$	$>100-2$	$2.0-2$	$250-2$	$1.1-2$	($E2$)	L_3
102.12	0.20	(102)		$\lesssim6-2$	$\gtrsim40-2$	$1.1-2$	$130-2$	$6.5-2$	$E2$	L_2
119.36	0.20	120.0	0.6	$46\pm5-3$	$13\pm2-1$	$2.2-1$	$5.8-1$	$28-1$	$E2/M1$	
137.15	0.03	137.2*	0.6	$94\pm10-1$	$49\pm6-2$	$16-2$	$43-2$	$190-2$	$E2$	
143.00	0.20	143.5	0.6	$26\pm13-2$	$40\pm20-2$	$13-2$	$38-2$	$170-2$	$E2/M1$	
160.02	0.20	160.2	0.6	$16\pm5-2$	$16\pm7-2$	$9.7-2$	$30-2$	$120-2$	not $M1$	185
163.4 163.6		163.3	0.6	$13\pm4-2$	$13\pm5-2$	$9.3-2$	$29-2$	$110-2$	$E1$	185
167.05	0.20	167.2	1.3	$52\pm16-3$	$25\pm10-2$	$8.8-2$	$27-2$	$107-2$	$E2$	
		198.9	0.6	$36\pm7-3$		$5.7-2$	$17-2$	$66-2$	($E1$)	
208.0		208.0	0.6	$18\pm3-2$	$28\pm8-3$	$1.1-3$	$36-3$	$0.9-3$	$E2$	L_3
219.96	0.15	219.9	0.6	$66\pm16-3$	$26\pm7-2$	$4.4-2$	$13-2$	$50-2$	$E2/M1$	
224.13	0.16					$4.2-2$	$13-2$	$48-2$	not $E2$	
234.48	0.26	232.6	0.8	$37\pm8-3$	$9\pm3-2$	$3.8-2$	$11-2$	$44-2$	$E2$	^{185}Os
252.45	0.15	251.9	0.6	$70\pm26-3$	$13\pm5-2$	$3.1-2$	$9.1-2$	$35-2$	$E2$	
261.23	0.14	(261)		$\lesssim5-2$	$\gtrsim16-2$	$2.8-2$	$8.3-2$	$31-2$	($M1$)	
268.98	0.14	269.0	0.6	$48\pm16-3$	$25\pm7-2$	$2.7-2$	$7.8-2$	$29-2$	$M1$	
272.80	0.16	(273)		$\lesssim15-2$	$\gtrsim3-2$	$2.6-2$	$7.5-2$	$28-2$		
276.54	0.14	276.6	0.6	$48\pm7-2$	$29\pm7-3$	$25-3$	$73-3$	$280-3$	$E1$	
284.26	0.15	284.6	0.6	$12\pm4-2$	$7\pm3-2$	$2.3-2$	$6.8-2$	$25-2$	$E2$	
292.98	0.20			$<10-2$	$>5-2$	$2.2-2$	$6.4-2$	$24-2$		
296.75	0.06	296.8*	0.6	$17\pm2\ 0$	$58\pm7-3$	$21-3$	$61-3$	$230-3$	$E2$	
302.86	0.11	302.8	0.6	$12\pm5-2$	$8\pm4-2$	$2.0-2$	$5.7-2$	$21-2$	$E2$	
305.59	0.11	(306)		$\lesssim8-2$	$\gtrsim9-2$	$1.9-2$	$5.6-2$	$21-2$	not $E1$	
309.64	0.12	309.9	0.6	$13\pm3-2$	$14\pm4-2$	$1.9-2$	$5.4-2$	$20-2$	$M1/E2$	
311.85	0.15	(312)		$\lesssim5-2$	$\gtrsim18-2$	$1.9-2$	$5.3-2$	$19-2$	($M1$)	185
321.16	0.19					$1.7-2$	$4.8-2$	$18-2$	$E2$	K/L_2
326.55	0.21			$<2-2$	$>15-2$	$1.7-2$	$4.7-2$	$17-2$	($M1$)	
330.22	0.17	330.2	0.6	$6\pm2-2$	$5\pm2-2$	$1.6-2$	$4.6-2$	$16-2$	$E2$	
334.02	0.17	334.0	0.6	$5\pm2-2$	$10\pm5-2$	$1.5-2$	$4.4-2$	$16-2$	$E2/M1$	
342.50	0.12			$<4-2$	$>10-2$	$1.5-2$	$4.2-2$	$15-2$	not $E1$	
351.73	0.13	351.4	0.9	$52\pm19-2$	$33\pm12-3$	$14-3$	$39-3$	$140-3$	$E2$	
364.90	0.18	364.8	0.6	$22\pm5-2$	$27\pm9-3$	$13-3$	$36-3$	$130-3$	$E2$	
387.93	0.18			$<4-2$	$>10-2$	$1.1-2$	$3.1-2$	$11-2$	($M1$)	
403.29	0.16	(403)		$\lesssim4-2$	$\gtrsim10-2$	$1.0-2$	$2.8-2$	$10-2$	($M1$)	188

TABLE I. (*Continued*).

