Decay scheme and transition probabilities of ^{85}Rb

T. F. Fazzini, P. R. Maurenzig, G. Poggi, and N. Taccetti
Istituto di Fisica dell'Università, Firenze, Italy,
and Istituto Nazionale di Fisica Nucleare, Sezione di Firenze, Italy
(Received 6 October 1981)

The decay scheme of ^{85}Rb up to 2.4 MeV excitation energy was investigated by the ^{84}Kr(p,γ) reaction and Coulomb excitation with alpha particles. Singles and γ-γ coincidence spectra were recorded. Doppler shift attenuation measurements in gas were performed using the same gas as stopper medium. Lifetimes or lifetime limits were determined for 20 levels by Coulomb excitation and the Doppler shift attenuation method. An existing ambiguity referring to the lifetime of the second excited level has been removed.

NUCLEAR REACTIONS ^{84}Kr(p,γ), Coulomb excitation by alpha bombardment. $E_p = 1.85-2.87$ MeV. $E_\alpha = 3$ MeV. Natural Kr gas target; $p = 0.1-106\times10^5$ Pa. Doppler shift attenuation in gas. Measured: level energies, branching ratios, decay scheme, lifetimes.

INTRODUCTION

The aim of this work was to study the decay scheme and to measure transition probabilities in ^{85}Rb. The existing information on the γ-decay modes was mainly based on inelastic neutron scattering,[1,2] electron capture in ^{85}Sr,[3–5] β^- decay of ^{85}Kr,[6–8] and Coulomb excitation,[9] while levels were known from single particle transfer reactions.[10,11] High spin states were studied by ^{82}Se(^{6}Li,$3n\gamma$) and ^{82}Se(^{7}Li,$4n\gamma$) reactions.[12] Recently a Nuclear Data Sheets (NDS) compilation[13] based on results from a further $(n,n'\gamma)$ experiment[14] established a coherent decay scheme up to excitation energy of about 2 MeV; no new information on transition probabilities has been reported.

The ^{84}Kr(p,γ) reaction has been used in the present experiment which consisted of γ-γ coincidence, excitation function, and Doppler shift attenuation (DSA) measurements. A Coulomb excitation measurement via the ^{85}Rb(α,α') reaction has also been performed. The decay scheme we obtained, mainly in good agreement with the recent compilation, gives some information on previously unobserved levels and their decay modes. Two independent lifetime measurements of the first $\frac{1}{2}^-$ level are given, solving an existing ambiguity.[9,13,14] Lifetimes of many transitions in ^{85}Rb are established and some lifetime limits are set. Preliminary results of these measurements have already been reported.[15]

EXPERIMENTAL METHOD

In almost all the measurements hereafter reported natural Kr gas, at pressures ranging from 0.1 to 106 $\times10^5$ Pa, was bombarded by the proton beam of the 3 MV Van de Graaff accelerator of Istituto Nazionale di Fisica Nucleare (INFN) at the University of Florence, with beam currents varying from 10 to 1000 nA.

Detectors and data acquisition system

The detectors used during the present experiment were an intrinsic germanium (IG) low-energy photon spectrometer (LEPS) of 1 cm^3 active volume (0.5 keV resolution at 122 keV), a second IG LEPS of 13 cm^3 active volume (0.6 keV at 122 keV), a 25% Ge(Li) (1.8 keV at 1.33 MeV), a 10% Ge(Li) (2.2 keV at 1.33 MeV), a 7.6$\times$7.6 cm NaI integral line, and 22.8$\times$20.3 cm active shield NaI crystal coupled to four 4.4 cm phototubes. In the following the germanium detectors will be referred to as IG1, IG2, 25% Ge, and 10% Ge, respectively.

Data have been collected by means of a 2116 HP computer controlling a multiplexed analog to digital converter (ADC) system. During coincidence runs, data were stored on tape in the standard three parameter mode for later off-line analysis.

The gas target arrangement

The seal between the gaseous target and the vacuum of the beam pipe was provided by a nickel window of various thicknesses (from 1.8 to 3 mg/cm^2) and diameters (0.5 to 2 mm). In order to handle the broad range of pressures and to match the specific requirements of each run, three different gas cells were used. The first one, usable in the pressure range up to 2×10^5 Pa, made it possible to perform very low energy γ-ray measurements since the sealing against the outside was provided by a 0.12 mm Mylar window. For gas pressures up to 20×10^5 Pa, a gas cell described in Ref. 16 has been used, while a small cell was especially designed for runs where pressures as high as 100×10^5 Pa were employed. In the first two cells the distance from the entrance foil to the stopper (Ta or Au) could be varied. In the following the gas cells will be referred to as first, second, and third cell, respectively.

Excitation function, Coulomb excitation, and coincidence measurements

Excitation function measurements were performed in the effective proton-energy range (i.e., after passing through the nickel window) of 1850–2870 keV by 45 keV steps, the gas thickness being managed to be about 40 keV. Gamma spectra were taken by the 25% Ge. In order to perform Coulomb excitation measurements a 1.7 mg/cm^2 thick natural Rb target, deposited on a graphite backing, was bombarded by 3 MeV α particles and spectra were collected with the 10% Ge.

