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ON THE INTERPRETATION OF THE ^{14}C FINE STRUCTURE OBSERVED IN THE ^{223}RA DECAY.

. M. Hussonnois, J.F. Le Du and L. Brillard,
Institut de Physique Nucléaire, BP N° 1
91406 Orsay Cedex, France

. G. Ardisson
Laboratoire de Radiochimie, Université de Nice
06034 Nice Cedex, France

On the interpretation of the ^{14}C fine structure observed in the ^{223}Ra decay

M. Hussonnois, J.F. Le Du and L. Brillard
Institut de Physique Nucléaire, BP N°1, F91406 Orsay, France

G. Ardisson
Laboratoire de Radiochimie,Université de Nice, F06034 Nice-Cédex, France

The low hindrance factors observed in the ^{14}C decay of ^{223}Ra to the ^{209}Pb excited states at 779 and 1423 keV are interpreted as a consequence of the similitude of the wave functions describing the uncoupled neutron in ^{223}Ra, Ω = 3/2 ⟨3/2[631]⊗3/2[761]⟩, and in the two first excited states of ^{209}Pb, namely the $1i_{11/2}$ and $1j_{15/2}$ shell model orbits.

The most significant feature deduced from the first observation of a lines spectrum in the ^{223}Ra ^{14}C decay, described in the paper of Brillard et al[1], is related to the low hindrance factors (HF = 2.7) of the ^{14}C branches to the first two excited states in the ^{209}Pb daughter nucleus whose energies, spins and parities are respectively 778.8 keV (I^{π}= $11/2^{+}$) and 1423 keV (I^{π}= $15/2^{-}$); conversely, the ^{209}Pb ground state I^{π}= $9/2^{+}$ is only fed by 15% of the ^{14}C decays, with an hindrance factor of 518 and a log $T_{1/2}$(s) value of 16.0 ± 0.1. This situation is directly comparable to that known in the α -decay of odd-A nuclides in which the decay to the daughter ground state is hindered, and at least one transition to one excited state possesses a low hindrance factor.

In the various models[2] used up to now, only the ^{209}Pb ground state was assumed to be fed with log $T_{1/2}$(s) =15.2 (given the value Q = 31.85 MeV). However, some authors took into account the feeding of the daughter excited states. Thus, Greiner and Scheid[3] extended the Analytical Super Asymetric Fission Model (ASAFM) of Poenaru et al[4] by allowing the decay to excited states; this excitation model (EXM) predicts that the total decay probability can be more than five times greater than that calculated for the ground state only. Particularly, in the case of ^{14}C emission from ^{223}Ra, these authors foresee a branching ratio b= λ^{*}/λ^{T} = 0.60, in which λ^{*} is the sum of the decay constants to the ^{209}Pb excited states and λ^{T} is the total decay constant for the ^{14}C emission. Although this model allows a substantial feeding of the ^{209}Pb excited states, its previsions do not offer a detailed analysis of the feeding of the daughter nucleus various states and do not reproduce the observed hindrance to the ^{209}Pb ground state. On the other hand, Henning and Kutschera[5] computed the ^{14}C decay constants to the ^{209}Pb excited states from the Gamow factor G calculated from the classical WKB method; the partial half-lives thus obtained are in agreement with the experimental results[1], except for the ^{14}C branch to the ^{209}Pb ground state, for which an enhancement is expected, i.e. log $T_{1/2}$(s)= 13.54 .

If we except the model of Blendowske et al[6], which use the microscopic wave functions of ^{14}C, ^{209}Pb and ^{223}Ra nuclei to calculate the spectroscopic factor S relative to the ^{209}Pb ground state, the models cited above do not account for the detailed structure of the wave functions of the nuclear states involved in the parent and the daughter nuclei.

Indeed, we think that the favoured ^{14}C decay from ^{223}Ra to the two ^{209}Pb first excited states (I^{π} = $11/2^{+}$ and $15/2^{-}$) might be interpreted by the similitude of the wave functions describing the odd neutron in the ^{223}Ra and ^{209}Pb nuclei.

Taking into account the recently measured ^{223}Ra ground state nuclear spin I= 3/2 (ref 7), which disagrees with the commonly adopted value $I^{\pi}=1/2^{+}$ (ref 8,9), a recent reinvestigation about ^{223}Ra nuclear structure by Sheline et al[10] pointed out that the experimental data were rather well reproduced admitting for this nuclide a static octupole deformation β_3= 0.1, in addition to the quadrupole deformation β_2= 0.129. This stable octupole deformation implies the existence of a so-called " parity-doublet ", K^{π} = $3/2^{\pm}$ $\{3/2[631] \otimes 3/2[761]\}$ describing both the ground state and the first excited rotational bands, in which the 3/2[631] and 3/2[761] Nilsson orbitals characterising the uncoupled neutron arise from the respective "high-spin" $1i_{11/2}$ and $1j_{15/2}$ shell model orbits.