Transition energy (keV) E_e	ΔE_e	E_γ	ΔE_γ	γ-ray intensity	Conversion coefficient Expt	$E1$	$E2$	$M1$	Order	Remarks
406.55	0.18	406.6	0.6	5±2 −2	4±2 −2	1.0 −2	2.8 −2	9.5 −2	$E2$	185
420.74	0.14	420.5	0.6	76±12 −2	24±5 −3	9.2 −3	25 −3	86 −3	$E2$	185
434.78	0.08	434.8*	0.6	82±10 −1	23±3 −3	8.9 −3	24 −3	80 −3	$E2$	
441.50	0.17	441.4	0.6	41±8 −2	27±6 −3	8.6 −3	23 −3	77 −3	$E2$	185
446.3 447.0		447.0	0.6	12±4 −2	5±2 −2	0.8 −2	2.2 −2	7.5 −2	$E2/M1$	
451.36	0.64	451.6	0.6	32±8 −3	>10 −3	8.2 −3	22 −3	72 −3	($E1$)	188
463.5		463.5	0.6	5±2 −2	6±3 −2	0.8 −2	2.0 −2	6.8 −2	$M1/E2$	
476.90	0.21	476.7	1.3	12±4 −2	32±13 −3	7.3 −3	19 −3	62 −3	$E2/M1$	188
489.2		489.6	0.6	2±1 −1	20±10 −3	7.0 −3	18 −3	59 −3	$E2$	185
515.50	0.26	514.8	0.6	16±4 −2	15±4 −3	6.3 −3	16 −3	52 −3	$E2$	185
542.17	0.38	(542)		$\lesssim$8 −2	$\gtrsim$20 −3	5.9 −3	14 −3	45 −3	not E1	187
551.43	0.30	550.9	1.5	14±3 −2	10±3 −3	5.5 −3	14 −3	43 −3	$E2$	185
557.99	0.42	558.0	0.6	26±4 −2	4±1 −3	5.4 −3	14 −3	42 −3	$E1$	
		561.3	0.6	15±2 −2		5.3 −3	13 −3	41 −3	($E1$)	
565.42	0.36	565.6	0.6	26±4 −2	12±3 −3	5.2 −3	13 −3	40 −3	$E2$	
570.31	0.49	570.5	0.6	25±4 −2	28±6 −4	52 −4	130 −4	390 −4	($E1$)	
584.42	0.19	584.4*	0.6	13±3 −1	13±4 −3	4.9 −3	12 −3	37 −3	$E2$	
592.40	0.91	591.8	0.6	5±1 −2	16±4 −3	4.8 −3	12 −3	36 −3	$E2$	^{185}Os
599.58	0.69	599.4	0.6	46±7 −3	20±6 −3	4.6 −3	11 −3	34 −3	$M1/E2$	
622.15	0.21	622.2	0.6	88±12 −2	10±2 −3	4.3 −3	10 −3	31 −3	$E2$	
630.31	0.21	630.2	0.6	14±5 −1	8±3 −3	4.2 −3	10 −3	29 −3	$E2$	
636.23	0.21	636.2*	0.6	15±2 −1	12±2 −3	4.1 −3	9.9 −3	29 −3	$E2$	
649.78	0.70	649.4	0.6	50±8 −2	6±2 −3	3.9 −3	9.4 −3	28 −3	($E1/E2$)	
661.86	0.71	661.3	1.1	28±7 −2	6±2 −3	3.7 −3	9.1 −3	27 −3	($E1/E2$)	
671.77	0.75	671.4	0.6	28±13 −2	2±1 −3	3.6 −3	8.9 −3	26 −3	$E1$	
679.49	0.49	678.7	0.6	16±5 −2	8±3 −3	3.5 −3	8.6 −3	25 −3	$E2$	
684.81	0.41	684.9	0.6	24±9 −2	9±4 −3	3.5 −3	8.5 −3	25 −3	$E2$	
		701.2	0.6	26±7 −2		3.3 −3	8.1 −3	23 −3	($E1$)	
705.72	0.94	705.8	0.6	31±9 −2	6±2 −3	3.3 −3	8.0 −3	23 −3	$E2$	
712.65	0.41	712.4	0.6	64±24 −2	34±12 −4	32 −4	78 −4	220 −4	$E1$	
729.48	0.42	728.9	0.6	35±5 −2	75±20 −4	30 −4	75 −4	210 −4	$E2$	
760.03	0.40	760.0	0.6	18±3 −2	70±15 −4	28 −4	69 −4	190 −4	$E2$	187
767.30	0.25	767.3*	0.6	11±3 −1	90±30 −4	27 −4	68 −4	180 −4	$E2$	
773.06	0.26	773.1*	0.6	23±4 −1	70±14 −4	27 −4	67 −4	180 −4	$E2$	
780.83	0.42	781.4	0.8	26±5 −2	80±20 −4	26 −4	66 −4	170 −4	$E2$	
794.2	1.2			<5 −2	>100 −4	25 −4	64 −4	170 −4	($M1$)	
		802.4	0.6	10±2 −2		25 −4	62 −4	160 −4	($E1$)	
805.47	0.51	806.2	0.9	18±4 −2	13±4 −3	2.5 −3	6.2 −3	16 −3	$M1$	185
841.31	0.30	841.3*	0.6	12±2 −1	60±12 −4	23 −4	56 −4	140 −4	$E2$	
884.97	0.98	884.9	0.6	12±3 −2	40±10 −4	21 −4	51 −4	130 −4	$E2$	
933.18	0.33	933.2*	0.6	12±1 −1	48±7 −4	19 −4	46 −4	110 −4	$E2$	

TABLE I. (*Continued*).

