Data Assessment of $^{14}N(p,p_0)^{14}N$ Cross Sections

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Summary

The data sets on IBANDL were compared with the data in the original references. Details are given on the discrepancies found. A thorough search for other available experimental data was performed. The search was restricted to the (p,p_0) cross sections measured for ^{14}N and for backscattering angles in the 100-180º range as these are the most common angles encountered in Ion Beam Analysis Laboratories. Existing measured cross sections were compared and checked for discrepancies and gaps. Most discrepancies occur around the resonances at proton energies ~1050 keV, ~1750 keV and ~2350 keV. The exact height and position of these resonances should be carefully studied to resolve these discrepancies. Most of the existing data correspond to scattering angles in the 150º-170º region, below 3 MeV. Data should be obtained for energies above 3 MeV and for scattering angles between 125º and 145º.

1. Discrepancies between IBANDL data sets and original data

The data sets on IBANDL were compared with the data in the original references. When several data sets for the same angle and reference were present on IBANDL, a consistency check between them was also performed.

A good agreement was found for the majority of data sets. Two discrepancies were identified. A first discrepancy was observed for the 159.5° scattering angle (Φ) data set in [BAS1959] (data set nº 8 in table 1). The discrepancy consisted of an energy shift between the IBANDL data set and the original data as shown on figure 1. The origin of the shift could not be determined. The energy values on IBANDL do not correspond to energy in the center of mass frame of reference or to an erroneous transformation of the original values (already given in the laboratory frame of reference) to laboratory frame of reference. A new file was created from the original data using the digitizing procedure explained in chapter 2. The new data set is included in Annex 1 for future up-loading if deemed appropriate.

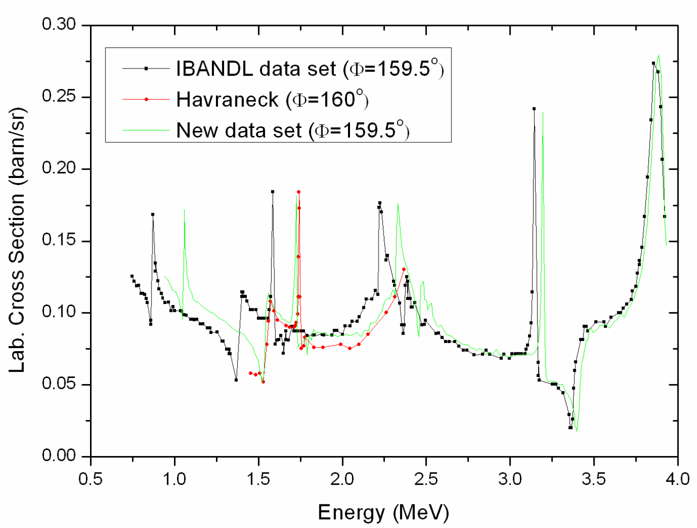

Fig. 1. Comparison between the IBANDL data set for Φ=159.5º from [BAS1959] and the new digitized data set. Data with a similar scattering angle (Φ=160º) from [HAV1991] is included for comparison.

A second discrepancy was found between the three 152.1° scattering angle data sets in IBANDL, taken from reference [HAG1957]. Data set nº 12 (see table 1), in the 1040-1080 keV energy range, and 13 (see table 1), in the 1470-1620 keV energy range, agree with the data shown on figures 2 and 3 of the original paper. The data set nº 11 (see table 1), which covers the 630-1820 keV energy range, also agrees with the data on figure 1 of the original paper. However, the data in set nº 11 do not agree with the data in the other two sets in the overlapping energy ranges. Figure 2 shows a comparison of the 152.1° scattering angle data taken from IBANDL. Major differences are observed in the resonance around 1050 keV, both in energy position and intensity. The maximum of the ~1050 keV resonance in figure 2 is 3.61 in units of ratio to Rutherford. This corresponds to a cross section value, in the laboratory frame of reference, of 0.230 barn/sr. In the center of mass frame of reference, this value would be 0.262 barn/sr. However, looking at figure 1 in [HAG1957], the maximum is well below 0.225 barn/sr. This indicates that this discrepancy is already present in the original paper and relates to the fact that data set nº11 was measured with a thick adenine target, whereas data sets nº 12 and nº 13 with a thin target, prepared by N implantation into a Be surface.

