Study of the astrophysical $^{25}Al(p,\gamma)^{26}Si$ nuclear reaction

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Outline

* Nuclear shell model and sd-shell nuclei.

* Importance of Silicon in astrophysics.

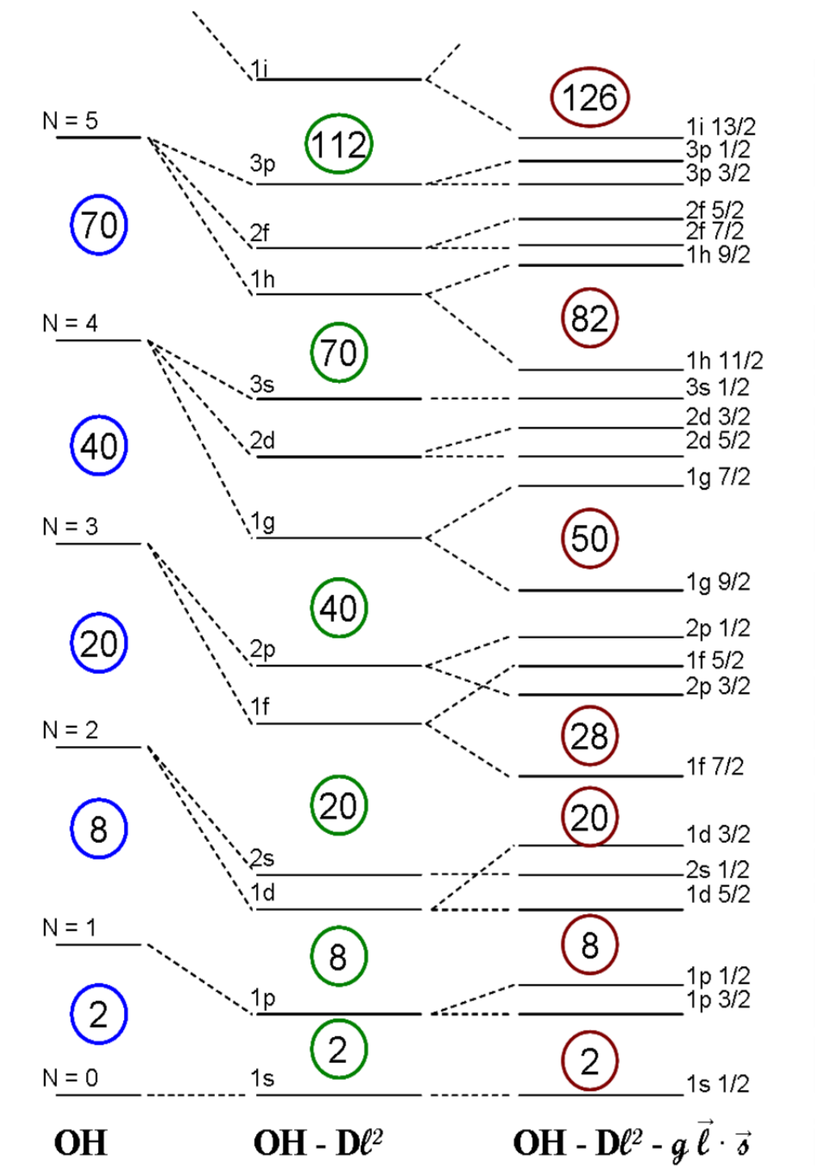
* Spectroscopic properties of ^{26}Si.

