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A.Berinde, I.David, L.Trache

# FEEDING OF YRAST STATES IN $^{89}$Nb

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## Introduction

The nucleus $^{89}$Nb belongs to the region of the mass table in which Z is near 38 and where a fairly strong subshell closure is observed. The neutron number approaches N=50, this being a strong shell closure ($^{88}_{38}$Sr 50 core).

Previously some levels were populated by the $^{92}$Mo (p,$\gamma$) /1/ and $^{89}$Y ($^{3}$He,3n$\gamma$) /2/ reactions. Gallagher et al. have measured the decay of the $J^{\pi} = 9/2^{+}$ /3/ ground state of $^{89}$Mo to various levels of $^{89}$Nb and most recently Diano et al. studied $^{89}$Nb in $^{90}$Zr (p,2n$\gamma$), $^{89}$Y ($^{3}$He,3n$\gamma$), and $^{90}$Zr ($^{3}$He,p3n$\gamma$) /4/ reactions.

## Results

We studied this nucleus through the reaction $^{74}$Ge($^{19}$F,4n$\gamma$).

Standard in-beam gamma-ray spectroscopy methods have been applied: measurements of gamma-ray excitation functions ($E_{^{19}F}$ = 50-70 MeV), gamma-ray angular distributions (E = 62 MeV), and gamma-gamma coincidences (E = 62 MeV) were performed with a heavy-ion beam accelerated at the Bucharest FN tandem Van de Graaf.

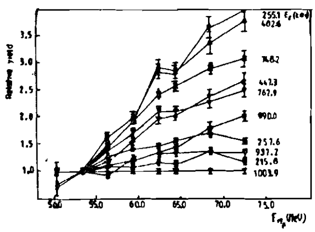


Fig. 1. Double ratios

$$R = \frac{i_{\gamma}(E_{\gamma}, E_F)}{i_{\gamma}(1003\ \mathrm{keV}, E_F)} \Big/ \frac{i_{\gamma}(E_{\gamma}, 53\ \mathrm{MeV})}{i_{\gamma}(1003\ \mathrm{keV}, 53\ \mathrm{MeV})} .$$

In fig.1 gamma-ray yields as functions of incident energy are shown for the transitions in $^{89}$Nb observed in the present reaction. The slopes of the yield curves increase with excitation energy of the levels involved. The entry states of residual nuclei, however, are normally much higher in energy than the investigated levels so that the latter are populated mainly by cascade feeding in heavy-ion induced fusion-evaporation reactions. Thus more detailed information can be derived from a plot of the excitation functions of the direct feeding cross sections $\sigma_F(i, E_x, E_F)$ for a set of reference lines of the yrast levels, which are shown in fig.2. The intensities are normalized to the ground state transition.

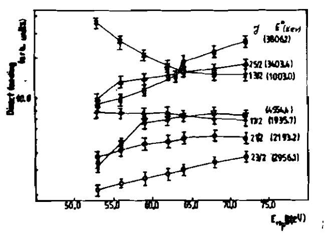

Fig. 2. Excitation functions of the feeding cross-section $\sigma_F(i,E_x,E_F)$ for a set of reference lines of the yrast levels.

In particular it appears that the measurement of the excitation function of the direct feeding cross section to a level gives us directly the spin of the level. The direct feeding is the population of the level by continuum gamma-rays from the primarily populated states. We obtain the direct feeding of a particular level as a difference between the sum of all gamma-lines depopulating a particular level and the sum of all discrete gamma-transitions which populate that level.

Although side feeding intensity curves are associated with relatively large errors (the nuclear alignment may slightly change with incident energy; the additional gamma-rays populating these levels, which are not observed in the gamma-gamma coincidence measurement exist) they provide more reliable arguments for spin discrimination than plots of total yields which may mainly reflect the cascade feeding.

The ordering of transitions is based on singles and coincidence intensities; the $J^{\pi}$ assignments are based on the side feeding, angular distribution and branching ratio (fig.3). Transitions from the 35 and 830 keV levels were not observed in the present study because of high angular momentum (16-20ħ) induced in our reaction; these levels were observed by Gallagher et al., and are included to clarify the level scheme.

## Discussion

An explanation of the states observed can be given on the basis of the shell model.

The levels in $^{89}_{41}Nb_{48}$ can be explained either as due to the seniority of three states $\pi\nu^{-2}$ coupled to $^{90}_{40}Zr_{50}$, either as due to the seniority of five-states $\pi^3\nu^{-2}$ coupled to $^{88}_{38}Sr_{50}$.