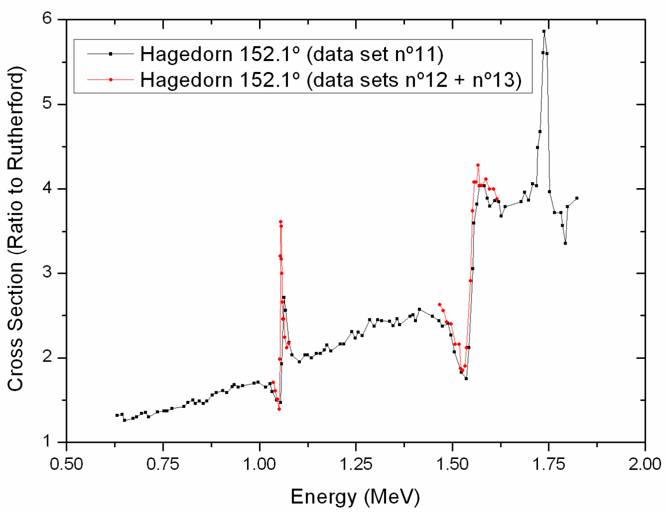

Fig. 2. Comparison of the 152.1º scattering angle data taken from IBANDL.

Table 1 list all available data sets on IBANDL for the $^{14}N(p,p_0)^{14}N$ reaction and recommended actions to be taken, if any, regarding each particular case.

Table 1 – Original data sets from IBANDL.

Nº	Reaction	Lab. Scattering Angle	Energy Range (keV)	Reference	Comments	Recommended Actions
1	$^{14}N(p,p_0)^{14}N$	178.7º	1740-1760	[HAG1957]	A scattering angle of 158.7º is indicated in [HAG1957].	Change scattering angle to 158.7º.
2	$^{14}N(p,p_0)^{14}N$	178.0º	500-2500	[RAM2002]		
3	$^{14}N(p,p_0)^{14}N$	170.0º	1450-2300	[RAU1985]		
4	$^{14}N(p,p_0)^{14}N$	170.0º	2700-3100	[YAN1991]		
5	$^{14}N(p,p_0)^{14}N$	167.2º	3610-4080	[OLN1958]		
6	$^{14}N(p,p_0)^{14}N$	165.0º	1860-3000	[LAM1967]		
7	$^{14}N(p,p_0)^{14}N$	160.0º	1450-2370	[HAV1991]		
8	$^{14}N(p,p_0)^{14}N$	159.5º	750-3920	[BAS1959]	The data in this file do not match the data in [BAS1959].	Replace existing data set with new file (see table 2).
9	$^{14}N(p,p_0)^{14}N$	158.7º	1790-1810	[HAG1957]		
10	$^{14}N(p,p_0)^{14}N$	155.2º	1860-3000	[LAM1967]		
11	$^{14}N(p,p_0)^{14}N$	152.0º	630-1820	[HAG1957]	A scattering angle of 152.1º is a better correspondence to the 154º center of mass scattering angle indicated in [HAG1957]. See also text.	Change scattering angle to 152.1º.
12	$^{14}N(p,p_0)^{14}N$	152.1º	1040-1080	[HAG1957]	See text.	
13	$^{14}N(p,p_0)^{14}N$	152.0º	1470-1620	[HAG1957]	A scattering angle of 152.1º is a better correspondence to the 154º center of mass scattering angle indicated in [HAG1957]. See also text.	Change scattering angle to 152.1º.
14	$^{14}N(p,p_0)^{14}N$	150.0º	840-1890	[TAU1956]		
15	$^{14}N(p,p_0)^{14}N$	150.0º	2480-3230	[JIA2005]	Incorrect year in reference.	Change reference (see chapter 4).
16	$^{14}N(p,p_0)^{14}N$	147.2º	940-2410	[BAS1959]		
17	$^{14}N(p,p_0)^{14}N$	140.0º	500-2500	[RAM2002]		
18	$^{14}N(p,p_0)^{14}N$	85.9º	880-2470	[BAS1959]		

2. Other available experimental data

A thorough search for other available experimental data was performed. The search was restricted to the (p,p_0) cross sections measured for ^{14}N and for backscattering angles in the 100-180º range as these are the most common angles encountered in Ion Beam Analysis Laboratories.