Transition energy (keV) E_e	ΔE_e	E_γ	ΔE_γ	γ-ray intensity	Conversion coefficient Expt	$E1$	$E2$	$M1$	Order	Remarks
943.56	0.40	943.6	0.6	20±4 −2	18±5 −3	1.8 −3	4.5 −3	11 −3	$M1$	188
959.6	1.5	958.3	0.6	12±4 −2	30±10 −4	18 −4	44 −4	100 −4	($E1/E2$)	
1011.08	0.50	1010.4	0.6	11±2 −2	15±5 −3	1.6 −3	4.0 −3	9.2 −3	$M1$	188
1026.54	0.32	1026.5*	0.6	22±4 −2	17±4 −3	1.6 −3	3.9 −3	8.9 −3	$M1$?	188, $E0$?
		1046.6	0.6	10±2 −2		1.5 −3	3.8 −3	8.6 −3	($E1$)	
1057.08	0.37	1057.1*	0.6	65±10 −2	45±8 −4	15 −4	37 −4	83 −4	$E2$	
1107.1	1.5	1107.1	0.6	22±4 −2	32±9 −4	14 −4	35 −4	74 −4	$E2$	
1122.0		1121.1	0.6	14±5 −2	<10 −4	14 −4	34 −4	72 −4	($E1$)	
1148.1	2.0	1149.7	0.6	9±3 −2	22±7 −4	13 −4	33 −4	69 −4	($E1/E2$)	
1171.53	0.52	1171.5	0.6	18±4 −2	90±20 −4	13 −4	31 −4	66 −4	$M1$	188
1187.90	0.36	1187.9*	0.6	42±7 −2	47±10 −4	13 −4	31 −4	64 −4	$E2/M1$	
1264.65	0.80	1264.8	0.6	23±4 −2	26±7 −4	11 −4	27 −4	55 −4	$E2$	
1314.36	0.59	1314.2	0.6	36±8 −2	28±8 −4	11 −4	25 −4	50 −4	$E2$	
1323.69	0.65	1323.7	0.6	22±5 −2	32±8 −4	10 −4	25 −4	49 −4	$E2/M1$	
1332.3		1334.0	1.5	34±8 −3	23±8 −3	1.0 −3	2.5 −3	4.8 −3	some $E0$	188
1342.5		1343.1	1.1	9±3 −2	20 −4	9.9 −4	24 −4	45 −4	not $M1$	
1363.5		1361.4	0.6	9±2 −2	<20 −4	9.8 −4	23 −4	45 −4	not $M1$	$D2364$
1378.1		1378.1	0.6	18±10 −2	<20 −4	9.6 −4	23 −4	44 −4	not $M1$	$D2400$
1439.9	1.5	1440.5	1.5	16±3 −2	37±9 −4	8.9 −4	21 −4	39 −4	$M1$	
1467.1	1.8	1466.4	1.5	18±4 −2	17±6 −4	8.5 −4	20 −4	37 −4	$E2$	188
1508.05	0.72	1508.1*	1.5	28±5 −2	46±12 −4	8.1 −4	19 −4	34 −4	$M1$	
1597.14	0.84	1596.7	1.5	17±6 −2	41±18 −4	7.4 −4	18 −4	31 −4	$M1$	$D2617$
1621.7	2.0	1622.2	1.5	47±13 −3	64±19 −4	7.3 −4	17 −4	30 −4	$M1$	188, $E0$?
1647.42	0.63	1647.4*	1.5	98±15 −2	25±6 −4	7.1 −4	17 −4	27 −4	$M1$	
1690.2		1690.8	1.9	5±1 −2		6.8 −4	16 −4	27 −4		185
1700.99	0.74	1701.0*	1.5	55±7 −2	24±5 −4	6.7 −4	16 −4	27 −4	$M1$	
1737.8	2.0	1737.3	1.5	13±3 −2	31±10 −4	6.5 −4	15 −4	25 −4	$M1$	185
1751.36	0.86	1751.4	1.5	19±3 −2	32±8 −4	6.4 −4	15 −4	25 −4	$M1$	
1789.0	2.0			<3 −2	>10 −3	6.2 −4	14 −4	23 −4	($E0$)	
1800.1	2.5			<3 −2	>10 −3	6.1 −4	14 −4	23 −4	($E0$)	
1869.0		1868.5*	2.0	7±3 −2	<20 −4	5.7 −4	13 −4	21 −4		185
1953.1		1953.5	2.0	25±6 −3	<60 −4	5.1 −4	12 −4	18 −4		
2340.5		2340.4	2.0	21±4 −3	90±30 −4	4.0 −4	8.5 −4	12 −4	some $E0$	188
2383.4		2384.0	2.0	55±14 −3	60±20 −4	3.9 −4	8.2 −4	11 −4	some $E0$	
2396.9		2399.7	2.0	51±12 −3	50±20 −4	3.8 −4	8.1 −4	11 −4	some $E0$	
2616.7		2616.5	2.0	52±13 −3	33±11 −4	3.3 −4	6.9 −4	8.8 −4	some $E0$	
2678.0		2679.5	2.0	29±7 −3	60±20 −4	3.2 −4	6.5 −4	8.2 −4	some $E0$	
2747.5		(2748)		<50 −3	>40 −4	3.1 −4	6.2 −4	7.6 −4	(some $E0$)	
		2781.6	3.0	49±11 −3		3.0 −4	6.0 −4	7.3 −4		
		2790.8	3.0	30±7 −3		3.0 −4	6.0 −4	7.3 −4		
2825.6		2826.6	4.0	27±6 −3	<50 −4	2.9 −4	5.5 −4	7.0 −4		
		2836.4	4.0	11±2 −2		2.9 −4	5.4 −4	7.0 −4		
2854.4		2854.4	4.0	34±8 −3	<40 −4	2.9 −4	5.4 −4	6.8 −4		
		2913.4	4.0	21±5 −3		2.8 −4	5.3 −4	6.4 −4		
		2961.8	4.0	8±2 −3		2.7 −4	5.2 −4	6.2 −4		
		2966.2	4.0	20±4 −3		2.7 −4	5.2 −4	6.1 −4		
		2978.5	4.0	16±4 −3		2.7 −4	5.1 −4	6.0 −4		
2994.5		2994.5*	5.0	14±3 −3	<100 −4	2.6 −4	5.1 −4	5.9 −4		
		3006.2	5.0	27±7 −3		2.6 −4	5.1 −4	5.9 −4		
3043.3		3038.3	5.0	10±3 −3	<150 −4	2.6 −4	5.0 −4	5.7 −4		
		3128.0	5.0	7±2 −3		2.4 −4	4.7 −4	5.2 −4		

ards. Such lines are marked with an asterisk in Table I. The consistency between internal and external standards was excellent.

The photopeak efficiencies of the Ge(Li) detectors as a function of γ-ray energy up to 1836 keV were determined with the IAEA sources, whose absolute disintegration rates were known. For higher γ-ray energies, ^{56}Co and ^{228}Th sources, not calibrated for disintegration rate, were used. The relative intensities of lines in ^{56}Co and ^{228}Th decay are accurately known.[8] The measured intensity of the 846.5-keV line in ^{56}Co was normalized to fit the efficiency curve established with IAEA sources; from this normalization the detector efficiency at other ^{56}Co line energies (2398.9, 3202.3, and 3254.0 keV) could be determined. Similarly, with ^{228}Th the normalization was made at 583.1 keV to provide a calibration point at 2614.5 keV. The intrinsic peak detector efficiencies were found to be independent of source geometry over the range of source-to-detector distances used in this work. The method used in the analysis for energies and intensities of standard spectra is described below.

III. ANALYSIS OF SPECTRA

A. Energy and Intensity Determinations

Analysis of spectra in terms of energy and intensity was made according to a method in which a triangle is fitted to each experimental peak. Amplifier gains corresponded to about 0.7 keV/channel for the low-energy region and 1.2 keV/channel at higher energies, resulting in peaks four to five channels wide at half-height and about eight channels wide at 0.1 height.

The "triangle method" is as follows: A spectrum is plotted on a linear scale. Background, almost always a straight line in a limited region, is estimated by inspection. The difference between a peak region and the background line is plotted on an expanded scale such that the channel number can be read to 0.05 channel. A straight line is then drawn through the points (typically three) representing the rising portion of the peak; a similar line is drawn for the trailing portion. The intersection of these lines defines the peak channel number. The product of the peak height H at the apex of the triangle and the width W at $0.5H$ is taken to be proportional to the intensity of the line. For a peak to be accepted as real, W was required to be within ± 0.5 keV of the value expected from standard sources. Doublets were resolved by fitting standard (triangular) peak shapes from standard sources or from a well-resolved ^{186}Ir line of nearly the same energy.

The energy corresponding to a channel number was obtained by a least-squares fit to internal-standard energies from conversion-electron spectrometry and the energies of the external standard sources listed in Sec. II C. The fit was improved by the addition of a very small quadratic term. Peak channels and intensities of the standards were obtained with the triangle method.

B. Errors

Spectra obtained at BNL and at Clark were from different sources prepared on different accelerators and counted on different detectors. The analyses of the two groups of spectra were performed entirely independently by different persons; the energy or intensity disagreements between the two analyses, even for very weak lines, were less than the errors quoted in Table I.

Unless otherwise indicated in Table I, the error in energy has been estimated to be ± 0.6 keV up to 1400 keV, ± 1.5 keV in the range 1400–2000 keV, ± 2.0 keV between 2000 and 2700 keV, ± 3.0 keV between 2700 and 2800 keV, and ± 5.0 keV above 3000 keV. These estimates were based on errors in energies of standards, the standard deviation in the least-squares fit, the consistency with which a peak was assigned an energy in two or more spectra, the degree to which a peak was resolved from other peaks, and the height of a peak compared to the Compton background beneath it. For high-energy lines, the position of the double-escape peak helped to confirm the energy of the full-energy peak.

