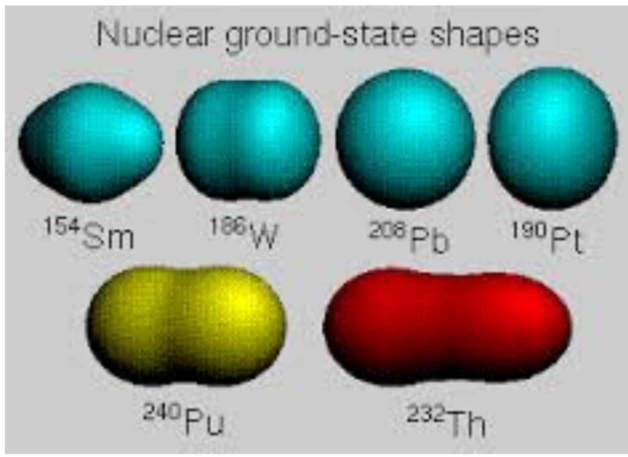
Shapes


Nuclear ground-state shapes
^{154}Sm
^{186}W
^{208}Pb
^{190}Pt
^{240}Pu
^{232}Th


nature
GOING PEAR-SHAPED
Exotic radium-224 atomic nuclei seen at CERN
STAYING IN TOUCH
HEATED ARGUMENT
THE AGE OF THE BRAIN


tangerine?
lemon?
banana?
pear?

Nuclear shapes

The first evidence for a non-spherical nuclear shape came from the observation of a quadrupole component in the hyperfine structure of optical spectra. The analysis showed that the electric quadrupole moments of the nuclei concerned were more than an order of magnitude greater than the maximum value that could be attributed to a single proton and suggested a deformation of the nucleus as a whole.

- Schüler, H., and Schmidt, Th., Z. Physik 94, 457 (1935)
- Casimir, H. B. G., On the Interaction Between Atomic Nuclei and Electrons, Prize Essay, Taylor's Tweede Genootschap, Haarlem (1936)

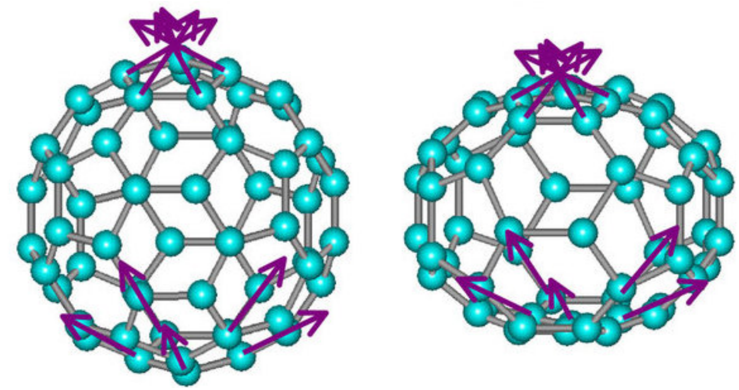
The question of whether nuclei can rotate became an issue already in the very early days of nuclear spectroscopy

- Thibaud, J., Comptes rendus 191, 656 (1930)
- Teller, E., and Wheeler, J. A., Phys. Rev. 53, 778 (1938)
- Bohr, N., Nature 137, 344 (1936)
- Bohr, N., and Kalckar, F., Mat. Fys. Medd. Dan. Vid. Selsk. 14, no, 10 (1937)

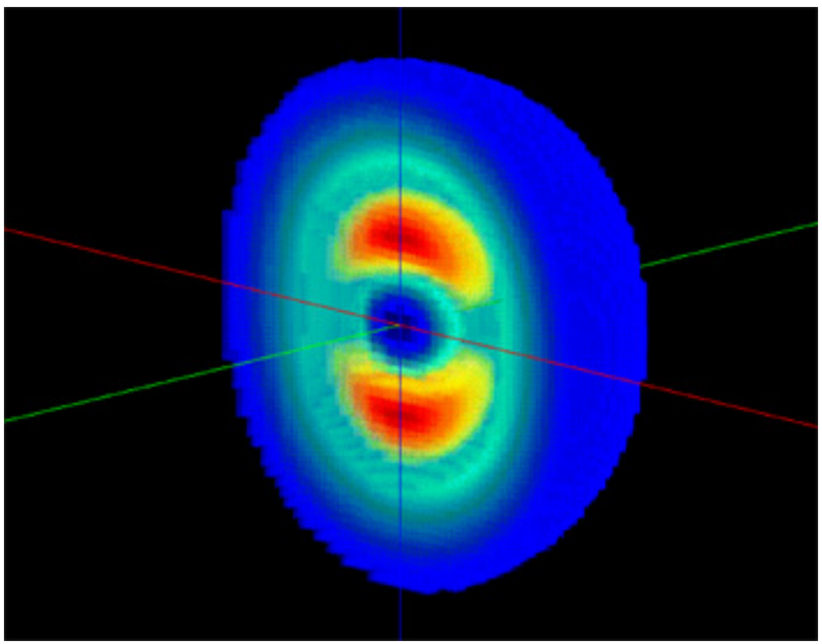
Can perfectly spherical nucleus rotate?