The γ-γ coincidence measurements were performed between the 25% Ge and the 10% Ge detectors placed at 90° with respect to the beam direction and on opposite sides of the first target cell. The tantalum stopper and nickel window were shielded. In order to extend the analysis to the very

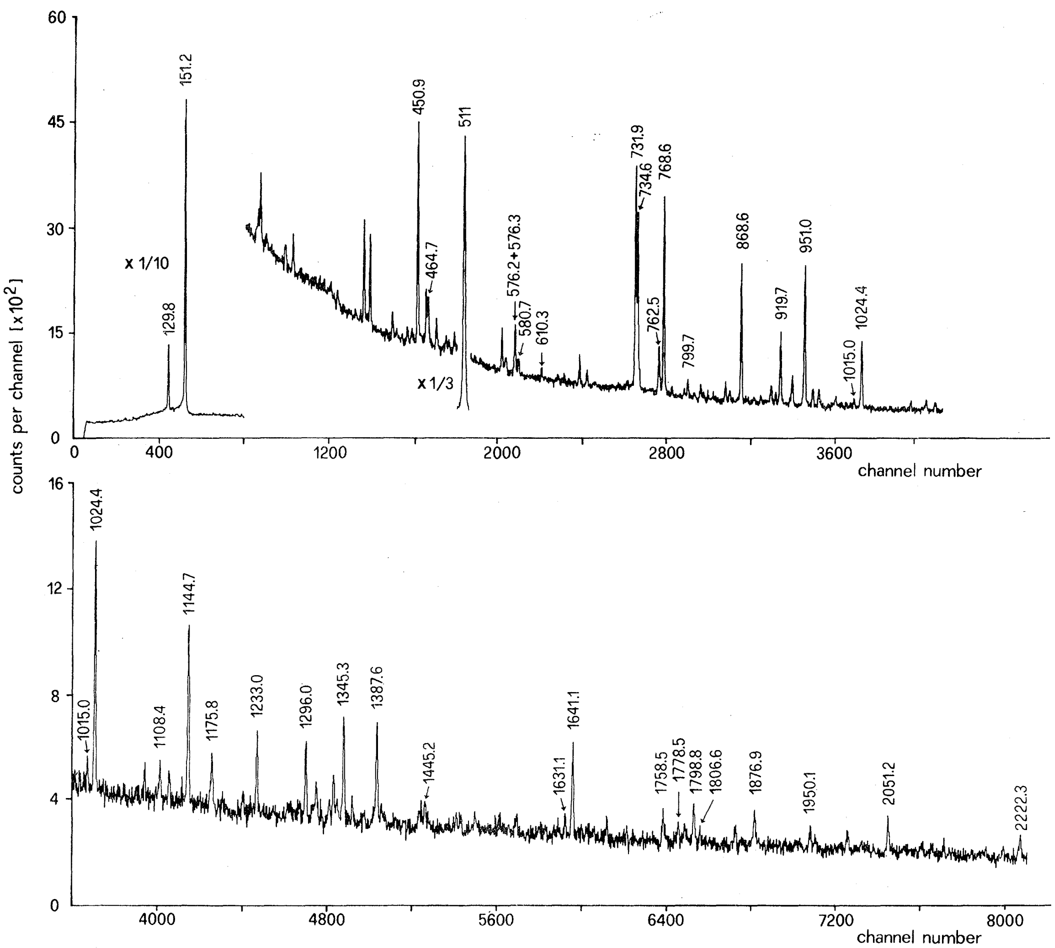

FIG. 1. Ge(Li) gamma spectrum at 55° in coincidence with γ rays of an energy greater than 2 MeV detected at 0°. Energies of prominent transitions in ^{85}Rb are indicated in keV.

low energy-transition region, a shorter run was performed in which coincidence events between the 25% Ge and the IG1 LEPS were recorded.

In another run γ-γ coincidences were performed between a 7.6×7.6 cm NaI detector mounted at 0° with respect to the beam direction and the 25% Ge placed at 55°. The 55° γ spectrum (see Fig. 1) in coincidence with high energy (>2 MeV) γ rays made possible a fairly accurate determination of the relative intensities of transitions from ^{84}Kr$(p,\gamma)^{85}$Rb. In fact, this coincidence requirement got rid of lines and background coming from (p,n) and (p,p') reactions while preserving, in the adopted geometry, the axial symmetry around the beam direction. The second cell was used in this run with Kr gas at $p = 6\times10^5$ Pa. Efficiency calibration was performed by putting a ^{152}Eu source inside the chamber.

DSA measurements

The krypton gas has been used as a target as well as a stopper medium in DSA measurements. In order to measure lifetimes of low energy γ rays, the IG1 detector was mounted 10 cm apart from the target at 0° and 90° with respect to the beam for shifted and unshifted peak-position measurements, respectively; in the 0° runs, the pressure varied from 0.1×10^5 to 15×10^5 Pa. The beam stopper was made of gold and ^{57}Co and ^{51}Cr sources gave energy reference points.