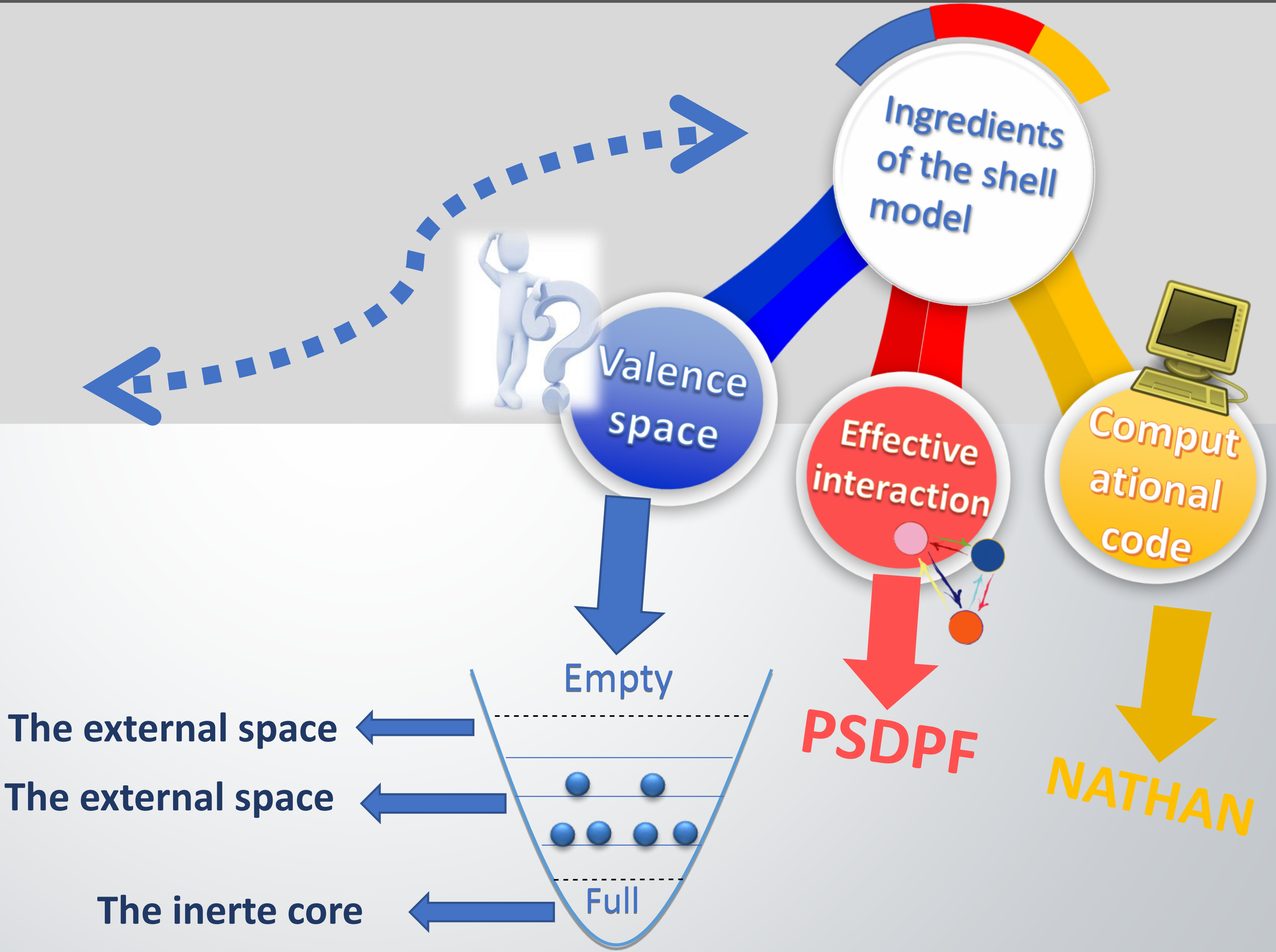
* ^{26}Si excitations of interest for the thermonuclear $^{25}Al(p,\gamma)^{26}Si$ reaction.

* Rate of reaction through a narrow resonance.

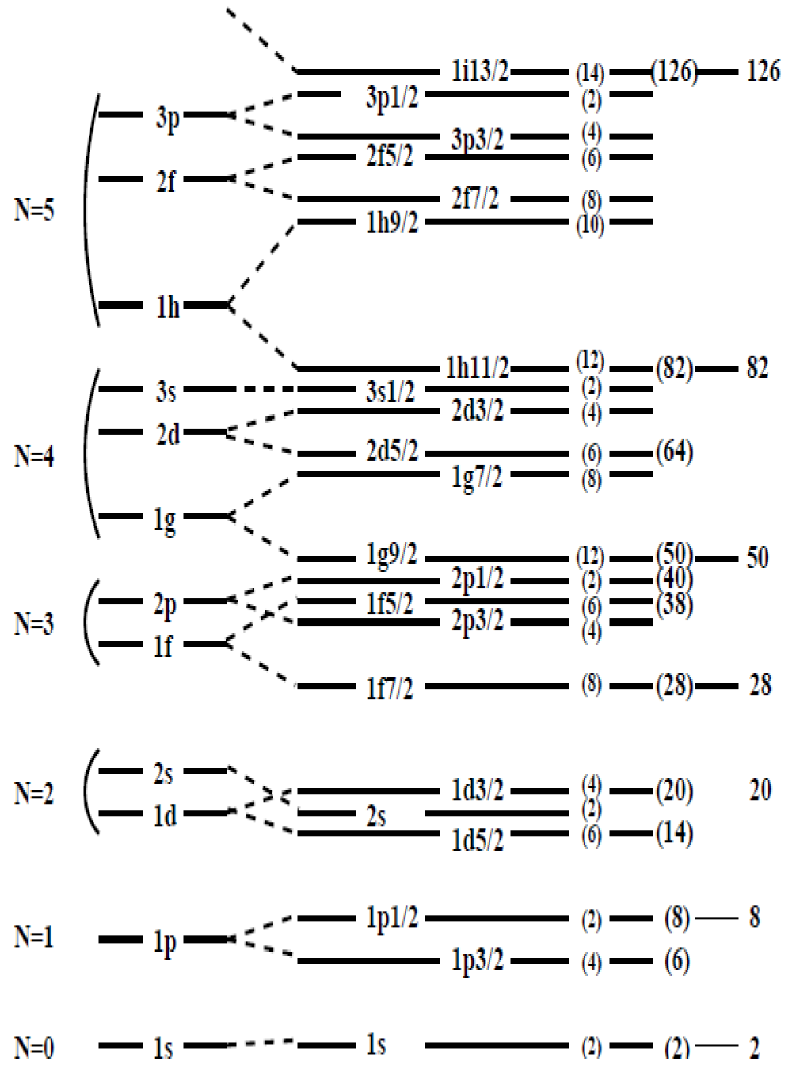
* Conclusion.

