Shell-model calculations of rp-process rates for the P-29(p,gamma)S-30 and P-30(p,gamma)S-31 reactions

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OUTLINE

Introduction

Application of the Isobaric Mass Multiplet Equation

Brief review of Interactions USDA and USDB

Comparison with Exp and the older USD

Application of the IMME to S-30 levels, etc.

Calculation of (p,gamma) reaction rates

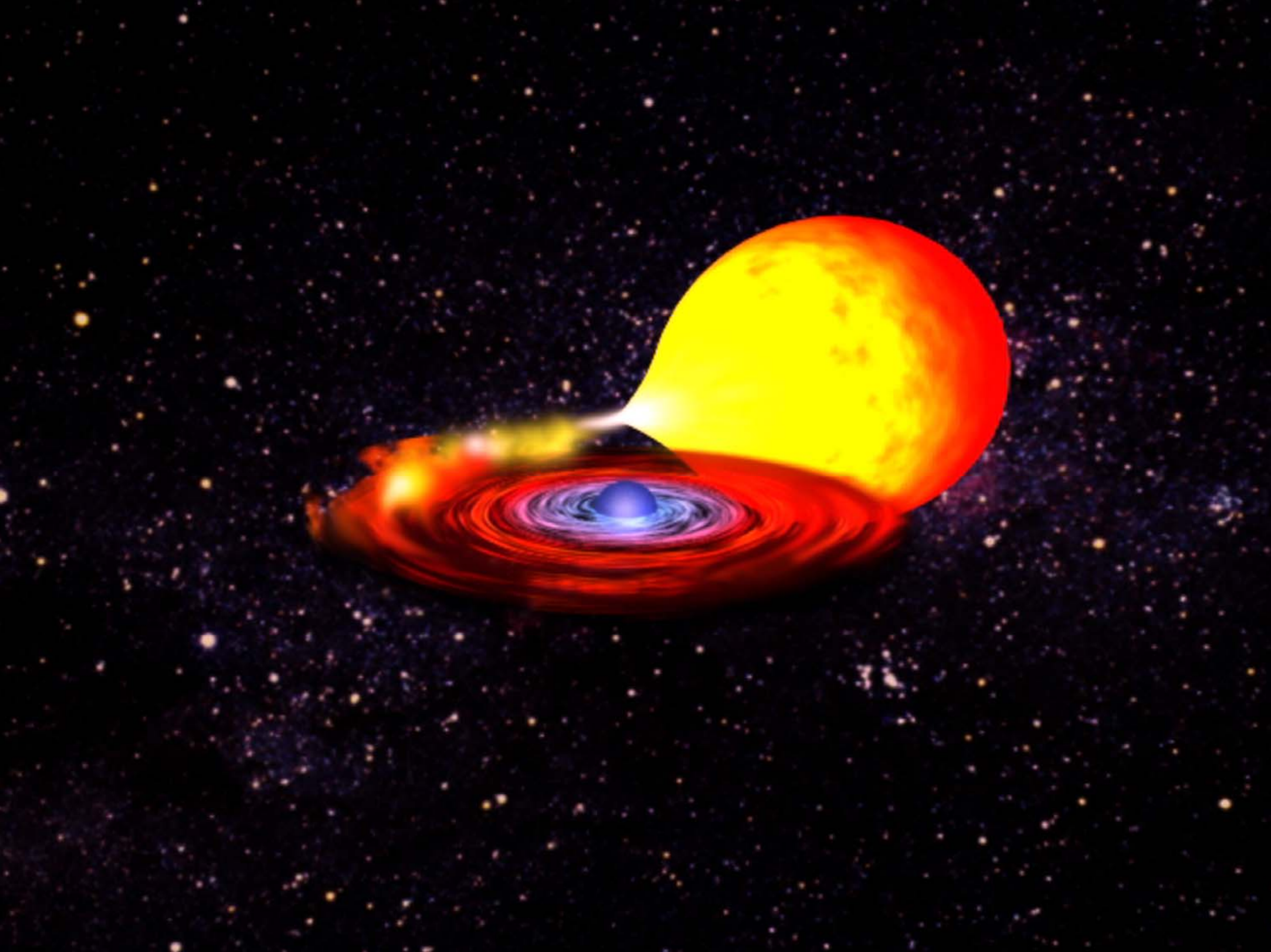
Conclusions

INTRODUCTION

Many levels in the final nuclei of the rp process, such as ^{26}Si, ^{30}S and ^{36}K, are not well known, thus requiring theoretical input.

The total rp-process reaction rate depends on the partial gamma decay widths and the proton decay widths of states in the final nucleus (above the proton-emission threshold) and their Q values.

We calculate the widths using a composite interaction with USDA/USDB as the charge-independent parts, and Q from the IMME.



Application of the Isobaric Mass Multiplet Equation (IMME)

