Centre for Photonuclear Experiments Data
(http://cdfe.sinp.msu.ru)

Skobeltsyn Institute of Nuclear Physics
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Moscow, Russia

Investigation of quadrupole deformation of nucleus and its surface dynamic vibrations

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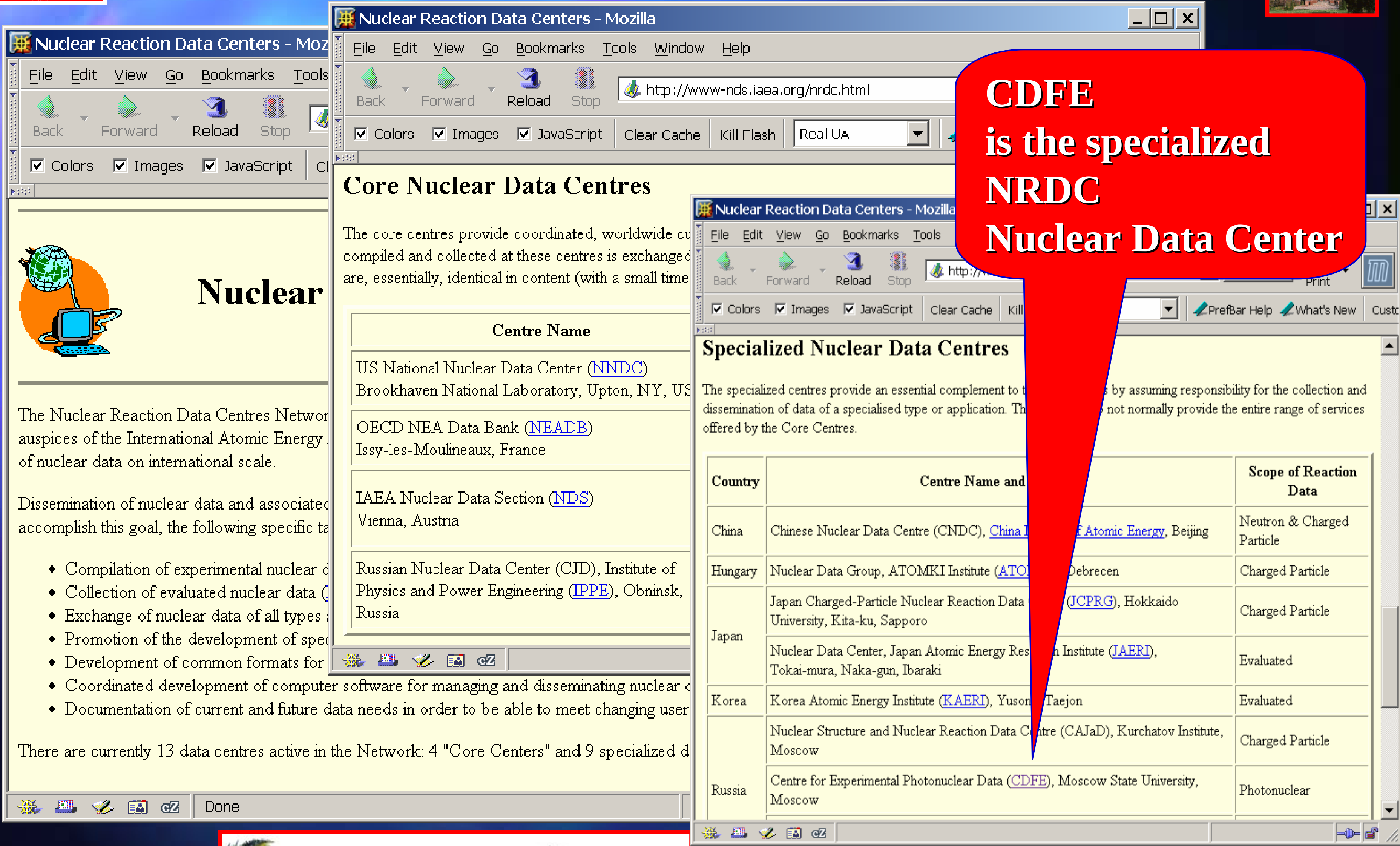
Vadim Orlin, Nikolai Peskov,
Vladimir Varlamov

Nice, France, April 22 - 27



Nuclear

The Nuclear Reaction Data Centres Networ auspices of the International Atomic Energy of nuclear data on international scale.

Dissemination of nuclear data and associated accomplish this goal, the following specific ta

- Compilation of experimental nuclear d
- Collection of evaluated nuclear data (
- Exchange of nuclear data of all types
- Promotion of the development of spec
- Development of common formats for
- Coordinated development of computer software for managing and disseminating nuclear d
- Documentation of current and future data needs in order to be able to meet changing user

There are currently 13 data centres active in the Network: 4 "Core Centers" and 9 specialized d

Core Nuclear Data Centres

The core centres provide coordinated, worldwide cu compiled and collected at these centres is exchanged are, essentially, identical in content (with a small time

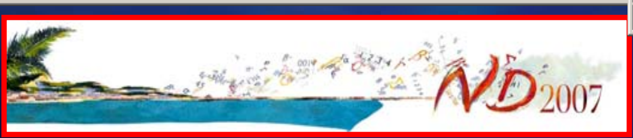
Centre Name
US National Nuclear Data Center (NNDC) Brookhaven National Laboratory, Upton, NY, US
OECD NEA Data Bank (NEADB) Issy-les-Moulineaux, France
IAEA Nuclear Data Section (NDS) Vienna, Austria
Russian Nuclear Data Center (CJD), Institute of Physics and Power Engineering (IPPE), Obninsk, Russia

Specialized Nuclear Data Centres

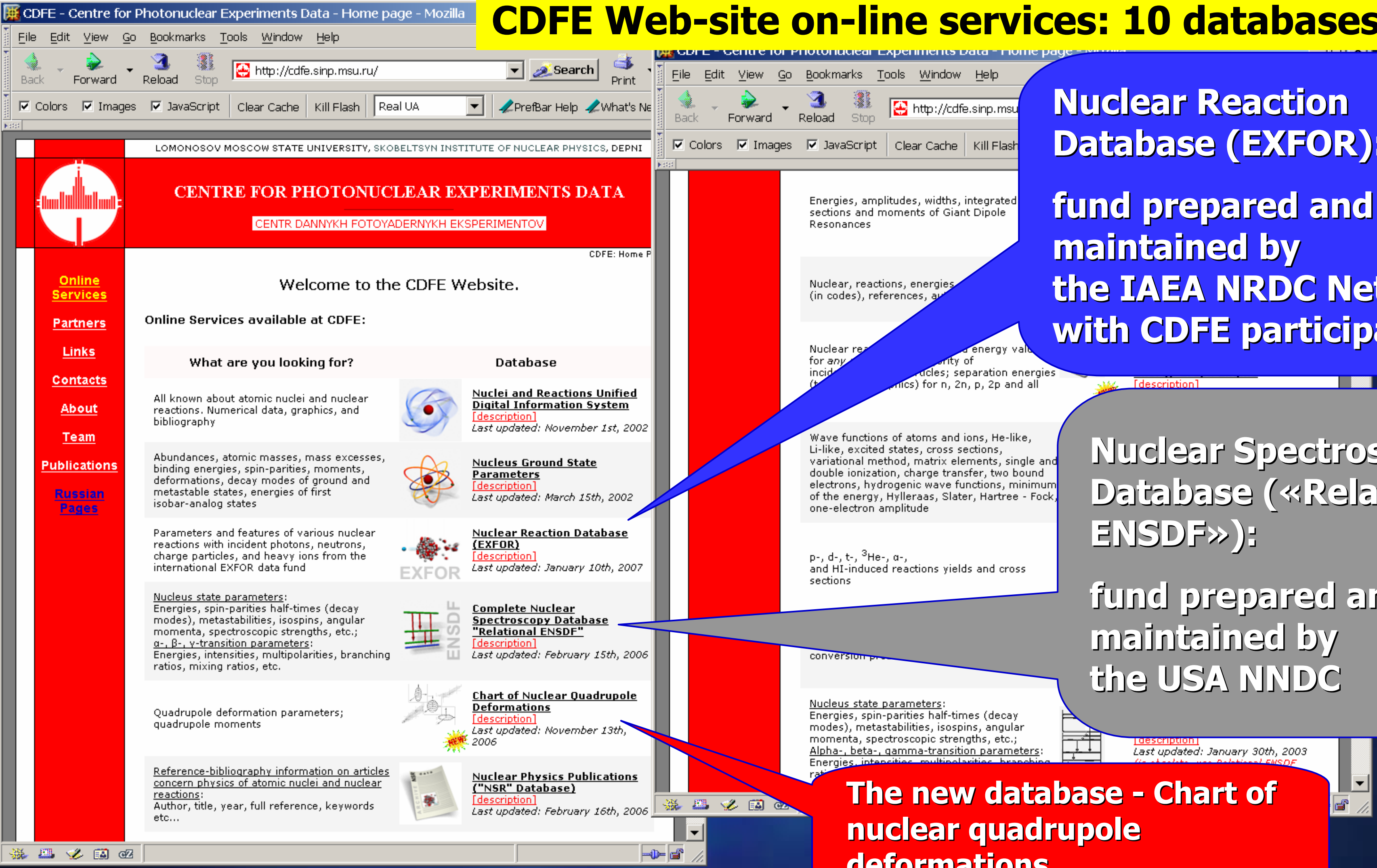
The specialized centres provide an essential complement to t by assuming responsibility for the collection and dissemination of data of a specialised type or application. Th not normally provide the entire range of services offered by the Core Centres.

