SPECTRA AND ELECTROMAGNETIC PROPERTIES
OF THE NEUTRON-EXCESS NUCLEUS $^{132}\text{In}$

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Abstract
Spectra of levels and transition rates are calculated for the odd–odd particle–hole neutron excess nucleus $^{132}\text{In}$ in the framework of the RPA approach.

By now, nuclei far from the stability line including those close to the doubly magical ones are of the great both experimental and theoretical interest. In our previous papers [1, 2] we studied long chains of isotones having $N = 82$ and $N = 50$, while in the papers [3, 4] we considered chains of isotopes with $Z = 28$ and $Z = 50$, that include $^{78}\text{Ni}$, $^{100}\text{Sn}$ and $^{132}\text{Sn}$. The $^{132}\text{Sn}$ and some neighboring nuclei were considered in the papers [5, 6]. Odd–odd nuclei $^{132}\text{Sb}$ and $^{134}\text{Sb}$, for which experimental information was available, were studied by us in details in papers [7, 8] and [9, 10]. Recently, there appeared experimental research [11], where the authors determined spectrum of low-lying levels in odd–odd particle–hole nucleus $^{132}\text{In}$, which is close to the doubly-magical $^{132}\text{Sn}$. Here, we carry out detailed theoretical research of $^{132}\text{In}$ including calculation of the spectra of levels and electromagnetic characteristics of this nucleus.

The corresponding equations for determination of spectrum of levels may be obtained by applying the algebra characteristic to the RPA approach, or by applying the Green functions method. In the last case, the eigenvalues correspond to the poles of the particle-hole Green function, where the particle-hole two-body matrix elements are used as an irreducible block in the particle-hole channel (this method is nothing but the ladder approximation in the case of particle–particle Green function).

For odd–odd particle-hole nuclei corresponding equations that define spectrum of levels and amplitudes of states have the form

$$
\begin{pmatrix}
A & B \\
B & C
\end{pmatrix}
\begin{pmatrix}
x \\
y
\end{pmatrix}
= \omega_k
\begin{pmatrix}
x \\
-y
\end{pmatrix},
$$

(1)

where

$$
\begin{pmatrix}
x_{ab} \\
y_{a'b'}
\end{pmatrix} = f_{\alpha\beta}(\omega_k) = \langle JM(\omega_k) | \sum_{m_\alpha m_\beta} C_{J_\alpha J_\beta}^{JM} \langle a_{\alpha\ell_\alpha m_\alpha} \rangle \langle a_{\beta\ell_\beta m_\beta} \rangle (1)^{\ell_\beta + j_\beta - m_\beta} a^{+}_{a_{\alpha\ell_\alpha m_\alpha} a_{\beta\ell_\beta m_\beta}} | 0 \rangle.
$$

(2)
Here, dashed indices correspond to states below the Fermi surface, those without dashes – to states above the Fermi surface, while \(|\bar{0}\rangle\) corresponds to the correlated ground state of the magical nucleus. In Eq. (1),

\[
A_{\alpha\beta,\mu\nu} = \langle j_{\alpha} j_{\beta} | \hat{\vartheta} | j_{\mu} j_{\nu} \rangle + (\varepsilon_\alpha - \varepsilon_\beta)\delta_{\alpha\mu}\delta_{\beta\nu}; \quad B_{\alpha\beta,\mu\nu} = \langle j_{\alpha} j_{\beta} | \hat{\vartheta} | j_{\mu} j_{\nu} \rangle;
\]

\[
C_{\alpha\beta,\mu\nu} = \langle j_{\alpha} j_{\beta} | \hat{\vartheta} | j_{\mu} j_{\nu} \rangle - (\varepsilon_\alpha - \varepsilon_\beta)\delta_{\alpha\mu}\delta_{\beta\nu}.
\]

(3)

If we represent the two-body interaction \(\hat{\vartheta}\) in the form \(\hat{\vartheta} = \hat{V}^0 + \hat{V}^1 \tilde{r}_1 \tilde{r}_2\), then we have for the particle-hole matrix elements entering formulas (3) the expression

\[
a \langle j_{\alpha} j_{\beta} | \hat{\vartheta} | j_{\mu} j_{\nu} \rangle_a = -\sum_{J_0} (2J_0 + 1)W[j_{\nu} j_{\mu} j_{\alpha} j_{\beta}; J_0] \times
\]

\[
\times \left[ \langle j_{\nu} j_{\alpha} J_0 | \hat{V}^0 - \hat{V}^1 | j_{\beta} j_{\mu} J_0 \rangle + (-1)^{j_\beta + j_\mu + J_0 + 1}\langle j_{\nu} j_{\alpha} J_0 | 2\hat{V}^1 | j_{\mu} j_{\beta} J_0 \rangle \right] (1)^{\ell_\beta + \ell_\nu}.
\]