Lifetimes of transitions with energies up to 2.2 MeV were measured by performing a coincidence DSA experiment. Data were collected on the 25% Ge in coincidence with γ rays detected by the 20.3×22.8 cm NaI crystal mounted at 90° with respect to the beam direction and to the germanium detector axis. In runs where the 25% Ge was placed at 0°, the pressure varied from 1 to 106×10^5 Pa. ^{60}Co and ^{207}Bi sources gave fixed energy points in the 90° and 0° coincidence runs. In the off-line analysis different gate settings were used on the NaI spectrum in order to sort Ge(Li) gamma spectra suitable for peak position determination of either source reference lines or ^{85}Rb relevant transitions. In both singles and coincidence DSA runs, the fraction of ^{85}Rb ions recoiling in the solid stopper was estimated to be less than 1.5% in the worst case.

The decrease of the gas density due to beam heating[17] has been checked by measuring the energy shift and the yield of γ lines at 20, 200, and 400 nA beam currents for various pressures and setups. A density decrease of about 15% with respect to the zero-current limiting value has been estimated for the actual DSA measurements and taken into account in the calculation of F values (see below).

Branching ratio of the 281.0 keV level

Special care was devoted to the measurement of the intensity ratio of the 281.0 keV line with respect to the 129.8 keV one, both deexciting the first $\frac{1}{2}^-$ level of ^{85}Rb. Gamma rays of 278.2 and 282.8 keV belonging to ^{64}Cu and ^{61}Ni, respectively, produced via ^{64}Ni(p,n) and ^{61}Ni(p,p') on the entrance foil, had to be strongly suppressed by proper shielding. However a γ line of 279.5 keV still remained, being produced in the same target gas (presumably on ^{78}Kr via a p,γ reaction). Moreover a large Compton background mainly deriving from an intense annihilation peak (associated with pair production by high energy γ transitions) was present in the region around 300 keV.

An anti-Compton Spectrometer system consisting of IG2 and the 22.8×20.3 cm NaI(Tl) active shield was used in order to improve the peak-to-background ratio. The first cell was used with only a small target region being seen by the IG detector. The nickel foil, the tantalum stopper, and all other target regions were shielded by a 20 mm thick lead sheet. The pressure was kept constant at 1.6×10^6 Pa. The spurious contribution to the branching owing to the sum effect of the 129.8−151.2 keV lines was kept as low as 0.07% by the small (9×10^{-4} sr) solid angle. Figure 2 shows the Compton-suppressed spectrum. The efficiency measurement was performed by placing a ^{152}Eu source on various positions along the beam path in the gas cell, even in the shielded region, so that shadowing of target zones due to the lead collimator edges was taken into account.

EXPERIMENTAL RESULTS AND DISCUSSION

Excitation function

The yield of all the γ transitions belonging to ^{85}Rb showed a smooth behavior in the whole energy range and, owing to the proton energy straggling after passing through the nickel foil and to the target thickness (~40 keV), no prominent resonances have been observed.