In the case of intensities, error estimates are based on counting statistics, reproducibility of replicate measurements, and difficulty of resolving doublets. For some lines, indicated in column 11 of Table I, errors are unusually large because sizable corrections were necessary for contributions of impurity lines.

C. Intensity Scale

One of the chief motivations of this work was to determine internal conversion coefficients. The γ-ray intensity scale must be suitably normalized such that the γ-ray intensities and the conversion-electron intensities of Refs. 1 and 2 are internally consistent. A number of strong transitions in ^{186}Os are known to be pure $E2$ from L-subshell ratios or from systematics. These transitions are members of the ground-state rotational band or are cross-band transitions between the γ band and ground band. The γ-ray intensity scale has been chosen such that the conversion coefficients of the transitions of 137.2, 296.8, 434.8, 630.3, 636.2, 767.3, 773.1, 841.8, and 933.2 keV correspond to $E2$ when the conversion-electron intensities of Ref. 1 are divided by the γ-ray intensities reported here. The intensity scale of Ref. 2 has been normalized to that of Ref. 1.

Neither set of conversion-electron data explicitly indicates an error in intensity measurements. The errors in internal-conversion coefficients have been obtained from the errors in the γ-ray measurements combined

[8] ^{56}Co: K. W. Dolan, D. K. McDaniels, and D. D. Wells, Phys. Rev. **148**, 1151 (1966); G. Murray, R. L. Graham, and J. S. Geiger, Nucl. Phys. **63**, 353 (1965). ^{228}Th: G. T. Emery and W. R. Kane, Phys. Rev. **118**, 755 (1960).

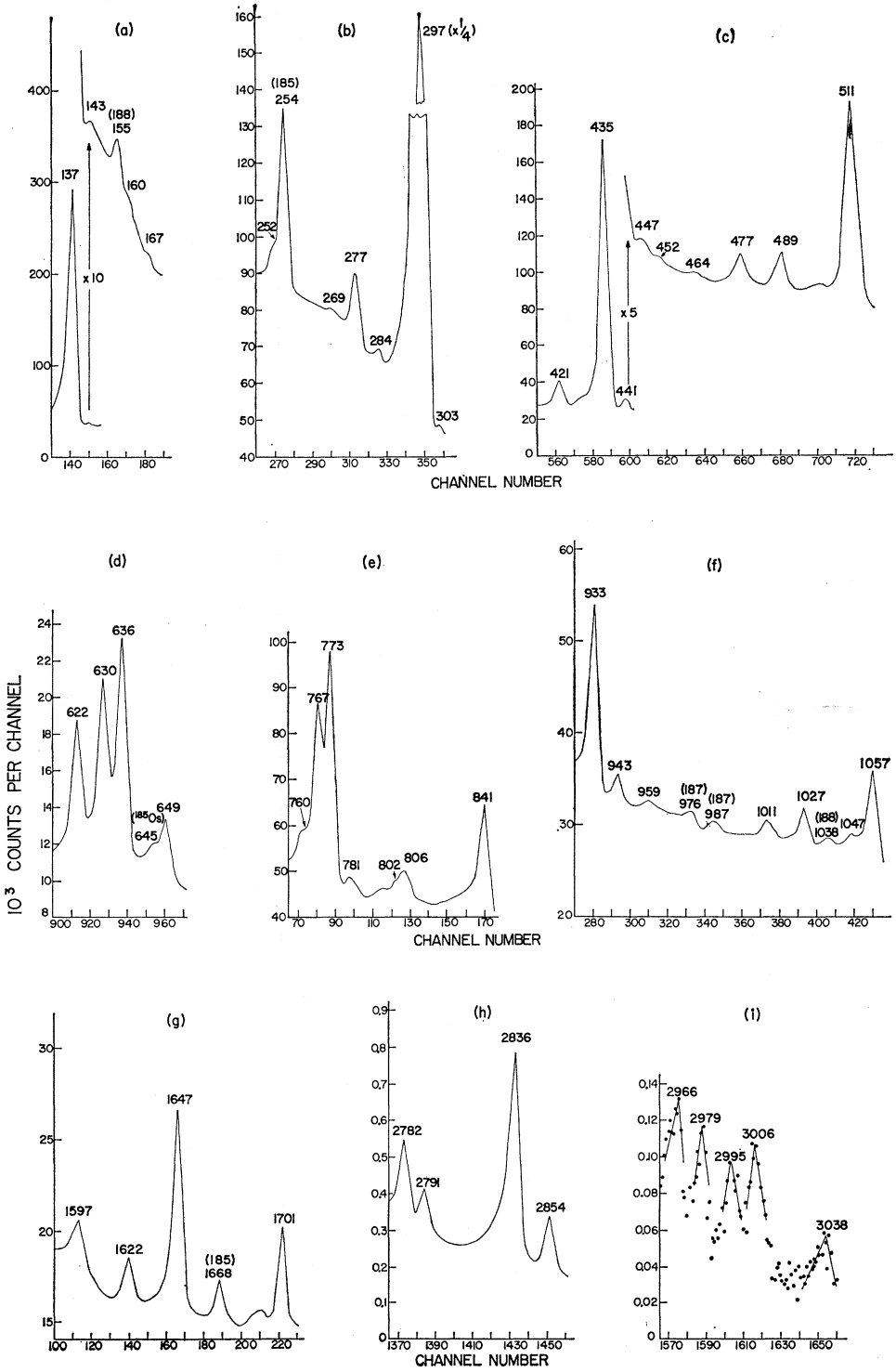

FIG. 2. Gamma-ray spectra of ^{186}Ir decay. Selected regions were chosen to indicate the general quality of the data. Experimental points are explicitly shown only in (i). A peak is labeled by its energy rounded off to the nearest keV. An impurity line is identified by a mass assignment in parentheses for Ir nuclides other than ^{186}Ir. One ^{185}Os line is also indicated. Note the zero suppression in some spectra. Energy ranges of the spectra are in keV (a) 130–175, (b) 245–306, (c) 415–517, (d) 615–656, (e) 755–845, (f) 930–1062, (g) 1580–1772, (h) 2770–2860, and (i) 2955–3045. The ordinate scale is not sufficiently expanded to show some of the weak lines reported in Table I. All ordinate scales have the same units: thousands of counts per channel.

