# Nuclear Structure Study Of $^{188}$Os

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## Abstract

The energy level scheme of $^{188}$Os has been established on the basis of γ-γ coincidence measurements. Ge(Li) and HPGe detectors were employed to study the gamma spectra produced in the β-decay of $^{188}$Re to $^{188}$Os. Fourteen new transitions and four new levels at 1660, 1871, 1948 and 2034 keV are suggested. Relative intensities from singles measurements, branching ratios $\alpha_k$ and log*ft* values were calculated and multipolarities, spins and parities deduced.

## Introduction

The nucleus of $^{188}$Os can be populated either $\beta^-$ decay of $^{188}$Re, or by EC/$\beta^+$ of $^{188}$Ir. The former mode of decay is preferable due to its relatively longer half-life. There have been many early experimental investigations of the decay of $^{188}$Re to $^{188}$Os.

The extensive studies involving e-e, e-γ and γ-γ coincidences from both $^{188}$Re and $^{188}$Ir were performed by Warner and Sheline(1). The detectors used were two NaI(Tl) scintillation counters. The works of Wyly et al(2) and Yamazaki(3), based on β-γ directional correlation in $^{188}$Re and $^{188}$Ir decay respectively, mainly confirmed previous data without providing new results. Harmatz and Handley(4), using both modes of decay, established a spin/parity of $2^-$ for the 1035 keV level. This was in contradiction with the measurement made later by Bashandy and Hanna(5) where a high resolution, double focussing beta-ray spectrometer was used. The spin/parity of this level was suggested to have $3^-$. Yamazaki and sato(6) suggested a decay scheme on basis of β–γ and γ–γ coincidence measurements using three Ge(Li) γ-ray spectrometers. A total of three energy gates at 155, 478 and (633 + 635) keV were taken to construct the decay scheme $^{188}$Os nucleus. The level proposed by Harmatzand Handley4 at 1075 keV was not seen. The level at 1035 was suggested to have spin/parity of $2^+$ in contradiction with $2^-$ [4] and $3^-$ [5]

suggested earlier. Two levels at 789($3^+$) and 1808 keV were observed for the first time to be populated in the decay of $^{188}$Re ($1^-$). These levels were well established levels from the EC/$\beta^+$ decay of $^{188}$Ir ($2^-$). Two new levels at 1457 ($1^+$, $2^+$) and 2021($2^+$) were proposed.

The most recent work on the $\beta^-$ decay of $^{188}$Re was that Svoren et al(7) constructed decay scheme based on the energy sum relation using large volume high resolution Ge(Li) detector. Eleven transitions were considered to be new. Energies at 794, 963, 967 and 1170 keV observed by Yamazaki(6) were also seen but were attributed to the radiative background of the laboratory. None of the others at 641, 880 and 1230 keV were observed. There was no coincidence measurement being made. The level scheme was constructed based on the energy sum relations. This resulted in 18 energy levels of which 5 levels were suggested to be populated for the first time by $\beta^-$ decay of $^{188}$Re. These levels were: 478 and 1843 keV observed in $^{188}$Ir EC/$\beta^+$ decay, 1480 and 1705 keV observed by Shama and Hintz[11] from (p,t) reaction studies, and 1414 keV observed from reaction ($\alpha$,2n$\gamma$) by Yates et al[14]. The level at 2021 keV seen by Yamazaki and Sato[6] was suggested to have energy of 2023 keV. The energy level determination using 1856 and 2023 keV transitions differ by 1.6 keV.

In studying the nuclear properties of $^{188}$Os, the methods of $\beta^-$ and EC/$\beta^-$ decay were not the only means probing $\beta^-$ this nucleus. There were several reaction studies being performed earlier, Casten et al( 8) measured the $\gamma$–$\gamma$ coincidence from $^{188}$Os($^{16}$O, $^{16}$O$\gamma$) reaction. The detectors used were NaI (Tl). Milner et al[9] used two reaction modes $^{188}$Os($\alpha$,$\alpha$'$\gamma$) and $^{188}$Os($^{16}$O,$^{16}$O$\gamma$), while Lan and Saladin(10) employ He, $^{16}$O and sulphur ions in their coulomb excitation studies. In search of $0^+$ states Sharma and Hintz(11) employ a (p,t) reaction. In the $^{186}$W($\alpha$,2n) $^{188}$Os study, Warner et al(12) were able to identify up to spin $12^+$ in the ground state bands (GSB). Yamazaki et al(13) using the same reaction technique, would only identify up to $10^+$ of the (GSB) and $5^+$ of the $\gamma$-band. A $\gamma$–$\gamma$ coincidence studies the same reaction, using 19 gates, led Yates et al(14) to propose a $6^+$ state at 1424, and a $4^+$ at 1279 keV. A level at 1414 with spin/parity $3^-$ was also established. Other reaction study pertaining to this nucleus was $^{190}$Os(p,t) by Thompson et al(15) assigned the level at 1823 keV, a $0^+$ spin parity, in contradiction with other workers.