Nuclear shell model and sd-shell nuclei





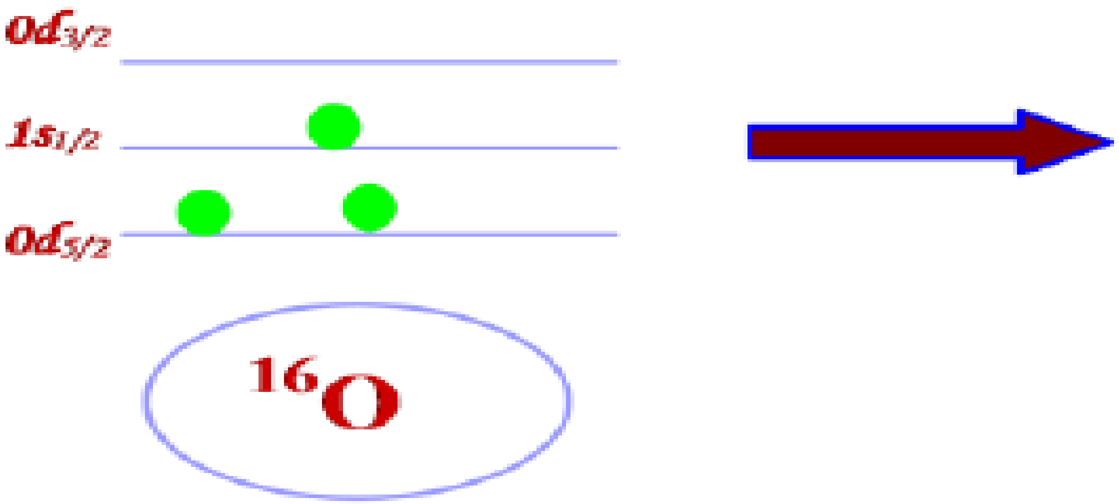
Nuclear shell model and sd-shell nuclei



THE SD-SHELL NUCLEI ARE THOSE HAVING A NUMBER OF PROTONS (Z) AND NEUTRONS (N) BETWEEN 8 AND 20 (I.E NUCLEI FROM ^{16}O TO ^{40}CA

Nuclear shell model and sd-shell nuclei

USD
(USDA/B)