Example: To determine levels in ^{30}S

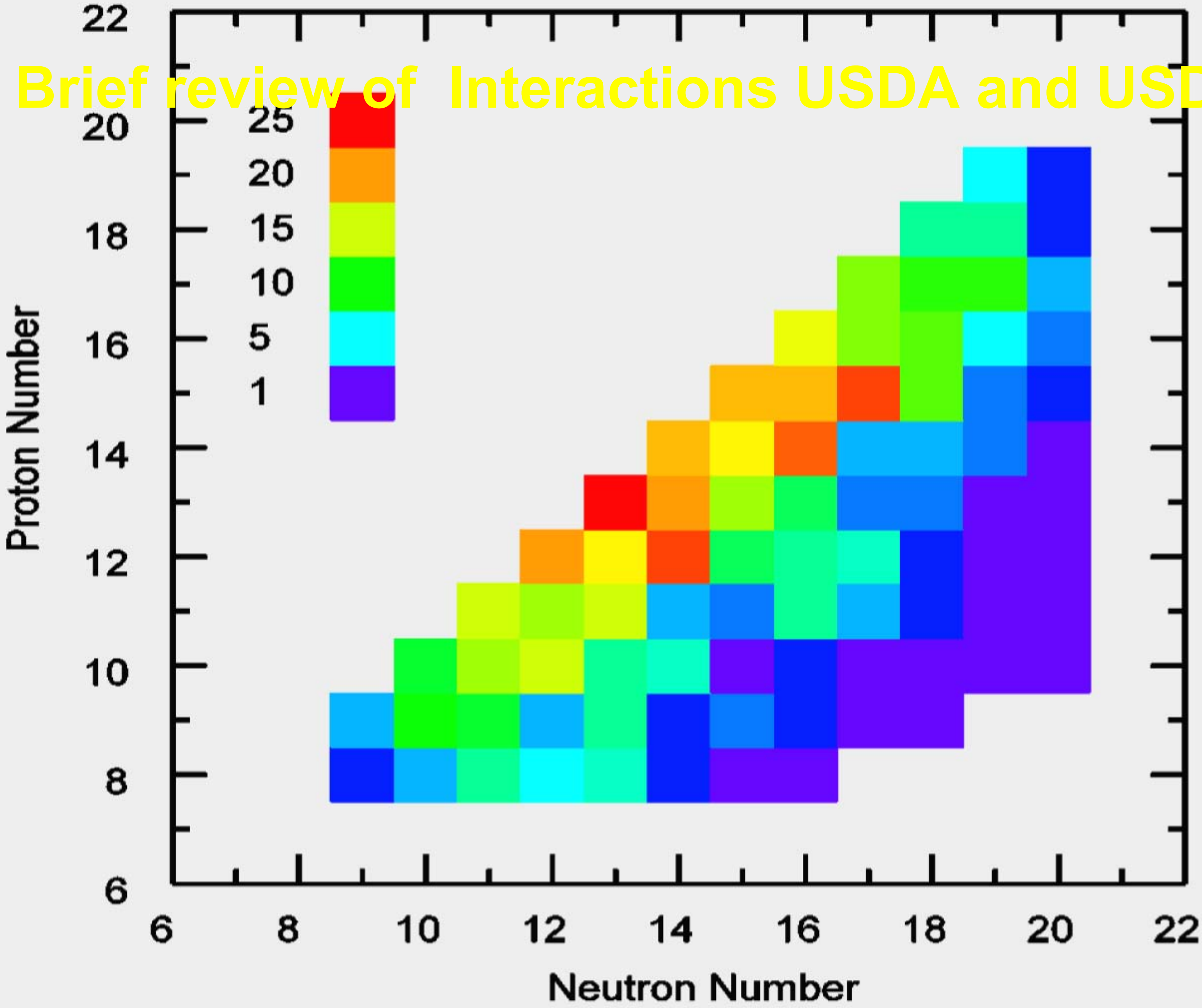
According to the IMME $B = a + bT_z + cT_z^2$
where B = binding energy of a state.

It follows that
$B(^{30}S) = 2B(^{30}P)_{exp} – B(^{30}Si)_{exp} + 2c_{th}$.

If the analogue states are known the only theoretical input is the value of c.

In 1989 W E Ormand and B A Brown (NP A 491, 1) reproduced 42 b coefficients with an rms deviation of 27 keV and 26 c coefficients with an rms dev of 9 keV using a charge-dependent Hamiltonian for A=18-22 and A=34-39. We use USDA/B for the charge-independent part. The full composite Hamiltonians will be referred to as usda-cdpn and usdb-cdpn.

Brief review of Interactions USDA and USDB



EXPERIMENTAL DATA

- With neutron-rich nuclei and previously omitted nuclei we used 608 levels in 77 nuclei

FITTING PROCEDURE

- Minimize deviations (chi-squared) between theor. and exp. energies in several iterations

For USDA, 30 well-determined LC's
(170 keV rms)

For USDB, 56 well-determined LC's
(130 keV rms)

Generally good agreement with experiment for all sd-shell observables calculated with the effective interactions USDA and USDB
[Richter, Mkhize, Brown,
Phys. Rev. C 78, 064302 (2008)]

Optimal g factors and effective charges were determined from least-square fits to 48 magnetic moments, 26 quadrupole moments, 111 M1 transitions and 144 E2 transitions.

e_p	e_n	g_{lp}	g_{sp}	g_{tp}	g_{ln}	g_{sn}	g_{tn}
1.36	0.45	1.174	5.00	0.24	-0.11	-3.44	-0.16
1.5	0.5	1	5.586	0	0	-3.86	0

(free-nucleon)

For level energies USDB provided a superior agreement (130 keV rms fit deviations). USD overbinds both the n-rich F and O isotopes. Both USDB and USDA gave improved binding energies for neutron-rich nuclei compared to USD

