Nuclear Structure Study of the Mirror Nuclei ^{22}Ne and ^{22}Mg around the ^{21}Na+Proton Threshold

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- The PSDPF interaction obtained using fitting procedure: 0 and 1 ħω states throughout the sd shell,

- To validate this interaction, we test it by calculating excitation energies and electromagnetic transition observables for nuclei at the begin and the end of the shell and particularly for different isotopic chains to see the evolution of these properties for a fixed Z and increasing N

Results for the mirror nuclei ^{22}Ne and ^{22}Mg

- The resonant radiative capture reaction $^{21}Na(p,\gamma)^{22}Mg$

⟹ in nucleosynthesis

(breakout of the hot CNO cycle)

the cross sections ⟹ spin-parity assignments

(around the proton- threshold at ~ 5.51 MeV)

- The structure of ^{22}Mg is not well known because it is experimentally difficult to reach

- Comparison with the well studied mirror ^{22}Ne is recommended

- ~ 6.35 MeV

<u>Experimentally</u>

^{22}Ne spectrum contains :

- ✓ 14 reported states with well defined J^{π}
- ✓ 12 + states and 2 – states

- ~ 6.35 MeV

<u>Experimentally</u>

^{22}Mg spectrum contains :

- ✓ 16 reported states with not so well fixed J^{π}

- <u>PSDPF</u> : ~ 6.35 MeV
- ✓ 15 predicted states
- ✓ 12 + states and 3 – states

The proposed spectra versus experiment

^{22}Ne		^{22}Mg		PSDPF	
Ex	J^π	Ex	J^π	Ex	J^π_n
0	0^+	0	0^+	0	0^+_1
1,275	2^+	1,247	2^+	1,363	2^+_1
3,358	4^+	3,308	4^+	3,418	4^+_1
4,456	2^+	4,402	2^+	4,295	2^+_2
5,146	2^-	5,006	$0^+,1,2,3,4^+$	4,987	2^-_1
5,332	1^+	5,318	$2^+,3,4^+$	5,408	1^+_1
5,363	2^+	5,035	2^+	5,187	2^+_3
5,524	$(4)^+$	5,293	$(3^+,4^+,5^+)$	5,473	4^+_2
5,641	3^+	5,452	$(2^+,3^+)$	5,468	3^+_1
5,910	3^-	5,838	$2^+,3,4^+$	5,632	3^-_1
6,120	2^+	5,711	2^+	6,243	2^+_4
6,234	0^+	5,962	0^+	6,273	0^+_2
		6,046		6,288	0^-_1
6,310	$(6)^+$	6,254	(6^+)	6,326	6^+_1
6,347	4^+	6,247	(4^+)	6,287	4^+