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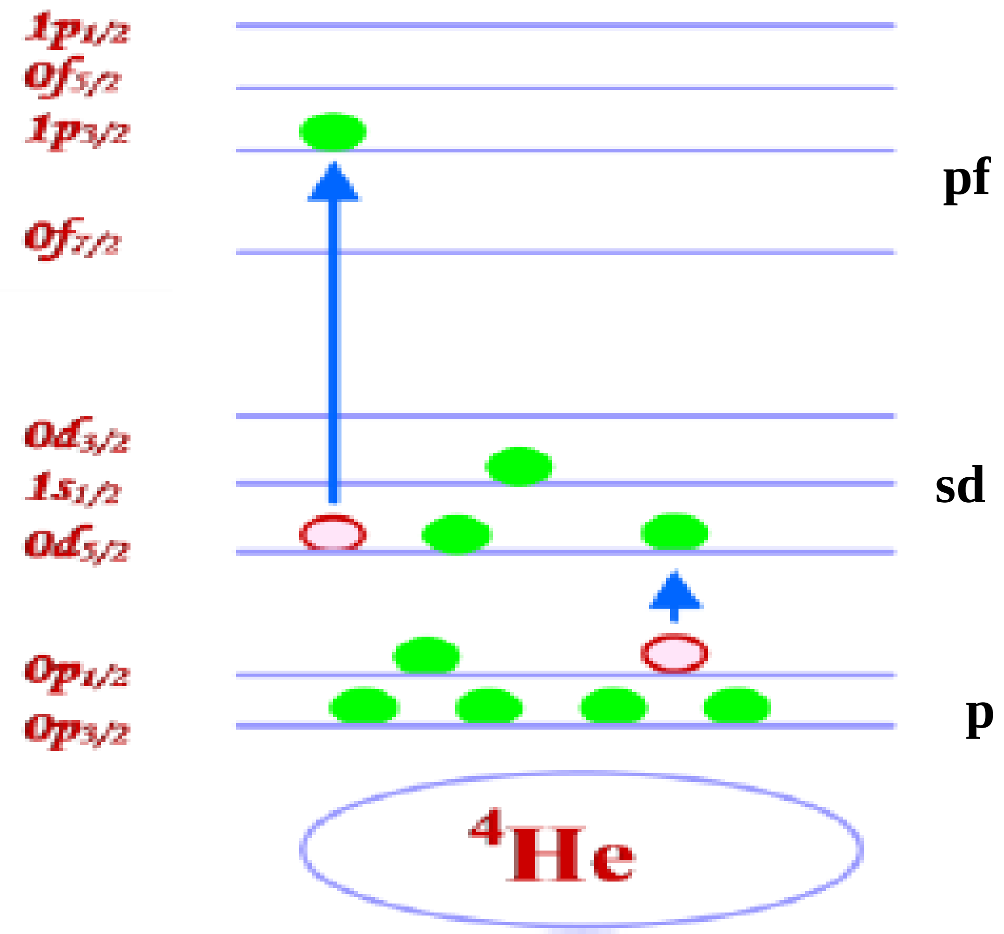
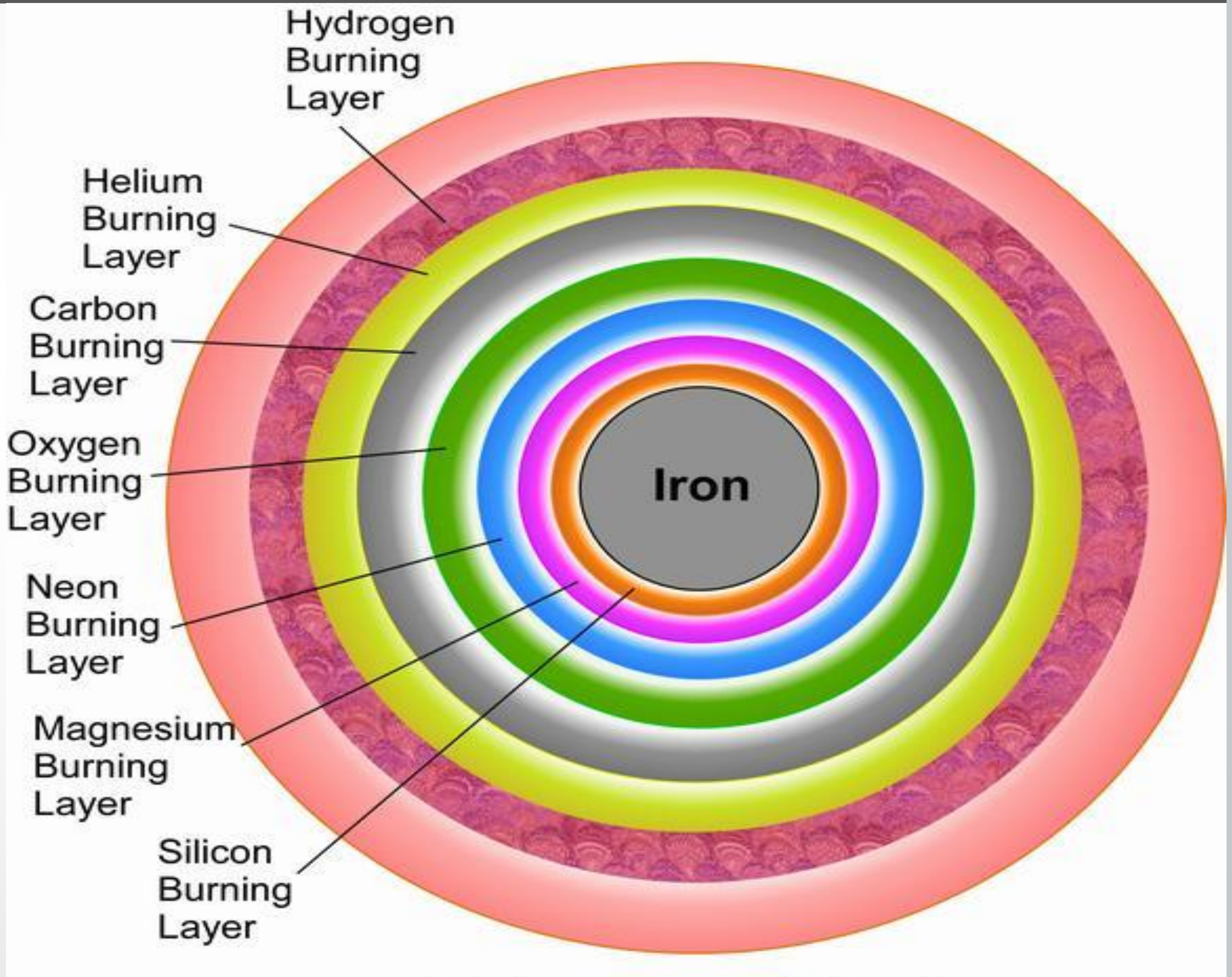


Importance of Silicon in astrophysics

As it is the eighth most abundant element in the Universe, silicon has a significant astrophysical interest. This element plays a crucial role in the comprehension of nucleosynthesis, especially, the galactic chemical evolution,which begins when gravitational contraction raises the stars core temperture to 2.7-3.5(GK).



End Stage of a 20M$_\odot$ Star

Importance of Silicon in astrophysics

*$^{23}Al(p,\gamma)^{24}Si$ → **Type I x ray bursts.**

*$^{25}Al(p,\gamma)^{26}Si$ → **Type I x ray bursts, Carbon-burning and Explosive neon-burning.**

*$^{23}Ne(\alpha,p)^{26}Mg$ → **Explosive Ne/C burning (2.3 GK), Convective shell C/Ne burning (1.4 GK).**

Importance of Silicon in astrophysics

*$^{26}Al(p,\gamma)^{27}Si$ → Hydrogen-burning.

*$^{26}Mg(p,\gamma)^{27}Al$ → Hydrogen-burning (MgAl cycle).

*$^{31}P(p,\gamma)^{28}Si$

*$^{27}Al(p,\gamma)^{28}Si$

} → Hydrogen burning.

$^{25}Al(p,\gamma)^{26}Si$

Spectroscopic properties of ^{26}Si

* The structures of ^{26}Si is not well known and it is experementally difficult to reach because they have N<Z.

* We used its mirror nucleus ^{26}Mg to determine the J^{π} assignments in the neutron deficient isotopes ^{26}Si.

* We calculated, using the PSDPF interaction, its excitation energies from 0 to ~ 9 Mev.