All data appeared in graphical form in the original references. The procedure used to digitize the cross section plots was as follows. The appropriate figure in the pdf file of the original paper was copied as a bmp file. This file was imported on to an ORIGIN© graph with the exact dimensions and scale of the bmp picture. The screen reader utility of ORIGIN© was used to determine as accurately as possible the (x,y) position of each point. The data in its original units were then converted to a (Energy, Cross Section) file, with energy in MeV and cross section in barn/sr, both in the laboratory frame of reference. This procedure was used whenever the scale and resolution of original figures allowed an accurate determination of the position of each separate data point (case (a) in table 2). In some instances, the resolution or scale of the original figure did not permit the exact position of each individual data point to be determined (case (b) in table 2). In this case a smooth curve was drawn by hand over the relevant experimental points. This smooth curve was then digitized at irregular intervals using the screen reader utility of ORIGIN©. This digitizing procedure is similar to the one used in reference [TES1995].

Table 2 lists the additional data sets found in the literature, digitized and up-loaded into IBANDL. Data set nº 31 was not uploaded, so as not to duplicate entries on the data base. Annex 1 presents data set nº 31 in tabular form to allow up-loading if such is deemed appropriate.

Table 2 – Additional data sets found in the literature and digitized.

Nº	Reaction	Lab. Scattering Angle	Energy Range (keV)	Reference	Comments	Digitizing procedure
19	$^{14}N(p,p_0)^{14}N$	109.1º	1900-3000	[LAM1967]	Data taken from fig. 1 in reference.	(b)
20	$^{14}N(p,p_0)^{14}N$	110.0º	1710-1830	[FEG1959]	Data taken from fig. 4 in reference.	(a)
21	$^{14}N(p,p_0)^{14}N$	110.0º	2300-2540	[FEG1959]	Data taken from fig. 5 in reference.	(a)
22	$^{14}N(p,p_0)^{14}N$	121.5º	1040-1080	[HAG1957]	Data taken from fig. 2 in reference.	(a)
23	$^{14}N(p,p_0)^{14}N$	121.5º	1460-1620	[HAG1957]	Data taken from fig. 3 in reference.	(a)
24	$^{14}N(p,p_0)^{14}N$	121.5º	1730-1760	[HAG1957]	Data taken from fig. 4 in reference.	(a)
25	$^{14}N(p,p_0)^{14}N$	121.5º	1790-1810	[HAG1957]	Data taken from fig. 4 in reference.	(a)
26	$^{14}N(p,p_0)^{14}N$	121.8º	1500-3500	[BOL1957]	Data taken from fig. 2 in reference.	(b)
27	$^{14}N(p,p_0)^{14}N$	130.0º	1710-1830	[FEG1959]	Data taken from fig. 4 in reference.	(a)
28	$^{14}N(p,p_0)^{14}N$	130.0º	2300-2540	[FEG1959]	Data taken from fig. 5 in reference.	(a)
29	$^{14}N(p,p_0)^{14}N$	138.1º	1500-3500	[BOL1957]	Data taken from fig. 2 in reference.	(b)
30	$^{14}N(p,p_0)^{14}N$	153.4º	1000-3000	[FEG1959]	Data taken from fig. 3 in reference. Data in 1710-1830 and 2300-2550 keV range taken from detailed figure 4 and 5 in reference.	(b)
31	$^{14}N(p,p_0)^{14}N$	159.5º	900-3920	[BAS1959]	Data taken from fig. 2 in reference.	(b)
32	$^{14}N(p,p_0)^{14}N$	167.2º	1000-4080	[OLN1958]	Data taken from fig. 1 in reference. Data in 3610-4080 keV range, detailed in figure 3 in reference, was already on IBANDL (data set nº5, table 1) and was incorporated in the file.	(b)

3. Comparison of existing measured cross sections: discrepancies and gaps

Figures 3 and 4 present in graphical form all the cross sections listed in table 1 and 2. In the graphs both the energy and the cross section are given in the laboratory frame of reference, with energy units in MeV and cross section units in barn/sr.

