result in a longer-lived activity which would have been detected during the course of many other studies.

In order to search for a short half-life due to Sc^{42}, potassium metal was bombarded repeatedly with alpha particles of energy of ~18 Mev and the activity was counted with anthracene crystal. The counts were started about $\frac{1}{4}$ sec after the bombardments and displayed with the aid of a relay circuit on nine scalers each counting a period of 32/60 sec. A strong activity with a half-life of 0.62 ± 0.05 sec (error limit) was found. It is due to high-energy positrons since it was found with a bias of several Mev and the annihilation peak observed with a NaI crystal showed the same decay. The intensity of this radiation was several times stronger than the intensity of the activity due to Ti^{43} ($t_{\frac{1}{2}}\sim0.6$ sec) produced by alpha particles on calcium and measured with the same arrangement.

The activity is concluded to be due to Sc^{42} because of the following reasons: (1) From its intensity, it must be due to one of the major reactions from alpha particles on potassium. No possible impurity or minor reaction like $(\alpha,n\alpha)$ on potassium can produce higher activity due to the reaction $Ca^{40}(\alpha,n)Ti^{43}$, although there is strong competition between the latter reaction and the (α,p) reaction.[5] (2) The threshold for producing Sc^{41} (0.87 sec) by an $(\alpha,2n)$ reaction is higher than 20 Mev. (3) High-energy positrons are expected from Sc^{42}. (4) The half-life lies in the range of values expected.

In Fig. 1, the half-life of Sc^{42} is plotted together with

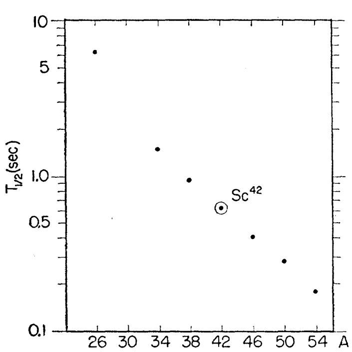

FIG. 1. Half-lives of the 0^+-0^+ transitions in $A=4n+2$ positron emitters.

the half-lives of known 0^+-0^+ positron transitions in the nuclides of this type. The observed half-life lies right on the curve, strongly suggesting that the 0^+ state is the ground state. This indicates that the energy suppression due to the spin interaction of the proton and neutron outside of the core is smaller than the energy suppression due to the configuration mixing in the 0^+ state.[6]

No attempt has been made yet to measure the positron end point, but according to the semiempirical formula given by Peaslee[7] it should be 5.70 Mev. This energy together with the measured half-life gives a $\log ft$ of 3.6, which is considerably higher than in the cases of Al^{26}, Cl^{34}, and K^{38}. Actually, Peaslee's formula gives much higher $\log ft$ for higher A, in which cases only the half-life of the possible 0^+-0^+ transition[8] is known. Since this increase in $\log ft$ value, or the failure of complete overlap of $T=1$ wave function, is noticed in the measurements of Hunt and Zaffarano[9] on Cl^{34} and K^{38}, it is of interest to know the end point of the positrons of 0^+-0^+ transitions of this type in the higher-A region.

The author is grateful to Professor E. Bleuler for his kind help and discussions in the course of this study.

† Supported by the U. S. Atomic Energy Commission.

* On leave from the University of Tokyo, Tokyo, Japan.

1 P. Stähelin, Phys. Rev. **92**, 1076 (1953).
2 O. Kofoed-Hansen, Phys. Rev. **92**, 1075 (1953).
3 S. A. Moszkowski and D. C. Peaslee, Phys. Rev. **93**, 455 (1954).
4 R. W. King and D. C. Peaslee, Phys. Rev. **90**, 1001 (1953).
5 H. Morinaga, Phys. Rev. **97**, 1185 (1955).
6 E. Bleuler and H. Morinaga, Phys. Rev. **99**, 658(A) (1955).
7 D. C. Peaslee, Phys. Rev. **95**, 717 (1954).
8 W. M. Martin and S. W. Breckon, Can. J. Phys. **30**, 643 (1952).
9 W. A. Hunt and D. J. Zaffarano, U. S. Atomic Energy Commission Ames Laboratory Report ISC-469, 1954 (unpublished).

