Assessment of the $^{16}O(d,p)^{17}O$ and $^{16}O(d,\alpha)^{14}N$ cross sections

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The $^{16}O(d,p_1)^{17}O$ reaction is known to be very popular for oxygen analysis. A relatively wide plateau in the 800-900 keV energy region provides favorable conditions for IBA and so the cross section in this region was measured in a number of works. Most of the results were obtained at 150° (see Fig. 1) and therefore additional measurements are needed in a wide interval of angles.

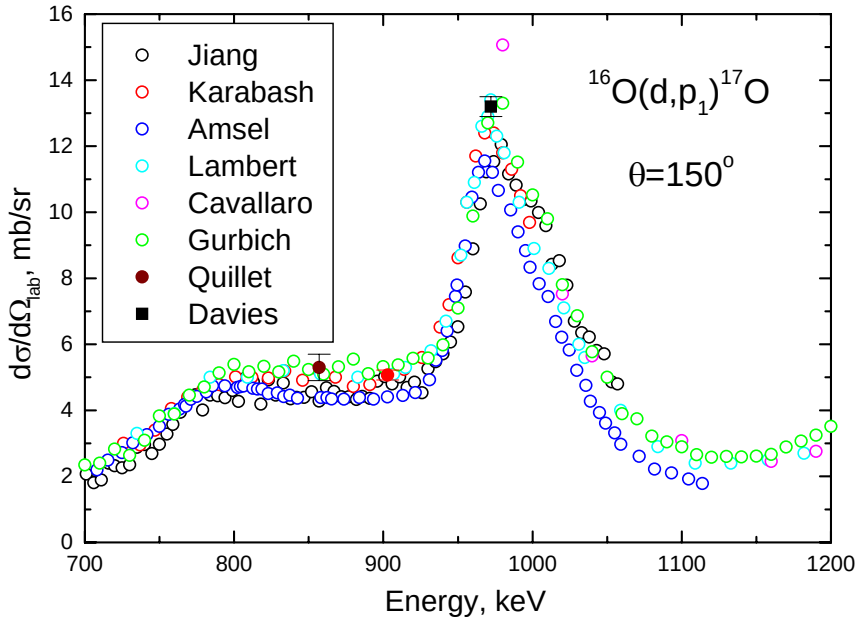

Fig. 1. Experimental data available for the $^{16}O(d,p_1)^{17}O$ reaction in the energy range from 700 to 1200 keV at 150°. Solid points represent the data reported in a numerical form.

An ambiguity should be noted concerning the $^{16}O(d,p_1)^{17}O$ cross section obtained by Amsel et al. and presented by the authors in graphical form in five original publications [1-5]. There is every indication that the data are the same in all the figures. Strange enough, but none of the papers contains a description of the cross section measurements. Thus nothing is known about experimental conditions at which the data were obtained. The scattering angle is 165° lab in the figures in all the papers except for [2] where the scattering angle is not explicitly indicated at all. However it is the figure from [2] that is reproduced in Handbooks [6-7], the cross section being attributed to the angle of 150°. This angle was mentioned in the paper [2], but on another occasion.

There are at least two papers [3,8] where Amsel et al. demonstrate an application of the $^{16}O(d,p_1)^{17}O$ cross section to particular studies, with the experimental setup being presented in the figures. The detector is fixed at 165° in both cases. Amsel's data are compared in Fig.2 with the data sets obtained for 150° [9] and 164°15′ [10] and the agreement is much better for the 164°15′ case in the plateau region. The decrease of the cross section with increasing angle for backward angles corresponds to the angular distribution shown in Fig. 3.

