I.N.Boboshin, V.V.Varlamov, B.S.Ishkhanov, and E.A.Romanovsky

NEW DOUBLE MAGIC NUCLEUS ^{96}Zr AND CONDITIONS FOR EXISTENCE OF NEW MAGIC NUCLEI

- ***What does it mean - ^{96}Zr is «double magic nucleus»?***
- ***Why numbers N = 56 and Z = 40 can be treated as pair of magic ones?***
- ***What is known about shell structure of «new» magic nuclei?***
- ***Are there other «new» magic nuclei?***

MSU SINP CENTRE FOR PHOTONUCLEAR EXPERIMENTS DATA

MSU SINP CDFE Web-site

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CENTRE FOR PHOTONUCLEAR EXPERIMENTS DATA

CENTR DANNYKH FOTOYADERNYKH EKSPERIMENTOV

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- Publications
- Russian Pages

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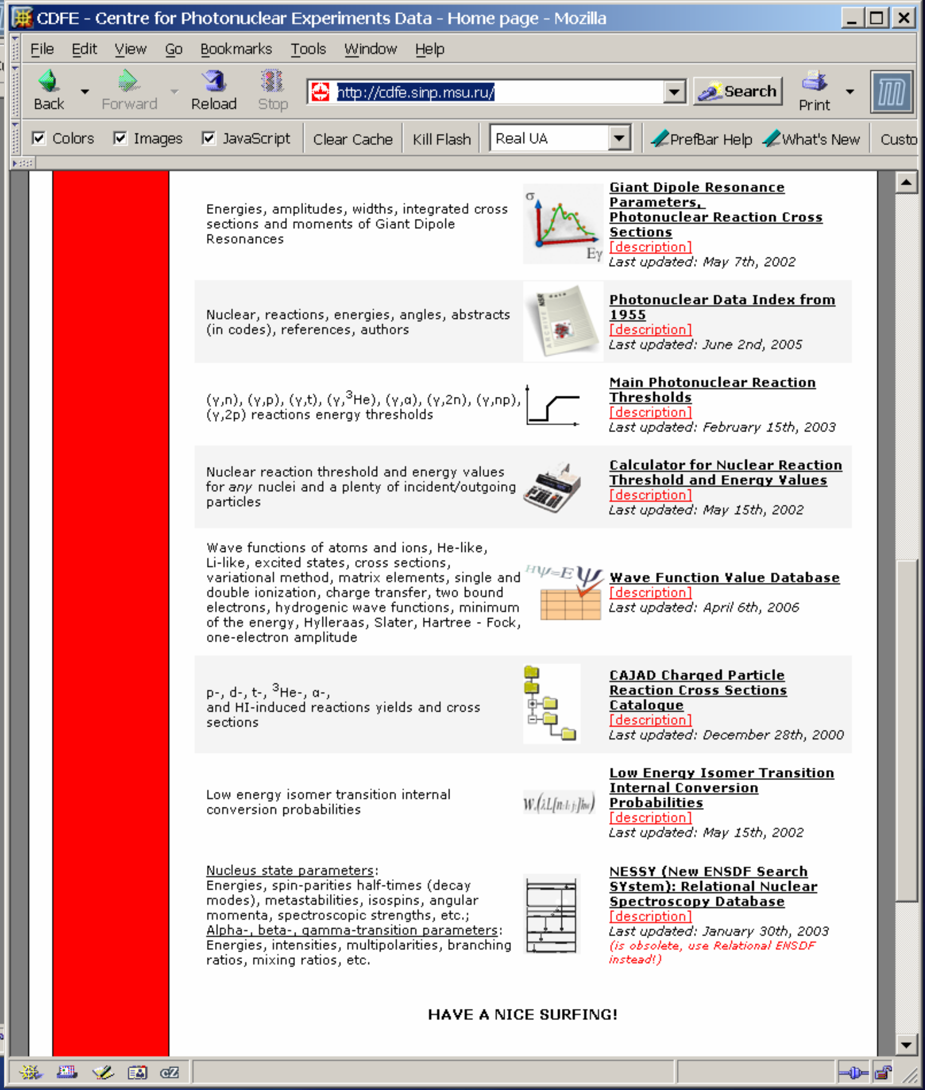
Online Services available at CDFE:

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	**Nuclear Reaction Database (EXFOR)** [description] *Last updated: March 31th, 2006*
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.	**Complete Nuclear Spectroscopy Database "Relational ENSDF"** [description] *Last updated: February 15th, 2006*
Quadrupole deformation parameters; quadrupole moments	**Chart of Nuclear Quadrupole Deformations** [description] *Last updated: April 4th, 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 cross sections and moments of Giant Dipole Resonances	**Giant Dipole Resonance Parameters, Photonuclear Reaction Cross Sections** [description] *Last updated: May 7th, 2002*
Nuclear, reactions, energies, angles, abstracts (in codes), references, authors	**Photonuclear Data Index from 1955** [description] *Last updated: June 2nd, 2005*
(γ,n), (γ,p), (γ,t), (γ,^{3}He), (γ,α), (γ,2n), (γ,np), (γ,2p) reactions energy thresholds	**Main Photonuclear Reaction Thresholds** [description] *Last updated: February 15th, 2003*
Nuclear reaction threshold and energy values for *any* nuclei and a plenty of incident/outgoing particles	**Calculator for Nuclear Reaction Threshold and Energy Values** [description] *Last updated: May 15th, 2002*
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	**Wave Function Value Database** [description] *Last updated: April 6th, 2006*
p-, d-, t-, ^{3}He-, α-, and HI-induced reactions yields and cross sections	**CAJAD Charged Particle Reaction Cross Sections Catalogue** [description] *Last updated: December 28th, 2000*
Low energy isomer transition internal conversion probabilities	**Low Energy Isomer Transition Internal Conversion Probabilities** [description] *Last updated: May 15th, 2002*
Nucleus state parameters: Energies, spin-parities half-times (decay modes), metastabilities, isospins, angular momenta, spectroscopic strengths, etc.; Alpha-, beta-, gamma-transition parameters: Energies, intensities, multipolarities, branching ratios, mixing ratios, etc.	**NESSY (New ENSDF Search SYstem): Relational Nuclear Spectroscopy Database** [description] *Last updated: January 30th, 2003* *(is obsolete, use Relational ENSDF instead!)*

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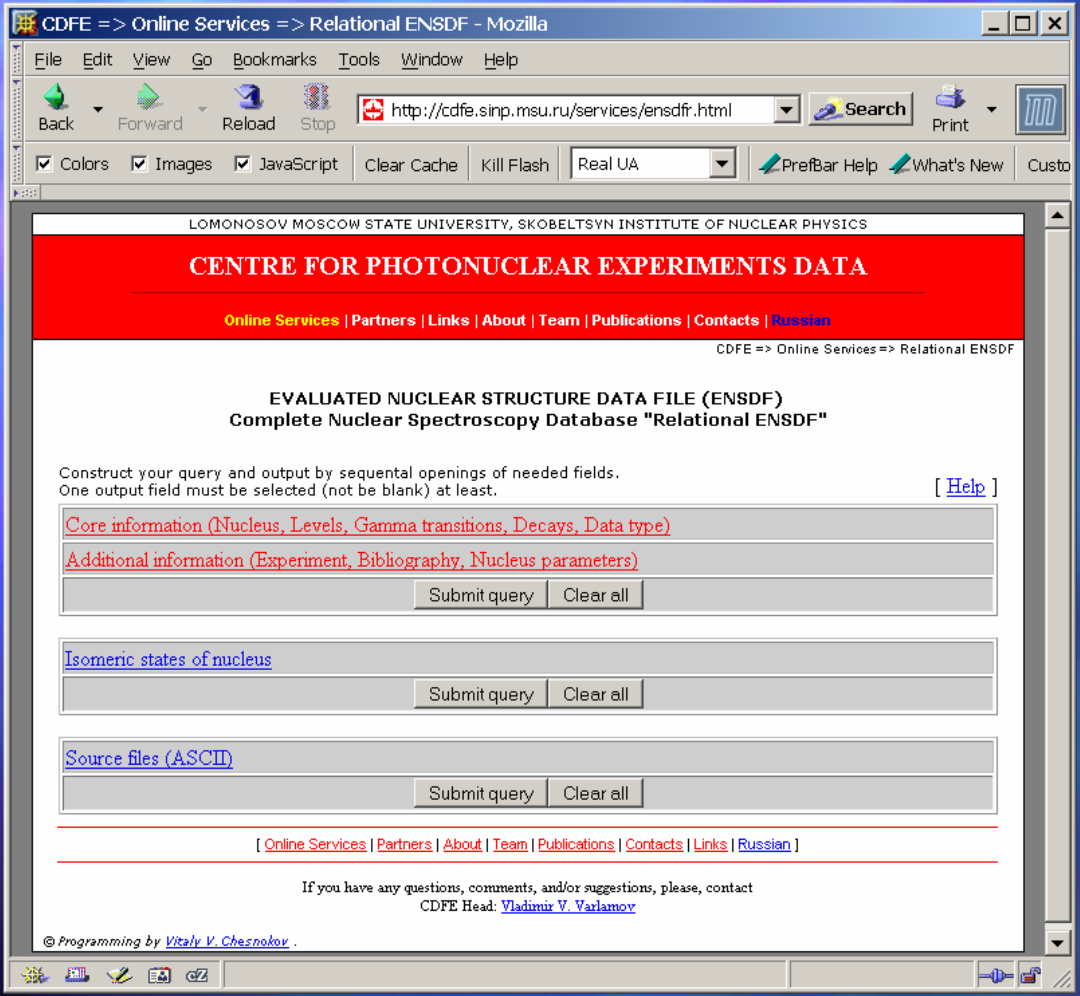

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Complete Nuclear Spectroscopy Database "Relational ENSDF"

Construct your query and output by sequental openings of needed fields.
One output field must be selected (not be blank) at least.

[Help]

Core information (Nucleus, Levels, Gamma transitions, Decays, Data type)

Additional information (Experiment, Bibliography, Nucleus parameters)

Submit query | Clear all

Isomeric states of nucleus

Submit query | Clear all

Source files (ASCII)

Submit query | Clear all

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If you have any questions, comments, and/or suggestions, please, contact
CDFE Head: Vladimir V. Varlamov

© Programming by Vitaly V. Chesnokov .

Informational «Russian matreshka»:

one can open one-to-another part in any direction - from top to bottom and back

- **nucleus**
- **level**
- **gamma-transition**
- **final nucleus**
- **decay**
- **experiment**
- **...**

Database «Relational ENSDF”: all published data on stable and radioactive nuclei (~ 3200).

Relational ENSDF

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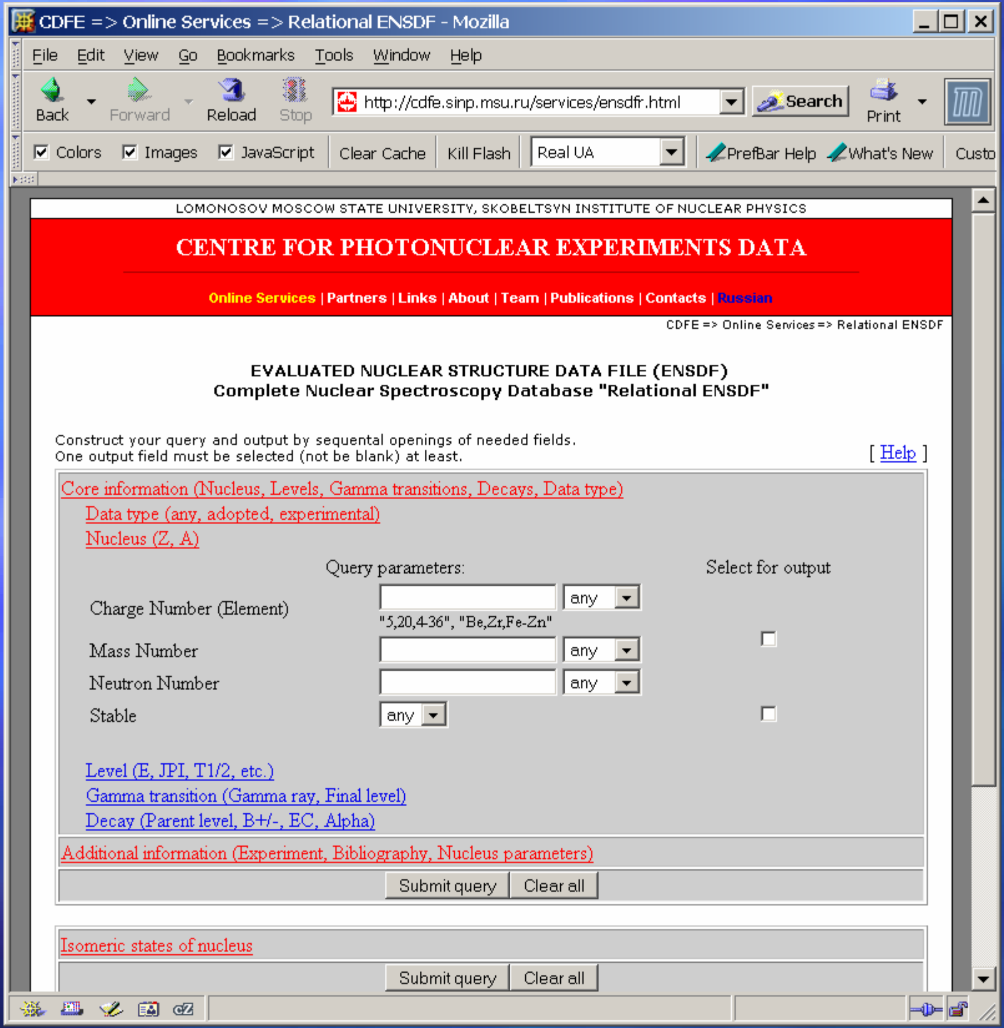

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Construct your query and output by sequental openings of needed fields.
One output field must be selected (not be blank) at least.

