NUCLEAR SPINS AND MAGNETIC MOMENTS OF SOME NEUTRON-DEFICIENT RUBIDIUM ISOTOPES

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ABSTRACT

The nuclear spins and magnetic moments of some neutron-deficient rubidium isotopes have been measured by atomic-beam magnetic resonance techniques at the ISOLDE facility, CERN. The following results have been obtained : ^{77}Rb , $I = 3/2$, $\mu_I = 0.652(7)$ n.m.; ^{78}Rb , $I = 0$; $^{78\text{m}}\text{Rb}$, $I = 4$, $\mu_I = 2.56(3)$ n.m.; ^{79}Rb , $I = 5/2$, $\mu_I = 3.36(4)$ n.m., and $^{84\text{m}}\text{Rb}$, $I = 6$. The data on the light rubidium isotopes gives evidence for deformed nuclear shapes.

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NUCLEAR MOMENTS (static) $^{77,78,78}, ^{79,84\text{m}}\text{Rb}$; measured J.
 $^{77,78\text{m},79}\text{Rb}$; measured a, deduced μ .
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1. INTRODUCTION

The nuclides close to the center of the region $28 < (N,Z) < 50$ are supposed to exhibit strongly deformed nuclear shapes. The subshell closures apparent in the $N = 38$ isotones of the elements $_{30}\text{Zn}$, $_{32}\text{Ge}$ and $_{34}\text{Se}$, and in the $Z = 40$ zirconium isotopes close to $N = 50$, are here completely lost, as evidenced by the low-lying 2^+ states in the doubly-even nuclides of the elements $_{36}\text{Kr}$, $_{38}\text{Sr}$ and $_{40}\text{Zr}^{1)}$. Experimental data on odd-A and doubly-odd nuclides in this region are therefore highly desirable in order to obtain information on the deformation and on the configuration assignments. In the present work, we report on nuclear spins and magnetic moments of neutron-deficient rubidium isotopes, measured by atomic-beam magnetic resonance (ABMR) techniques. The results obtained will be discussed in terms of the strong-coupling model.

2. EXPERIMENTAL PROCEDURE

The radioactive rubidium isotopes investigated in the present work were obtained as spallation products in a target of niobium powder irradiated with 600 MeV protons from the synchro-cyclotron at CERN. Following mass separation in the ISOLDE on-line isotope separator²⁾, the ion beams were directed to the oven position of the ABMR apparatus³⁾. The production yield curve of rubidium from the separator⁴⁾ shows a maximum at mass number $A = 81$ of about 10^{10} atoms/sec; decreasing to 10^7 atoms/sec, the lower limit of atoms required in our applications, at mass number $A = 76$.

The on-line oven system, used in the main part of the present work, is described in detail in refs.^{3,5)}. The oven consists simply of a tantalum foil placed at a 45° angle both to the incoming ion beam and to the optical axis of the atomic-beam apparatus. The foil is covered with a layer of yttrium in order to lower the surface work function, thus allowing the alkalis to evaporate as atoms rather than ions. The ABMR experiments were made on the atomic-beam of rubidium isotopes continuously evaporated from the heated oven foils.

In some early measurements, the rubidium isotopes, collected on aluminum foils, were put together with some grams of potassium in a closed volume oven which was heated by electron bombardment to produce an atomic-beam. Due to the relatively long half-lives of the rubidium isotopes investigated, this off-line procedure was not too large a drawback. In fact, a higher signal to background ratio was obtained than in the on-line experiments. However, the time-consuming hyperfine structure measurements were all made using on-line techniques.

The activity transmitted through the ABMR apparatus was collected on aluminum foils and subsequently measured with appropriate types of detectors; thin plastic scintillators for the detection of the β^+ -decay of $^{77},^{78},^{78\text{m}},^{79}\text{Rb}$ and $\text{Ge}(\text{Li})$

detectors for the γ -decay of $^{84\text{m}}\text{Rb}$.

The ABMR experiments were performed in the $^2\text{S}_{1/2}$ electronic ground state of rubidium having the splitting factor $g_J = 2.0023319(14)$, ref.⁶⁾. The Breit-Rabi diagram describing the hyperfine structure of a $J = \frac{1}{2}$ atomic system is discussed in our paper on cesium⁵⁾, as is the experimental procedure for measurements of nuclear spins and moments.