Country	Centre Name and	Scope of Reaction Data
China	Chinese Nuclear Data Centre (CNDC), China I f Atomic Energy, Beijing	Neutron & Charged Particle
Hungary	Nuclear Data Group, ATOMKI Institute (ATO Debrecen	Charged Particle
Japan	Japan Charged-Particle Nuclear Reaction Data (JCPRG), Hokkaido University, Kita-ku, Sapporo	Charged Particle
	Nuclear Data Center, Japan Atomic Energy Res h Institute (JAERI), Tokai-mura, Naka-gun, Ibaraki	Evaluated
Korea	Korea Atomic Energy Institute (KAERI), Yuson Taejon	Evaluated
Russia	Nuclear Structure and Nuclear Reaction Data Centre (CAJaD), Kurchatov Institute, Moscow	Charged Particle
	Centre for Experimental Photonuclear Data (CDFE), Moscow State University, Moscow	Photonuclear

CDFE
is the specialized
NRDC
Nuclear Data Center



CDFE Web-site on-line services: 10 databases



LOMONOSOV MOSCOW STATE UNIVERSITY, SKOBELTSYN INSTITUTE OF NUCLEAR PHYSICS, DEPNI

CENTRE FOR PHOTONUCLEAR EXPERIMENTS DATA

CENTR DANNYKH FOTOYADERNYKH EKSPERIMENTOV

Welcome to the CDFE Website.

Online Services available at CDFE:

What are you looking for?	Database
All known about atomic nuclei and nuclear reactions. Numerical data, graphics, and bibliography	**Nuclei and Reactions Unified Digital Information System** [description] *Last updated: November 1st, 2002*
Abundances, atomic masses, mass excesses, binding energies, spin-parities, moments, deformations, decay modes of ground and metastable states, energies of first isobar-analog states	**Nucleus Ground State Parameters** [description] *Last updated: March 15th, 2002*
Parameters and features of various nuclear reactions with incident photons, neutrons, charge particles, and heavy ions from the international EXFOR data fund	EXFOR **Nuclear Reaction Database (EXFOR)** [description] *Last updated: January 10th, 2007*
Nucleus state parameters: Energies, spin-parities half-times (decay modes), metastabilities, isospins, angular momenta, spectroscopic strengths, etc.; α-, β-, γ-transition parameters: Energies, intensities, multipolarities, branching ratios, mixing ratios, etc.	ENSDF **Complete Nuclear Spectroscopy Database "Relational ENSDF"** [description] *Last updated: February 15th, 2006*
Quadrupole deformation parameters; quadrupole moments	**Chart of Nuclear Quadrupole Deformations** [description] NEW! *Last updated: November 13th, 2006*
Reference-bibliography information on articles concern physics of atomic nuclei and nuclear reactions: Author, title, year, full reference, keywords etc...	**Nuclear Physics Publications ("NSR" Database)** [description] *Last updated: February 16th, 2006*

Energies, amplitudes, widths, integrated sections and moments of Giant Dipole Resonances

Wave functions of atoms and ions, He-like, Li-like, excited states, cross sections, variational method, matrix elements, single and double ionization, charge transfer, two bound electrons, hydrogenic wave functions, minimum of the energy, Hylleraas, Slater, Hartree - Fock, one-electron amplitude

p-, d-, t-, ^{3}He-, α-,
and HI-induced reactions yields and cross sections

Nucleus state parameters:
Energies, spin-parities half-times (decay modes), metastabilities, isospins, angular momenta, spectroscopic strengths, etc.;
Alpha-, beta-, gamma-transition parameters:

[description]
Last updated: January 30th, 2003

Nuclear Reaction Database (EXFOR):

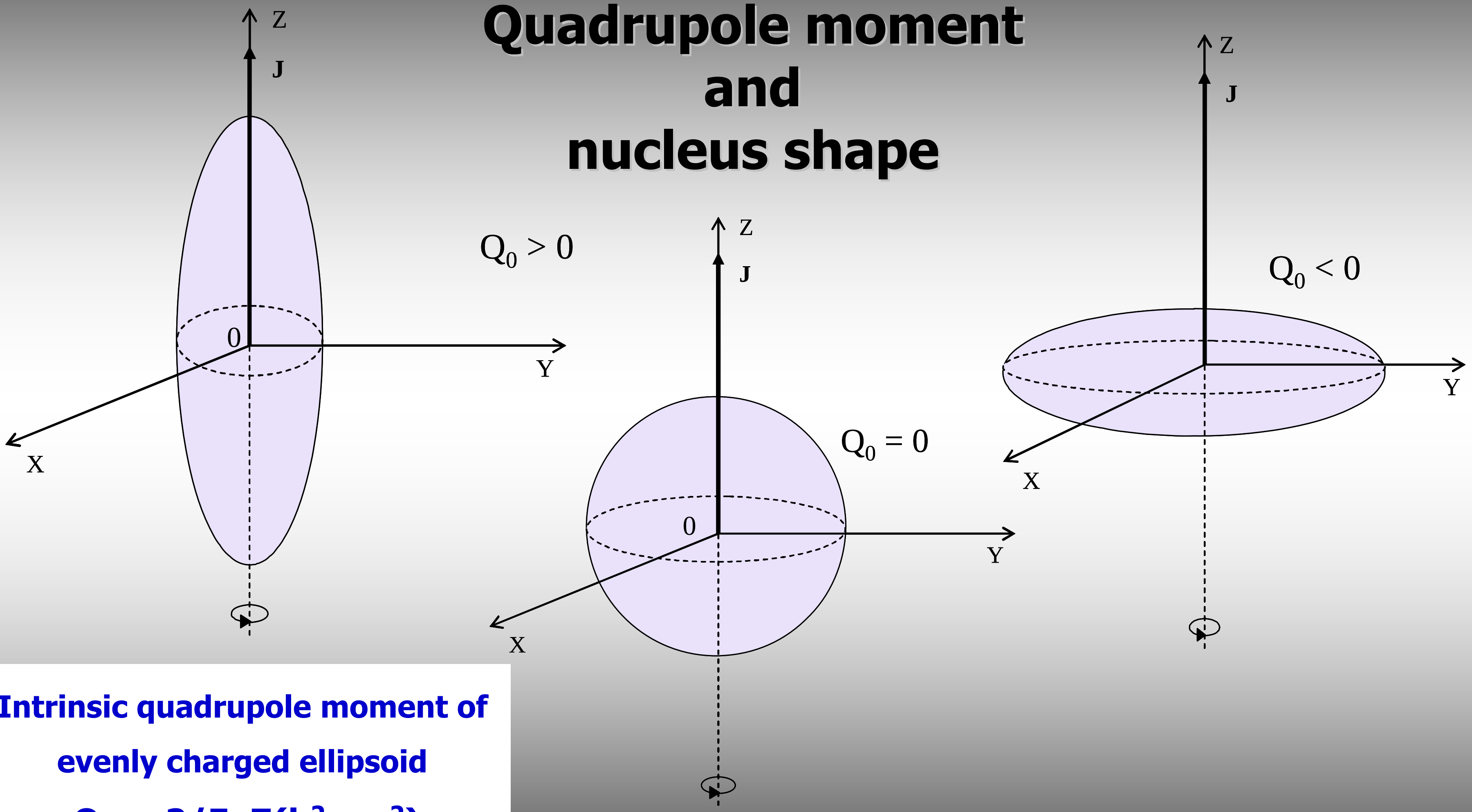
fund prepared and maintained by the IAEA NRDC Network with CDFE participation

Nuclear Spectroscopy Database («Relational ENSDF»):

fund prepared and maintained by the USA NNDC

The new database - Chart of nuclear quadrupole deformations

Quadrupole moment and nucleus shape



Intrinsic quadrupole moment of evenly charged ellipsoid

$$Q_0 = 2/5\ Z(b^2 - a^2)$$

Quadrupole deformation parameter δ from quadrupole moment Q data

Intrinsic quadrupole moment of evenly charged ellipsoid - $Q_0 = 2/5\ Z(b^2 - a^2)$,
where b is large, and a is small ellipsoid axises.

Quadrupole deformation parameter δ
(degree of nucleus shape deviation from sphere) - $\delta = 0.3\ (b^2 - a^2)/2 < r^2 >$.

For $< r^2 > = (b^2 + 2a^2)/5$ and $Q_0 = 4/3\ Z < r^2 > \delta$ - $\delta = 0.75\ Q_0 / (Z \langle r^2 \rangle)$

“Q-type” data.

$$Q_{exp.lab.} = Q_0\ (3K^2 - I(I + 1)) / ((I + 1)(2I + 3)),$$

where I is spin of state, K is I’s projection on symmetry axis.

$\langle r^2 \rangle = 0.6R_0^2(1 + 10/3(\pi a_0/R_0)^2)/(1 + (\pi a_0/R_0)^2)$ $(A \leq 100)$ and/or $\langle r^2 \rangle = 0.6(1.2\ A^{1/3})^2$ $(A > 100)$,
where ($R_0 = 1.07A^{1/3}$ fm и $a_0 = 0.55$ fm) – Woods-Saxon potential radial part parameters.

