ON PROBABILITIES OF E2 TRANSITIONS BETWEEN
POSITIVE-PARITY STATES IN $^{160}$Dy NUCLEUS

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Abstract

Reduced probabilities $B(E2)$ of $\gamma$ transitions between states of positive
parity in the $^{160}$Dy nucleus are calculated within the framework of the
interacting boson model (IBM-1). The results are compared with the
experimental data.

Thorough and comprehensive investigations of the $^{160}$Er $\rightarrow^{160m,g}$Ho $\rightarrow^{160}$Dy decay have yielded new extensive experimental data on excited states and $\gamma$ transitions between them in the $^{160}$Dy nucleus [1]. In particular, observation of over 100 new levels and over 500 new $\gamma$ transitions is reported and about 150 multipolarities are said to be established for the first time. The $^{160m,g}$Ho $\rightarrow^{160}$Dy decay scheme proposed by the authors includes practically all known and newly discovered $\gamma$ transitions except few of them whose total intensity is 0.9% of decays. In [2] we made an attempt to describe theoretically energy positions of most excited states of positive parity and to reproduce energies of levels belonging to ground rotational, gamma, and other rotational bands manifesting themselves in this nucleus.

In this paper, using our data [1] on intensities and energies of $\gamma$ transitions de-exciting positive-parity levels with known $T_{1/2}$ [3], we found experimental values of reduced probabilities $B(E2)$ by the formula

$$B(E2)_{\gamma} = \frac{\ln 2}{T_{1/2}} \frac{I_{\gamma} 10^2}{\sum I_{tot} 1.23E_{\gamma}^5}, \quad (1)$$

where $\sum I_{tot}$ is the sum of total intensities of all $\gamma$ transitions de-exciting a particular level. For $\gamma$ transitions presumably exciting but not yet observed
experimentally only limiting $B(E2)$ values were found from the upper bounds of their intensities experimentally determined by us and the energies known from the positions of their corresponding levels.

The thus obtained probabilities $B(E2)$ are compared with our calculations within the interacting boson model ($IBM-1$) determining the transition operator $T(E2)$ as [4]:

$$T(E2) = \alpha (d^\dagger s + s^\dagger \bar{d})(2) + \frac{\beta}{\sqrt{5}} (d^\dagger \bar{d})(2).$$

The absolute values $B(E2, 2^+_2 \rightarrow 0^+_1) = 4.43(34)$ and $B(E2, 2^+_2 \rightarrow 0^+_1) = 192.6(88)[W.u.]$ measured by us were used in the calculations to determine the parameters $\alpha = 1.914$ and $\beta = 1.515$.

The results of comparing experimental and calculated $B(E2)$ for each of the levels with the known $T_{1/2}$ are presented in Tables 1.0–1.6, where columns 2 show characteristics of the levels under consideration, including the sum of intensities of their complete de-excitation, and columns 3, 4, 5 show characteristics of particular $\gamma$ transitions connecting them with the corresponding final states whose characteristics are given in columns 6 and 7. It is evident from Tables 1.0–1.6 (see columns 8 and 9) that calculations are in a good agreement with the experimental values.

In Tables 2.0–2.19 experimental $B(E2)$ are compared with theoretical values for particular excited states whose half-live times $T_{1/2}$ are unknown but which have one or a few $\gamma$ transitions with the known multipolarity $E2$. Then experimental reduced probabilities $B(E2)$ of $\gamma$ transitions from these levels were calculated by using the data [1] and the relation

$$B(E2)_{\gamma} = B(E2)_0 \frac{I_1 E_{\gamma}^5}{I_0 E_{\gamma}^5},$$

Here the lower index “$o$” marks the theoretical value of $B(E2)_0$ calculated for each level using the $IBM-1$. Further, taking this theoretical value of $B(E2)_0$ as experimental value and using (3) one can estimate other competing $\gamma$ transitions for the experimentally known energies $E_{\gamma}$ and intensities $I_0$ of the corresponding $\gamma$ transition of $E2$ type. In the tables so calculated values of $B(E2)$ are marked with the symbol “≡”. There is rather good agreement between theory and experiment for a majority of $\gamma$ transitions with the known transition type and multipolarity. The $\gamma$ transitions with considerable disagreement between theoretical and experimental $B(E2)$ values make it only possible to conclude that these transitions are not of $E2$ type, while those with only slight disagreement between these values allow an assumption that these transitions might be of $E2$ type. However, it is only after the experiment that the final conclusions can be drawn.

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References

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### Table 1.0

| \( E_{(levi)} \) [keV] | \( \sigma L \) | \( E_r(\Delta E_r) \) [keV] | \( I_r(\Delta I_r) \) [rel. un.] | \( E_{(levf)} \) [keV] | \( I_f^\pi \) | \( B(E2) \) [W.u.] | \( \text{Exper.} \) | \( \text{Calc.} \) |
|-------------------------|---------------|----------------|-------------------------------|-------------------|------------|----------------|----------------|----------------|
| 86.8                    | \( 2_1^+ \)   | E2             | 86.79(2)                      | 808(30)           | 0.0        | 192.6(88)     | 193.0          |

\( T_{1/2}(\Delta T_{1/2}) \) = 2.026(12) ns

\( \Sigma I_{tot}(\Delta I_{tot}) \) = 4590(120)

### Table 1.1

| \( E_{(levi)} \) [keV] | \( \sigma L \) | \( E_r(\Delta E_r) \) [keV] | \( I_r(\Delta I_r) \) [rel. un.] | \( E_{(levf)} \) [keV] | \( I_f^\pi \) | \( B(E2) \) [W.u.] | \( \text{Exper.} \) | \( \text{Calc.} \) |
|-------------------------|---------------|----------------|-------------------------------|-------------------|------------|----------------|----------------|----------------|
| 283.8                   | \( 4_1^+ \)   | E2             | 197.03(2)                     | 850(22)           | 86.8       | 286(17)       | 272.4          |

\( T_{1/2}(\Delta T_{1/2}) \) = 103(5) ps

\( \Sigma I_{tot}(\Delta I_{tot}) \) = 1062(28)