The present work on $^{188}$Os populated by the $\beta^-$ decay of $^{188}$Re was undertaken to remove discrepancies observed earlier, especially as regards to the level scheme.

**Experimental details and results**

The radioactive source used was $^{188}$W, produced by double neutron capture of natural $^{188}$W(95% pure), The reaction is of the form $^{188}$W(2n,$\gamma$) $^{188}$W. The $^{188}$W decays with a half-life of 70 days to $^{188}$Rewhich further decays ($T_{1/2}$=17 h) to $^{188}$Os. The source was left for three weeks to allow for 24 hrs $^{187}$W activity to die away. Two singles spectra were taken with large volume (60 cc 12% efficient) true coaxial Ge(Li) detector with a resolution of 2 keV ( FWHM for the 1332 keV peak of $^{60}$Co). A HPGe detector 31% efficient a resolution of 1.7 keV was also used to confirm the intensity of low energy $\gamma$-rays, and a separate compton suppression system provide another independent check. In one further case a 2 cm Pb absorber was placed in front of the 12% efficient Ge(Li) detector to suppress intense low energy $\gamma$-rays which are source of sum peaks.

Fig(1) shows a single spectrum and table (1) gives the relative intensities of $\gamma$-ray measured following the $\beta^-$ decay of $^{188}$Re to $^{188}$Os. Fourteen new $\gamma$-rays at 650, 785, 107, 1238, 1355, 1505, 1660, 1711, 1793, 1846,1871, 1888,1975, and 2034 keV are reported with intensities related to I(478 keV = 100) being 0.047, 0.58, 0.21, 0.20, 0.046, 0.38, 0.64, 0.25, 0.057, 0.052, 0.16, 0.25, 0.24, and 0.17. The intensities of $\gamma$-rays are compared with work of Svoren et al(7) and Yamazaki and Sato(6) . The present results are consistent with the results of Svoren et al (7) for most parts. The only discrepancy observed is for the 825 $\gamma$-ray. The present result obtained an intensity of 2.2(4) while Svoren et al(7), quoted a value of 4.9(5). Although the present value is almost 50% that of Svoren et al(7), it is consistent with intensity of 1.7(6) obtained in the (n,$\gamma$) reaction[15]. Furthermore, a value of 3.8(10) obtained by Yamazaki and Sato(6) is only slightly higher.

The analysis of singles spectra enables a total of 52 gamma rays to be identified with computer code SAMPO 80[16] for the purpose of peak fitting and energy calibration.

In constructing the decay scheme of $^{188}$Os, the $\gamma$–$\gamma$ coincidence measurements were taken by gating on the eight peaks at 155, 322, 478, (633+635), 829, 931, 1132 and (1149+1150) keV using the 12% Ge(Li) and 31% HPGe detectors. The gate at 155 is needed to confirm the

existence of a 478 keV level with spin/parity $4^+$. This level was suggested for the first time by Svoren et al(7) to be populated in the $\beta^-$ decay of $^{188}$Re (spin/parity $1^-$). The suggestion was based entirely on energy sum consideration. The 322 keV gate was chosen to confirm the presence of a 790 keV $3^+$. The selection of the 829 keV lines as gate helped to confirm a new level at 1948 keV. A strong coincidence was expected with a transition at 486 keV, previously observed by Yamazaki and Sato(6) and Svoren et al(7) but not placed in the decay scheme. The gate at 1931 keV was needed to confirm a level 1871 keV. Typical coincidence spectra are shown in Figs (2 and 3), of the 52 $\gamma$-rays observed in the singles spectrum 38 were seen in the coincedence spectra. The three at 650, 1354 and 1846 keV with intensities 0.047, 0.046 and 0.052 were too weak to show up in the coincidence spectra. The remaining 11 higher energy transitions go directly to the ground state.