TABLE II. Transitions unconfirmed by other conversion-electron data and by γ-ray data.[a]

Transition energy (keV)	Transition energy (keV)	Transition energy (keV)	Transition energy (keV)
89.1	335.0	1100.8	1743.0
104.3	352.4	1183.4	1805.2
114.6	431.8	1393.6	1815.2
118.3	440.6	1398.1	1906.0
144.0	467.81*	1474.5	1939.5
148.9	469.1	1483.9	2259.9
149.1	476.1	1495.1	2312.0
186.5	525.67*	1515.8	2360.8
226.1	620.9	1527.8	2389.3
278.4	853.5	1547.5	2412.6
281.3	883.0	1582.7	2428.9
293.5	1023.3	1601.9	2497.6
299.45*	1033.9	1615.8	2512.6
322.63*	1053.8	1625.5	2563.6
326.9	1066.5	1631.5	2732.7
333.0	1071.0	1693.4	

[a] Transitions marked with an asterisk are from Ref. 1; the remainder are from Ref. 2

in quadrature with errors in conversion-electron intensities estimated from the number of significant figures reported.

D. Impurity Lines

No radiations from nuclides nonisotopic with ^{186}Ir were seen except for ^{185}Os and a small amount of ^{24}Na. The former was present from the decay of its ^{185}Ir parent in spectra obtained long after chemical separation. In general, however, ^{185}Ir, ^{187}Ir, and ^{188}Ir lines were invariably seen in the spectra. No evidence was found for the reported 1.7-h ^{186}Ir isomer, although the times at which spectra were taken were typically too long after irradiation to have favored a short-lived species. Recent experiments directed specifically toward confirming the existence of the 1.7-h species have been negative.[9]

Spectra from sources prepared with ^{4}He bombardments were each measured at least twice. Consider the ratio of decay factors of 10.5-h ^{187}Ir to 15.8-h ^{186}Ir. After a period of 50 h, a typical interval between spectra, the ratio of distintegration rates ^{187}Ir/^{186}Ir has decreased by a factor of 3; for 41-h ^{188}Ir the ratio ^{188}Ir/^{186}Ir has increased by a factor of 4. Thus it was relatively straightforward to identify and correct for the contributions from ^{187}Ir and ^{188}Ir. In addition, in the former case a 28-MeV irradiation with ^{4}He led to increased yield of the $(\alpha, 2n)$ product; the stronger ^{187}Ir lines were readily identified.

In the case of 14.0-h ^{185}Ir, however, the ratio of disintegration rates ^{185}Ir/^{186}Ir has decreased by only the factor 0.8 after a 50-h interval; decay is not a reliable means of identifying ^{185}Ir lines. In the 21-MeV ^{3}He runs, the yield of ^{185}Ir was much greater than in 40-MeV ^{4}He runs; lines of increased intensity in the spectra from ^{3}He runs, relative to well-known ^{186}Ir lines in the same spectra, were assigned to ^{185}Ir.

The present work indicates that some of the transitions assigned to ^{186}Ir decay by the conversion-electron groups should be placed in other Ir nuclides. This is discussed further in Sec. V B.

IV. RESULTS

Typical γ-ray spectra are shown in Fig. 2 for several limited regions of energy distributed over the range 100–3000 keV. Energies of peaks have been rounded off to the nearest keV for purposes of labeling. In Table I are summarized the detailed results for energies, intensities, and conversion coefficients.

In column 10 a multipole order has been assigned for most transitions from a comparison of experimental

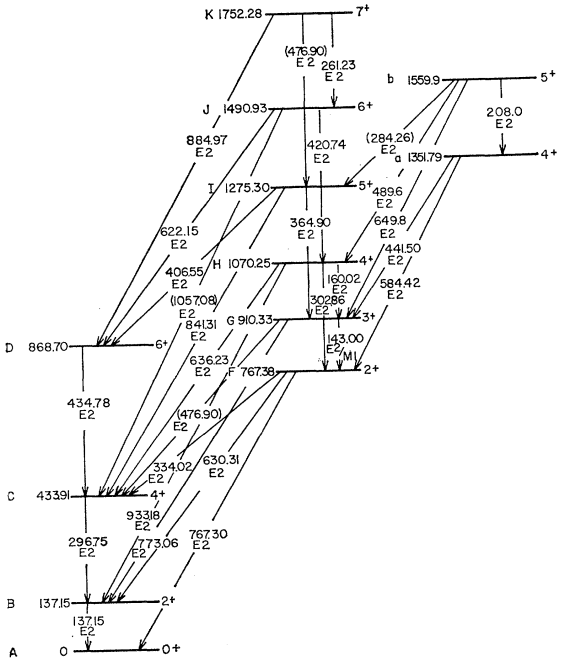

FIG. 3. Partial level scheme of ^{186}Os emphasizing the ground-state rotational band, the $K=2$ γ-vibrational band, and a possible $K=4$ band with level a as its base. Transition energies (in keV) and level energies deduced from their sums and differences are from Ref. 1 where available; otherwise γ-ray energies have been used. Multipolarities are from Table I. Spins and parities assigned are those considered to be most probable. Transition energies in parentheses indicate transitions placed more than once.

[9] K. J. Hofstetter (private communication).

and calculated conversion coefficients.[10] Throughout the table, the assignement $E2$ does not exclude appreciable mixing of $M1$ and vice versa. The designation $E2/M1$ is used when evidence for mixing is strong; the first term indicates the larger component. In a few cases (e.g., 649.78 keV) the conversion coefficient is consistent with the transition being either $E1$ or $E2$. Such transitions are denoted $(E1/E2)$. In a number of cases, a conversion-electron or γ-ray intensity may be missing when the other is known. An upper limit to the electron or γ-ray intensity can generally be estimated from an inspection of lowest measured intensities in the same energy region. Multipole-order assignments based on conversion coefficients calculated from electron or γ-ray intensity limits are given either in parenthesis in column 10 or are stated in a negative way (e.g., not $M1$). Such assignments are to be regarded with caution.

In general, L-subshell conversion-coefficient ratios are much more sensitive to multipole order than are α_K or α_L. At low transition energies, the evidence from conversion-coefficient ratios was weighted more heavily than that from α_K or α_L in assigning a multipole order. No significant disagreement was found between the two types of information, however.

For a number of high-energy transitions (1332.2, 2340.5, 2383.4, 2396.9, 2616.7, and 2678.0 keV) α_K is too large by factors well outside of experimental error for the transitions to be $M1$, and some $E0$ character is ascribed to these transitions. In addition, transitions at 1789.0 and 1800.1 keV, which were reported in both Refs. 1 and 2, appear to have no accompanying γ rays and may be pure $E0$ transitions. These transitions are discussed further in Sec. V D.

The conversion-electron data in Refs. 1 and 2 are not entirely in agreement: Some transitions were not seen by both groups; transition energies and electron intensities differ somewhat. For the purposes of the present work, the following procedure was adopted. Listed in Table I are all transitions observed either by both electron groups or in this γ-ray study. Electron data excluded by this scheme are listed in Table II. A direct comparison between the two sets of conversion-electron data can be made only up to 1800 keV, the highest energy for which Ref. 1 has reported results. Above this energy, a transition whose intensity was reported in Ref. 2 was included in Table II as unconfirmed if the upper limit to the γ-ray intensity at that energy was less than the intensity expected for an $M1$ transition. Such γ-ray intensity limits were typically a factor of 10 smaller. Transitions whose electron intensities were reported as "weak" in Ref. 2 were included in Table II if no evidence for a γ ray could be found.

