# $0^+$ States in $^{230}$Th

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To investigate $0^+$ states in $^{230}$Th the $^{232}$Th(p,t) reaction has been performed in the excitation range up to 2600 keV at the Q3D magnetic spectrograph. The intensity of the 25 MeV proton beam was 1-2 $\mu$A on target and the energy resolution was about 7 keV. The target consisted of a 100 $\frac{\mu g}{cm^2}$ thick layer of $^{232}$Th evaporated on a 22 $\frac{\mu g}{cm^2}$ thick carbon backing.
In (p,t) the $0^+$ transfer angular distributions have steeply rising cross sections going to very low scattering angles. This allows to identify these states in otherwise dense and complicated spectra. Figure 1 compares 13 angular distributions of excited $0^+$ states in $^{230}$Th with DWBA calculations. The ten $0^+$ states marked by an asterisk have been observed for the first time. Table 1 compares all experimentally observed levels with the data set from NNDC/ENSDF. The assignment of quantum numbers besides $0^+$ is ongoing.
In deformed axially symmetric nuclei the quantization with respect to the intrinsic symmetry axis splits excitation modes with angular momentum J into states distinguished by their K quantum numbers ranging from 0 to J. To what an extent the structure of the low lying $0^+$ states is then given by collective excitations, by monopole pairing vibrations, by intruder configurations, by particle-hole, particle-particle or particle-core coupling effects or by two-quasiparticle excitations will be discussed in the next article. The comparison of $0^+$ states in $^{232}$U, $^{230}$Th and $^{228}$Th with IBA calculations in the sdpf boson space suggests strong contribution of the collective double octupole degree of freedom.

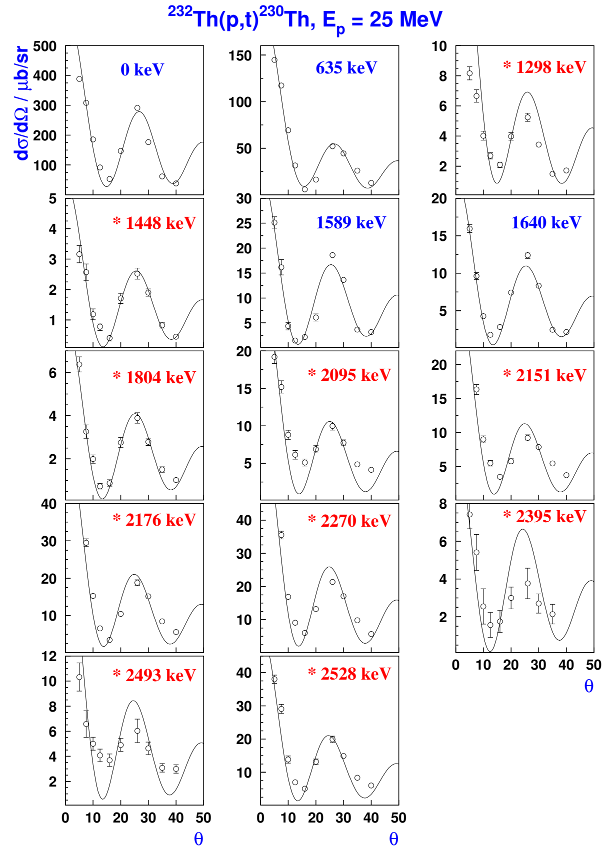


Fig. 1: Differential cross sections of $0^+$ states in $^{230}$Th with DWBA calculations. Levels marked with an asterisk have been observed for the first time.