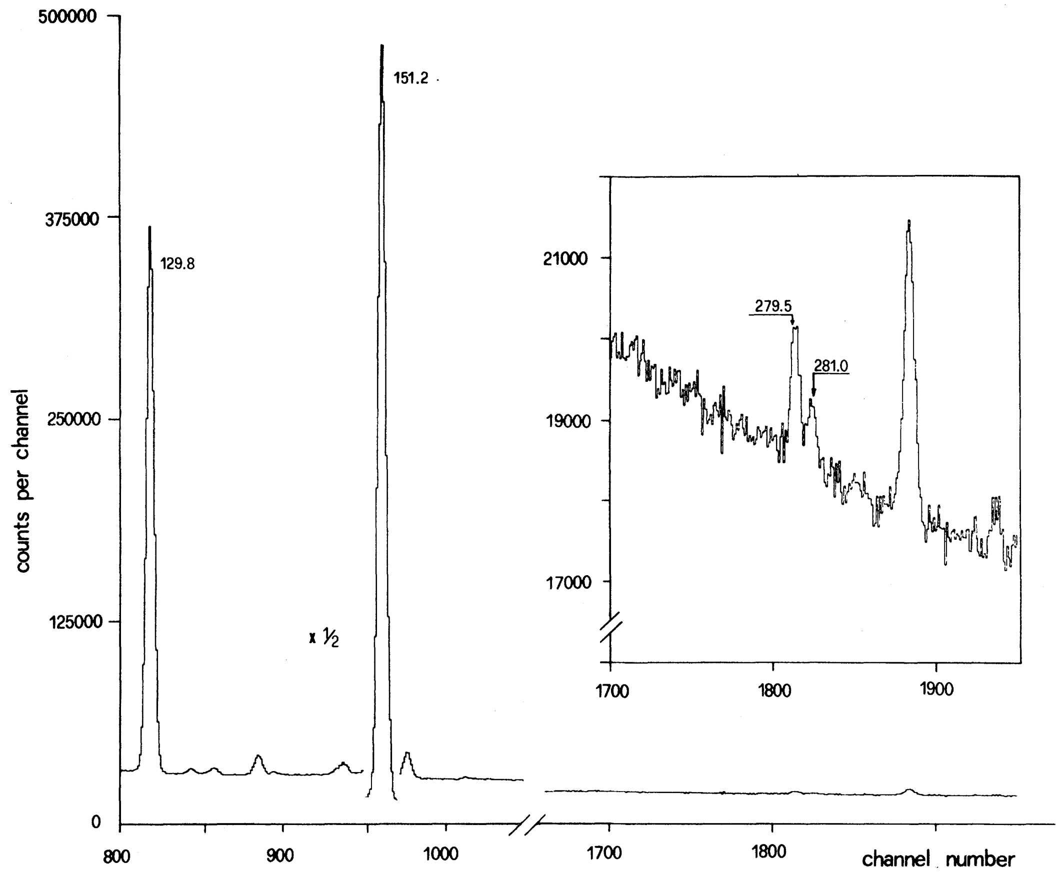

FIG. 2. Compton-suppressed IG spectrum. Energies of relevant transitions are indicated in keV.

Decay scheme

The decay scheme deriving from our measurements is shown in Fig. 3; only small pieces of information are added with respect to the decay scheme we presented earlier.[15] The agreement with the recent compilation[13] is almost complete. It is to be noted that from our coincidence data the 576.3 keV rays have a double assignment as transitions from levels at 1444.9 and 1496.4 keV. We were not able to discriminate two contributions in the 1233.0 keV γ line as reported in Ref. 14; we thus leave the intensities of γ lines deexciting the 1384.3 keV level in parentheses. The γ decay of levels at 2202.4 keV populated in the (d,^{3}He) (Ref. 18) and (t,d) (Ref. 10) reactions and at 2373.5 keV populated in the (^{3}He,d) (Ref. 11) reaction has been observed for the first time. Previously unobserved levels at 1668.6, 1929.7, 2028.1, 2039.5, and 2087.6 keV have been identified. The quoted γ-ray energies are deduced from the spectra collected at 90° with respect to the beam. Table I summarizes the energy sum analysis; the overall agreement is very good except for the levels at 950.9 and 1175.8 keV which are suspected[13] to be doublets.

An intensity for the 281.0 keV transition of 4.5% with respect to the $\frac{1}{2}^- \to \frac{3}{2}^-$ one of 129.8 keV was reported[9] while Barnard *et al.*[14] gave an upper limit of 1%; for the same branching ratio we measured (0.58 ± 0.06) %. The quoted result is corrected for sum peak effect and for internal conversion in the hypothesis of a pure $M1$ multipolarity for the $\frac{1}{2}^- \to \frac{3}{2}^-$ transition. This hypothesis is justified by the fact that the 151.2 keV line, having a lifetime of 1 ns, is known to be a pure $M1$ transition[7,19]; it is therefore hard to admit a larger $E2$ contribution in the 129.8 keV transition whose lifetime is much shorter (see below).

DSA analysis and results

The calculation of the theoretical Doppler shift attenuation factors $F(p\tau,\beta)$ follows the procedure

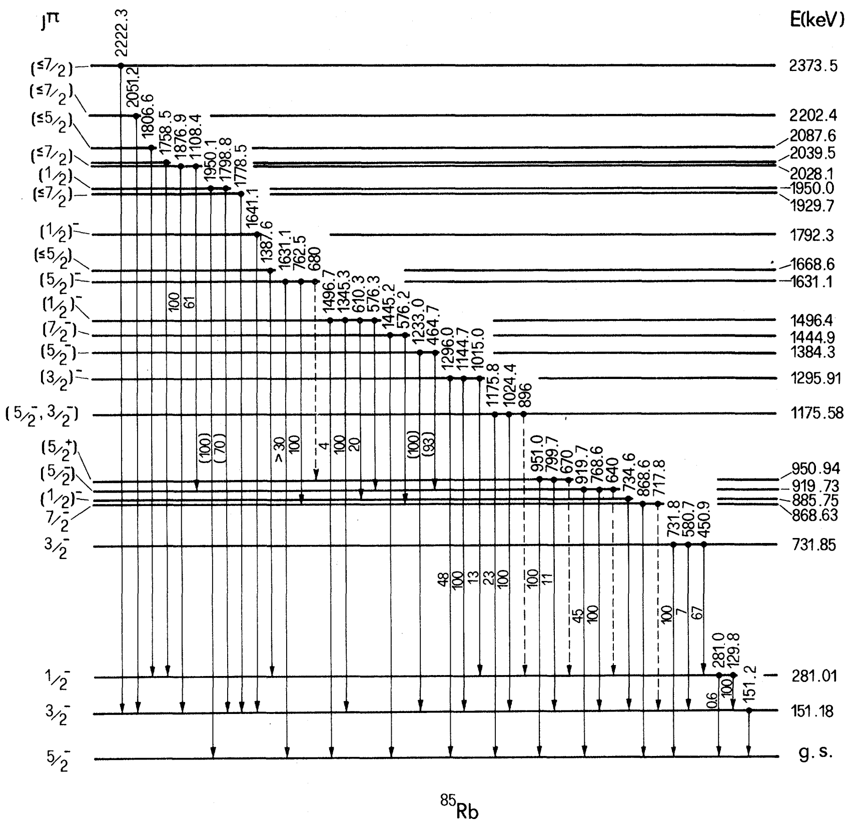

FIG. 3. Decay scheme of excited levels in ^{85}Rb as derived in the present work. Most of the J^{π} assignments are taken from Ref. 13.

reported in Ref. 16 except for the evaluation of the specific energy loss of the recoiling ^{85}Rb atoms: The function $(dE(v)/dx)$ has been deduced from the data of Ref. 20 which should be the most accurate ones for our case ($\epsilon \simeq 0.09$ in LSS units[21]).