[Help]

Core information (Nucleus, Levels, Gamma transitions, Decays, Data type)
  Data type (any, adopted, experimental)
  Nucleus (Z, A)

	Query parameters:		Select for output
Charge Number (Element)	"5,20,4-36", "Be,Zr,Fe-Zn"	any	☐
Mass Number		any	
Neutron Number		any	
Stable	any		☐

  Level (E, JPI, T1/2, etc.)
  Gamma transition (Gamma ray, Final level)
  Decay (Parent level, B+/-, EC, Alpha)

Additional information (Experiment, Bibliography, Nucleus parameters)

Submit query | Clear all

Isomeric states of nucleus

Submit query | Clear all

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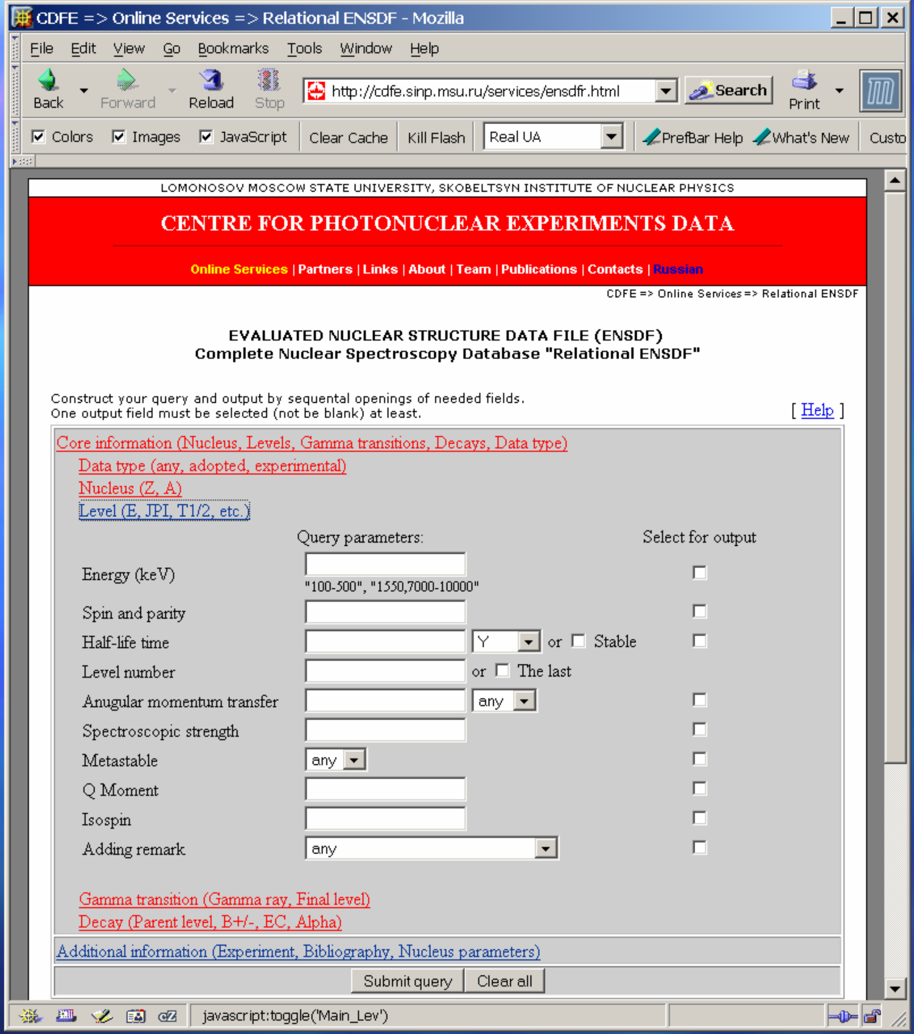

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[Help]

Core information (Nucleus, Levels, Gamma transitions, Decays, Data type)
- Data type (any, adopted, experimental)
- Nucleus (Z, A)
- Level (E, JPI, T1/2, etc.)

	Query parameters:	Select for output
Energy (keV)	"100-500", "1550,7000-10000"	☐
Spin and parity		☐
Half-life time	Y or ☐ Stable	☐
Level number	or ☐ The last	
Anugular momentum transfer	any	☐
Spectroscopic strength		☐
Metastable	any	☐
Q Moment		☐
Isospin		☐
Adding remark	any	☐

- Gamma transition (Gamma ray, Final level)
- Decay (Parent level, B+/-, EC, Alpha)

Additional information (Experiment, Bibliography, Nucleus parameters)

Submit query | Clear all

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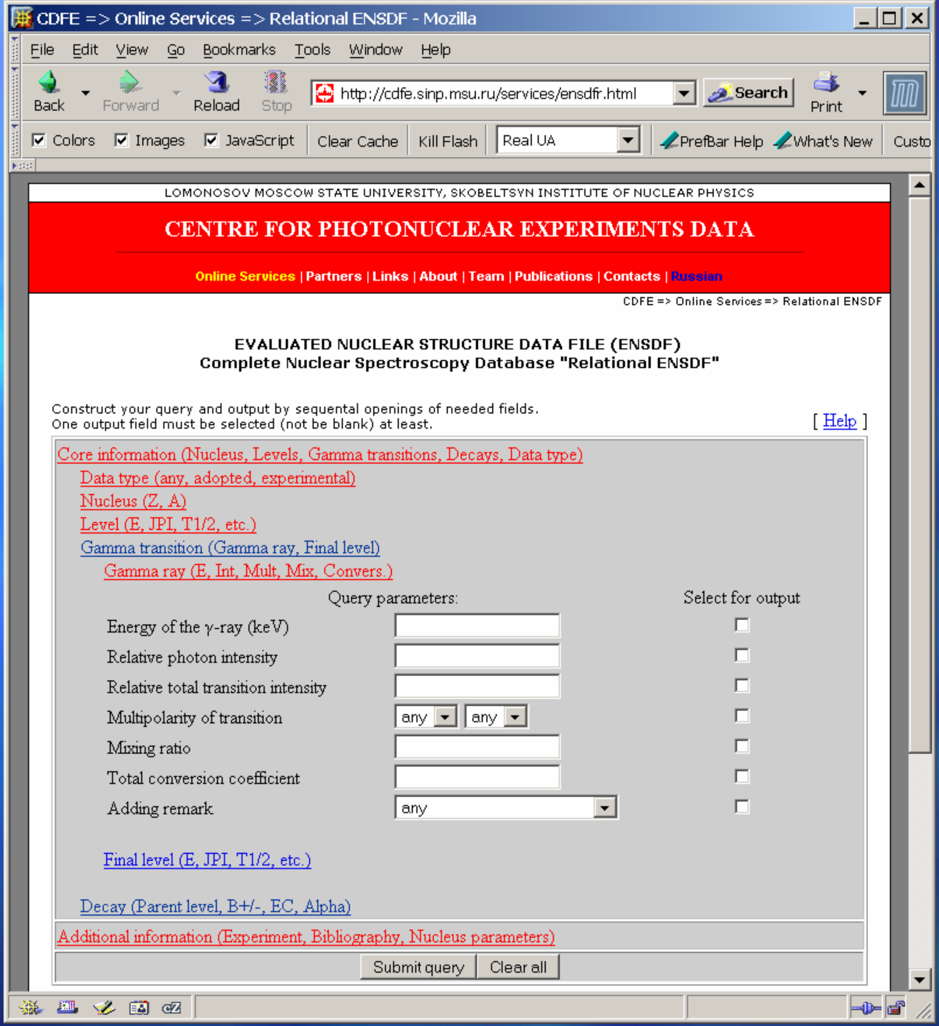

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[Help]

Core information (Nucleus, Levels, Gamma transitions, Decays, Data type)
  Data type (any, adopted, experimental)
  Nucleus (Z, A)
  Level (E, JPI, T1/2, etc.)
  Gamma transition (Gamma ray, Final level)
    Gamma ray (E, Int, Mult, Mix, Convers.)

	Query parameters:	Select for output
Energy of the γ-ray (keV)		☐
Relative photon intensity		☐
Relative total transition intensity		☐
Multipolarity of transition	any any	☐
Mixing ratio		☐
Total conversion coefficient		☐
Adding remark	any	☐

    Final level (E, JPI, T1/2, etc.)
  Decay (Parent level, B+/-, EC, Alpha)
Additional information (Experiment, Bibliography, Nucleus parameters)

Submit query Clear all

Informational «Russian matreshka»:

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- **gamma-transition**
- **final nucleus**
- **decay**
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- **...**

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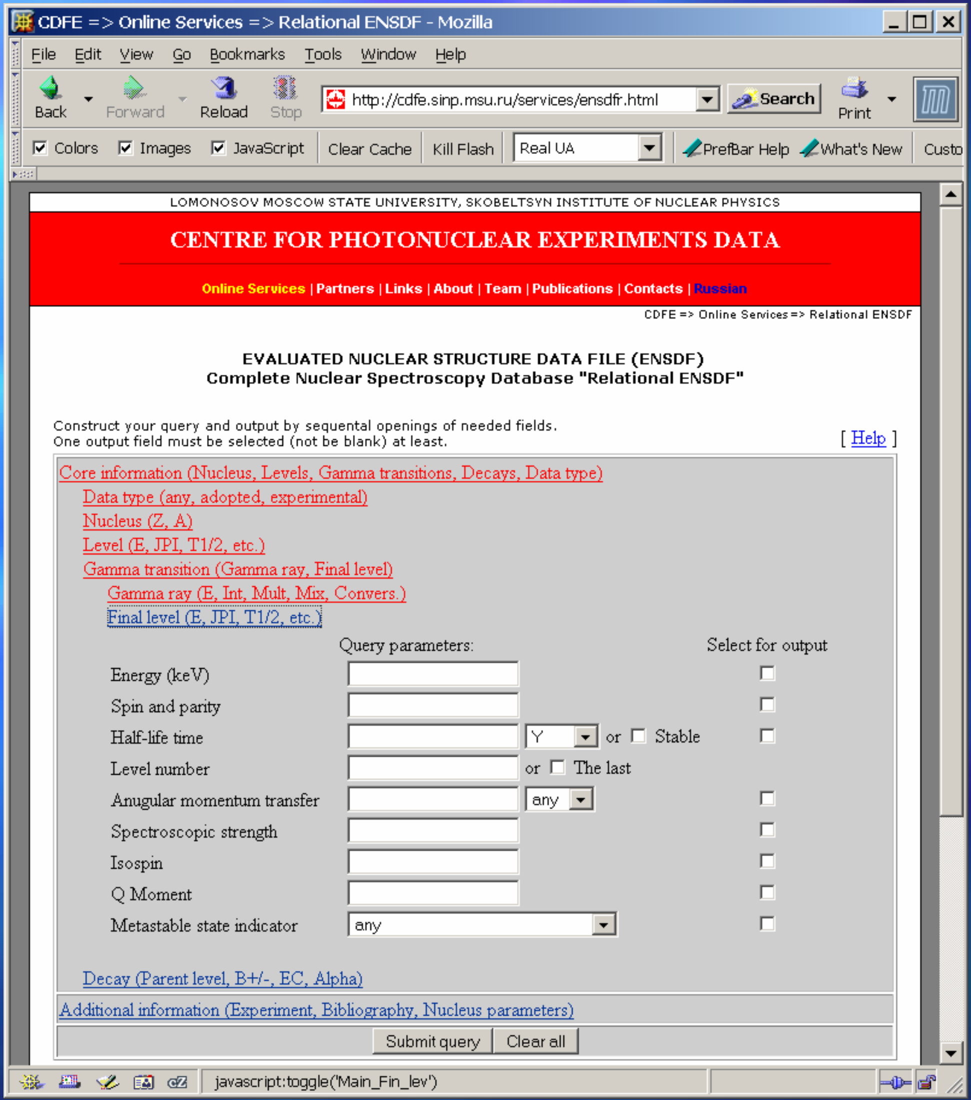

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  - Level (E, JPI, T1/2, etc.)
  - Gamma transition (Gamma ray, Final level)
    - Gamma ray (E, Int, Mult, Mix, Convers.)
    - Final level (E, JPI, T1/2, etc.)