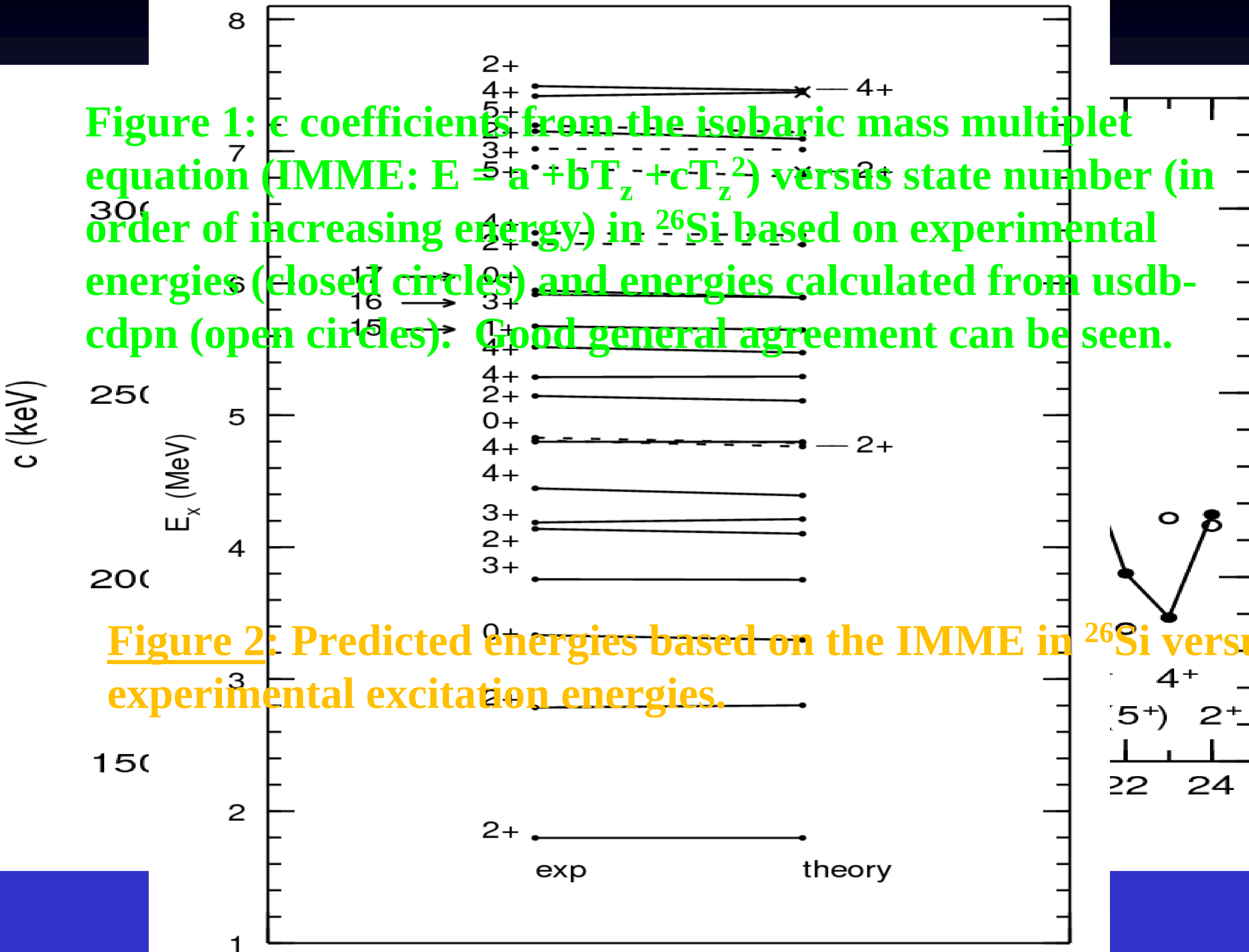


Figure 1: c coefficients from the isobaric mass multiplet equation (IMME: $E = a + bT_z + cT_z^2$) versus state number (in order of increasing energy) in ^{26}Si based on experimental energies (closed circles) and energies calculated from usdb-cdpn (open circles). Good general agreement can be seen.

<u>Figure 2</u>: Predicted energies based on the IMME in ^{26}Si versus experimental excitation energies.

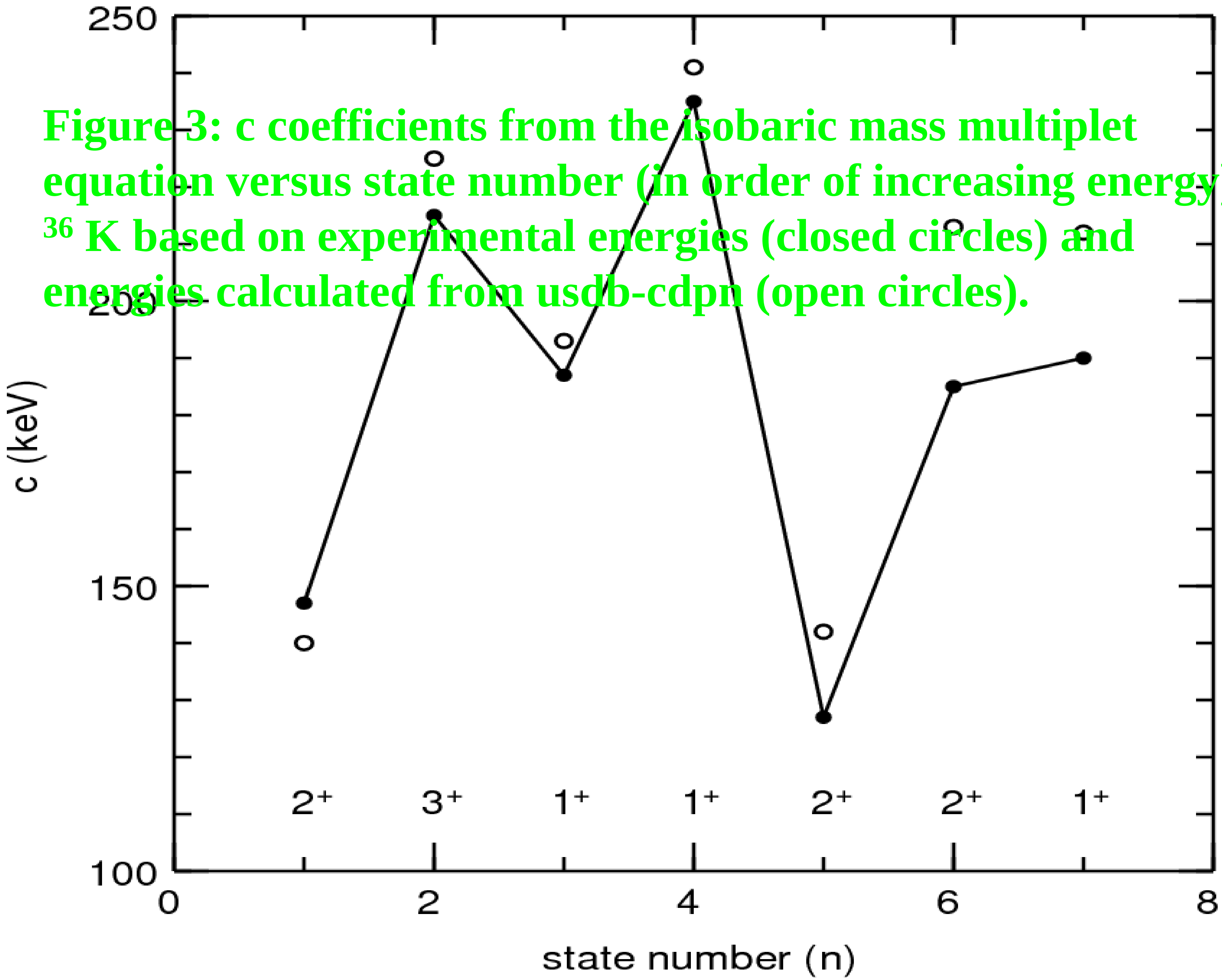


Figure 3: c coefficients from the isobaric mass multiplet equation versus state number (in order of increasing energy) in ^{36}K based on experimental energies (closed circles) and energies calculated from usdb-cdpn (open circles).