The low-lying (positive and negative parity) levels have been tentatively identified as having the seniority of three structures ( $\pi\nu^{-2}$ or $\pi^3\nu^{-2}$ ).



1) The systematics of positive parity states in $^{87}_{39}Y_{48}$, $^{89}Nb$, $^{91}Nb$:

$$|J^{\pi}\rangle = \sum_{J'} C^{(J)}_{J'} \,|(g_{9/2})_{\pi}\cdot(g_{9/2})^{-2}_{\nu J'}\,;\,J^{\pi}\rangle \quad \text{for } ^{87}Y,$$

$$|J^{\pi}\rangle = \sum_{J'} B^{(J)}_{J'} \,|(g_{9/2})_{\pi}\cdot(g_{9/2})^{-2}_{\pi J'}\,;\,J^{\pi}\rangle \quad \text{for } ^{91}Nb,$$

2) The systematics of negative parity states in $^{87}Y$, $^{89}Nb$, $^{91}Nb$:

$$|J^{\pi}\rangle = \sum_{J'} E^{(J)}_{J'} \,|(p_{1/2})_{\pi}\cdot(g_{9/2})^{-2}_{\nu J'}\,;\,J^{\pi}\rangle \quad \text{for } ^{87}Y,$$

$$|J^{\pi}\rangle = \sum_{J'} D^{(J)}_{J'} \,|(p_{1/2})_{\pi}\cdot(g_{9/2})^{2}_{\pi J'}\,;\,J^{\pi}\rangle \quad \text{for } ^{91}Nb,$$

3) The recent measurement of the high spin structure of $^{88}Zr$ /5/ suggests that these configurations can be strongly mixed ( $\pi g_{9/2}\cdot(\nu g_{9/2})^{-2}$ and $(\pi g_{9/2})^3$). For the high-lying levels (E* > 3.8 MeV) the interaction of five quasiparticles in the $1g_{9/2}$ orbital (three-proton and two-neutron holes) must be considered.

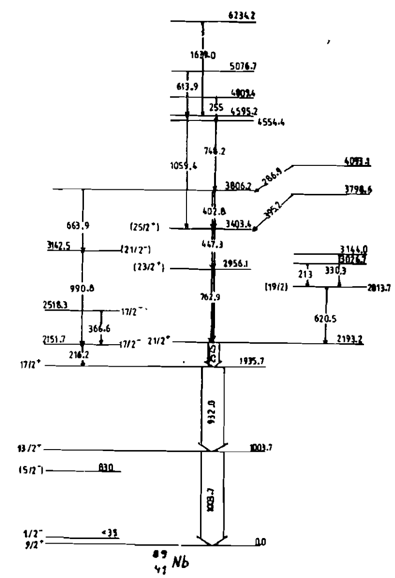

Fig. 3. Level scheme for $^{89}Nb$ obtained in the present work. All indicated coincidences were observed. Levels for which no gamma-rays are shown are taken from the results of Gallagher et al. /3/

On the other hand, the similarity of the strong $\gamma$-ray cascade in $^{89}Nb$ with the ground quasiband cascade in the neighbouring even-even nuclei $^{88}_{40}Zr_{48}$ and $^{90}_{42}Mo_{48}$ suggests that these states could be regarded as resulting from a weak coupling of a proton particle or hole to their core excitations.

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Беринде А., Давид Й., Траче Л. E7-86-359

Заселение ираст-состояний в $^{89}$Nb


На пучке тяжелых ионов $^{19}$F в xn$\gamma$-канале реакции исследовалась структура уравнений $^{89}$Nb. Измерения проводились с помощью Ge(Li)-спектрометров. Измерена функция возбуждения прямого заселения уровней квазиротационных полос в области энергий ионов от 50 МэВ до 70 МэВ. Измерены угловые распределения гамма-квантов с использованием техники гамма-гамма совпадений. Указываются спины и четности новых энергетических уровней. В рамках оболочечной модели проведена интерпретация полученных данных.



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Feeding of Yrast States in $^{89}$Nb


The level structure of $^{89}$Nb has been investigated using the ($^{19}$F, xn$\gamma$) reaction and in-beam gamma-ray spectroscopy. The measurements were performed with the $\gamma$-$\gamma$ coincidence technique using Ge(Li)-detectors. The direct feeding excitation functions of the quasirotational band levels and the angular distribution of gamma-rays have been measured in the ion energy range from 50 MeV to 70 MeV. New energy levels, their spins and parities are inducated.The data are explained on the basis of the shell model.



The investigation has been performed at the Laboratory of Nuclear Reactions, JINR.

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