Nuclear deformation: Jahn-Teller effect. The Jahn–Teller theorem (1937) states that any nonlinear molecule with a spatially degenerate electronic ground state will undergo a geometrical distortion that removes that degeneracy, because the distortion lowers the overall energy of the species.

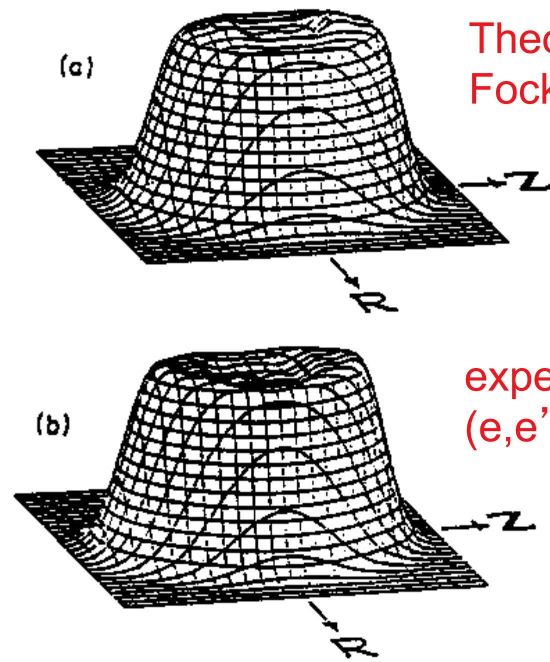
Cs_3C_{60}



http://www.nature.com/ncomms/journal/v3/n6/full/ncomms1910.html



The intrinsic shape of the deuteron by combining the results from experiments at JLab

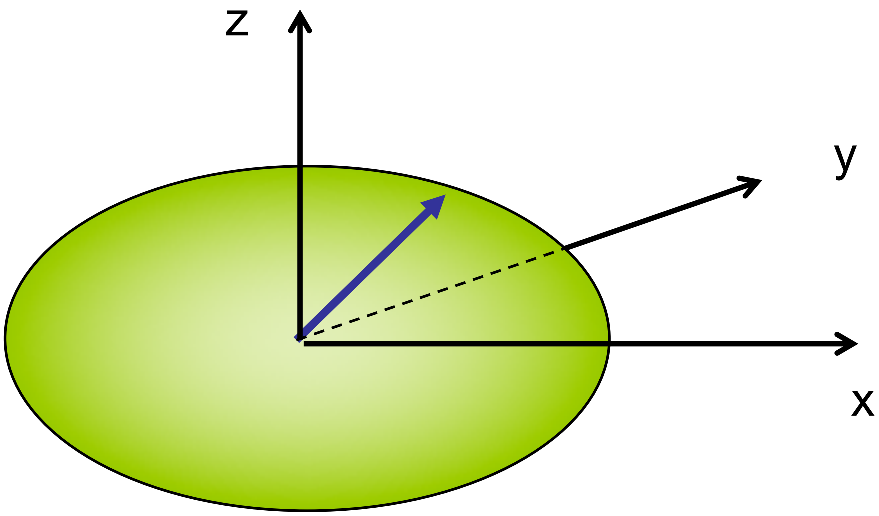


Theory: Hartree-Fock

experiment: (e,e’) Bates

Shape of a charge distribution in ^{154}Gd

How to describe nuclear shapes?