RMSD = 125 KeV

RMSD = 198 KeV

EMT properties of ^{22}Ne

E_i (MeV)	(J^{π}_i)	E_f (MeV)	(J^{π}_f)	ζ (EXP)	ζ (PSDPF)	γ mult.	R_k(EXP)		γ mult.	R_k(PSDPF)
1,275	(2^+)	0	(0^+)	5.24 ps 7	4.86 ps	E2	100		E2	100
3,358	(4^+)	1,275	(2^+)	325 fs 9	308 fs	E2	100		E2	100
4,456	(2^+)	1,275 0	(2^+) (0^+)	53 fs 9	3 fs	E2+M1 E2	97.0 3.0	20 20	E2+M1 E2	97.5 2.5
5,146	(2^-)	4,456 1,275 0	(2^+) (2^+) (0^+)	1.1 ps 3	0.5 ps	E1+M2 E1+M2	47 53	3 3	E1+M2 E1+M2 M2	0 91 9
5,332	(1^+)	1,275 0 4,456	(2^+) (0^+) (2^+)	1.6 fs 3	1.0 fs	E2+M1 M1	33 67	5 5	E2+M1 M1 E2+M1	23 49 28
5,363	(2^+)	1,275 0	(2^+) (0^+)	99 fs 17	6 fs	E2+M1 E2	86 14	3 3	E2+M1 E2+M1	99 1
5,524	(4^+)	3,358 1,275	(4^+) (2^+)	33 fs 4	12 fs	E2+M1 E2	98.4 1.6	3 3	E2+M1 E2	98.9 1.1
5,641	(3^+)	3,358 1,275	(4^+) (2^+)	< 4 fs	3.7 fs	E2+M1 E2+M1	31 69	2 2	E2+M1 E2+M1	25 75
5,910	(3^-)	4,456 3,358 1,275	(2^+) (4^+) (2^+)	48 fs 16	198 fs	E1+M2 E1+M2	15 15 70	4 4 3	E1+M2 E1+M2 E1+M2	57 1 35
6,120	(2^+)	4,456 1,275 0	(2^+) (2^+) (0^+)	35 fs 13	7 fs	E2+M1 E2+M1 E2	14 83 3	3 3 2	E2+M1 E2+M1 E2	16 84 0
6,234	(0^+)	5,332 1,275	(1^+) (2^+)	346 fs 115	14 fs		100		M1 E2	21 79
6,234	(0^-)	5,332 1,275 5,146	(1^+) (2^+) (2^-)		496 fs				E1 M2 E2	85 13.5 1.5
6,310	(6^+)	3,358	(4^+)	69 fs 6	65 fs	E2	100		E2	100
6,347	(4^+)	3,358 5,524 5,910	(4^+) (4^+) (3^-)	19 fs 4	2 fs	E2+M1	100		E2+M1 E2+M1 E2+M1	82 2 16

EMT properties of ^{22}Mg

E_i (MeV)	(J^{π}_i)	E_f (MeV)	(J^{π}_f)	ζ (EXP)	ζ (PSDPF)	γ mult.	R_k(EXP)		γ mult.	R_k(PSDPF)
1,247	(2^+)	0	(0^+)	3.0 ps *11*	4.0 ps	E2	100		E2	100
3,308	(4^+)	1,247	(2^+)	288 fs *65*	277 fs	E2	100		E2	100
4,402	(2^+)	3,308	(4^+)	< 30 fs	3 fs		5	4	E2	0
		1,247	(2^+)			E2+M1	87	4	E2+M1	100
		0	(0^+)				8	4	E2	0
5,006	(2^-)	4,402	(2^+)	< 24 ns	0.6 ps		100		E1+M2	0.4
		1,247	(2^+)						E1+M2	97.7
		0	(0^+)						M2	1.9
5,035	(2^+)	1,247	(2^+)	< 1.0 ns	6.0 fs	E2+M1	88	4	E2+M1	90
		0	(0^+)				12	4	E2	10
5,293	(4^+)	3,308	(4^+)	63 fs 22	16 fs	(E2+M1)	100		E2+M1	100
5,318	(1^+)	1,247	(2^+)	< 24 ns	1.4 fs		70	*15*	E2+M1	32
		0	(0^+)				30	*15*	M1	68
5,452	(3^+)	3,308	(4^+)	< 1.0 ns	4.5 fs		22	2	E2+M1	23
		1,247	(2^+)			(E2+M1)	78	2	E2+M1	77
5,711	(2^+)	1,247	(2^+)	40 fs *14*	8 fs	E2+M1	87	3	E2+M1	80
		0	(0^+)				13	3	E2	11
		4,402	(2^+)						E2+M1	9
5,838	(3^-)	3,308	(4^+)	< 24 ns	0.2 ps		20	*15*	E1+M2	1
		1,247	(2^+)				80	*15*	E1+M2	33
		4,402	(2^+)						E1+M2	54
		5,006	(2^-)						E2+M1	6
		5,035	(2^+)						E1+M2	4
		5,293	(4^+)						E1+M2	1
5,962	(0^+)	5,318	(1^+)		27.6 fs				M1	15
		1,247	(2^+)						E2	85
6,046	(0^-)	5,318	(1^+)		870 fs				E1	78.4
		1,247	(2^+)						M2	20.2
		5,006	(2^-)						E2	1.4
6,247	(4^+)	3,308	(4^+)	< 24 ns	3 fs		100		E2+M1	92
		5,293	(4^+)						E2+M1	5
		1,247	(2^+)						E2+M1	3
6,254	(6^+)	3,308	(4^+)		51 fs	(E2)			E2	100