[10] L. A. Sliv and I. M. Band, in *Alpha-, Beta-, and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (North-Holland Publishing Co., Amsterdam, 1965), p. 1661.

TABLE III. Transitions assignable to Ir nuclides other than ^{186}Ir.[a]

Transition energy (keV)	Mass assignment
173.8	188
211.5	187
288.80*	not 186
289.0	not 186
411.73*	187
426.34*	187
456.86*	not 186
693.65*	185
745.1*	185
1017.9*	188
1138.8*	187
1309.5	187
2000.1	187

[a] Transitions marked with an asterisk are from Ref. 1; the remainder are from Ref. 2.

The transition energy listed in column 1 is taken taken from Ref. 1 in those cases in which the Brookhaven group observed a transition. For each such transition energy the associated error is listed in column 2. In Ref. 2 errors in transition energy were not explicitly assigned. In the case of electron lines reported only in Ref. 2, no error is listed.

Conversion-electron intensities, from which conversion coefficients were calculated, were obtained by averaging the results of Refs. 1 and 2 if both groups observed a transition.

V. DISCUSSION

A. Ground-State and γ-Vibrational Bands

The γ-ray data confirm completely the levels which have been proposed as members of the ground-state and γ-vibrational bands except for the 8^+ member of the ground band. All of the expected intraband and interband transitions (see Fig. 3) have been found in the γ-ray spectrum except the 299.45-keV transition KE.[11] The multipole order assigned to each transition is consistent with that required by level systematics.

The $8^+ \rightarrow 6^+$ transition in the ground band is thought by the electron-spectrometry groups to be the 584.42-keV transition,[1,2] although in Ref. 2 the transition has also been placed between a level a at 1352.0 keV [12] and

[11] As in Ref. 1, transitions are designated with letters identifying the initial and final levels.

[12] In the present discussion, the energies of levels proposed in Ref. 2 are used as given there. Subsequent reevaluation of energy sums and differences have led to slightly different values for the energies (see Table IV).

TABLE IV. Intensities of transitions depopulating levels of ^{186}Os in decay of ^{186}Ir. Intensities are on the same scale as in Table I.

Proposed excited state			Deexciting transitions[a]		Transition intensity	
Designation	Energy (keV)	I^π	Energy (keV)	Final state	Out	In
B	137.15±0.03	2^+	137.15	*A*	21.7±2.2	24.2±2.6
C	433.91±0.07	4^+	296.75	*B*	18.2±2.5	13.9±1.1
D	868.70±0.10	6^+	434.78	*C*	8.5±1.0	1.79±0.15
F	767.38±0.10	2^+	334.02	*C*	0.06	
			630.31	*B*	1.47	
			767.30	*A*	1.15	
					2.68±0.60	3.23±0.52
G	910.33±0.10	3^+	143.00	*F*	0.54	
			(476.90)	*C*	0.06	
			773.06	*B*	2.27	
					2.87±0.53	<1.97±0.17
H	1070.25±0.10	4^+	160.02	*G*	0.27	
			302.86	*F*	0.13	
			636.23	*C*	1.48	
			933.18	*B*	1.25	
					3.13±0.28	2.33±0.15
I	1275.30±0.13	5^+	364.90	*G*	0.23	
			406.55	*D*	0.05	
			841.31	*C*	1.25	
					1.53±0.22	0.54±0.07
J	1490.93±0.13	6^+	420.74	*H*	0.79	
			622.15	*D*	0.89	
			(1057.08)	*C*	0.33	
					2.01±0.18	<0.63±0.09
K	1752.28±0.17	7^+	261.23	*J*	<0.07	
			(476.90)	*I*	0.06	
			884.97	*D*	0.12	
					<0.25±0.05	<0.09±0.04
N	1194.45±0.14	$2, 3, 4^+$	(284.26)	*G*	0.06	
			760.03	*C*	0.18	
			(1057.08)	*B*	0.32	
					0.54±0.08	0.19±0.06
a	1351.79±0.20	4^+	441.50	*G*	0.42	
			584.42	*F*	1.27	
					1.69±0.35	0.76±0.06
P	1451.90±0.16	4^+	542.17	*G*	<0.06	
			684.81	*F*	0.24	
			(1341.36)	*B*	0.18	
					<0.48±0.11	0.43±0.09
Q	1461.09±0.19	4^+	592.40	*D*	0.05	
			1026.54	*C*	0.22	
			1323.69	*B*	0.22	
					0.49±0.07	0.65±0.20
e	1480.3±0.3	3^-	570.31	*G*	0.25	
			712.65	*F*	0.64	
			1046.6	*C*	0.10	
			1343.1	*B*	0.09	
					1.08±0.25	...

TABLE IV. (*Continued*).

Proposed excited state Designation	Energy (keV)	I^π	Deexciting transitions[a] Energy (keV)	Final state	Transition intensity Out	In
b	1559.9±0.3	5^+	208.0	*a*	0.24	
			(284.26)	*I*	0.07	
			489.6	*H*	0.24	
			649.78	*G*	0.50	
					1.12±0.05	•••
c	1812.5±0.3	5^+	321.16	*J*	0.03	
			351.73	*Q*	0.55	
			943.56	*D*	0.20	
			1378.1	*C*	0.18	
					0.96±0.23	0.21±0.03
R	1875.40±0.20	4^+	599.58	*I*	0.05	
			679.49	*N*	0.16	
			(805.47)	*H*	0.09	
			1107.1	*F*	0.23	
			1439.9	*C*	0.16	
			1737.8	*B*	0.13	
					0.82±0.08	•••
T	2056.38±0.24	5^+	305.59	*K*	<0.09	
			565.42	*J*	0.26	
			780.83	*I*	0.26	
			1187.90	*D*	0.42	
			1621.7	*C*	0.05	
					<1.08±0.10	•••
U	2081.21±0.20	4^+	268.98	*c*	0.07	
			729.48	*a*	0.35	
			(805.47)	*I*	0.09	
			1011.08	*H*	0.11	
			1171.53	*G*	0.18	
			(1314.36)	*F*	0.18	
			1647.42	*C*	0.98	
					1.96±0.19	1.83±0.20
V	2152.06±0.20	5^-	70.88	*U*	1.83	
			661.86	*J*	0.28	
			701.2	*P*	0.26	
			802.4	*a*	0.10	
					2.47±0.23	0.28±0.13
f	2772.5±1.6	4^+	959.6	*c*	0.14	
			1700.99	*H*	0.55	
			2340.4	*C*	0.02	
					0.71±0.06	~0.02
d	2821.0±2.1	4^+	671.77	*V*	0.28	
			1361.4	*Q*	0.09	
			1751.36	*H*	0.19	
			1953.5	*D*	0.06	
			2384.0	*C*	0.03	
					0.65±0.14	0.14±0.04
g	2965.0±1.2	$0, 1, 2^+$	2826.6	*B*	0.03	
			2966.2	*A*	0.02	
					0.05±0.03	0.08±0.03
h	2993.1±1.5	2^+	1800.1	*N*	0.03	
			2854.4	*B*	0.034	
			2994.5	*A*	0.014	
					0.08±0.02	0.05±0.01

TABLE IV. (*Continued*).