	Query parameters:		Select for output
Energy (keV)			☐
Spin and parity			☐
Half-life time		Y or ☐ Stable	☐
Level number		or ☐ The last	
Anugular momentum transfer		any	☐
Spectroscopic strength			☐
Isospin			☐
Q Moment			☐
Metastable state indicator	any		☐

- Decay (Parent level, B+/-, EC, Alpha)
- Additional information (Experiment, Bibliography, Nucleus parameters)

Submit query | Clear all

Informational «Russian matreshka»:

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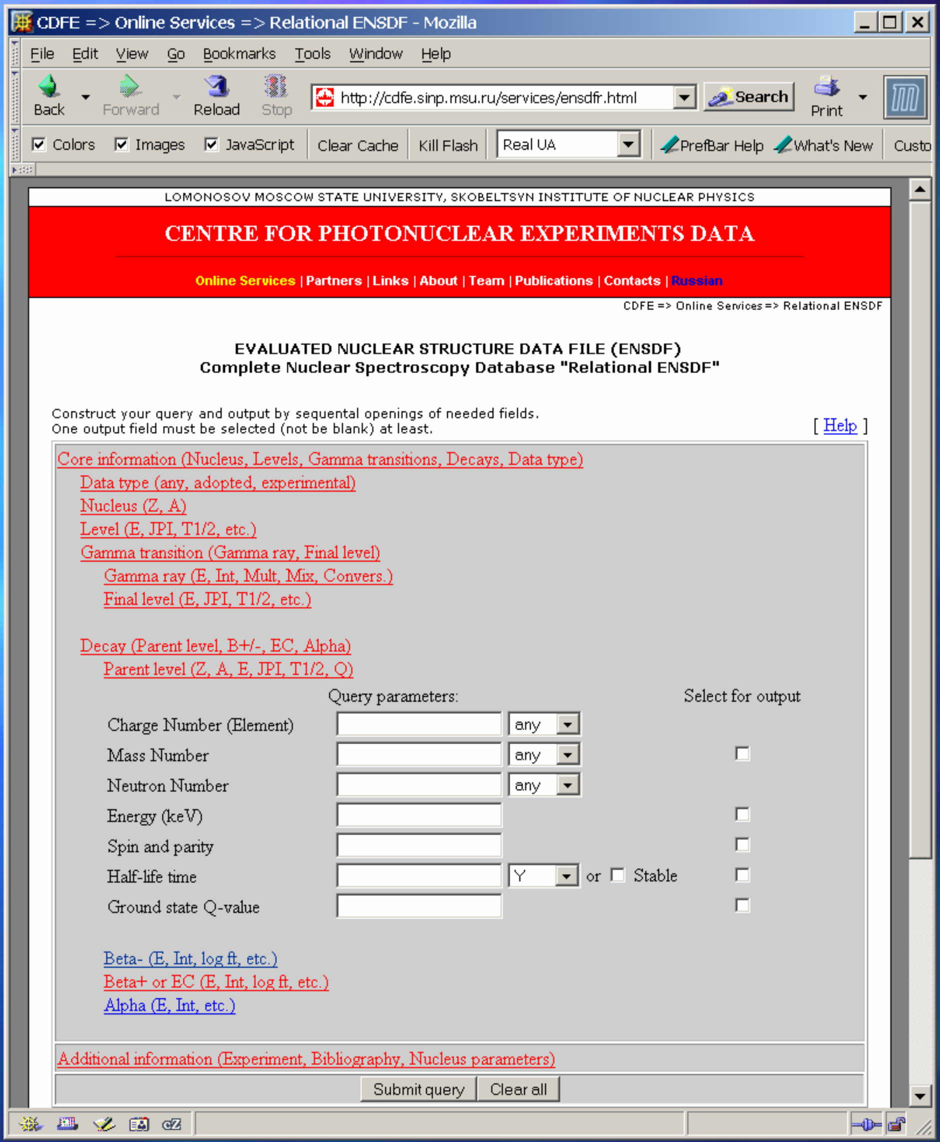

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- Nucleus (Z, A)
- Level (E, JPI, T1/2, etc.)
- Gamma transition (Gamma ray, Final level)
  - Gamma ray (E, Int, Mult, Mix, Convers.)
  - Final level (E, JPI, T1/2, etc.)
- Decay (Parent level, B+/-, EC, Alpha)
  - Parent level (Z, A, E, JPI, T1/2, Q)

	Query parameters:		Select for output
Charge Number (Element)		any	
Mass Number		any	☐
Neutron Number		any	
Energy (keV)			☐
Spin and parity			☐
Half-life time		Y or ☐ Stable	☐
Ground state Q-value			☐

  - Beta- (E, Int, log ft, etc.)
  - Beta+ or EC (E, Int, log ft, etc.)
  - Alpha (E, Int, etc.)

Additional information (Experiment, Bibliography, Nucleus parameters)

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Relational ENSDF

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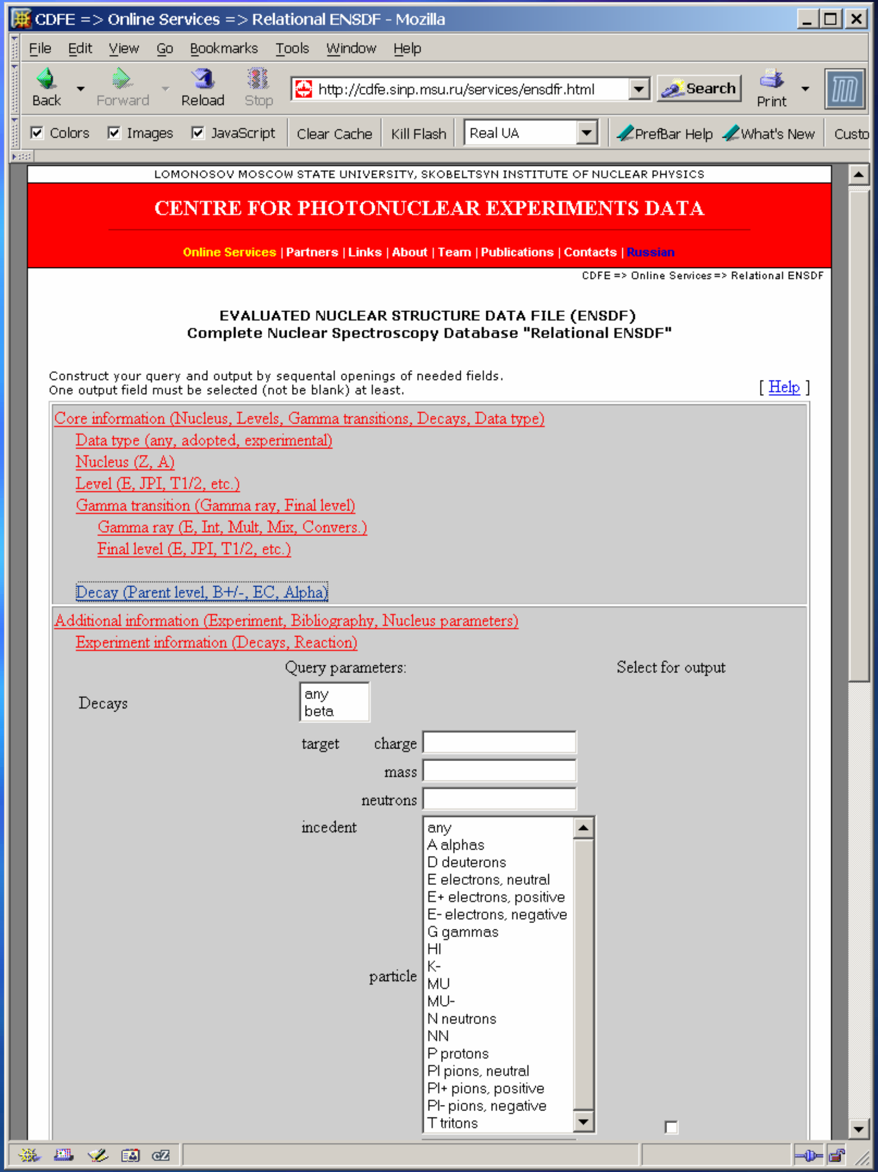

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Construct your query and output by sequential openings of needed fields.
One output field must be selected (not be blank) at least.

[Help]

- Core information (Nucleus, Levels, Gamma transitions, Decays, Data type)
  - Data type (any, adopted, experimental)
  - Nucleus (Z, A)
  - Level (E, JPI, T1/2, etc.)
  - Gamma transition (Gamma ray, Final level)
    - Gamma ray (E, Int, Mult, Mix, Convers.)
    - Final level (E, JPI, T1/2, etc.)
  - Decay (Parent level, B+/-, EC, Alpha)
- Additional information (Experiment, Bibliography, Nucleus parameters)
  - Experiment information (Decays, Reaction)

Query parameters: Select for output

Decays: any / beta

target: charge / mass / neutrons

incedent particle: any, A alphas, D deuterons, E electrons, neutral, E+ electrons, positive, E- electrons, negative, G gammas, HI, K-, MU, MU-, N neutrons, NN, P protons, PI pions, neutral, PI+ pions, positive, PI- pions, negative, T tritons ☐

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- nucleus
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- ...

Database «Relational ENSDF”: all published data on stable and radioactive nuclei (~ 3200).

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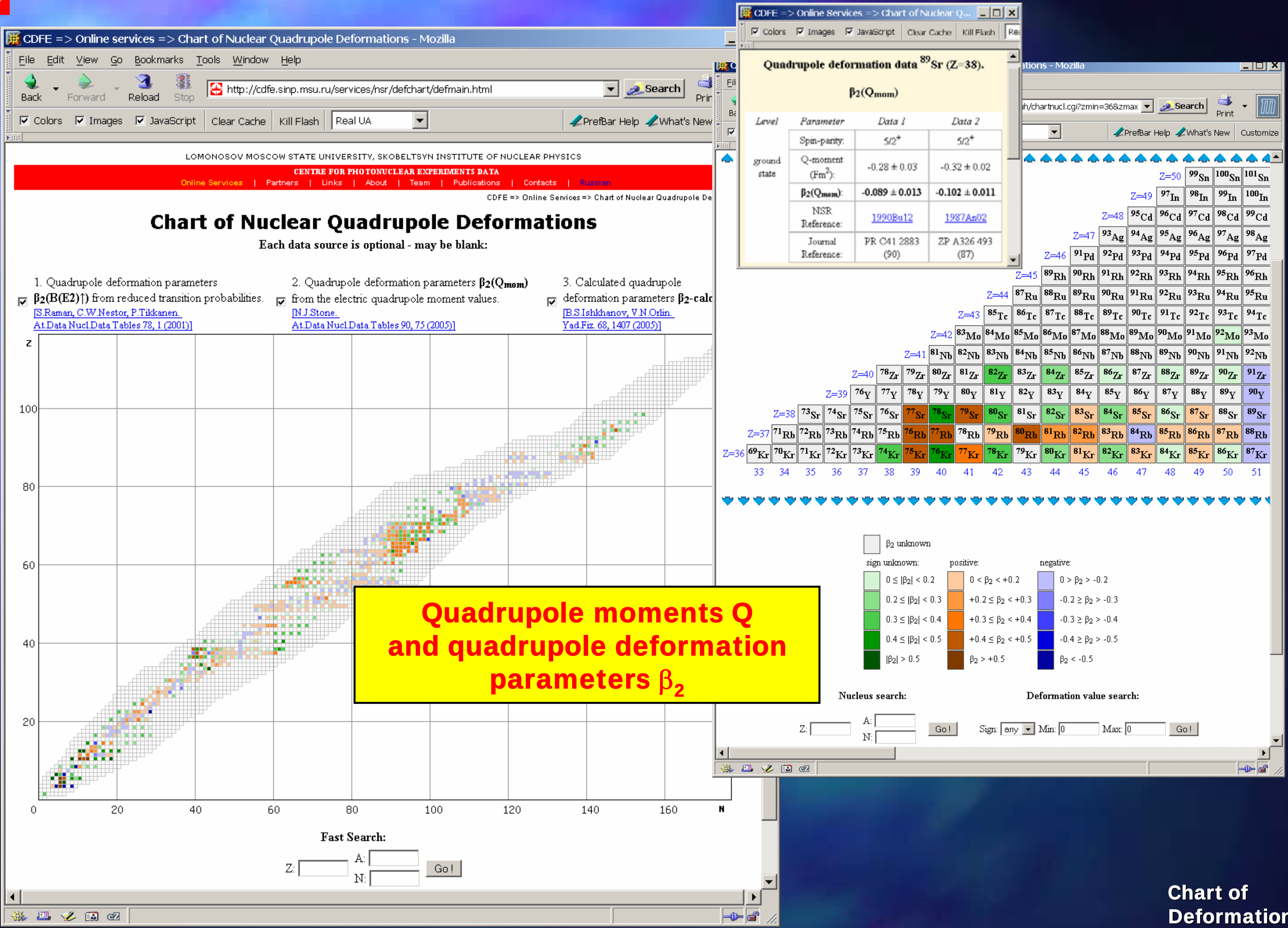

http://cdfe.sinp.msu.ru/services/nsr/defchart/defmain.html

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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 !

CDFE => Online Services => Chart of Nuclear Q...

Quadrupole deformation data ^{89}Sr (Z=38).

$\beta_2(Q_{mom})$

Level	*Parameter*	*Data 1*	*Data 2*
ground state	Spin-parity:	$5/2^+$	$5/2^+$
	Q-moment (Fm^2):	-0.28 ± 0.03	-0.32 ± 0.02
	$\beta_2(Q_{mom})$:	**-0.089 ± 0.013**	**-0.102 ± 0.011**
	NSR Reference:	1990Bu12	1987An02
	Journal Reference:	PR C41 2883 (90)	ZP A326 493 (87)

⬜	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 !

Quadrupole moments Q and quadrupole deformation parameters β_2

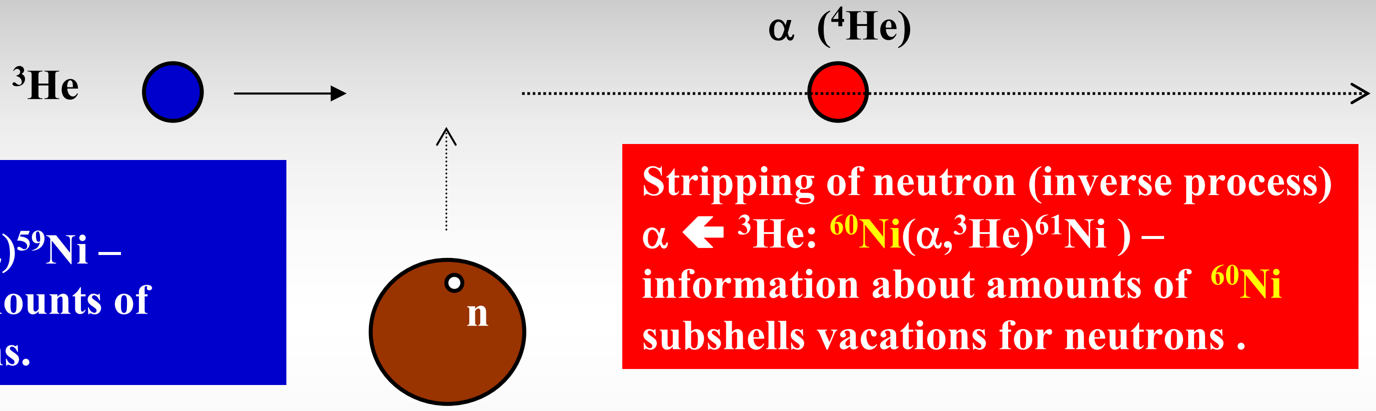
Chart of Deformations

7/4/2007

NUCLEAR STRUCTURE AND RELATED TOPICS,
Dubna, June 13 - 17, 2006

Nucleus one-particle structure investigation: joint nucleon stripping and pick-up reaction data analysis

Reaction (→) ^{60}Ni(^{3}He, α)^{59}Ni of neutron pick-up by ^{60}Ni



Neutron pick-up
^{3}He ➔ α : ^{60}Ni(^{3}He, α)^{59}Ni –
information about amounts of
^{60}Ni subshells neutrons.