^{22}Ne

- **0^{+} properties**

- Ex(exp) = 6.234 MeV
- Ex(Th) = 6.273 MeV
- τ_m (exp)= 346 fs 115
- τ_m (Th) = 14 fs

- **0^{-} properties**

- Ex(exp) = 6.234 MeV
- Ex(Th) = 6.288 MeV
- τ_m (exp) = 346 fs 115
- τ_m (Th) = 496 fs

^{22}Mg

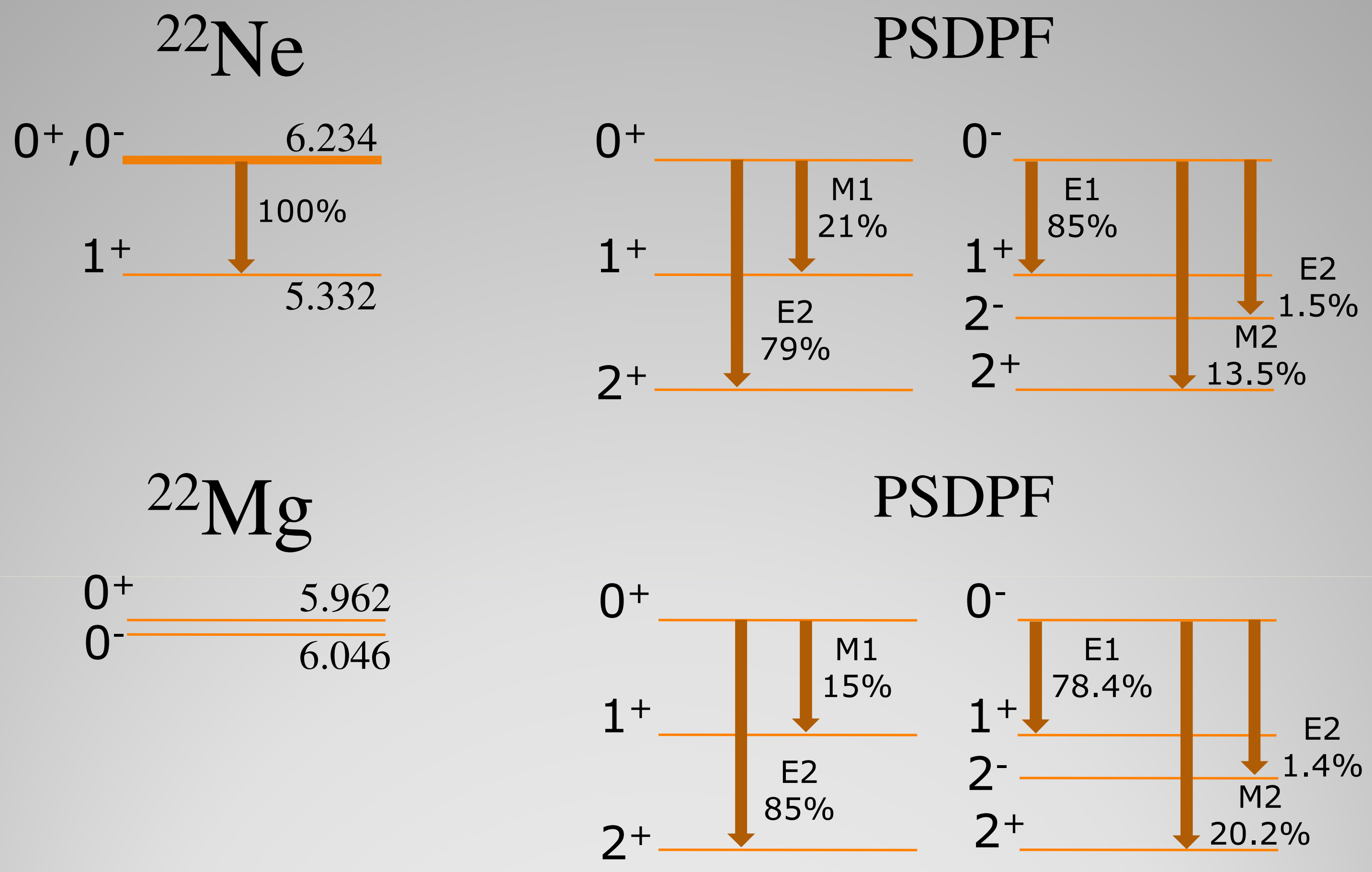
- **0^{+} properties**

- Ex(exp) = 5.962 MeV
- Ex(Th) = 6.273 MeV
- τ_m (exp) = ?
- τ_m (Th) = 27.6 fs

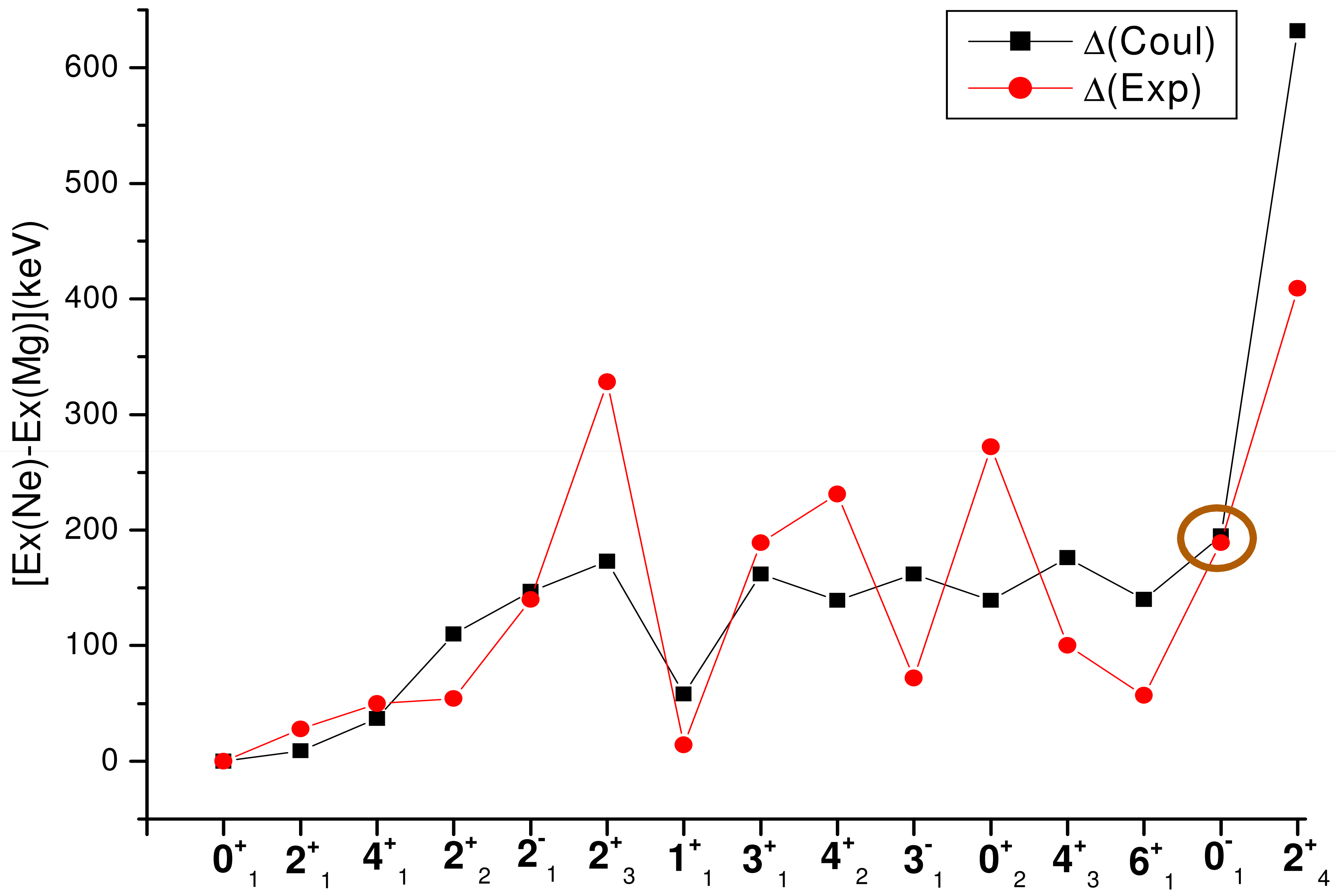
- **0^{-} properties**

- Ex(exp) = 6.046 MeV
- Ex(Th) = 6.288 MeV
- τ_m (exp) = ?
- τ_m (Th) = 870 fs

Examine now the gamma decay schemes



This is another good argument of the existence of a 0^- state in the 2 mirror nuclei



Δ(Coul)
Δ(Exp)
[Ex(Ne)-Ex(Mg)](keV)
0
100
200
300
400
500
600
0+1 2+1 4+1 2+2 2-1 2+3 1+1 3+1 4+2 3-1 0+2 4+3 6+1 0-1 2+4

	$p_{1/2}$	$p_{3/2}$	$d_{5/2}$	$s_{1/2}$	$d_{3/2}$	$f_{7/2}$	$p_{3/2}$	$f_{5/2}$	$p_{1/2}$	$p_{1/2}$	$p_{3/2}$	$d_{5/2}$	$s_{1/2}$	$d_{3/2}$	$f_{7/2}$	$p_{3/2}$	$f_{5/2}$	$p_{1/2}$