3. RESULTS

3.1 Nuclear spins

The spin measurements were made in weak external magnetic fields, corresponding to the Zeeman region for the hyperfine structure. According to the relation $\nu = g_J \mu_B B / h(2I+1)$, there is only one observable resonance transition frequency (within one F-level) for each nuclear spin value. The spin search in rubidium, made in the fields $\mu_B B / h = 1.378, 2.964$ and 4.029 MHz, covered the values $I = \frac{1}{2} - 11\frac{1}{2}$ in the odd-A isotopes and $I = 0 - 7$ in the doubly-odd ones. The results obtained in the nuclides $^{77,78,78\text{m},79,84\text{m}}\text{Rb}$ are collected in table 1.

The 21 min isomeric state in ^{84}Rb decays to the ground state by emitting three γ -rays of the energies 216, 248 and 464 keV (cf. fig. 1). These γ -rays, detected in a Ge(Li) detector, were used to measure the $^{84\text{m}}\text{Rb}$ activity reaching the collector position of the ABMR apparatus. In an off-line experiment, a sample of ^{84}Rb , accumulated for 20 min, was evaporated from an atomic-beam oven. By applying the frequencies corresponding to the spin values $I = 6$ and $I = 7$ in exposing two collectors alternately, the γ -spectra shown in fig. 1 were obtained. The experiment lasted 20 min, and the spectra shown are the results of a 5 min counting. A strong spin $I = 6$ resonance signal is observed, while the $I = 7$ activity equals the apparatus background. The same results were obtained for combinations of spin $I = 6$ with other integer spin values.

A similar experiment was made in ^{78}Rb . Following a 15 min accumulation, the two collectors were exposed alternately at the spin $I = 0$ and $I = 4$ frequencies. The results from this isomer separation are shown in fig. 2. The two decay curves correspond to the 17 min ground state and the 6 min isomeric state, respectively. The β -counting began after an experimental period of 12 min; the starting intensities giving information on the relative isomer to ground state production yield from the separator.

Particular attention was paid to the ground state of ^{78}Rb , in which resonance signals were observed at the $I = 0$ frequencies. Such signals may also be obtained in the case of a non-zero spin and a small hyperfine structure separation. In order to check the possibility of a non-zero spin, we made a careful frequency scan in a field of $\mu_B B / h = 1.378$ MHz, from 700 kHz below to 200 kHz above the spin $I = 0$ frequency. Only one resonance signal was observed, having a line width

FWHM = 40 kHz (cf. the bottom part of fig. 3).

In the upper part of fig. 3, we give the observable transition frequencies as a function of dipole hyperfine constant for the cases $I = 1$ and $I = 2$. As a consequence of the small values of a , the strong-field selection rules $\Delta M_J = 1$ and $\Delta M_I = 0$ are valid already at the low field of $\mu_B/h = 1.378$ MHz (0.985 gauss). Three transitions may be observed in the case $I = 1$ and five in the case $I = 2$. The transition frequencies are degenerate for a dipole constant equal to zero, and coincide with the spin $I = 0$ frequency. Since only one resonance signal was observed experimentally at the $I = 0$ frequency, we may first exclude a non-zero spin and an a -factor larger than, say, 50 kHz. However, the experimental resonance curve may consist of an unresolved multiplet provided the a -factor is sufficiently small. In this region, the three transitions observable in a spin $I = 1$ nuclide are centered around the $I = 0$ frequency with spacings equal to $\pm a$ MHz. The spacings are $\pm a$, $\pm 2a$ MHz in the case $I = 2$. Assuming the experimental resonance curve to be composed of three unresolved lines having widths of 30 kHz; the width of the potassium calibration line at this field, we get an a -factor of 5 kHz. This is an upper limit in the case of a non-zero spin, since spin values larger than $I = 1$ would imply a larger number of resonances and thus a smaller dipole constant. The corresponding upper limit of the nuclear magnetic moment may be calculated to be 3×10^{-6} n.m. The appearance of such a small magnetic moment in a doubly-odd nucleus is indeed highly improbable. Therefore, we may assign with confidence a nuclear spin $I = 0$ to the ground state of ^{78}Rb .

The nuclear ground state spin of the 36.8 sec nuclide ^{76}Rb has previously been measured to be $I = 1$ by RADOP techniques at ISOLDE⁷⁾. This result was reproduced in our measurements. Furthermore, no resonance signals were obtained for higher spin values, associated with a possible isomeric state.