Figure 3 shows the cross section data available in the 109.1º-150º scattering angle range. Data sets with similar angles are shown together. In figure 3(a) the Lambert 109.1º data agree with the Ferguson 110º data for energies outside the resonances. The same is true for the Hagedorn 121.5º data and the Bolmgren 121.8º data. However, the exact position and height of the resonances do not match, particularly for the Hagedorn 121.5º and Bolmgren 121.8º data sets. In the Bolmgren data, both at 121.8º and 138.1º (figure 3(b)) the resonance maxima are always considerably lower than those of other data sets at similar scattering angles.

In figure 3(b) the Ramos 140º data appear too low when compared with the Bolmgren 138.1º data and the Tauftest 150º data (figure 3(c)). In figure 3(c) the Bashkin 147.2º data appear to be too high, when compared with the data taken at lower or similar angles: Fersuson 130º and Bolmgren 138.1º, figure 3(b), and Tauftest 150º, figure 3(c).

Figure 4 shows the cross section data available in the 152.1º-178º scattering angle range. Data sets with similar angles are shown together. In figure 4(a) all data sets agree for energies outside the resonances. However, the exact position and height of the resonances do not match, which is particularly relevant for data with very similar scattering angles as the Hagedorn 152.1º and Ferguson 153.4º data sets. Similar comments can be made as to the data in figure 4(b) and 4(c). In addition, in the case of figure 4(c), the Ramos 178º cross section data appear consistently lower and Yang 170º cross section data consistently higher than the others with a similar scattering angle.

From the discussion above it is clear that most discrepancies occur around the resonances at proton energies ~1050 keV, ~1750 keV and ~2350 keV. The exact height and position of these resonances should be carefully studied to resolve these discrepancies.

Also, most of the data correspond to scattering angles in the 150º- 170º region, below 3 MeV. Data should be obtained for energies above 3 MeV and for scattering angles between 125º and 145º.