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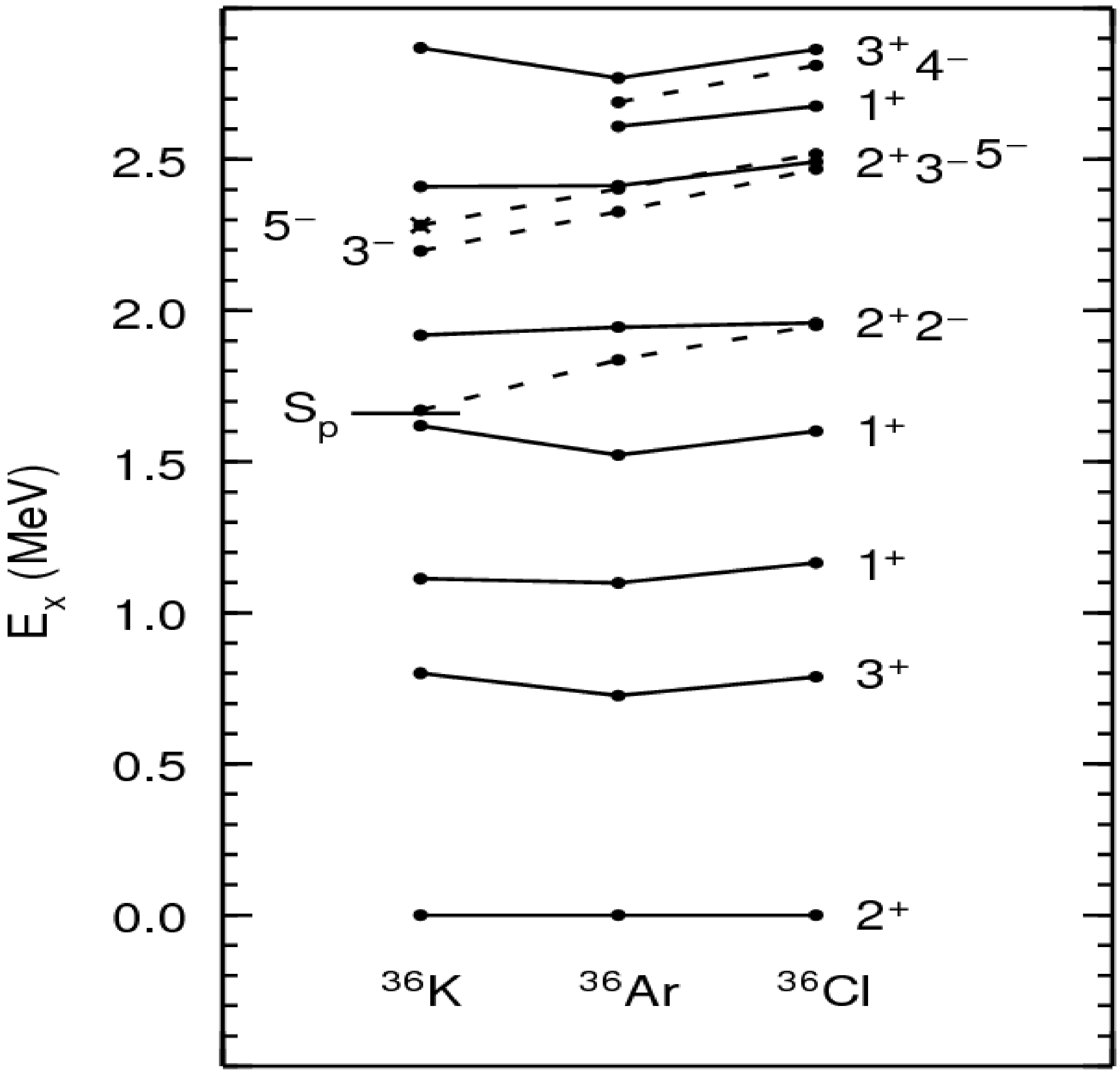

