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NUCLEAR GROUND STATE SPINS OF THE FRANCIUM ISOTOPES $^{208-213,220-222}$Fr

C. Ekström *
Department of Physics, Chalmers University of Technology and
University of Gothenburg, Gothenburg, Sweden.

S. Ingelman and G. Wannberg
Institute of Physics, University of Uppsala, Uppsala, Sweden.

M. Skarestad +
EP Division, CERN, Geneva, Switzerland

and

The ISOLDE Collaboration, CERN, Geneva, Switzerland.

ABSTRACT

The nuclear ground state spins of some francium isotopes have been measured using on-line atomic-beam magnetic resonance techniques. The following results have been obtained : ^{208}Fr I = 7, ^{209}Fr I = $^{9}/_{2}$, ^{210}Fr I = 6, ^{211}Fr I = $^{9}/_{2}$, ^{212}Fr I = 5, ^{213}Fr I = $^{9}/_{2}$, ^{220}Fr I = 1, ^{221}Fr I = $^{5}/_{2}$ and ^{222}Fr I = 2. The spin values are discussed briefly in terms of current nuclear models.

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* Present address : EP Division, CERN, CH-1211 Geneva 23, Switzerland.

\+ Present address : Department of Chemistry, University of Oslo,
N-1000 Oslo 3, Norway.

1. INTRODUCTION

A large range of francium isotopes are obtained in high yields at the ISOLDE facility, CERN, as spallation products from 600 MeV proton reactions in a target of graphite cloth impregnated with uranium, followed by on-line surface ionization and mass separation [1] (cf. Fig. 1). In a previous paper [2], we reported on an on-line oven foil system which efficiently converts an ion-beam of alkalis from the separator to an atomic-beam, and on the measurements of nuclear spins and moments of several cesium isotopes using atomic-beam magnetic resonance (ABMR) techniques. The same methods have been used in the present work to measure the nuclear spins of some francium isotopes. The element francium is here for the first time subjected to ABMR measurements.

2. EXPERIMENTAL PROCEDURE AND RESULTS

Referring to the work on cesium [2], we limit our presentation of the experimental procedure to details specific to the present work on francium.

The francium experiments were performed on-line, i.e. guiding the ion-beam from the isotope separator directly to a heated tantalum foil covered with a layer of yttrium, from which the activity evaporated continuously in the form of free atoms. Details on the design and operation of the on-line ABMR apparatus may be found in ref. [3].

The nuclides transmitted through the apparatus were measured by recording the α-decay with surface barrier detectors. The low background count rate of the detectors was of vital importance in the experiments on nuclides at the low-yield wings of the production yield curve (cf. Fig. 1). In the case of the β-decaying nucleus ^{222}Fr, it was shown more efficient to study the α-decay of the 38 sec daughter nucleus ^{222}Ra.

The simple electronic structure of the alkali elements makes them particularly suited for atomic-beam measurements [2]. Since the electronic splitting factor of francium has not been determined, our measurements were made under the assumption $g_J = 2.0028$. Spin measurements performed in weak external magnetic fields are, however, not sensitive to small variations in the g_J-value. According to the formula relating the nuclear spin to the resonance frequency [2]

$$\nu = g_J \frac{\mu_B B}{h} \frac{1}{2I+1}$$

we obtain at the strongest field used in the measurements, $\mu_B B/h = 6.185$ MHz, a maximum difference of 6 kHz in the resonance frequency assuming $g_J = 2.0023$ or 2.0033. This difference is smaller than the line width of the resonance signals which is about 30 kHz.

The spin search was made according to the equation above. The final results, shown in Table 1, were established by the observation of resonance signals in two different external magnetic fields; $\mu_B B/h$ = 4.482 and 6.185 MHz, and by the absence of resonance signals at the frequencies corresponding to other spin values. Spin values in the range I = $^1/_2$ - $^{11}/_2$ were checked in the odd-A isotopes and I = 0 - 7 in the doubly-odd ones. The radioactive decay curves of resonance signals in ^{210}Fr and ^{211}Fr are shown in Fig. 2.