3.2 Nuclear magnetic moments

The hyperfine structure separations of the isotopes $^{77,78\text{m},79}\text{Rb}$ were measured by following the $\Delta F = 0$ single-quantum transitions, changing the sign of the effective magnetic moment, into successively stronger external magnetic fields. The identification of the single-quantum transitions were made on the basis of the low rf-power required for saturation and, in one external magnetic field for each isotope, the double-quantum transition was verified at the expected frequency. Typical examples of resonance curves observed in $^{77,78\text{m},79}\text{Rb}$ are exhibited in fig.4.

The experimental results are collected in table 2, where also the residuals, χ^2 and the dipole constants obtained in a least-squares fit of the experimentally observed resonances to the Breit-Rabi formula, assuming either a positive or a negative sign of the nuclear g -factors, are given. The uncertainties in the dipole constants have been obtained by assigning an error of one fourth of the FWHM to both the rubidium and the potassium calibration resonances. The goodness of the

fits allows us to assign a positive sign to the g-factors in all three cases.

The hyperfine structure separations $\Delta\nu$ and the nuclear magnetic moments μ_I are easily calculated from the measured dipole constants a using the relations :

$$\Delta\nu = a(I + 1/2) \quad (1)$$

and

$$\mu_I = \mu_{I_{\text{ref}}} \frac{a}{a_{\text{ref}}} \frac{I}{I_{\text{ref}}} \quad (2)$$

As reference isotope we have chosen ^{85}Rb , in which $\mu_I = 1.3533507(8)$ n.m. (corrected for diamagnetic shielding) ref.⁸⁾, $a = 1011.910813(2)$ MHz ref.⁹⁾, $I = 5/2$ ref.⁸⁾. An additional uncertainty of 1% on the magnetic moments is included to account for the unknown hyperfine structure anomaly.

Our final results on $^{77,78,79}\text{Rb}$ are given in table 3. This table presents an up-to-date list of nuclear spins, ground state hyperfine structure separations and nuclear magnetic moments of neutron-deficient rubidium isotopes.

4. DISCUSSION

A measure of the rms deformation of even-even nuclei may be obtained from the energies of the first excited 2^+ states using the empirical relation of Grodzins¹¹⁾

$$\beta = \left(\frac{204}{\hbar^2/2J A^{7/3}} \right)^{1/2} \quad (3)$$

where the rotational parameter $\hbar^2/2J$ equals $E_2+/6$. The deformation parameters in the region $28 < (N,Z) < 50$ calculated from eq.(3) are shown to be close to those obtained from the $B(E2)$ -values^{12,13)} where available. A slight overestimation is observed for the lighter elements. Since we are interested in the main trends rather than the absolute values of the deformation we have made use of the simple relation (3). The deformation parameters divided by the values expected from the single-particle model, $\beta_{\text{sp}} = 1.59/Z^{12})$, giving a measure of the collectivity, are given graphically in fig. 5 for the region $28 < (N,Z) < 50$. The shell closures at the magic numbers $N = 50$ and $Z = 28$ are here easily identified. It is also evident that the development of deformation is counteracted by the subshell closures at $N = 38$ and $Z = 40$. However, in the center of the region $28 < (N,Z) < 50$ the collective effects increase rapidly as evidenced by the large values of β/β_{sp} for the light krypton ($Z = 36$) and strontium ($Z = 38$) isotopes. The light rubidium ($Z = 37$) isotopes $^{77,78,79}\text{Rb}$, investigated in this work, are located close to this region of maximum deformation. This fact justifies an attempt to interpret the measured nuclear spins and moments in terms of the strong-coupling model. The sequence of heavier rubidium isotopes is passing a transition region of intermediate deformation on the way to the shell closure at $N = 50$.

The single-particle states relevant to the discussion of the nuclear structure in the region $28 < (N,Z) < 50$ are shown in fig. 6. For both protons and neutrons, one may expect negative parity levels originating from the shell model states $p_{3/2}$, $f_{5/2}$ and $p_{1/2}$, and positive parity levels from $g_{9/2}$.