Quadrupole deformation parameter from reduced transition $0^+ \to 2_1^+$ probability B(E2)↑

$\beta_2 = (4\pi/3\ Z\ R_0^2)[B(E2;\ 0^+ \to 2^+_1)/e^2]^{1/2}$ - "*B*-type" data,

where $B(E2;\ 0^+ \to 2^+_1)$ is reduced transition probability of E2-transition from nucleus ground state into first excited 2^+-state, and $R_0^2 = (1.2\ A^{1/3}\ \text{см})^2$.

$$\delta = 0.75\ Q_0 / (Z\ \langle r^2 \rangle) \approx 0.95\ \beta_2$$

Sources of information on deformation parameter β_2

1. **Quadrupole moments Q:**

N.J.Stone. Table of Nuclear Magnetic Dipole and Electric Quadrupole Moments. Atomic and Nuclear Data Tables. 2005. V. 90. P. 75.

2. **Reduced transition probabilities B(E2)↑:**

S.Raman, C.W.Nestor, P.Tikkanen. Transition Probability from the Ground to the First-Excited 2^+ State of Even-Even Nuclides. Atomic Data and Nuclear Data Tables. 2001. V. 78. P. 1.

3. **Theoretical calculation of β_2 (equilibrium nucleus shape from the conditions of minimization of single-particle energies sum):**

B.S.Ishkhanov, V.N.Orlin. Yadernaya Fizika. 2005. V. 68. P. 1197.

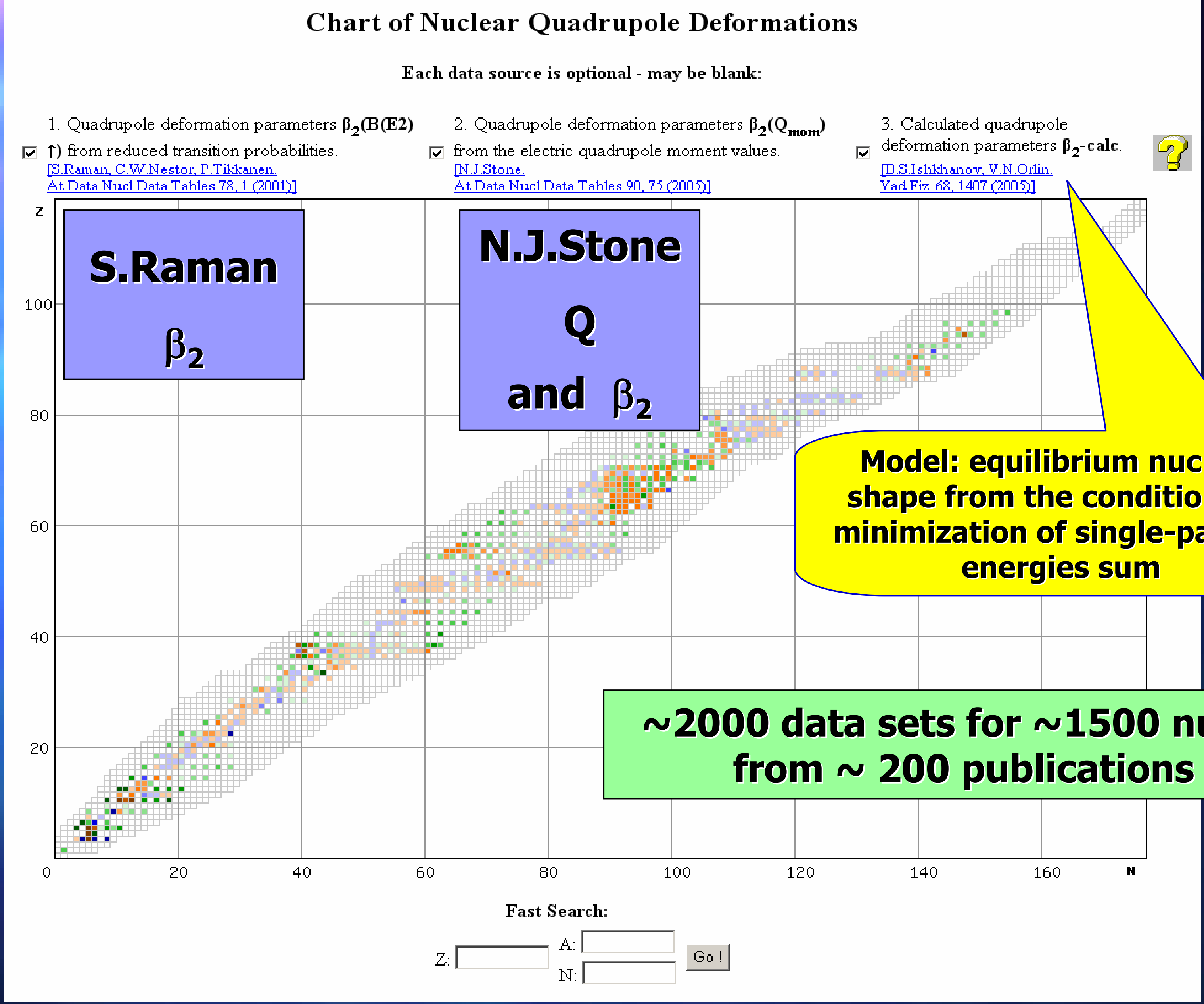


Chart of Nuclear Quadrupole Deformations

Each data source is optional - may be blank:

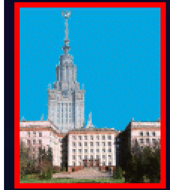
☑ 1. Quadrupole deformation parameters $\beta_2(B(E2)\uparrow)$ from reduced transition probabilities.
[S.Raman, C.W.Nestor, P.Tikkanen.
At.Data Nucl.Data Tables 78, 1 (2001)]

☑ 2. Quadrupole deformation parameters $\beta_2(Q_{mom})$ from the electric quadrupole moment values.
[N.J.Stone.
At.Data Nucl.Data Tables 90, 75 (2005)]

☑ 3. Calculated quadrupole deformation parameters β_2-calc.
[B.S.Ishkhanov, V.N.Orlin.
Yad.Fiz. 68, 1407 (2005)]

Fast Search:

Z: ☐ A: ☐ N: ☐ Go !



S.Raman

β_2

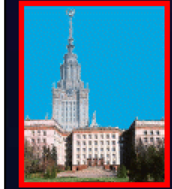
N.J.Stone

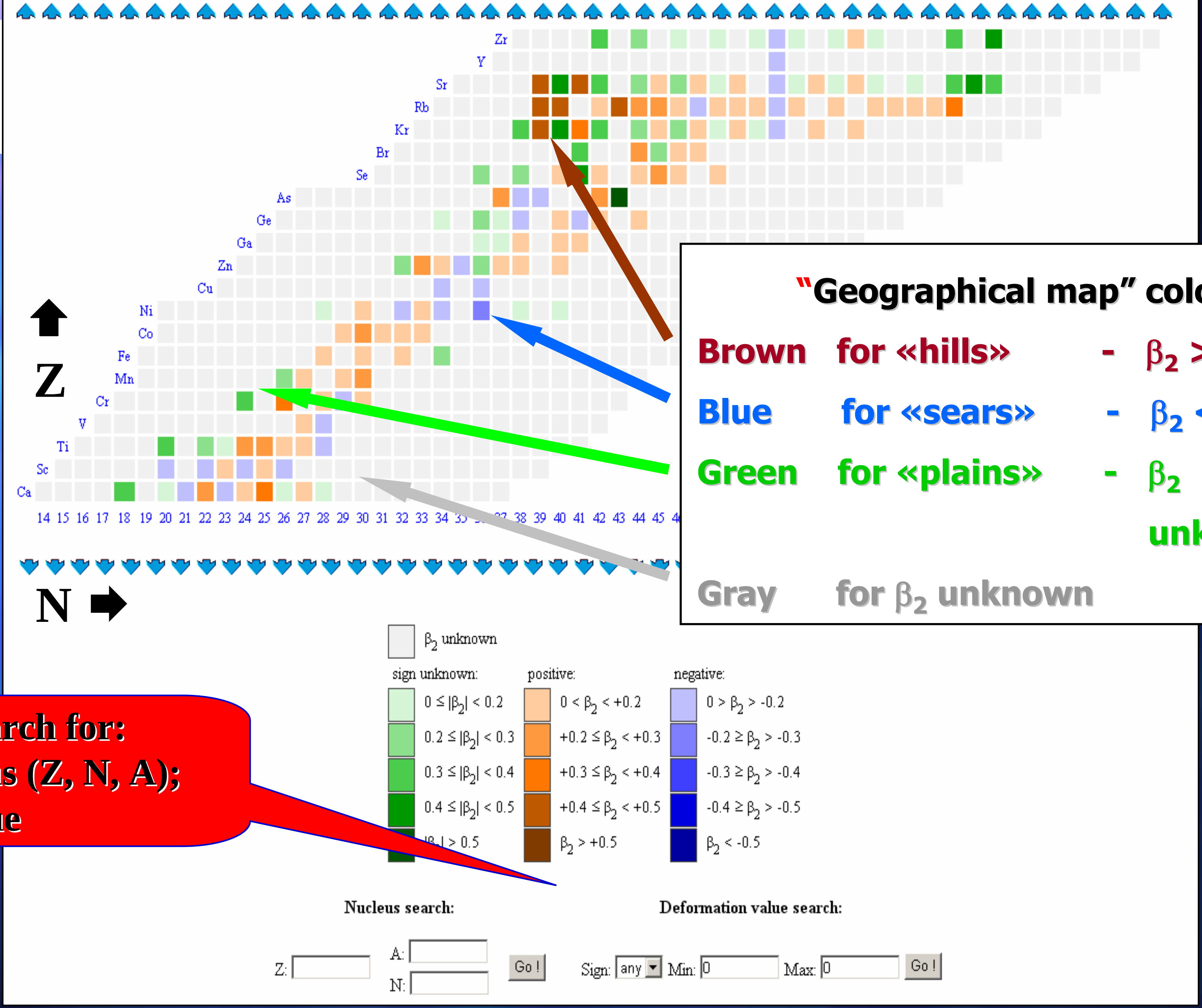
Q

and β_2

Model: equilibrium nucleus shape from the conditions of minimization of single-particle energies sum

