Generating an Inversion on a Nuclear Transition – Photopumping of $^{103}$Rh

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Abstract. Quite a number of proposals for a gamma-ray laser have been made over the years. One first step on the way to a gamma-ray laser is an inversion between nuclear states. For the natural isotope $^{103}$Rh we have the favorable condition that there are two low-lying nuclear levels at energies of 357 keV and 295 keV with lifetimes of 107 ps and 9.7 ps, respectively. With two Nuclear Resonance Fluorescence (NRF) measurements the population of these low-lying levels via feeding from higher-lying levels was investigated. Altogether 26 higher-lying nuclear levels that show a branching to one or even both interesting low-lying levels have been found. Summing over all contributions from these feeding levels this results in a population inversion between the levels at 357 keV and 295 keV of $^{103}$Rh.

Key words: gamma-ray laser, nuclear resonance fluorescence, photoactivation.

1. Motivation and introduction

Due to the fast progress in the development of high-power lasers during the last years the excitation of nuclear levels by laser pulses approaches the domain of feasible experiments. Intensities of $10^{18} - 10^{20}$ W/cm$^2$ can be reached at modern laser facilities. At these high intensities electrons with energies in the MeV range can be produced in the laser plasma due to relativistic effects [5, 8, 13]. These electrons then can induce nuclear reactions or excite nuclear levels directly or via bremsstrahlung.

The main aim of experiments in nuclear spectroscopy using pulsed lasers is the study of possible gamma-ray laser schemes. Even if present-day laser parameters are not sufficient to produce a detectable amplification of nuclear transitions, it seems to be conceivable that this can be achieved in the not too distant future.

First photon scattering experiments performed at the Stuttgart bremsstrahlung facility [9] should clarify whether the basic requirement for a gamma-ray laser ([1] and Refs. therein), a population inversion of nuclear levels, could be realized. The proposed excitation mechanism is the photoexcitation of higher-lying states which then can feed lower-lying levels. Favorable conditions are met, if two neighboring levels exist in an isotope of which the higher-lying state has a substantially longer lifetime as compared to that of the lower-lying level. The isotope $^{103}$Rh represents an appropriate candidate. This nucleus has two low-lying excited states at 295
and 357 keV, respectively, with spins of $J^\pi = 3/2^-$ and $5/2^-$ as can be seen in the simplified low-energy level- and photo-pumping scheme shown in Figure 1. Photoexcitation from the ground state ($J^\pi = 1/2^-$), predominantly via dipole excitations, leads to intermediate states with spins of 1/2 or 3/2. These excited states then can decay back to the ground state or can feed the two low-lying states via transitions of low multipolarity. In the case of a comparable feeding of both low-lying states an inversion can be reached since the lifetime of the 357 keV state ($\tau_2 = 107$ ps) is much longer than that of the 295 keV level ($\tau_1 = 9.7$ ps).

### 2. Experimental method

#### 2.1. Nuclear Resonance Fluorescence Technique

Photon scattering off bound states, Nuclear Resonance Fluorescence (NRF), represents the most sensitive technique to study low-lying dipole excitations in heavy nuclei, both of electric and magnetic character ([9] and Refs. therein). Precise excitation energies $E_x$, ground-state transition widths $\Gamma_0$, and also decay branching ratios can be extracted from the spectra of the scattered photons measured in NRF experiments. These quantities can be converted into reduced transition probabilities $B(E1)^\dagger$, $B(M1)^\dagger$ or lifetimes $\tau$. For nuclear structure investigations additionally model-independent information on the spins and parities of the photo-excited levels can be deduced from angular distribution and linear polarization measurements, respectively (in the favorable cases of even–even nuclei, see [9]).

In bremsstrahlung-induced NRF experiments one automatically integrates over the narrow resonances due to the continuous energy distribution of the photon beam. The corresponding total scattering intensity $I_{s,f}$, integrated over the full solid angle, is given by

$$I_{s,f} = g \cdot \left( \frac{\hbar c}{E_x} \right)^2 \cdot \frac{\Gamma_0 \Gamma_f}{\Gamma}.$$

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**Figure 1.** Simplified low-energy level scheme of $^{103}$Rh. Only one feeding level (designated by $E^*$) is shown schematically.