$$R(\theta,\varphi) = c(\alpha) R_0 \left[1 + \sum_{\lambda=1} \sum_{\mu=-\lambda}^{\lambda} \alpha^*_{\lambda\mu} Y_{\lambda\mu}(\theta,\varphi) \right]$$

volume conservation

radius of the sphere
with the same volume

deformation parameters
For axial shapes $\mu=0$

$$\beta_\lambda \equiv \alpha_{\lambda\mu}$$

a) λ=1 (dipole); μ=-1,0,1

$$\int_V \vec{r} d^3 r = 0$$

center of mass conservation

3 conditions, they fix $\alpha_{1\mu}$

b) λ=2 (quadrupole); μ=-2,-1,0,1,2

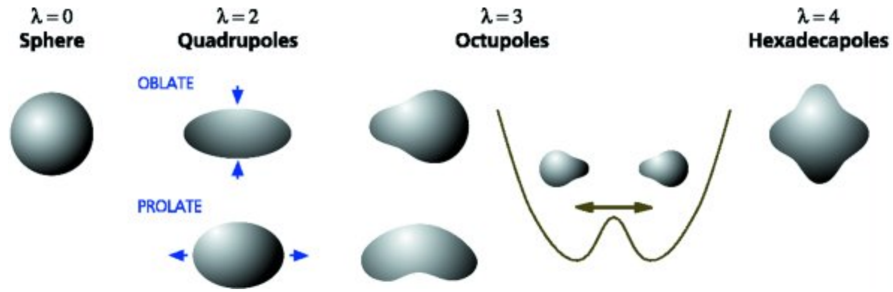
$$\alpha_{2\,1} = \alpha_{2\,-1} = 0, \quad \alpha_{2\,2} = \alpha_{2\,-2}$$

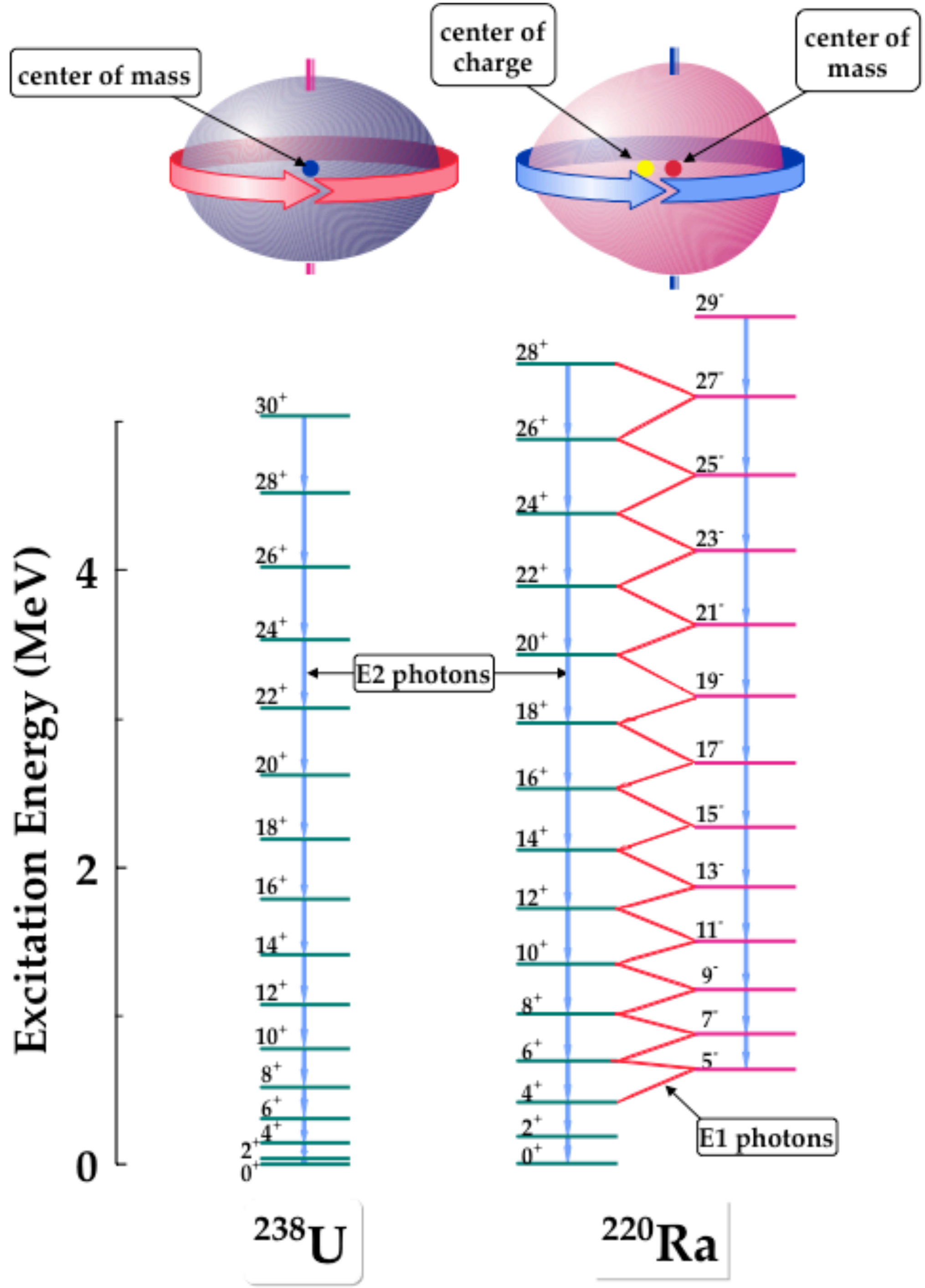
3 conditions, they fix three Euler angles

