EPJ Web of Conferences **93**, 01045 (2015)
DOI: 10.1051/epjconf/20159301045

Levels of ^{186}Re populated in thermal neutron capture reaction

J. Bērziņš[1,a], T. Krasta[1,b], L. Simonova[1], M. Jentschel[2], and W. Urban[3]

[1] *Institute of Solid State Physics, University of Latvia, LV-1063, Riga, Latvia*
[2] *Institut Laue-Langevin, F-38042, Grenoble Cedex, France*
[3] *Faculty of Physics, University of Warsaw, 00-681 Warsaw, Poland*

Abstract. Levels of ^{186}Re have been studied in the thermal neutron capture reaction with an enriched ^{185}Re target. Evaluation of spectrum measured with GAMS5 allowed to obtain energies and intensities of more than 500 γ-lines assigned to ^{186}Re. Most of the obtained transitions have been placed in the model-independent level scheme of the doubly odd ^{186}Re nucleus, taking into account the available data of earlier experiments as well as the results of recent ^{187}Re$(p,d)^{186}$Re reaction measurements. Structure of the ^{186}Re low-lying levels has been analysed in terms of the particle-plus-rotor coupling model.

1 Introduction

The doubly-odd ^{186}Re nucleus is a close neighbour to the ^{188}Re which has been an object of our previous studies [1]. It has been shown that the experimentally established high density of positive parity levels below 1 MeV, as well as properties of some two-quasiparticle configurations indicate coexistence of axially-symmetric and non-axial deformation modes in ^{188}Re. It is expected that ^{186}Re, having two neutrons less, would have stable axially-symmetric deformation for all low-lying states.

Previous thermal neutron capture studies of the ^{186}Re levels have been carried out more than 40 years ago [2, 3] resulting in the development of model-interpreted level scheme up to about 1 MeV. Important data about depopulation of high spin levels have been obtained in the decay study [4] of the long-lived (2×10^5 years) isomer of ^{186}Re. However, a number of unsolved structure problems remained, especially for positive parity levels.

Recently, the ^{187}Re$(p,d)^{186}$Re reaction measurements have been performed [5] with the Munich Q3D spectrograph. Energies of the ^{186}Re levels have been obtained with a high-resolution particle spectroscopy up to 2.5 MeV excitation energy. More than 30 levels have been observed for the first time.

We present the preliminary results of new thermal neutron capture study of ^{186}Re levels performed at ILL. The obtained experimental data, in combination with the (p,d) reaction results [5], provide ample material for further development of the ^{186}Re level scheme.

[a] e-mail: jberzins@latnet.lv
[b] e-mail: krasta@latnet.lv

2 Experimental methods and results

The ^{185}Re$(n_{th},\gamma)^{186}$Re reaction measurements have been performed at the high-flux reactor of ILL. The target was made of metallic rhenium powder with enrichment to 97% of ^{185}Re. Secondary γ-ray spectra have been measured in the energy range from 100 keV to 2 MeV with the high-resolution crystal-diffraction spectrometer GAMS5. Evaluation of spectra in the first, second, and third reflection orders allowed to obtain energies and intensities of more than 500 γ-lines assigned to ^{186}Re. The most prominent admixture lines were from the ^{187}Re$(n_{th},\gamma)^{188}$Re reaction.

Obtained ^{186}Re γ-line energies have essentially higher resolution than those of the earlier crystal-diffraction measurements [2], especially in the energy range above 300 keV. However, due to very high density of γ-lines in the summary spectrum, resolving of many complex lines was unsatisfactory. One should combine the single spectrum data with the results of $\gamma\gamma$-coincidence measurements performed at the PF1B cold neutron beam of ILL. Evaluation of these data is in progress.

The present model-independent level scheme of ^{186}Re [6] includes population and depopulation data for 50 levels with excitation energies up to about 1 MeV. Most of the intense γ-line energies obtained in our GAMS5 measurements have been assigned to transitions linking these levels. It allowed to determine energy values for all earlier known ^{186}Re levels with higher precision.

Using new spectroscopic information obtained in both, our thermal neutron capture experiments and the (p,d) reaction measurements [5], we have started work at further development of the ^{186}Re level scheme in the energy range between 400 keV and 1 MeV. As yet, we propose following changes in the ^{186}Re model-independent level scheme.