~2000 data sets for ~1500 nuclei from ~ 200 publications





⬜ β_2 unknown

sign unknown:	positive:	negative:
🟩 $0 \le \lvert\beta_2\rvert < 0.2$	🟧 $0 < \beta_2 < +0.2$	🟦 $0 > \beta_2 > -0.2$
🟩 $0.2 \le \lvert\beta_2\rvert < 0.3$	🟧 $+0.2 \le \beta_2 < +0.3$	🟦 $-0.2 \ge \beta_2 > -0.3$
🟩 $0.3 \le \lvert\beta_2\rvert < 0.4$	🟧 $+0.3 \le \beta_2 < +0.4$	🟦 $-0.3 \ge \beta_2 > -0.4$
🟩 $0.4 \le \lvert\beta_2\rvert < 0.5$	🟧 $+0.4 \le \beta_2 < +0.5$	🟦 $-0.4 \ge \beta_2 > -0.5$
🟩 $\lvert\beta_2\rvert > 0.5$	🟫 $\beta_2 > +0.5$	🟦 $\beta_2 < -0.5$

Nucleus search:

Z: ☐ A: ☐ N: ☐ Go !

Deformation value search:

Sign: any ▾ Min: 0 Max: 0 Go !

"Geographical map" colours:

Brown for «hills» - $\beta_2 > 0$;

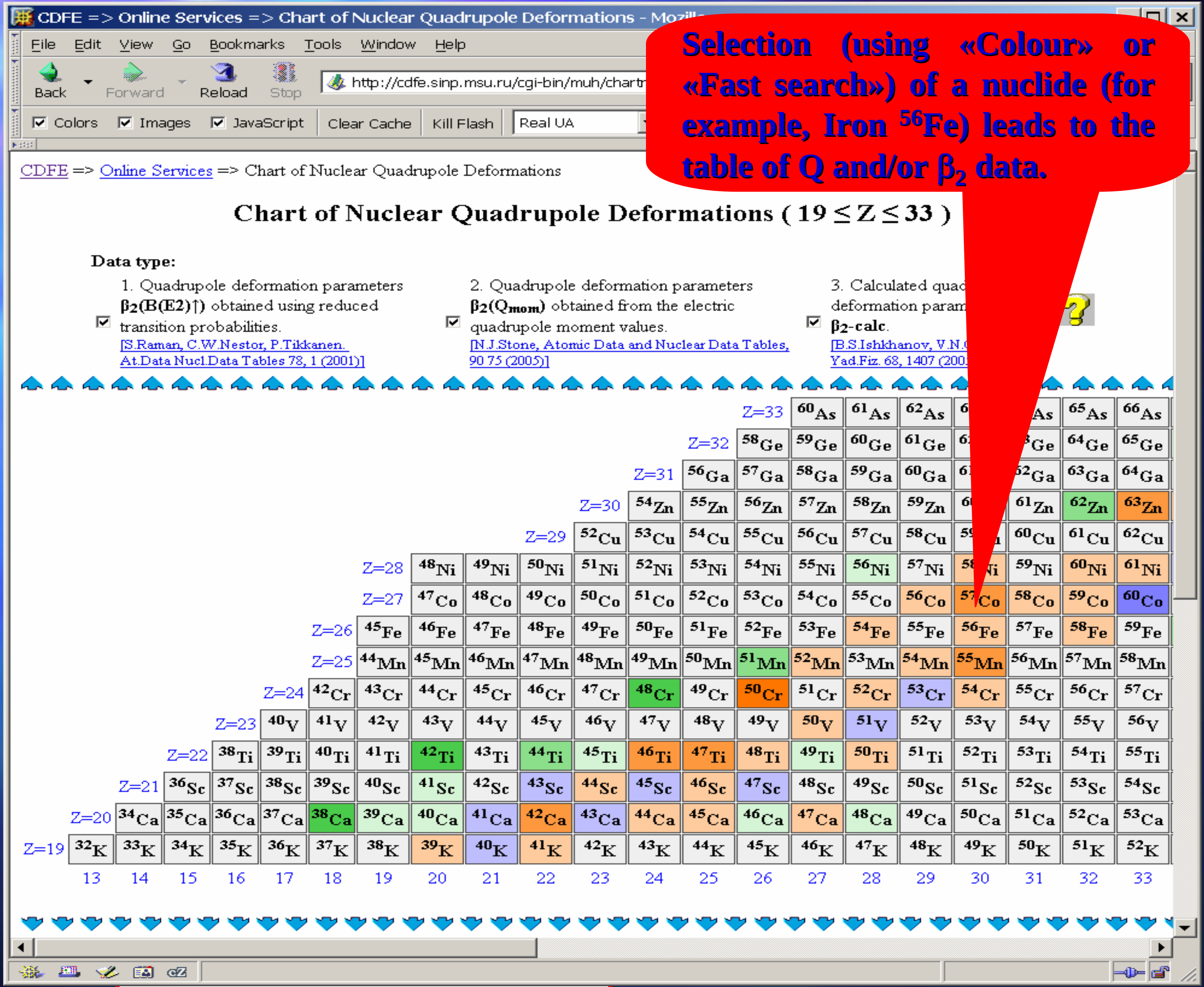
Blue for «sears» - $\beta_2 < 0$;

Green for «plains» - β_2 sign unknown

Gray for β_2 unknown

Fast search for:

- nucleus (Z, N, A);
- β_2 value



CDFE => Online Services => Chart of Nuclear Quadrupole Deformations

Chart of Nuclear Quadrupole Deformations ($19 \le Z \le 33$)

Data type:

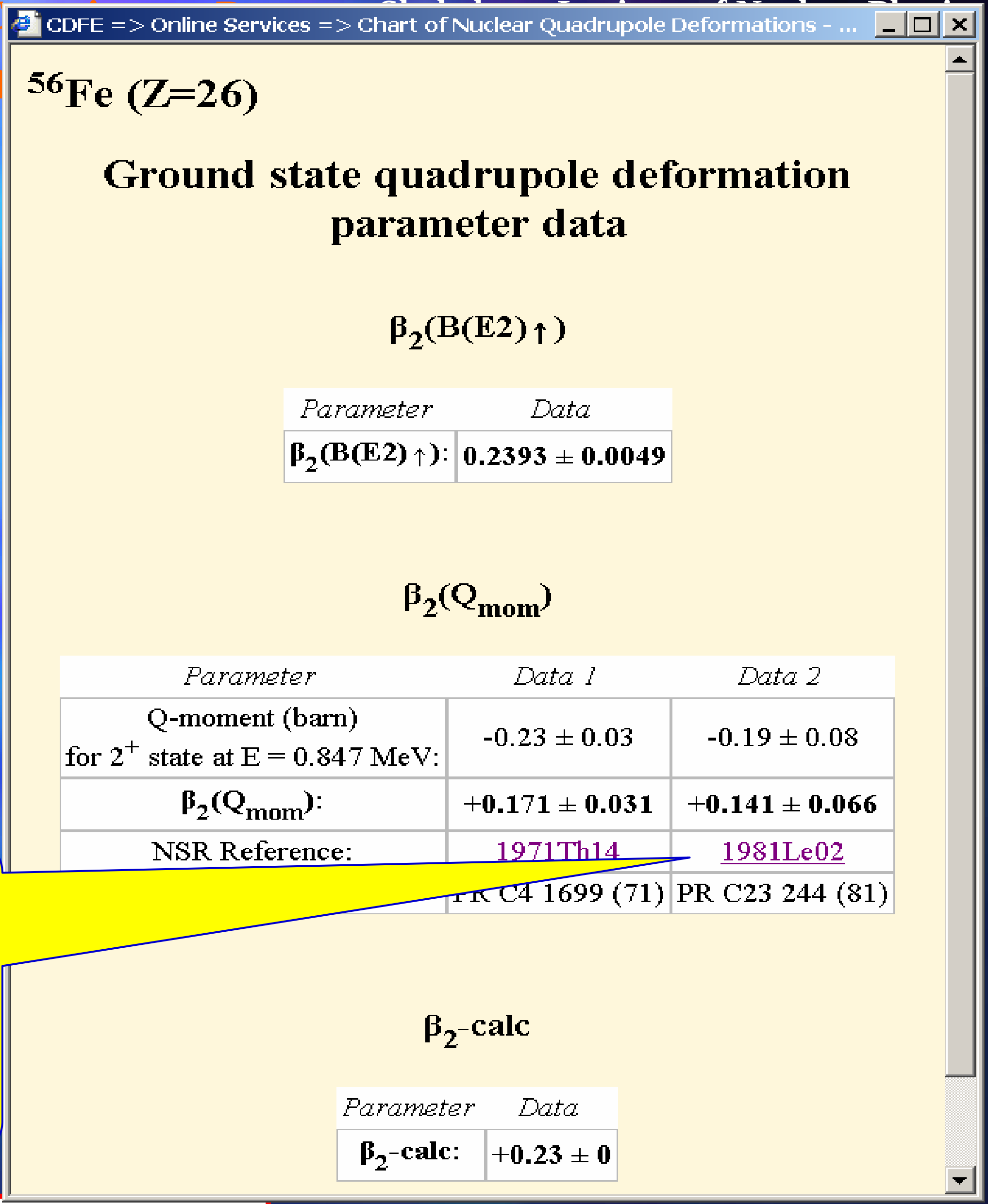
☑ 1. Quadrupole deformation parameters **$\beta_2(B(E2)\uparrow)$** obtained using reduced transition probabilities.
[S.Raman, C.W.Nestor, P.Tikkanen. At.Data Nucl.Data Tables 78, 1 (2001)]