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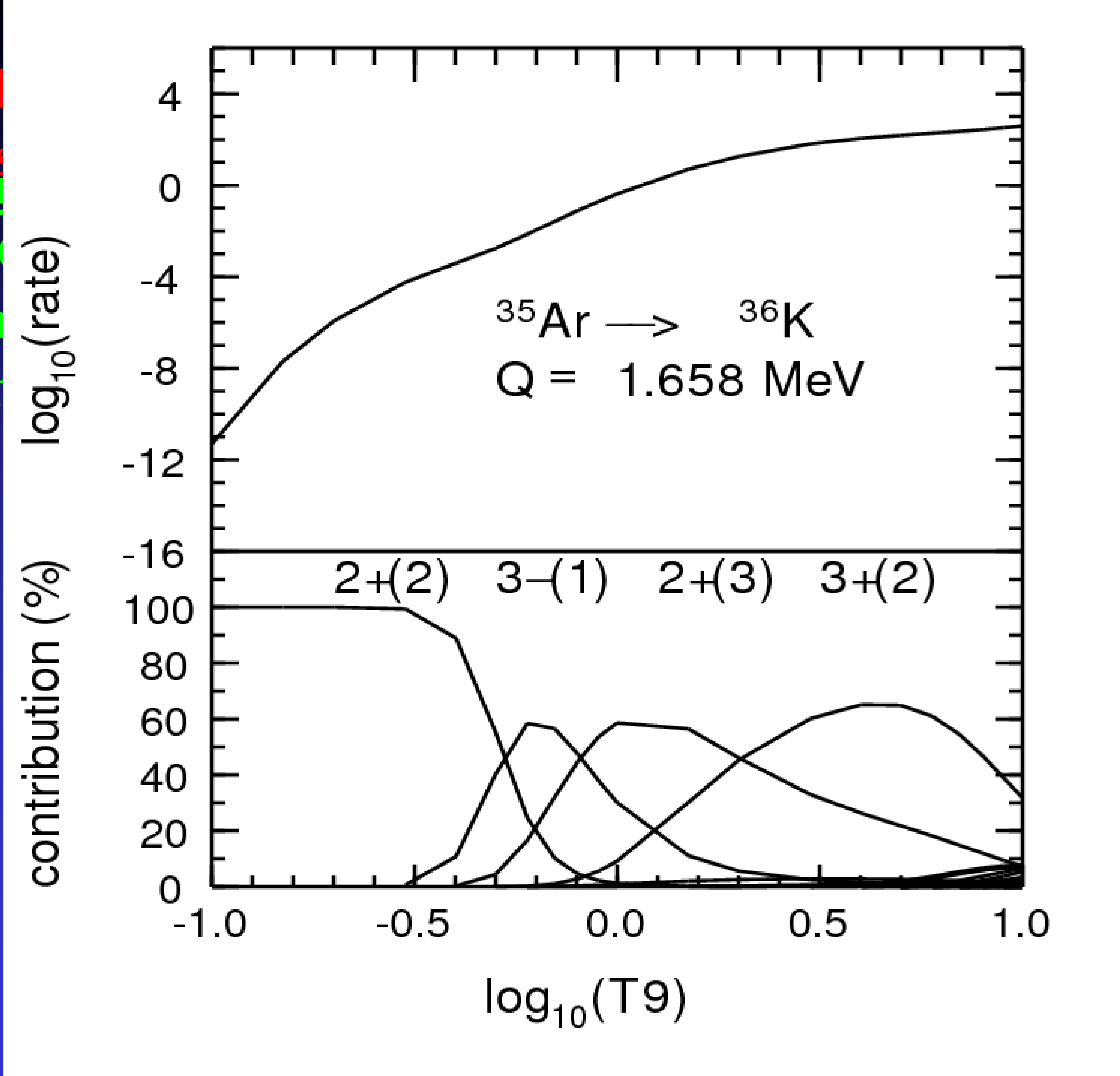
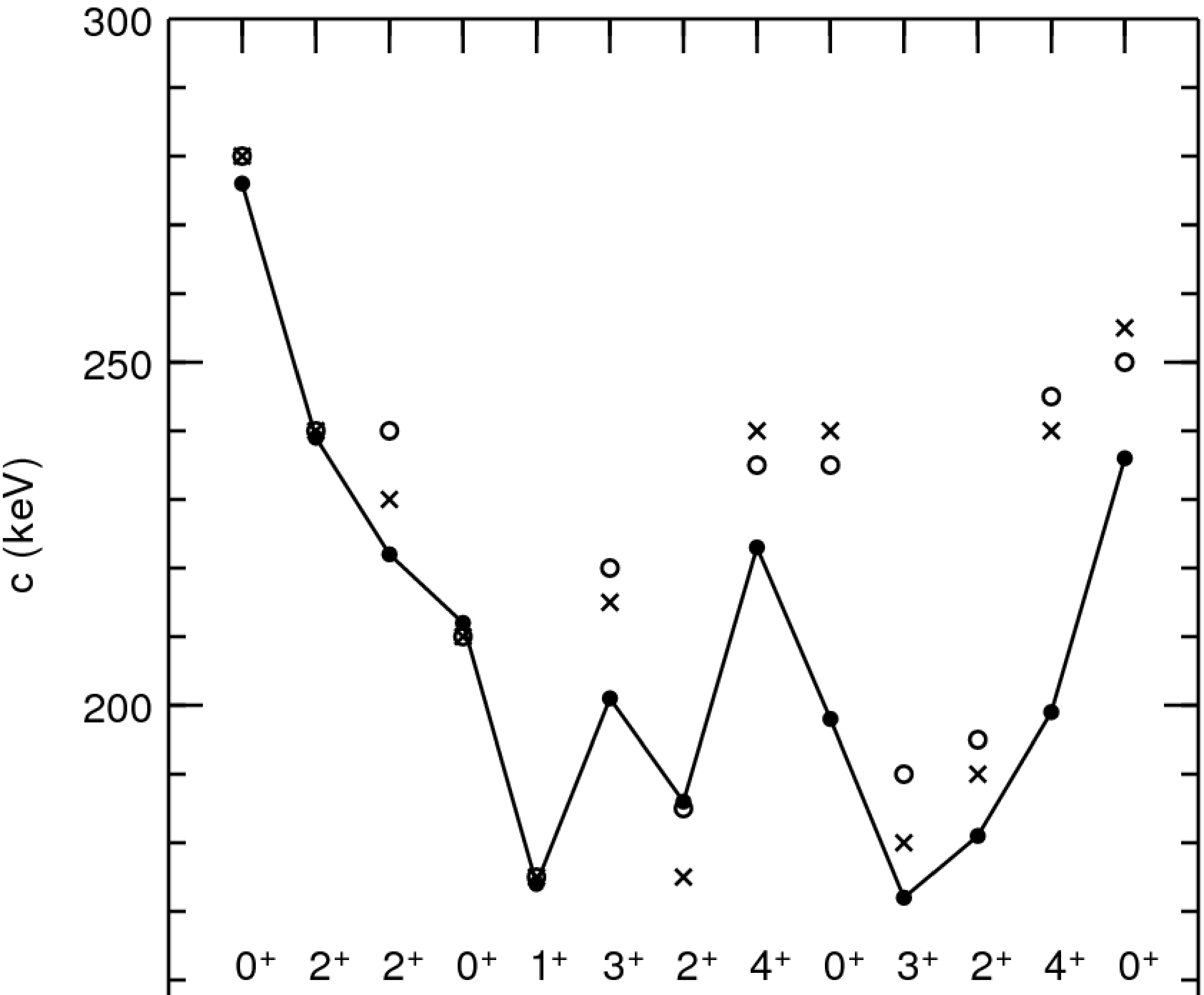
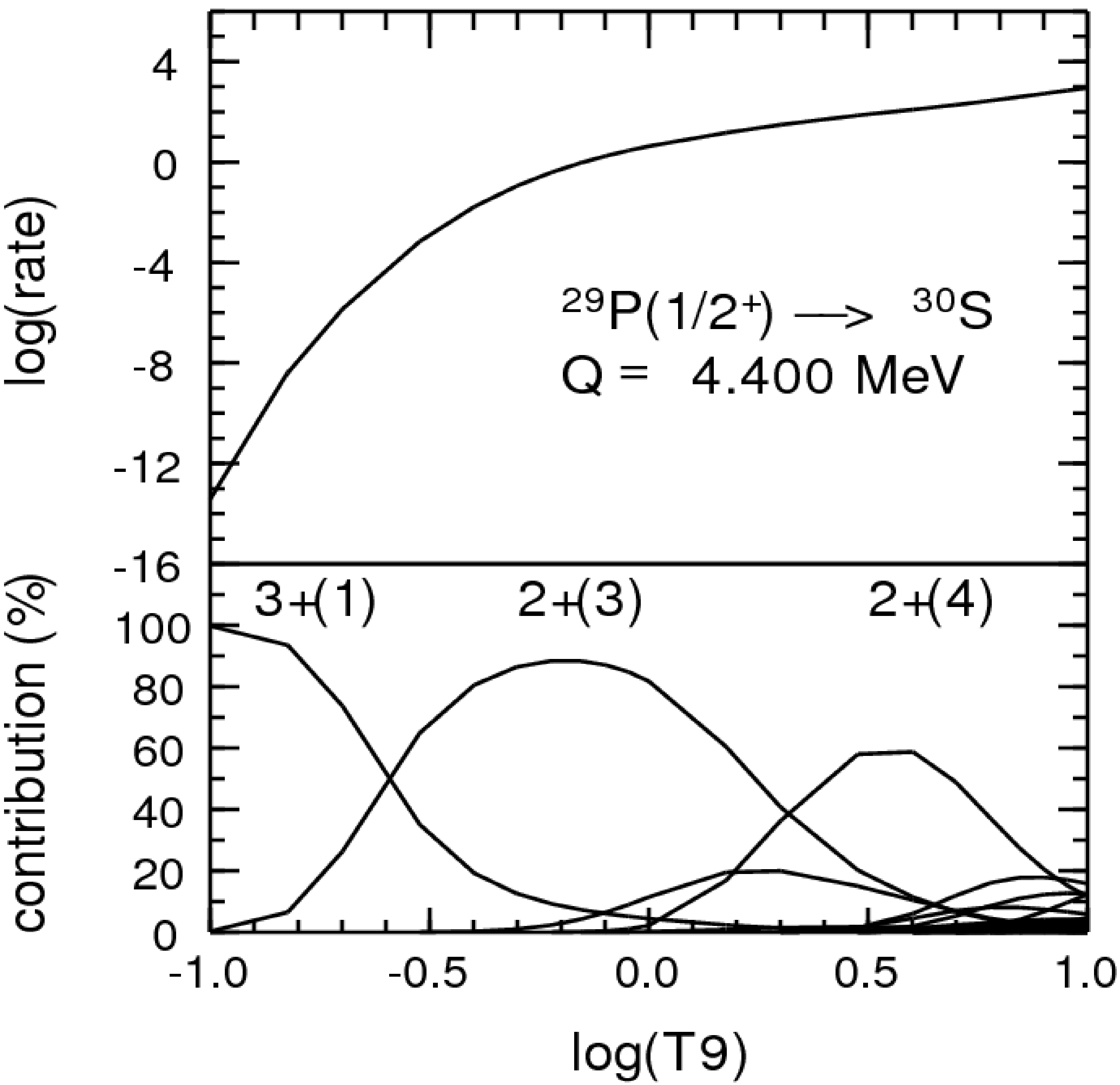