For each γ line a weighted least squares procedure has been followed, in which the input data are the experimental energies $E(p)$, at 0° and pressure p, plus the one at 90° treated as the $E(p)$ value at $p=\infty$. These values are compared with the expression $\Delta E_0 F(p\tau,\bar{\beta})+E_0$. In this expression the lifetime τ and the unshifted energy E_0 are free parameters and $\Delta E_0=\bar{\beta}E_0$ is the corresponding maximum Doppler shift, $\bar{\beta}=\bar{v}/c$ being the average ^{85}Rb recoil velocity along the target-counter direction. For each pressure the value $\bar{\beta}$ has been deduced from the capture reaction kinematics and from the experimental yield as a function of the proton energy along the target thickness.

Table II contains the results of the DSA analysis; the quoted uncertainty in the τ_m values is only statistical and has been calculated according to Ref. 22 and corresponds to a 68% confidence level. According to Ref. 16 the final uncertainty must be increased by a 20% contribution due to systematic errors associated with gas temperature and uncertainty in the slowing down of ^{85}Rb ions in the Kr gas. When known, lifetime measurements from other experiments are reported. In Fig. 4 the experimental $F=[E(p)-E_0]/\Delta E_0$ points, together with the theoretical values calculated as described above, are reported for some γ lines of ^{85}Rb.

151.2 keV transition. Its lifetime is known[13] to be 1.07 ± 0.07 ns. This lifetime is almost at the long lifetimes limit of the DSA method in gases and in fact Fig. 4 shows that only the first four points determine the lifetime; its fitted value of 930^{+220}_{-180} ps turns out to be in agreement with the known value.

129.8 keV transition. The whole $F(p)$ curve is reproduced by the experimental points and a lifetime of 56^{+10}_{-8} ps is the best fit value.[23] The $B(E2)\uparrow$ value for the transition to the first $\frac{1}{2}^-$ level which

TABLE I. Energies of excited levels and transitions in ^{85}Rb. Values are in keV.

γ-cascade energies	Sum	Level energies (weighted averages)
151.182 ± 0.013	151.182 ± 0.013	151.182 ± 0.013
129.83 ± 0.02, 151.182 ± 0.013	281.01 ± 0.02	281.01 ± 0.02
281.01 ± 0.05	281.01 ± 0.05	
450.85 ± 0.02, 129.83 ± 0.02, 151.182 ± 0.013	731.86 ± 0.03	
580.69 ± 0.15, 151.182 ± 0.013	731.87 ± 0.15	731.85 ± 0.02
731.84 ± 0.02	731.84 ± 0.02	
868.63 ± 0.03	868.63 ± 0.03	868.63 ± 0.03
734.57 ± 0.03, 151.182 ± 0.013	885.75 ± 0.03	885.75 ± 0.03
768.55 ± 0.03, 151.182 ± 0.013	919.73 ± 0.03	919.73 ± 0.03
919.72 ± 0.05	919.72 ± 0.05	
799.65 ± 0.08, 151.182 ± 0.013	950.83 ± 0.08	950.94 ± 0.03
950.96 ± 0.03	950.96 ± 0.03	
1024.38 ± 0.04, 151.182 ± 0.013	1175.56 ± 0.04	1175.58 ± 0.04
1175.78 ± 0.14	1175.78 ± 0.14	
1014.98 ± 0.21, 129.83 ± 0.02, 151.182 ± 0.013	1295.99 ± 0.22	
1144.72 ± 0.04, 151.182 ± 0.013	1295.90 ± 0.04	1295.91 ± 0.04
1295.95 ± 0.09	1295.95 ± 0.09	
464.66 ± 0.11, 919.72 ± 0.05	1384.38 ± 0.12	1384.33 ± 0.10
1233.01 ± 0.20, 151.182 ± 0.013	1384.19 ± 0.20	
576.20 ± 0.20, 868.63 ± 0.03	1444.83 ± 0.20	1444.87 ± 0.19
1445.2 ± 0.6	1445.2 ± 0.6	
576.30 ± 0.20, 919.72 ± 0.05	1496.02 ± 0.20	1496.41 ± 0.09
610.30 ± 0.30, 734.57 ± 0.03, 151.182 ± 0.013	1496.05 ± 0.30	
1345.29 ± 0.07, 151.182 ± 0.013	1496.47 ± 0.07	
1496.7 ± 0.6	1496.7 ± 0.6	
(762.50 ± 0.05, 868.63 ± 0.03)[a]	(1631.13 ± 0.06)	(1631.13 ± 0.06)
1631.10 ± 0.5	1631.10 ± 0.5	
1387.63 ± 0.06, 129.83 ± 0.02, 151.182 ± 0.013	1668.64 ± 0.06	1668.64 ± 0.06
1641.09 ± 0.08, 151.182 ± 0.013	1792.27 ± 0.08	1792.27 ± 0.08
1778.53 ± 0.25, 151.182 ± 0.013	1929.71 ± 0.25	1929.7 ± 0.3
1798.84 ± 0.14, 151.182 ± 0.013	1950.02 ± 0.19	1950.03 ± 0.18
1950.1 ± 0.5	1950.1 ± 0.5	
1108.44 ± 0.19, 919.72 ± 0.05	2028.16 ± 0.19	2028.11 ± 0.11
1876.90 ± 0.14, 151.182 ± 0.013	2028.08 ± 0.14	
1758.5 ± 0.3, 129.83 ± 0.02, 151.182 ± 0.013	2039.5 ± 0.3	2039.5 ± 0.3
1806.6 ± 0.6, 129.83 ± 0.02, 151.182 ± 0.013	2087.6 ± 0.6	2087.6 ± 0.6
2051.2 ± 0.5, 151.182 ± 0.013	2202.4 ± 0.5	2202.4 ± 0.5
2222.3 ± 0.4, 151.182 ± 0.013	2373.5 ± 0.4	2373.5 ± 0.4

