THE ROLE OF ^{20}Ne STATES IN THE ^{19}F$(p,\alpha)^{16}$O REACTION CROSS SECTION AT LOW ENERGY*

I. Lombardo

Istituto Nazionale di Fisica Nucleare — Sezione di Catania
via S. Sofia 64, 95123, Catania, Italy

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The ^{19}F$(p,\alpha)^{16}$O reaction has a twofold importance: it allows to investigate the spectroscopy of low angular momentum high-energy states in the self-conjugate ^{20}Ne nucleus and, at low energy, it is important to astrophysical models aiming at describing the nucleosynthesis of fluorine in stars. In this proceeding, we discuss preliminary results of a comprehensive R-matrix analysis of the ^{19}F$(p,\alpha_0)^{16}$O and ^{19}F$(p,\alpha_\pi)^{16}$O reactions and $p+^{19}$F elastic cross-section data.

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1. Introduction

The spectroscopy of the self-conjugate ^{20}Ne nucleus at excitation energies above the proton emission threshold ($S_p = 12.844$ MeV) can be profitably explored by analysing cross-section data of proton-induced nuclear reactions on ^{19}F target [1–3]. Even at low energies, several reaction channels are energetically available: the elastic scattering channel [1], the inelastic scattering to the $E_x = 107$ keV and $E_x = 191$ keV excited states in ^{19}F [4], the ^{19}F$(p,\alpha_0)^{16}$O ($Q = 8.114$ MeV) reaction [5–11], the ^{19}F$(p,\alpha_\pi)^{16}$O (being E_x in ^{16}O equal to 6.05 MeV; this state decays by e^+e^- pair emission, and this explains the subscript π) reaction [5, 12–15], and the ^{19}F$(p,\alpha_\gamma)^{16}$O (E_x in ^{16}O = 6.13, 6.92, 7.12 MeV) group of reactions [10, 12, 14, 16]. The radiative capture reaction ^{19}F$(p,\gamma)^{20}$Ne has a cross section well smaller than the other reaction channels [17, 18]. Because of conservation laws in nuclear forces, only natural-parity states of ^{20}Ne can decay to the α_0 and α_π channels [3]. This selectivity makes this reaction very well suited to study the spectroscopy of natural parity states of ^{20}Ne at $E_x > 12.844$ MeV.

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Unfortunately, the poor and fragmentary cross-section data published in the literature [19] often leads to ambiguities in the determination of resonance parameters, as visible in Ref. [20]. Anyway, in recent times, some groups made a comprehensive revision of all the available data set for the $^{19}\mathrm{F}(p,\alpha_0)^{16}\mathrm{O}$ reaction data [21] and for the elastic scattering data [22, 23]. Starting from such analyses, we performed a comprehensive R-matrix fit of cross-section data in a quite broad energy domain, with the aim of confirming some tentative J^π assignment of ^{20}Ne states. Some of them, near to the proton emission threshold, are relevant in the determination of the $^{19}\mathrm{F}(p,\alpha)^{16}\mathrm{O}$ reaction rate, with potential astrophysical implication in the destruction of fluorine in AGB stars [7, 21, 24–27].

2. Discussion of available experimental data

In recent times, a comprehensive re-analysis of the $^{19}\mathrm{F}(p,\alpha_0)^{16}\mathrm{O}$ angle-integrated cross-section data [21] was published in the literature. The comparison of several data sets, and the presence of overlap regions between them, allowed to critically disentangle the behavior of the cross section and the need of relative normalizations factors between the various data sets. This data set covers the energy range of $E_p \approx 0.2$–3.5 MeV, and if it is integrated with the high-energy data of [28], it allows to disentangle the behavior of such reaction cross section up to ≈ 12 MeV. The availability of high-energy points is important because the $^{19}\mathrm{F}(p,\alpha_0)^{16}\mathrm{O}$ reaction can proceed in a sizable part via a direct mechanism, whose contribution can be reasonably estimated by analysing the highest energy data points. The $^{19}\mathrm{F}(p,\alpha_\pi)^{16}\mathrm{O}$ cross-section database was built by using the absolute data of [5, 12, 13, 15] and including also data from the unpublished report [29]. Concerning the elastic scattering data, we used the absolute differential cross-section data at $\theta_{\mathrm{lab}} = 135, 145^\circ$ from Ref. [5]: they are in good agreement with other data sets, including ones benchmarked with thick target experiments [22, 23]. In the R-matrix fit of data, we allowed only a very small (within 5% difference) overall normalization factor of the cross-section scale to account for eventual normalization errors present in the original measurement. Some of the preliminary results of the R-matrix analysis are briefly described in the following section.

