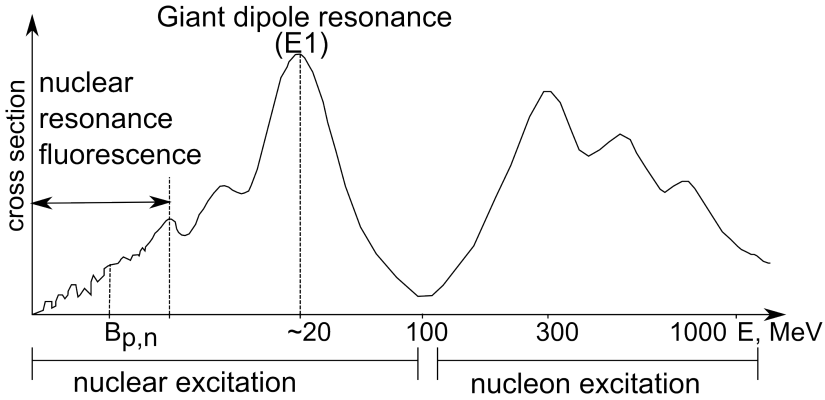
Microscopic description of E1 resonance in light nuclei

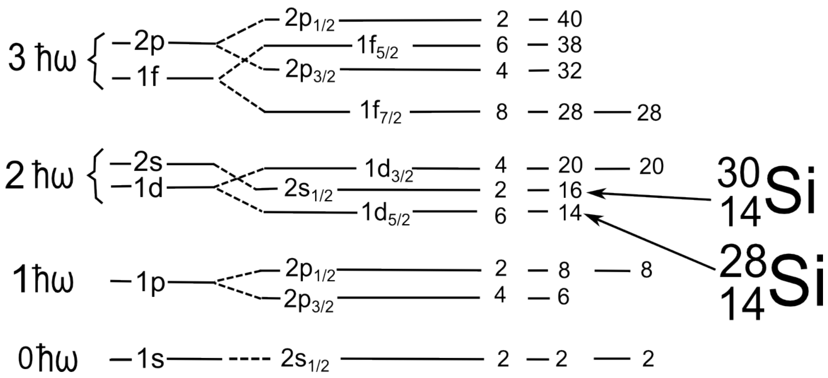
Goncharova N.G, Tretyakova T. Yu, Fedorov N.A.
SINP MSU

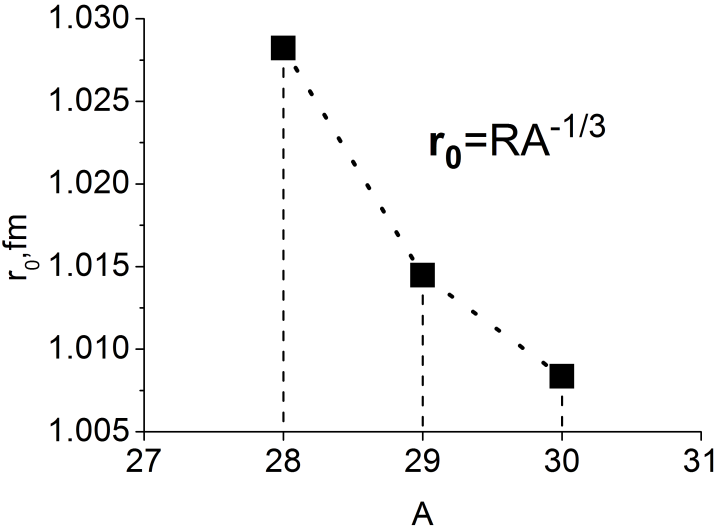
JUNE 27, 2015

Plan

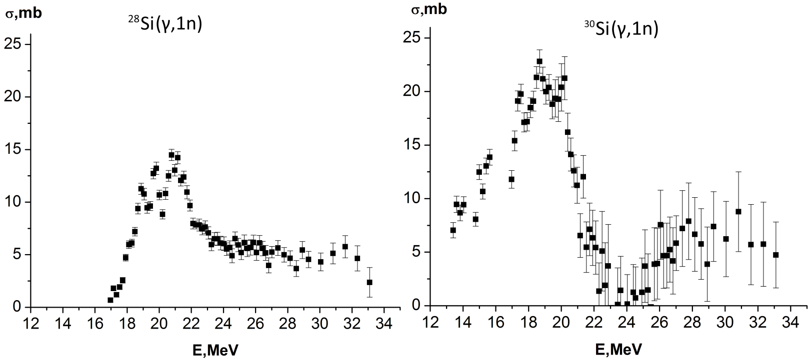
1. Introduction
2. Silicon isotopes
3. Model of particle-core coupling (PCC)
4. Resonance excitation schemes
5. Form factors of $E1$ resonance
6. Results