☑ 2. Quadrupole deformation parameters **$\beta_2(Q_{mom})$** obtained from the electric quadrupole moment values.
[N.J.Stone, Atomic Data and Nuclear Data Tables, 90 75 (2005)]

☑ 3. Calculated quac
deformation param
β_2-calc.
[B.S.Ishkhanov, V.N.(
Yad.Fiz. 68, 1407 (200

Z=33															^{60}As	^{61}As	^{62}As	6	As	^{65}As	^{66}As
Z=32														^{58}Ge	^{59}Ge	^{60}Ge	^{61}Ge	6	Ge	^{64}Ge	^{65}Ge
Z=31													^{56}Ga	^{57}Ga	^{58}Ga	^{59}Ga	^{60}Ga	6	^{2}Ga	^{63}Ga	^{64}Ga
Z=30												^{54}Zn	^{55}Zn	^{56}Zn	^{57}Zn	^{58}Zn	^{59}Zn	6	^{61}Zn	^{62}Zn	^{63}Zn
Z=29											^{52}Cu	^{53}Cu	^{54}Cu	^{55}Cu	^{56}Cu	^{57}Cu	^{58}Cu	5	^{60}Cu	^{61}Cu	^{62}Cu
Z=28								^{48}Ni	^{49}Ni	^{50}Ni	^{51}Ni	^{52}Ni	^{53}Ni	^{54}Ni	^{55}Ni	^{56}Ni	^{57}Ni	^{58}Ni	^{59}Ni	^{60}Ni	^{61}Ni
Z=27								^{47}Co	^{48}Co	^{49}Co	^{50}Co	^{51}Co	^{52}Co	^{53}Co	^{54}Co	^{55}Co	^{56}Co	^{57}Co	^{58}Co	^{59}Co	^{60}Co
Z=26							^{45}Fe	^{46}Fe	^{47}Fe	^{48}Fe	^{49}Fe	^{50}Fe	^{51}Fe	^{52}Fe	^{53}Fe	^{54}Fe	^{55}Fe	^{56}Fe	^{57}Fe	^{58}Fe	^{59}Fe
Z=25							^{44}Mn	^{45}Mn	^{46}Mn	^{47}Mn	^{48}Mn	^{49}Mn	^{50}Mn	^{51}Mn	^{52}Mn	^{53}Mn	^{54}Mn	^{55}Mn	^{56}Mn	^{57}Mn	^{58}Mn
Z=24						^{42}Cr	^{43}Cr	^{44}Cr	^{45}Cr	^{46}Cr	^{47}Cr	^{48}Cr	^{49}Cr	^{50}Cr	^{51}Cr	^{52}Cr	^{53}Cr	^{54}Cr	^{55}Cr	^{56}Cr	^{57}Cr
Z=23					^{40}V	^{41}V	^{42}V	^{43}V	^{44}V	^{45}V	^{46}V	^{47}V	^{48}V	^{49}V	^{50}V	^{51}V	^{52}V	^{53}V	^{54}V	^{55}V	^{56}V
Z=22				^{38}Ti	^{39}Ti	^{40}Ti	^{41}Ti	^{42}Ti	^{43}Ti	^{44}Ti	^{45}Ti	^{46}Ti	^{47}Ti	^{48}Ti	^{49}Ti	^{50}Ti	^{51}Ti	^{52}Ti	^{53}Ti	^{54}Ti	^{55}Ti
Z=21			^{36}Sc	^{37}Sc	^{38}Sc	^{39}Sc	^{40}Sc	^{41}Sc	^{42}Sc	^{43}Sc	^{44}Sc	^{45}Sc	^{46}Sc	^{47}Sc	^{48}Sc	^{49}Sc	^{50}Sc	^{51}Sc	^{52}Sc	^{53}Sc	^{54}Sc
Z=20		^{34}Ca	^{35}Ca	^{36}Ca	^{37}Ca	^{38}Ca	^{39}Ca	^{40}Ca	^{41}Ca	^{42}Ca	^{43}Ca	^{44}Ca	^{45}Ca	^{46}Ca	^{47}Ca	^{48}Ca	^{49}Ca	^{50}Ca	^{51}Ca	^{52}Ca	^{53}Ca
Z=19	^{32}K	^{33}K	^{34}K	^{35}K	^{36}K	^{37}K	^{38}K	^{39}K	^{40}K	^{41}K	^{42}K	^{43}K	^{44}K	^{45}K	^{46}K	^{47}K	^{48}K	^{49}K	^{50}K	^{51}K	^{52}K
	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33

Selection (using «Colour» or «Fast search») of a nuclide (for example, Iron ^{56}Fe) leads to the table of Q and/or β_2 data.



^{56}Fe (Z=26)

Ground state quadrupole deformation parameter data

$\beta_2(B(E2)\uparrow)$

Parameter	*Data*
$\beta_2(B(E2)\uparrow)$:	**0.2393 ± 0.0049**

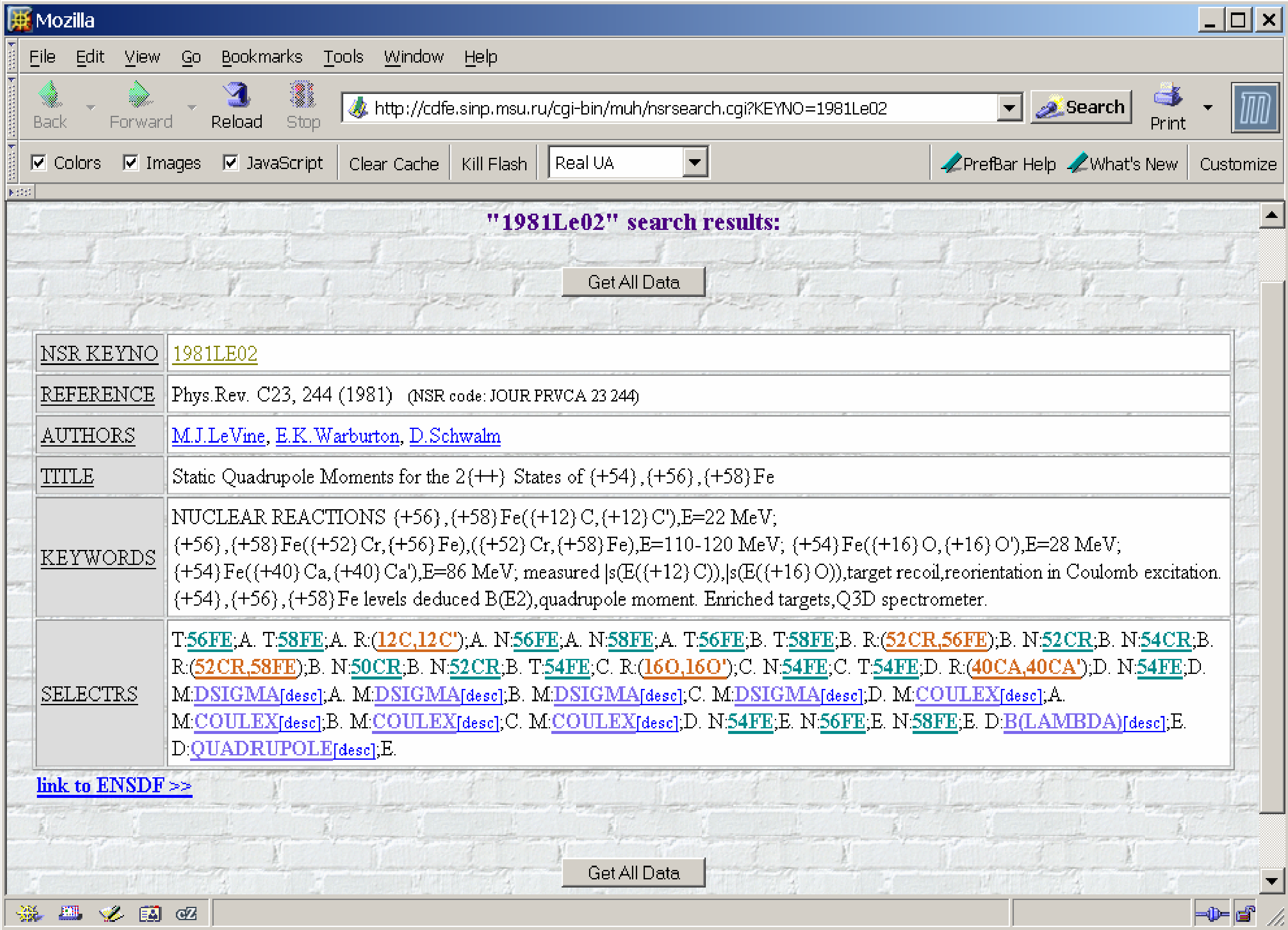
$\beta_2(Q_{mom})$

Parameter	*Data 1*	*Data 2*
Q-moment (barn) for 2^+ state at E = 0.847 MeV:	-0.23 ± 0.03	-0.19 ± 0.08
$\beta_2(Q_{mom})$:	**+0.171 ± 0.031**	**+0.141 ± 0.066**
NSR Reference:	1971Th14	1981Le02
	PR C4 1699 (71)	PR C23 244 (81)