0.01083925	2	4	2	0	2	0	0	0	0	1	4	1	1	1	0	0	0	0
0.01775216	2	4	2	0	2	0	0	0	0	1	4	2	1	0	0	0	0	0
0.01173522	2	4	2	0	2	0	0	0	0	2	3	2	1	0	0	0	0	0
0.01526562	2	4	2	1	1	0	0	0	0	1	4	1	2	0	0	0	0	0
0.01992269	2	4	2	1	1	0	0	0	0	1	4	2	0	1	0	0	0	0
0.01257051	2	4	2	1	1	0	0	0	0	1	4	2	1	0	0	0	0	0
0.02328984	2	4	2	1	1	0	0	0	0	1	4	3	0	0	0	0	0	0
0.01441246	2	4	2	1	1	0	0	0	0	2	3	2	0	1	0	0	0	0
0.01563034	2	4	2	1	1	0	0	0	0	2	3	3	0	0	0	0	0	0
0.01527262	2	4	2	2	0	0	0	0	0	1	4	1	1	1	0	0	0	0
0.02953421	2	4	2	2	0	0	0	0	0	1	4	2	1	0	0	0	0	0
0.01561822	2	4	2	2	0	0	0	0	0	2	3	2	1	0	0	0	0	0
0.01507258	2	4	3	0	1	0	0	0	0	1	4	1	1	1	0	0	0	0
0.01447996	2	4	3	0	1	0	0	0	0	1	4	2	0	1	0	0	0	0
0.03261885	2	4	3	0	1	0	0	0	0	1	4	2	1	0	0	0	0	0
0.02185823	2	4	3	0	1	0	0	0	0	1	4	3	0	0	0	0	0	0
0.01491854	2	4	3	0	1	0	0	0	0	2	3	1	1	1	0	0	0	0
0.01565984	2	4	3	0	1	0	0	0	0	2	3	2	0	1	0	0	0	0
0.02070415	2	4	3	0	1	0	0	0	0	2	3	2	1	0	0	0	0	0
0.01965140	2	4	3	0	1	0	0	0	0	2	3	3	0	0	0	0	0	0