Giant dipole resonance
(E1)
cross section
nuclear
resonance
fluorescence
Bp,n
~20
100
300
1000
E, MeV
nuclear excitation
nucleon excitation


3 ħω
2p
1f
2p$_{1/2}$
1f$_{5/2}$
2p$_{3/2}$
1f$_{7/2}$
2 — 40
6 — 38
4 — 32
8 — 28 — 28
2 ħω
2s
1d
1d$_{3/2}$
2s$_{1/2}$
1d$_{5/2}$
4 — 20 — 20
2 — 16
6 — 14
1ħω
1p
2p$_{1/2}$
2p$_{3/2}$
2 — 8 — 8
4 — 6
0ħω
1s
2s$_{1/2}$
2 — 2 — 2
$^{30}_{14}$Si
$^{28}_{14}$Si



1.030
1.025
1.020
1.015
1.010
1.005
r0,fm
$r_0=RA^{-1/3}$
27
28
29
30
31
A


σ,mb
^{28}Si(γ,1n)
25
20
15
10
5
0
12 14 16 18 20 22 24 26 28 30 32 34
E,MeV
σ,mb
^{30}Si(γ,1n)
25
20
15
10
5
0
12 14 16 18 20 22 24 26 28 30 32 34
E,MeV

Within the PCC version, the wave functions for the ground and excited states of the nucleus being considered can be represented as the following expansions:

$$|J_f T_f\rangle = \sum \alpha_f^{J' T' j_f} |(J' E' T')_{(A-1)} \times (n_f l_f j_f) : J_f T_f\rangle$$

$$|J_i T_i\rangle = \sum C_i^{J' T' j_i} |(J' E' T')_{(A-1)} \times (n_i l_i j_i) : J_i T_i\rangle$$

where $|(J' E' T')_{(A-1)}\rangle$ is core wave function, and $|(n_f l_f j_f)\rangle$-particle wave function.

Model of particle-core coupling (PCC)

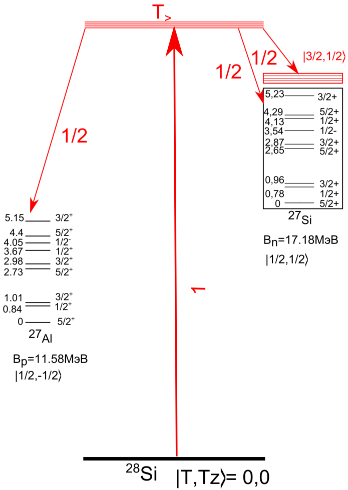
$$|J_f T_f\rangle = \sum \alpha_f^{J' T' j_f} |(J' E' T')_{(A-1)} \times (n_f l_f j_f) : J_f T_f\rangle, \qquad (1)$$

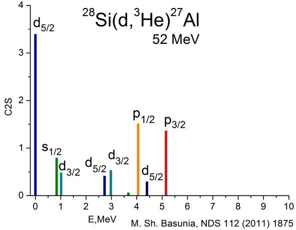
$$|J_i T_i\rangle = \sum C_i^{J' T' j_i} |(J' E' T')_{(A-1)} \times (n_i l_i j_i) : J_i T_i\rangle, \qquad (2)$$

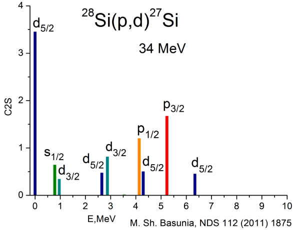
- The coefficients $\alpha_f^{J' T' j_f}$ arise upon the diagonalization of the Hamiltonian in the basis of the configurations
- Coefficients $C_i^{J' T' j_i}$ were estimated with the aid of experimental data on the spectroscopy of direct nucleon-pickup reactions: $C_i^{J' T' j_i} \approx \sqrt{\frac{S_i}{\sum S_k}}$, where S_i is the spectroscopic factor of the reaction that leads to the excitation of the $(J' E' T')$ level of the final-state nucleus $(A-1)$
- $\sum S_k$ is the sum of spectroscopic factors of the states with (J', T')
- Photonuclear cross-section in E1 resonance area can be estimated by form factor calculation in photopoint $q = E_{exc}$.