(4)

If we consider nucleus of the type “magical +p − n”, then the indices “\(\alpha, \mu\) correspond to protons (\(p\)), while “\(\beta, \nu\)” – to neutrons (\(n\)). In this case, the “upper” solutions \(\omega_k^+\) of Eq. (1) correspond to the nucleus “magical+p − n”, while the “lower” ones \(\omega_k^-\) – to nucleus “magical −p + n”. The solutions of Eq. (1) are connected with the excitation energies by the relations

\[
E_k(p + n^{-1}) = \omega_k^+ + B(Z + 1, N - 1) - B(Z, N),
\]

\[
E_k(p^{-1} + n) = -\omega_k^- + B(Z - 1, N + 1) - B(Z, N),
\]

(5)

where \(B\) are corresponding ground state binding energies.

For nucleus “magical +p − n” amplitudes “\(x\)” are large, while amplitudes “\(y\)” are small, and they appear only to the ground state correlations. At once, the situation is reverse if we consider nucleus of the type “magical−p + n” (\(\omega_k = \omega_k^-\)).

Amplitudes “\(x\)” and “\(y\)” are normalized by the relation

\[
\left| \sum_{\alpha\beta} x^J_{j_\alpha j_\beta}(\omega_{k_1})x^J_{j_\alpha j_\beta}(\omega_{k_2}) - \sum_{\alpha\beta} y^J_{j_\alpha j_\beta}(\omega_{k_1})y^J_{j_\alpha j_\beta}(\omega_{k_2}) \right| = \delta_{k_1k_2}.
\]

(6)

If we define the reduced matrix element by the relation

\[
\langle J' M' | \hat{T}_{\lambda \nu} | JM \rangle = (-1)^{J' - M'} \binom{J'}{M'} \binom{\lambda}{\mu} \langle J'|\hat{T}_{\lambda}\rangle \langle |JM\rangle, \]

(7)

then the reduced transition matrix element for the transition \(|J(\omega_1^+)\rangle \to |J'(\omega_2^+)\rangle\) has the form

\[
\langle J'(\omega_2^+)\| \hat{m}(\lambda) \| J(\omega_1^+)\rangle = [(2J + 1)(2J' + 1)]^{1/2} \left\{ \sum_{\alpha\beta\mu} (x^J_{j_\alpha j_\beta}(\omega_1^+)x^J_{j_\alpha j_\beta}(\omega_1^+)} - \right.
\]

\[
- y^J_{j_\alpha j_\beta}(\omega_1^+)y^J_{j_\alpha j_\beta}(\omega_1^+) W[\lambda j_\mu j_{\beta}; j_\alpha J'] \langle j_\mu | \hat{m}(\lambda) \| j_\alpha \rangle \pm
\]

\[
\pm \sum_{\alpha\beta\nu} (x^J_{j_\alpha j_\beta}(\omega_1^+))x^J_{j_\alpha j_\beta}(\omega_1^+) - y^J_{j_\alpha j_\beta}(\omega_1^+)y^J_{j_\alpha j_\beta}(\omega_1^+)) \times
\]

\[
\times W[\lambda j_\beta J'; j_\nu J] \langle j_\nu | \hat{m}(\lambda) \| j_\beta \rangle \right\},
\]

(8)
where the sign (+) refers to $\lambda \Lambda$, while (−) to $\lambda \lambda$ transitions. For nucleus “magical $-p+n$”, when $\omega_k = \omega_k$, the expression (8) should be multiplied by $(-1)\lambda$.

The quantities “$\varepsilon$” entering Eq. (3) are single-particle energies generated by the mean field potential of the form,

$$U(\vec{r}, \vec{s}) = U \cdot f(r) + U_{ts} \cdot \frac{1}{r} \frac{df}{dr} \vec{t} \vec{s}; \quad f(r) = \frac{1}{1 + \exp[(r-R)/a]},$$

(9)

where

$$U = V_0 \left(1 - \beta \frac{N - Z}{A} t_Z \right), \quad U_{ts} = V_{ts} \left(1 - \beta_{ts} \frac{N - Z}{A} t_Z \right), \quad R = r_0 A^{1/3},$$

$t_Z = 1/2$, for neutrons and $t_Z = -1/2$ for protons. In the case of protons the Coulomb potential of the uniformly charged sphere with radius $R_c = r_c A^{1/3}$ was added to (9).