## Discussion the decay scheme

The decay scheme of $^{188}$Os following the $\beta^-$ decay of $^{188}$Re was established on the basis of the g-g coincidence results with eight energy gates and the energy sum relations. The decay scheme is shown in Fig.(4), on the left side of the figure are shown the energies of the levels, the branching ratios (BR) obtained for each level, the log*ft* values (taking $Q_{\beta^-}$ = 2.119 MeV)(17,18), spins and parities. The numbers at the base of the arrows indicate the energy of transition, and the new transitions together with new levels are shown as dashed lines. The present level scheme agrees well with the results of Yamazaki and Sato(6), and Svoren et al[7]. Table(2) shows the branching ratios (BR's), the log*ft* values for the $\beta^-$ decay of $^{188}$Re and the deduced spins and parities. The BR's were calculated from the total intensity balance between the intensity of decay and feeding $\gamma$-rays for each level. The BR to the ground states was taken to be (70.8E0.2)%, an average between the values of Svoren et al(7) and Singh and Viggar(17). The log*ft* values were calculated according to the relations given in Ref(19), the end point energies of the $\beta^-$ decay were calculated using $Q_{\beta^-}$(max) of 2.119MeV(17,18). The deduced spins/parities were worked out according to the $\beta^-$ decay selection rules. It is reasonable to assume that is no $\beta^-$ feeding to the 478 keV level with spin/parity $4^+$, from $1^-$ $^{188}$Re parent. In order to establish a zero (BR) it is

implied that the total γ intensities populating the level is at least equal to the depopulating γ intensity. The only γ-transition observed in this level is that at 312 keV, with a relative intensity of 0.41. However, the depopulating transition at 322 keV has a relative intensity of 1.47, greater than the populating intensity. To be consistent with no $\beta^-$ feeding of the 478($4^+$) keV level, an additional transition with a relative intensity of at least 1.33 should populate this level. One possibility is that a transition at 155.24 keV occurs between the 633 keV level and that at 478 keV. Such a transition would be a doublet with intense 154.99 keV line (energy difference only 0.25 keV). The present work suggests that 0.73% of the total γ intensity of a doublet 155 keV transition would populate that 478 keV level.

A through knowledge of the internal conversion coefficients is required to aid in the assignment of transition multipolarities and for the determination of total transitions intensities needed in computation of $\beta^-$ decay branching ratios. The multipolarity of the energy transitions were determined by comparing experimental conversion coefficient $\alpha_k$ with the theoretical values of Hager and Setzer[19] for the E1, E2, E3 and M1 multipolarities. The experimental $\alpha_k$ was evaluated from our gamma-ray intensities reported in this paper and the k-shell, conversion electron intensities I(k) given by Ref.(21). The values of $\alpha_k$ obtained, together with the theoretical values for different multipolarities are furnished in table(3).

Yamazaki and Sato(6), from studies of the $^{188}$Re decay included energies at 641, 795, 880, 965, 1170 and 1230 keV in their decay scheme. Two of these were not observed in the present work and four were identified as background: 641 from $^{80}$Br, 795 from $^{134}$Cs, 880 from $^{185}$Os and 1230 from $^{182}$Ta. From the eleven new transitions suggested by Svoren et al(7)only nine were observed. The gamma ray at 810 keV was observed but was attributed to the radiative background from $^{58}$Co. The none observance of the 624 keV transition in the present work eliminates the possibility of a level at 1414 keV being populated by $\beta^-$ feeding. Such a level was observed in the ($\alpha$,2n$\gamma$) reaction studies(14) and was even suggested for the first time to be populated in the $^{188}$Re decay7. To be consistent Yates et al(14) assigned to that 1414 keV level a spin/parity of $3^-$, which is however, unlikely to be populated in the $\beta^-$ decay of $1^-$ $^{188}$Re.

The 1948 keV level is confirmed from the coincidence results of the 486 keV transition. Yamazaki and Sato(6) and Svoren et al(7) observed

both this transition, but they could not place in the level Scheme. The present result has, for the first time been able to place the 486 keV transition in the $^{188}$Os decay scheme.

The present experimental evidence relating to the 2023 keV level is now conclusive. Both Yamazaki and Sato(6) and Svoren et al(7) observed the transition at 1865 keV in the 188Re decay. The suggested that this transition depopulates the level at 2023 keV, although energetically the sum of 1865 keV and 155 keV differ by 2.6 keV from 2023 keV. The present accurate energy measurements indicate that energetically the 1865 keV transition does not fit between the 2023 and 155 keV levels. Since the $Q_{\beta}^{-}$(max) of $^{188}$Re is 2199 keV, the 2023 keV transition can only be associated with the depopulation of a 2023 keV level.

The new level at 1660 keV is suggested due to the observation of three new transitions at 1660, 1505 and 1027 keV. A weak coincidence of the 1027 keV transition with the 478 keV gate supports the suggestion for the level at 1660 keV. The direct decay to the ground state favours a $2^{+}$ spin/parity assignment to this level. This is in agreement with the log*ft* value of 9.53.

The new level at 1948 keV is proposed to accommodate two new γ-rays. A 486 keV transition was found in coincidence with 931 keV gate. This transition was observed by Yamazaki and Sato(6) and Svoren et al[7], but could not be placed in the decay scheme. The presence of the new level is also strongly supported by the observation of new transition at 1793 keV. The log*ft* value of 7.27 is consistent with a spin/parity of $2^{+}$.