0.01576752	2	4	3	1	0	0	0	0	0	1	4	1	1	1	0	0	0	0
0.01028718	2	4	3	1	0	0	0	0	0	1	4	1	2	0	0	0	0	0
0.02712517	2	4	3	1	0	0	0	0	0	1	4	2	0	1	0	0	0	0
0.01856228	2	4	3	1	0	0	0	0	0	1	4	2	1	0	0	0	0	0
0.02319745	2	4	3	1	0	0	0	0	0	1	4	3	0	0	0	0	0	0
0.01738473	2	4	3	1	0	0	0	0	0	2	3	2	0	1	0	0	0	0
0.01962589	2	4	3	1	0	0	0	0	0	2	3	2	1	0	0	0	0	0
0.02980163	2	4	3	1	0	0	0	0	0	2	3	3	0	0	0	0	0	0
0.01920002	2	4	4	0	0	0	0	0	0	1	4	1	1	1	0	0	0	0
0.02128135	2	4	4	0	0	0	0	0	0	1	4	2	0	1	0	0	0	0
0.02093333	2	4	4	0	0	0	0	0	0	1	4	2	1	0	0	0	0	0
0.01506836	2	4	4	0	0	0	0	0	0	2	3	1	1	1	0	0	0	0
0.01228703	2	4	4	0	0	0	0	0	0	2	3	2	0	1	0	0	0	0
0.04006584	2	4	4	0	0	0	0	0	0	2	3	2	1	0	0	0	0	0
0.05409302	2	4	4	0	0	0	0	0	0	2	3	3	0	0	0	0	0	0

```
OC    1.985844   3.982180   2.752972   0.647044   0.626558   0.003326 }υ
OC    0.000793   0.000767   0.000516
OC    1.497768   3.541019   1.883927   0.638461   0.437415   0.000590 }π
OC    0.000145   0.000631   0.000044
```