The potential (9) was used by us in [12] and it ensures a good description of single-particle spectra in nuclei near closed shells. In our calculations, we used the following values of the entering parameters: $V_0 = -51.55$ MeV, $V_{ts} = 32.4$ MeV $\cdot$ fm$^2$, $a(p) = 0.63$ fm, $a(n) = 0.66$ fm, $\beta = 1.31$, $\beta_{ts} = -0.6$, $r_0 = 1.27$ fm, $r_c = 1.25$ fm. For the better description of data on $^{132}$In, here in our calculations we used experimental values of the single-particle energies, obtained from the data on the excitation and binding energies of the corresponding nuclei, if these data are available, see [13–16]. These single-particle energies are close to those generated by the potential (9).

The two-body interaction used by us here has the form

$$\hat{\vartheta} = \hat{V}^0 + \hat{V} \tilde{\tau}_1 \tilde{\tau}_2 = \left( V + V_\sigma \tilde{\sigma}_1 \tilde{\sigma}_2 + V_\tau \tilde{\tau}_1 \tilde{\tau}_2 + V_\tau \tilde{\sigma}_1 \tilde{\sigma}_2 \tilde{\tau}_1 \tilde{\tau}_2 + V_\tau \tilde{\tau}_1 \tilde{\tau}_2 S_{12} \tilde{\tau}_1 \tilde{\tau}_2 \right) \times$$

$$= \exp \left(-\frac{r_{12}}{r_0^2} \right) + \frac{2}{r_0^2} \left( \frac{1}{2} - \hat{t}_Z(1) \right)\left( \frac{1}{2} - \hat{t}_Z(2) \right).$$

(10)

In our calculations, we used two sets of parameters. The interaction RPA1 corresponds to the following values of parameters: $V = -9.95$, $V_\sigma = 2.88$, $V_\tau = -1.47$, $V_\tau = 5.90$, $V_\tau = 4.91$, $V_\tau = 1.51$ (all these values are in MeV), and $r_0 = 1.8$ fm. These parameters were defined by us before [17–19] from the description of different experimental data near $^{208}$Pb and $^{146}$Gd.

In the RPA calculations of long chains of isotopes and isotones we used also the interaction RPA2 of the same form (10), but with the parameters $V = -16.65$, $V_\sigma = 2.33$, $V_\tau = -3.00$, $V_\tau = 3.35$, $V_\tau = 4.33$, $V_\tau = 3.00$ (MeV), and $r_0 = 1.75$ fm. In the case of identical particles this interaction coincides with that from the paper [20]. The RPA2 interaction also well reproduces the pattern of proton–neutron multiplet splitting in odd-odd nuclei close to $^{208}$Pb.

Electromagnetic moments and transition rates were calculated by using the effective multipole operators of the form

$$\hat{m}_{2\mu}(E2) = e^{\mu \lambda = 2}_{\mu = 2}(e ff) \cdot r^2 Y_{2\mu} (\theta, \phi),$$

$$\hat{m}_{1\mu}(M1) = \mu_N \cdot \sqrt{\frac{3}{4\pi}} \left[ g^{\mu \lambda = 2}_{\mu = 2}(e ff) \cdot \ell + g^{\mu \lambda = 2}_{\mu = 2}(e ff) \cdot \ell + g_2 \tau_3 r^2 Y_{2 \otimes \phi} \right],$$

(11)

Here, the values of gyromagnetic ratios and of the effective charges were the same as in our previous papers [18], notably $e^{\mu \lambda = 2}_{\lambda = 2}(e ff) = 1.6|e|$, $e^{\mu \lambda = 2}_{\lambda = 2}(e ff) = 0.9|e|$, $g^{\mu \lambda = 2}_{\mu = 2}(e ff) = 1.102$, $g^{\mu \lambda = 2}_{\mu = 2}(e ff) = -0.005$, $g^{\mu \lambda = 2}_{\mu = 2}(e ff) = 3.79$, $g^{\mu \lambda = 2}_{\mu = 2}(e ff) = -2.04$ and $g_2 = -0.031 \text{ fm}^{-2}$. In Eq. (11) $\tau_3 = +1$ for neutrons and $\tau_3 = -1$ for protons.
Table 1: Energies (in MeV) and electromagnetic moments of the positive parity levels in $^{132}$In.
Magnetic moments are in the units of $\mu_N$, while the quadrupole moments are in the units of $|e| \cdot \text{fm}^2$. Electromagnetic moments are calculated by using the interaction RPA2.