The 1871 keV is suggested for the first time as a result of the presence of three new transitions at energies 685, 1238 and 1871 keV. The coincidence results of the transitions 785 and 1238 keV with 931 and 478 keV gates respectively supports this suggestion. The direct decay to the ground state favours a spin/parity of $2^{+}$. This is consistent with the log*ft* value of 8.3.

The new level at 2034 keV is suggested by the observation of two new transitions at 2034 and 1888 keV. Since the $Q_{\beta}^{-}$(max) of $^{188}$Re is 2199 keV, the 2034 keV line can only be associated with the depopulating of 2034 keV level. The transition at 1880 keV first energetically between this 2034 keV level and first excited state at 155 keV. The coincidence result of 155 keV gate reveal a weak coincidence with 1888 keV transition. From these facts it is believed that the 1888 keV transition

depopulates the level at 2034 keV. The direct ground state decay favours a $2^+$ spin/parity assignment.

## Conclusion

Extensive gamma rays singles and $\gamma$–$\gamma$ coincidence measurements enable the construction of a comprehensive decay scheme of $^{188}$Os following (17) hr of $^{188}$Re. The present work includes fourteen new gamma
rays for which the energies are 650, 785, 1027, 1238, 1355, 1505, 1660, 1711, 1793, 1846, 1871, 1888, 1975 and 204 keV. The decay scheme includes four new excited levels at 1660, 1871, 1984 and 2034 keV are proposed. The observed spectra rule out the existence of transition reported by Svoren et al(7) at 558, 624 and 811 keV, also the energy level at 1414 keV. The 486 keV transition has been able to be place in the decay scheme.

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**Table (1) Relative intensities of γ-rays emitted from the decay of $^{188}W$**

| Energy (keV) | Intensities related to I (477) = 100 | | |
|---|---|---|---|
| | Present | Ref. (7) | Ref. (6) |
| 154.99 (04) | 1450 (114) | 1432 (35) | 1545 (150) |
| 312.22 (25) | 0.38 (9) | 0.31 (7) | - |
| 322.72 (31) | 1.62 (11) | 1.51 (10) | 1.62 (2) |
| 453.34 (12) | 7.5 (5) | 6.78 (18) | 7.2 (4) |
| 477.95 (11) | 100 | 100 | 100 |
| 485.9 (28) | 8.0 (4) | 7.50 (31) | 8.1 (3) |
| 514.87 (25) | 0.54 (5) | 0.49 (5) | - |
| 633.01 (10) | 119.97 (98) | 119.57 (108) | 141 (14) |
| 635.22 (15) | 13.73 (98) | 14.18 (46) | - |
| 650.13 (18) | 0.047 (7) | - | - |
| 672.59 (10) | 10.81 (43) | 10.63 (31) | 10.3 (1) |
| 785.42 (28) | 0.58 (18) | - | - |
| 825.44 (25) | 2.23 (35) | 4.89 (49) | 3.8 (10) |
| 829.5 (12) | 39.57 (107) | 39.29 (108) | 39.8 (40) |

| | | | |
|---|---|---|---|
| 845.20 (12) | 0.62 (9) | 0.69 (5) | 0.6 (2) |
| 931.31 (6) | 54.23 (16) | 54.04 (14) | 58.3 (60) |
| 1017.57 (12) | 1.25 (18) | 1.43 (12) | 1.60 (4) |
| 1027.24 (28) | 0.21 (5) | - | - |
| 1070.98 (25) | 0.057 (13) | 0.077 (15) | - |
| 1132.23 (11) | 8.31 (30) | 8.46 (37) | 9.4 (9) |
| 1149.62 (16) | 1.51 (36) | 1.65 (39) | 3.6 (4) |
| 1150.76 (16) | 1.51 (36) | 1.65 *39) | - |
| 1174.35 (25) | 1.73 (9) | 1.94 (15) | 1.2 (3) |
| 1191.83 (14) | 1.07 (5) | 1.33 (9) | 1.2 (3) |
| 1209.72 (25) | 0.30 (3) | 0.28 (3) | - |
| 1238.51 (25) | 0.20 (3) | - | - |
| 1302.42 (32) | 0.58 (8) | 0.62 (9) | - |
| 1304.96 (31) | 0.44 (9) | 0.52 (8) | - |
| 1307.99 (14) | 6.60 (39) | 6.47 (3) | 6.6 (7) |
| 1323.16 (12) | 1.01 (15) | 0.83 (6) | 1.3 (4) |
| 1354.71 (15) | 0.046 (10) | - | - |
| 1457.55 (8) | 1.86 (18) | 1.91 (12) | 1.8 (4) |
| 1505.34 (25) | 0.38 (11) | - | - |
| 1549.36 (25) | 0.19 (5) | 0.25 (5) | - |
| 1610.32 (10) | 8.22 (47) | 9.41 (40) | 10.5 (18) |
| 1652.81 (15) | 0.27 (6) | 0.32 (5) | - |
| 1660.28 (24) | 0.64 (12) | - | - |
| 1669.48 (21) | 0.78 (10) | 1.02 (8) | 0.6 (2) |
| 1711.19 (20) | 0.25 (7) | - | - |
| 1785.19 (13) | 1.23 (15) | 1.99 (11) | 2.6 (3) |
| 1793.23 914) | 0.057 (13) | - | - |