Only two deformation parameters left (Hill- Wheeler coordinates):

$$\alpha_{20} = \beta \cos\gamma, \quad \alpha_{22} = \frac{1}{\sqrt{2}} \beta \sin\gamma$$

c) λ=3 (octupole)
d) λ=4 (hexadecapole)
e) …





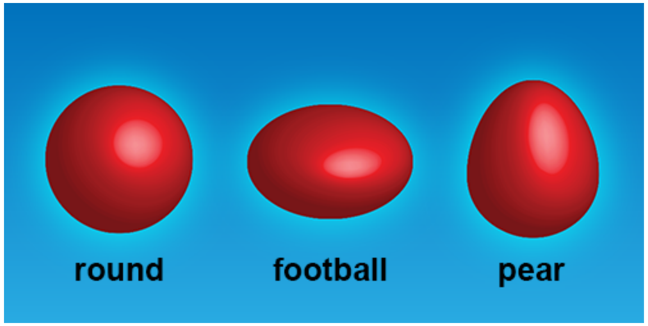
center of mass
center of charge
center of mass
Excitation Energy (MeV)
0
2
4
30+
28+
26+
24+
22+
20+
18+
16+
14+
12+
10+
8+
6+
4+
2+
0+
E2 photons
28+
26+
24+
22+
20+
18+
16+
14+
12+
10+
8+
6+
4+
2+
0+
29-
27-
25-
23-
21-
19-
17-
15-
13-
11-
9-
7-
5-
E1 photons
238U
220Ra

