Direct measurement of the $^{18}$F(p,$\alpha$)$^{15}$O reaction for application to nova $\gamma$-ray emission

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Nucleosynthesis of $^{18}$F ($T_{1/2} = 110$ min)

- $\gamma$-ray emission at 511 keV: annihilation of the $\beta^+ \text{ with the expanding envelope}$
- Seed nucleus: $^{16}$O  \rightarrow CO and ONe novae
- Hydrodynamical calculations  \rightarrow SHIVA code  
  \text{José & Hernanz (1998)}
- Main nuclear uncertainty:  $^{18}$F(p,$\alpha$)$^{15}$O
- Large uncertainty on $\gamma$-ray flux

Other nuclear uncertainties: $^{17}$O(p,$\gamma$)$^{18}$F and $^{17}$O(p,$\alpha$)$^{14}$N

\text{TUNL + Orsay (CSNSM)}
$^{18}\text{F}(p,\alpha)^{15}\text{O}$ current status

de Séréville et al. 2003
Kozub et al. 2005
Coszach et al. 1995
Rehm et al. 1995
Graulich et al. 2001
Bardayan et al. 2002

direct

$(d,p)$

Indirect

Mirror nuclei

$(p,p) + (p,\alpha)$

Uncertainties
- Total widths
- Missing levels
- Interferences
Interferences effect / experimental method

- Interference effect in the Gamow peak
- low intensity $^{18}$F beam and cross section → difficult to measure below 300 keV
- Direct measurement at higher energies → 4 energies
- R-matrix analysis

\[ S(E) \ [\text{keV} \cdot \text{b}] \]

\[ E_{\text{c.m.}} \ [\text{MeV}] \]
Experimental set-up: \( p(^{18}\text{F}, \alpha)^{15}\text{O} \)

**Set-up:**

- **\(^{18}\text{F}\) and \( \alpha \) source
- **CH\(_2\)** target
- **Al** degraders

**Detector positions:**
- **LEDA 1:** solid angle
- **LEDA 2:** coincidence efficiency (30%)

**LEDA detectors:**
- (Louvain LN + Edinburg)
- Davinson et al. NIM A 2000
- silicon multistrip detectors (300 \( \mu \)m)
- sector with 16 annular strips
- energy resolution (\( \approx \) 30 keV FWHM)

**Target:** \( \text{CH}_2 \approx 70 \mu\text{g/cm}^2 \)
- covered c.m. energy range / counting rate

**Degraders:** Al (95, 500, 670 \( \mu\text{g/cm}^2 \))
- \( E_{c.m.} = 665, 485, 400 \text{ keV} \)
Production of $^{18}$F ($T_{1/2} = 110$ min):

- $^{18}$O(p,n)$^{18}$F \( E_p @ 15 \text{ MeV} \)
- chemical extraction (45 min) -> CH$_3$$^{18}$F
- 1 bunch of $^{18}$F / 2h (0.5 to 1Ci!)
- 17 bunches of $^{18}$F over 1 ½ week

(Cogneau et al. NIM A 1999)

Acceleration:

- $E^{^{18}}$F = 13.8 MeV (nominal)
- $I \approx 10^6$ pps
- rejection of $^{18}$O contamination

Characterization:

- PIPS detector at 0°
- energy after each degrader
- $^{18}$O / $^{18}$F < 0.5%
$^{18}\text{F} + \text{p}: \alpha - ^{15}\text{O}$ coincidences ON resonance

Coincidences LEDA1 x LEDA2

→ clear identification of $^{18}\text{F}(\text{p},\alpha)^{15}\text{O}$ events

$E_{\text{cm}} = 665 \text{ keV} \rightarrow 4150 \text{ events}$

$E_{\text{cm}} = 700 \text{ keV} \rightarrow 1450 \text{ events}$
$^{18}\text{F} + p$: $\alpha - ^{15}\text{O}$ coincidences OFF resonance

Coincidences LEDA1 x LEDA2

$\rightarrow$ very clean selection of events

$E_{cm} = 485$ keV $\rightarrow$ 180 events

$E_{cm} = 400$ keV $\rightarrow$ 35 events
Differential cross-section

Normalization

→ Elastic scattering $^{18}$F + $^{12}$C in LEDA2 + CH$_2$ stoechiometry

→ good agreement with $l = 0$

ON resonance 3/2+)

→ checked OFF resonance

E$_{c.m.}$ = 700 keV
Absolute cross-section

Good agreement with the $E_r = 665$ keV resonance parameters
Good agreement with previous experimental data
Interferences between $3/2^+$ states in $^{19}$Ne [1]

- Four $3/2^+$ resonances: $E_r = 8, 38, 665, 827$ keV

- $E_r = 827$ keV small $\alpha$-width ($\Gamma_\alpha = 0.35$ keV) → no effect in Gamow peak region
Interferences between $3/2^+$ states in $^{19}\text{Ne}$ [2]

- $E_r = 8$ or $38$ keV which level is contributing and how?
  → mainly one of the two: $^{18}\text{F}(d,p)^{19}\text{F}$

**Two cases**

![Graphs showing S-factor vs. c.m. energy for different $E_r$ values]
Conclusion

Present experiment: $^{18}\text{F}(p,\alpha)^{15}\text{O}$ direct measurement at low energy

Constraints on interference sign for $3/2^+$ levels:

→ complex situation depending on spectroscopic properties of low lying levels ($\Gamma_p$, $\Gamma_\alpha$)
→ All cases: (+ - -) favored
                    (+ - +) rejected
→ Dominant $E_\gamma = 38\text{ keV}$: (+ + +) Favored (constructive)
                     (+ - -) Rejected (destructive)
                     (+ - +)
                     (+ + -)

Also $1/2^+$ levels: see P. Descouvemont’s talk

Near perspectives (accepted experiments):
→ Determine properties of low lying resonances
→ Measurements at lower energies (direct or THM)
Collaboration

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