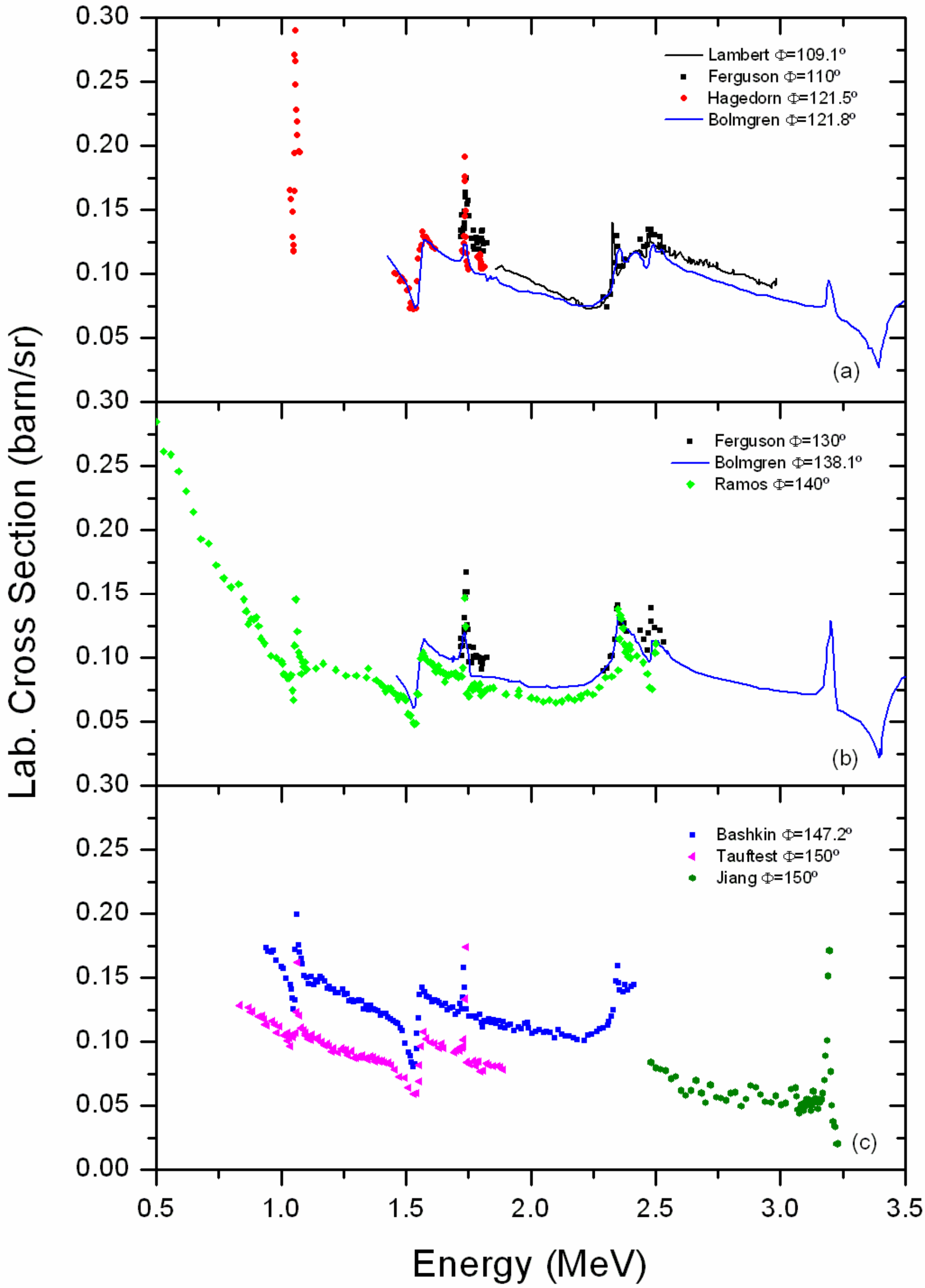

Fig. 3. Cross section for the $^{14}N(p,p_0)^{14}N$ reaction at scattering angles in the 109.1°-150° range. Proton energy, scattering angles and cross-section values are given in the laboratory frame of reference.

