Title
LOW-LYING NUCLEAR ENERGY LEVELS IN THE HEAVY ELEMENT REGION AND THE APPLICABILITY OF CERTAIN NUCLEAR MODELS



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# LOW-LYING NUCLEAR ENERGY LEVELS IN THE HEAVY ELEMENT REGION AND THE APPLICABILITY OF CERTAIN NUCLEAR MODELS

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Berkeley, California

Outline
J.O. Rasmussen
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# Low-Lying Nuclear Energy Levels in the Heavy Element Region and the Applicability of Certain Nuclear Models

I. Introduction.

A. Objectives of nuclear spectroscopy.

B. The development of single particle models.

1. ESP, PF, UM.

2. Strong coupling approximation of UM.

II. Application of models to heavy region (Ra and above).

A. Serious trouble for ESP.

1. Low-lying E1 transitions.

2. Too many levels (8 in $Pu^{239}$ under 400 kev).

3. Magnetic moments of like spin nuclei of unlike sign. ($U^{233}$ and $U^{235}$)

4. Large quadrupole moments. ($U^{235}$ ~+8 barns)

5. "Rotational bands" evidence of collective excitation.

B. Trouble for PF.

1. Model capable of showing collective features, but

2. Large Q's the most serious trouble.

a. Need protons within closed shells to participate.

C. UM brings nucleons in closed shells into participation as well deformed by particles outside closed shells.

D. The large deformation approximation of UM.

1. Consequences to level structure.

a. Still have particle excitations as treated by PF.

b. Superimposed on each particle excitation level should be rotational band structure and vibrational structure, analogous to molecular spectra.

III. The rotational bands.

III. A. Nucleus not a rigid solid rotator (by exclusion principle), so angular momentum carried in surface waves--the matter in the tidal bulges.

B. Even-even nuclei bands.

1. First excited state always 2+ and considered a rotational level in heavy region.

Slide 1 (excited state) — 2. Slide shows striking decrease and regularity of energy as nucleon pairs are added to $Pb^{208}$ core. ($Pb^{208}$ point incorrect--is 3-.)

Slide 2 (band en. formula) ee — 3. Higher members of bands in even-even "rotation-vibration" interaction. Smooth trend of

Slide 3 (R and E for heavies) — Smooth trend of R with A and of E with Z. E is a measure of perturbation by high states, perhaps particle as well as vibrational.

Slide 4 (R and E for rare earths) — Church and Goldhaber have found a similar smooth correlation of E as well as R, but with neutron number.

C. Odd mass nuclei--rotational bands.

Slide 5 (Band en. formula for $I_o \neq 0$) — 1. Bands on any base state not spin zero have base spin and progression including $I_o + 1$, $I_o + 2$, etc. Rotational energy proportional to $I(I + 1)$.

Slide 6 (Odd band slide) — 2. Several bands of three members have been found in heavy region by alpha spectroscopy. All $I_o = 5/2$. R higher than ee neighbors.

IV. Testing the approximate quantum numbers.

Slide 7 (Coupling diagram) — A. Discussion of coupling in large deformation case.

1. Quantum numbers--$j$, $K$, $\Omega$, $\eta_\beta$, $\eta_\gamma$

2. Restriction to energies <<1 Mev

allows $\eta_\beta = \eta_\gamma = 0$ and $K = \Omega$, so have just two numbers

K and j to check on.

B. Tests of K.

1. One good test is provided by odd-odd beta emitters of 2- type. K selection rule discussion. King and Peaslee's observation of general slowness of 2- to 2+ transitions (13 cases).

Slide 8 ($Np^{238}$ decay scheme) — 2. Beta decay of $Np^{238}$. 2- to 2+ slower than any of 13 examples above, suggesting K purity greatest in heavy region.

IV. B. 3. In general, relative intensities of either $\beta$ or $\gamma$ transitions to two or more members of a rotational band provide valuable tests on K purity of states involved.

4. Theory says K improves with increasing distortion.

C. Tests of j.

1. Theory says j gets worse with increasing distortion--deformation mixes states of like spin and parity but different j. For certain states j may stay fairly good--the opposite parity orbital; the high I.

Slide 9 K = 1/2 rotational slide

2. Rotational bands in the special case $\Omega = K = 1/2$.
Irregular patterns depending on j of odd particle.
$Pu^{239}$, I = 1/2, can be compared concluding j not very good.
$U^{235}$, I = 5/2 may be such a case, but very poor agreement with possible bands can be found. j not too good.

Slide 10 odd Z $\mu$'s

3. Magnetic moments.

a. Odd proton nuclei

$Am^{241}$ and $Am^{243}$ - speculation.

$Np^{237}$ 60 kev - calculation from M1-E2 mixture of a rotational band $\gamma$ transition.
Conclude j not too good.

b. Odd neutron nuclei.
$U^{235}$ ($U^{233}$)
$Th^{229}$
Conclude j not too good.

Decay scheme previously drawn on board

D. Decay scheme of $Am^{241}$ as illustration of principles.

1. Pointing out quantum numbers. Conclusion that ground state must be based on $i_{13/2}$ proton. Predict $\mu \sim +2.7$.

2. The E1 lifetime problem (of 6 measured—2 are slow
4 are fast)
show how j forbidden and how small participation of neutron structure or proton orbitals of another shell needed.

3. Alpha decay hypothesis.

No-hindrance groups may often correspond to no change of odd nucleon wave function. Then $\alpha,\gamma$ angular correlation in $Am^{241}$ and $Am^{243}$ may be understood as due to $\ell = 0$, $\ell = 2$ mixture in alpha waves.
Segall and I believe large quadrupole moments will make $\ell$ mixtures a general occurrence in heavy region.

IV. E. Alpha decay rates to rotational bands.

1. The Hill-Wheeler directed alpha decay concept.

2. Fine structure groups as Legendre components of the correlation function between alpha and symmetry axis.

Slide 11
4+
hindrance

3. Experimentally 2+ states have nearly unhindered alpha decay, but the 4+ go through unusual variation. Attempts being made to integrate the coupled Schrödinger equations for barrier penetration.

F. What needs to be done.

1. Theory.

2. Experiment.