Lifetime Measurements in ^{80}Kr and ^{81}Rb†

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We measure the lifetimes of excited states in ^{81}Rb and in the core nucleus ^{80}Kr. Ratios of reduced transition probabilities in ^{80}Kr are consistent with those given by the rotational model. The $B(E2)$ of the $\frac{13}{2}^+$ state in ^{81}Rb is in agreement with the particle-plus-rotor value and inconsistent with the weak-coupling prediction. The $B(E2)$ values of the $\frac{17}{2}^+$ and $\frac{21}{2}^+$ states lie much higher than predicted by several models.

The coupling of a $g_{9/2}$ proton to an even-even core can lead to high-spin states which one may describe in terms of relatively simple concepts, e.g., weak coupling (W)[1] or Coriolis mixed wave functions.[2-4] Since the knowledge of electromagnetic matrix elements is often an efficient tool for distinguishing between different models, measurements of lifetimes and possibly of g factors are highly desirable. The purpose of this paper is to present and discuss results of lifetime measurements in ^{81}Rb and in the core nucleus ^{80}Kr. We will briefly summarize the existing information on both nuclei.

The excited levels of ^{80}Kr, and in particular those belonging to the yrast sequence, have been extensively studied[5,6] by means of $(\alpha, xn\gamma)$ reactions, and the spin assignments are unambiguous (Fig. 1). The levels of ^{81}Rb populated by β decay have been investigated by Broda *et al.*[7]; these are mainly low-spin, negative-parity states. High-spin, positive-parity states in ^{81}Rb, produced by ^{79}Br$(\alpha, 2n)$, have been investigated by Friederichs *et al.*[8] γ-γ coincidence measurements showed the existence of a 623-875-1024-keV cascade feeding the 86.4-keV $\frac{9}{2}^+$ isomeric state. Subsequent angular-distribution measurements suggested a quadrupole character of the cascade γ's, thus favoring the spin sequence $\frac{9}{2}$-$\frac{13}{2}$-$\frac{17}{2}$-$\frac{21}{2}$ (Fig. 1). A closer look at the level schemes shows that the excitation energies in the band built upon the $\frac{9}{2}^+$ state in ^{81}Rb are very close to the corresponding values in ^{80}Kr. This relationship is characteristic of the strongly Coriolis-decoupled states[2,4] and, to a certain extent, of weak-coupling states. A careful search for other possible transitions depopulating the $\frac{17}{2}^+$ and $\frac{21}{2}^+$ states, besides those given in Fig. 1, has been unsuccessful.

The investigated nuclei have been produced in the reactions ^{65}Cu(^{18}O,$p2n$)^{80}Kr and ^{65}Cu(^{19}F, $p2n$)^{81}Rb by using a 52.5-MeV ^{18}O beam and a 50-MeV ^{19}F beam of the Köln tandem accelerator, respectively. Lifetimes of the low-lying states have been measured by means of the recoil-distance Doppler-shift (RDDS) technique. The self-supporting, 1–2-μm thick, ^{65}Cu targets have been mounted in a plunger system described elsewhere.[9] Recoil nuclei and beam were stopped in a stretched 20-μm Ta foil. The flight distance was varied by means of a micrometer screw with an accuracy of 1 μm. The evenness of the Cu targets, which was checked under a microscope, turned out to be better than 1 μm. γ rays were measured at 0° by Ge(Li) detectors having an energy resolution of 2.1–3.2 keV at 1.33 MeV. Spectra were accumulated for 24 different flight distances ranging from 0 to 1 mm. The data were analyzed according to the method described by Lieb *et al.*[10] The spectra were normalized by means of the strong 301-keV peak due to Coulomb excitation in the ^{181}Ta stopper.

A few lifetimes (Table I) have been measured by the Doppler-shift attenuation method (DSAM); the targets have been evaporated on an Au back-

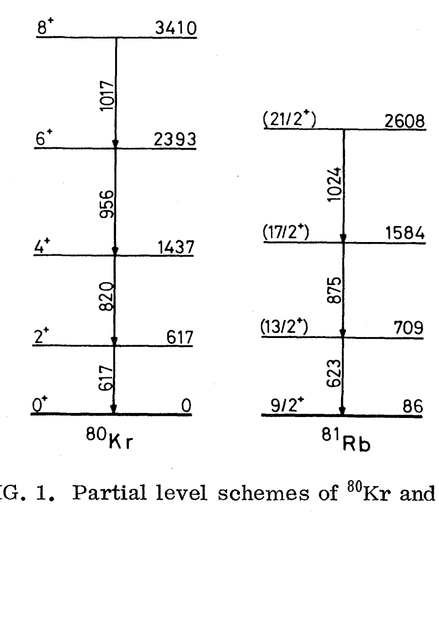

FIG. 1. Partial level schemes of ^{80}Kr and ^{81}Rb.

TABLE I. Lifetimes and reduced transition probabilities. RA, rotation aligned; M, Mottelson (Ref. 4); W, Weak coupling.