| | | | |
|---|---|---|---|
| 1802.13 911) | 3.59 (22) | 3.61 (17) | 4.1 (5) |
| 1807.61 (28) | 0.19 (3) | 0.11 (2) | - |
| 1486.46 (12) | 0.052 (13) | - | - |
| 1865.2 (16) | 0.46 (9) | 0.54 (5) | 0.6 (2) |
| 1871.21 (21) | 0.16 (5) | - | - |
| 1888.74 (22) | 0.26 (9) | - | - |
| 1940.68 (15) | 0.29 (6) | 0.20 (2) | - |
| 1957.29 (15) | 1.04 (8) | 1.51 (11) | 1.61 (3) |
| 1975.91 (12) | 0.24 (16) | - | - |
| 2022.76 (10) | 0.21 (5) | 0.17 (2) | - |
| 2043.86 (10) | 0.17 (5) | - | - |

**Table (2) Summary of the level properties in $^{188}$Os**

| Energy Level (keV) | $E_{\beta}^{-}$ (keV) | $\Sigma I_{\gamma}$ feed | $\Sigma I_{\gamma}$ decay | B.R* % | log*ft* | Deduced J |
|---|---|---|---|---|---|---|
| 154.99 | 1964.71 | 189.26 | 2638.66 | 25.82 | 8.43 | 2 |
| 477.71 | 1641.99 | 1.75 | 1.74 | - | - | 4 |
| 632.94 | 1486.76 | 69.22 | 223.72 | 1.63 | 9.17 | 2 |
| 790.07 | 1329.63 | 14.12 | 14.11 | - | - | 3 |
| 1086.29 | 1033.41 | 0.58 | 62.26 | 0.65 | 9.00 | 0 |
| 1304.79 | 814.91 | - | 2.65 | 0.0279 | 10.01 | 2 |
| 1457.78 | 661.92 | - | 4.70 | 0.0495 | 9.47 | 2 |
| 1462.49 | 657.21 | 8.00 | 50.72 | 0.45 | 0.851 | 2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1478.15 | 641.55 | - | 1.63 | 0.017 | 9.88 | 0 |
| 1660.26 | 459.44 | - | 1.23 | 0.013 | 9.53 | 2 |
| 1704.24 | 415 | - | 0.25 | 0.0026 | 10.09 | 0 |
| 1765.24 | 354.46 | - | 16.56 | 0.17 | 8.07 | 0 |
| 1807.55 | 312.15 | - | 6.86 | 0.072 | 8.26 | 2 |
| 1824.80 | 294.90 | - | 1.85 | 0.019 | 8.70 | 0 |
| 1842.66 | 277.04 | - | 0.30 | 0.0032 | 9.44 | 2 |
| 1865.69 | 254.00 | - | 0.71 | 0.0075 | 9.06 | 2 |
| 1871.45 | 248.25 | - | 0.94 | 0.0099 | 8.25 | 2 |
| 1940.62 | 179.08 | - | 9.82 | 0.10 | 7.25 | 2 |
| 1948.36 | 171.34 | - | 8.06 | 0.08 | 7.27 | 2 |
| 1957.21 | 162.49 | - | 4.63 | 0.048 | 7.45 | 2 |
| 1975.91 | 143.79 | - | 0.24 | 0.0025 | 8.55 | 2 |
| 2022.76 | 96.94 | - | 0.21 | 0.0022 | 7.95 | 2 |
| 2043.79 | 75.91 | - | 0.44 | 0.0046 | 7.16 | 2 |

* B.R. of ground state assumed 70.8% an average between the works of Svoren et al (7) and Singh et al(17).