Synopsis: Nucleus is Surprisingly Pear Shaped

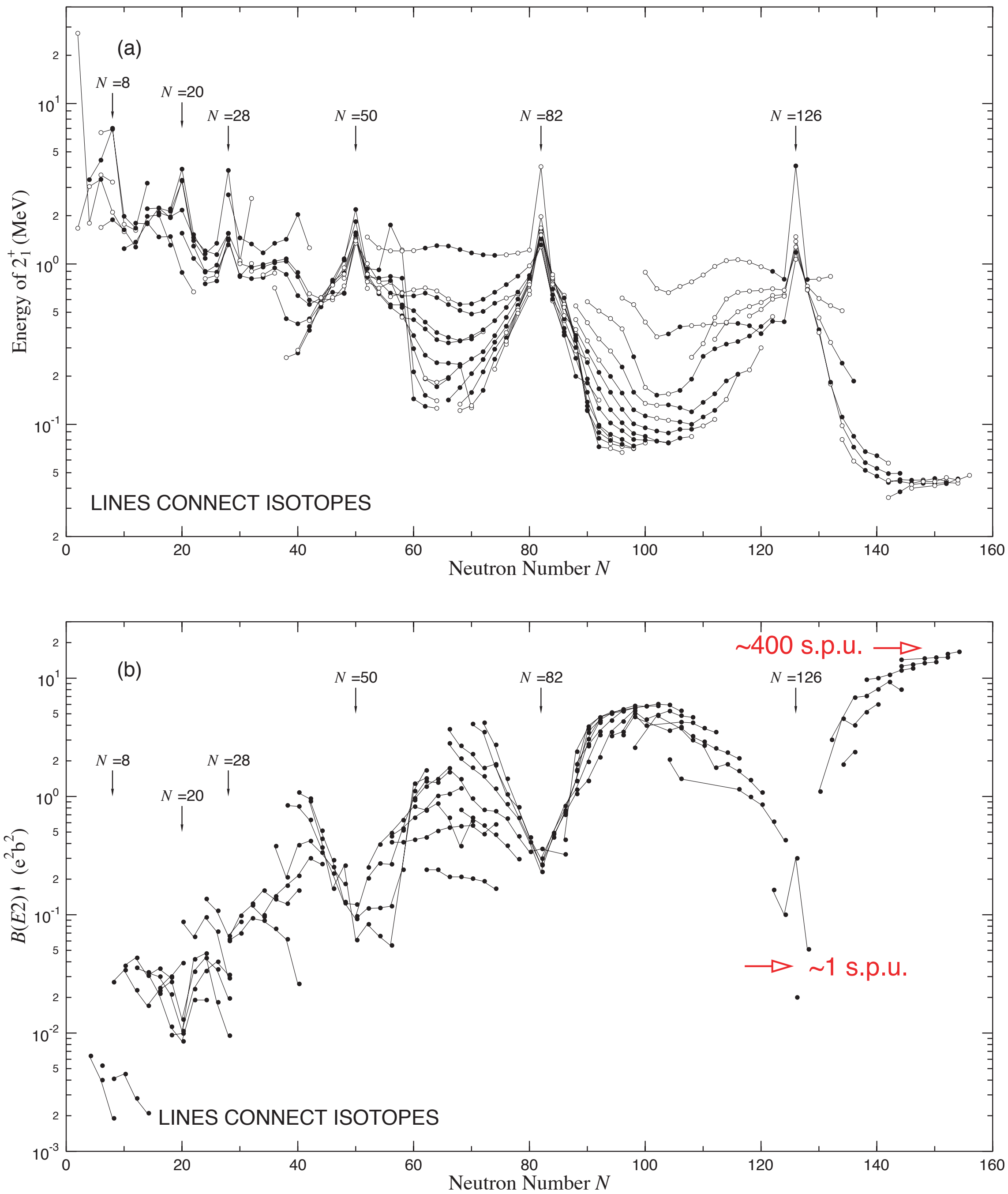
http://physics.aps.org/synopsis-for/10.1103/PhysRevLett.116.112503

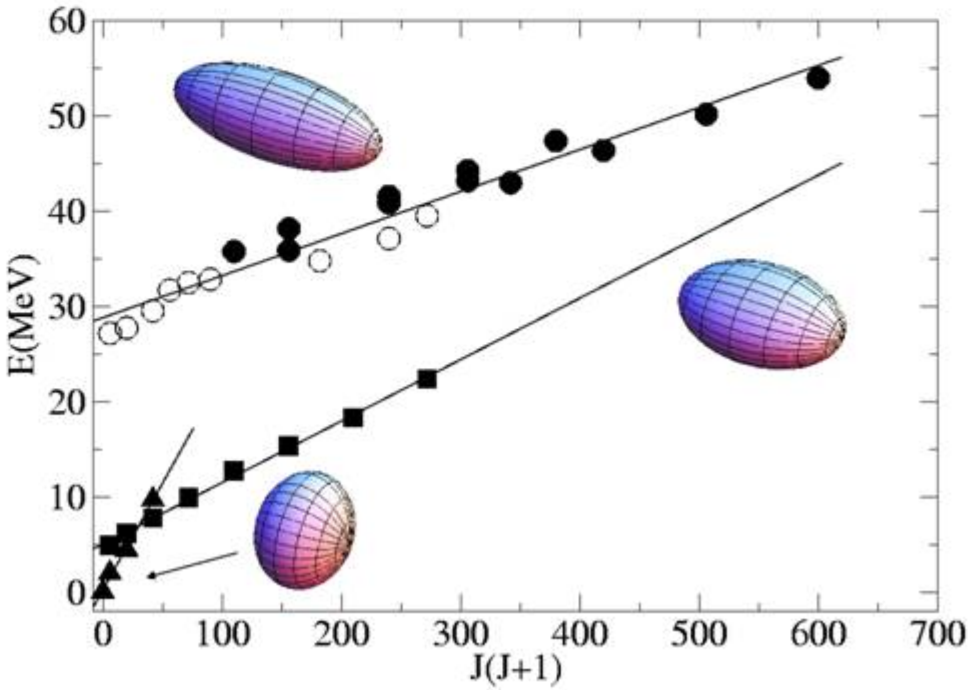
Most nuclei are round or slightly squashed, like a football. But in certain nuclei, protons and neutrons arrange in a more pear-shaped configuration. Only a handful of these distorted nuclei have been seen in experiments. Now, researchers have confirmed that ^{144}Ba is a member of this exclusive club. Moreover, it may be more distorted than theorists expected, a finding that could challenge current nuclear structure models. For decades, theorists have predicted that ^{144}Ba should be asymmetric. But until now, there were no techniques that allowed a sufficient number of the short-lived barium isotopes to be prepared and studied before they decayed.