New Type of Selection Rules in β Decay of Strongly Deformed Nuclei

G. ALAGA*

CERN, Theoretical Study Division at the Institute for Theoretica Physics, University of Copenhagen, Copenhagen, Denmark

(Received July 25, 1955)

IT is well known that in regions between closed shells (especially in the region $150<A<190$) the nuclei have deformed equilibrium shapes.[1] A classification of the nuclear ground state and excited states in this region has been recently suggested by Mottelson and Nilsson.[2] They assume essentially a single particle moving in a spheroidal harmonic potential well with appropriate spin-orbit coupling.

It is instructive to study the limiting case of very large deformations, because then there is an approximate separation of the motion, into oscillations along the symmetry axis and oscillations in the plane perpendicular to this axis.[2] For a classification of the states, one can then use the quantum numbers N, μ_z, Λ, and Ω. N is the principal quantum number of the oscillator, μ_z the quantum number of the oscillations along the asymmetry axis, Λ the component of the particle orbital angular momentum along the symmetry axis, and Ω the projection of the total particle angular momentum on the symmetry axis.

TABLE I. Selection rules for allowed transitions.

Operators	Selection rules				
1	$\Delta N=0$,	$\Delta\mu_z=0$,	$\Delta\Lambda=0$,	$\Delta\Omega=0$,	No
$\boldsymbol{\sigma}$	$\Delta N=0$,	$\Delta\mu_z=0$,	$\Delta\Lambda=0$,	$\Delta\Omega=0,\pm1$	No

TABLE II. Selection rules for first forbidden transitions.

Operators		Selection rules		
$\boldsymbol{\sigma}\cdot\mathbf{r}$	$\Delta N=\pm1$	$\Delta\mu_z=\pm1,\ \Delta\Lambda=0$	$\Delta\Omega=0$	Yes
$\boldsymbol{\sigma}\cdot\boldsymbol{\nabla}$		$\Delta\mu_z=0,\ \ \Delta\Lambda=\pm1$		
$\mathbf{r}$	$\Delta N=\pm1$	$\Delta\mu_z=\pm1,\ \Delta\Lambda=0,\ \ \Delta\Omega=0$		Yes
		$\Delta\mu_z=0,\ \ \Delta\Lambda=\pm1,\ \Delta\Omega=\pm1$		
$\boldsymbol{\sigma}\times\mathbf{r}$	$\Delta N=\pm1$	$\Delta\mu_z=\pm1,\ \Delta\Lambda=0,\ \ \Delta\Omega=\pm1$		Yes
$\boldsymbol{\sigma}\times\boldsymbol{\nabla}$		$\Delta\mu_z=0,\ \ \Delta\Lambda=\pm1,\ \Delta\Omega=0,\pm1$		
B_{ij}	$\Delta N=\pm1$	$\Delta\mu_z=\pm1,\ \Delta\Lambda=0,\ \ \Delta\Omega=0,\pm1$		Yes
		$\Delta\mu_z=0,\ \ \Delta\Lambda=\pm1,\ \Delta\Omega=0,\pm1,\pm2$		

The list of selection rules for allowed and first forbidden β transitions associated with these quantum numbers is given in Tables I and II.[3] We confine ourselves to the transitions with $\Delta I=\Delta\Omega$, i.e., we omit rotational branchings and K-forbidden transitions.[4] It is seen that besides the selection rules on $\Omega(=K)$ there are also selection rules on the other quantum numbers. We shall refer to those transitions which are permitted with respect to the selection rules of all quantum numbers as unhindered transitions, "*u*." The transitions which are permitted by the selection rules on Ω and I, but forbidden because of selection rules on other quantum numbers we shall call hindered transitions, "*h*."