The 180.1(5) keV peak in the (p,d) spectrum [5] is in good agreement with the proposed 179.67(3) keV 6^-

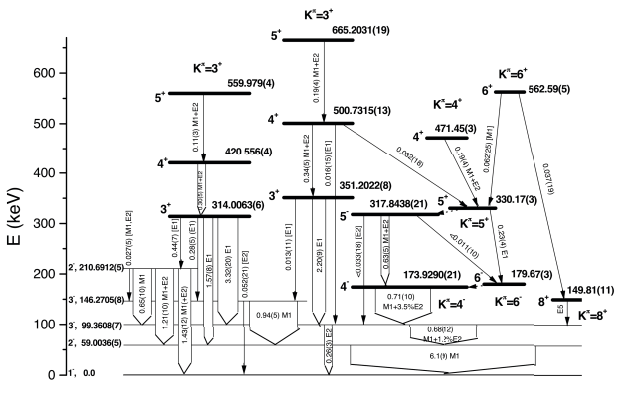

Figure 1. Partial positive parity level scheme of ^{186}Re. Intensities are normalized to 100 neutron captures. In figure, transition line width is proportional to the total intensity ($I_\gamma + I_e$).

level, which we believe to be a level analogous to the 172.1 keV 6^- bandhead in ^{188}Re. Earlier [2], this level has been proposed at 186 keV. The 179.7 keV level should decay with a ~5.8 keV E2 transition to the 173.9 4^- bandhead which can be confirmed by $\gamma\gamma$-coincidences.

New populating and depopulating transitions have been assigned to the ~330, ~471, and ~562 keV levels [6] proposed on the basis of $\gamma\gamma$-coincidence measurements in [3]. The assigned linking transitions (see figure 1) allowed to determine the energies of these levels more precisely and confirm their spin-parity assignments.

3 Discussion and conclusions

Both ^{186}Re, and ^{188}Re nuclei have the same $K^\pi = 1^-$ ground state and structure of both nuclei is interpreted using the same proton (5/2[402], 9/2[514]) and neutron (1/2[510], 3/2[512], 7/2[503], 9/2[505], 11/2[615]) orbits. However, due to the proximity of the transitional deformation region, the two neutron difference results in essential dissimilarities of both nuclear structures. The most prominent differences are associated with the high j neutron orbits 9/2[505] and 11/2[615]: the absence of the low-lying $K^\pi = 0^+$ band, and the presence of the $K^\pi = 8^+$ long-lived isomer state in the low-energy level scheme of ^{186}Re.

In order to provide guidances for the interpretation of higher lying levels, we have performed theoretical calculations of the ^{186}Re level structure in the framework of the core plus two-quasiparticles nuclear model with the axially-symmetric Nilsson potential. The program ASYRPN described in [7] has been employed with deformation parameters ε_2=0.20, and ε_4=0.065. The central residual NN-interaction with short and long range components and spin polarization [8] have been taken the same as in the case of ^{188}Re. However, for our preliminary model calculations of ^{186}Re level structure, we have not included tensor terms of the residual NN-interaction.

While the obtained agreement between experimental and calculated negative parity rotational bands of ^{186}Re is satisfactory, the description of positive parity states discloses several problems. First, the anomalous $K^\pi = 3^+$ rotational band at 351.2 keV. Second, the presently assigned position of the $K^\pi = 1^+$ band (601.62 keV) is most probably too high since the neutron orbit 7/2[503] quasiparticle energy should be only slightly higher than in ^{188}Re. And, of course, there is a question about the low energy of the neutron orbit 11/2[615] (the $K^\pi = 3^+$ (p:5/2[402]-n:11/2[615]) bandhead at 314.01 keV and the $K^\pi = 8^+$ (p:5/2[402]+11/2[615]) bandhead at 149.81 keV) which can be reproduced only by rising μ value for the $N = 6$ shell. It can indicate that, in order to reproduce correctly the single-particle states of transitional nuclei at $A \sim 190$, one shall use the Woods-Saxon potential. Or apply more advanced theory based on the relativistic mean field approach accounting for spin-orbital interaction innately.

At the present stage of our work, we believe that the presently adopted [6] structure interpretation of the ^{186}Re positive parity levels requires additional validation, both experimental and theoretical.

A possible solution for the problems existing in the positive parity level scheme of ^{186}Re could be obtained via the change of structure interpretation for the $I^\pi = 8^+$ long-lived isomeric level at 149.8 keV. We believe that the argumentation of Seegmiller et al. [4] for the preference of the (p:5/2[402]+n:11/2[615]) configuration over (p:9/2[514]+n:7/2[503]) is not decisive enough. One cannot predict with certainty which $K^\pi = 8^+$ state would be lower in ^{186}Re. Assignment of the (p:9/2[514]+n:7/2[503]) configuration would agree with the observed populating transition from the $K^\pi = 6^+$ (p:9/2[514]+n:3/2[512]) bandhead at 562.6 keV.

References

[1] M. Balodis et al., Nucl. Phys. A **847**, 121 (2010)
[2] P. G. Lanier et al., Phys. Rev. **178**, 1919 (1969)
[3] J. Glatz, Z. Phys. **265**, 335 (1973)
[4] D. W. Seegmiller, M. Lindner, R. A. Meyer, Nucl. Phys. A **185**, 94 (1972)
[5] C. Wheldon et al., J. Phys. G **36**, 095192 (2009)
[6] C. M. Baglin, NDS **99**, 1 (2003)
[7] S. E. Larsson, G. Leander, I. Ragnarsson, Nucl. Phys. A **307**, 189 (1978)
[8] J. P. Boisson, R. Piepenbring, W. Ogle, Phys. Rep. **26C**, 99 (1976)