300
250
200
c (keV)
0+ 2+ 2+ 0+ 1+ 3+ 2+ 4+ 0+ 3+ 2+ 4+ 0+



$^{29}P(1/2^+) \longrightarrow {}^{30}S$
Q = 4.400 MeV
log(rate)
4
0
-4
-8
-12
-16
3+(1)
2+(3)
2+(4)
contribution (%)
100
80
60
40
20
0
-1.0
-0.5
0.0
0.5
1.0
log(T9)

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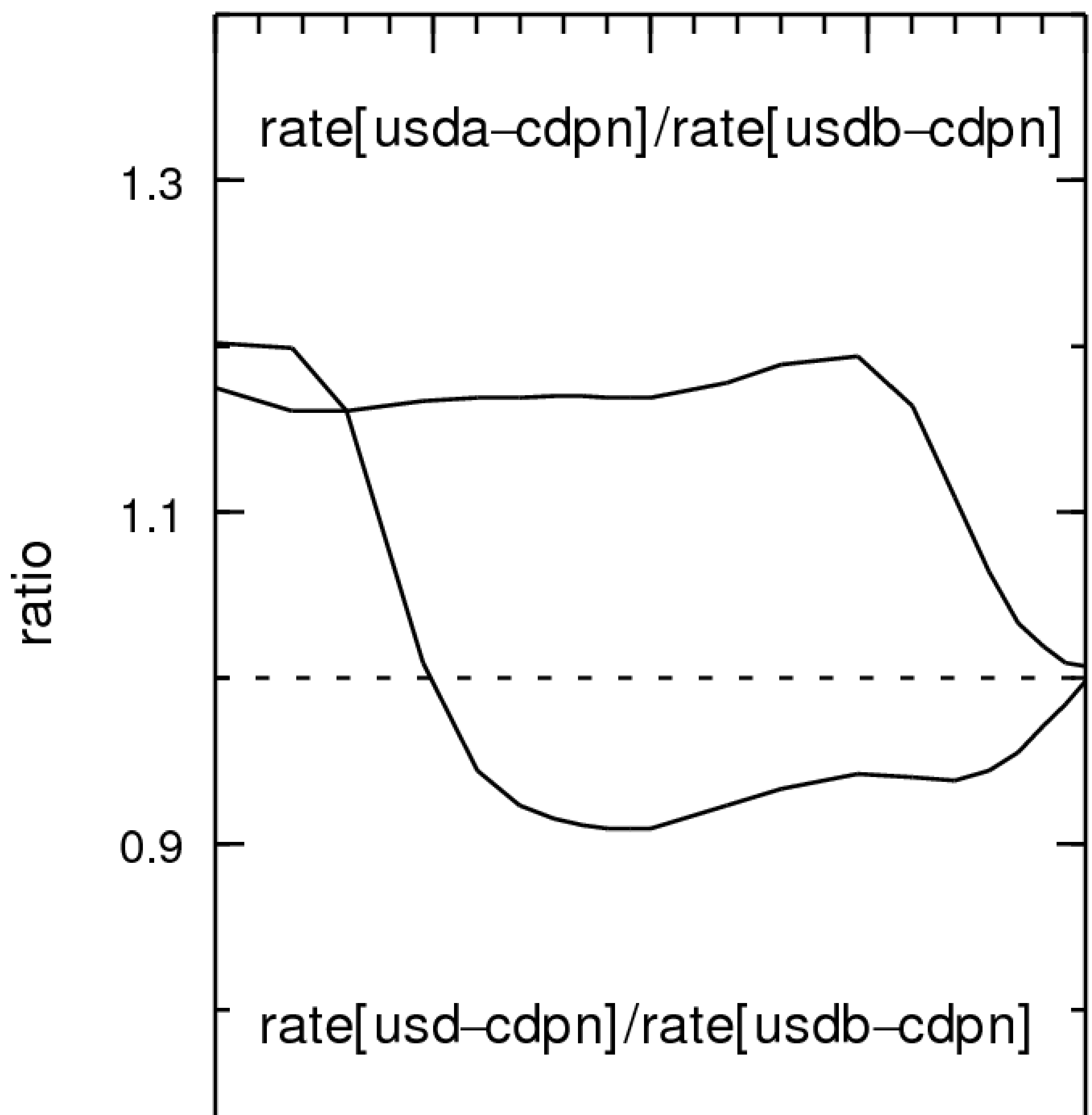