| Level | Energy RPA1 | Energy RPA2 | Magnetic moment | Quadrupole moment | Leading configuration |
|-------|-------------|-------------|-----------------|-------------------|----------------------|
| $0^+_1$ | 1.852 | 1.799 | 0.000 | 0.000 | $\pi^2p_{1/2}, \nu^3p_{1/2}$ |
| $1^+_1$ | 1.511 | 1.563 | $-0.110 \ E+01$ | $-0.774 \ E+01$ | $\pi^2p_{1/2}, \nu^3p_{3/2}$ |
| $1^+_2$ | 1.954 | 1.982 | 0.419 $\ E+00$ | 0.958 $\ E+00$ | $\pi^2p_{1/2}, \nu^3p_{1/2}$ |
| $2^+_1$ | 1.474 | 1.509 | $-0.838 \ E+00$ | $-0.157 \ E+02$ | $\pi^2p_{1/2}, \nu^3p_{3/2}$ |
| $2^+_2$ | 2.083 | 2.084 | $-0.254 \ E+01$ | $-0.910 \ E+01$ | $\pi^2p_{3/2}, \nu^2f_{7/2}$ |
| $3^+_1$ | 0.488 | 0.507 | $-0.137 \ E+01$ | $-0.216 \ E+02$ | $\pi^2p_{1/2}, \nu^2f_{7/2}$ |
| $3^+_2$ | 1.848 | 1.871 | $-0.586 \ E+00$ | $-0.213 \ E+02$ | $\pi^2p_{3/2}, \nu^2f_{7/2}$ |
| $4^+_1$ | 0.510 | 0.533 | $-0.819 \ E+00$ | $-0.251 \ E+02$ | $\pi^2p_{1/2}, \nu^2f_{7/2}$ |
| $4^+_2$ | 1.743 | 1.746 | 0.315 $\ E+00$ | $-0.162 \ E+02$ | $\pi^2p_{3/2}, \nu^2f_{7/2}$ |
| $4^+_3$ | 2.036 | 2.025 | 0.484 $\ E+00$ | $-0.273 \ E+02$ | $\pi^2p_{1/2}, \nu^1h_{9/2}$ |
| $5^+_1$ | 1.878 | 1.912 | 0.178 $\ E+01$ | $-0.992 \ E+01$ | $\pi^2p_{3/2}, \nu^2f_{7/2}$ |
| $5^+_2$ | 1.961 | 1.972 | 0.128 $\ E+01$ | $-0.240 \ E+02$ | $\pi^2p_{1/2}, \nu^1h_{9/2}$ |

Results of our calculations are demonstrated in Tables 1–6. Structure of states, as well as the magnitudes of the magnetic dipole and electric quadrupole moments of the positive and negative parity levels of $^{132}$In with excitation energies less than 2 MeV are shown in Tables 1 and 2. Calculations demonstrate that most of states, especially those with the low excitation energies, are rather “pure”, and may be characterized by the quantum numbers of the leading configuration. The lowest levels are the states of negative parity and belong to the configuration $\{\pi^1g_{9/2}, \nu^2f_{7/2}\}$. Energies of these levels as well as the character of the multiplet splitting are in a good agreement with the results of the experiment, graphically shown in [11]. In Tables 3 and 4 we show calculated values of the $E2$ transition rates $B(E2)$ between the states of the positive (Table 3) and negative (Table 4) parities. Note, that in case of the lowest levels that belong to the configuration $\{\pi^1g_{9/2}, \nu^2f_{7/2}; J\}$, transitions with $\Delta J = 1$ are enhanced, while the transitions with $\Delta J = 2$ are retarded. This is opposite as compared to levels of the lowest proton-neutron multiplet $\{\pi^1g_{7/2}, \nu^2f_{7/2}; J\}$ in $^{134}$Sb, where the transitions with $\Delta J = 1$ are retarded, while the transitions with $\Delta J = 2$ are enhanced [10]. In Tables 5 and 6 one can see our results relating to the $M1$ transition rates. Parallel with the $B(M1)$ values, we also show here signs of the ratios $\langle J^\pi||\hat{m}(E2)||J^\pi\rangle/\langle J^\pi||\hat{m}(M1)||J^\pi\rangle$, that are obtained in our calculations. Together with other data from Tables 3–6 this enables one to calculate the values of the mixing parameter $\delta$, that may be defined in the angular correlation experiments.