Stripping of neutron (inverse process)
α 🡨 ^{3}He: ^{60}Ni(α,^{3}He)^{61}Ni) –
information about amounts of ^{60}Ni
subshells vacations for neutrons .

^{60}Ni → ^{59}Ni

^{60}Ni → ^{61}Ni

Pick-up data:
transferred neutron parameters

$$\overbrace{S \quad l \quad j}$$

j = J for even-even nucleus
(J_0 = 0) final level spin

From ^{59}Ni levels data →

Nucleon stripping and pick-up reaction data joint evaluation method

Basic idea: renormalization (n^+ и n^-) of experimental data for equation

$$n^+ S^+_{nlj}(E_x) + n^- S^-_{nlj}(E_x) = 2j + 1$$

be valid for three one-particle orbitals closest to Fermi enery ($(n,l,j) = (n_1,l_1,j_1), (n_2,l_2,j_2), (n_3,l_3,j_3)$).

The join solution of those three equations – determination of n^+ and n^- and evaluation of spectroscopic strenghts and j values for different transitions.

Obtaining (R.K.Bansal, etc, Phys.Lett., 19 (1965) 223)
of occupation probabilities

$$N_{nlj} = \frac{\left[n^{-}S^{-}_{nlj} + (2j+1-n^{+}S^{+}_{nlj})\right]}{2(2j+1)}$$

and energies

$$-E_{nlj} = (1-N_{nlj})\left[B(A+1)-e^{+}_{nlj}\right] + N_{nlj}\left[B(A)+e^{-}_{nlj}\right]$$

of one-particle orbitals ($\varepsilon^{+}_{n,l,j}$, $\varepsilon^{-}_{n,l,j}$ – centres of gravity of final nucleus levels spectroscopic strengths distributions for stripping and pick-up reactions, B(A) и B (A+1) – nucleon separation energy values.

Method of joint evaluation efficiency:

Putting into consistency (n = 0.93 - 1.04) C^2S values for ^{59}Co levels using (^{60}Ni(d,^{3}He)^{59}Co and ^{60}Ni(^{3}H,α)^{59}Co) reaction data.

Level energy, keV	J^π	L	C^2S	
			before	after
0	***$7/2^-$***	***3***	***3.81 - 6.61 (27%)***	***3.55 - 3.96 (5%)***
1087	***$3/2^-$***	***1***	***0.15 - 0.29 (32%)***	***0.14 - 0.16 (2%)***
1291	$3/2^-$	1	0.07 - 0.07	0.07*
1493	$1/2^-$	1	0.03	0.03*
1493	$5/2^-$	3	0.22	0.20 - 0.23
1749	$7/2^-$	3	0.60 - 1.01 (25%)	0.56 - 0.62 (5%)
2048	$7/2^-$	3	0.48 - 0.80 (25%)	0.45 - 0.50 (6%)

Various subshells energie values and occupation probabilities were obtained for many nuclei

^{42,44,46,48,50,52,54}Ca,

^{50,52,54,56,58,60,62}Cr,

^{54,56,58}Fe,

^{58,60,62,64}Ni,

^{84,86,88}Sr,

^{90,92,94,96}Zr,

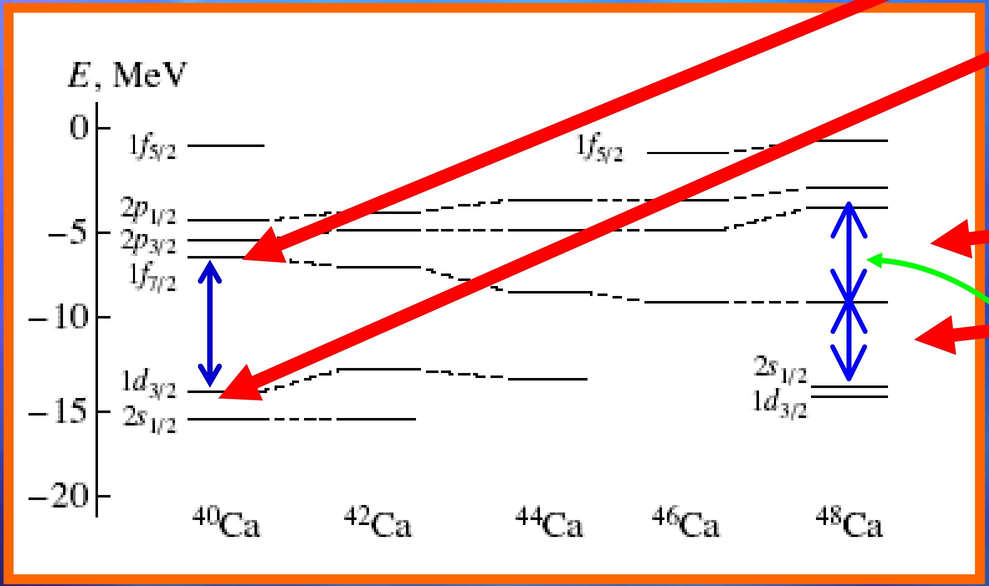
^{112,114,116,118,120,122,124}Sn,

and some others

between those were presented also nuclei with noticeable neutron excess.

Many data

Neutron subshells of ^{40,42,44,46,48}Ca: typical picture of magic nuclei formation

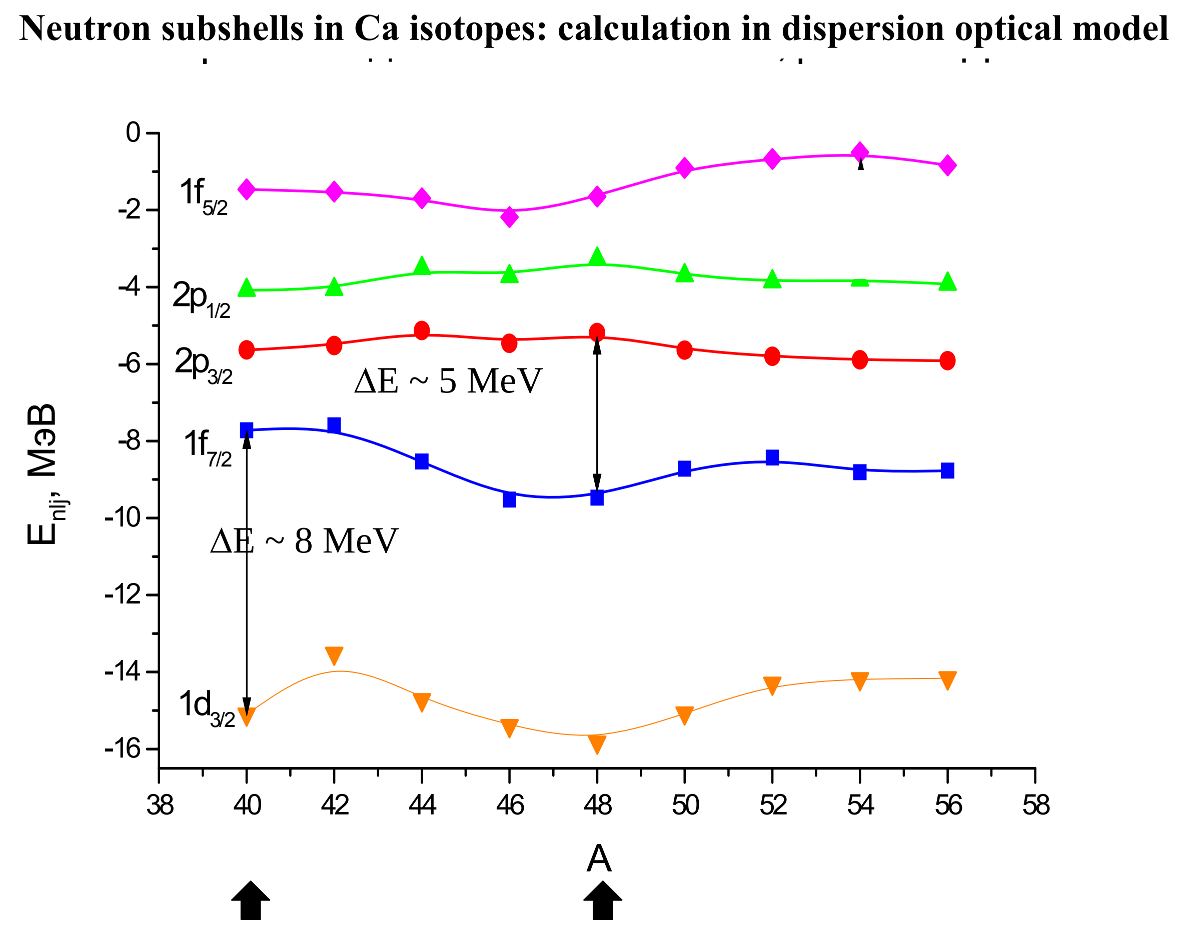


^{40}Ca (20,20) - double magic nuclei - ^{48}Ca (20,28)

In ^{40}Ca
$1f_{7/2}$ - subshell is empty, but $1d_{3/2}$ - filled and there is very large (~ 10 MeV) energy gap between them.

Increasing in neutron number on $1f_{7/2}$ leads to its lowering and decreasing of $1d_{3/2}$-$1f_{7/2}$ energy gap but increasing of $1f_{7/2}$- $2p_{3/2}$ gap.

In ^{48}Ca
filled (closed) $1f_{7/2}$ -subshell is placed between empty $2p_{3/2}$-subshell and closed $2s_{1/2}$-subshell and became a separate shell (energy gap $1f_{7/2}$- $2p_{3/2}$ is enough large (~ 4 MeV)).

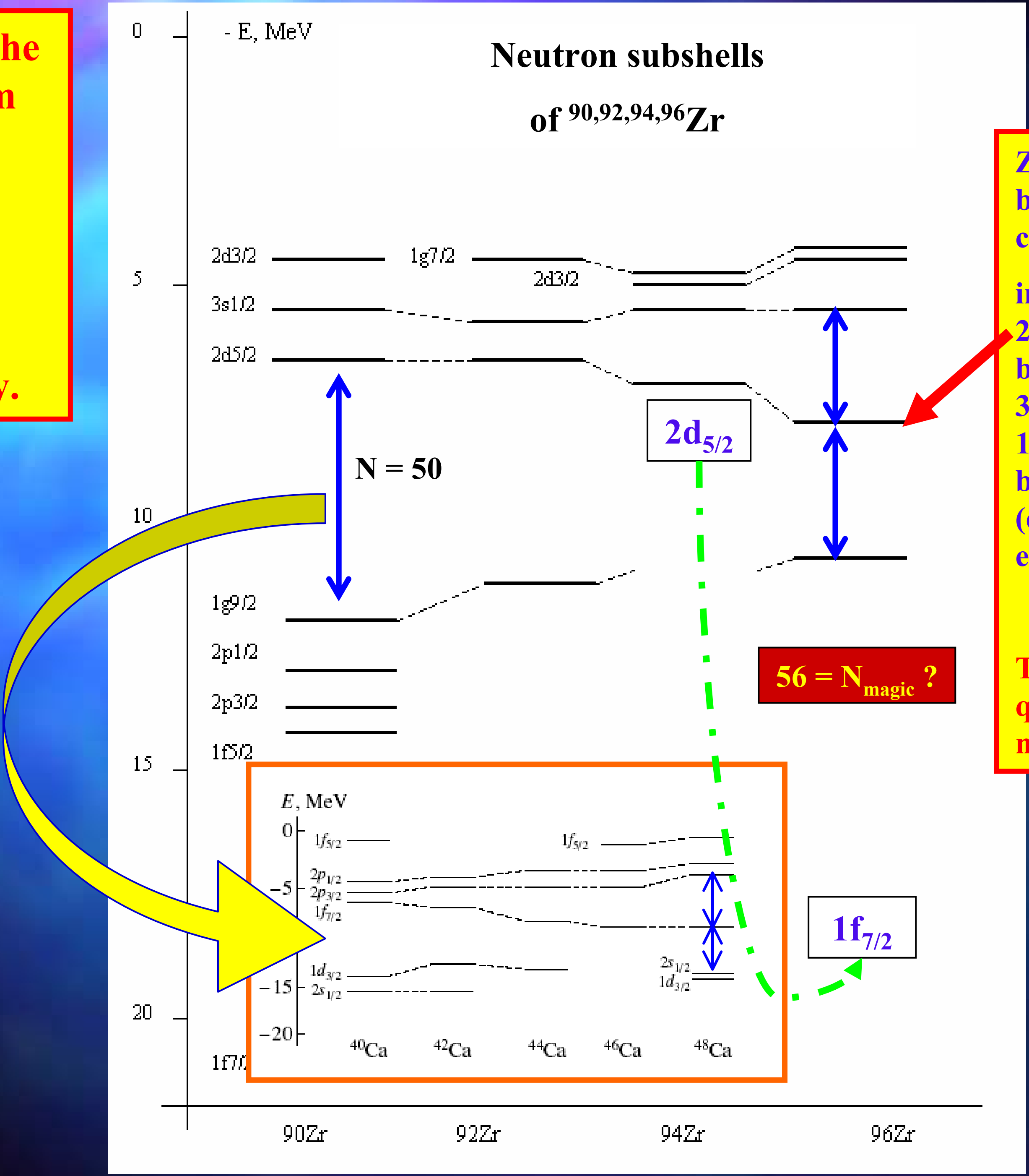


Neutron subshells in Ca isotopes: calculation in dispersion optical model

Large energy gaps between refered subshells in magic nuclei are well described in dispersion optical model (DOM).

Ca gaps

Those are the results from which the problem of new magic nuclei appeared very clearly.



