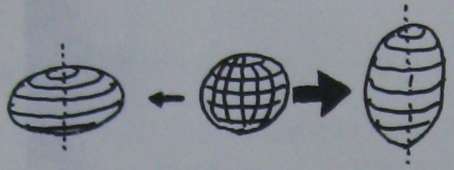
YKIS01, YITP, Kyoto, 2001/11/7

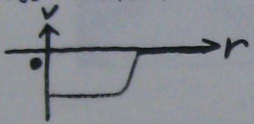
Origin of Prolate Dominance of Nuclear Deformation

N. Tajima, N. Suzuki (Fukui), Y.R. Shimizu (Kyushu)

- Why are there much more prolate nuclei than oblate nuclei ?



- Because ....
  - . Woods-Saxon radial profile (H. Frisk, 1990)



→ $\vec{\ell}^2$ term of the Nilsson potential

  - . unique-parity high-j intruder seems strongly involved
    → $\vec{\ell}\cdot\vec{s}$ potential (N.T., 1996)

- We study how

$$\frac{\#\text{prolate nuclei}}{\#\text{prolate nuclei} + \#\text{oblate nuclei}}$$

changes when the Nilsson potential is modified.

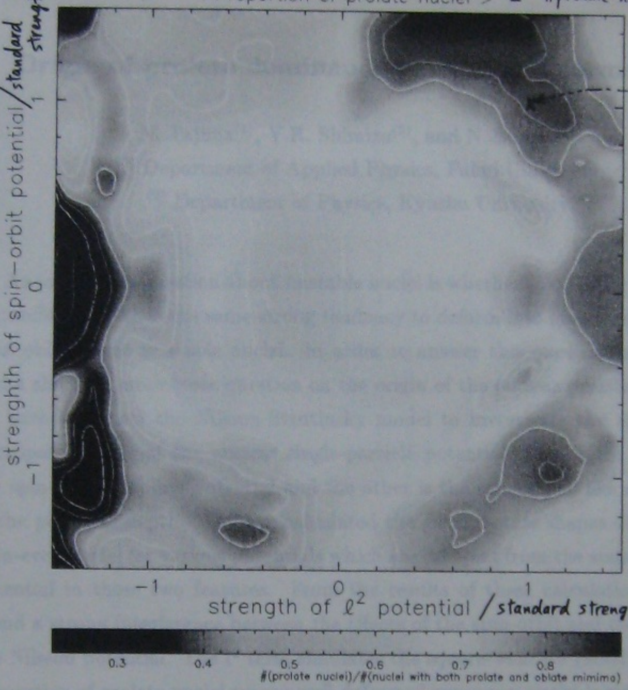
$$U(r) = \frac{1}{2}\left(\omega_\perp^2 x^2 + \omega_\perp^2 y^2 + \omega_\parallel^2 z^2\right) + 2\hbar\omega_0 r_t^2 \sqrt{\frac{4\pi}{9}}\,\varepsilon_4 Y_{40}(\hat{r})$$

$$+ f_{\ell s}\, 2\kappa\hbar\omega_0 \vec{\ell}_t\cdot\vec{s} - f_{\ell\ell}\,\kappa\mu\hbar\omega_0\left(\vec{\ell}_t^{\,2} - \langle\vec{\ell}_t^{\,2}\rangle_N\right)$$

$$-1.5 \lesssim \begin{matrix} f_{\ell s} \\ f_{\ell\ell} \end{matrix} \lesssim 1.5$$

- P.R. C64, 037301 (2001)
  ~~1991~~ ← error in abstract !

< Proportion of prolate nuclei > = #prolate nucl. / (#prolate nucl. + #oblate nu among 1834 even-even nucle