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Table 2: Energies (in MeV) and electromagnetic moments of the negative parity levels in $^{132}\text{In}$. Magnetic moments are in the units of $\mu_N$, while the quadrupole moments are in the units of $|e| \cdot \text{fm}^2$. Electromagnetic moments are calculated by using the interaction RPA2.

| Level | Energy RPA1 | Energy RPA2 | Magnetic moment | Quadrupole moment | Leading configuration |
|-------|-------------|-------------|-----------------|-------------------|----------------------|
| $1_1^-$ | 0.926       | 0.821       | 0.443 E+01      | 0.408 E+01        | $\pi 1g_{9/2}, \nu 2f_{7/2}$ |
| $2_1^-$ | 0.356       | 0.381       | 0.389 E+01      | 0.944 E+01        | $\pi 1g_{9/2}, \nu 2f_{7/2}$ |
| $2_2^-$ | 2.101       | 2.117       | 0.176 E+01      | 0.813 E+00        | $\pi 1g_{9/2}, \nu 1h_{9/2}$ |
| $3_1^-$ | 0.171       | 0.167       | 0.368 E+01      | 0.153 E+02        | $\pi 1g_{9/2}, \nu 2f_{7/2}$ |
| $3_2^-$ | 1.169       | 1.164       | 0.641 E+01      | 0.174 E+02        | $\pi 1g_{9/2}, \nu 3p_{3/2}$ |
| $3_3^-$ | 1.931       | 1.910       | 0.252 E+01      | 0.116 E+01        | $\pi 1g_{9/2}, \nu 1h_{9/2}$ |
| $4_1^-$ | 0.105       | 0.113       | 0.384 E+01      | 0.167 E+02        | $\pi 1g_{9/2}, \nu 2f_{7/2}$ |
| $4_2^-$ | 0.884       | 0.891       | 0.628 E+01      | 0.357 E+02        | $\pi 1g_{9/2}, \nu 3p_{3/2}$ |
| $4_3^-$ | 1.472       | 1.489       | 0.545 E+01      | 0.317 E+02        | $\pi 1g_{9/2}, \nu 3p_{1/2}$ |
| $4_4^-$ | 1.768       | 1.805       | 0.330 E+01      | 0.180 E+01        | $\pi 1g_{9/2}, \nu 1h_{9/2}$ |
| $4_5^-$ | 2.127       | 2.156       | 0.507 E+01      | 0.146 E+02        | $\pi 1g_{9/2}, \nu 2f_{5/2}$ |
| $5_1^-$ | 0.040       | 0.041       | 0.404 E+01      | 0.153 E+02        | $\pi 1g_{9/2}, \nu 2f_{7/2}$ |
| $5_2^-$ | 0.834       | 0.831       | 0.521 E+01      | 0.360 E+02        | $\pi 1g_{9/2}, \nu 3p_{3/2}$ |
| $5_3^-$ | 1.474       | 1.483       | 0.695 E+01      | 0.334 E+02        | $\pi 1g_{9/2}, \nu 3p_{1/2}$ |
| $5_4^-$ | 1.739       | 1.737       | 0.409 E+01      | 0.171 E+01        | $\pi 1g_{9/2}, \nu 1h_{9/2}$ |
| $5_5^-$ | 2.131       | 2.139       | 0.596 E+01      | 0.161 E+02        | $\pi 1g_{9/2}, \nu 2f_{5/2}$ |
| $6_1^-$ | 0.049       | 0.059       | 0.445 E+01      | 0.156 E+02        | $\pi 1g_{9/2}, \nu 2f_{7/2}$ |
| $6_2^-$ | 0.993       | 1.022       | 0.532 E+01      | 0.190 E+02        | $\pi 1g_{9/2}, \nu 3p_{3/2}$ |
| $6_3^-$ | 1.658       | 1.692       | 0.489 E+01      | 0.365 E+01        | $\pi 1g_{9/2}, \nu 1h_{9/2}$ |
| $6_4^-$ | 2.023       | 2.041       | 0.640 E+01      | 0.180 E+02        | $\pi 1g_{9/2}, \nu 2f_{5/2}$ |
| $7_1^-$ | gr.st.      | gr.st.      | 0.478 E+01      | 0.133 E+02        | $\pi 1g_{9/2}, \nu 2f_{7/2}$ |
| $7_2^-$ | 1.695       | 1.708       | 0.570 E+01      | 0.581 E+01        | $\pi 1g_{9/2}, \nu 1h_{9/2}$ |
| $8_1^-$ | 0.210       | 0.253       | 0.527 E+01      | 0.130 E+02        | $\pi 1g_{9/2}, \nu 2f_{7/2}$ |
| $8_2^-$ | 1.620       | 1.649       | 0.648 E+01      | 0.719 E+01        | $\pi 1g_{9/2}, \nu 1h_{9/2}$ |
| $9_1^-$ | 1.997       | 2.059       | 0.729 E+01      | 0.110 E+02        | $\pi 1g_{9/2}, \nu 1h_{9/2}$ |
Table 3: $E2$ transition rates $B(E2)$ in units of $e^2 \cdot \text{fm}^4$ between the levels of positive parity in $^{132}\text{In}$. Calculations are performed by using the interaction RPA2.