Nuclear levels directly associated with the shell model states are easily identified in nuclei close to the shell closures. As evidenced by the experimental nuclear spins and magnetic moments (cf. table 3), the ground states of the odd-A rubidium isotopes $^{83,85}\text{Rb}$ are characterized by the proton state $f_{5/2}$, ^{87}Rb by $p_{3/2}$ and the isomeric state in ^{85}Rb by $g_{9/2}$. The 2^- ground state and the (6^-) isomeric state in ^{86}Rb may be explained by coupling a $g_{9/2}$ neutron to the $f_{5/2}$ and $p_{3/2}$ protons, respectively. The magnetic moment of the 2^- ground state in ^{84}Rb is about 25% smaller than that in ^{86}Rb , indicating additional components in the nuclear wave function. The nuclear spin $I = 6$ of the isomeric state in ^{84}Rb , determined in this work, combined with the proposed negative parity of the state¹⁴⁾, may be accounted for by the configuration $6^-(\pi p_{3/2} \vee g_{9/2})$.

The single-particle energy levels for protons as a function of the deformation parameter ϵ , shown in fig. 6, have been calculated within the modified oscillator model¹⁶⁾ using the $A = 78$ shell parameters $\kappa_p = 0.0695$ and $\mu_p = 0.425$. These parameters were obtained from a linear interpolation between the $A = 70$ and $A = 100$ parameters proposed in ref.¹⁷⁾. The corresponding diagram for odd neutrons, $\kappa_n = 0.0720$ and $\mu_n = 0.320$, exhibits larger energy separations between the levels $p_{3/2}$ and $f_{5/2}$ and the levels $p_{1/2}$ and $g_{9/2}$. In the calculations, the hexadecapole deformation parameter ϵ_4 as well as the asymmetry parameter γ were set equal to zero.

The nuclear spins and magnetic moments of the light rubidium isotopes $^{77-79}\text{Rb}$, determined in this work, deviates significantly from systematic trends and the results from earlier spectroscopic works. Interpreted in terms of the strong-coupling model, the data, however, provides a consistent picture of the nuclear structure in this region. The different states may be associated with certain Nilsson model configurations, or at least the main component of the configurations. The data on the nuclear magnetic moments has been decisive for this interpretation. An early interpretation, based only on the nuclear spins¹⁸⁾, has to be revised to a large extent.

The nuclear spin $I = 3/2$ and the small magnetic moment $\mu_I = 0.652(7)$ n.m. of ^{77}Rb strongly indicate an association with the proton orbital $[312 \ 3/2]$. The theoretical magnetic moments of this orbital, calculated with the $A = 78$ shell parameters and the following g-factors : $g_R = 0.45$, $g_l = 1$ and $g_s = g_s^{\text{free}}$ or $0.6 g_s^{\text{free}}$, are shown in fig. 7. There is a close agreement between the experimental and theoretical values.

The surprisingly large magnetic moment $\mu_I = 3.36(4)$ n.m. of the $I = 5/2$ ground

state of ^{79}Rb clearly shows that the levels originating from the $g_{9/2}$ shell are involved; i.e. the parity of the state has to be positive. This in agreement with the results from a recent spectroscopic work on the decay of $^{79}\text{Rb}^{19)}$, correcting previous erroneous assignments of $3/2^-$ and $5/2^-^{20,21)}$. The rotational band built on the $5/2^+$ ground state of ^{79}Rb has so far not been observed. Although the levels probably represent a mixture of deformed Nilsson-model states from $g_{9/2}$, it seems reasonable to assume that the orbital $[422\ 5/2]$ constitutes the main component of the $5/2^+$ ground state. As shown in fig. 7, the theoretical moments of the orbital $[422\ 5/2]$ account satisfactorily for the experimental result.

The magnetic moment of the $3/2^-$ ground state of ^{81}Rb , $\mu_I = 2.05(2)$ n.m. $^{8)}$, is quite different from that of ^{77}Rb , indicating a different orbital assignment. The orbital $[301\ 3/2]$ is here suggested on the basis of the agreement between the experimental and theoretical moments. However, the rotational band built on the $3/2^-$ state is slightly perturbed giving evidence for Coriolis mixing of the Nilsson orbitals with $K = 1/2, 3/2$ and $5/2$. Friederichs et al. $^{22)}$ have been able to reproduce the level structure by the axially symmetric Coriolis coupling model. By placing the Fermi level at the orbital $[312\ 3/2]$, the main components of the wave functions were found to be due to the orbitals $[310\ 1/2]$ and $[312\ 3/2]$; with about 90% squared amplitude of $[312\ 3/2]$ in the $3/2^-$ ground state. This result is, however, in disagreement with our suggestion of the orbital $[301\ 3/2]$ as the ground state in ^{81}Rb . The rotational bands built on the $3/2^-$ states in $^{77}\text{Br}^{23)}$ and $^{73}\text{As}^{24)}$ are much more perturbed because of the smaller deformation and the stronger Coriolis interaction.