Spectroscopic properties of ^{26}Si

(ENERGY SPECTRA)

E(Si)		*E(Mg)*		*Shell model*		
E_{exc} (MeV)	J^π	E_{exc} (MeV)	J^π	E_{exc} (MeV)	J^π	ΔE=Eth-Eexp
0	0^+	0	0^+	0	0^+_1	0
1,797	2^+	1,809	2^+	1,878	2^+_1	0,081
2,787	2^+	2.938	2^+	3,042	2^+_2	0,255
3,336	0^+	3.589	0^+	3,829	0^+_2	0,493
3,758	(3^+)	3.942	3^+	3,990	3^+_1	0,232
4,139	2^+	4,333	2^+	4,590	2^+_3	0,451
4,188	(3^+)	4,350	3^+	4,389	3^+_2	0,201
4,446	(4^+)	4,319	4^+	4,397	4^+_1	-0,049
4,797	(4^+)	4,901	4^+	5,013	4^+_2	0,216
4,811	(2^+)	4,835	2^+	4,944	2^+_4	0,133
4,831	(0^+)	4,972	0^+	4,909	0^+_3	0,078
5,148	2^+	5,292	2^+	5,50	2^+_5	0,352
5,289	4^+	5,476	4^+	5,553	4^+_3	0,264
5,518	(4^+)	5,716	4^+	5,925	4^+_4	0,407
5,676	1^+	5,691	(1^+)	5,693	1^+_1	0,017
5,890	0^+					

Spectroscopic properties of ^{26}Si

(ENERGY SPECTRA)

5,929	3^+	6,125	3^+	6,283	3^+_3	0,354
5,946	(0^+)	6,256	0^+	6,278	0^+_4	0,332
6,295	2^+	6,745	2^+	6,668	2^+_6	0,373
6,383	(2^+)	6,623	(4^+)	6,815	4^+_5	0,432
6,461	0^+	6,634		6,668	1^+_2	0,207
6,766		7,062	1^-	6,663	1^-_1	-0,103
6,787	3^-	6,876	3^-	6,716	3^-_1	-0,071
6,811				6,736	2^-_1	-0,074
6,880	(0^+)	7,200	$(0,1)^+$	8,070	0^+_5	1,190
7,019	(3^+)	7,246	3^+	7,341	3^+_4	0,323
7,154	2^+	7,100	2^+	6,936	2^+_7	-0,218
7,199	(5^+)	6,978	(5^+)	7,086	5^+_1	-0,112
7,418	(4^+)	7,677	(4^+)	7,530	4^+_6	0,112
7,496	2^+	7,371	2^+	7,214	2^+_8	-0,282
7,522	(5^-)	7,396	(5^+)	7,447	5^+_2	-0,075
7,607		7,542	(2^-)	7,697	2^-_2	0,091
7,674	(2^+)	7,818	$(2,3)^+$	7,575	2^+_9	-0,099