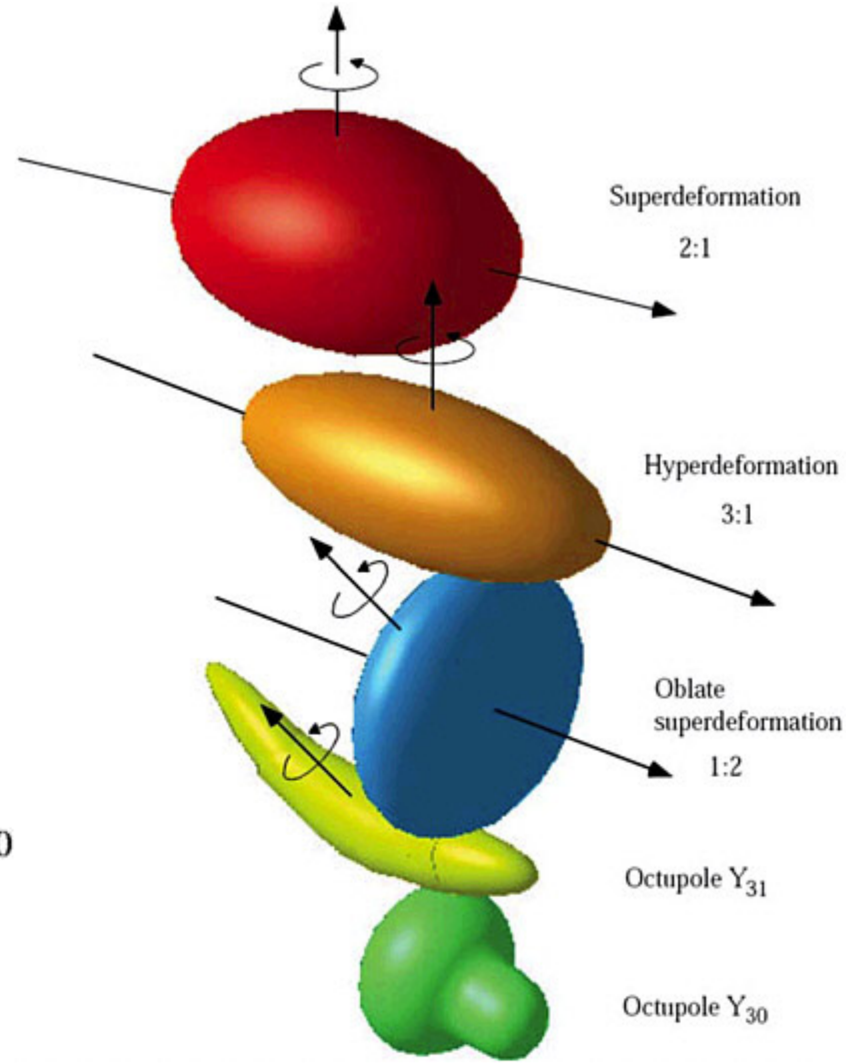
A team of scientists from the US, the UK, and France used Argonne National Lab's CARIBU fission source and ATLAS accelerator to prepare a beam of ^{144}Ba , which they collided with a lead foil to kick the nuclei into excited states. By analyzing the spectrum of gamma rays emitted by the nuclei, the researchers found the strengths of several octupole transitions.