| Transition $i \rightarrow f$ | $B(E2; i \rightarrow f)$ | Transition $i \rightarrow f$ | $B(E2; i \rightarrow f)$ |
|-----------------------------|--------------------------|-----------------------------|--------------------------|
| $2^+_1 \rightarrow 0^+_1$   | 0.454 E+02               | $3^+_2 \rightarrow 3^+_1$   | 0.264 E+02               |
| $2^+_2 \rightarrow 0^+_1$   | 0.837 E+01               | $4^+_1 \rightarrow 3^+_1$   | 0.813 E+01               |
| $1^+_2 \rightarrow 1^+_1$   | 0.889 E+02               | $4^+_3 \rightarrow 3^+_1$   | 0.744 E+02               |
| $2^+_1 \rightarrow 1^+_1$   | 0.243 E+02               | $4^+_1 \rightarrow 3^+_2$   | 0.303 E+01               |
| $2^+_2 \rightarrow 1^+_1$   | 0.287 E-01               | $5^+_1 \rightarrow 3^+_1$   | 0.506 E+02               |
| $3^+_1 \rightarrow 1^+_1$   | 0.801 E+02               | $5^+_2 \rightarrow 3^+_1$   | 0.140 E+02               |
| $3^+_2 \rightarrow 1^+_1$   | 0.161 E+01               | $4^+_1 \rightarrow 3^+_2$   | 0.488 E+02               |
| $2^+_1 \rightarrow 1^+_2$   | 0.601 E+02               | $4^+_2 \rightarrow 3^+_2$   | 0.558 E+02               |
| $2^+_2 \rightarrow 1^+_2$   | 0.231 E+01               | $4^+_3 \rightarrow 3^+_2$   | 0.737 E-02               |
| $3^+_1 \rightarrow 1^+_2$   | 0.949 E-02               | $5^+_1 \rightarrow 3^+_2$   | 0.263 E+02               |
| $3^+_2 \rightarrow 1^+_2$   | 0.121 E+01               | $5^+_2 \rightarrow 3^+_2$   | 0.880 E+01               |
| $2^+_2 \rightarrow 2^+_1$   | 0.203 E+00               | $4^+_1 \rightarrow 4^+_1$   | 0.537 E+02               |
| $3^+_1 \rightarrow 2^+_1$   | 0.124 E+02               | $4^+_3 \rightarrow 4^+_1$   | 0.241 E-01               |
| $3^+_2 \rightarrow 2^+_1$   | 0.280 E+01               | $5^+_1 \rightarrow 4^+_1$   | 0.544 E+02               |
| $4^+_1 \rightarrow 2^+_1$   | 0.972 E+02               | $5^+_2 \rightarrow 4^+_1$   | 0.229 E+01               |
| $4^+_2 \rightarrow 2^+_1$   | 0.891 E+00               | $4^+_3 \rightarrow 4^+_2$   | 0.618 E-01               |
| $4^+_3 \rightarrow 2^+_1$   | 0.149 E-02               | $5^+_1 \rightarrow 4^+_2$   | 0.845 E+02               |
| $3^+_1 \rightarrow 2^+_2$   | 0.170 E+02               | $5^+_2 \rightarrow 4^+_2$   | 0.203 E+02               |
| $3^+_2 \rightarrow 2^+_2$   | 0.902 E+00               | $5^+_1 \rightarrow 4^+_3$   | 0.215 E+01               |
| $4^+_1 \rightarrow 2^+_2$   | 0.309 E+02               | $5^+_2 \rightarrow 4^+_3$   | 0.673 E+01               |
| $4^+_2 \rightarrow 2^+_2$   | 0.380 E+02               | $5^+_2 \rightarrow 5^+_1$   | 0.100 E+02               |
| $4^+_3 \rightarrow 2^+_2$   | 0.606 E+01               |                             |                          |
Table 4: $E2$ transition rates $B(E2)$ in units of $e^2 \cdot \text{fm}^4$ between the states of negative parity in $^{132}\text{In}$. Calculations are performed by using the interaction RPA2.