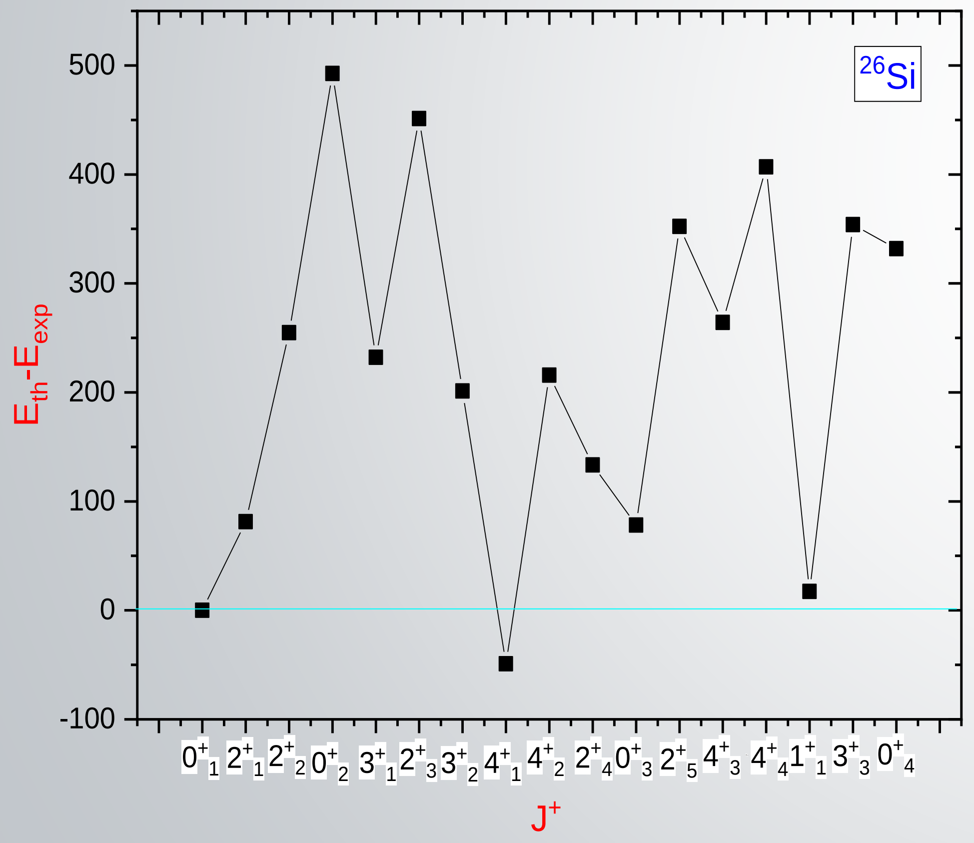
Spectroscopic properties of ^{26}Si

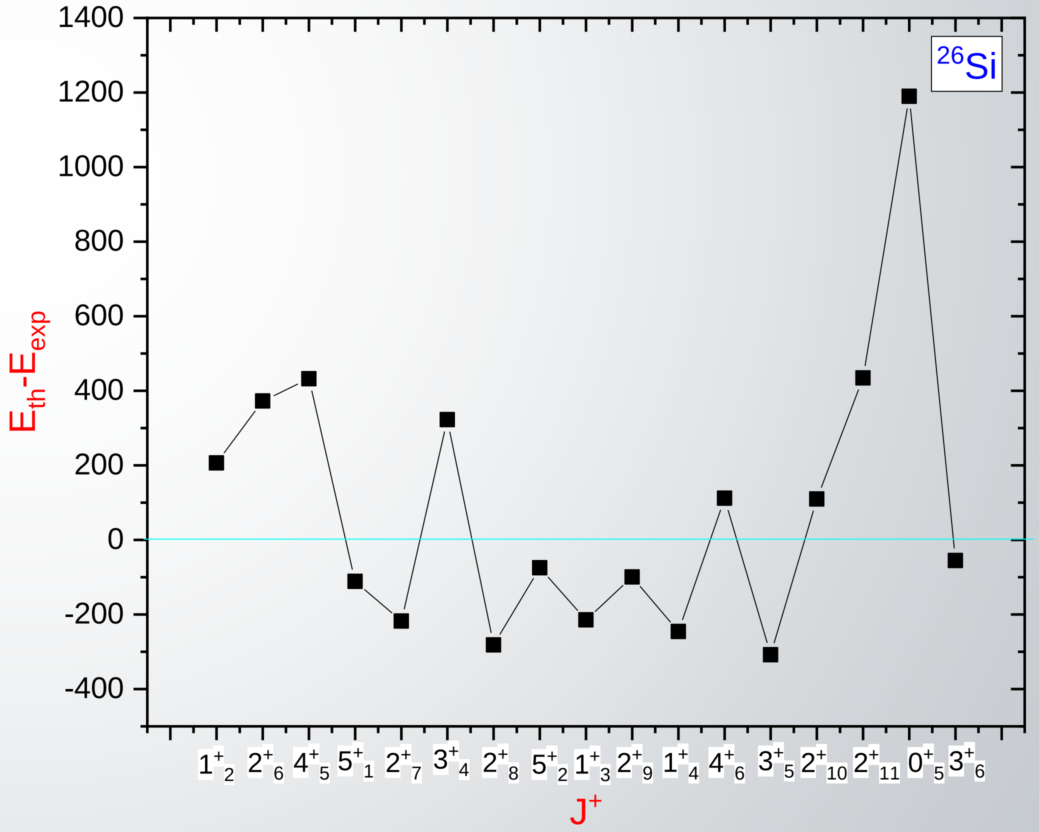
(ENERGY SPECTRA)

7,701	(3^-)	7,349	3^-	7,495	3^-_2	-0,206
7,886	(1^-)	7,261		7,492	1^-_2	-0,394
7,921		7,697	$1(^-)$	7,734	1^-_3	-0,187
7,963		7,283	(4^-)	7,898	4^-_1	-0,064
8,008	(3^+)	7,726	3^+	7,700	3^+_5	-0,308
8,144	$(1^-,2^+)$	7,428	$(0,1)^+$	7,930	1^+_3	0,214
8,223	(1^-)	8,227	1^-	8,077	1^-_4	-0,145
8,254		7,824	3^-	7,937	3^-_3	-0,317
8,269	(2^+)	7,840	2^+	8,379	2^+_{10}	0,110
8,283		7,851		7,951	2^-_3	-0,331
8,356	(3^+)	8,251	(3^+)	8,301	3^+_6	-0,055
8,431		8,034		8,160	2^-_4	-0,271
8,558	(2^+)	8,052	$2(^+)$	8,993	2^+_{11}	0,435
8,689	$(1^-,2^+)$	8,576		8,443	1^+_4	-0,246