In Tables III and IV, we list the data for allowed and first forbidden transitions in odd-A nuclei in the region $150<A<190$. The classification is that given by Mottelson and Nilsson[2] where one also can find the references to the experimental literature.

From Tables III and IV one can see that the hindered or unhindered nature of the transition is clearly reflected in the experimental ft value.[5] For allowed transitions the unhindered group (only two examples) have $\log ft<5.5$, while the hindered group have $6.0<\log ft<6.8$. The first forbidden transitions with $\Delta I=0$, or 1 have $6.0<\log ft<7.7$ if unhindered, while $7.2<\log ft<8.3$ if hindered. The one example of an unhindered first forbidden $\Delta I=2$ transition has $\log ft=8.2$, while the single hindered transition of this type has $\log ft\geqq 8.7$.

TABLE III. The table lists the experimental ft values and theoretical classification of the allowed β transitions in the region of strongly deformed nuclei. In columns 1, 2, and 3 are listed the isotopes of parent and daughter nucleus, and the excitation energy of the level populated in the daughter. The asymptotic quantum numbers (N, μ_z, Λ, Ω) corresponding to the orbital assignments of reference 2 are given in columns 4 and 5; the number in brackets is the identifying number for these orbits employed in the same reference. Column 6 gives the hindered or unhindered classification of the transitions resulting from these quantum numbers. The experimental ft value is given in the last column.

Parent	Daughter	Excit. of final	Orbit Parent	Orbit Daughter	Add. class.	(ft) exp.
$_{62}Sm^{153}$	$_{63}Eu^{153}$	~0.60	5,2,1,3/2(52)	5,3,2,5/2(36)	*h*	~6.5
$_{63}Eu^{155}$	$_{64}Gd^{155}$	0.106	4,1,3,5/2(27)	6,4,2,5/2(55)	*h*	6.6
$_{68}Er^{171}$	$_{69}Tm^{171}$	0.426	5,1,2,5/2(44)	5,2,3,7/2(35)	*h*	6.5
$_{70}Yb^{175}$	$_{71}Lu^{175}$	0.395	5,1,4,7/2(41)	5,1,4,9/2(32)	*u*	4.8
$_{70}Yb^{177}$	$_{71}Lu^{177}$	0	6,2,4,9/2(49)	4,0,4,7/2(25)	*h*	6.2
$_{71}Lu^{177}$	$_{72}Hf^{177}$	0.321	4,0,4,7/2(25)	6,2,4,9/2(49)	*h*	6.3
$_{76}Os^{191}$	$_{77}Ir^{191}$	0.171	5,0,5,9/2(40)	5,0,5,11/2(28)	*u*	5.3

TABLE IV. The table lists the experimental ft value and theoretical classification of the first forbidden transition in the region of strongly deformed nuclei. The material is arranged in the same manner as in Table III. The first part of the table corresponds to the $\Delta I=0$ or 1 transitions: the last two transitions listed have $\Delta I=2$.