| Transition $i \rightarrow f$ | $B(E2; i \rightarrow f)$ | Transition $i \rightarrow f$ | $B(E2; i \rightarrow f)$ |
|-----------------------------|--------------------------|-----------------------------|--------------------------|
| $2^-_1 \rightarrow 1^-_1$   | 0.147 E+02               | $6^-_2 \rightarrow 4^-_1$   | 0.145 E+00               |
| $3^-_1 \rightarrow 1^-_1$   | 0.623 E+00               | $5^-_1 \rightarrow 4^-_2$   | 0.296 E+02               |
| $3^-_2 \rightarrow 1^-_1$   | 0.290 E+02               | $5^-_2 \rightarrow 4^-_2$   | 0.567 E+02               |
| $3^-_1 \rightarrow 2^-_1$   | 0.398 E+02               | $6^-_1 \rightarrow 4^-_2$   | 0.176 E+02               |
| $3^-_2 \rightarrow 2^-_1$   | 0.576 E+02               | $6^-_2 \rightarrow 4^-_2$   | 0.520 E+01               |
| $4^-_1 \rightarrow 2^-_1$   | 0.760 E-01               | $5^-_2 \rightarrow 5^-_1$   | 0.344 E+02               |
| $4^-_2 \rightarrow 2^-_1$   | 0.778 E+01               | $6^-_1 \rightarrow 5^-_1$   | 0.189 E+03               |
| $3^-_2 \rightarrow 3^-_1$   | 0.466 E+02               | $6^-_2 \rightarrow 5^-_1$   | 0.997 E+01               |
| $4^-_1 \rightarrow 3^-_1$   | 0.994 E+02               | $7^-_1 \rightarrow 5^-_1$   | 0.243 E+00               |
| $4^-_2 \rightarrow 3^-_1$   | 0.377 E+02               | $6^-_1 \rightarrow 5^-_2$   | 0.492 E+02               |
| $5^-_1 \rightarrow 3^-_1$   | 0.936 E-01               | $6^-_2 \rightarrow 5^-_2$   | 0.109 E+03               |
| $5^-_2 \rightarrow 3^-_1$   | 0.963 E+00               | $7^-_1 \rightarrow 5^-_2$   | 0.432 E+02               |
| $4^-_1 \rightarrow 3^-_2$   | 0.141 E+02               | $6^-_2 \rightarrow 6^-_1$   | 0.157 E+02               |
| $4^-_2 \rightarrow 3^-_2$   | 0.129 E+01               | $7^-_1 \rightarrow 6^-_1$   | 0.199 E+03               |
| $5^-_1 \rightarrow 3^-_2$   | 0.455 E+01               | $8^-_1 \rightarrow 6^-_1$   | 0.168 E+01               |
| $5^-_2 \rightarrow 3^-_2$   | 0.116 E+02               | $7^-_1 \rightarrow 6^-_2$   | 0.154 E+02               |
| $4^-_2 \rightarrow 4^-_1$   | 0.550 E+02               | $8^-_1 \rightarrow 6^-_2$   | 0.744 E+02               |
| $5^-_1 \rightarrow 4^-_1$   | 0.162 E+03               | $8^-_1 \rightarrow 7^-_1$   | 0.131 E+03               |
| $5^-_2 \rightarrow 4^-_1$   | 0.124 E+02               | $9^-_1 \rightarrow 7^-_1$   | 0.226 E+00               |
| $6^-_1 \rightarrow 4^-_1$   | 0.267 E+00               | $9^-_1 \rightarrow 8^-_1$   | 0.370 E+01               |
Table 5: $M1$ transition rates $B(M1)$ between the levels of positive parity in $^{132}$In in units of $\mu_N^2$. Signs in brackets correspond to the signs of the ratios of the reduced transition matrix elements, $\langle f|\hat m(E2)|i\rangle/\langle f|\hat m(M1)|i\rangle$. Calculations are performed by using the interaction RPA2.