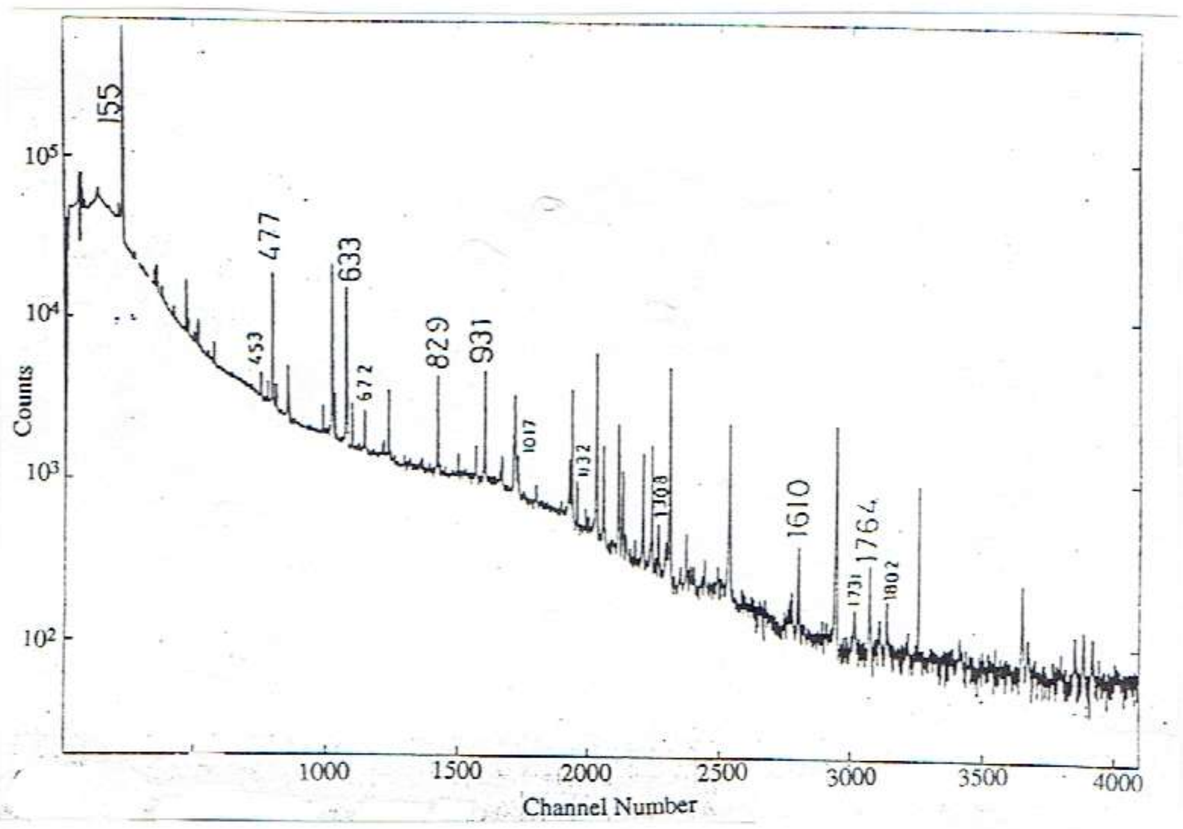


**Fig. (1) $\gamma$-ray singles spectrum following $\beta$ decay of $^{188}$W (peak energies in keV )**

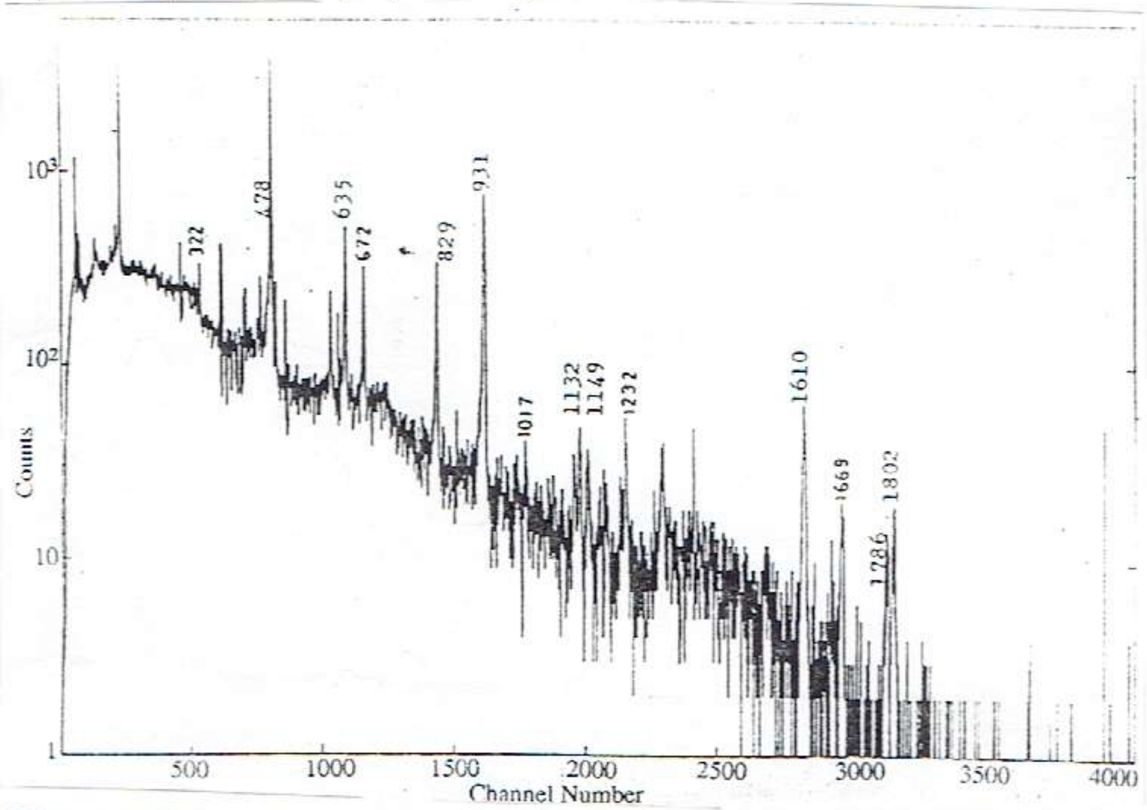