Parent	Daughter	Excit. of final	Orbit Parent	Orbit Daughter	Add. class.	(ft) exp.
$_{62}Sm^{153}$	$_{63}Eu^{153}$	0	5,2,1,3/2(52)	4,1,3,5/2(27)	*h*	7.4
$_{62}Sm^{153}$	$_{63}Eu^{153}$	0.103	5,2,1,3/2(52)	4,1,1,3/2(33)	*u*	6.8
$_{63}Eu^{155}$	$_{64}Gd^{155}$	0	4,1,3,5/2(27)	5,2,1,3/2(52)	*h*	8.2
$_{63}Eu^{157}$	$_{64}Gd^{155}$	0	4,1,3,5/2(27)	5,2,1,3/2(52)	*h*	8.0
$_{64}Gd^{159}$	$_{65}Tb^{159}$	0	5,2,3,5/2(44)	4,1,1,3/2(33)	*h*	7.3
$_{66}Dy^{165}$	$_{67}Ho^{165}$	0	6,3,3,7/2(54)	5,2,3,7/2(35)	*u*	6.2
$_{68}Er^{169}$	$_{69}Tm^{169}$	0	5,2,1,1/2(63)	4,1,1,1/2(43)	*u*	6.1
$_{69}Tm^{171}$	$_{70}Yb^{171}$	0	4,1,1,1/2(43)	5,2,1,1/2(63)	*u*	6.4
$_{70}Yb^{175}$	$_{71}Lu^{175}$	0	5,1,4,7/2(41)	4,0,4,7/2(25)	*u*	6.3
$_{70}Yb^{177}$	$_{71}Lu^{177}$	0.146	6,2,4,9/2(49)	5,1,4,9/2(32)	*u*	7.0
$_{71}Lu^{177}$	$_{72}Hf^{177}$	0	4,0,4,7/2(25)	5,1,4,7/2(41)	*u*	6.8
$_{73}Ta^{183}$	$_{74}W^{183}$	0.453	4,0,4,7/2(25)	5,0,3,7/2(48)	*u*	6.8
$_{73}Ta^{185}$	$_{74}W^{185}$	0	4,0,4,7/2(25)	5,1,4,7/2(41)	*u*	6.3
$_{74}W^{185}$	$_{75}Re^{185}$	0	5,1,4,7/2(41)	4,0,2,5/2(31)	*h*	7.5
$_{74}W^{187}$	$_{75}Re^{187}$	0	5,1,4,7/2(41)	4,0,2,5/2(31)	*h*	8.0
$_{68}Er^{171}$	$_{69}Tm^{171}$	0	5,1,2,5/2(50)	4,1,1,1/2(43)	*u*	8.2
$_{73}Ta^{183}$	$_{74}W^{183}$	0.209	4,0,4,7/2(25)	5,1,2,3/2(62)	*h*	8.7

The selection rules here discussed may also be of help in the discussion of electron-capture transitions where often the disintegration energy is not known and therefore the ft value may not be available. Thus in the electron capture decay of Hf^{175} ($I=5/2-$) to Lu^{175}, the transition to the excited ($I=5/2+$) configuration at 342 kev is found to compete successfully with the higher energy transition to the $I=7/2+$ ground state.[6] This may be understood in terms of the nucleonic states involved which are for Hf^{175} (5,1,2,5/2) and for the Lu^{175} ground state and excited state (4,0,4,7/2) and (4,0,2,5/2), respectively. Thus, the ground-state transition is hindered while the excited-state transition is not.

It is a pleasure for me to thank Dr. Aage Bohr and Dr. Ben R. Mottelson for suggesting this problem and for their continuous interest and advice. Further, I wish to thank Dr. K. Alder and Dr. S. G. Nilsson for many helpful discussions.

* At present at the Institute R. Bosković, Zagreb, Yugoslavia.

[1] A. Bohr and B. R. Mottelson, *Beta and Gamma Ray Spectroscopy*, edited by K. Siegbahn (North Holland Publishing Company, New York, 1955), Chap. 17 and the references given there.
[2] S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat-fys. Medd. **29**, No. 16 (1955); B. R. Mottelson and S. G. Nilsson, Phys. Rev. **99**, 1615 (1955). See also the more detailed report of this work to appear in *Kongelige Danske Videnskabernes Selskab, Matematisk-fysiske Meddelelser.*
[3] A more detailed report on the calculation of ft values for strongly deformed nuclei is in preparation; see also G. Alaga, dissertation, University of Zagreb, 1955 (unpublished).
[4] Alaga, Alder, Bohr, and Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **29**, No. 9 (1955).
[5] Similar selection rules for certain γ transitions have been found by S. G. Nilsson (private communication).
[6] Burford, Perkins, and Haynes, Phys. Rev. **99**, 3 (1955).