- real atomic nuclei 86% prol

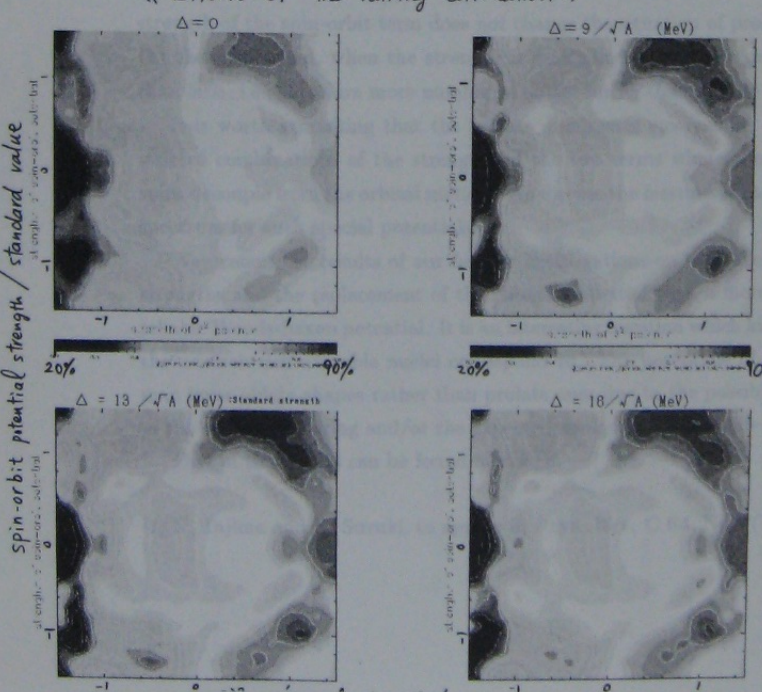
← oblate 60% region in between

← No spin-orbit coupling
H. Frisk

←

←

《 Effects of the Pairing Correlation 》



Plotted quantity is

$$\frac{\#\text{prolate nuclei}}{\#\text{prolate nucl.} + \#\text{oblate nucl}}$$

for 1834 even-even nuclei
with · $8 \leq Z \leq 126$
· $8 \leq N \leq 184$
· n-drip to p-drip

It looks that
both prolate and oblate
dominances are enhanced
by pairing.

$31^2 = 961$ points calc. in each pan
80 days it with 833MHz EV68 alp
YITP computer facility
parallel machine

ykis01a-tex 1/8/1

Origin of prolate dominance of nuclear deformation

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An interesting question about unstable nuclei is whether they, being far from the β-stability line, have the same strong tendency to deform into prolate shapes rather than oblate ones as stable nuclei. In order to answer this question, as well as to find a clue to a more basic question on the origin of the nuclear prolate dominance, we have employed the Nilsson-Strutinsky model to investigate the effects of two principal features of the nuclear single-particle potential: One is the existence of the spin-orbit coupling potential and the other is the square-well like radial profile of the potential depth. We have calculated the ground-state shapes of about 2000 even-even nuclei for various potentials which are different from the standard nuclear potential in these two features. From the results of these calculations, we have found a strong interference between the effects of the spin-orbit and the l^2 terms of the Nilsson potential. The l^2 term simulates the square-well-like radial profile. The proportion of prolate nuclei among well-deformed even-even nuclei is more than 80% by using the standard strengths for the two terms. Multiplication of ± 1 or 0 to the strength of the spin-orbit term does not change the situation of prolate dominance. On the other hand, when the strength is multiplied by $\pm\frac{1}{2}$, the proportion is less than 50%, i.e., there are more number of oblate nuclei than prolate ones.

It is worth remarking that the prolate dominance emerges for such a very restricted combinations of the strengths of the two terms where the real or pseudo spins decouple from the orbital motion. We discuss the features of the single-particle spectrum for such special potentials.

We present the results of our further investigations on the effect of the pairing strengths and the replacement of the Nilsson potential with a more quantitatively reliable Woods-Saxon potential. It is an interesting question which kind of potentials the neutron-rich unstable nuclei correspond to. The potentials of drip-line nuclei may favor oblate shapes rather than prolate ones due to the possible enhancement of the neutron's pairing and/or the expected weakening of the spin-orbit coupling.

Part of the results can be found in Ref.[1].

[1] N. Tajima and N. Suzuki, to appear in Phys. Rev. C **64**, No.3 (~~1991~~). 037301
2001

Nov. 7, 2001, YITP, Kyoto
Nov. 2, 2000, INT, Seattle

Why are there much more prolate nuclei than oblate ones ?

N. Tajima, N. Suzuki (Fukui Univ.)
Y. R. Shimizu (Kyushu Univ.)

- Macroscopic (Coulomb) or collective effects (W. Zickendraht, 1985) are not strong enough.
- Shell effect of anisotropic harmonic oscillator (Castel et al., 1990) is rather neutral.
- Woods-Saxon radial profile (H. Frisk, 1990)
- unique-parity high-j intruder due to spin-orbit potential (N.T. et al., 1996)

We study

the ratio of prolate nuclei among well deformed nuclei, R_p,

as a function of the strengths of ls and l^2 potentials of the Nilsson model.