[a]A contribution from a 762.7 keV γ line of ^{83}Rb is present.

TABLE II. Lifetimes of levels in ^{85}Rb.

Level energy (keV)	γ-ray energy (keV)	τ_m (ps)	Present work χ^2 norm	Others τ_m (ps)
151.2	151.2	930^{+220}_{-180}	1.2	1070 ± 70[a]
281.0	129.8	56^{+10}_{-8}	0.6	
		58 ± 6	(Coulomb excitation)	
731.9	450.9	$6.3^{+2.5}_{-1.8}$	1.3	6.2 ± 0.43[b]
	731.9	$5.9^{+1.6}_{-1.2}$	0.9	
868.6	868.6	$3.2^{+0.9}_{-0.7}$	1.5	4.2 ± 0.6[b]
				3.0 ± 0.7[c]
885.7	734.6	$1.12^{+0.24}_{-0.14}$	0.5	
919.7	768.6	$(0.67^{+0.06}_{-0.06})$[d]	0.2	
	919.7	$(0.54^{+0.25}_{-0.20})$[d]	1.0	
950.9	950.9	$4.0^{+1.0}_{-0.8}$	1.4	
1175.8	1024.4	$0.90^{+0.25}_{-0.20}$	0.9	
	1175.8	$1.4^{+1.3}_{-0.6}$	0.5	
1295.9	1144.7	$0.25^{+0.15}_{-0.12}$	0.9	
1384.3	1233.0	$(1.4^{+0.7}_{-0.6})$[d]	1.1	
1496.4	1345.3	$0.5^{+0.4}_{-0.3}$	1.6	
1631.1	762.5	$(0.5^{+0.3}_{-0.2})$[e]	0.7	
1668.6	1387.6	$0.26^{+0.16}_{-0.14}$	0.7	
1792.3	1641.1	$0.0^{+0.17}$	1.1	
1929.7	1778.5	$0.0^{+0.14}$	0.9	
1950.1	1798.8	$0.6^{+0.7}_{-0.5}$	0.6	
	1950.1	$0.2^{+0.7}_{-0.2}$	0.5	
2028.1	1108.4	$1.7^{+2.5}_{-1.0}$	0.6	
	1676.9	$1.2^{+0.6}_{-0.5}$	0.6	
2087.6	1806.6	$0.0^{+0.4}$	0.6	
2202.4	2051.2	$0.4^{+0.4}_{-0.3}$	0.5	
2373.5	2222.3	$0.1^{+0.4}_{-0.1}$	0.8	

[a]Reference 13.
[b]Reference 9.
[c]Reference 24.
[d]See text.
[e]A contribution from a 762.7 keV γ line from ^{82}Kr$(p,\gamma)^{83}$Rb is present.

mainly decays through the 129.8 keV γ line to the $\frac{3}{2}^-$ level is known[9] to be 16 ± 2 e^2fm^4; from our Coulomb excitation measurement we obtained 17 ± 2 e^2fm^4, in excellent agreement. From the 281.0-129.8 keV branching ratio of 0.58% reported in the preceding paragraph a lifetime of 58 ± 6 ps is deduced for the 281.0 keV level, thus confirming the DSA value.

450.9 and 731.9 keV transitions. Both deexcite the 731.9 keV level and actually their lifetimes of $6.3^{+2.5}_{-1.8}$ ps and $5.9^{+1.6}_{-1.2}$ ps, respectively, coincide well within the statistical uncertainties. The lifetime of this level was also determined[9] by Coulomb excitation and DSA measurements to be 6.2 ± 0.4 ps.