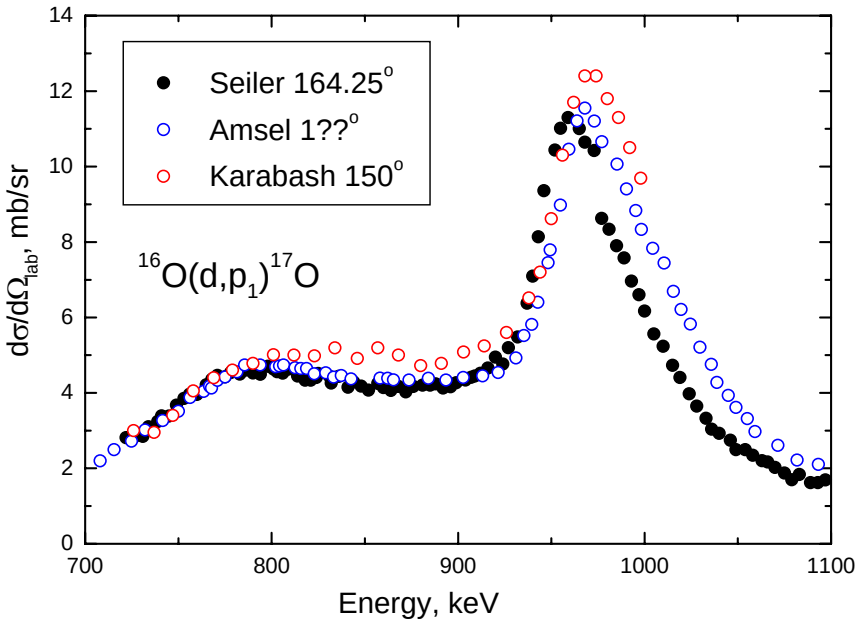

Fig. 2. Comparison of Amsel's data with results obtained for 150° and 165°.

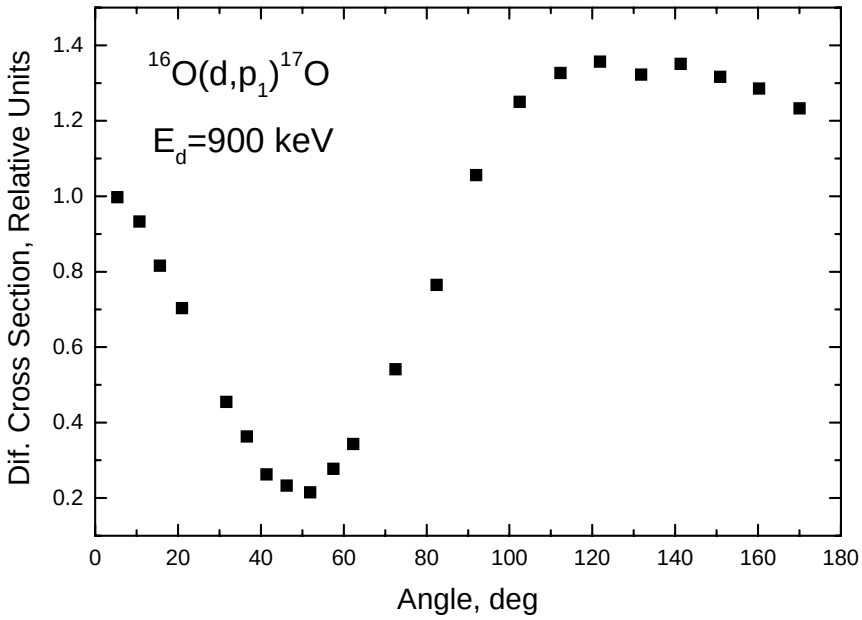

Fig. 3. Angular distribution for the $^{16}O(d,p_1)^{17}O$ reaction at 900 keV [11].

Summing up it seems likely that the angle in Handbooks [6-7] was assigned to the data by mistake, however Prof. Amsel tends to believe that the good number for the scattering angle is 150° [12]. His reasons are derived from speculations about preferable experimental conditions for application of the reaction rather than grounded on some notes or reminiscences concerning the cross section measurements.

Special efforts were applied for absolute calibration of the $^{16}O(d,p_1)^{17}O$ cross section in Refs. [13-16]. The obtained results along with the absolute data from [9] and [17] published in tabular form are compared in Table 1.

Table 1. Absolute values for the $^{16}O(d,p_1)^{17}O$ cross section

Energy, keV	Cross section, mb/sr	Target	Reference
857	5.3±0.4	Ta_2O_5	Quillet
903	5.07±0.15	Al_2O_3	Karabash
972	13.6±0.4	Ta_2O_5	Lennard89
972	13.3±0.4	Ta_2O_5	Davies80
972	13.2±0.3	Ta_2O_5	Davies83
857 969 974 979	4.28±0.11 11.22±0.45 11.53±0.46 12.05±0.48	SiO_2	Jiang

All the results except for [17] are in a good agreement. As is seen from Table 1 the peak in the cross section [17] is shifted by 7 keV and the values are lower both at the plateau and for the peak. The peak to plateau ratio is 2.82 in [17] versus 2.57 in average for the other works.