$$\begin{aligned} U(\mathrm{r}) &= \frac{1}{2}\left(\omega_\perp^2 x^2 + \omega_\perp^2 y^2 + \omega_\parallel^2 z^2\right) + 2\hbar\omega_0 r_t^2 \sqrt{\frac{4\pi}{9}}\epsilon_4 Y_{40}(\hat{r}) \\ &\quad + \underline{f_{ls}}2\kappa\hbar\omega_0 \mathrm{l}_t\cdot\mathrm{s} - \underline{f_{ll}}\kappa\mu\hbar\omega_0\left(\mathrm{l}_t^2 - \langle \mathrm{l}_t^2\rangle_N\right) \end{aligned}$$

- volume conservation: $\omega_\perp^2\omega_\parallel = \text{constant.} \rightarrow \omega_\perp(\epsilon_2), \omega_\parallel(\epsilon_2)$
- ϵ_4 optimized for each ϵ_2 as well as $\epsilon_4 = 0$ calculation
- standard κ and μ of Bengtsson and Ragnarsson (1985)
- pairig force such that average pairing gap $\bar{\Delta} = \begin{Bmatrix}16\\13\\9\\0\end{Bmatrix}/\sqrt{A}$ MeV
- Strutinsky method
- 1834 even even nuclei with $8 \le Z \le 126$ and $8 \le N \le 184$ between drip lines for each of $\underset{\downarrow\,31}{\cancel{17}} \times \underset{\downarrow\,31}{\cancel{17}}$ sets of (f_{ll}, f_{ls}) $[-1.5, 1.5]\times[-1.5, 1.5]$

Summary of the results

1. Standard $\mathrm{l}\cdot\mathrm{s}$ and $\mathrm{l}^2 \Rightarrow R_\mathrm{p} = 0.86$.
2. Changing $\mathrm{l}\cdot\mathrm{s}$ strength $\Rightarrow$ Strong interference: with $f_{ll} = 1$,

f_{ls}	−1	−0.5	0	0.5	1
R_p	0.81	0.44	0.78	0.45	0.86

3. H. Frisk's idea is confirmed. ($f_{ls} = 0$ line)
4. harmonic oscillator has a weak prolate preference (R_p=0.55 at $f_{ll} = f_{ls} = 0$)
5. Y_{40} [redacted]
6. Pairing [redacted]

} as shown in figures.
analyses in progress.

Discussion

Prolate dominance observed in real nuclei may be a result of an accidental combination of the strengths of the two potentials.

Frisk's idea applies in situations where there is

- spin decoupling at (f_{ll}, f_{ls})=(1,0)
- pseudo spin decoupling at (f_{ll}, f_{ls})=(1,1)
- any kind of spin decoupling at (f_{ll}, f_{ls})=(1,-1) ?

There has been opinions (intuitions) that

the pseudo spin symmetry must have a fundamental origin,

Bohr-Mottelsonn (1969), Ginocchio (1997).

The prolate dominance may also be the same.

poster

【3-minute presentation for Poster】

1. I would like to discuss on the origin of the prolate dominance of nuclear deformation.
2. Namely, the question is "why are there much more number of prolate nuclei than oblate nuclei?"
3. Its possible explanations are, first,
   the Woods-Saxon like radial profile of the single-particle potential
   namely the $\vec{l}^2$ term in the case of the Nilsson potential
   and, second, the spin-orbit potential
   (I noticed the unique-parity high-j intruder orbitals seem strongly involved in giving rise to the prolate dominance)
4. Then we study how the proportion of prolate nuclei (among prolate and oblate nuclei) changes when the Nilsson potential is modified by multiplying constant factors to the strengths of the spin-orbit and the $\vec{l}^2$ terms

1 min

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5. This is a color-gradation plot of the proportion of prolate nuclei as a function of the multiplication factor to the $\vec{l}^2$ term and that to the spin-orbit term
6. The actual nuclear potential correspond to this point with coordinates (1, 1)
7. where, indeed, 86% of nuclei are prolate.
8. As Hans Frisk argued the $\vec{l}^2$ term favors prolate shapes
9. What we found is the addition of the spin-orbit potential causes a strong interference
10. If the strength (of the spin-orbit potential) was a half of the actual value there would be more number of oblate nuclei than prolate nuclei
11. This situation may be related to the change of the nuclear potential toward the neutron drip line
12. However pairing is also important near the drip line

1min10sec

So, I studied, next, the effects of the pairing correlation

13. The first panel was calculated without pairing, the second with reduced pairing, the third with standard pairing, the fourth with enhanced pairing
14. It looks both prolate and oblate dominances are enhanced by pairing
15. This investigation is still in progress

Thank you very much

40 sec