The odd-neutron nucleus ^{77}Kr exhibits two distinct rotational bands built on the $5/2^+$ ground state and the $3/2^-$ excited state $^{25)}$. The well developed $3/2^-$ rotational band, having a rotational parameter $h^2/2J$ as low as 34 keV, has been interpreted as arising from the neutron orbital $[301\ 3/2]$, while the $5/2^+$ rotational band is due to the deformed orbitals associated with the $g_{9/2}$ state; the ground state being described mainly by the orbital $[422\ 5/2]$.

We may thus attempt an interpretation of the measured spin $I = 0$ of ^{78}Rb , and the spin $I = 4$ and the magnetic moment $\mu_I = 2.56(3)$ n.m. of $^{78\text{m}}\text{Rb}$ in terms of the configuration assignments in the neighbouring nuclides $^{77,79}\text{Rb}$ and ^{77}Kr .

The most natural description of the ground state of ^{78}Rb is obtained by combining the ground state assignments of ^{79}Rb and ^{77}Kr ; i.e. by the configuration $0^+ \{ \pi [422\ 5/2] \nu [422\ 5/2] \}$. One may also combine the $3/2^-$ ground state of ^{77}Rb with the $3/2^-$ excited state of ^{77}Kr to get a nuclear spin $I = 0$. In both cases a positive parity is obtained. It seems difficult to make combinations giving negative parity to the $I = 0$ ground state of ^{78}Rb , as suggested in several spectroscopic works $^{26-29)}$. Therefore, the interpretation of the beta-decay data of ^{78}Rb in terms of a $0^+ \rightarrow 0^+$ isospin-forbidden ground state to ground state transition appears attractive $^{30)}$.

The magnetic moment of the 4^- isomeric state in ^{78}Rb , $\mu_I = 2.56(3)$ n.m., is in close agreement with the theoretical values obtained from the configuration $4^- \{ \pi[422 \frac{5}{2}] \nu[301 \frac{3}{2}] \}$ (cf. fig. 7); i.e. by combining the $\frac{5}{2}^+$ ground state of ^{79}Rb and the $\frac{3}{2}^-$ excited state of ^{77}Kr . Combinations involving the proton orbitals $[301 \frac{3}{2}]$ or $[312 \frac{3}{2}]$ are shown to give too small magnetic moments to account for the experimental value.

The nuclear spin and magnetic moment of the doubly-odd nuclide ^{80}Rb have been determined by Neugart et al.¹⁰⁾ to be $I = 1$ and $\mu_I = -0.0836(6)$ n.m. Positive parity is proposed from decay studies³¹⁾. The small magnetic moment is well reproduced by the configuration $1^+ \{ \pi[312 \frac{3}{2}] \nu[301 \frac{1}{2}] \}$ as shown in fig. 7. In the neighbouring odd-neutron nuclide ^{79}Kr , Sawa et al.³²⁾ have observed a rotational band built on the $\frac{1}{2}^-$ ground state, interpreted in terms of the Nilsson orbital $[301 \frac{1}{2}]$.

The failure to explain the measured magnetic moment $\mu_I = 0.554(3)$ n.m. of ^{82}Rb ¹⁰⁾ by simple configuration assignments (cf. fig. 7) is evidently due to the fact that we have reached the transition region between the strongly deformed nuclei in the center of the region $28 < (N,Z) < 50$ and the spherical nuclei close to $N = 50$. Larsson et al.³³⁾ have applied the axially asymmetric Coriolis coupling model to the quasi-rotational bands in the nuclides $^{75,77}\text{Se}$. The level structure is well reproduced assuming asymmetric nuclear shapes; $\epsilon = 0.29$ and $\gamma \approx 30^\circ$. An extension of these calculations to other nuclides in the present region would be highly desirable.

One may note that the magnetic moments of the bromine isotopes ^{79}Br and ^{80}Br are close to those of the isotones ^{81}Rb and ^{82}Rb , respectively. In this context, it would be of great interest to measure the magnetic moment of the $\frac{3}{2}^-$ ground state of ^{77}Br to find out whether the same decrease in magnitude will be seen, as that observed in the rubidium isotopes when going from ^{81}Rb to ^{77}Rb . The same interest is attached to the (1^+) ground state of ^{78}Br ; i.e. whether the magnetic moment is close to that of the isotone ^{80}Rb or to that of ^{82}Rb .