At higher energies the data were measured at various angles and comparison is difficult (Fig. 4). The significant difference between the data from [18] (150°) and [19] (142.2°) near 1.6 MeV in Fig. 4 can be caused by the cross section resonance behavior.

Scarce information is available for the $^{16}O(d,p_0)^{17}O$ and $^{16}O(d,\alpha_0)^{14}N$ cross sections. The comparison between the $^{16}O(d,p_0)^{17}O$ data from [18] and [19] demonstrates reasonable agreement (Fig. 5).

Cumulative information on the studied cross sections is presented in Table 2. Some ambiguity should be mentioned concerning Ref. [10]. The conversion of the angle from the laboratory system into the centre-of-mass one depends on the energy. So it is impossible to assign the same c.m. angle to all points of the excitation function as is done in the paper. There is no

indication whether the correct c.m. angle was applied in conversion of the measured yield into the cross section. It worth noting that the dependence of the angle conversion rate on energy is actually small.

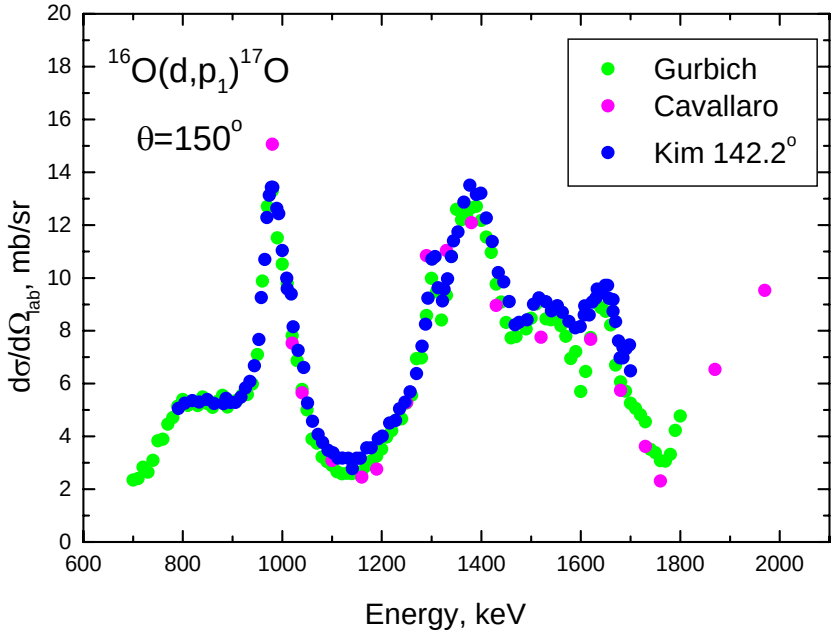

Fig. 4. Comparison of different data for the $^{16}O(d,p_1)^{17}O$ reaction in a wide energy region (Cavallaro's excitation function was constructed from angular distributions presented in [20]).