$$F_{EJ}^2 = \frac{1}{2J_i + 1} |\langle J_f T_f || \hat{T}_1^{el}(q = \omega) || J_i T_i\rangle|^2. \qquad (3)$$

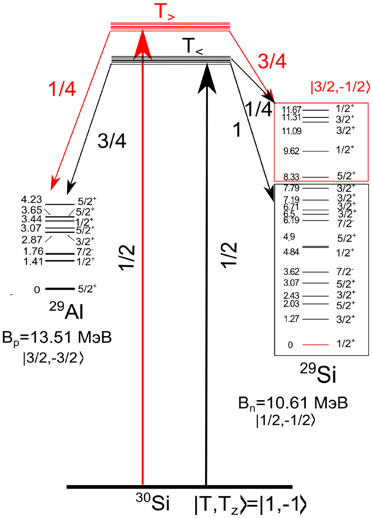
$E1$ resonance excitation in ^{28}Si

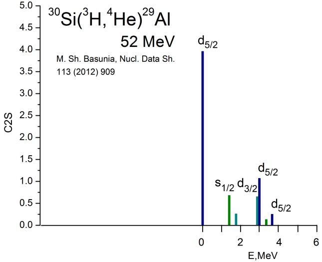


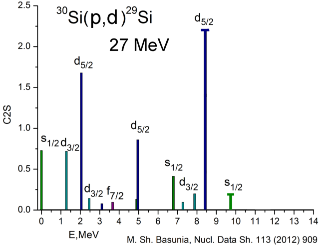




$E1$ resonance excitation in ^{30}Si





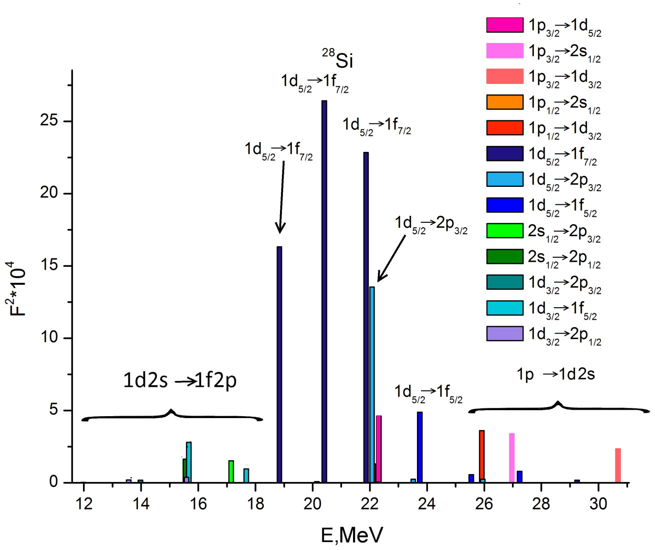


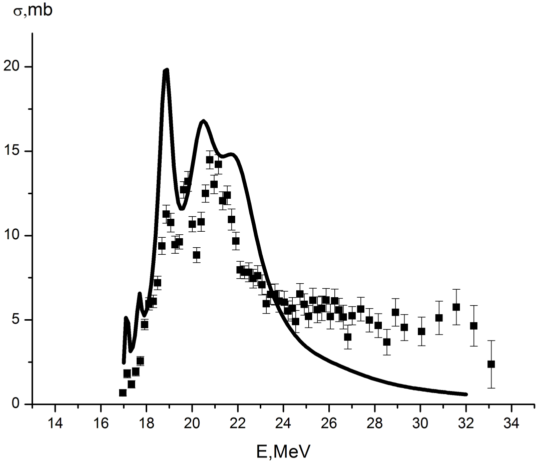
- Basis parameters

Nucleus, $\lvert\vec{T}\rvert$	^{28}Si	^{30}Si $T = 1$	^{30}Si $T = 2$
Basis dimension	25	38	13
Reaction	^{28}Si(p,d) $T_p = 34$MeV	^{30}Si(p,d) $T_{\mathrm{p}} = 27$MeV	^{30}Si(p,d) $T_{\mathrm{p}} = 27$MeV