### Table 1.2

| \( E_{(levi)} \) [keV] | \( \sigma L \) | \( E_r(\Delta E_r) \) [keV] | \( I_r(\Delta I_r) \) [rel. un.] | \( E_{(levf)} \) [keV] | \( I_f^\pi \) | \( B(E2) \) [W.u.] | \( \text{Exper.} \) | \( \text{Calc.} \) |
|-------------------------|---------------|----------------|-------------------------------|-------------------|------------|----------------|----------------|----------------|
| 581.1                   | \( 6_1^+ \)   | E2             | 297.25(6)                     | 71.6(23)          | 283.8      | 4.43(34)      | 4.5            |

\( T_{1/2}(\Delta T_{1/2}) \) = 18.6(10) ps

\( \Sigma I_{tot}(\Delta I_{tot}) \) = 76.4(23)

### Table 1.3

| \( E_{(levi)} \) [keV] | \( \sigma L \) | \( E_r(\Delta E_r) \) [keV] | \( I_r(\Delta I_r) \) [rel. un.] | \( E_{(levf)} \) [keV] | \( I_f^\pi \) | \( B(E2) \) [W.u.] | \( \text{Exper.} \) | \( \text{Calc.} \) |
|-------------------------|---------------|----------------|-------------------------------|-------------------|------------|----------------|----------------|----------------|
| 966.2                   | \( 2_2^+ \)   | E2,M1          | 385.68(8)                     | 1.87(19)          | 581.1      | 6.43(34)      | 6.4            |

\( T_{1/2}(\Delta T_{1/2}) \) = 3.43(25) ps

\( \Sigma I_{tot}(\Delta I_{tot}) \) = 1.9(2)

### Table 1.4

| \( E_{(levi)} \) [keV] | \( \sigma L \) | \( E_r(\Delta E_r) \) [keV] | \( I_r(\Delta I_r) \) [rel. un.] | \( E_{(levf)} \) [keV] | \( I_f^\pi \) | \( B(E2) \) [W.u.] | \( \text{Exper.} \) | \( \text{Calc.} \) |
|-------------------------|---------------|----------------|-------------------------------|-------------------|------------|----------------|----------------|----------------|
| 966.8                   | \( 8_1^+ \)   | E2,M1          | 69.82(5)                      | <0.1              | 1280.0     | <17980        | 148.0          |

\( T_{1/2}(\Delta T_{1/2}) \) = 1.2(1) ps

\( \Sigma I_{tot}(\Delta I_{tot}) \) = 1349.8(1)

### Table 1.5

| \( E_{(levi)} \) [keV] | \( \sigma L \) | \( E_r(\Delta E_r) \) [keV] | \( I_r(\Delta I_r) \) [rel. un.] | \( E_{(levf)} \) [keV] | \( I_f^\pi \) | \( B(E2) \) [W.u.] | \( \text{Exper.} \) | \( \text{Calc.} \) |
|-------------------------|---------------|----------------|-------------------------------|-------------------|------------|----------------|----------------|----------------|
| 1349.8                  | \( 2_2^+ \)   | E2             | ~194.0                        | <0.1              | 1155.8     | <108.6        | 3.2            |

\( T_{1/2}(\Delta T_{1/2}) \) = 30.5(38) ps

\( \Sigma I_{tot}(\Delta I_{tot}) \) = 1049.1(1)

\( \Sigma I_{tot}(\Delta I_{tot}) \) = 1262.8(2)

\( \Sigma I_{tot}(\Delta I_{tot}) \) = 1349.8(1)

\( \Sigma I_{tot}(\Delta I_{tot}) \) = 1076.0(1)

\( \Sigma I_{tot}(\Delta I_{tot}) \) = 1262.8(2)

\( \Sigma I_{tot}(\Delta I_{tot}) \) = 1349.8(1)
Table 1.6

| $E_{\text{levi}}$ [keV] | $\sigma L$ | $E_{\gamma}(\Delta E_{\gamma})$ [keV] | $I_{\gamma}(\Delta I_{\gamma})$ | $E_{\text{levi}}f$ [keV] | $I_{\gamma}^\pi$ | $B(E2)$ [W.u.] | Exper. | Calc. |
|-------------------------|-----------|-----------------------------------|---------------------------------|--------------------------|----------------|------------------------|--------|-------|
| 1694.4                  |           |                                   |                                 |                           |                |                         |        |       |
| $I_{\gamma}^\pi$        | 4$\pi$+   | ~86.5                             | <0.1                            | 1607.9                   | 4$\pi$+        | <3.7                    | 5.0    |       |
| $T_{1/2}(\Delta T_{1/2})$ | 180(35) ps | ~87.5                             | <0.1                            | 1606.9                   | 6$\pi$+        | <0.4                    | 1.3    |       |
| $\Sigma I_{\text{tot}}(\Delta \Sigma I_{\text{tot}})$ | 3436(60)  | ~90.6                             | <0.1                            | 1603.8                   | 4$\pi$+        | <0.3                    | 0.9    |       |
|                         |           | ~172.0                             | <0.1                            | 1522.4                   | 4$\pi$+        | <0.01                   | 9.8    |       |
|                         |           | ~176.0                             | <0.1                            | 1518.4                   | 2$\pi$+        | <0.01                   | 1.0    |       |
|                         |           | ~255.8                             | <0.1                            | 1438.6                   | 6$\pi$+        | <0.002                   | 0.4    |       |
|                         |           | ~305.0                             | <0.1                            | 1349.8                   | 2$\pi$+        | <0.0007                  | 2.9    |       |
| E2                      | 405.70(2) | 25.6(6)                           | 1288.7                          | 5$\pi$+                  | 0.041(8)       | 0.3                     |       |       |
| E2                      | 538.54(2) | 285(6)                            | 1155.8                          | 4$\pi$+                  | 0.11(2)        | 0.05                    |       |       |
| E2                      | 645.24(3) | 1027(26)                         | 1049.1                          | 3$\pi$+                  | 0.16(3)        | 0.2                     |       |       |
| E2                      | 728.17(2) | 2062(40)                         | 966.2                           | 2$\pi$+                  | 0.18(4)        | 0.08                    |       |       |
|                         |           | ~1113.3                           | <0.1                            | 581.1                    | 6$\pi$+        | <0.000001               | 0.0004 |       |
| E2,M1                   | 1410.5(3) | 10.2(5)                           | 283.8                           | 4$\pi$+                  | 0.000003(1)    | 0.003                   |       |       |
|                         | 1607.6(3) | 0.75(25)                          | 86.8                            | 2$\pi$+                  | 0.00001(1)     | 0.006                   |       |       |