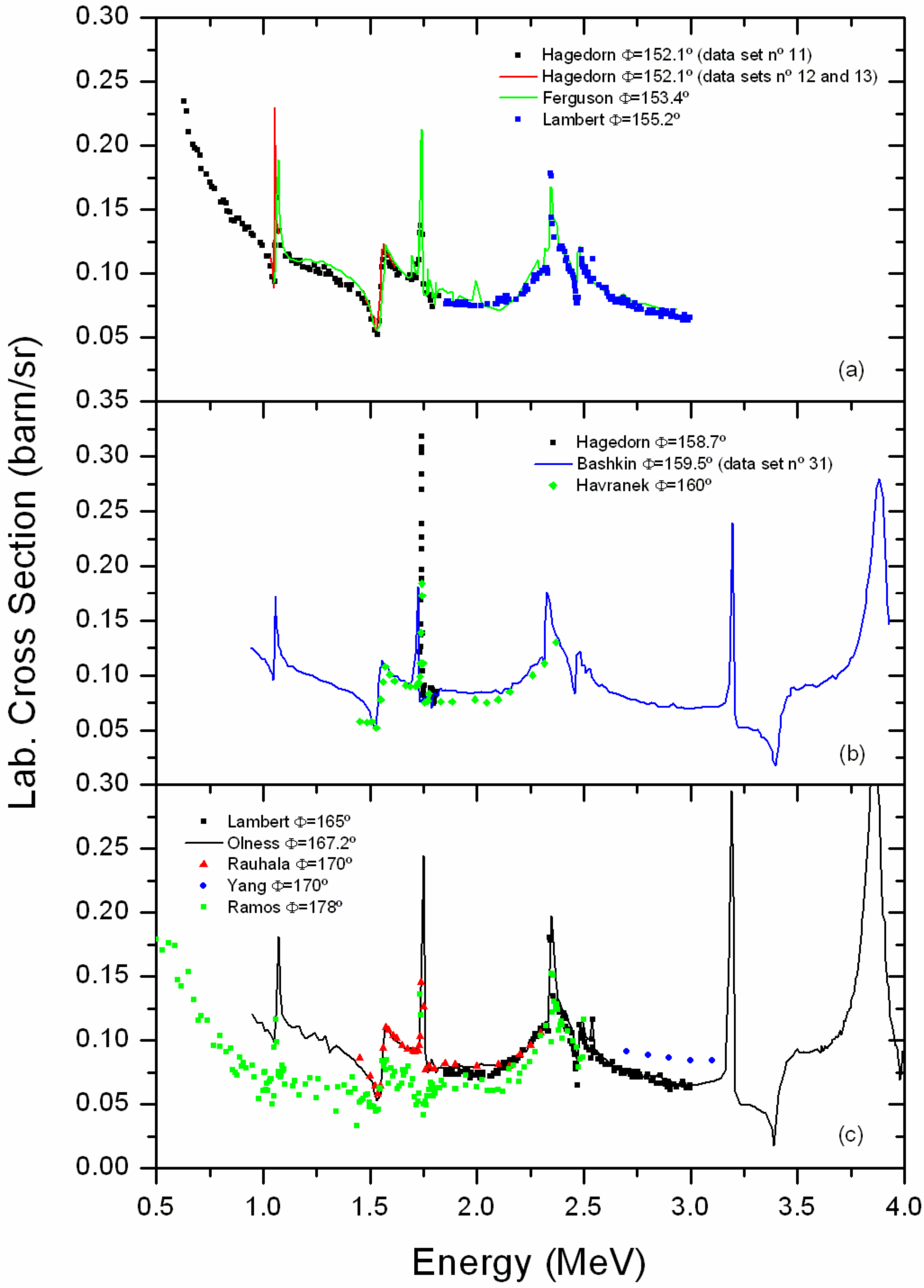

Fig. 4. Cross section for the $^{14}N(p,p_0)^{14}N$ reaction at scattering angles in the 152.1º-178º range. Proton energy, scattering angles and cross-section values are given in the laboratory frame of reference.

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Annex 1

Table A1 presents the digitized data from [BAS1959] corresponding to the 159.5º scattering angle in tabular form. In the table, both the energy and the cross section are given in the laboratory frame of reference, with energy units in MeV and cross section units both in barn/sr and ratio to Rutherford (rr).

Table A1- Data set nº 31 [BAS1959].