β_2-calc

Parameter	*Data*
β_2-calc:	**+0.23 ± 0**

Selection of reference code leads to the correspondent data set of anothe database - «Nuclear Science Reference» and throuh it to other main CDFE databases. Fund is prepared and maintained by the USA NNDC.



http://cdfe.sinp.msu.ru/cgi-bin/muh/nsrsearch.cgi?KEYNO=1981Le02

"1981Le02" search results:

NSR KEYNO	1981LE02
REFERENCE	Phys.Rev. C23, 244 (1981) (NSR code: JOUR PRVCA 23 244)
AUTHORS	M.J.LeVine, E.K.Warburton, D.Schwalm
TITLE	Static Quadrupole Moments for the 2{++} States of {+54},{+56},{+58}Fe
KEYWORDS	NUCLEAR REACTIONS {+56},{+58}Fe({+12}C,{+12}C'),E=22 MeV; {+56},{+58}Fe({+52}Cr,{+56}Fe),({+52}Cr,{+58}Fe),E=110-120 MeV; {+54}Fe({+16}O,{+16}O'),E=28 MeV; {+54}Fe({+40}Ca,{+40}Ca'),E=86 MeV; measured |s(E({+12}C)),|s(E({+16}O)),target recoil,reorientation in Coulomb excitation. {+54},{+56},{+58}Fe levels deduced B(E2),quadrupole moment. Enriched targets,Q3D spectrometer.
SELECTRS	T:56FE;A. T:58FE;A. R:(12C,12C');A. N:56FE;A. N:58FE;A. T:56FE;B. T:58FE;B. R:(52CR,56FE);B. N:52CR;B. N:54CR;B. R:(52CR,58FE);B. N:50CR;B. N:52CR;B. T:54FE;C. R:(16O,16O');C. N:54FE;C. T:54FE;D. R:(40CA,40CA');D. N:54FE;D. M:DSIGMA[desc];A. M:DSIGMA[desc];B. M:DSIGMA[desc];C. M:DSIGMA[desc];D. M:COULEX[desc];A. M:COULEX[desc];B. M:COULEX[desc];C. M:COULEX[desc];D. N:54FE;E. N:56FE;E. N:58FE;E. D:B(LAMBDA)[desc];E. D:QUADRUPOLE[desc];E.

link to ENSDF >>

Investigation of deformation parameter data $|\beta_2|$, obtained from

1) quadrupole moments - "*Q*-type" data

2) reduced transition probability data - "*B*-type" data.

All nuclei studied are quite clearly separated into two groups:

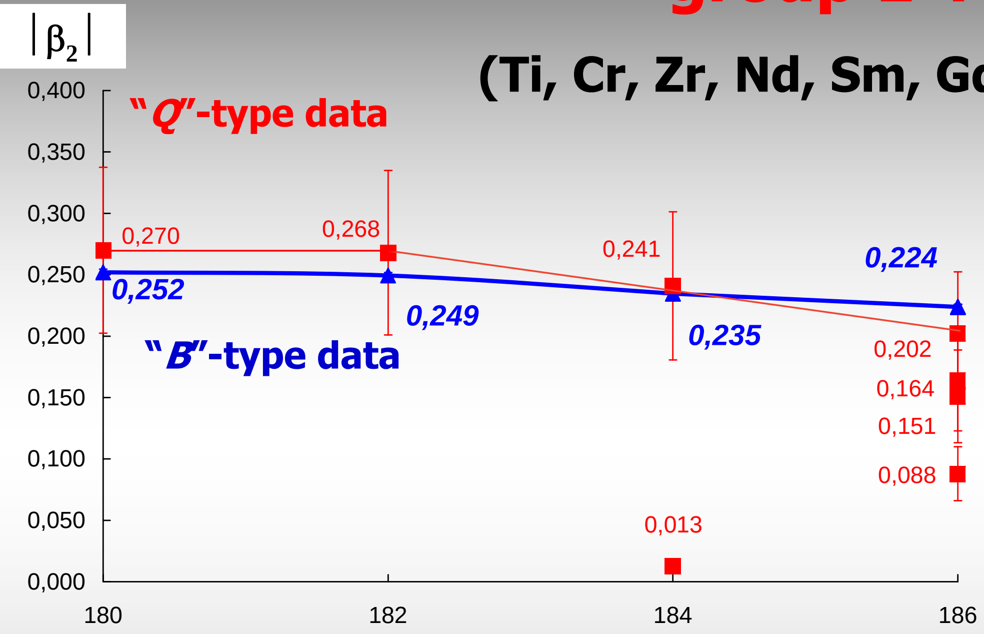
"group 1": "*B*-type" data have the same order values as "*Q*-type" ones
(Ti, Cr, Zr, Nd, Sm, Gd, Dy, Er, W, Os, Ra).

"group 2": "*B*-type" data are (~ evidently) larger than "*Q*-type" data
(C, Si, Ar, Ca, Fe, Ni, Zn, Ge, Se, Kr, Sr, Mo, Ru, Pd, Cd, Sn, Te, Ba, Yb, Hf, Pt, Pb).

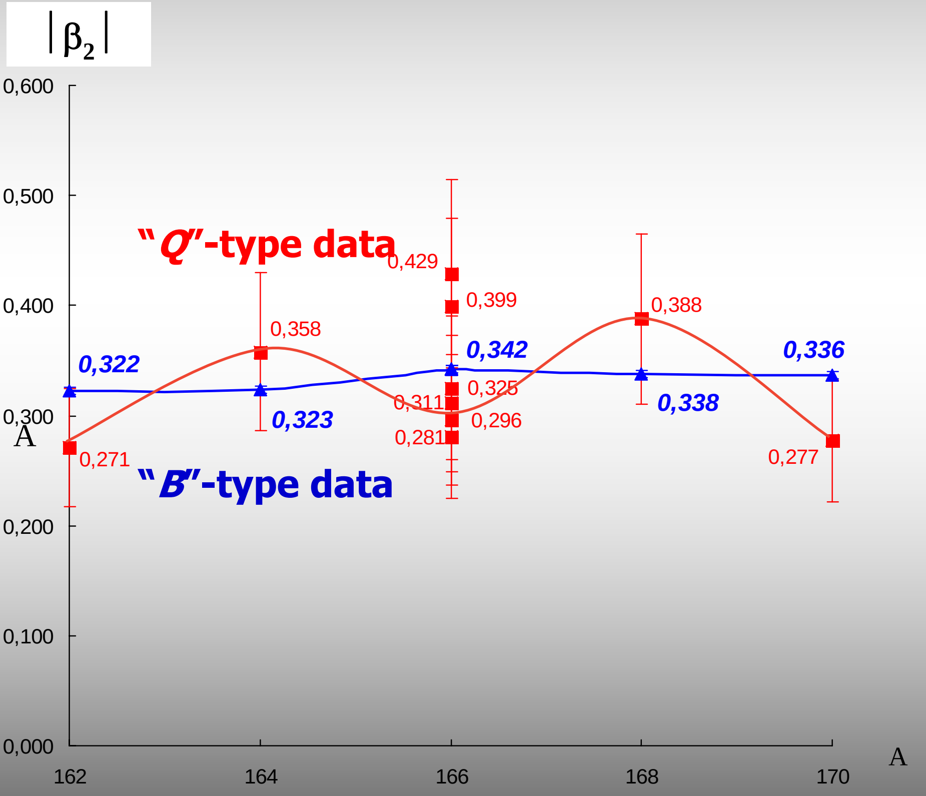
Only few exceptions (Mg, Xe, Hg, U - conditionally "group 3"):
data for some isotopes look as those for "group 1" and for other - as for "group 2".

"group 1": "Q" ≈ "B"

(Ti, Cr, Zr, Nd, Sm, Gd, Dy, Er, W, Os, Ra)