| NDS | | (p,t) | NDS | | (p,t) | NDS | | (p,t) | NDS | | (p,t) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $E_x$ [keV] | $J^\pi$ | $E_x$ [keV] | $E_x$ [keV] | $J^\pi$ | $E_x$ [keV] | $E_x$ [keV] | $J^\pi$ | $E_x$ [keV] | $E_x$ [keV] | $J^\pi$ | $E_x$ [keV] |
| 0.0 | 0+ | 0.0 | | | 1448.3(10) | | | 1870.6(10) | | | 2295.6(20) |
| 53.20(2) | 2+ | 53.1(2) | 1485.6 | | 1486.2(10) | 1902.7(1) | 1,2+ | | 2298.6 | 1,2+ | |
| 174.10(3) | 4+ | 174.0(2) | | | 1493.9(15) | | | 1908.1(10) | | | 2306.5(5) |
| 356.6 (5) | 6+ | 356.3(2) | | | 1508.5(15) | | | 1915.7(15) | 2313 | 17- | |
| 508.16(5) | 1- | 508.2(2) | 1520.4 | 10+ | | | | 1927.2(10) | 2314.3(2) | 1,2+ | |
| 571.77(10) | 3- | 571.8(4) | | | 1525.7(15) | | | 1937.9(10) | | | 2318.1(10) |
| 594.1 (5) | 8+ | 594.1(4) | 1572.9 | 14+ | | | | 1947.1(10) | | | 2330.3(20) |
| 634.9 (1) | 0+ | 635.0(2) | 1573.5 | 1(-),2+ | 1575.4(15) | 1949 | 15- | | | | 2338.8(20) |
| 677.6 (1) | 2+ | 677.6(2) | 1589.8 | 0+ | 1589.3(5) | 1949.8(1) | 1,2+ | | 2368.9(2) | | |
| 686.7 | 5- | | | | 1595.0(15) | | | 1957.2(10) | | | 2371.0(15) |
| 769.6 | 4+ | | | | 1611.4(15) | 1966.9(2) | 1,2+ | | | | 2384.7(10) |
| | | 775.0(8) | 1617.5 | 13- | | | | 1968.6(10) | | | 2394.7(20) |
| 781.37(5) | 2+ | 781.7(3) | | | 1616.4(15) | 1971.5 | 16+ | | 2397.8 | 18+ | |
| 825.8 (2) | 3+ | 825.9(10) | | | 1619.0(15) | 1973.4(2) | (1+,2+) | | | | 2401.1(20) |
| 852.4 (4) | 7- | 853.2(10) | 1628(2) | | 1630.6(10) | | | 1977.3(20) | | | 2412.2(10) |
| 879.7 | 10+ | | 1638.5(2) | (2,0+) | 1639.7(10) | | | 1987.2(15) | | | 2424.1(5) |
| 883.6 | 4+ | 884.5(5) | | | 1654.8(10) | 2000.9(1) | 1,2+ | 2000.3(20) | | | 2436.1(20) |
| | | 923.6(10) | 1663(3) | | | 2010.1(2) | 1,2+ | 2011.4(10) | | | 2444.1(20) |
| 951.94(5) | 1- | 953.1(10) | | | 1668.5(10) | 2024.7 | 1+,2+ | 2022.6(20) | | | 2451.8(20) |
| 971.69(10) | 2- | 972.9(10) | | | 1680.8(10) | | | 2029.0(20) | | | 2462.9(10) |
| 1009.7 | 2+ | | 1695.7(1) | 1(-),2+ | 1695.4(10) | | | 2037.3(10) | | | 2474.3(20) |
| 1012.5 (4) | 3- | 1012.3(5) | | | 1711.0(20) | | | 2049.6(20) | | | 2478.4(10) |
| 1040.0 | 6+ | 1040.9(10) | 1718(3) | | | 2078.3(2) | | | | | 2493.1(10) |
| 1052.6 (12) | 3+ | 1053.0(10) | | | 1724.6(10) | | | 2086.2(20) | | | 2502.2(10) |
| 1065.6 | 9- | 1067.0(15) | 1744.9 (1) | | 1745.1(20) | | | 2094.8(5) | | | 2512.6(20) |
| 1079.26(10) | (2-) | 1080.8(15) | | | 1748.0(20) | | | 2105.1(15) | | | 2517.6(20) |
| 1108.2 | 4+ | 1109.0(5) | | | 1751.2(20) | | | 2118.9(5) | | | 2527.7(5) |
| 1109.0 | 5- | | | | 1762.3(20) | 2122.8 | 1,2+ | | | | 2537.3(10) |
| 1127.85 | 3- | 1126.7(5) | | | 1769.3(20) | | | 2131.5(10) | | | 2549.4(20) |
| | | 1175.1(20) | 1770.7(1) | 1,2+ | | 2133.2(2) | | | | | 2556.1(20) |
| 1178.6 | 5+ | | 1775.2(1) | 1,2+ | 1774.1(20) | | | 2138.7(10) | | | 2563.2(20) |
| 1196.8 | (4-) | | | | 1783.7(20) | 2151.8 | 1,2+ | 2151.5(5) | | | 2575.7(20) |
| 1207.8 | 12+ | | 1789.4(5) | 1(-),2+ | | | | 2167.4(20) | | | 2587.7(20) |
| 1251.4 | 8+ | | | | 1794.0(10) | | | 2176.0(10) | | | 2601.5(5) |
| | | 1258.7(20) | | | 1803.7(10) | | | 2187.0(10) | | | 2615.3(20) |
| | | 1283.7(20) | 1810.7(1) | 1,2+ | | | | 2197.1(10) | | | 2624.7(20) |
| 1297.1 | | 1298.2(10) | | | 1813.3(10) | | | 2207.5(10) | | | 2639.6(10) |
| 1321.9 | 11- | 1323.0(10) | | | 1825.4(10) | | | 2216.3(20) | | | 2658.9(20) |
| | | 1337.6(5) | 1839.6(2) | 1(-),2+ | 1839.8(10) | | | 2226.9(5) | | | 2666.0(10) |
| | | 1361.3(15) | 1849.6(1) | (2+) | | | | 2240.9(20) | | | 2681.0(20) |
| 1375.3 | 1,2+ | 1378.3(15) | | | 1852.8(10) | | | 2255.7(10) | | | 2695.0(20) |
| 1400.9 | 2+ | 1402.2(15) | 1858.2(6) | | | | | 2269.8(5) | | | |
| | | 1421.2(10) | | | 1860.6(10) | 2282.8(5) | 1,2+ | 2282.1(15) | | | |

Table 1: Comparison of excitation energies from the (p,t) reaction with information from NNDC/ENSDF