868.5 keV transition. The corresponding lifetime turns out to be $3.2^{+0.9}_{-0.7}$ ps. This value is to be compared with values of 4.2 ±0.6 ps (Ref. 9) and 3.0 ± 0.7 ps.[24]

For the other measured lifetimes in ^{85}Rb no comparison is possible. For the 919.7 keV level, the

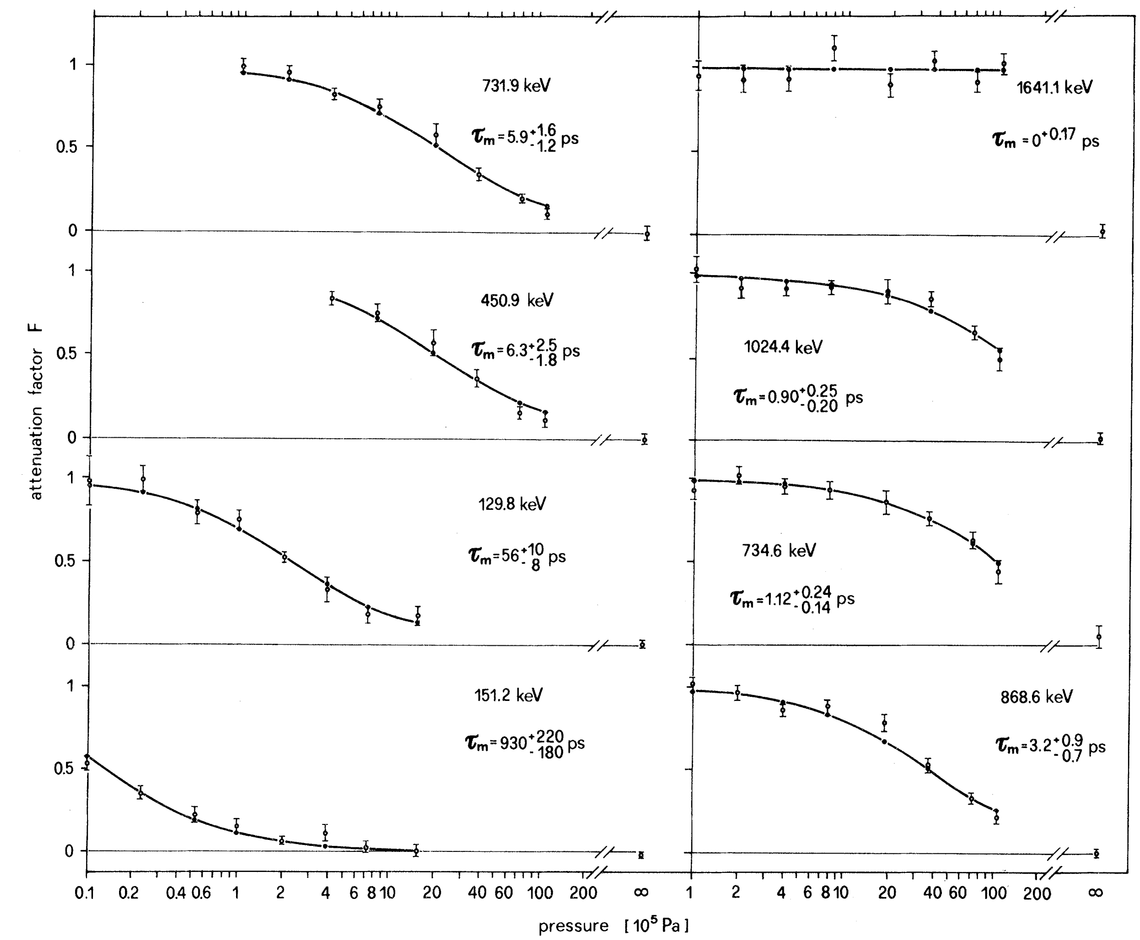

FIG. 4. Experimental attenuation factors F for various transitions in ^{85}Rb are given by open circles. Continuous curves are interpolated through the full dots which represent the theoretical F values calculated as described in the text. The 90° unshifted energy has been converted to the experimental $p=\infty$ attenuation factor (see text).

measured transition lifetimes are in parentheses since they are overestimated by about two tenths of a picosecond, due to the sizeable feeding from levels with comparable lifetimes. The lifetime of the 1384.3 keV level is also reported in parentheses due to a possible double origin of the 1233.0 keV γ line.[14] Lifetime measurements and decay scheme suggest for the levels at 1668.6 and 2087.6 keV an upper limit of $J \leq \frac{5}{2}$ and for levels at 1929.7, 2028.1, 2202.4, and 2373.5 keV an upper limit of $J \leq \frac{7}{2}$. For the other levels lifetime values and branching ratios are consistent with the existing J^{π} assignments.