Proposed excited state Designation	Energy (keV)	I^π	Deexciting transitions[a] Energy (keV)	Final state	Transition intensity Out	In
i	3050.0±0.7	4^+	1597.14	*P*	0.17	
			2616.5	*C*	0.05	
			2913.4	*B*	0.02	
					0.24±0.06	0.17±0.03
j	3114.6±1.2	4^+	292.98	*d*	<0.10	
			342.50	*f*	~0.04	
			2679.5	*C*	0.029	
			2978.5	*B*	0.016	
					<0.19±0.05	0.10±0.01
k	3216.4±0.8	$2, 3^+$	102.12	*j*	<0.10	
			167.05	*i*	0.08	
			224.13	*h*	0.05	
			252.45	*g*	0.08	
			2781.6	*C*	0.05	
					<0.36±0.05	...
l	3269.6±1.1	6^+	219.96	*i*	0.08	
			447.0	*d*	0.12	
			2399.7	*D*	0.05	
			2836.4	*C*	0.11	
					0.36±0.05	...

[a] Transitions in parentheses have been placed more than once; intensities were divided equally. Transition energies are from Ref. 1 where available; otherwise γ-ray energies were used.

level *F*, the 2^+ member of the γ band at 767.38 keV. The reaction groups[4,5] assigned the $8^+ \rightarrow 6^+$ transition to the 551.43-keV line. The present work does not make possible a clear distinction between these choices; both transitions are *E*2 and either could fit. Preliminary evidence from coincidence experiments,[7] however, supports the existence of a level at 1352.0 keV; the 584.42-keV transition is probably the transition *aF*.

B. Other Levels Proposed in Ref. 1

Four transitions reported in Ref. 1 but not observed by Harmatz and Handley or found in the γ-ray spectrum are listed in Table II. Of these, only the 299.45-keV transition *KE* was placed in the level scheme. Since the energy of the 8^+ state *E* is open to question, eliminating these transitions does not otherwise affect the levels proposed in Ref. 1.

An additional eight transitions in Ref. 1, listed in Table III, appear to be assignable to other Ir activities. The 456.86- and 1138.8-keV transitions were not placed in the level scheme of Ref. 1. Eliminating the 411.73- and 1017.9-keV transitions, *MF* and *MC*, casts doubt on the existence of level *M* at 1179.20 keV. In Ref. 1 the evidence for *M* was also considered to be weak. The remaining transitions in and out of *M* are at 268.98 keV (*MG*), 272.80 keV (*PM*), and 311.85 keV (*JM*). The 268.98-keV transition can be placed elsewhere (as *Uc*; see Table IV). The latter two γ rays could not be resolved clearly. Presumably they correspond to weak transitions.

If the transitions at 288.80 and 1017.9 keV, *PL* and *PC*, are eliminated in addition to *PM*, the case for level *P* is weakened. Only the transitions *PF*, *PG*, and *PB* remain and *PB* also fits as *UF*. The γ-ray data, however, show that the 701.2-keV *E*1 transition fits as the transition *VP*.

The loss of the 426.34-keV and 693.65-keV transitions, assigned as *NF* and *QF*, does not seriously affect the status of levels *N* and *Q*; many other transitions in and out of these levels remain.

The consequence of this classification of data in Tables II and III is to eliminate level *M* in the level scheme of Ref. 1; other levels are only slightly affected. The γ-ray data tend to support several of the levels of Ref. 1 but also weaken the arguments for others. This is discussed further in Sec. V E.

C. Levels Proposed in Ref. 2

Harmatz and Handley suggest the existence of 14 levels which are different from those in Ref. 1. The evidence for such levels is considered in the light of the classification of data in Tables II and III; 64 transitions given in Ref. 2 have either not been confirmed or are assignable to other nuclides. Of these, 37 transitions had not been fitted into the level scheme of Ref. 2 and cannot affect the 14 above-mentioned levels.

An analysis of the remaining 27 transitions leads to the following result. The case for the level proposed in Ref. 2 at 1380.0, 1606.0, 1722.3, 1755.1, 1780.1,