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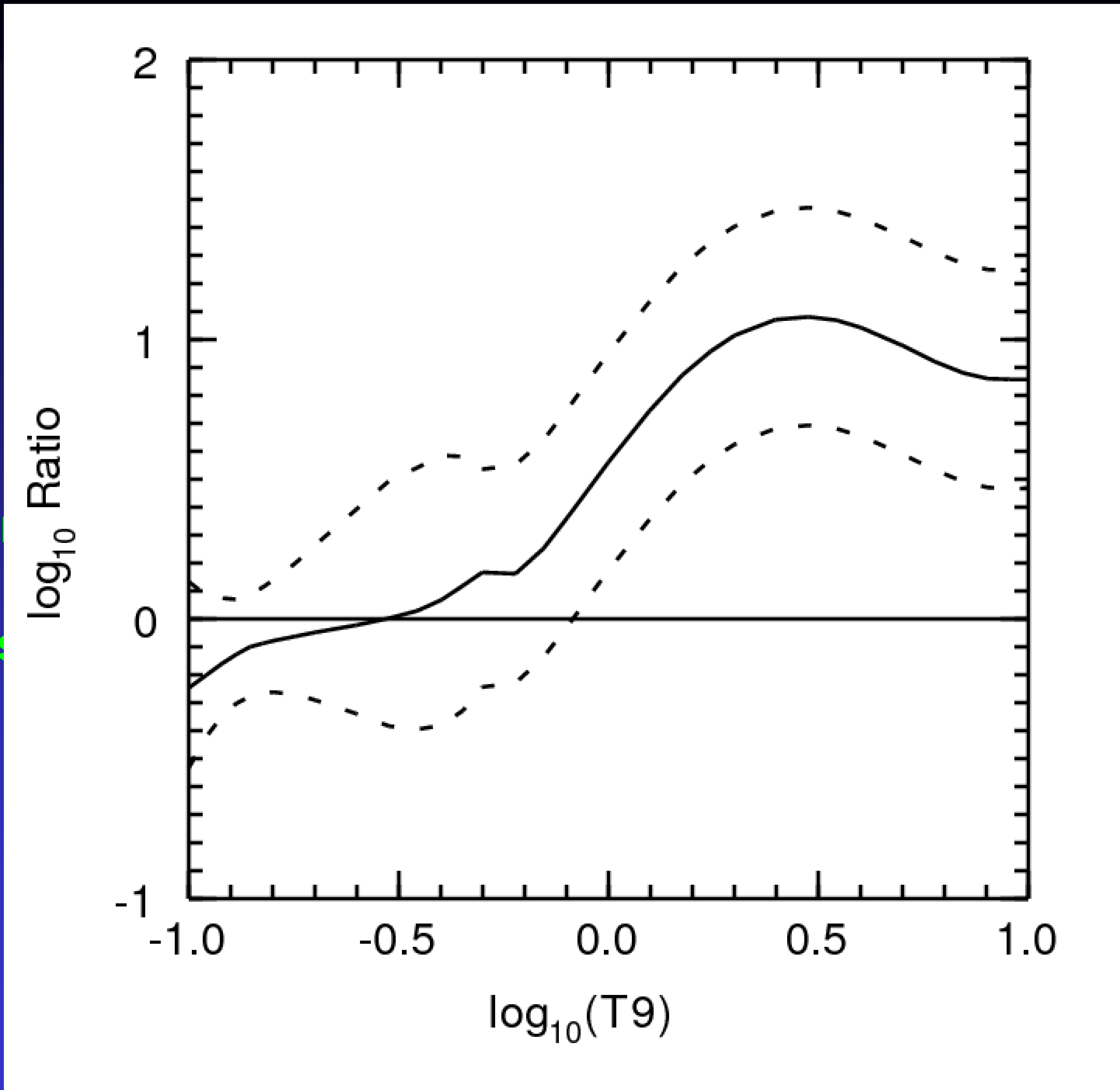

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31).
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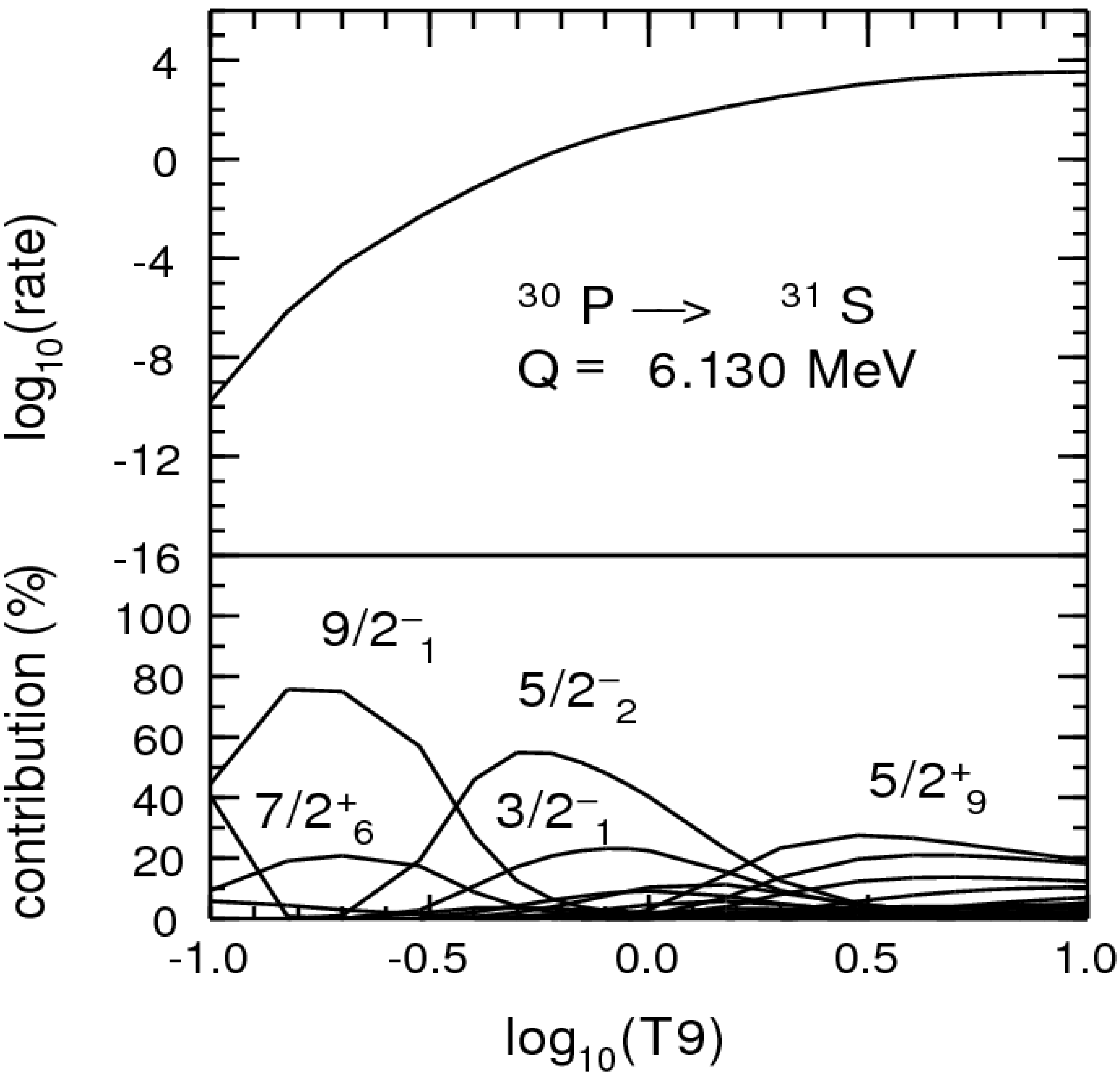