CONCLUSIONS

In a paper by Krishan *et al.*[25] transition probabilities of the first excited levels in ^{85}Rb have been calculated in the frame of a semimicroscopic model in which the proton quasiparticle motion is coupled to the quadrupole vibration of the core nuclei ^{84}Kr or ^{86}Sr. The lifetime of the first $\frac{1}{2}^-$ level, calculated as 77 ps, agrees very well with our experimental value. In that paper, the value of 2 ps calculated for the lifetime of the first $\frac{5}{2}^-$ excited level was compared with that of the 868.6 keV level which is presently known[13] to be $\frac{7}{2}^-$. The correct comparison would rather be with the ($\frac{5}{2}^-$) 919 keV level whose lifetime we estimated in the order of 0.5 ps. The detailed knowledge of the decay scheme, of J^π assignments, and the established transition probabilities in ^{85}Rb make possible now a much more stringent test of the model.

ACKNOWLEDGMENTS

Many thanks are due to Prof. P. G. Bizzeti and M. Bini for many stimulating discussions and for providing us with the computer code for calculating the theoretical attenuation factors. The skillfull technical assistance of Mr. A. Pecchioli is also acknowledged.

[1]R. P. Torti. V. M. Cottles, V. R. Dave, J. A. Nelson, and R. M. Wilenzick, Phys. Rev. C 6, 1686 (1972).

[2]E. Barnard, N. Coetzee, J. A. M. De Villiers, D. Reitmann, and P. Van Der Merwe, Z. Phys. 260, 197 (1973).

[3]E. Vatai, A. C. Xenoulis, K. R. Baker, F. Tolea, and R. W. Fink, Nucl. Phys. A219, 595 (1974).

[4]W. S. Pratt, J. Inorg. Nucl. Chem. 39, 919 (1977).

[5]D. J. Thomas Z. Phys. A 289, 51 (1978).

[6]D. J. Horen, Nucl. Data Sheets B 5, 131 (1971).

[7]F. K. Wohn, W. L. Talbert, Jr., and J. K. Halbig, Nucl. Phys. A152, 561 (1970).

[8]L. D. McIsaac, R. J. Gehrke, J. E. Cline, and R. L. Heath, Aerojet Nuclear Company, Idaho Falls, Report No. ANCR-1088, 1972, p. 387.

[9]P. D. Bond and G. J. Kumbartzki, Nucl. Phys. A205, 239 (1973).

[10]R. C. Ragaini, J. D. Knight, and W. T. Leland, Phys. Rev. C 8, 988 (1973).

[11]L. R. Medsker, J. N. Bishop, S. C. Headly, and H. T. Fortune, Phys. Rev. C 10, 2117 (1974).

[12]J. W. Peters, A. Dewald, W. Gast, A. Geberg, D. Hippe, H. W. Schuh, K. O. Zell, and P. Von Brentano, *Structure of Medium-Heavy Nuclei 1979,* Proceedings of a conference, Rhodes, Greece, 1979, edited by G. S. Anagnostatos *et al.* (Institute of Physics, Bristol, U.K., 1980).

[13]J. W. Tepel, Nucl. Data Sheets, 30, 501 (1980).

[14]E. Barnard, D. W. Mingay, D. Reitmann, and J. W. Tepel, Z. Phys. A 296, 295 (1980).

[15]T. F. Fazzini, P. R. Maurenzig, G. Poggi, and N. Taccetti, contributed abstract to the Proceedings of the International Conference on Nuclear Physics, Berkeley, 1980, Lawrence Berkeley Laboratory Report No. LBL-11118.

[16]M. Bini, P. G. Bizzeti, A. M. Bizzeti Sona, and R. A. Ricci, Phys. Rev. C 6, 784 (1972), and references therein.

[17]D. K. McDaniels, I. Bergqvist, D. Drake, and J. T. Martin, Nucl. Instrum. Methods 99, 77 (1972).

[18]J. R. Comfort, J. R. Duray, and W. J. Braithwaite, Phys. Rev. C 8, 1354 (1973).

[19]N. A. Voinova, A. I. Egorov, V. Yu, and A. G. Sergeev, Izv. Akad. Nauk. SSSR. Ser. Fiz. 35, 861 (1971) [Bull. Acad. Sci. USSR, Phys. Ser. 35, 794 (1972)].

[20]H. Oetzmann, A. Fenerstein, H. Grahmann, and S. Kalbitzer, Phys. Lett. 55A, 170 (1975).

[21]J. Lindhard, M. Scharff, and H. E. Schiøtt, K. Dan. Vidensk. Selsk. Mat. Fys. Medd. 33, No. 14 (1963).

[22]D. Cline and P. M. S. Lesser, Nucl. Instrum. Methods 82, 291 (1970).

[23]This value supersedes the one reported in Ref. 15 obtained from a preliminary analysis of a test run. The final analysis with a better evaluation of the actual gas density due to the beam heating gives $\tau_m = 49 \pm 10$ ps. However, this result has not been included in the τ value reported in Table II owing to the difficulty in estimating the error introduced by the low energy tail of an intense 136 keV tantalum peak underlying the 130 keV line.

[24]I. K. Lemberg and A. A. Pasternak, Izv. Akad. Nauk. SSSR, Ser. Fiz. 38, 1600 (1974) [Bull. Acad. Sci. USSR Phys. Ser. 38, 35 (1974)].

[25]K. Krishan, S. K. Basu, and S. Sen, Phys. Rev. C 13, 2055 (1976).