The magnetic moment of the 1^- ground state of ^{76}Br has been measured to be $\mu_I = -0.5482(1)$ n.m.⁹⁾. This value may be explained by the configuration $1^- \{ \pi[312 \frac{3}{2}] \nu[422 \frac{5}{2}] \}$, the neutron orbital being the ground state of ^{77}Kr and, following the trends in rubidium, the proton orbital $[312 \frac{3}{2}]$ probably describing the ground state of ^{75}Br . By analogy with ^{76}Br one may thus suggest the configuration $1^- \{ \pi[312 \frac{3}{2}] \nu[422 \frac{5}{2}] \}$ also to the rubidium isotope ^{76}Rb , in which the nuclear spin has been determined to be $I = 1$ in a RADOP experiment at ISOLDE⁷⁾.

The nuclear parities given to the rubidium isotopes $^{76-79}\text{Rb}$ in table 3 are those suggested by the present experimental and theoretical investigation. For the heavier rubidium isotopes, the parities are quite well established from spectroscopic works and from systematics.

The conclusions drawn from the present measurements of nuclear spins and magnetic moments are mainly in terms of configuration assignments; i.e. nuclear structure information. In order to obtain more specific data on the nuclear deformations, it would be of great interest to investigate the level structure built on the different states and to measure the isotope shifts and the quadrupole moments.

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Table 1
Results from the spin measurements in rubidium

Isotope	Half-life	Measured spin I
^{77}Rb	3.9 min	$3/2$
^{78}Rb	17.7 min	0
$^{78\text{m}}\text{Rb}$	6.0 min	4
^{79}Rb	23.0 min	$5/2$
$^{84\text{m}}\text{Rb}$	21 min	6

Table 2
Experimentally observed single-quantum transitions in the nuclides $^{77}, ^{78\text{m}}, ^{79}\text{Rb}$,
together with the results from the fitting procedure

Isotope	Frequency of calibration transition in ^{39}K (MHz)	$\mu_B B/h$ (MHz)	Observed resonance frequency (MHz)	$g_I > 0$			$g_I < 0$		
				Residual (MHz)	χ^2	Dipole constant (MHz)	Residual (MHz)	χ^2	Dipole constant (MHz)
^{77}Rb	11.118(7)	20.751(12)	10.584(7)	-0.002			-0.007		
	23.446(7)	40.914(11)	21.265(7)	-0.003			-0.009		
	52.148(10)	79.871(12)	43.068(13)	0.002	0.123	812.5(34)	0.007	1.678	820.6(35)
$^{78\text{m}}\text{Rb}$	10.030(7)	18.839(12)	4.212(7)	0.000			-0.010		
	44.432(7)	70.267(9)	15.983(7)	0.001			-0.023		
	124.780(20)	152.165(17)	35.590(8)	0.000	0.005	1195.2(56)	0.008	12.503	1265.4(63)
^{79}Rb	10.030(7)	18.839(12)	6.301(7)	-0.001			-0.022		
	23.446(7)	40.914(11)	13.756(7)	0.003			-0.037		
	49.194(8)	76.258(10)	25.837(7)	-0.002			-0.052		
	136.290(12)	161.713(10)	55.860(8)	0.000	0.142	2511.0(93)	0.014	76.862	2814.0(118)

Table 3

Summary of experimentally determined nuclear spins,
ground state hyperfine structure separations
and nuclear magnetic moments of neutron-deficient rubidium isotopes

