Lawrence Berkeley National Laboratory
Recent Work

Title

THEORETICAL ESTIMATES OF THE RATES OF RADIOACTIVE DECAY OF RADIUM ISOTOPES BY 14C EMISSION

Permalink

https://escholarship.org/uc/item/9gz3z4n2

Authors

Shi, Y.-J.
Swiatecki, W.J.

Publication Date

1984-09-01

eScholarship.org Powered by the California Digital Library
University of California

UC 4+34C

LBL-18366
Preprint c.1

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

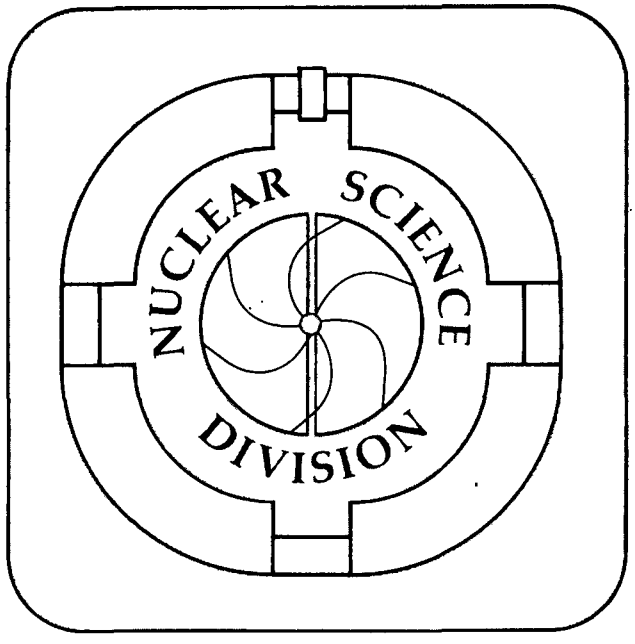
RECEIVED
LAWRENCE
BERKELEY LABORATORY
OCT 17 1984
LIBRARY AND
DOCUMENTS SECTION

Submitted to Physical Review Letters

THEORETICAL ESTIMATES OF THE RATES OF RADIOACTIVE DECAY OF RADIUM ISOTOPES BY ^{14}C EMISSION

Y.-J. Shi and W.J. Swiatecki

September 1984



For Reference
Not to be taken from this room

LBL-18366
c.1

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

LBL-18366

Theoretical Estimates of the Rates of Radioactive Decay of Radium Isotopes by ^{14}C Emission

Shi Yi-Jin*

and

W. J. Swiatecki

Nuclear Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

September, 1984

This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

*Permanent address: Institute of Atomic Energy, P. O. Box 275 (18), Beijing, China

LBL-18366

Theoretical Estimates of the Rates of Radioactive Decay of Radium Isotopes by ^{14}C Emission

Shi Yi-Jin*

and

W. J. Swiatecki

Nuclear Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Abstract: The measured branching ratios for the decays of $^{222,223,224}Ra$ by alpha or ^{14}C emissions can be accounted for within a factor of 10 in terms of the ratios of Gamow penetrabilities through potential-energy barriers consisting of a Coulomb repulsion, the nuclear proximity attraction and an interpolation between the configuration of tangent fragments and the configuration of the parent nucleus.

This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

*Permanent address: Institute of Atomic Energy, P. O. Box 275 (18), Beijing, China

In this note we would like to point out that, in the spirit of ref. 7, the branching ratios between α-particle and ^{14}C radioactivity, reported in ref. 1 (see also refs 2,3), can be interpreted with reasonable accuracy (within a power of 10, or so) by a quantal tunneling calculation, provided a realistic estimate of the potential-energy barrier is used.

To construct the deformation-energy barrier of a Ra nucleus disintegrating into a pair of fragments (Rn + α or Pb + ^{14}C), we added to the Coulomb repulsion between the fragments the nuclear proximity attraction from refs. 2,3. After contact of the fragments, when the approximation of two spherical fragments ceases to be applicable, we used for the deformation energy a smooth, power-law interpolation between the contact configuration and the configuration of the parent nucleus (where the deformation energy is zero by definition). The explicit formula for the deformation energy V(L) is thus as follows:

$$V(L) = -Q + \frac{Z_1 Z_2 e^2}{r} + V_p(z) \qquad \text{for } L > L_c \tag{1}$$

$$V(L) = a\,(L - L_o)^{\nu} \qquad \text{for } L_o < L < L_c \quad . \tag{2}$$

In the above, L is the major axis (i.e. the overall length) of the configuration in question, L_c refers to its value at contact (equal to the sum of the fragment diameters), L_o is the diameter of the parent nucleus, Q is the energy released in the disintegration, Z_1 and Z_2 are the atomic numbers of the fragments, r is the distance between fragment centers, z is the distance between the near surfaces of the fragments and V_p is the proximity potential, given by

$$V_p(z) = K\Phi(z/b) \quad , \tag{3}$$

where

$$K = 4\pi\bar{R}\gamma b \tag{4}$$

and Φ is the universal nuclear proximity function of ref. 2, to which an approximation, given in ref. 3, reads as follows:

$$\Phi(\zeta) \approx -4.41e^{-\zeta/0.7176} \qquad \text{for } \zeta \geq 1.9475 \tag{5}$$

$$\Phi(\zeta) \approx -1.7817 + 0.9270\zeta + 0.01696\zeta^2 - 0.05148\zeta^3$$

$$\text{for } 0 \leq \zeta \leq 1.9475 \tag{6}$$

In the above, $\zeta = z/b$, b is the width (diffuseness) of the nuclear surface ($b \approx 1$ fm) and γ is the specific nuclear surface tension, for which we used the expression given in ref. 2:

$$\gamma = 0.9517\ [1 - 1.7826\ (\tfrac{N-Z}{A})^2]\text{MeV/fm}^2 \quad , \tag{7}$$

where N,Z,A are the neutron, proton and mass numbers of the parent nucleus. The reduced radius $\bar{R}$ is given by

$$\bar{R} = C_1C_2/(C_1 + C_2) \quad , \tag{8}$$

where C_i are the central radii of the fragments, related to the effective sharp radii R_i by

$$C \approx R - \frac{b^2}{R} \quad . \tag{9}$$

Reference 2 gives the following semi-empirical formula for R in terms of the mass number A

$$R = 1.28\, A^{1/3} - 0.76 + 0.8\, A^{-1/3} \quad . \tag{10}$$

Disregarding ground-state deformations, the value of L_o in eq. 2 is given by 2C, where C is the central radius of the parent nucleus, calculated also according to eqs. 9,10.

The requirement of a smooth fit for V(L) at $L = L_c$ defines the coefficients a and ν in eq. 2 as

$$\nu = V_c'/(L_c - L_o)V_c \quad , \tag{11}$$

$$a = V_c/(L_c - L_o)^{\nu} \quad , \tag{12}$$

where the subscript "c" refers to contact, and

$$V_c' = \frac{dV}{dL}\bigg|_c = -\frac{Z_1 Z_2 e^2}{r_c^2} + K \frac{d}{dz}\Phi(z/b)\bigg|_c$$

$$= -\frac{Z_1 Z_2 e^2}{r_c^2} + 0.9270\ K/b \quad . \tag{13}$$

Here, r_c is the center separation at contact and 0.9270 is the dimensionless derivative of Φ at $\zeta = 0$.

The standard WKB expression for the Gamow penetrability factors was used both for the α particle and ^{14}C, the effective mass in the disintegration degree of freedom being taken simply as the reduced mass M_r of the fragments, since most of the barrier (also in the case of ^{14}C) corresponds to separating fragments beyond scission.

The above formulae, including all relevant nuclear parameters, were taken from refs. 2,3, without any adjustments. The resulting ratios of the penetrability factors for α and ^{14}C emissions from ^{222}Ra, ^{223}Ra and ^{224}Ra were found to be 1.678×10^{-9}, 6.903×10^{-9} and 6.147×10^{-11}, respectively. The ratios of these numbers to the measured branching ratios are 4.5, 11.3 and 0.83. Since the Gamow penetrability factors (for ^{14}C) are in the range $10^{32} - 10^{38}$, agreement within about a factor of 10 implies an accuracy in the estimated deformation-energy barriers of a few percent.

The reasons why, in the present calculations, the penetrability ratios are several orders of magnitude smaller than for a pure Coulomb barrier cut off at a contact distance parameterized as $r_o(A_1^{1/3} + A_2^{1/3})$, as in refs. 1,4, are the inclusion of the nuclear proximity interaction and the use of more realistic expressions for the nuclear radii (eqs. 9,10).

A fuller account of these calculations, (ref. 6), including estimates of branching ratios for other exotic decays, will be published separtely.

We benefited from discussions with S. Gales, A. Ghiorso, M. Nitschke, P.B. Price and S. Yashita. One of us (S.Y.-J.) enjoyed the hospitality of the Theory Group of the Lawrence Berkeley Laboratory's Nuclear Science Division.

This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract DE-AC03-76SF00098.

References

1. P.B. Price, J.D. Stevenson, S.W. Barwick and H.L. Ravn, preprint Aug. 1984, to be published.
2. J. Blocki, J. Randrup, W.J. Swiatecki and C.F. Tsang, Annals of Phys. 105 (1977) 427.
3. J. Blocki and W.J. Swiatecki, Annals of Phys. 132 (1981) 53.
4. H.J. Rose and G.A. Jones, Nature 307 (1984) 245.
5. S. Gales, E. Hourani, M. Hussonnois, J.P. Schapira, L. Stab and M. Vergnes, Phys. Rev. Lett. 53 (1984) 759.
6. Shi Yi-Jin and W.J. Swiatecki, Lawrence Berkeley Laboratory preprint LBL-18349, Sept. 1984.
7. D. N. Poenaru, M. Ivascu, A. Sandulescu and W. Greiner, J. Phys G: Nucl Phys. 10 (1984) L183 and references therein.

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720