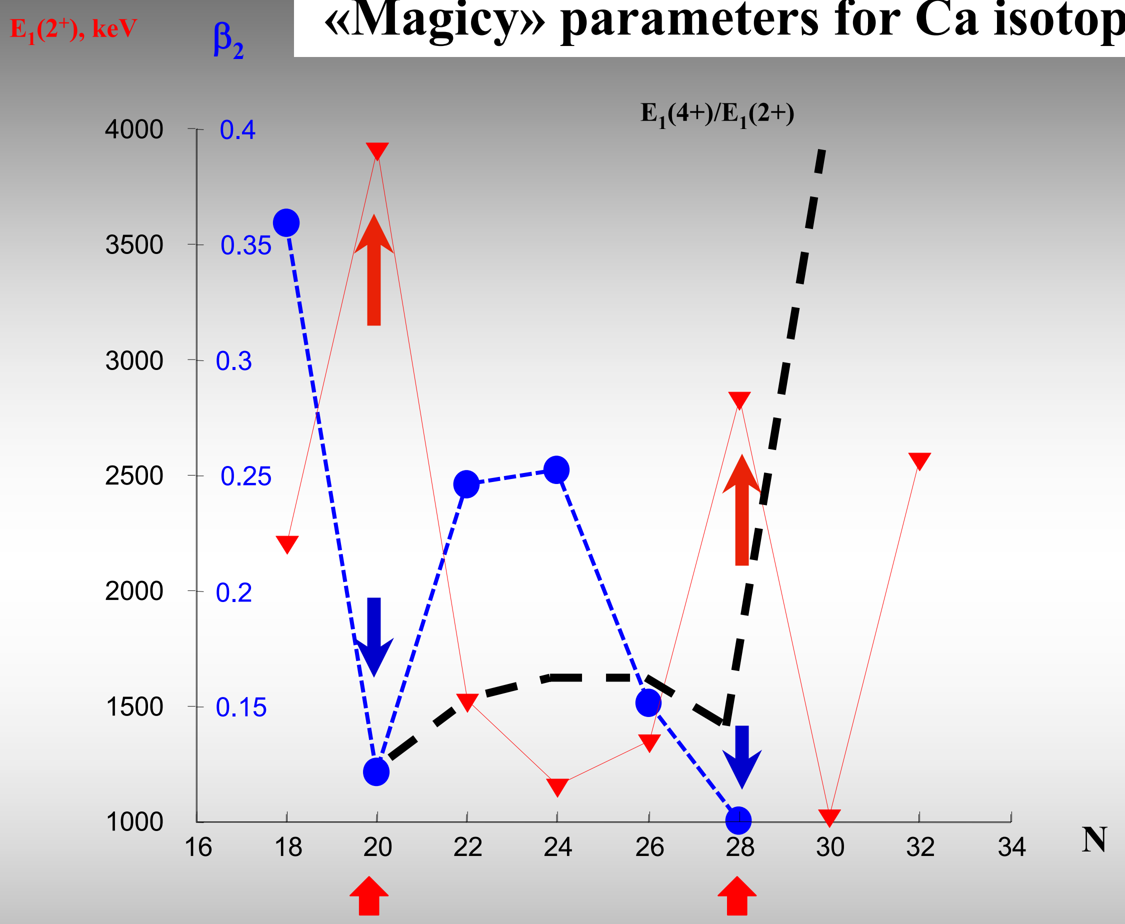
Neutron subshells of ^{90,92,94,96}Zr

Zr - Ca subshells behaviour clear correlation:

in ^{96}Zr $2d_{5/2}$ -subshell is placed is between empty $3s_{1/2}$-subshell and closed $1g_{9/2}$-subshell and became a separate shell (energy gap $2d_{5/2}$- $3s_{1/2}$ is enough large (~ 5 MeV)).

Therefore important question appears: is not nucleus ^{96}Zr magic one?

«Magicy» parameters for Ca isotopes (Z = 20)

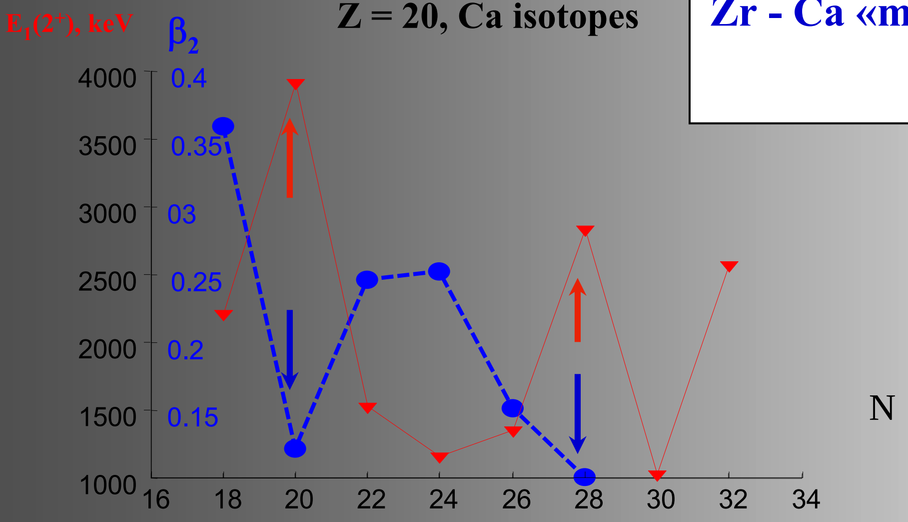


Double-magic (20,20) ^{40}Ca

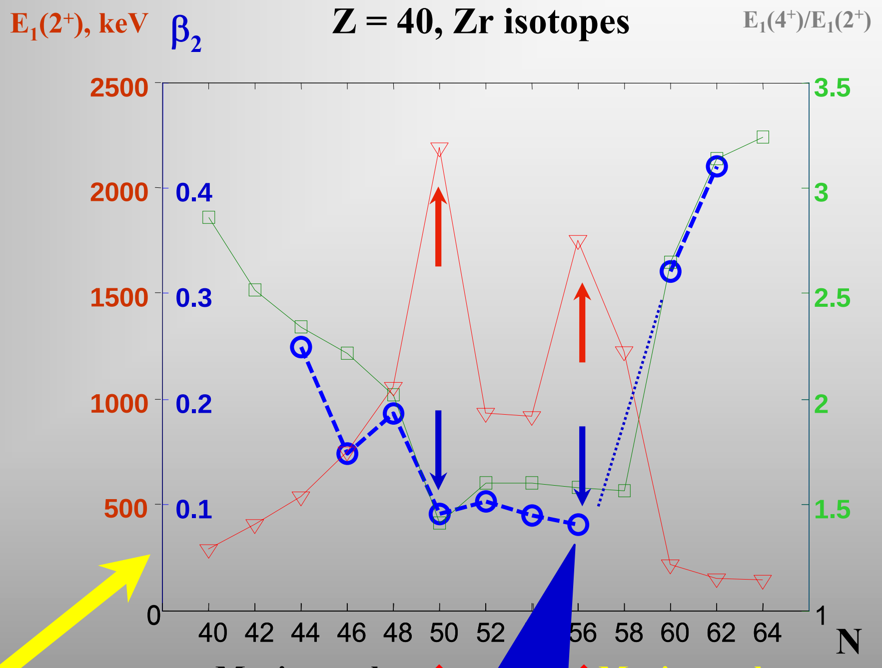
Double-magic ^{48}Ca (20,28)

Zr - Ca «magicy» parameters behaviour

clear correlation



Two clear maxima in $E_1(2^+)$ and minima in β_2 at double magic ^{40}Ca(20,20) and double magic ^{48}Ca(20,28).



Two clear maxima in $E_1(2^+)$ and minima in β_2 (as in $E_1(4^+)/E_1(2^+)$ ratio at magic nucleus ^{90}Zr(40,50) and at what - ^{96}Zr(40,56) ?

Magic number ⬆
N = 50: ^{90}Zr(40, 50)

⬆Magic number
N = 56: ^{96}Zr(40, 56)

^{96}Zr quadrupole deformation (β_2 = 0.08) is less not only than those for neighboring Zr isotopes but than of those for double magic ^{40}Ca (β_2 = 0.123) and ^{48}Ca (β_2 = 0.106).

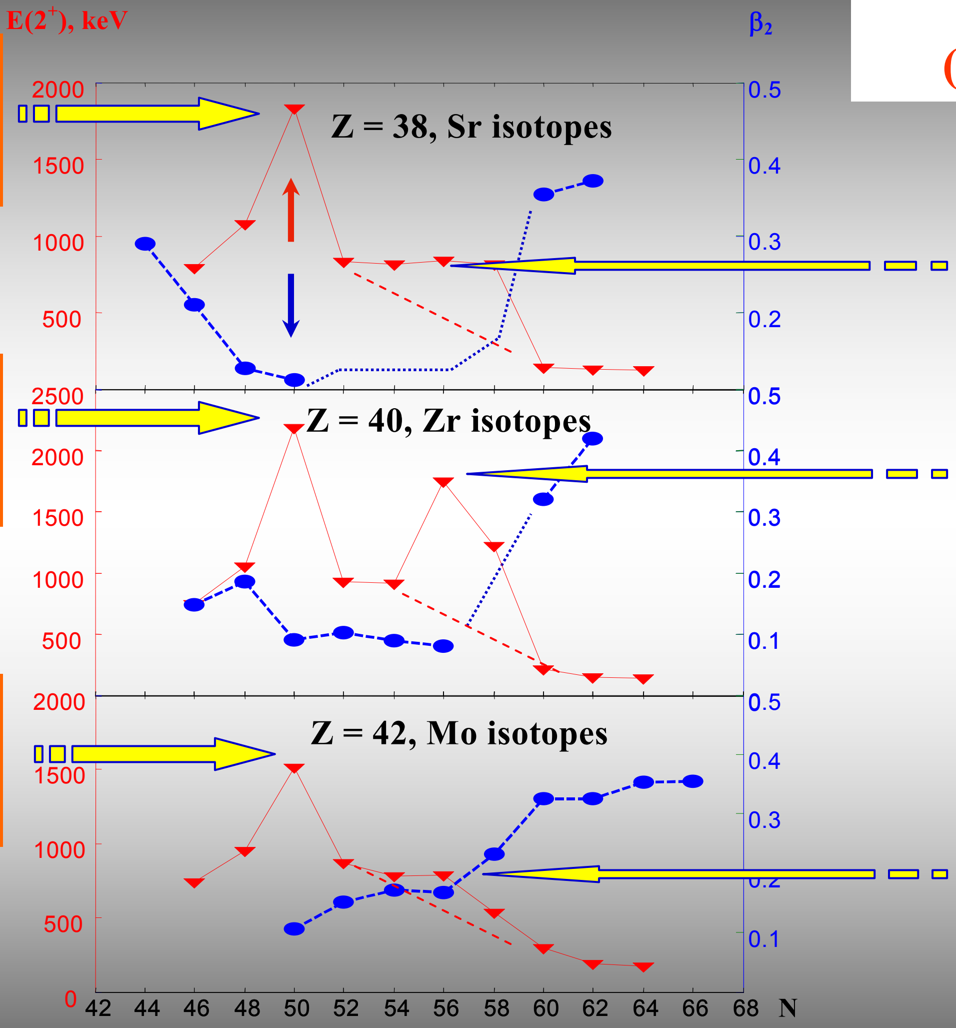
^{96}Zr - magic nucleus (N = 56).

Is N = 56 magic number
(only for Z = 40)?

N = 50
is magic
for Z = …, 36, 38

N = 50
is magic
for Z = 40

N = 50
is magic
for Z = …42, 44, …

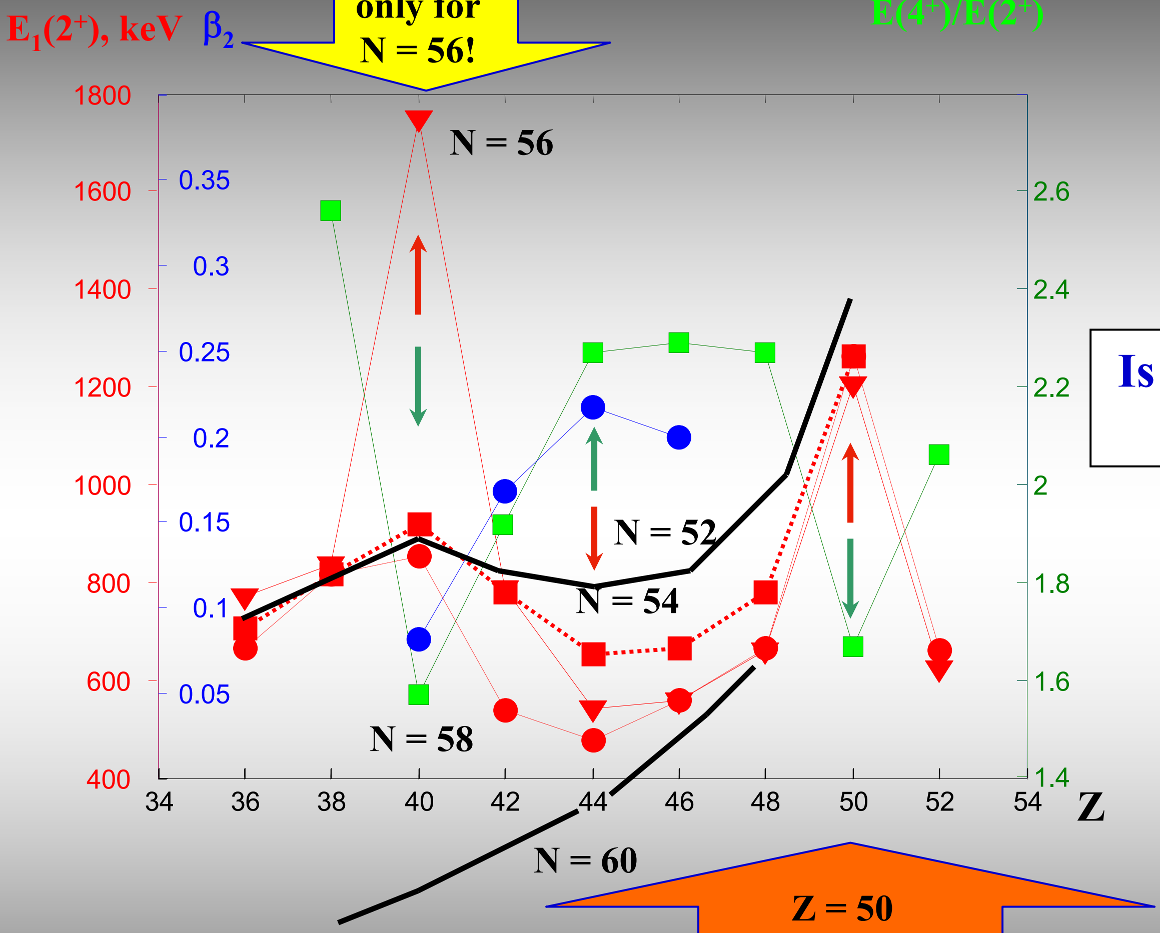


May be N = 56
is «slightly» magic
for Z = 38 ?