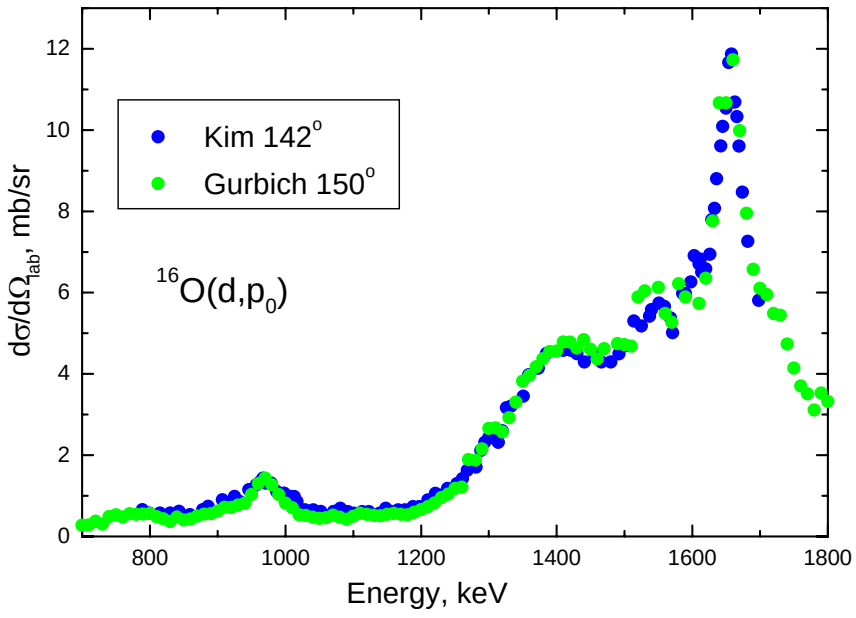

Fig. 5. Comparison of different data for the $^{16}O(d,p_0)^{17}O$ reaction.

Table 2. Cumulative information on the deuteron induced reactions for ^{16}O.

Energy range (MeV)	Reaction	Target	The energy (MeV) of angular distribution measurement	The angle of excitation function measurement	Error	Data presentation	Notes	Ref.
0.8-1.7	(d,p_0), (d,p_1), (d,α_0)	Gas		51.4, 66.9, 86.7, 127.7, 142.2, 164.3	5%	Graph	Added to IBANDL	Kim
0.7-1.0	(d,p_1)	Al_2O_3, 62.8 $\mu g/cm^2$		150	3-5%	Table		Karabash
0.98-1.97	(d,d_0), (d,p_0), (d,p_1), (d,α_0)	Gas	0.98, 1.02, 1.04, 1.10, 1.16, 1.19, 1.25, 1.29, 1.34, 1.38, 1.43, 1.52, 1.62, 1.68, 1.73, 1.76, 1.87, 1.970.98, 1.02, 1.04, 1.10, 1.16, 1.19, 1.25, 1.29, 1.34, 1.38, 1.43, 1.52, 1.62, 1.68, 1.73, 1.76, 1.87, 1.97		6%	Graph	Excitation function for 150° derived from angular distributions was added to IBANDL	Cavallaro
0.857	(d,p_1)	Ta_2O_5, $361 \cdot 10^{15}$ cm^{-2}		150	7.5%	Value		Quillet
0.972	(d,p_1)	Ta_2O_5		150	2%	Value	Added to IBANDL	Davies80, Davies83
0.7-1.8	(d,p_0), (d,p_1)	Al_2O_3, 60 $\mu g/cm^2$		150	7.5%	Graph, IBANDL	Mistakes were corrected in the IBANDL files	Gurbich
0.972	(d,p_1)	Ta_2O_5		150		Value	Added to IBANDL	Lennard89
0.7-1.2	(d,p_1)	Ta_2O_5		150	5%	Table	Added to IBANDL	Lennard91
0.7-1.06	(d,p_1), (d,α_0)	SiO_2		150	4%	Table, Graph		Jiang
0.55-0.66	(d,p_0)	Ta_2O_5		150	10%	Graph		Berty

Table 2 continued

0.65-2.0	(d,p_0), (d,p_1), (d,α_0)	Gas		164.25	5%	Graph	Added to IBANDL (EXFOR data converted from c.m. to lab.) instead of data from NDT.	Seiler
0.5-3.0	(d,p_0), (d,p_1), (d,α_0)	SiO_2, Ta_2O_5		135	12%	Graph	Added to IBANDL (EXFOR data) instead of Jarjis' data.	Debras
0.8-2.0	(d,p_0), (d,p_1), (d,α_0)	Ta_2O_5	0.900, 0.950, 0.986, 1.013, 1.040, 1.067, 1.069, 1.145, 1.206, 1.266, 1.299, 1.310, 1.385	90, 135, 165 (d, α); 10, 87, (d,p0,1)		Graph		Amsel64
0.42-1.12	(d,p_1)	Presumably Ta_2O_5		150(?), 165(?)		Graph		Amsel [1-5]
0.84-1.02	(d,α_0)	SiO_2		160		Graph		Picraux
0.76-0.95	(d,p_1), (d,α_0)	SiO_2		145		Graph		Turos

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