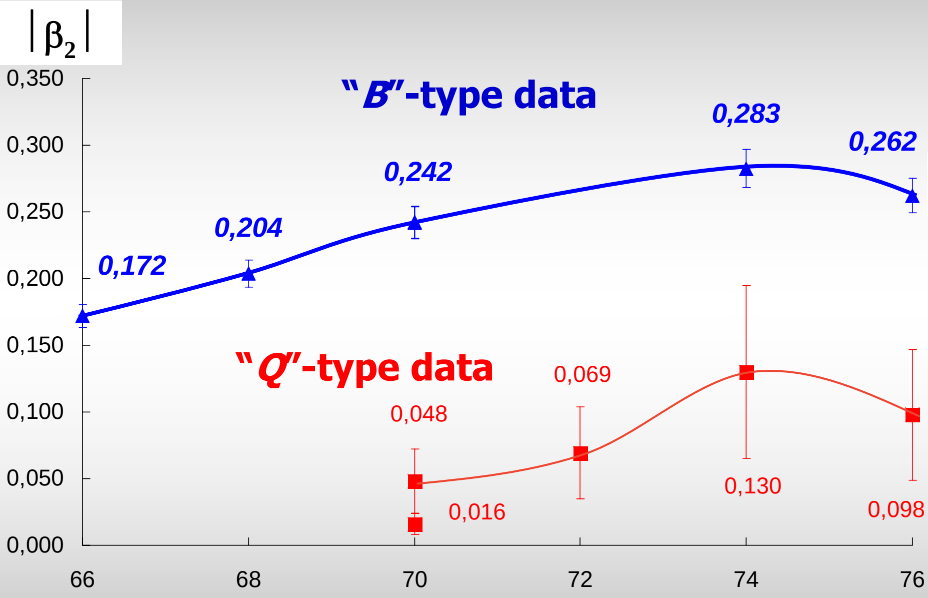
W isotopes



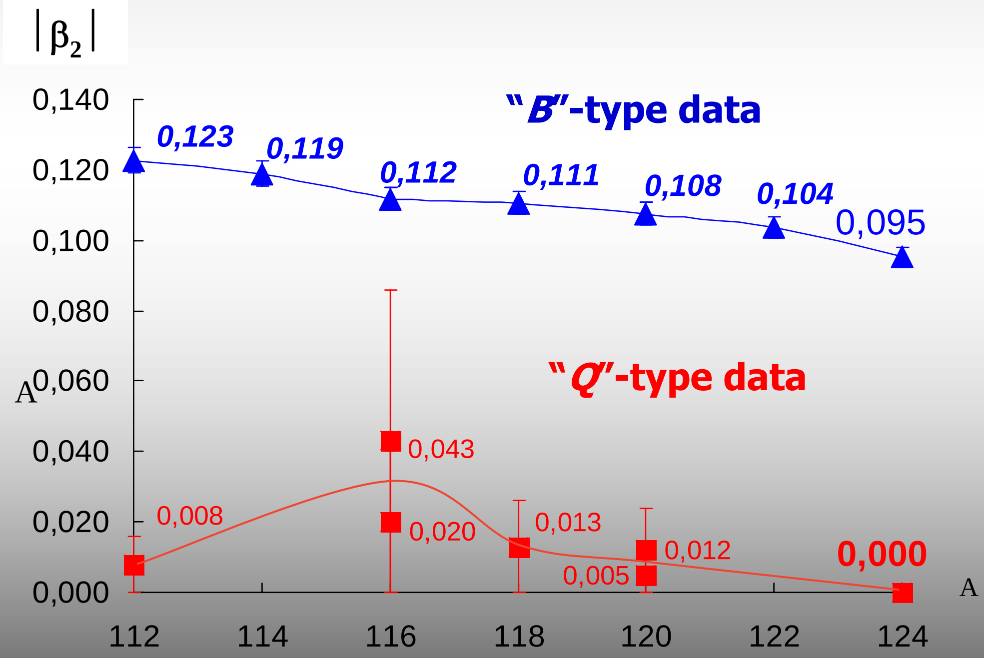
Er isotopes

“group 2”: “B” > (>>) “Q”

(C, Si, Ar, Ca, Fe, Ni, Zn, Ge, Se, Kr, Sr, Mo, Ru, Pd, Cd, Sn, Te, Ba, Yb, Hf, Pt, Pb)



Ge isotopes

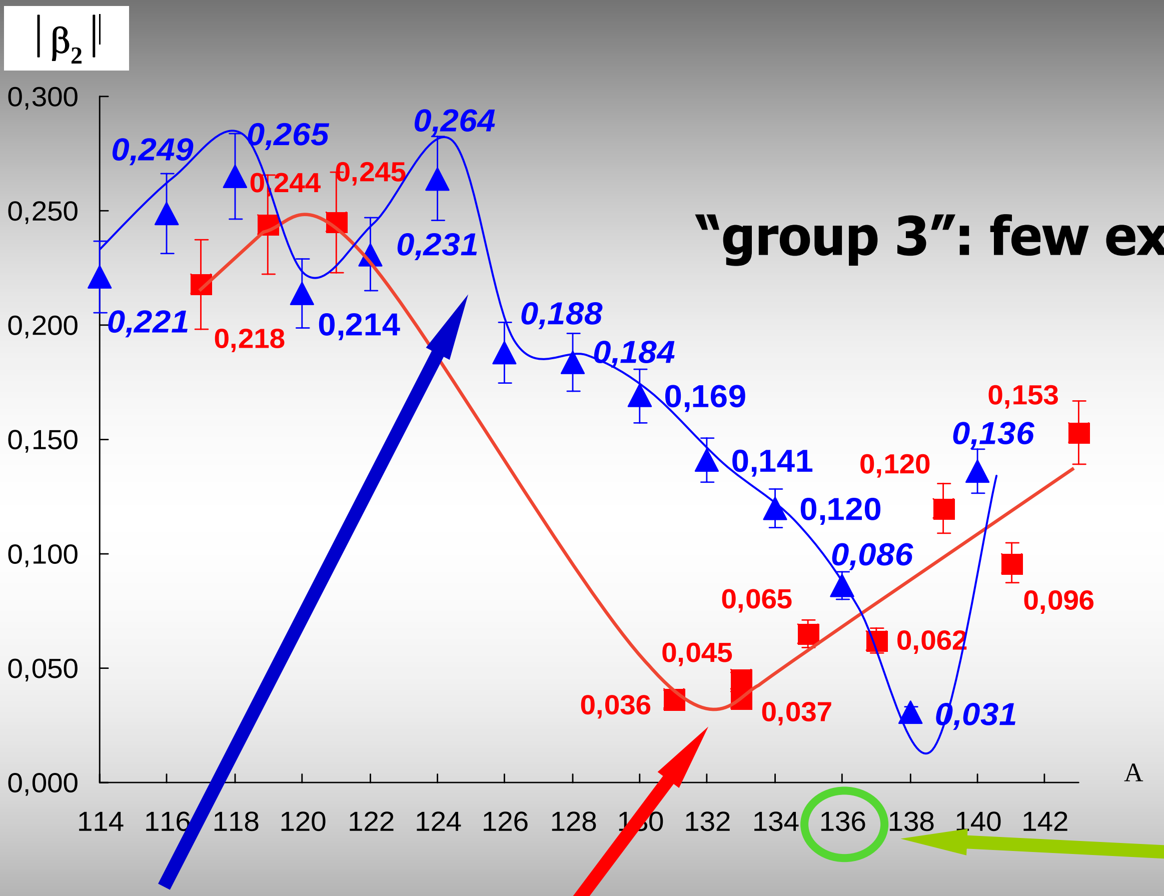


Sn isotopes

“group 3”: few exceptions

Xe isotopes

(Mg, Xe, Hg, U)



“*Q*”-type data

Magic nucleus

“*B*”-type data are larger than “*Q*” for isotopes (A = 116, 118,124 - 136, …)

“*Q*”-type data are larger than “*B*” for isotopes (A = 119, 121, 137 - 139,…)

The difference between absolute value $|\beta_2|$ data derived from Q and B(E2)↑ values can be explained in the fame of assumption about the connection of quadrupole deformation parameter with vibration of surface of nucleus in ground state.

This assumption means that “Q-type” data do not take into account such nucleus surface vibrations, but “B-type” data do that.
In other words: “B-type” data are affected not only by static nucleus deformation depended on its shape, but also by dynamical nucleus deformation that came from its surface vibration.

Rotating nucleus model:

nucleus is rigid, it has static deformation, its excitation is produced by its rotation. Probability of transition between any states of rotation band is

$$B(E2;\ KJ_1 \rightarrow KJ_2) = (5/16\pi)e^2Q_0^2\langle J_1K20|J_2K\rangle^2,$$

where J is state spin, K is spin proection to the axis of symmetry, Q_0 is intrinsic nucleus quadrupole moment, $\langle J_1K20|J_2K\rangle$ is vectror summation coefficient.

Partially, for E2 transition $0^+ \rightarrow 2^+$:

$$B(E2;\ 0^+ \rightarrow 2^+) = ((3/4\pi)eZR_0^2)^2(\beta_2)^2,$$

and correspondingly:

$$\beta_2 = (4\pi/3\,Z\,R_0^2)[B(E2;\ 0^+ \rightarrow 2_1^+)/e^2]^{1/2}$$

- "*B*"-type data

Vibrating nucleus model:

nucleus is not rigid,
its surface vibrates,
amplitude depends on
1) excitation state energy and
2) nucleus rigidity (toughness).

For harmonic oscillator with spheric equilibrium shape the average amplitude of nucleus shape difference from spherical one in ground state is

$$\langle 0|\alpha_{2\mu}|0\rangle = 0,$$

squared deformation is

$$\beta_0^2 = \langle\Sigma|\alpha_{2\mu}|^2\rangle = \frac{\hbar}{2B_2\omega_2}(5+2N) \neq 0 \text{ for } N = 0,$$

where B_2 is mass coefficient, ω_2 is vibration frequency and N is phonon number.

$$B(E2;\ n_2 = 0 \rightarrow n_2 = 1) = ((3/4\pi)eZR_0^2)^2(\beta_0)^2.$$

β_0 can be interpreted as «dynamic deformation».