Table 2.0

| $E_{\text{levi}}$ [keV] | $\sigma L$ | $E_{\gamma}(\Delta E_{\gamma})$ [keV] | $I_{\gamma}(\Delta I_{\gamma})$ | $E_{\text{levi}}f$ [keV] | $I_{\gamma}^\pi$ | $B(E2)$ [W.u.] | Exper. | Calc. |
|-------------------------|-----------|-----------------------------------|---------------------------------|--------------------------|----------------|------------------------|--------|-------|
| 1049.1                  |           |                                   |                                 |                           |                |                         |        |       |
| $I_{\gamma}^\pi$        | 3$\pi$+   | 82.96(5)                          | <0.2                            | 966.2                    | 2$\pi$+        | <294.0                  | 291.4  |       |
| $T_{1/2}(\Delta T_{1/2})$ | E2        | 765.30(5)                         | 252(6)                          | 283.8                    | 4$\pi$+        | 5.6(3)                  | 3.8    |       |
| $\Sigma I_{\text{tot}}(\Delta \Sigma I_{\text{tot}})$ | 1387(31)  | 962.32(2)                         | 1130(30)                        | 86.8                     | 2$\pi$+        | 7.9(3)                  | ≡7.9   |       |

Table 2.1

| $E_{\text{levi}}$ [keV] | $\sigma L$ | $E_{\gamma}(\Delta E_{\gamma})$ [keV] | $I_{\gamma}(\Delta I_{\gamma})$ | $E_{\text{levi}}f$ [keV] | $I_{\gamma}^\pi$ | $B(E2)$ [W.u.] | Exper. | Calc. |
|-------------------------|-----------|-----------------------------------|---------------------------------|--------------------------|----------------|------------------------|--------|-------|
| 1155.8                  |           |                                   |                                 |                           |                |                         |        |       |
| $I_{\gamma}^\pi$        | 4$\pi$+   | (M1)                              | 106.86(2)                       | 0.10(5)                  | 1049.1         | 3$\pi$+                  | 91(49) | 215   |
| $T_{1/2}(\Delta T_{1/2})$ | E2        | 189.66(3)                         | 1.88(23)                        | 966.2                    | 2$\pi$+        | 97(2)                  | ≡97    |       |
| $\Sigma I_{\text{tot}}(\Delta \Sigma I_{\text{tot}})$ | 521(11)   | 574.73(5)                         | 4(1)                           | 581.1                    | 6$\pi$+        | 0.8(3)                  | 1.0    |       |
|                         |           | 872.02(2)                         | 351(10)                         | 283.8                    | 4$\pi$+        | 8.8(19)                 | 8.2    |       |
|                         |           | 1069.04(3)                        | 160(4)                          | 86.8                     | 2$\pi$+        | 1.5(3)                  | 2.4    |       |

Table 2.2

| $E_{\text{levi}}$ [keV] | $\sigma L$ | $E_{\gamma}(\Delta E_{\gamma})$ [keV] | $I_{\gamma}(\Delta I_{\gamma})$ | $E_{\text{levi}}f$ [keV] | $I_{\gamma}^\pi$ | $B(E2)$ [W.u.] | Exper. | Calc. |
|-------------------------|-----------|-----------------------------------|---------------------------------|--------------------------|----------------|------------------------|--------|-------|
| 1280.0                  |           |                                   |                                 |                           |                |                         |        |       |
| $I_{\gamma}^\pi$        | 0$\pi$+   | ~313.8                            | <0.2                            | 966.2                    | 2$\pi$+        | <14.2                  | 13.1   |       |
| $T_{1/2}(\Delta T_{1/2})$ | (E2)      | 1193.17(3)                        | 13.8(6)                         | 86.8                     | 2$\pi$+        | 1.23(8)                  | ≡1.23  |       |
| $\Sigma I_{\text{tot}}(\Delta \Sigma I_{\text{tot}})$ | 13.9(6)   |                                   |                                 |                           |                |                         |        |       |

Table 2.3

| $E_{\text{levi}}$ [keV] | $\sigma L$ | $E_{\gamma}(\Delta E_{\gamma})$ [keV] | $I_{\gamma}(\Delta I_{\gamma})$ | $E_{\text{levi}}f$ [keV] | $I_{\gamma}^\pi$ | $B(E2)$ [W.u.] | Exper. | Calc. |
|-------------------------|-----------|-----------------------------------|---------------------------------|--------------------------|----------------|------------------------|--------|-------|
| 1288.7                  |           |                                   |                                 |                           |                |                         |        |       |
| $I_{\gamma}^\pi$        | 5$\pi$+   | ~132.9                            | <0.2                            | 1155.8                   | 4$\pi$+        | <213.3                  | 150.6  |       |
| $T_{1/2}(\Delta T_{1/2})$ | E2        | 239.57(7)                         | 2.74(11)                        | 1049.1                   | 3$\pi$+        | 154(9)                  | ≡154   |       |
| $\Sigma I_{\text{tot}}(\Delta \Sigma I_{\text{tot}})$ | 146.2(31) | 707.60(2)                         | 27.9(6)                         | 581.1                    | 6$\pi$+        | 6.95(51)                 | 4.96   |       |
|                         |           | E2,M1                             |                                 |                           |                |                         |        |       |
|                         |           | 1004.86(2)                        | 115(3)                          | 283.8                    | 4$\pi$+        | 4.96(39)                 | 6.44   |       |
### Table 2.4

| $E_{\text{levi}}$ [keV] | $\sigma_L$ | $E_\gamma(\Delta E_\gamma)$ [keV] | $I_\gamma(\Delta I_\gamma)$ [rel. un.] | $E_{\text{levif}}$ [keV] | $I_\gamma^\pi$ | B(E2) [W.u.] | Exper. | Calc. |
|-------------------------|------------|----------------------------------|---------------------------------------|-----------------|------------|----------------|---------|-------|
| 1438.6                  |            |                                   |                                       |                 |            |                |         |       |
| $I_\gamma^\pi$          | 6$^+$      | ~149.9                           | <0.1                                  | 1288.7          | 5$^+$     | <321.8         | 109.7   |       |
| $T_{1/2}(\Delta T_{1/2})$ | E2        | 282.84(9)                        | 1.39(13)                              | 1155.8          | 4$^+$     | 187(25)        | ≡187   |       |
| $\sum I_{\text{tot}}(\Delta I_{\text{tot}})$ | 26.9(51) |                                  |                                       |                 |            |                |         |       |