This 0^- state has a very fragmented wave function

- One proton jump
- (~50%) $p_{1/2}$ ⇨ sd
- (~50%) $p_{3/2}$ ⇨ sd

Final spectra

^{22}Ne		^{22}Mg	
Ex	J^{π}	Ex	J^{π}
0	0^+	0	0^+
1,275	2^+	1,247	2^+
3,358	4^+	3,308	4^+
4,456	2^+	4,402	2^+
5,146	2^-	5,006	2^-
5,332	1^+	5,318	1^+
5,363	2^+	5,035	2^+
5,524	4^+	5,293	4^+
5,641	3^+	5,452	3^+
5,910	3^-	5,838	3^-
6,120	2^+	5,711	2^+
6,234	0^+	5,962	0^+
6,234	0^-	6,046	0^-
6,310	6^+	6,254	6^+
6,347	4^+	6,247	4^+

Conclusion

- *^{22}Mg structure is of nuclear astrophysical interest, especially their J^{π} assignements*
- *Experimentally, the ^{22}Mg spectrum is not so well known as the one of ^{22}Ne*
- *A comparison with the well studied mirror nucleus ^{22}Ne is important as well as with shell model using our 0 and 1 ħω PSDPF interaction*
- *This comparison leads to the proposed existence of a 0^- state in the two mirror nuclei and to a one to one level correspondence of ^{22}Ne and ^{22}Mg between 0 and ~6.35 MeV of excitation*