**Fig.(2) Coincidence spectrum for $^{188}$Os gated with the 155 keV transition (peak enrgies in keV )**

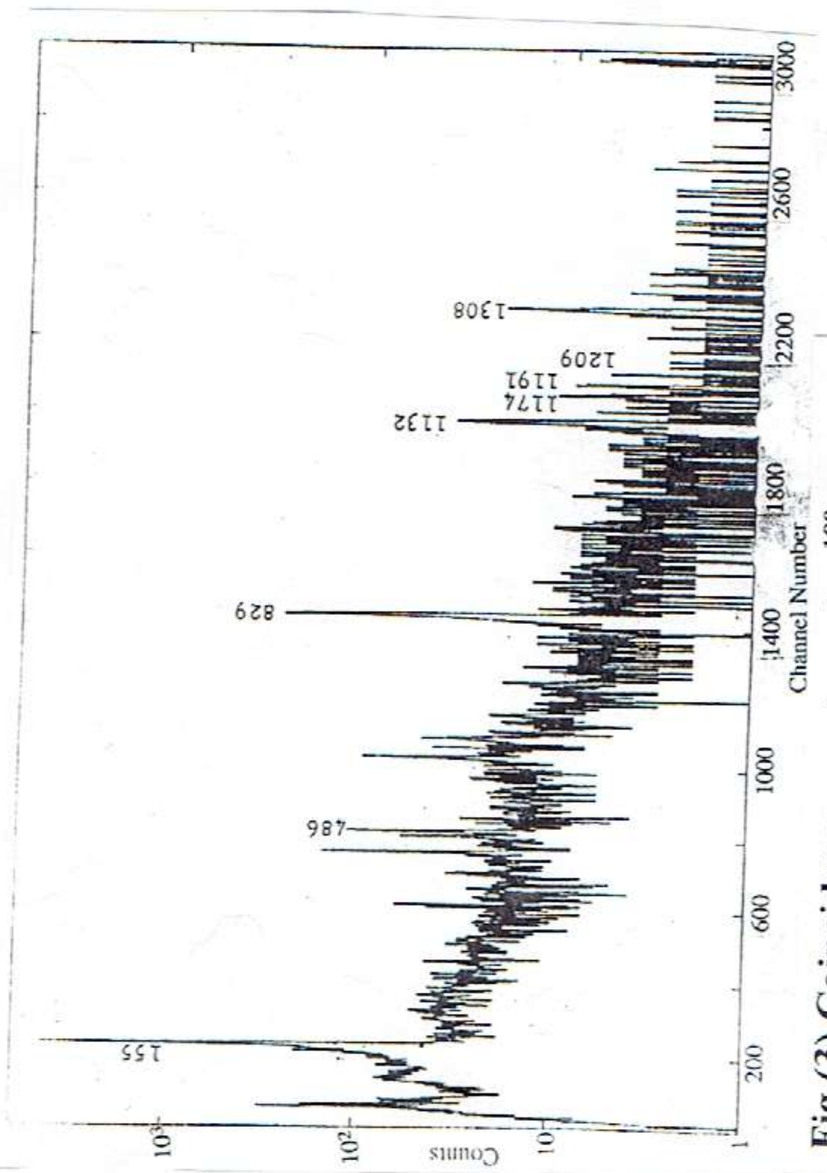


Fig.(3) Coincidence spectrum for $^{188}$Os gated with the 477 keV transition (peak enrgies in keV )