### Table 2.5

| $E_{\text{levi}}$ [keV] | $\sigma_L$ | $E_\gamma(\Delta E_\gamma)$ [keV] | $I_\gamma(\Delta I_\gamma)$ [rel. un.] | $E_{\text{levif}}$ [keV] | $I_\gamma^\pi$ | B(E2) [W.u.] | Exper. | Calc. |
|-------------------------|------------|----------------------------------|---------------------------------------|-----------------|------------|----------------|---------|-------|
| 1456.7                  |            |                                   |                                       |                 |            |                |         |       |
| $I_\gamma^\pi$          | 0$^+$      | ~106.9                           | <0.1                                  | 1349.8          | 2$^+$     | <15.56        | 0.02    |       |
| $T_{1/2}(\Delta T_{1/2})$ | E2,M1      | 490.62(4)                        | 1.5(4)                                | 966.2           | 2$^+$     | 0.12(3)        | 15.72   |       |
| $\sum I_{\text{tot}}(\Delta I_{\text{tot}})$ | 41.5(30)  |                                  |                                       |                 |            |                |         |       |

### Table 2.6

| $E_{\text{levi}}$ [keV] | $\sigma_L$ | $E_\gamma(\Delta E_\gamma)$ [keV] | $I_\gamma(\Delta I_\gamma)$ [rel. un.] | $E_{\text{levif}}$ [keV] | $I_\gamma^\pi$ | B(E2) [W.u.] | Exper. | Calc. |
|-------------------------|------------|----------------------------------|---------------------------------------|-----------------|------------|----------------|---------|-------|
| 1518.4                  |            |                                   |                                       |                 |            |                |         |       |
| $I_\gamma^\pi$          | 2$^+$      | ~61.7                            | <0.1                                  | 1456.7          | 0$^+$     | ~191.8         | 137.7   |       |
| $T_{1/2}(\Delta T_{1/2})$ |           | ~168.6                           | <0.1                                  | 1349.8          | 2$^+$     | ~1.260         | 0.007   |       |
| $\sum I_{\text{tot}}(\Delta I_{\text{tot}})$ | 50.4(32)  |                                  |                                       |                 |            |                |         |       |

### Table 2.7

| $E_{\text{levi}}$ [keV] | $\sigma_L$ | $E_\gamma(\Delta E_\gamma)$ [keV] | $I_\gamma(\Delta I_\gamma)$ [rel. un.] | $E_{\text{levif}}$ [keV] | $I_\gamma^\pi$ | B(E2) [W.u.] | Exper. | Calc. |
|-------------------------|------------|----------------------------------|---------------------------------------|-----------------|------------|----------------|---------|-------|
| 1522.4                  |            |                                   |                                       |                 |            |                |         |       |
| $I_\gamma^\pi$          | 4$^+$      | ~83.8                            | <0.1                                  | 1438.6          | 6$^+$     | <24383.3       | 2.4     |       |
| $T_{1/2}(\Delta T_{1/2})$ |           | ~172.6                           | <0.1                                  | 1349.8          | 2$^+$     | ~259.2         | 207.9   |       |
| $\sum I_{\text{tot}}(\Delta I_{\text{tot}})$ | 3.9(5)    |                                  |                                       |                 |            |                |         |       |

### Table 2.8

| $E_{\text{levi}}$ [keV] | $\sigma_L$ | $E_\gamma(\Delta E_\gamma)$ [keV] | $I_\gamma(\Delta I_\gamma)$ [rel. un.] | $E_{\text{levif}}$ [keV] | $I_\gamma^\pi$ | B(E2) [W.u.] | Exper. | Calc. |
|-------------------------|------------|----------------------------------|---------------------------------------|-----------------|------------|----------------|---------|-------|
| 1518.4                  |            |                                   |                                       |                 |            |                |         |       |
| $I_\gamma^\pi$          | 2$^+$      | ~61.7                            | <0.1                                  | 1456.7          | 0$^+$     | ~191.8         | 137.7   |       |
| $T_{1/2}(\Delta T_{1/2})$ |           | ~168.6                           | <0.1                                  | 1349.8          | 2$^+$     | ~1.260         | 0.007   |       |
| $\sum I_{\text{tot}}(\Delta I_{\text{tot}})$ | 50.4(32)  |                                  |                                       |                 |            |                |         |       |

### Table 2.9

| $E_{\text{levi}}$ [keV] | $\sigma_L$ | $E_\gamma(\Delta E_\gamma)$ [keV] | $I_\gamma(\Delta I_\gamma)$ [rel. un.] | $E_{\text{levif}}$ [keV] | $I_\gamma^\pi$ | B(E2) [W.u.] | Exper. | Calc. |
|-------------------------|------------|----------------------------------|---------------------------------------|-----------------|------------|----------------|---------|-------|
| 1522.4                  |            |                                   |                                       |                 |            |                |         |       |
| $I_\gamma^\pi$          | 4$^+$      | ~83.8                            | <0.1                                  | 1438.6          | 6$^+$     | <24383.3       | 2.4     |       |
| $T_{1/2}(\Delta T_{1/2})$ |           | ~172.6                           | <0.1                                  | 1349.8          | 2$^+$     | ~259.2         | 207.9   |       |
### Table 2.8