Spectroscopic properties of ^{26}Si

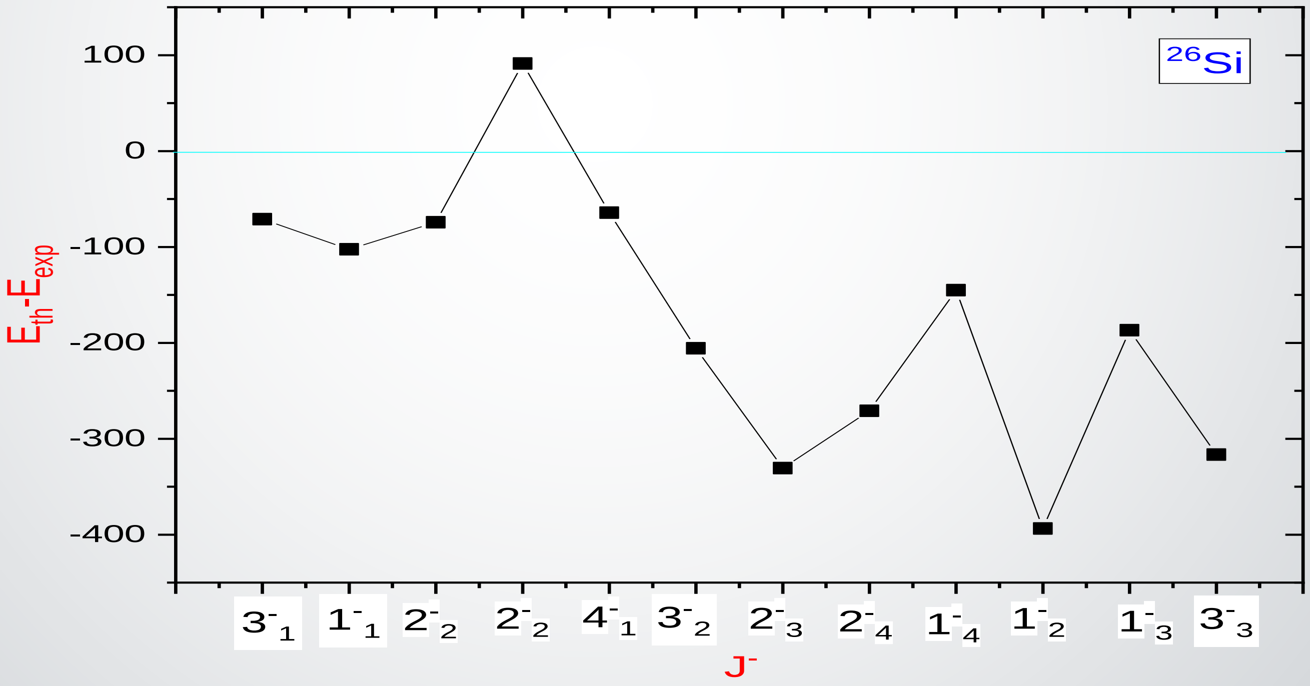
(ENERGY SPECTRA)





Spectroscopic properties of ^{26}Si

(ENERGY SPECTRA)



^{26}Si Excitations of interest for thermonuclear ^{25}Al(p,γ)^{26}Si reaction

* The ^{25}Al(p,γ)^{26}Si reaction is important for our understanding of the ^{26}Si abundance in massive stars.

* States in ^{26}Si above the proton threshold energies (Sp =5.514 MeV), have an astrophysical interest and play a crucial role in the calculation of the ^{25}Al(p,γ) reaction rate.

* We propose the J^{π} assignments of states of astrophysical interest as fellow.

^{26}Si Excitations of interest for thermonuclear $^{25}Al(p,\gamma)^{26}Si$ reaction

E(Si)	E(Si)	Shell model (Si)	Shell model (Si)
E_{EX}(Mev)	J^{π}	E_{ex}(Mev)	J^{π}_{i}
5,518	(4^+)	5,925	4^+_4
5,676	1^+	5,693	1^+_1
5,890	0^+		
5,929	3^+	6,283	3^+_3
5,946	(0^+)	6,278	0^+_4
7,154	2^+	6,936	2^+_7
7,418	(4^+)	7,53	4^+_6
7,496	2^+	7,214	2^+_8
7,522	(5^-)	7,447	5^+_2
7,674	(2^+)	7,575	2^+_9
7,701	(3^-)	7,495	3^-_2
8,886	(1^-)	7,492	1^-_2
8,008	(3^+)	7,7	3^+_5
8,222	(1^-)	8,077	1^-_4
8,269	(2^+)	8,379	2^+_{10}
8,356	(3^+)	8,301	3^+_6

Rate of reaction through a narrow resonance

In this case, the resonance energy must be ‘near’ to the relevant energy range ΔE to contribute to the stellar reaction rate.

The contribution of a single narrow resonance to the stellar reaction rate is given as:

$$N_A\langle\sigma v\rangle=1{,}54\times 10^{11}(\mu T_9)^{(-3/2)}(\omega\gamma)\exp\left(\frac{-E_r}{KT}\right) cm^3 s^{-1} mol^{-1}$$

Here T_9 is the temperture in GK, $E_r = E_f - E_i$ is the resonance energy in the center of mass system, the resonance strength in MeV for proton capture is given by:

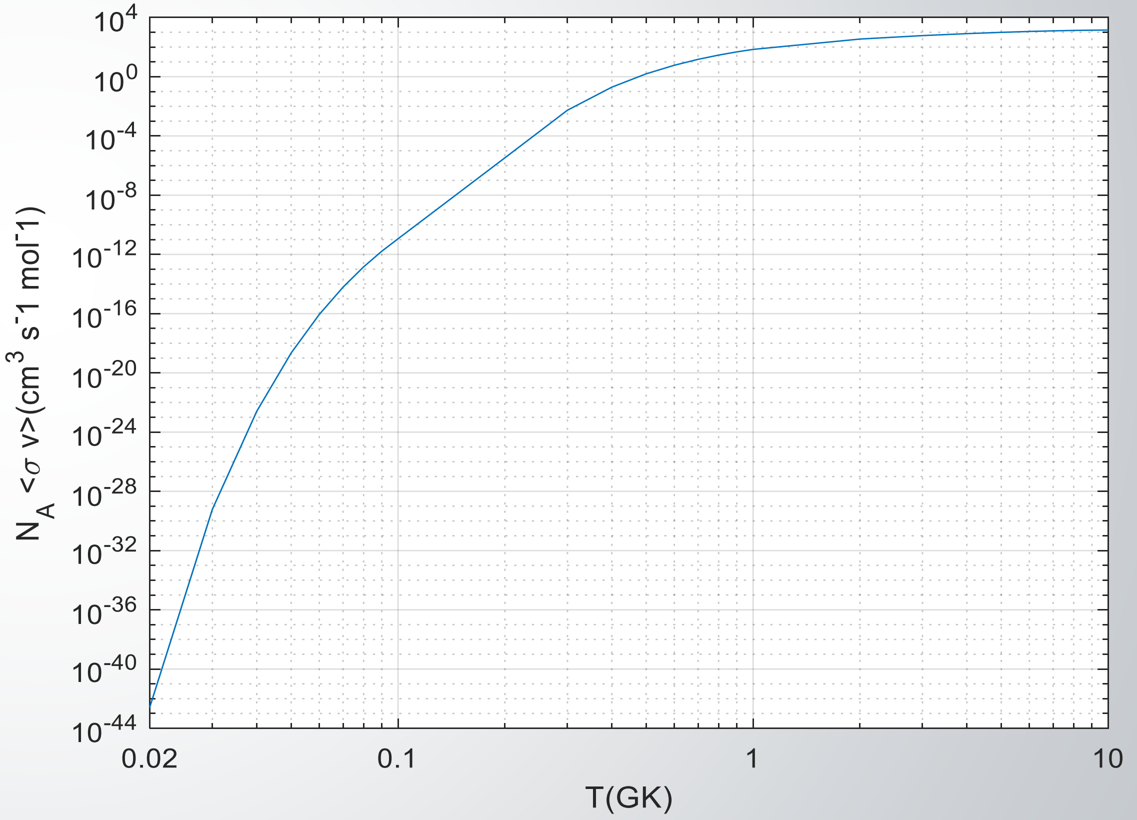
$$\omega\gamma_{if} = \frac{(2J_f+1)}{(2J_p+1)(2J_i+1)}\frac{\Gamma_{pif}\Gamma_{\gamma f}}{\Gamma_{totalf}}$$

$\Gamma_{total} = \Gamma_{pif} + \Gamma_{\gamma f}$ is a total width of the resonance level and J_i, J_p and J_f refer to the terget, the proton projectile $(J_p = 1/2)$, and states in the final nucleus, respectively, which in turn depends mainly on the total and partial widths of the resonance, and the reaction rate is determined by the smaller one of the widths.

Rate of reaction through a narrow resonance

E_{ex} (MeV)	J^π	Γ_p (eV)	$\Gamma_\gamma(th)$ (eV)	E_{res} (MeV)	ωγ (th) (eV)
5,676	1^+_1	1.3×10^{-9}	1.20×10^{-1}	0.162	3.25×10^{-10}
5,929	3^+_3	2.9	9.20×10^{-2}	0.415	5.2×10^{-2}
5,946	0^+_4	1.9×10^{-2}	5.70×10^{-3}	0.432	3.65×10^{-4}
6,295	2^+_6	5.06×10^{-1}	6.90×10^{-2}	0.781	2.53×10^{-2}
6,383	4^+_5	1.22×10^{-1}	1.66×10^{-2}	0.869	1.09×10^{-2}
6,811	2^-_1	0.11	2.77×10^{-1}	1.297	3.28×10^{-2}
7,019	3^+_4	8.7×10^{2}	2.27×10^{-1}	1.505	1.32×10^{-1}
7,154	2^+_7	2.7×10^{3}	2.75×10^{-1}	1.640	11.46×10^{-2}
7,418	4^+_6	1.1×10^{3}	3.31×10^{-1}	1.904	2.48×10^{-1}
7,496	2^+_8	15.9×10^{3}	1.12×10^{-1}	1.982	4.67×10^{-2}
7,674	2^+_9	30.1×10^{3}	5.36×10^{-1}	2.160	2.23×10^{-1}
7,701	3^-_2	41×10^{3}	8.39×10^{-1}	2.187	4.89×10^{-1}
7,886	1^-_2	22.8×10^{3}	6.21×10^{-1}	2.372	15.52×10^{-2}
8,008	3^+_5	3.6×10^{3}	1.75×10^{-1}	2.494	10.21×10^{-2}

Electromagnetic properties of states in ^{26}Si



Calculated $^{25}Al(p,\gamma)^{26}Si$ astrophysical reaction rate

Conclusion

- ^{26}Si structure is of nuclear astrophysical interest, especially, its J^{π} assignments, Which play a crucial role in the calculation of the ^{25}Al(p,γ) reaction.
- Experimentally, the ^{26}Si spectrum is not so well known as the one of ^{26}Mg.
- A comparaison with the mirror nuclei ^{26}Mg is important as well as with shell model using our (0+1) $\hbar\omega$ PSDPF interaction.
- This study led us to confirm the uncertain states (states with uncertain J^{π}) and to predict J^{π} assignments for the unidentified ones (states with unknown J^{π}). The J^{π} assignments for states of astrophysical interest were also proposed.
- This rp-process reaction rate ^{25}Al(p,γ) is crucial nuclear physics input to astrophysical models of nucleosynthesis in novae, supernovae and explosive hydrogen burning. We calculated it for ^{26}Si.

THANK YOU!