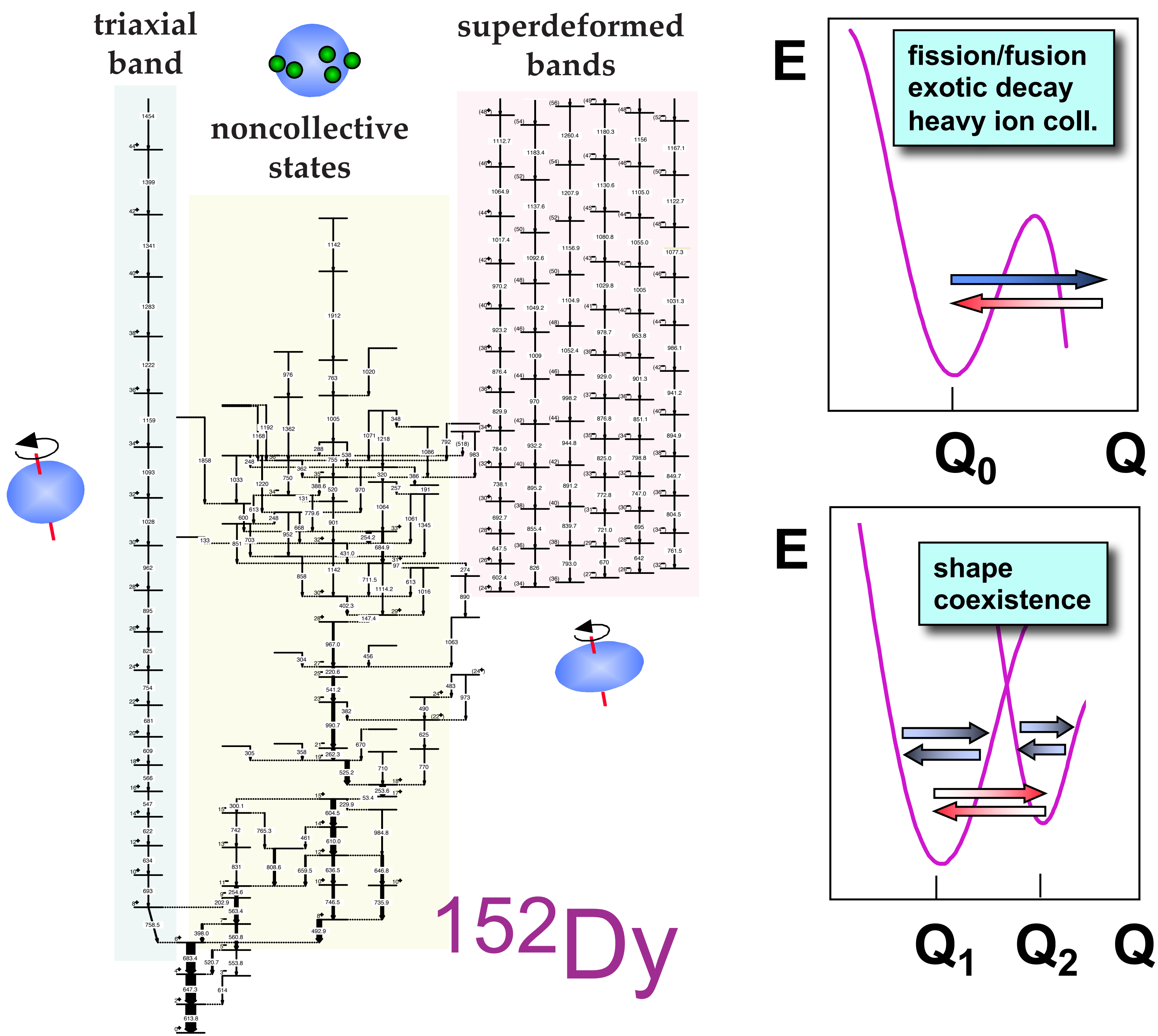


S. Raman et al., Atomic Data & Nuclear Data Tables 78, 1




E(MeV)
J(J+1)
0
10
20
30
40
50
60
0
100
200
300
400
500
600
700


Superdeformation
2:1
Hyperdeformation
3:1
Oblate
superdeformation
1:2
Octupole Y_{31}
Octupole Y_{30}


triaxial band
noncollective states
superdeformed bands
152Dy
E
fission/fusion
exotic decay
heavy ion coll.
Q_0
Q
E
shape coexistence
Q_1
Q_2
Q