| \( E_{\text{levi}} \) [keV] | \( \sigma L \) | \( E_f(\Delta E_f) \) [keV] | \( I_f(\Delta I_f) \) [rel. un.] | \( E_{\text{levi}} \) [keV] | \( I_f^x \) | B(E2) [W.u.] | Exper. | Calc. |
|--------------------------|---------------|-----------------|----------------------|-----------------|---------|-------------|--------|------|
| \( T_{1/2}(\Delta T_{1/2}) \) | \( \sum I_{\text{tot}}(\Delta \sum I_{\text{tot}}) \) | ~81.4 | <0.1 | 1522.4 | 4+ | <6.580 | 0.0001 |
| \( \sum I_{\text{tot}}(\Delta \sum I_{\text{tot}}) \) | 4.8(9) | ~165.2 | <0.1 | 1438.6 | 6+ | <0.191 | 0.083 |
| E2 | 448.05(9) | 1.0(5) | 1155.8 | 4+ | <6.580 | 0.0001 |
| E2,M1 | 554.59(7) | 1.17(14) | 1049.1 | 3+ | <6.580 | 0.0001 |
| E2,1/2 | 637.8(4) | 1.5(5) | 966.2 | 2+ | <6.580 | 0.0001 |
| E2 | 1022.6(1) | 1.95(25) | 581.1 | 6+ | <6.580 | 0.0001 |
| E2 | 1319.95(25) | 1.0(5) | 283.8 | 4+ | <6.580 | 0.0001 |
| ~1517.0 | <0.1 | 86.8 | 2+ | <6.580 | 0.0001 |

### Table 2.9

| \( E_{\text{levi}} \) [keV] | \( \sigma L \) | \( E_f(\Delta E_f) \) [keV] | \( I_f(\Delta I_f) \) [rel. un.] | \( E_{\text{levi}} \) [keV] | \( I_f^x \) | B(E2) [W.u.] | Exper. | Calc. |
|--------------------------|---------------|-----------------|----------------------|-----------------|---------|-------------|--------|------|
| \( T_{1/2}(\Delta T_{1/2}) \) | \( \sum I_{\text{tot}}(\Delta \sum I_{\text{tot}}) \) | ~84.5 | <0.1 | 1522.4 | 4+ | <6.580 | 0.0001 |
| \( \sum I_{\text{tot}}(\Delta \sum I_{\text{tot}}) \) | 5.1(4) | ~318.2 | <0.1 | 1288.7 | 5+ | <6.580 | 0.0001 |
| E2 | 640.1(1) | 0.2(1) | 966.8 | 8+ | <6.580 | 0.0001 |
| E2 | 1025.76(7) | 1.48(15) | 581.1 | 6+ | <6.580 | 0.0001 |
| E2 | 1322.86(23) | 3.4(4) | 283.8 | 4+ | <6.580 | 0.0001 |

### Table 2.10

| \( E_{\text{levi}} \) [keV] | \( \sigma L \) | \( E_f(\Delta E_f) \) [keV] | \( I_f(\Delta I_f) \) [rel. un.] | \( E_{\text{levi}} \) [keV] | \( I_f^x \) | B(E2) [W.u.] | Exper. | Calc. |
|--------------------------|---------------|-----------------|----------------------|-----------------|---------|-------------|--------|------|
| \( T_{1/2}(\Delta T_{1/2}) \) | \( \sum I_{\text{tot}}(\Delta \sum I_{\text{tot}}) \) | ~89.5 | <0.2 | 1518.4 | 2+ | <2250.7 | 193.3 |
| \( \sum I_{\text{tot}}(\Delta \sum I_{\text{tot}}) \) | 3.5(8) | ~169.3 | <0.1 | 1438.6 | 6+ | <46.4 | 2.8 |
| (E2) | 319.19(9) | 0.31(15) | 1288.7 | 5+ | <2825.7 | 0.2 |
| (E2) | 452.0(3) | 0.33(12) | 1155.8 | 4+ | <2250.7 | 193.3 |
| (E2) | 558.8(2) | 0.65(9) | 1049.1 | 3+ | <2825.7 | 0.2 |
| (E2) | 641.7(1) | 1.0(5) | 966.2 | 2+ | <2825.7 | 0.2 |
| ~1026.8 | <0.2 | 581.1 | 6+ | <0.01 | 0.001 |
| ~1324.1 | <0.2 | 283.8 | 4+ | <0.01 | 0.001 |
| ~1521.1 | <0.1 | 86.8 | 2+ | <0.01 | 0.001 |

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**Note:** The tables are not transcribed in full due to the limitations of text-based processing. The tables are provided in a tabular format with columns for energy levels, uncertainties, and other relevant data. The entries are formatted to match the style and structure of the original documents.
### Table 2.11

| $E_{(lev)}$ [keV] | $\sigma L$ | $E_{\gamma}(\Delta E_{\gamma})$ [keV] | $I_{\gamma}(\Delta I_{\gamma})$ [rel. un.] | $E_{(lev)}$ [keV] | $I_{\gamma}^2$ | B(E2) [W.u.] | Exper. | Calc. |
|-------------------|------------|-------------------------------------|----------------------------------|-------------------|-------------|---------------|--------|------|
| $I_{1}^\pi$       | 7$_1^+$    | ~178.7                             | <0.1                             | 1438.6            | 6$_1^+$     | <758          | 80     |      |
| $T_{1/2}(\Delta T_{1/2})$ | 328.6(1) | 2.2(4)                             | 1288.7                          | 5$_1^+$           | 795(185)    | 205          |        |      |
| $\sum I_{tot}(\Delta \sum I_{tot})$ | 7.5(6)   | 0.6(1)                             | 966.8                           | 8$_1^+$           | 7.1(16)     | 5.5          |        |      |
| E2                | 1036.22(5) | 4.7(4)                             | 581.1                           | 6$_1^+$           | 5.4(7)      | =5.4         |        |      |

### Table 2.12

| $E_{(lev)}$ [keV] | $\sigma L$ | $E_{\gamma}(\Delta E_{\gamma})$ [keV] | $I_{\gamma}(\Delta I_{\gamma})$ [rel. un.] | $E_{(lev)}$ [keV] | $I_{\gamma}^2$ | B(E2) [W.u.] | Exper. | Calc. |
|-------------------|------------|-------------------------------------|----------------------------------|-------------------|-------------|---------------|--------|------|
| $I_{1}^\pi$       | 0$_1^+$    | ~189.8                             | <0.2                             | 1518.4            | 2$_1^+$     | <0.717        | 0.011  |      |
| $T_{1/2}(\Delta T_{1/2})$ | ~358.4 | <0.2                              | 1349.8                          | 2$_1^+$           | <0.03       | 2.22          |        |      |
| $\sum I_{tot}(\Delta \sum I_{tot})$ | 12.7(4)  | <0.1                              | 966.2                           | 2$_1^+$           | <0.0005     | 0.1495        |        |      |
| E2                | 1621.36(5) | 12.7(4)                           | 86.8                            | 2$_1^+$           | 0.001(1)    | =0.001        |        |      |