| Transition $i \to f$ | $B(M1; i \to f)$ | Transition $i \to f$ | $B(M1; i \to f)$ |
|----------------------|-----------------|----------------------|-----------------|
| $1_1^+ \to 0_1^+$    | 0.724 E-01      | $4_3^+ \to 3_1^+$   | 0.330 E-02 (+)  |
| $1_2^+ \to 0_1^+$    | 0.723 E-01      | $4_1^+ \to 3_2^+$   | 0.299 E+00 (-)  |
| $1_3^+ \to 1_1^+$    | 0.204 E+00 (-)  | $4_2^+ \to 3_2^+$   | 0.180 E+01 (+)  |
| $2_1^+ \to 1_1^+$    | 0.136 E-01 (+)  | $4_3^+ \to 3_2^+$   | 0.284 E-03 (+)  |
| $2_2^+ \to 1_1^+$    | 0.105 E-03 (-)  | $4_2^+ \to 4_1^+$   | 0.429 E+00 (-)  |
| $2_3^+ \to 1_2^+$    | 0.346 E-00 (-)  | $4_3^+ \to 4_1^+$   | 0.272 E-03 (+)  |
| $2_2^+ \to 2_1^+$    | 0.895 E-03 (-)  | $5_1^+ \to 4_1^+$   | 0.254 E+00 (-)  |
| $3_1^+ \to 2_1^+$    | 0.353 E-01 (-)  | $5_2^+ \to 4_1^+$   | 0.957 E-01 (-)  |
| $3_2^+ \to 2_1^+$    | 0.513 E-02 (-)  | $5_3^+ \to 4_2^+$   | 0.201 E-03 (+)  |
| $3_2^+ \to 2_2^+$    | 0.433 E-01 (-)  | $5_1^+ \to 4_2^+$   | 0.121 E+01 (+)  |
| $3_1^+ \to 2_2^+$    | 0.469 E-01 (+)  | $5_2^+ \to 4_2^+$   | 0.264 E+00 (+)  |
| $3_2^+ \to 2_2^+$    | 0.206 E+01 (+)  | $5_1^+ \to 4_3^+$   | 0.556 E-02 (-)  |
| $3_2^+ \to 3_1^+$    | 0.388 E+00 (+)  | $5_2^+ \to 4_3^+$   | 0.291 E-01 (-)  |
| $4_1^+ \to 3_1^+$    | 0.184 E-03 (-)  | $5_2^+ \to 5_1^+$   | 0.250 E-01 (+)  |
| $4_2^+ \to 3_1^+$    | 0.449 E+00 (+)  |                       |                 |

Table 6: $M1$ transition rates $B(M1)$ in units of $\mu_N^2$ between the levels of negative parity in $^{132}$In. Signs in brackets correspond to the signs of the ratios of the reduced transition matrix elements, $\langle f|\hat m(E2)|i\rangle/\langle f|\hat m(M1)|i\rangle$. Calculations are performed with the interaction RPA2.

| Transition $i \to f$ | $B(M1; i \to f)$ | Transition $i \to f$ | $B(M1; i \to f)$ |
|----------------------|-----------------|----------------------|-----------------|
| $2_1^- \to 1_1^-$    | 0.384 E+01 (+)  | $5_2^- \to 4_2^-$    | 0.204 E+01 (+)  |
| $3_1^- \to 2_1^-$    | 0.482 E+01 (+)  | $5_2^- \to 5_1^-$    | 0.795 E-02 (+)  |
| $3_2^- \to 2_1^-$    | 0.166 E+00 (+)  | $6_1^- \to 5_1^-$    | 0.351 E+01 (+)  |
| $3_2^- \to 3_1^-$    | 0.131 E+00 (+)  | $6_2^- \to 5_1^-$    | 0.223 E-01 (+)  |
| $4_1^- \to 3_1^-$    | 0.470 E+01 (+)  | $6_1^- \to 5_2^-$    | 0.842 E-05 (+)  |
| $4_2^- \to 3_1^-$    | 0.881 E-02 (+)  | $6_2^- \to 5_2^-$    | 0.956 E+00 (+)  |
| $4_1^- \to 3_2^-$    | 0.575 E-02 (-)  | $6_2^- \to 6_1^-$    | 0.188 E-02 (+)  |
| $4_2^- \to 3_2^-$    | 0.130 E-01 (+)  | $7_1^- \to 6_1^-$    | 0.257 E+01 (+)  |
| $4_2^- \to 4_1^-$    | 0.189 E-01 (+)  | $7_1^- \to 6_2^-$    | 0.821 E-01 (-)  |
| $5_1^- \to 4_1^-$    | 0.432 E+01 (+)  | $8_1^- \to 7_1^-$    | 0.134 E+01 (+)  |
| $5_2^- \to 4_1^-$    | 0.482 E-04 (-)  | $9_1^- \to 8_1^-$    | 0.967 E-02 (+)  |
| $5_1^- \to 4_2^-$    | 0.227 E-01 (-)  |                       |                 |
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