N = 56
is magic for
Z = 40 !

N = 56
is not magic for
Z = 42.

N = 56, Z = 40



Z = 40
is magic
only for
N = 56!

Is Z = 40 magic number (only for N = 56)?

Z = 50
is magic for
N = …, 52, 54,
56, 58, 60, ...

N=54-56-58

Z = 40 is magic number (for N = 56):

N increasing leads to increasing of the energy gap ΔE between closed $2p_{1/2}$ and empty $1g_{9/2}$ subshells twice from 1.56 MeV for ^{90}Zr to 3.11 MeV for ^{96}Zr

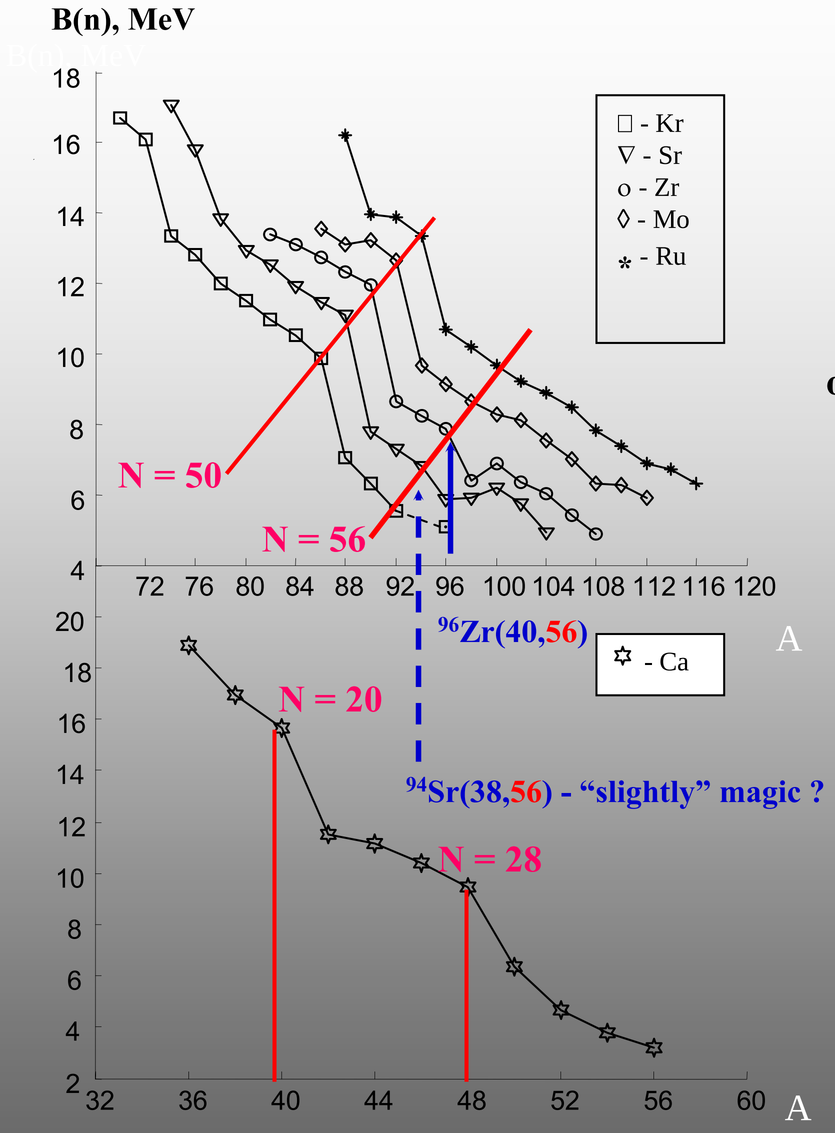
	ΔE, MeV	1.56	2.68	2.63	3.11
Nlj	Occupation probability energy	^{90}Zr	^{92}Zr	^{94}Zr	^{96}Zr
$1g_{9/2}$	N_{nlj}	0.06(5)	0.08(5)	0.09(5)	0.00(0)
	$-E_{nlj}$	5.41(54)	4.98(142)	6.74(80)	7.48(75)
$2p_{1/2}$	N_{nlj}	0.58(5)	0.49(3)	0.75(5)	0.81(5)
	$-E_{nlj}$	6.97(70)	7.66(77)	9.37(94)	10.59(106)
$1f_{5/2}$	N_{nlj}	1.00(2)	1.00(2)	1.00(2)	0.94(5)
	$-E_{nlj}$	10.37(110)	10.93(110)	11.490(115)	12.17(122)
$2p_{3/2}$	N_{nlj}	-	-	0.87(5)	-
	$-E_{nlj}$	-	-	11.11(112)	-

Nucleon occupation probabilities N_{nlj} and single-particle energies $-E_{nlj}$ (MeV) of proton orbits in nuclei ^{90,92,94,96}Zr

Thus,
systematical analysis of well-known data reveals the following: nuclei near to numbers Z = 40 and N = 56 show unique properties - the isotopes with Z = 40 behave so, as if crossing a magic line N = 56, and isotones with N = 56 - so, as if crossing a magic line Z = 40.

In the middle of this crossing there is a ^{96}Zr, which has a set of many properties, characteristics and parameters similar to those for typical magic nucleus.

So ^{96}Zr can be identified as new double magic nucleus.



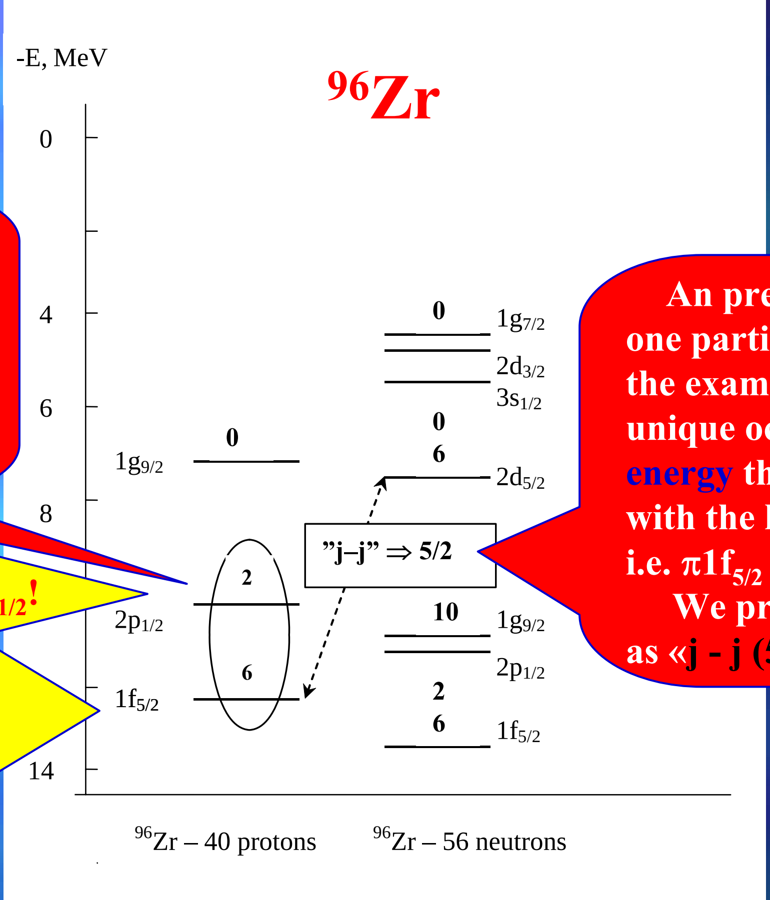
^{96}Zr(40,56)

^{94}Sr(38,56) - “slightly” magic ?

Irregularities in A-dependence

of neutron separation energy B(n)

MSU SINP CENTRE FOR PHOTONUCLEAR EXPERIMENTS DATA



^{96}Zr subshells "j–j"- connection ⇒ 5/2.

The magicy peak is achieved at the point, when both subshells are closed and additionally above one of them, i.e. $\pi 1f_{5/2}$, a closed subshell with $j = 1/2$, $\pi 2p_{1/2}$ occurs.

^{96}Zr - magic: 2 protons on $2p_{1/2}$!

^{94}Sr - «slightly» magic: no 2 protons on $2p_{1/2}$

An preliminary consideration - one particularly uncommon feature: in the examined case there is a rather unique occurrence, when near to Fermi energy there are two closed subshells with the large identical moment $j = 5/2$, i.e. $\pi 1f_{5/2}$ and $\nu 2d_{5/2}$.

We propose to call that phenomenon as «j - j (5/2) connection».

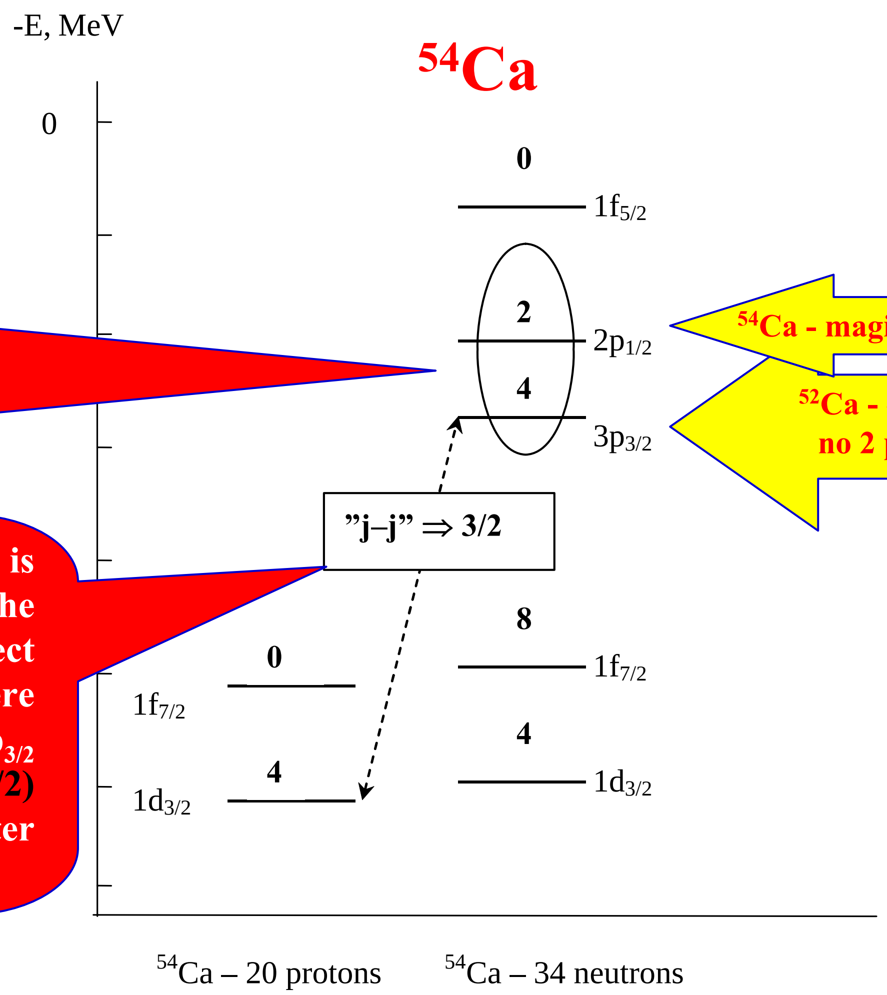
In this case numbers Z = 20 and N = 34 appear as magic then.

The magicy for these numbers pair (20,34) is discussed in press in comparison of those for (20,32) .

If the previous suggestion is applied to subshells with the moment j = 3/2, we should expect nothing but a nucleus ^{54}Ca: there are closed $\pi 1d_{3/2}$ (j = 3/2) and $\nu 2p_{3/2}$ (j = 3/2) subshells - j - j (3/2) connection - and above the latter there is a closed $\nu 2p_{1/2}$ (j = 1/2).