Finally, we propose a complete spectrum of ^{22}Mg up to ~ 6.35 MeV

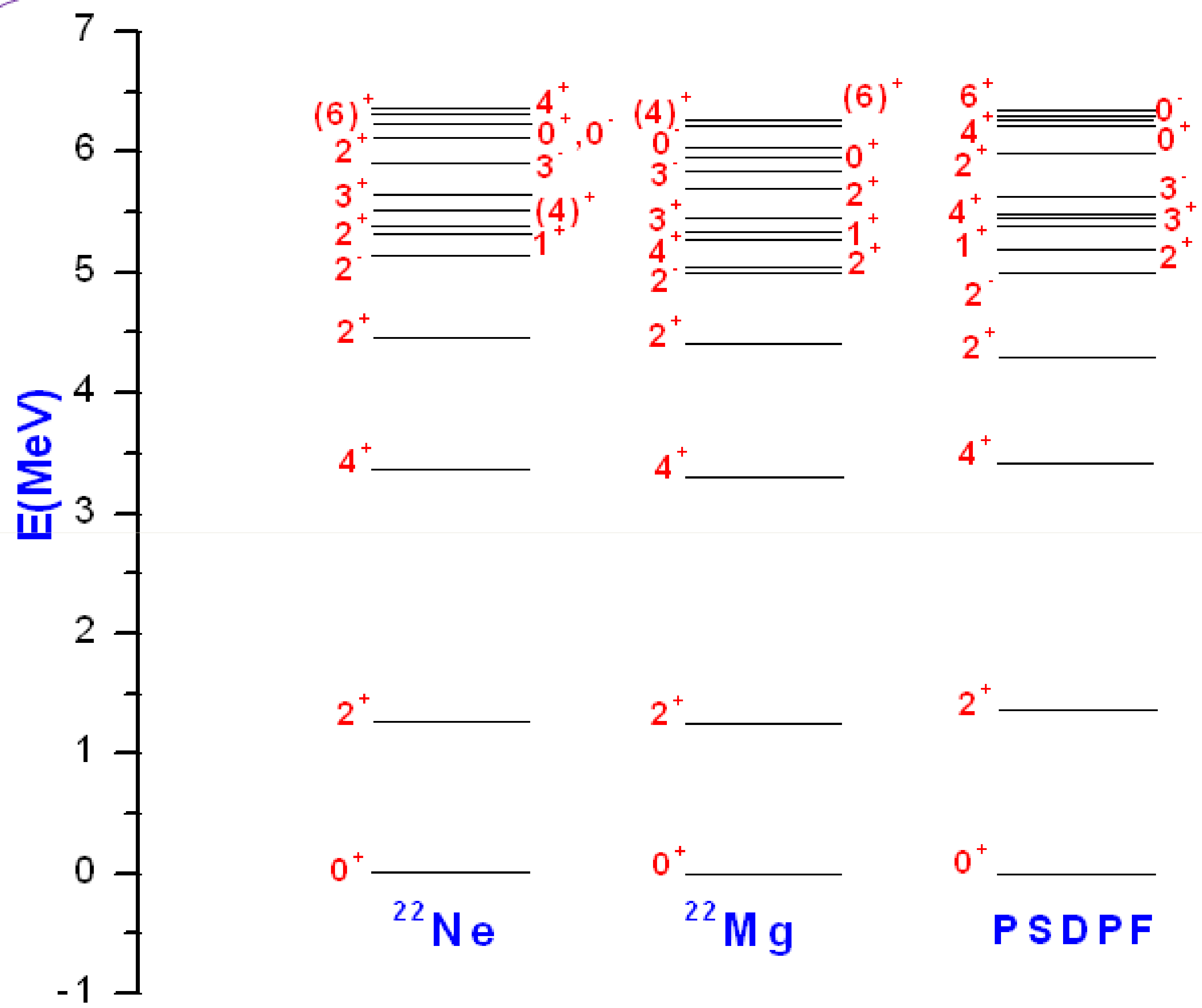
0^- states in ^{22}Na using PSDPF

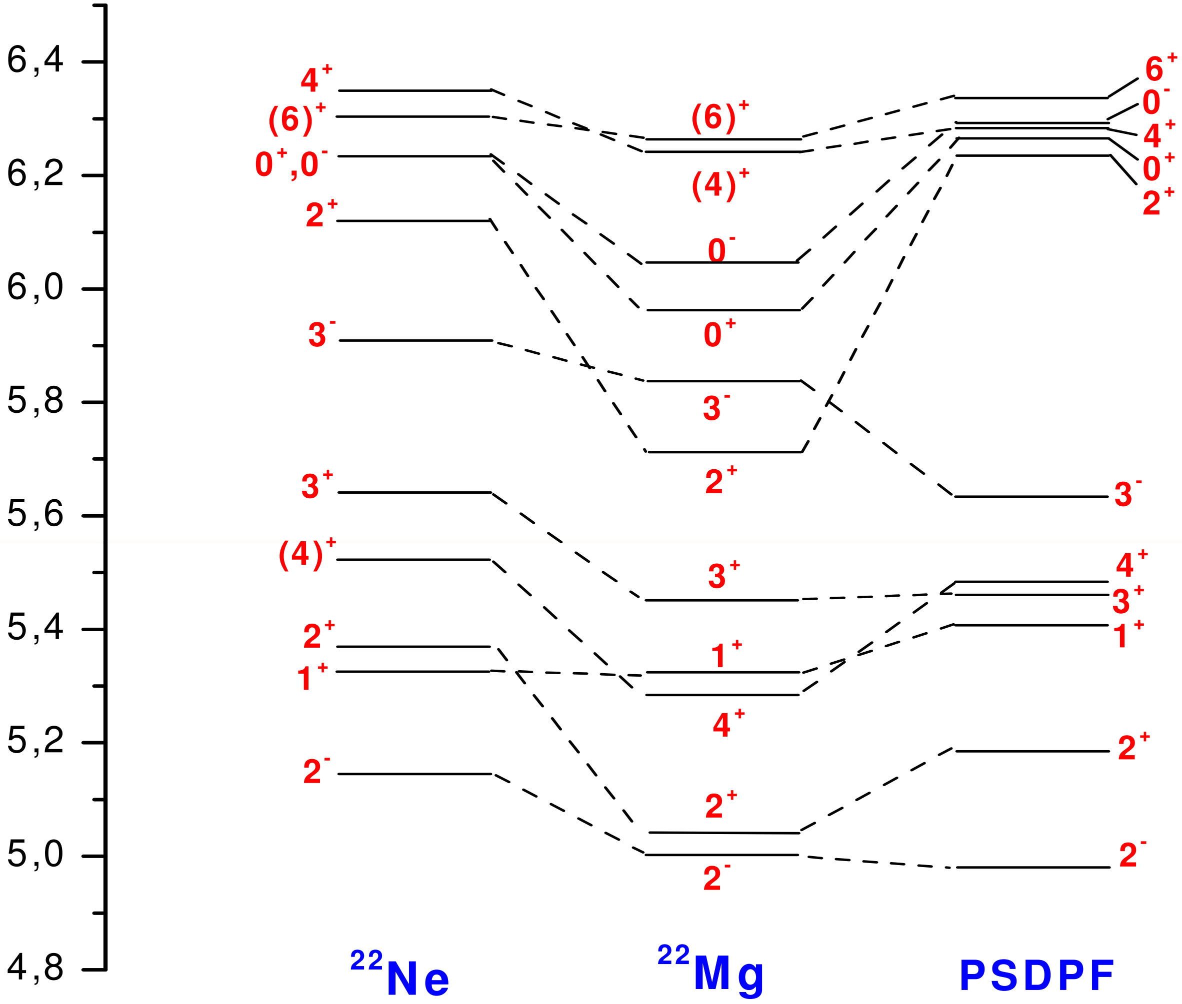
- 4.409 MeV
  Eexp= 4.296 MeV
- 6.007 MeV
- 6.749 MeV
- 6.995 MeV

$Ex(0^+_1)$ =707 keV : PSDPF

- 3.702 MeV
  Eexp= 3.639 MeV
- 5.300 MeV
- 6.042 MeV
- 6.288 MeV = $Ex(0^-)$
  ^{22}Ne,^{22}Mg

The 0^-_4 in ^{22}Na is a T = 1 state


E(MeV)
7
6
5
4
3
2
1
0
-1
22Ne
22Mg
PSDPF



6,4
6,2
6,0
5,8
5,6
5,4
5,2
5,0
4,8
4+
(6)+
0+,0-
2+
3-
3+
(4)+
2+
1+
2-
(6)+
(4)+
0-
0+
3-
2+
3+
1+
4+
2+
2-
6+
0-
4+
0+
2+
3-
4+
3+
1+
2+
2-
22Ne
22Mg
PSDPF