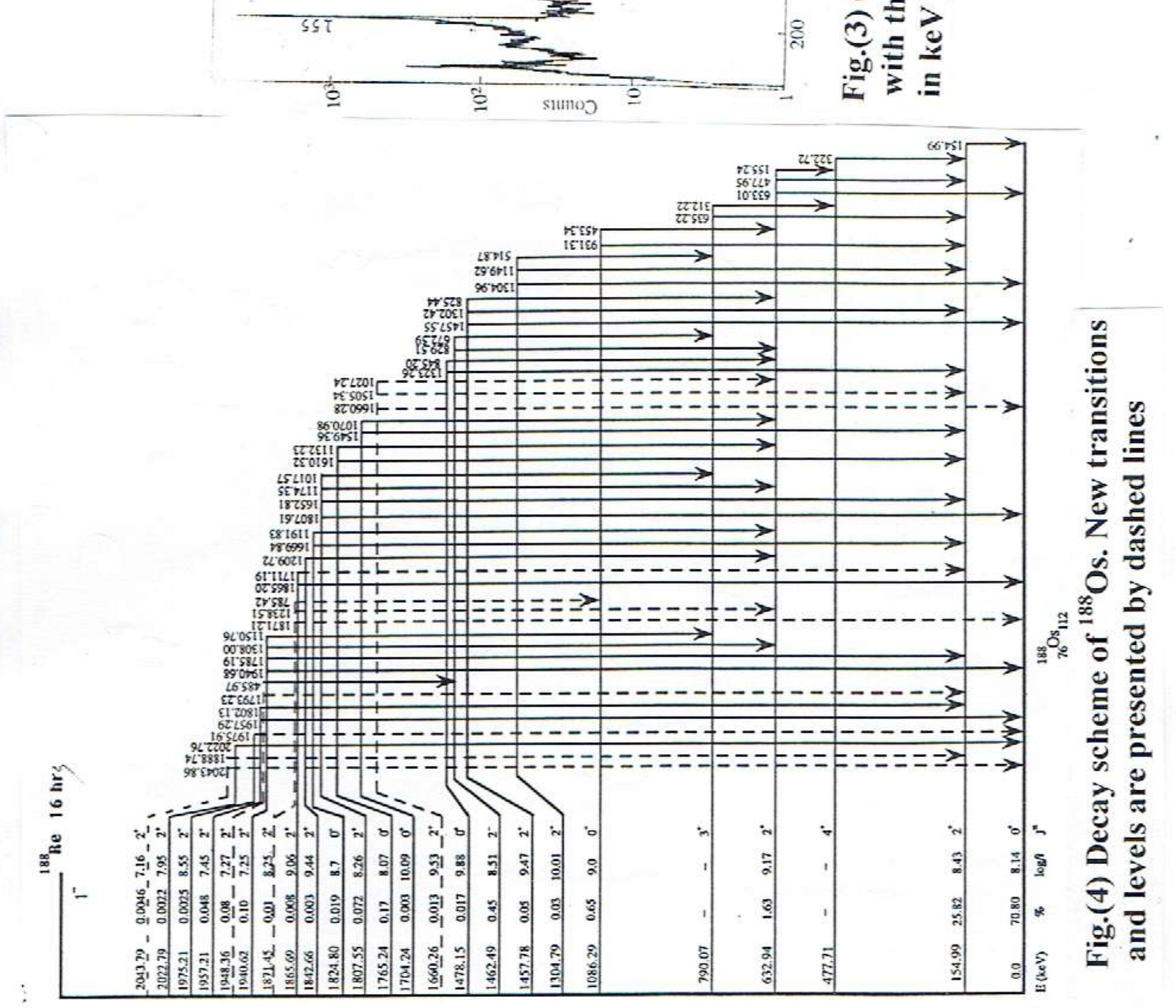


Fig.(4) Decay scheme of $^{188}$Os. New transitions and levels are presented by dashed lines

# دراسة مستويات الطاقة للنظير $Os^{-188}$

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## الخلاصة

تم تثبيت مستويات الطاقة للنظير $Os^{188}$ على اساس التطابق – كاما . منظومة القياس تتكون من كاشفين من الجرمانيوم النقى والاخر مطعم بالليثيوم لدراسة الطاقات الناتجه من اضمحلال $B^-$ للنظير المشع $Re^{-188}$ . اربعة عشر طاقة واربعة مستويات جديده (2034 KeV, 1948,1871,1660) اقترحت.

تم حساب الشده النسبيه لكل من الطاقات ونسبة التفرع فضلا" عن قيم Kα و iog ft ومتعددة الاقطاب لكل طاقة لاجل تحديد البرم والتماثل لكل مستوى.