^{54}Ca - magic: 2 protons on $2p_{1/2}$

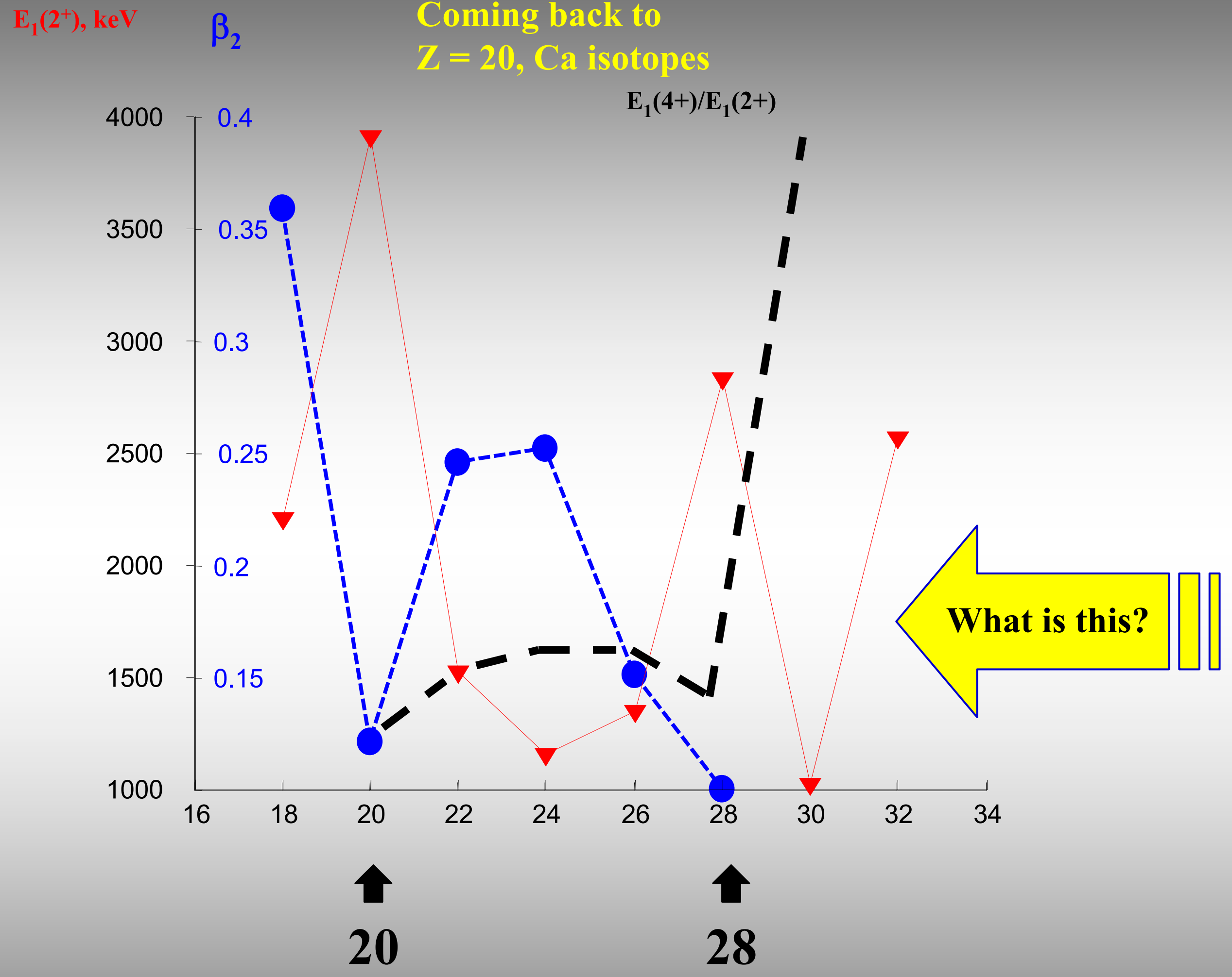
^{52}Ca - «slightly» magic: no 2 protons on $2p_{1/2}$



^{54}Ca subshells “j–j”- connection ” ⇒ 3/2.

^{54}Ca - pairs

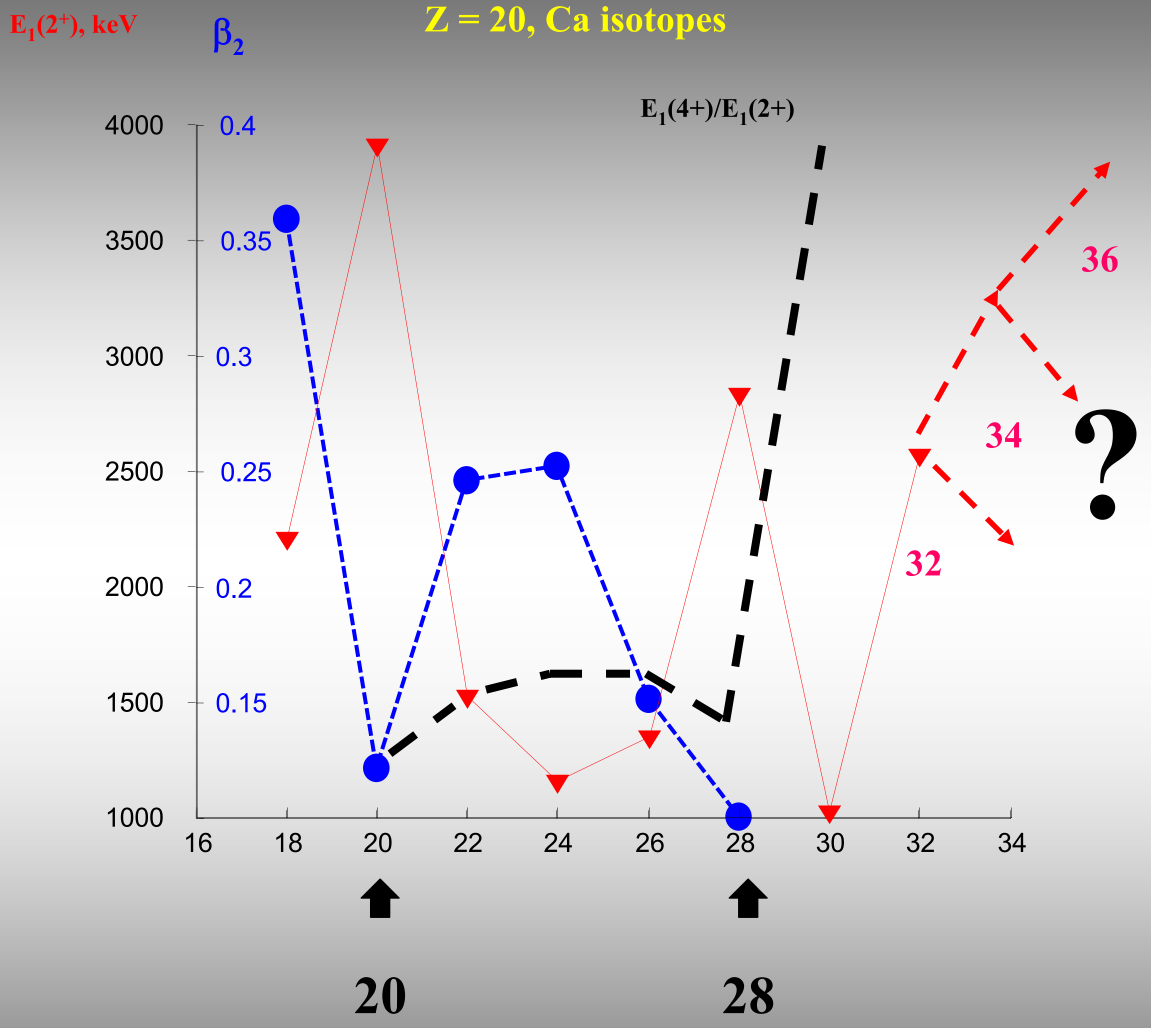
Coming back to $Z = 20$, Ca isotopes



Double magic ^{40}Ca(20, 20)

Double magic ^{48}Ca (20, 28)

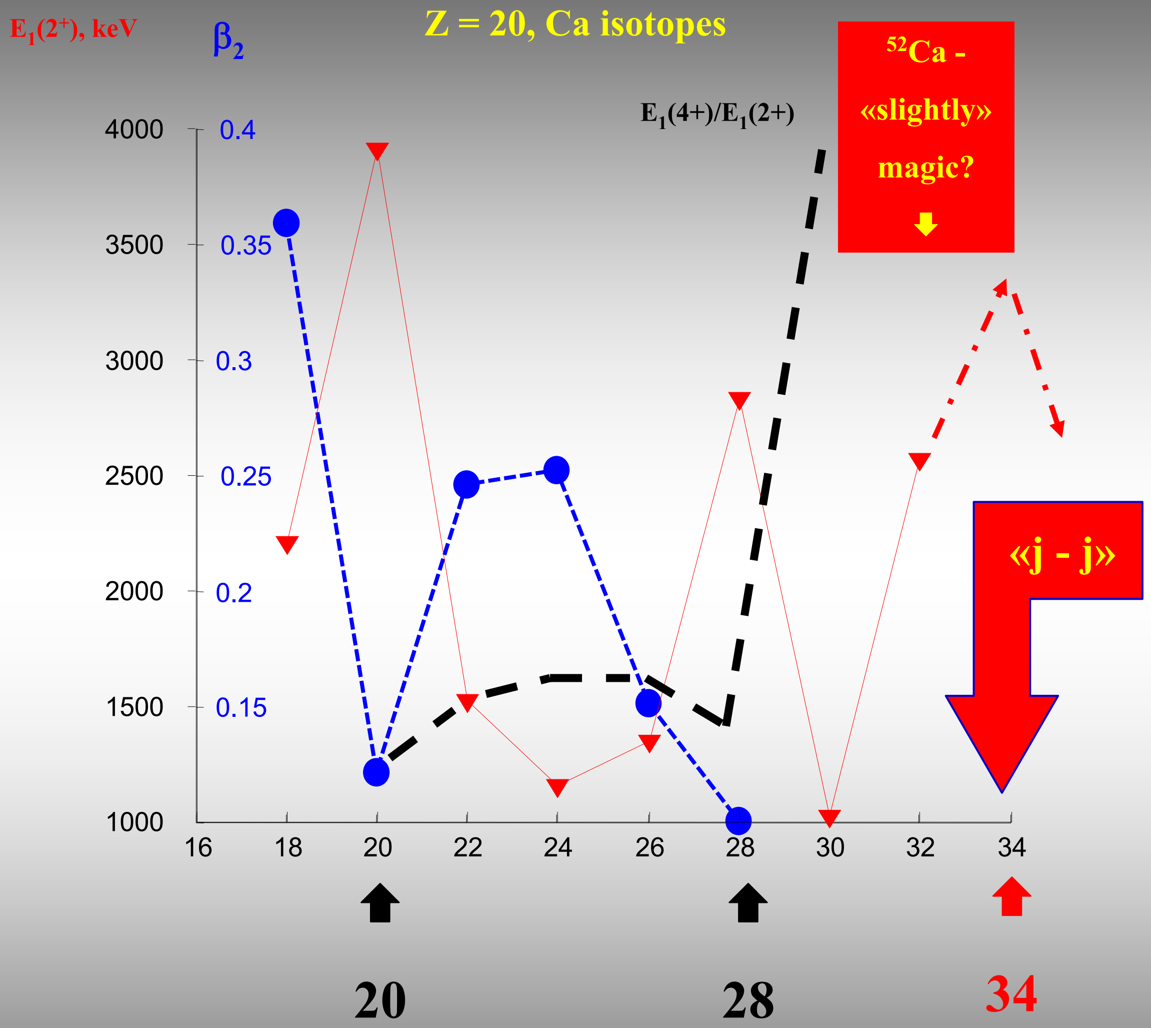
Z = 20, Ca isotopes



From double magic (20, 28)^{48}Ca → to what?

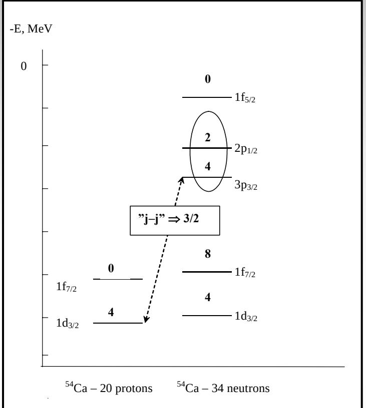
^{54}Ca - ?

Z = 20, Ca isotopes



From double magic(20, 28) ^{48}Ca →

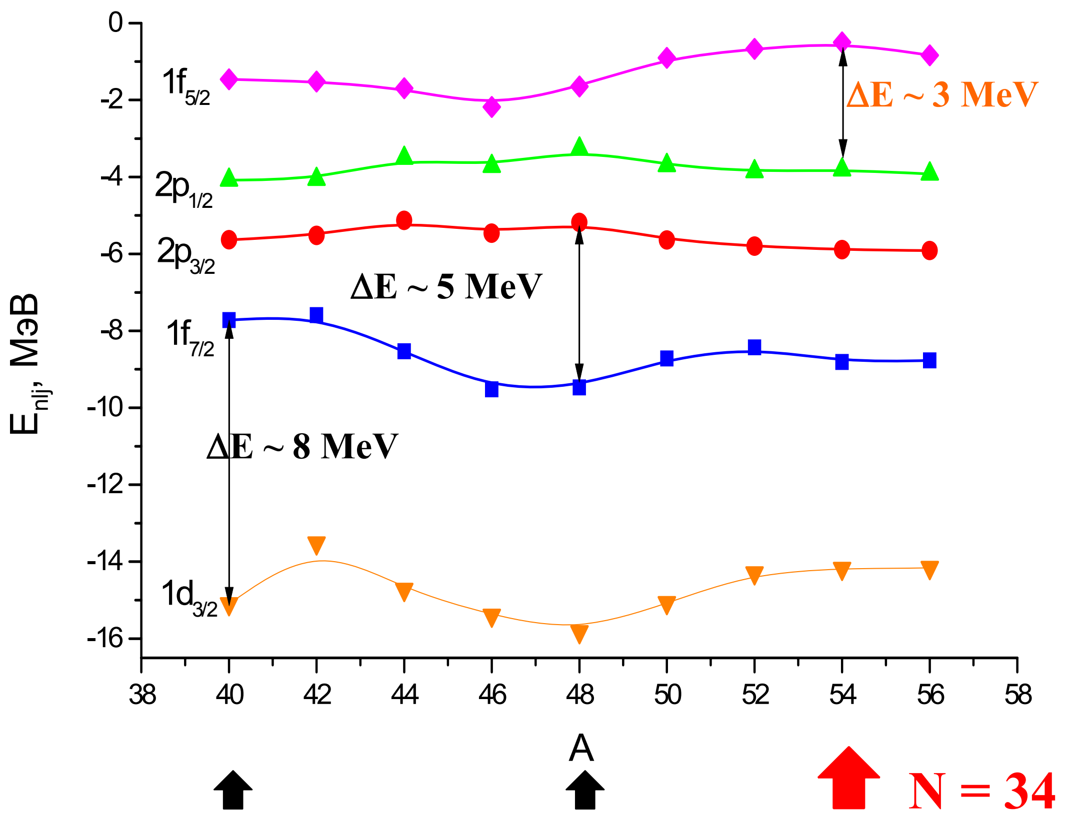
to double magic ^{54}Ca (20, 34) ?