^{80}Kr

I	E (keV)	τ_{exp} (ps)	$B(E2)_{exp}$ (fm^4e^2)	$B(E2)_{Rot}$	$B(E2)_{vibr}$
2^+	617	12.7±0.7[a]	722±40	722±40	722±40
4^+	820	2.4±0.2[a]	921±77	1031±57	1444±80
6^+	956	0.75±0.2[b]	1369±364	1137±63	2166±120
8^+	1017	0.6[b]	1256	1188±66	2888±160

^{81}Rb

I	E	τ_{exp}	$B(E2)_{exp}$	$B(E2)_{RA}$	$B(E2)_{M}$	$B(E2)_{W}$
$13/2^+$	623	8.7±0.5[a]	1004±58	1010±60	1030±60	722±40
$17/2^+$	876	0.31±0.04[b]	5125±660	1138±68	1140±68	1031±57
$21/2^+$	1024	0.16±0.03[b]	4550±850	1172±62	1180±70	1135±63

[a]RDDS. [b]DSAM.

ing. Spectra were taken at five angles between 0° and 90°. From the angular dependence of the centroid, lifetimes were evaluated using a code written by J. Naser. This program uses the Blaugrund approximation taking into account both electronic and nuclear stopping power.[11]

The intensities of the unshifted peak and of the Doppler-shifted peak for several transitions are plotted versus recoil distance in Fig. 2. Delayed-cascade feeding was taken into account only in the analysis of the $2^+ \to 0^+$ transition in ^{80}Kr and of the $\frac{13}{2}^+ \to \frac{9}{2}^+$ transition in ^{81}Rb. Since the lifetimes of the 4^+ and $\frac{17}{2}^+$ states are shorter, it has been more convenient to extract them from the shifted peaks. Only an upper limit $\tau_{17/2} = 0.65$ psec was obtained in this way. The value obtained from DSAM is $\tau_{17/2} = 0.31 \pm 0.06$ psec. The lifetimes of the 2^+ and 4^+ states in ^{80}Kr are in agreement with results obtained by Nolte *et al.*[12]

The experimental results are compared in Table I with the predictions of several models. All the theoretical $B(E2)$ values have been normalized to that of the 2^+ level in ^{80}Kr. The $B(E2)$ values in ^{80}Kr are in satisfactory agreement with the rotational ones and lie far from the vibrational ones; this is consistent with the conclusions drawn by McCauley and Draper[5] from excitation-energy systematics. It would, of course, be in-

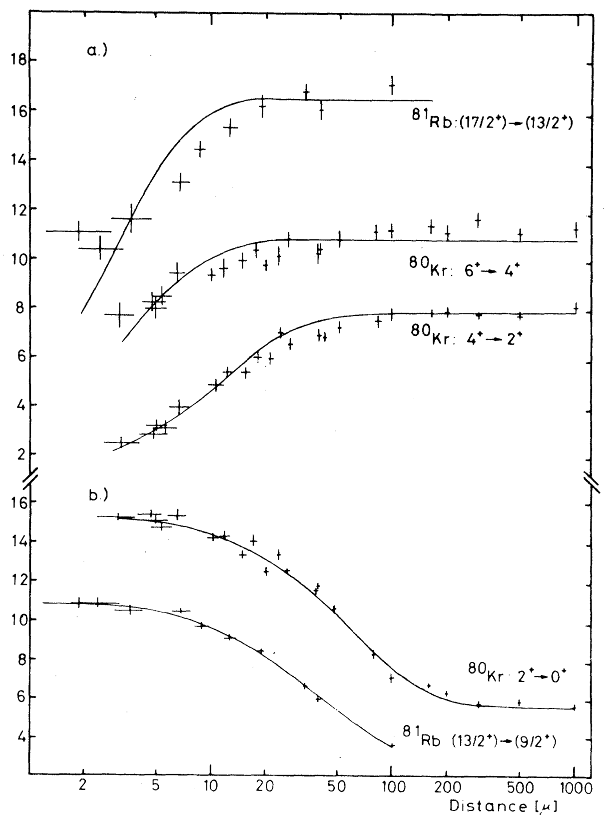

FIG. 2. Intensity of (a) Doppler-shifted peaks and of (b) unshifted peaks versus recoil distance.

teresting to extend lifetime measurements to other even Kr isotopes. If we assume that we are dealing with a $K=0$ rotational band, the deformation corresponding to the lifetime of the 2^+ state is $\delta=0.261\pm0.007$. The reduced transition probabilities in a rotor-plus-particle nucleus is given by

$$B(E2; I_i \to I_f) = (5e^2/16\pi Q_0^2) \times |\sum_\Omega c_\Omega^2 \langle I_i 2\Omega 0 | I_f \Omega\rangle|^2,$$

where Q_0 is the core intrinsic quadrupole moment and c_Ω is the amplitude of the $|I\Omega\rangle$ component in the wave function. Only Ω-diagonal contributions are taken into account.

The amplitudes c_Ω can be calculated in the rotation-aligned (RA) model by the simple approximate formula[3]

$$c_\Omega = d_{j\Omega}^{\,j}(\pi/2).$$

This approximation should be valid when the deformation is around $\delta=\pm0.2$. The corresponding $B(E2)$ values are given in Table I under the heading RA.

Mottelson[4] has shown that it is possible to calculate the amplitudes c_Ω in a simple way without imposing a restriction on the deformation; this calculation should be valid for relatively-high-spin states ($j \gg 1$). A linear recursion formula for c_Ω is rewritten as a second-order differential equation which is similar to that of a one-dimensional linear oscillator; the independent variable is Ω. The lowest oscillator state in Ω space has a width Ω_0 which is a function of the deformation and of the core moment of inertia. The amplitude c_Ω has the simple form

$$c_\Omega = [\Omega_0(2\pi)^{1/2}]^{-1}\exp[-\Omega^2/(2\Omega_0^2)].$$

If we use the deformation calculated above for ^{80}Kr and assume that it remains unchanged through the coupling with the particle, we obtain $B(E2)$ values represented in Table I under the heading M.

One sees that the experimental $B(E2)$ of the $\frac{13}{2}^+$-$\frac{9}{2}^+$ transition is in agreement with both rotor-plus-particle calculations with strong-Coriolis-force calculations. The hypothesis of weak coupling can be ruled out. As regards the higher $\frac{17}{2}^+$ and $\frac{21}{2}^+$ states, their lifetimes are much shorter than predicted, suggesting a drastic change of structure.

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