A	N	$T_{1/2}$	I^π	Hfs separation $\Delta\nu$ (MHz)	Magnetic dipole moment μ_I (n.m.)	Ref.
74	37	65 ms	0^+			4
75	38	17.0 sec				
76	39	36.8 sec	1^-			7
77	40	3.9 min	$3/2^-$	1625(7)	0.652(7)	a)
78	41	17.7 min	0^+			a)
		6.0 min	4^-	5378(25)	2.56(3)	a)
79	42	23.0 min	$5/2^+$	7533(28)	3.36(4)	a)
80	43	30 sec	1^+	- 233.936(2)	-0.0836(6)	10
81	44	4.58 h	$3/2^-$	5111.589(40)	2.05(2)	8,9
		32 min	$9/2^+$			9
82	45	1.3 min	1^+	1547.4(17)	0.554(6)	10
		6.3 h	5^-	3094.08265(30)	1.51(2)	8,9
83	46	86.2 d	$5/2^-$	3183.3(58)	1.43(2)	8,9
84	47	34.5 d	2^-	-3083.159(4)	-1.297(11)	8,9
		21 min	6^-			a)
85	48	stable	$5/2^-$	3035.732439(5)	1.3533507(8)	8,9
		1.0 μ s	$9/2^+$		6.075(63)	8
86	49	18.7 d	2^-	-3946.883(2)	-1.6920(14)	8,9
		1.02 min	$(6)^-$			
87	50	$5 \cdot 10^{10}$ y	$3/2^-$	6834.682614(1)	2.751816(2)	8,9

a) This work

FIGURE CAPTIONS

- Fig. 1 : Gamma-ray spectra from two collectors exposed to an atomic-beam of $^{84\text{m}}\text{Rb}$ while applying the spin $I = 6$ and $I = 7$ frequencies, respectively, in an external magnetic field $\mu_B/h = 4.029$ MHz.
- Fig. 2 : Isomer separated samples of ^{78}Rb . A half-life of 17 min was found in the decay of the sample exposed to the $I = 0$ frequency, while that corresponding to $I = 4$ yielded a half-life of 6 min. This attributes spin $I = 0$ to the ground state (for further discussion see the main text), and spin $I = 4$ to the isomeric state of ^{78}Rb .
- Fig. 3 : In the lower part of the figure is shown the result from a frequency scan of ^{78}Rb in the external magnetic field $\mu_B/h = 1.378$ MHz. The resonance curve obtained corresponds to the $I = 0$ transition frequency 2.760 MHz. From line width considerations (cf. the main text), an upper limit of 5 kHz may be put on the dipole constant a , or $3 \cdot 10^{-6}$ n.m. on the nuclear magnetic moment, in the case of a non-zero spin. The solid and dashed curves in the upper part of the figure correspond to strong-field transitions, $\Delta M_J = 1$, $\Delta M_I = 0$, in $I = 1$ and $I = 2$ nuclides, respectively, as functions of the dipole constant $|a|$. For positive values of a , the notations a , b , c , and a , b , c , d , e relate to $M_I = -1, 0, 1$ and $M_I = -2, -1, 0, 1, 2$ respectively. In the weak-field limit, valid for nuclides with "normal" dipole constants (a -factors of the order 10^3 MHz), the curves denoted by a correspond to the $\Delta F = 0$, $\Delta M_F = 1$ transitions, which at this field occur at 0.920 and 0.552 MHz, respectively.
- Fig. 4 : Resonance curves, corresponding to the single-quantum transitions in ^{77}Rb $I = 3/2$, $^{84\text{m}}\text{Rb}$ $I = 4$ and ^{79}Rb $I = 5/2$. The data were recorded in the external magnetic fields $\mu_B/h = 40.912$, 152.165 and 161.713 MHz, respectively (cf. table 2).
- Fig. 5 : Graphical representation of the ratio β/β_{sp} in the region $28 < (N,Z) < 50$. The deformation parameters β are calculated from eq.(3) using the E_{2+} - values compiled by Hadermann and Rester ¹⁵⁾, and β_{sp} , the single-particle deformation parameter¹²⁾, from $\beta_{\text{sp}} = 1.59/Z$. The highest point, ^{78}Sr , amounts to 9.85 units, while the lowest one, ^{90}Zr , appears at 3.12 units. Note the rapid development of collective effects in the center of the region $28 < (N,Z) < 50$.
- Fig. 6 : Nilsson diagram for odd-proton levels in the region $28 < (N,Z) < 50$, calculated with the $A = 78$ shell parameters $\kappa_p = 0.0695$ and $\mu_p = 0.425$. Full lines represent levels with positive parity, dashed lines negative parity.

Fig. 7 : Comparison between experimental and theoretical magnetic moments of the rubidium isotopes $^{77-82}\text{Rb}$. The theoretical moments, shown as a function of the deformation parameter ϵ , have been calculated using the $A = 78$ shell parameters. Two different g_s -factors have been used; $g_s = g_s^{\text{free}}$ and $g_s = 0.6 g_s^{\text{free}}$, given by dashed and solid lines, respectively.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7