### Table 2.13

| $E_{(lev)}$ [keV] | $\sigma L$ | $E_{\gamma}(\Delta E_{\gamma})$ [keV] | $I_{\gamma}(\Delta I_{\gamma})$ [rel. un.] | $E_{(lev)}$ [keV] | $I_{\gamma}^2$ | B(E2) [W.u.] | Exper. | Calc. |
|-------------------|------------|-------------------------------------|----------------------------------|-------------------|-------------|---------------|--------|------|
| $I_{1}^\pi$       | 2$_5^+$    | ~48.7                              | <0.1                             | 1708.2            | 0$_2^+$     | <17.1         | 6.2    |      |
| $T_{1/2}(\Delta T_{1/2})$ | ~62.5  | <0.1                              | 1694.4                          | 4$_6^+$           | <4.9        | 130.0         |        |      |
| $\sum I_{tot}(\Delta \sum I_{tot})$ | 52.4(2) | <0.2                              | 1607.9                          | 4$_2^+$           | <0.13       | 0.35          |        |      |
| E2,M1             | 234.5(1)  | 1.0(5)                             | 1522.4                          | 4$_2^+$           | 0.07(5)     | 0.53          |        |      |
|                   | ~238.4    | <0.1                              | 1518.4                          | 2$_4^+$           | <0.006      | 4.289         |        |      |
|                   | ~300.2    | <0.2                              | 1456.7                          | 0$_1^+$           | <0.004      | 2.399         |        |      |
|                   | ~407.1    | <0.1                              | 1349.8                          | 2$_2^+$           | <0.0004     | 8.4126        |        |      |
|                   | ~476.9    | <0.1                              | 1280.0                          | 0$_2^+$           | <0.0003     | 5.4849        |        |      |
|                   | ~601.1    | <0.2                              | 1155.8                          | 4$_3^+$           | <0.001 0.0001 | 2626       |        |      |
|                   | ~707.8    | <1.0                              | 1049.1                          | 3$_1^+$           | <0.0003     | 0.5650        |        |      |
|                   | ~790.7    | <2.0                              | 966.2                           | 2$_3^+$           | <0.000001   | 0.2769        |        |      |
| E2                | 1473.06(3) | 29.7(6)                           | 283.8                           | 4$_2^+$           | 0.0002(1)\equiv | =0.0002       |        |      |
| E2                | 1670.1(1) | 14(2)                             | 86.8                            | 2$_3^+$           | 0.000105     | 0.0025        |        |      |
|                   | ~1756.9   | <0.1                              | 0.0                             | 0$_1^+$           | <0.000001    | 0.0015        |        |      |
Table 2.14

| \( E_{(\text{lev})i} \) [keV] | 1802.2 | \( \sigma L \) | \( E_{\gamma}(\Delta E_{\gamma}) \) [keV] | \( I_{\gamma}(\Delta I_{\gamma}) \) [rel. un.] | \( E_{(\text{lev})f} \) [keV] | \( I_{\gamma}^x \) | B(E2) [W.u.] | Exper. | Calc. |
|-------------------------------|--------|-------------|-------------------------------|-----------------|-----------------|--------|----------------|--------|--------|
| \( T_{1/2}(\Delta T_{1/2}) \) | M1+E2  | 107.87(2)   | 12.2(2)                       | 1694.4          | 4+               | <267.6 | 273.2          |        |        |
| \( \Sigma I_{tot}(\Delta\Sigma I_{tot}) \) | 495(25) | 184.9       | 0.1                           | 1617.3          | 7+               | <4.541 | 0.224          |        |        |
|                               |        | -194.3      | 0.1                           | 1607.9          | 4+               | <3.544 | 0.007          |        |        |
|                               |        | -195.3      | 0.1                           | 1606.9          | 6+               | <3.4540| 0.0033         |        |        |
|                               |        | -198.5      | 0.2                           | 1603.8          | 4+               | <6.4   | 221.4          |        |        |
| E2                            |        | 279.76(15)  | 0.4(2)                        | 1522.4          | 4+               | 2.3(12) | 0.0006         |        |        |
| E2,M1                         |        | 363.66(3)   | 7.3(2)                        | 1438.6          | 6+               | 11.9(6)| 1.5            |        |        |
| E2                            |        | 513.51(4)   | 80(3)                         | 1288.7          | 5+               | 8.3(9) | 4.6            |        |        |
| E2                            |        | 646.40(8)   | 176(24)                       | 1155.8          | 4+               | 15.3(22)| 8.1           |        |        |
| E2                            |        | 753.11(2)   | 184(4)                        | 1049.1          | 3+               | 7.46(23)| ≡7.46          |        |        |
| E2,M1                         |        | 1221.21(5)  | 2.8(3)                        | 581.1           | 6+               | 0.010(1)| 0.0000         |        |        |
| E2                            |        | 1518.41(3)  | 4.5(3)                        | 283.8           | 4+               | 0.005(1)| 0.0000         |        |        |