3. Preliminary results from the R-matrix fit of data

We performed a comprehensive R-matrix fit of all the database discussed in the previous section by using the AZURE2 code [30, 31]. In Fig. 1, we show the preliminary results of the fit by solid lines: they reproduce in a quite satisfactory way all the $^{19}\mathrm{F}(p,\alpha_0)^{16}\mathrm{O}$ angle-integrated cross section

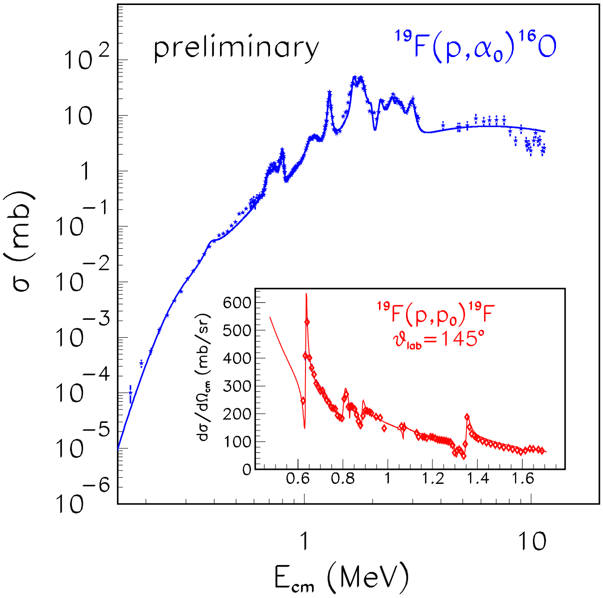

Fig. 1. (Colour on-line) The global $^{19}\mathrm{F}(p,\alpha_0)^{16}\mathrm{O}$ cross-section data set reported in Ref. [21] (blue stars) and the $p+^{19}\mathrm{F}$ elastic differential cross-section data at $\theta_{\mathrm{lab}} = 145°$ (red open diamonds in the inset). The blue (main histogram) and red (inset) solid lines show the results of preliminary R-matrix calculation made by including the $^{19}\mathrm{F}(p,\alpha_0)^{16}\mathrm{O}$, the $^{19}\mathrm{F}(p,\alpha_\pi)^{16}\mathrm{O}$ cross-section data set and the $p+^{19}\mathrm{F}$ elastic differential cross-section data at $\theta_{\mathrm{lab}} = 145°$.

and $p+^{19}\mathrm{F}$ elastic differential cross-section data at $\theta_{\mathrm{lab}} = 145°$ in the whole energy domain here explored. The obtained reduced chi-square values are ≈ 1.5 for the α_0 data and ≈ 4 for the elastic scattering data, while the partial width values are obtained with an average uncertainty of the order of 25%. To reproduce the high-energy part of $^{19}\mathrm{F}(p,\alpha_0)^{16}\mathrm{O}$ data, we included two broad high-energy poles (in s- and p-wave) that mimic the presence of direct reaction mechanisms. Such terms are also important to describe the very sub-Coulomb part of the cross section, as discussed in details in Refs. [7, 32, 33]. This represents an important point to minimize the uncertainties of the extrapolated S-factor in order to better estimate the reaction rate at astrophysical energies. Some preliminary constraints of the spectroscopy of ^{20}Ne can be obtained by means of the above discussed R-matrix fit. The tentatively reported 1^- assignment for the 13.522 MeV state and the 0^+ assignment for the 13.645 MeV state are supported by the present analysis. In the last case, in particular, the alternative 2^+ assignment reported in Ref. [3] is not able to reproduce the shape and amplitude of elastic scattering differential cross sections at backward angles in the $E_{\mathrm{cm}} = 0.8$ MeV region.

Similarly, all the resonance parameters of natural parity states involved in the various $p+^{19}$F reaction channels are under inspections and will be the subject of a forthcoming more extended paper.

New improved experimental data, including refined angular distributions of the $^{19}\mathrm{F}(p,\alpha_0)^{16}\mathrm{O}$ reaction at various incident energies, might give the possibility to further refine the results of R-matrix analyses. This could be made possible by means of innovative setups involving high-resolution hodoscopes capable to identifying alpha-particles at low energies [34].

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