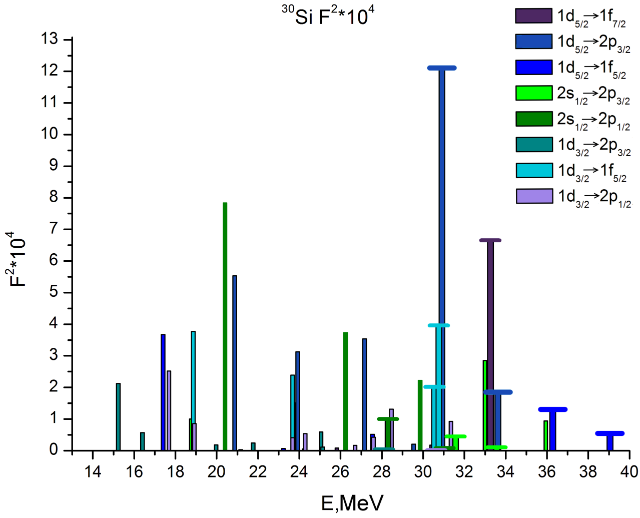
- Spectroscopy for ^{28}Si: R. L. Kozub Phys. Rev. 172 (1968) 1078–1094
- for ^{30}Si: 17. R.C. Haight *et al* Nucl. Phys. A241 (1975) 275

Form factors of $E1$ in ^{28}Si

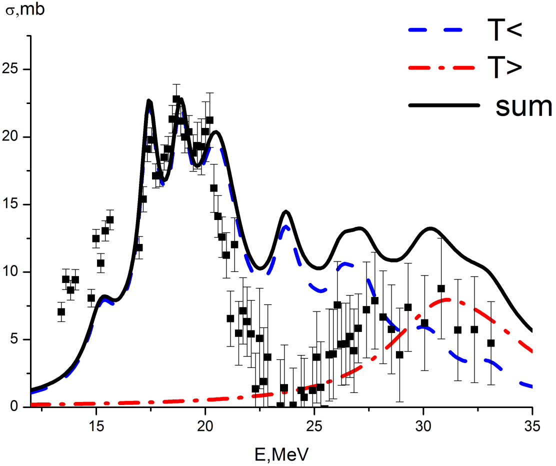




Experiment: R.E. Pywell *et al.* Phys.Rev.C 27 (1983) p960, reaction ^{28}Si(γ,n)^{27}Si



30Si F2*104
13
12
11
10
9
8
7
6
5
4
3
2
1
0
F2*104
14
16
18
20
22
24
26
28
30
32
34
36
38
40
E,MeV
1d5/2→1f7/2
1d5/2→2p3/2
1d5/2→1f5/2
2s1/2→2p3/2
2s1/2→2p1/2
1d3/2→2p3/2
1d3/2→1f5/2
1d3/2→2p1/2

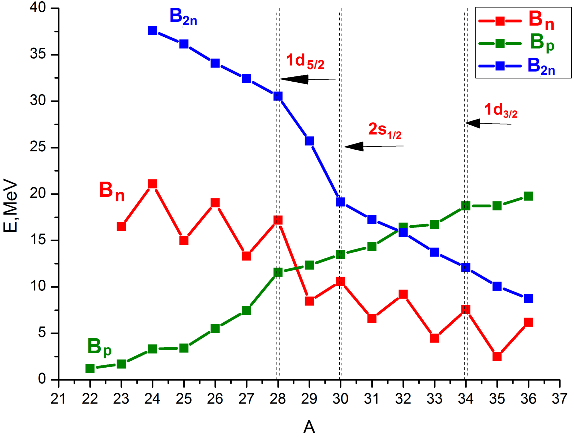


Experiment: R.E. Pywell *et al.* Phys.Rev.C 27 (1983) p960, reaction ^{30}Si(γ,n)^{29}Si

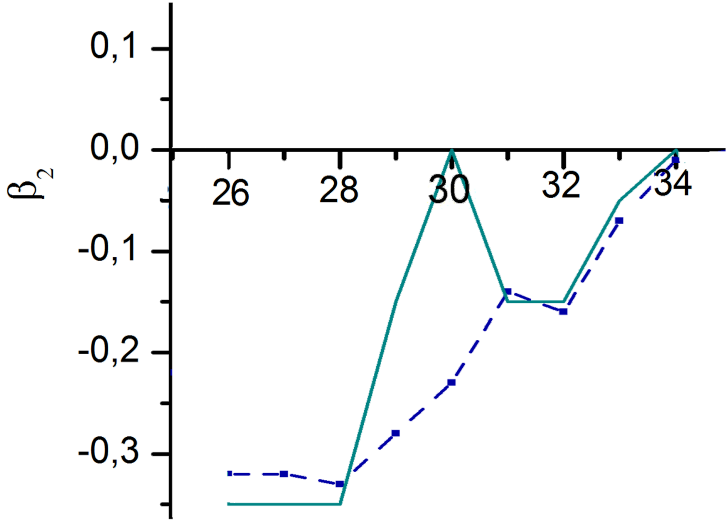
Thank you for your attention!