$^{30}P \longrightarrow\ ^{31}S$
Q = 6.130 MeV
$\log_{10}$(rate)
4
0
-4
-8
-12
-16
contribution (%)
100
80
60
40
20
0
$9/2^-_1$
$5/2^-_2$
$7/2^+_6$
$3/2^-_1$
$5/2^+_9$
-1.0
-0.5
0.0
0.5
1.0
$\log_{10}$(T9)

CONCLUSIONS

- We have considered (p,gamma) reactions leading to final nuclei in ^{26}Si (published), ^{36}K (published), ^{30}S (just completed) and ^{31}S (preliminary).

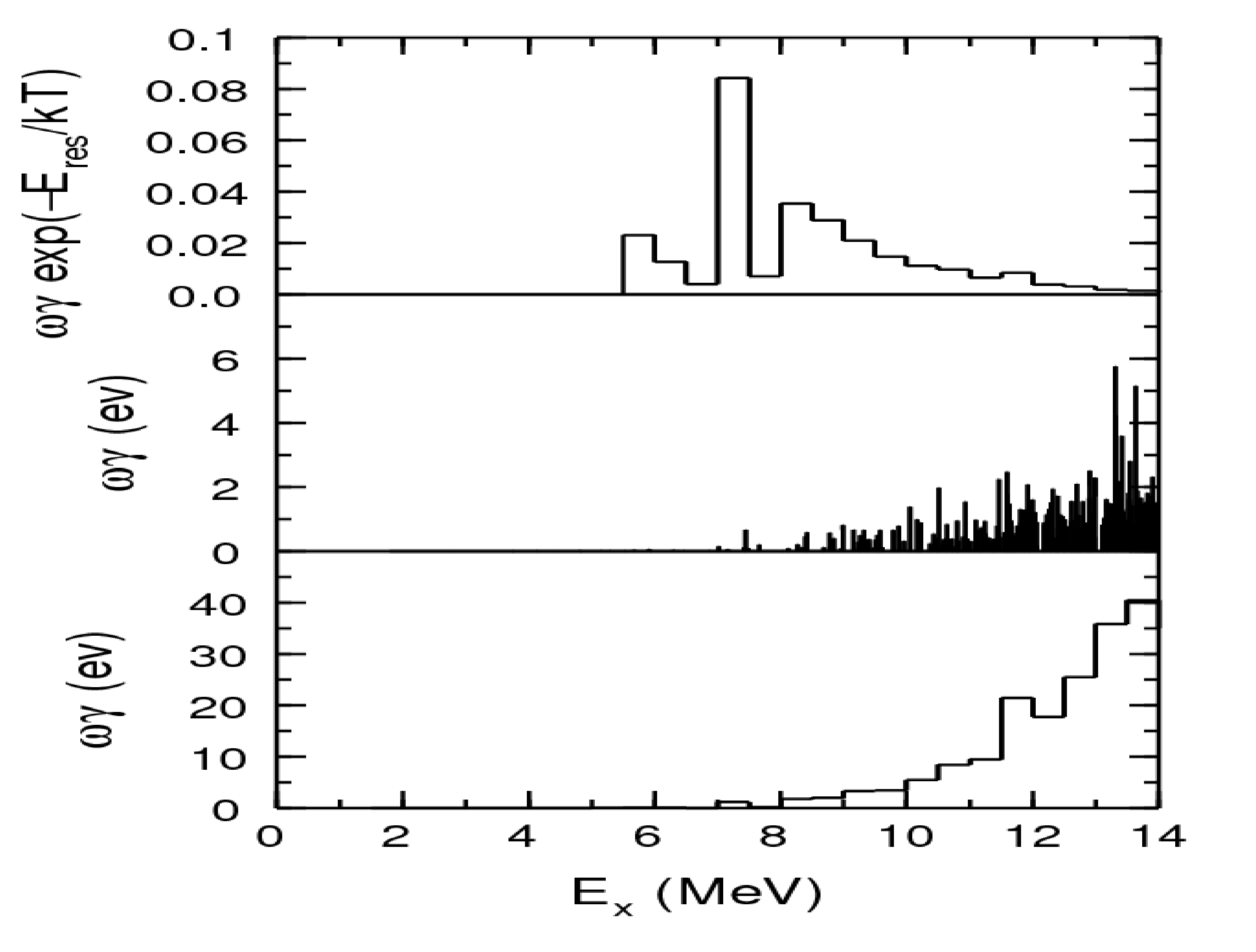
- Our method for determining energies of states in the final nuclei, based on the IMME with experimental energies for the T = 1 analogue states and the theoretical c-coefficients, should be extended to other cases in the sd shell.

- The use of different interactions and approximations gives an indication of the theoretical error in the rates

- The contribution of negative parity states should be taken into account from measurements, if possible, or using S and $T_{1/2}$ values from the mirror nuclei as an estimate


THANK YOU !

Figure 6. Relative contributions to the reaction rates for $x = -E_{res}/(kT)$ with T9 = 10. Resonant reaction rate $\alpha\ \Sigma_f\, \omega\gamma_{if}\, e^{-E_{res}/(kT)}$.



The Joint Institute for Nuclear Astrophysics

Why measure excitation energies ?

$$N_A <\sigma v> = 1.54\cdot 10^{11}(AT_9)^{-3/2}\,\omega\gamma\,[\mathrm{MeV}]\,e^{\frac{-11.605\,E_r[\mathrm{MeV}]}{T_9}}\ \frac{\mathrm{cm}^3}{\mathrm{s\ mole}} \qquad \omega\gamma = \frac{2J_r+1}{(2J_1+1)(2J_T+1)}\frac{\Gamma_p\Gamma_\gamma}{\Gamma}$$

$^{32}Cl(p,g)^{33}Ar$ Reaction rate for $T=0.4 \times 10^9$ K

Example: contribution from one individual resonance (5/2+)