Table 2.15

| \( E_{(\text{lev})i} \) [keV] | 1869.5 | \( \sigma L \) | \( E_{\gamma}(\Delta E_{\gamma}) \) [keV] | \( I_{\gamma}(\Delta I_{\gamma}) \) [rel. un.] | \( E_{(\text{lev})f} \) [keV] | \( I_{\gamma}^x \) | B(E2) [W.u.] | Exper. | Calc. |
|-------------------------------|--------|-------------|-------------------------------|-----------------|-----------------|--------|----------------|--------|--------|
| \( T_{1/2}(\Delta T_{1/2}) \) | 2s+    | -112.7      | <0.1                          | 1756.9          | 2+               | <0.58  | 7.86            |        |        |
| \( \Sigma I_{tot}(\Delta\Sigma I_{tot}) \) | 36.5(13) | -161.3      | <0.1                          | 1708.2          | 0+               | <0.095 | 108.248         |        |        |
|                               |        | -175.2      | <0.1                          | 1694.4          | 4+               | <0.64  | 7.578           |        |        |
|                               |        | -261.6      | <0.1                          | 1607.9          | 4+               | <0.0086| 0.0032          |        |        |
|                               |        | -265.8      | <0.1                          | 1603.8          | 4+               | <0.0079| 0.0002          |        |        |
|                               |        | -347.1      | <0.1                          | 1522.4          | 4+               | <0.0021| 1.2948          |        |        |
|                               |        | -351.1      | <0.1                          | 1518.4          | 2+               | <0.0020| 0.0086          |        |        |
|                               |        | -412.8      | <0.1                          | 1456.7          | 0+               | <0.0009| 0.0020          |        |        |
|                               |        | -519.7      | <0.5                          | 1349.8          | 2+               | <0.0014| 0.5669          |        |        |
|                               |        | -589.6      | <0.1                          | 1280.0          | 0+               | <0.0001| 0.3491          |        |        |
|                               |        | -713.7      | <0.1                          | 1155.8          | 4+               | <0.0001| 0.0351          |        |        |
|                               |        | 820.4       | 0.96(9)                       | 1049.1          | 3+               | 0.0003(3)| 0.0721        |        |        |
|                               |        | ~903.4      | <0.3                          | 966.2           | 2+               | <0.0001| 0.0382          |        |        |
| E2                            |        | 1585.6(2)   | 1.5(3)                        | 283.8           | 4+               | 0.0002(1)| 0.00002         |        |        |
| E2                            |        | 1782.73(4)  | 17.1(7)                       | 86.8            | 2+               | 0.0001(1)| ≡0.0001        |        |        |
| E2,M1                         |        | 1869.55(6)  | 7.1(3)                        | 0.0             | 0+               | 0.00000| 0.00000         |        |        |
Table 2.16

| $E_{\text{levi}}$ [keV] | $\sigma L$ | $E_f(\Delta E_f)$ [keV] | $I_f(\Delta I_f)$ [rel. un.] | $E_{\text{levi}f}$ [keV] | $I_f^\pi$ | $B(E2)$ [W.u.] | Exper. | Calc. |
|-------------------------|-----------|--------------------------|-------------------------------|--------------------------|---------|--------------|--------|-------|
|                         |           |                          |                               |                          |         |              |        |       |
| $I_1^\pi$               | 3_{+}    | 33.6                     | <0.1                          | 1869.5                   | 2_{+}   | <10544.2     | 11.8   |       |
| $T_{1/2}(\Delta T_{1/2})$ |            | -101.0                   | <0.1                          | 1802.2                   | 5_{+}   | <43.39       | 7.61   |       |
| $\sum I_{\text{tot}}(\Delta \sum I_{\text{tot}})$ |         | 25.4(8)                  |                               |                          |         |              |        |       |
|                         |           |                          |                               |                          |         |              |        |       |
| $E_2$                   | 1619.36(8) | 7.5(5)                   | 283.8                         | 4_{+}                    | 0.0031(2) | 0.0015       |        |       |
| $E_2$                   | 1816.39(3) | 11.3(3)                  | 86.8                          | 2_{+}                    | 0.0026(1) ≡ ≡0.0026 |       |        |       |

Table 2.17

| $E_{\text{levi}}$ [keV] | $\sigma L$ | $E_f(\Delta E_f)$ [keV] | $I_f(\Delta I_f)$ [rel. un.] | $E_{\text{levi}f}$ [keV] | $I_f^\pi$ | $B(E2)$ [W.u.] | Exper. | Calc. |
|-------------------------|-----------|--------------------------|-------------------------------|--------------------------|---------|--------------|--------|-------|
|                         |           |                          |                               |                          |         |              |        |       |
| $I_1^\pi$               | 6_{+}    | 126.94(2)                | 2.18(8)                       | 1802.2                   | 5_{+}   | 787(64)      | 0.0034 |       |
| $T_{1/2}(\Delta T_{1/2})$ |            | -128.0                   | <0.1                          | 1801.2                   | 8_{+}   | <34.64       | 2.66   |       |
| $\sum I_{\text{tot}}(\Delta \sum I_{\text{tot}})$ |         | 28.9(23)                 |                               |                          |         |              |        |       |
|                         |           |                          |                               |                          |         |              |        |       |
| E2,M1                   | 234.81(6) | 1.0(5)                   | 1694.4                        | 4_{+}                    | 16.67(842) | 0.63         |        |       |
| E2+(M1)                 | 311.90(6) | 0.91(7)                  | 1617.3                        | 7_{+}                    | 3.67(283) | 5.33         |        |       |
|                         |           |                          |                               |                          |         |              |        |       |
| E2,M1                   | 490.62(4) | 5(1)                     | 1438.6                        | 6_{+}                    | 2.09(45) | 4.56         |        |       |
| (E2)                    | 640.61(6) | 9(2)                     | 1288.7                        | 5_{+}                    | 0.99(23) | 1.80         |        |       |
| E2                      | 773.37(8) | 5.75(24)                 | 1155.8                        | 4_{+}                    | 0.25(1) ≡ ≡0.25 |       |        |       |
|                         |           |                          |                               |                          |         |              |        |       |
|                         |           |                          |                               |                          |         |              |        |       |
|                         |           |                          |                               |                          |         |              |        |       |
|                         |           |                          |                               |                          |         |              |        |       |
|                         |           |                          |                               |                          |         |              |        |       |
### Table 2.18