A	**J**^{P}	**E**$_{\mathbf{bin}}$**/A MeV**	**Abundance or T1/2**	**Decay Modes**
26	0^+	7924.707 ± 0.004	2.229 s	ε 100%
27	$5/2^+$	8124.337 ± 0.005	4.15 s	ε 100%
28	0^+	8447.744 ± 0.000	**92.223 ± 0.019 %**	
29	$1/2^+$	8448.635 ± 0.001	**4.685 ± 0.008 %**	
30	0^+	8520.654 ± 0.001	**3.092 ± 0.011%**	
31	$3/2^+$	8458.291 ± 0.001	157.3 m	β^-100%
32	0^+	8481.468 ± 0.009	153 y	β^-100%
33	$3/2^+$	8361.059 ± 0.021	6.1 s	β^-100%

Properties of silicon isotopes



Separation energies for one (B_n), two (B_{2n}) neutrons and one proton (B_p). Data from AME2012



The deformation parameter calculations in HF for silicon isotopes. The solid line–resuls from J.-P. Delaroche et al, Phys. Rev. C 81 (2010) 014303, dashed line–S.Goriley, At. Data and Nucl. Data Tables 77

A	β_2(B(E2)↑)	β_2($\mathbf{Q_{mom}}$)	β_2-calc	Charge radius
26	0.444 ± 0.022			
27		0.097 ± 0.006 (g.s.)		
28	0.407 ± 0.007	-0.352 ± 0.076 (2+)	-0.366	3.1224 ± 0.0024
29				3.1176 ± 0.0052
30	0.316 ± 0.007	+0.094 ± 0.118 (2+)	0.179	3.1336 ± 0.004
32	0.345 ± 0.031	+0.293 ± 0.05 (2+)	-0.23	
34	0.179 ± 0.036			
36	0.259 ± 0.042			
38	0.249 ± 0.048			

Data from CDFE: http://cdfe.sinp.msu.ru

We can estimate the $\Gamma_{i\to j}$ by formula (4)

$$\Gamma_{ij} = 2C_w\alpha_{ij}^2 k_{ij} P(l_j) T_{ij} \tag{4}$$

where C_w is the Wigner's width, α-coefficient from (1),

$$k_{ij} = \frac{\sqrt{2m_{particle}(E_i - E_f - E_{sep})}}{\hbar c},\ T_{ij} = \langle T_f T_{3f}\ T_{particle} T_{3\ particle} | T_i T_{3i}\rangle^2, \tag{5}$$

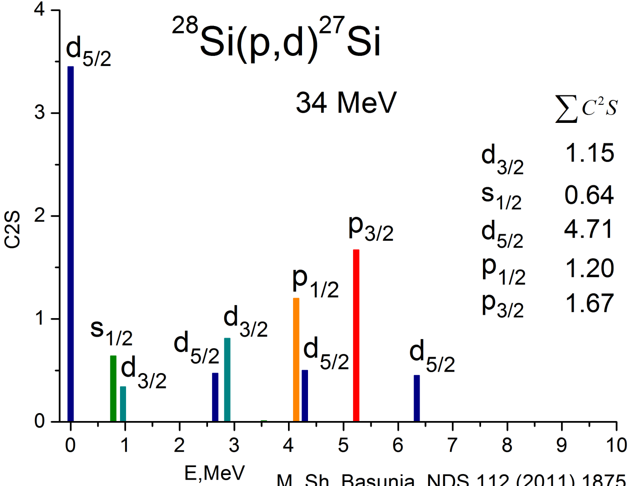
$P(l_j)$-penetrability of angular momentum barrier.

$$C_w = \frac{3(\hbar c)^2}{2r_{channel}^2 m_{particle} c^2} \quad \left[\frac{MeV^2 * fm^2}{fm^2 * MeV} = MeV\right] \tag{6}$$

$$f_i\left(1 + \frac{2arctg\left(\frac{2E_i}{\Gamma_i}\right)}{\pi}\right) = \frac{8\pi^2\alpha F_i^2}{E_i} \tag{7}$$

$$\sigma_{ij} = \frac{1}{\pi}\frac{f_i\Gamma_{ij}}{(E - E_i)^2 + \left(\frac{\Gamma_i}{2}\right)^2} \tag{8}$$

Spectroscopy of ^{28}Si



M. Sh. Basunia, NDS 112 (2011) 1875

Spectroscopy of ^{30}Si