3. DISCUSSION

The light francium isotopes studied in this work, ^{208}Fr - ^{213}Fr, appear in the corner Z > 82, N < 126, close to the shell closures. The shell model proton state $h_{9/2}$ here accounts for several ground states in the Z = 83 bismuth and Z = 85 astatine isotopes. The Z = 87 isotopes ^{209,211,213}Fr, with nuclear ground state spins I = $^9/_2$, may consequently be associated with the same assignment.

The shell model states available for neutrons just below the N = 126 shell closure are $p_{1/2}$ and $f_{5/2}$. The measured nuclear ground state spins in the doubly-odd francium isotopes ^{208,210,212}Fr are readily accounted for by coupling these neutron states to the $h_{9/2}$ proton state. In ^{212}Fr we have the configuration $5^-(\pi h_{9/2}\ \nu p_{1/2})$, the spin value being predicted by the coupling rules of ref.[4]. Taking into account the successive filling of the $f_{5/2}$ neutron shell, the nuclear spin I = 7 of ^{208}Fr and I = 6 of ^{210}Fr are both explained by the configuration $(\pi h_{9/2}\ \nu f_{5/2})$ and the coupling rules [4]. One may note that the spin sequence observed in the corresponding doubly-odd isotones of bismuth [5,6] is somewhat different from that in francium. It would therefore be of interest to make spin measurements in the interjacent astatine isotones in order to see whether trends may be observed.

The francium isotopes in the mass range A = 214 - 219 are too short-lived to be studied with the present atomic-beam technique. A possible exception is ^{219}Fr, but here the production yield has so far been too low. The half-lives and yields of the heavier francium isotopes again become favourable. The spin measurements in ^{220,221,222}Fr have given the results I = 1, $^5/_2$ and 2, respectively. These isotopes are located in a transition region between the spherical nuclei close to Z = 82, N = 126 and the strongly deformed actinides. It is thus very difficult to find simple configuration assignments accounting for the measured nuclear spins.

The proposed negative parity of the ^{221}Fr ground state [7] implies an association with the $h_{9/2}$ shell model state. Also in the case of a moderate nuclear deformation, it seems plausible to assume that the main component of the I = $^5/_2$ ground state of ^{221}Fr comes from the $h_{9/2}$ state.

The present direct measurement of the nuclear ground state spin of ^{220}Fr, I = 1, confirms the conclusion drawn by Briand et al. [8] from spectroscopic arguments. The positive parity of the state [8] implies a negative parity neutron coupled to the odd proton. Awaiting further experimental data in this region, we refrain from speculating on the configurations giving rise to the measured nuclear spins I = 1 and I = 2 of the doubly-odd francium isotopes ^{220}Fr and ^{222}Fr.

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Department of Physics
Chalmers University of Technology
S-40220 GOTEBORG 5

Institute of Physics
University of Uppsala
P.O. Box 530
S-75121 UPPSALA

EP Division
CERN
CH-1211 GENEVA 23

Table I. Summary of results from the spin measurements in francium

Isotope	Half-life	Measured spin I
^{208}Fr	59 sec	7
^{209}Fr	54 sec	$^9/_2$
^{210}Fr	3.18 min	6
^{211}Fr	3.08 min	$^9/_2$
^{212}Fr	19.3 min	5
^{213}Fr	34.7 sec	$^9/_2$
^{220}Fr	27.5 sec	1
^{221}Fr	4.8 min	$^5/_2$
^{222}Fr	14.8 min	2

FIGURE CAPTIONS

Fig. 1 : Experimental yields [9] of francium isotopes from a target of graphite cloth impregnated with 25 g uranium. The intensity of the 600 MeV proton beam was 1 μA. Our spin measurements, marked by crosses at the bottom of the figure, have covered all isotopes produced in yields above the lower limit of 10^6-10^7 atoms per second required in this type of experiments. However, increased beam intensities and improved experimental techniques may extend the present series.

Fig. 2 : The α-decays of samples of ^{210}Fr and ^{211}Fr being exposed at frequencies corresponding to the spins $I = 6$ and $I = {}^9/_2$, respectively.