On the other hand, the leading configurations of the last neutron in the ^{209}Pb ground and excited states are given by the following assignments[11]:

Energy (MeV)	I^{π}	configuration
0,0	$9/2^{+}$	$\nu(2g_{9/2})^{1}$
0.779	$11/2^{+}$	$\nu(1i_{11/2})^{1}$
1.423	$15/2^{-}$	$\nu(1j_{15/2})^{1}$
1.567	$5/2^{+}$	$\nu(3d_{5/2})^{1}$
2.032	$1/2^{+}$	$\nu(4s_{1/2})^{1}$
2.152	$1/2^{-}$	$\nu(2g_{9/2})^{2}{}_{0^+} + \nu(2f_{5/2})^{-1}$

So, if by analogy with the α-decay of odd-mass nuclei[12], the favoured ^{14}C transitions are those for which the uncoupled nucleon is left in the same particle state, then, in the case of ^{14}C cluster ^{223}Ra decay, the transitions favoured with regard to the odd neutron configuration should be those to the 1^{st} excited state at 779 keV (I^{π}= $11/2^{+}$) and to the 2^{nd} excited state at 1423 keV (I^{π}= $15/2^{-}$).

Besides, although the ^{14}C decay to the quasispherical ^{209}Pb nucleus was different from its α-decay to the moderately deformed ^{219}Rn nucleus (β_2= 0.100), our interpretation of favoured ^{14}C feedings, based on the existence of parity mixed orbitals in the ^{223}Ra ground state, closely parallels a recent investigation[13] of the α-decay properties of ^{223}Ra to ^{219}Rn excited states. In this study, allowing equally for a static octupole deformation ($\beta_3 \cong$ 0.1) for ^{219}Rn, Leander and Chen[13] found that the low HF values observed in the ^{223}Ra decay are correlated with high mixing amplitudes of the parent orbital Ω= 3/2 in the ^{219}Rn daughter nucleus excited states ; so, the states characterized by E, I^{π} values of 269 keV, $5/2^{+}$, 338 keV, $5/2^{+}$ and 447 keV, $5/2^{-}$, with respective values 82%, 76% and 71 % of configuration admixture amplitudes of the Ω = 3/2 (3/2[631] or 3/2[761]) parent orbital, are preferentially fed by α-decay with respective 4.7, 5.5 and 5.9 HF values. These low HF values are relatively close to those observed in the ^{14}C decay to the ^{209}Pb excited levels at 779 and 1423 keV, i.e. 2.7 and 2.7 respectively.

As concerns the angular momentum carried by the ^{14}C cluster

$$|I_f - I_i| \leq \quad l_{^{14}C} \leq I_f + I_i ,$$

the respective values to the ground state, the 779 keV and 1423 keV levels are respectively $l_{^{14}C}$ = 4, 4 and 7, taking into account $\Delta\pi = \pi_i \pi_f \, (-1)^l$. However, as indicated by Poenaru and Ivascu[2], the effects of the centrifugal barrier due to the angular momentum can be neglected up to 5 $\hbar$ units in the case of ^{14}C clusters.

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REFERENCES

1 L. BRILLARD, A.G. EL AYI, E. HOURANI, M. HUSSONNOIS,J.F. LE DU, L.H. ROSIER and L. STAB, C. R. Acad. Sci. Paris, 39, ser II, 1105 (1989).

2 D.N. POENARU and M.S. IVASCU, in Particle Emission from Nuclei, C.R.C. Press, Boca Raton Florida, vol 2, 127 (1989)

3 M. GREINER and W. SCHEID, J. Phys. G ,Nucl.Phys.,12 L229 (1986)

4 D. N. POENARU , M. IVASCU, H. SANDULESCU and W. GREINER, Phys. Rev., C32 572 (1985).

5 W. HENNING and W. KUTSCHERA, in Particle Emission From Nuclei,C.R.C. Press, Boca Raton Florida,vol 2 189 (1989).

6 R. BLENDOWSKE, T FLIESSBACH and H. WALLISER, Nucl.Phys., A464, 75 (1987).

7 S. A. AHMAD, W. KLEMPFT, R. NOUGART, E. W. OTTEN, K. WENDT and C. EKSTROM, Phys. Lett., 133B 47 (1983).

8 C. M. LEDERER and V. SHIRLEY, Table of Isotopes, J. Wiley & Sons, 1978, p. 1387.

9 C. MAPLES, Nuclear Data Sheets,22 243 (1977) .

10 R.K. SHELINE, Y.S. CHEN and G.A. LEANDER, Nucl. Phys.,A486 306 (1988).

11 M.J. MARTIN, Nuclear Data Sheets, 22 545 (1977).

12 J.O. RASMUSSEN Jr, Arkiv Fysik, 7 185 (1953).

13 G. A. LEANDER and Y.S CHEN, Phys. Rev., 37C 2744 (1988).