^{54}Ca subshells "j–j"- connection " ⇒ 3/2.

^{54}Ca - !

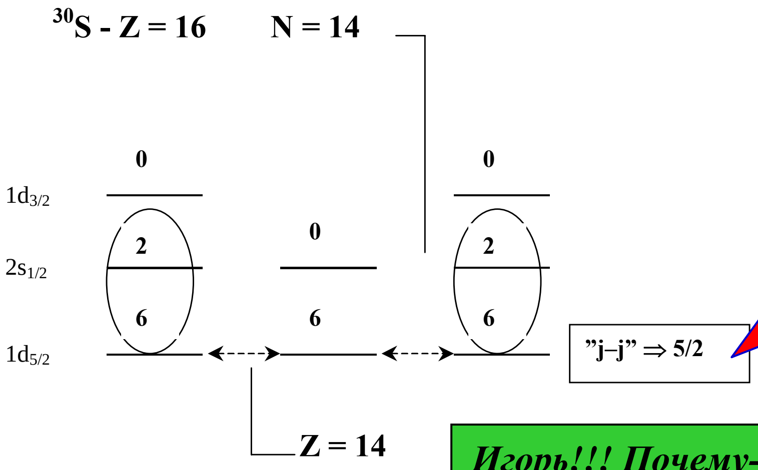
Neutron subshells in Ca isotopes: calculation in dispersion optical model



Large energy gaps between refered subshells in magic nuclei are well described in dispersion optical model (DOM).

Ca - gaps

^{30}S-^{30}Si



^{30}Si - ^{30}S subshells "j–j"- connect

If to apply that suggestion to subshells $\nu 1d_{5/2}$ and $\pi 1d_{5/2}$ - j - j (5/2) connection - and the above laying $(\pi/\nu)2s_{1/2}$, we should expect magic N = 16 for Z = 14, and magic Z = 16 for N = 14.

Surprisingly, but it really is like this. In Table the systematics of the first 2^+ level energies, $E_1(4^+)E_1(2^+)$ ratios and β_2 for nuclei with Z = 14 and N = 14 is presented. It is well visible, that in both cases the maximum is *reached at the conjugate numbers* Z/N = 16!

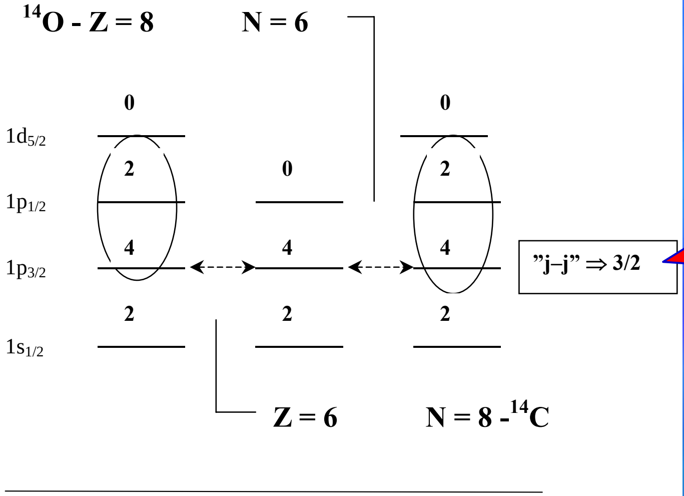
Игорь!!! Почему-то в этом случае в отличие от всех остальных (C, O, $^{54\text{-}52}$Ca, Zr-Sr) совсем (!) ничего хорошего не получается: добавление-убирание пары нуклонов заканчивается «абсолютно обычными» ядрами ^{28}Si и ^{32}S?!

N = 14									
Nucl	Z	E(2^+), keV	E(4^+)/E(2^+)	β_2	Nucl	N	E(2^+), keV	E(4^+)/E(2^+)	β_2
^{24}Ne	10	1982		0.41					
^{26}Mg	12	1809	2.39	0.48	^{26}Si	12	1796	2.92	0.44
^{28}Si	14	1780	2.6	0.41	^{28}Si	14	1779	2.6	0.42
^{30}S	16	2211		0.34	^{30}Si	16	2235	2.36	0.32
					^{32}Si	18	1942	2.69	0.35
					^{34}Si	***20***	***3228***		***0.18***
					^{36}Si	22	1399		0.26
					^{36}Si	24	1084		0.25

Magic number N = 20

^{30}Si - ^{30}S

^{14}C-^{14}O



^{14}C – ^{14}O subshells "j–j"- connection ⇒ 3/2.

Analogous sugestion to $\nu 1p_{3/2}$ and $\pi 1p_{3/2}$ - subshells - j - j (3/2) connection - and the above laying $(\pi/\nu)1p_{1/2}$ subshell leads not only to magic number Z =6 for N = 8, but to magic number N = 6 for Z = 8.

The systematics of the first 2^+ level energies, $E_1(4^+)E_1(2^+)$ ratios and β_2 for nuclei with Z = 6 and N = 6 confirms that in both cases «magicy» maximum is occured at Z/N = 6.

Z = 8					N = 6					Z = 6				
Nucl	N	E(2^+), keV	E(4^+)/E(2^+)	β_2	Nucl	Z	E(2^+), keV	E(4^+)/E(2^+)	β_2	Nucl	N	E(2^+), keV	E(4^+)/E(2^+)	β_2
					^{10}Be	4	3368		1.13	^{10}C	4	3354		0.82
					^{12}C	6	4439	3.17	0.59	^{12}C	6	4439	3.17	0.59
^{14}O	6	6590	1.5		^{14}O	8	6590	1.5		^{14}C	8	7012	1.53	0.36
^{16}O	***8***	***6917***	***1.5***	0.36	^{16}Ne	10	1690			^{16}C	10	1766	2.35	
^{18}O	10	1982	1.8	0.36						^{18}C	12	1620		
^{20}O	12	1674	2.13	0.21										

Addition of two $1p_{1/2}$ protons (to ^{14}C) or newtrons (to ^{14}O) leads to double magic ^{16}O.

Deletion of two $1p_{1/2}$ protons (from ^{14}O) or newtrons (from ^{14}C) leads to «slightly» magic ^{12}C.

Thus:

systematics of «magicy» parameters

energy of the first 2^+ level $E_1(2+)$
ratio of energies of first 4^+ and 2^+ levels $E_1(4+)/E_1(2+)$
quadrupole parameter β_2
neutron separation energy

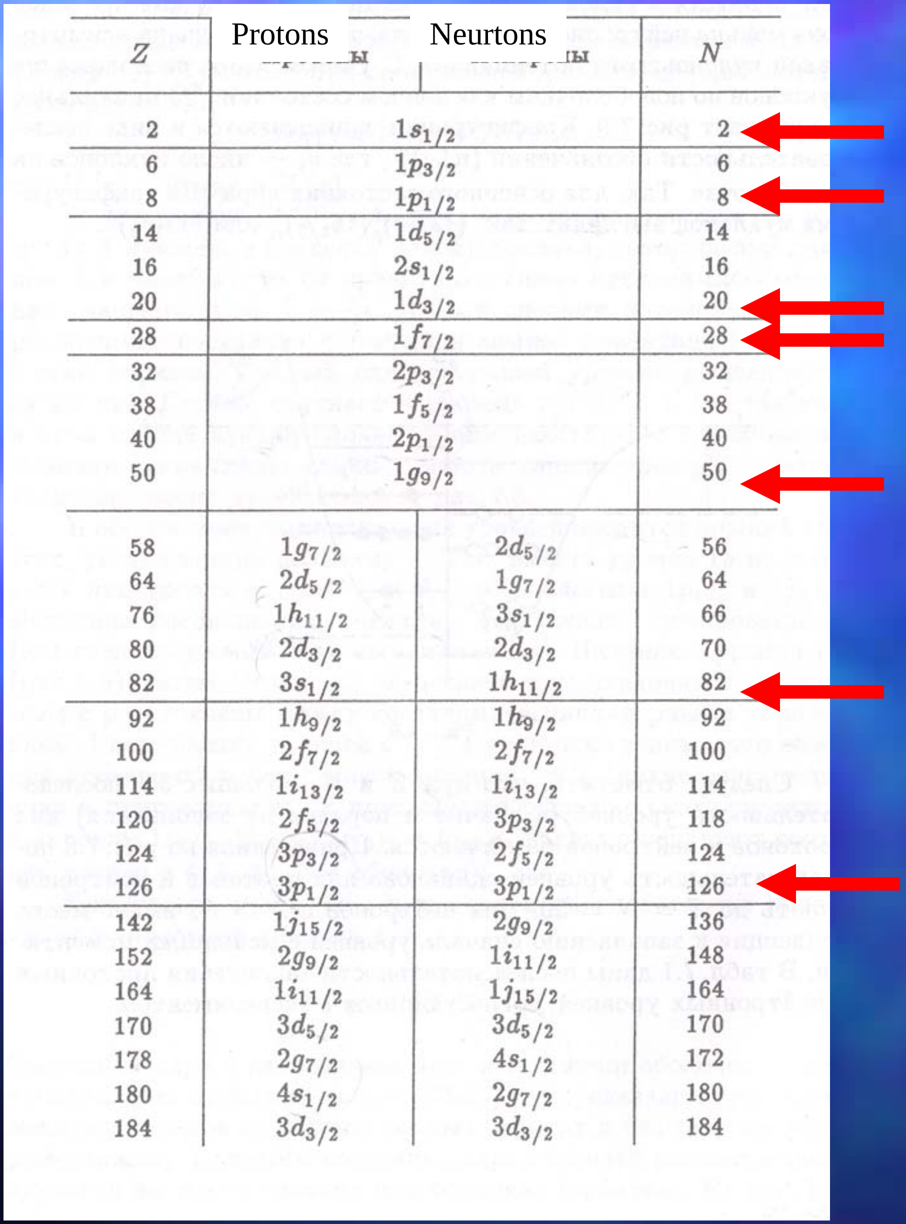
reveal existence of «new magic» nuclei with characteristic subshell structure (j - j connection)

^{14}C(6,8):	$\pi 1p_{3/2}$	- $\nu 1p_{3/2}{}^{\nu 1p1/2}$	(j - j ⇒ 3/2)
^{14}O(8,6):	$\pi 1p_{3/2}{}^{\pi 1p1/2}$	- $\nu 1p_{3/2}$	(j - j ⇒ 3/2)
^{30}Si(14,16):	$\pi 1d_{5/2}$	- $\nu 1d_{5/2}{}^{\nu 2s1/2}$	(j - j ⇒ 5/2)
^{30}S(16,14):	$\pi 1d_{5/2}{}^{\pi 2s1/2}$	- $\nu 1d_{5/2}$	(j - j ⇒ 5/2)
^{54}Ca(20,34):	$\pi 1d_{3/2}$	- $\nu 2p_{3/2}{}^{\nu 2p1/2}$	(j - j ⇒ 3/2)
^{96}Zr(40,56):	$\pi 1f_{5/2}{}^{\pi 2p1/2}$	- $\nu 2d_{5/2}$	(j - j ⇒ 5/2)

Final «hot» questions:

- What is the «magicy» phenomenon in general?
- Is there (what) a difference between traditional and «new» magic nuclei?
- Is «magicy» an quantity which can be more and less?
- What is the role of out nucleon (2 protons or 2 neutrons) pair?
- Can not we talk about an additional specific attractive proton-neutron interaction?

Thanks a lot
for your attention!



Z	Protons	Neurtons	N
2	$1s_{1/2}$		2
6	$1p_{3/2}$		6
8	$1p_{1/2}$		8
14	$1d_{5/2}$		14
16	$2s_{1/2}$		16
20	$1d_{3/2}$		20
28	$1f_{7/2}$		28
32	$2p_{3/2}$		32
38	$1f_{5/2}$		38
40	$2p_{1/2}$		40
50	$1g_{9/2}$		50
58	$1g_{7/2}$	$2d_{5/2}$	56
64	$2d_{5/2}$	$1g_{7/2}$	64
76	$1h_{11/2}$	$3s_{1/2}$	66
80	$2d_{3/2}$	$2d_{3/2}$	70
82	$3s_{1/2}$	$1h_{11/2}$	82
92	$1h_{9/2}$	$1h_{9/2}$	92
100	$2f_{7/2}$	$2f_{7/2}$	100
114	$1i_{13/2}$	$1i_{13/2}$	114
120	$2f_{5/2}$	$3p_{3/2}$	118
124	$3p_{3/2}$	$2f_{5/2}$	124
126	$3p_{1/2}$	$3p_{1/2}$	126
142	$1j_{15/2}$	$2g_{9/2}$	136
152	$2g_{9/2}$	$1i_{11/2}$	148
164	$1i_{11/2}$	$1j_{15/2}$	164
170	$3d_{5/2}$	$3d_{5/2}$	170
178	$2g_{7/2}$	$4s_{1/2}$	172
180	$4s_{1/2}$	$2g_{7/2}$	180
184	$3d_{3/2}$	$3d_{3/2}$	184

~ 200 stable nuclei -
classic
single-particle shell model

⇓

7 classic magic nimbers:
2, 8, 20, 28, 50, 82, 126

Some typical features of magic nuclei (compare to neighboring):

- those are more spheric (less deformed) - quadrupole deformation parameter β_2 is clearly smaller;
- energy of first $J^\pi = 2^+$ level is clearly higher;
- ratio of energies of first $J^\pi = 4^+$ and $J^\pi = 2^+$ levels is clearlt smaller;
- there are clear irragularities in nucleon separation energies;
- some others;

⇓

«magicy parameters»:

$E(2^+_1)$

$E(4^+_1)/ E(2^+_1)$

β_2