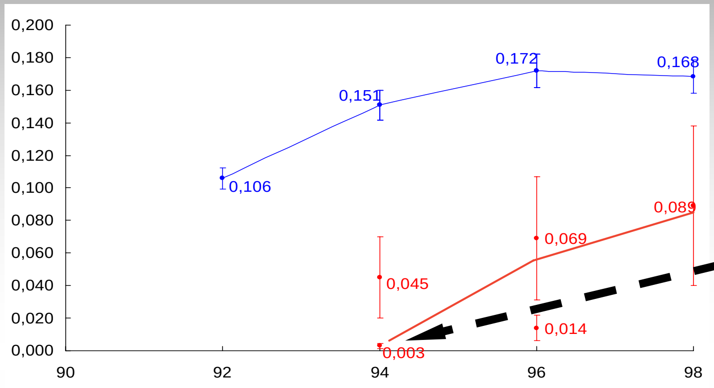
The possible physical explanation:

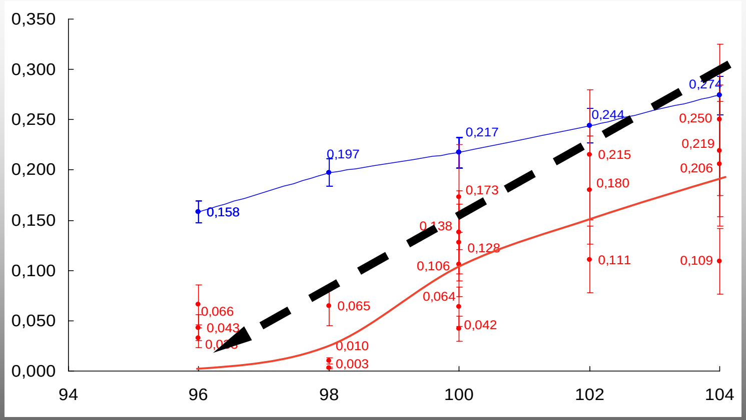
- For “group 1” (“B-type” ≈ “Q-type” data) the 2^{+}_{1}-level excitation is pure rotational, vibrations of nucleus in ground state (“zero vibrations”) are weak and the nucleus shape can be treated as static;

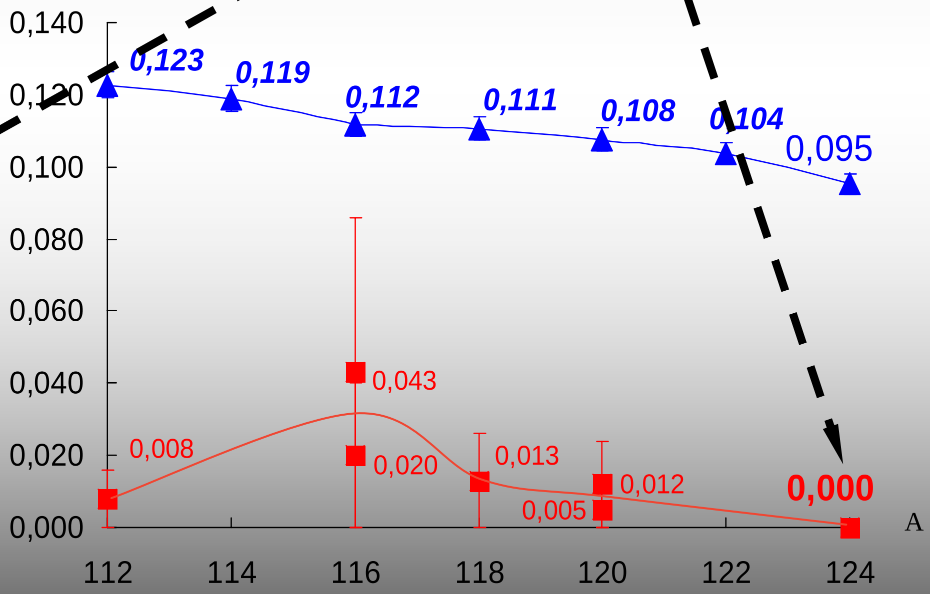
- For “group 2” (“B-type” data >> “Q-type” ones) “zero vibrations” play important role – there are the superposition of static and dynamical deformations which leads to effective increasing of nucleus deformation.

The rotating nucleus model can not be employed. But because the formulae connected β_2 and B(E2)↑ are formally the same in rotating and vibrating nucleus models it can be supposed that the “B-type” parameter of deformation is reflecting the effective increasing of nucleus deformation: nucleus can be treated as « trembled ».

Several isotopes were founded out for which "Q-type" parameter of deformation has value is ≈ 0, but "B-type" one is enough large – for example, ^{16}O, ^{40}Ca, ^{94}Mo, ^{96}Ru, ^{124}Sn, ^{144}Nd.







For isotopes for which $(\beta_2)_Q \approx 0$ the vibrating nucleus model in pure version can be applied and therefore C_2, spherical nucleus surface rigidity parameter, could be calculated:

$$(\beta_2)_B{}^2 = 5\hbar/(2B_2\omega_2), \qquad \hbar\omega_2 = E_{2_1^+} = \hbar\sqrt{C_2/B_2}$$

For some other nuclei with having static deformation but relatively weak α- and γ-vibrations rotational lines could be looked through and correspondingly deformed nucleus rigidity parameters $C_{2\beta}$, $C_{2\gamma}$, and vibration amplitudes a_β, a_γ could be calculated (if correspondent formulae could work)

$$\hbar\omega_\beta = E_{0_1^+} = \hbar\sqrt{C_{2\beta}/B_2} \qquad \hbar\omega_\gamma = E_{2_1^+} = \hbar\sqrt{C_{2\gamma}/B_2}$$

$$E_{2_1^+} = \hbar^2 J(J+1)/(6B_2\beta_2^2)\,|_{J=2} = \hbar^2/(B_2\beta_2^2) \qquad a^2_{\beta,\gamma} = \hbar/(2B_2\omega_{\beta,\gamma})$$

Nucleus	$(\beta_2)_B$	$(\beta_2)_Q$	C_2, MeV	$C_{2\beta}$, MeV	$C_{2\gamma}$, MeV	a_β	a_γ
^{16}O	**0.36**	**≈ 0.0**	**132**	—	—	—	—
^{18}O	0.36	0.09	39	—	—	—	—
^{22}Ne	0.56	0.59	—	?	49	?	0.21
^{24}Mg	0.61	0.44	—	82	36	0.20	0.24
^{28}Si	0.41	0.35	—	84	185	0.17	0.14
^{30}Si	0.32	0.09	56	—	—	—	—
^{40}Ca	***0.12***	***≈ 0.0***	***655***	—	—	—	—
^{42}Ca	***0.25***	***0.21***	—	***37***	***63***	***0.16***	***0.14***
^{50}Cr	0.29	0.31	—	?	127	?	0.11
^{52}Cr	0.22	0.07	71	—	—	—	—
^{102}Ru	0.22	0.13	—	—	—	—	—
^{124}Sn	**0.09**	**≈ 0.0**	**293**				
^{144}Nd	**0.13**	**≈ 0.0**	**102**	—	—	—	—
^{150}Nd	0.29	0.35	—	43	69	0.09	0.08
^{154}Sm	0.34	0.32	—	13	15	0.21	0.20
^{160}Gd	0.35	0.33	—	?	10	?	0.22
^{168}Er	0.34	0.34	—	16	7	0.19	0.24
^{178}Hf	0.28	0.27	—	20	19	0.17	0.18
^{182}W	0.25	0.27	—	210	240	0.05	0.05
^{186}Os	0.20	0.20	—	205	107	0.05	0.06

Rigid (C_2 - large) nuclei with zero static deformation $(\beta_2)_Q \approx 0$ and large dynamic deformation $(\beta_2)_B \neq 0$ - surface is trembling («zero vibrations»)

Nucleus	$(\beta_2)_B$	$(\beta_2)_Q$	C_2, MeV	$C_{2\beta}$, MeV	$C_{2\gamma}$, MeV	a_β	a_γ
^{16}O	0.36	≈ 0.0	**132**	—	—	—	—
^{18}O	0.36	0.09	39	—	—	—	—
^{22}Ne	0.56	0.59	—	?	49	?	0.21
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^{30}Si	0.32	0.09	56	—	—	—	—
^{40}Ca	***0.12***	***≈ 0.0***	***655***	—	—	—	—
^{42}Ca	***0.25***	***0.21***	—	***37***	***63***	***0.16***	***0.14***
^{50}Cr	0.29	0.31	—	?	127	?	0.11
^{52}Cr	0.22	0.07	71				—
^{102}Ru	0.22	0.13	—				
^{124}Sn	0.09	≈ 0.0	**2**				
^{144}Nd	0.13	≈ 0.0	**1**				
^{150}Nd	0.29	0.35	—				
^{154}Sm	0.34	0.32	—				
^{160}Gd	0.35	0.33	—				
^{168}Er	0.34	0.34	—				
^{178}Hf	0.28	0.27	—				
^{182}W	0.25	0.27	—				
^{186}Os	0.20	0.20	—				

^{40}Ca (double magic spherical nucleus) is very rigid (C_2 is large) but nevertheless its surface vibrates: clear dynamic deformation. Therefore it could be treated as "trembling" in ground state.

^{42}Ca is deformed and soft (both C_2 are small) nucleus, but its surface does not vibrate and therefore its deformation is clear "static".

Rigid (C_2 - large) nuclei with zero static deformation $(\beta_2)_Q \approx 0$ and large dynamic deformation $(\beta_2)_B \neq 0$ - surface is trembling («zero vibrations»)

Short summary:

- **For all isotopes of many nuclei both-type $|\beta_2|$ data are of the same value; those nuclei could be spherical and deformed; their surfaces do not vibrate;**
- **For all isotopes of many nuclei “B-type” $|\beta_2|$ data have values larger (in some cases significantly (factor ~ 1.5 – 2.0)) than “Q-type” data; the surfaces of such nuclei in ground states vibrate and nuclei have clear dynamic deformation and could be treated as “trembling”;**
- **There are only few nuclei for which the intermediate situation is observed;**
- **There are absolutely no nuclei for which “Q-type” data are larger than “B-type” ones.**

Investigation of quadrupole deformation of nucleus and its surface dynamic vibrations

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Thanks!

That’s all!

Thanks for your attention!