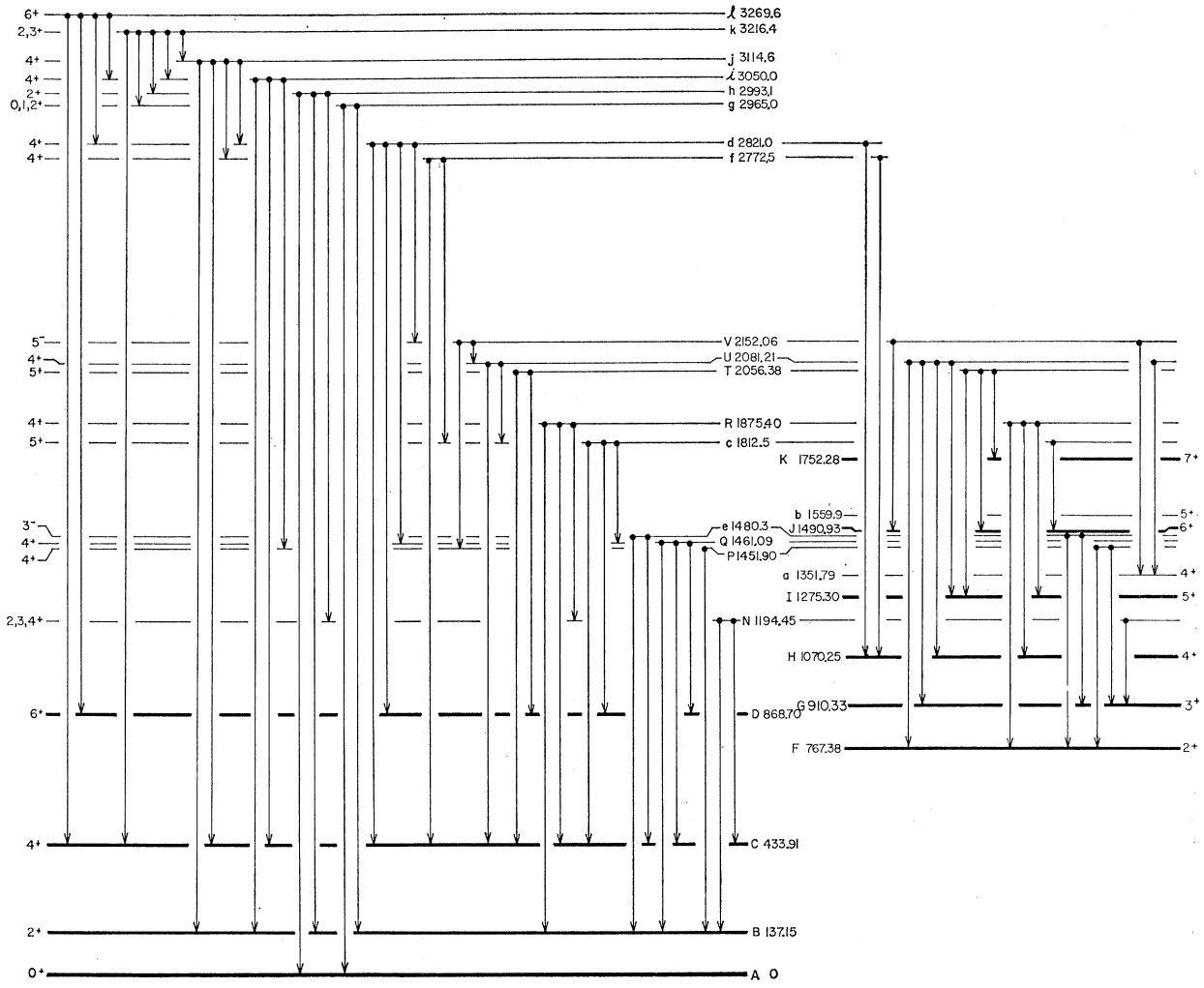

FIG. 4. Level scheme of ^{186}Os for all levels supported by the γ-ray and conversion-electron data. Energies are in keV. Transitions shown in Fig. 3 have been excluded. Horizontal lines corresponding to levels in the ground-state and γ-vibrational bands have been darkened to emphasize systematic relationships among transitions deexciting to these levels. See also the caption for Fig. 3.

1938.0, 2434.3, 2860.0, 2977.0, and 3181.1 keV is weakened. These levels, according to Harmatz and Handley, originally had a total of 44 transitions in and out; of these, 24 remain if unverified or isotopically misassigned transitions are excluded. Five of the 24 transitions can be placed elsewhere in a level scheme involving better established levels or are of the wrong multipole order to be consistent with the assignments of Ref. 2. The 10 levels then involve a total of 19 transitions (only one level has more than two) which would have to be placed elsewhere if the levels were eliminated.

Other levels proposed in Ref. 2 at 1352.0, 1560.0, 1812.7, and 2822.6 keV (designated *a*, *b*, *c*, and *d*, respectively) have at least four transitions each in or out and appear to be on sounder ground. This view is supported by additional transitions which can be assigned between these levels and those designated by capital letters.

D. High-Energy Transitions; Negative-Parity Levels

The high-energy γ-ray spectrum of ^{186}Ir is notable for many transitions (18 γ rays above 2000 keV), eight transitions with $E0$ components, and two additional transitions which may be pure $E0$. Davidson[13] has commented that, in high-Z nuclei, monopole transitions may compete favorably with $E2$ transitions. The energy available for electron capture is 3830 keV.[3] The high-energy transitions must then feed primarily low-lying members of the ground and γ bands. If this is the case, the deexciting levels must in general have low spin. The problem arises of how such levels would be populated by β decay of ^{186}Ir which is known to have high spin ($I=6$ or 7). Some of the transitions with $E0$ components are of such high energy that only

[13] J. P. Davidson, Rev. Mod. Phys. **37**, 105 (1965).

the ground-state band can be fed. The deexciting level then has $K=0$.

The level scheme of Ref. 1 includes only one negative-parity level, V at 2152.06 keV, though the possibility that some of the other levels might be of negative parity was not excluded. All of the levels proposed in Ref. 2 were of positive parity. The γ-ray data, however, indicate that a number of relatively strong transitions are $E1$. Because α_K values for $E1$ are much smaller than those for $E2$ or $M1$, several $E1$ transitions were evidently observable only as γ rays.

The γ-ray data are consistent with level V being a 5^- state. All other levels in Ref. 1 and the levels a, b, c, and d of Ref. 2 appear to have positive parity.

E. Partial Level Scheme

In Figs. 3 and 4 a level scheme is presented which combines the best features of those previously proposed, as judged with the aid of the γ-ray data of the present work. In addition, one negative-parity and seven positive-parity states are proposed to accommodate some of the $E1$ transitions and most of the high-energy and $E0$ transitions. These have been placed at 1480.3 (3^-), 2772.5 (4^+), 2965.0 (0, 1, 2^+), 2993.1 (2^+), 3050.0 (4^+), 3114.6 (4^+), 3216.4 (2, 3^+), and 3269.6 (6^+) keV. The new levels are designated by the letters e through l in order of increasing energy.

In revising the level scheme and in adding new levels, we have found that the number of instances in which a transition could be placed more than once was reduced if the levels of Ref. 1 at 1163.04 (L), 2031.32 (S), and 2234.10 (W) keV were dropped. Moreover, some transitions involved with these levels, which fit in terms of energy, had multipole orders inconsistent with the presumed parity and hence were better assigned elsewhere. Also intensity balance in and out of other levels was somewhat improved by reassignment of transitions involving these levels.

The energy assigned to a new level was calculated from a least-squares fit of the better-known transition energies coupled to the level. The most probable spin and parity assignments are indicated in Table IV and Fig. 4.

In Table IV transitions deexciting particular levels are listed, and transition intensities in and out are estimated from γ-ray intensities and conversion coefficients. Since the present scheme of 29 levels involves only 91 of the 127 transitions listed in Table I, intensity balance is not complete and β-ray branching to various levels could not be calculated. Some transitions which might have been assigned on the basis of energy sums alone have been left unassigned because coincidence data[7] indicate that these transitions must be placed elsewhere in the decay scheme.

Some of the level systematics proposed in Ref. 2 is supported by the present work. For example, Harmatz and Handley[2] proposed a $K=4$ two-phonon band beginning with the 4^+ level a at 1352 keV. The 5^+ and 6^+ members of the band were at 1560 and 1780 keV. We confirm the existence of the 1560-keV level (b). The pattern of decay of levels a and b to levels in the γ-vibrational band is consistent with a $K=4$ assignment.

Since many levels below 3500 keV are yet to be found, it seems premature to speculate about the possible systematic properties of other levels which are not members of the firmly established ground state and $K=2$ γ bands. We note, however, that the levels at 2821.0, 3050.0, 3114.6, and 3269.6 keV have $K=0$ since each appears to deexcite by a transition with an $E0$ component to a member of the ground-state band.

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