| $E_{(lev)}$ [keV] | $\sigma L$ | $E_{\gamma}(\Delta E_{\gamma})$ [keV] | $I_{\gamma}(\Delta I_{\gamma})$ [rel. un.] | $E_{(lev)f}$ [keV] | $I_{f}^\pi$ | B(E2) [W.u.] | Exper. | Calc. |
|-------------------|------------|--------------------------------------|--------------------------------------------|-------------------|------------|-------------|--------|-------|
| $I_1^\pi$         | 5$^+_1$    | ~120.2                               | <0.05                                      | 2074.2            | 7$^+_1$    | <55.1       | 4.74   |       |
| $T_{1/2}(\Delta T_{1/2})$ |           | ~265.2                               | <0.2                                       | 1929.2            | 6$^+_3$    | <4.22       | 3.80   |       |
| $\Sigma I_{tot}(\Delta I_{tot})$ |           | 19.7(8)                              |                                            |                   |            |             |        |       |
| ~291.2            | <0.1       | 1903.2                               | 3$^+_2$                                   | <1.32             | 113.66     |             |        |       |
| ~392.2            | <1.0       | 1802.2                               | 5$^+_3$                                   | <2.98             | 1.54       |             |        |       |
| ~474.0            | <0.2       | 1720.4                               | 6$^+_4$                                   | <0.23             | 4.89       |             |        |       |
| ~500.1            | <0.1       | 1694.4                               | 4$^+_6$                                   | <0.089            | 110.99     |             |        |       |
| ~577.1            | <0.2       | 1617.3                               | 7$^+_7$                                   | <0.087            | 0.515      |             |        |       |
| ~586.5            | <0.1       | 1607.9                               | 4$^+_8$                                   | <0.04             | 2.95       |             |        |       |
| ~587.5            | <0.1       | 1606.9                               | 6$^+_9$                                   | <0.04             | 5.98       |             |        |       |
| ~590.7            | <0.1       | 1603.8                               | 4$^+_3$                                   | <0.038            | 0.128      |             |        |       |
| ~672.0            | <0.2       | 1522.4                               | 4$^+_4$                                   | <0.04             | 7.65       |             |        |       |
| ~755.6(3)         | 0.3(1)     | 1438.6                               | 6$^+_5$                                   | 0.034(12)         | 0.200      |             |        |       |
| (E2) 905.76(16)   | 5.2(4)     | 1288.7                               | 5$^+_6$                                   | 0.236(36)         | 0.092      |             |        |       |
| E2 1038.59(4)     | 6.7(5)     | 1155.8                               | 4$^+_7$                                   | 0.154(16)=        | =0.154     |             |        |       |
| E2,M1 1145.33(4)  | 5.4(2)     | 1049.1                               | 3$^+_8$                                   | 0.076(10)         | 0.120      |             |        |       |
| ~1613.4           | <0.1       | 581.1                                | 6$^+_9$                                   | <0.0003           | 0.0019     |             |        |       |
| 1910.58(6)        | 0.79(9)    | 283.8                                | 4$^+_3$                                   | 0.0009(1)         | 0.0019     |             |        |       |

### Table 2.19

| $E_{(lev)}$ [keV] | $\sigma L$ | $E_{\gamma}(\Delta E_{\gamma})$ [keV] | $I_{\gamma}(\Delta I_{\gamma})$ [rel. un.] | $E_{(lev)f}$ [keV] | $I_{f}^\pi$ | B(E2) [W.u.] | Exper. | Calc. |
|-------------------|------------|--------------------------------------|--------------------------------------------|-------------------|------------|-------------|--------|-------|
| $I_1^\pi$         | 6$^+_6$    | ~120.6                               | <0.1                                       | 1978.3            | 8$^+_1$    | <0.024(4)   | 1.909  |       |
| $T_{1/2}(\Delta T_{1/2})$ |           | ~265.2                               | <0.2                                       | 1929.2            | 6$^+_3$    | <4.22       | 3.80   |       |
| $\Sigma I_{tot}(\Delta I_{tot})$ |           | 6.8(6)                               |                                            |                   |            |             |        |       |
| ~417.0            | <0.1       | 2681.9                               | 5$^+_7$                                   | <3.2890           | 0.0000     |             |        |       |
| ~904.5            | <1.0       | 2194.4                               | 5$^+_8$                                   | <0.685            | 79.735     |             |        |       |
| ~1024.7           | <0.1       | 2074.2                               | 7$^+_9$                                   | <0.037            | 4.713      |             |        |       |
| ~1169.7           | <0.1       | 1929.2                               | 6$^+_8$                                   | <0.019            | 4.752      |             |        |       |
| ~1296.7           | <0.1       | 1802.2                               | 5$^+_9$                                   | <0.011            | 0.257      |             |        |       |
| E2 1297.66(18)    | 0.5(2)     | 1801.2                               | 8$^+_1$                                   | 0.056(24)         | 0.490      |             |        |       |
| 1378.4(3)         | 0.8(3)     | 1720.4                               | 6$^+_2$                                   | 0.067(27)         | 1.851      |             |        |       |
| ~1404.5           | <0.1       | 1694.4                               | 4$^+_3$                                   | <0.008            | 137.009    |             |        |       |
| E2 1481.9(2)      | 3.4(3)     | 1617.3                               | 7$^+_1$                                   | 0.197=            | =0.197     |             |        |       |
| ~1491.0           | <0.1       | 1607.9                               | 4$^+_5$                                   | <0.006            | 0.487      |             |        |       |
| ~1492.0           | <0.1       | 1606.9                               | 6$^+_6$                                   | <0.006            | 9.276      |             |        |       |
| ~1495.1           | <0.1       | 1603.8                               | 4$^+_3$                                   | <0.006            | 0.0076     |             |        |       |
| ~1576.5           | <0.3       | 1522.4                               | 4$^+_3$                                   | <0.013            | 2.083      |             |        |       |
| ~1600.3           | <0.1       | 1438.6                               | 6$^+_2$                                   | <0.003            | 0.170      |             |        |       |
| ~1810.2           | <0.1       | 1288.7                               | 5$^+_7$                                   | <0.002            | 0.089      |             |        |       |
| ~1943.1           | <0.1       | 1155.8                               | 4$^+_3$                                   | <0.002            | 0.121      |             |        |       |
| 2132.1(3)         | 0.5(1)     | 966.8                                | 8$^+_1$                                   | 0.0047(12)        | 0.0005     |             |        |       |
| 2518.7(9)         | 0.7(2)     | 581.1                                | 6$^+_2$                                   | 0.0029(9)         | 0.0029     |             |        |       |
| ~2815.1           | <0.1       | 283.8                                | 4$^+_3$                                   | <0.002            | 0.0003     |             |        |       |