Energy	σ	σ	Energy	σ	σ	Energy	σ	σ
(MeV)	*(barn/sr)*	*(rr)*	*(MeV)*	*(barn/sr)*	*(rr)*	*(MeV)*	*(barn/sr)*	*(rr)*
0.940	0.1251	1.65	1.512	0.0567	1.93	1.924	0.0845	4.66
0.951	0.1242	1.68	1.523	0.0514	1.78	1.954	0.0845	4.81
0.960	0.1227	1.69	1.530	0.0558	1.95	1.972	0.0835	4.84
0.967	0.1209	1.68	1.534	0.0630	2.21	1.988	0.0841	4.95
0.978	0.1188	1.70	1.537	0.0710	2.50	2.006	0.0841	5.05
0.987	0.1161	1.69	1.539	0.0787	2.78	2.021	0.0850	5.18
1.000	0.1146	1.71	1.542	0.0933	3.31	2.048	0.0841	5.26
1.008	0.1146	1.74	1.544	0.1003	3.57	2.072	0.0850	5.44
1.015	0.1120	1.72	1.550	0.1072	3.84	2.086	0.0867	5.63
1.027	0.1090	1.71	1.556	0.1100	3.97	2.102	0.0846	5.58
1.035	0.1037	1.66	1.557	0.1138	4.12	2.112	0.0835	5.56
1.042	0.1018	1.65	1.564	0.1096	4.00	2.130	0.0876	5.93
1.047	0.0954	1.56	1.571	0.1096	4.04	2.142	0.0876	5.99
1.054	0.1345	2.23	1.586	0.1061	3.98	2.158	0.0876	6.08
1.057	0.1541	2.57	1.591	0.1037	3.92	2.169	0.0930	6.52
1.058	0.1722	2.88	1.603	0.1009	3.87	2.189	0.0928	6.63
1.061	0.1547	2.60	1.610	0.0998	3.86	2.203	0.0939	6.80
1.062	0.1491	2.51	1.621	0.0992	3.89	2.223	0.0987	7.27
1.065	0.1428	2.42	1.631	0.0989	3.92	2.235	0.1003	7.47
1.068	0.1386	2.36	1.640	0.0957	3.84	2.252	0.1081	8.17
1.072	0.1306	2.24	1.654	0.0950	3.88	2.267	0.1096	8.40
1.074	0.1271	2.19	1.663	0.0950	3.92	2.283	0.1096	8.52
1.080	0.1236	2.15	1.673	0.0935	3.90	2.299	0.1159	9.13
1.084	0.1183	2.07	1.686	0.0928	3.93	2.306	0.1159	9.19
1.092	0.1159	2.06	1.697	0.0948	4.07	2.309	0.1140	9.06
1.102	0.1144	2.07	1.713	0.1194	5.22	2.316	0.1124	8.99
1.114	0.1092	2.02	1.718	0.1371	6.04	2.320	0.1497	12.02
1.127	0.1077	2.04	1.720	0.1589	7.01	2.329	0.1761	14.24
1.138	0.1077	2.08	1.727	0.1815	8.07	2.340	0.1669	13.63
1.157	0.1051	2.10	1.730	0.1129	5.04	2.347	0.1532	12.59
1.178	0.1031	2.13	1.731	0.0861	3.85	2.354	0.1462	12.08
1.198	0.1018	2.18	1.735	0.0761	3.42	2.369	0.1366	11.43
1.216	0.1003	2.21	1.745	0.0782	3.55	2.381	0.1336	11.30
1.232	0.0994	2.25	1.760	0.0798	3.69	2.391	0.1277	10.89
1.246	0.0983	2.28	1.768	0.0811	3.78	2.393	0.1273	10.87
1.266	0.0959	2.29	1.780	0.0832	3.93	2.400	0.1242	10.67
1.295	0.0944	2.36	1.784	0.0782	3.71	2.419	0.1168	10.19
1.319	0.0920	2.39	1.791	0.0704	3.37	2.426	0.1120	9.83
1.352	0.0885	2.41	1.795	0.0791	3.80	2.433	0.1081	9.54
1.382	0.0865	2.46	1.802	0.0841	4.07	2.441	0.1003	8.92
1.395	0.0861	2.50	1.817	0.0811	3.99	2.446	0.0939	8.37
1.416	0.0845	2.53	1.821	0.0852	4.21	2.448	0.0891	7.96
1.436	0.0808	2.48	1.830	0.0885	4.42	2.457	0.0835	7.52
1.466	0.0763	2.45	1.841	0.0856	4.32	2.464	0.1009	9.14
1.475	0.0732	2.37	1.852	0.0865	4.43	2.467	0.1183	10.73
1.484	0.0708	2.33	1.870	0.0859	4.48	2.483	0.1218	11.19
1.496	0.0680	2.27	1.887	0.0859	4.56	2.490	0.1092	10.10
1.503	0.0636	2.14	1.901	0.0861	4.64	2.503	0.1085	10.13
1.507	0.0602	2.04	1.912	0.0841	4.59	2.508	0.1022	9.59

Table A1- Data set nº 31 (cont).

Energy	σ	σ	**Energy**	σ	σ	**Energy**	σ	σ
(MeV)	***(barn/sr)***	***(rr)***	***(MeV)***	***(barn/sr)***	***(rr)***	***(MeV)***	***(barn/sr)***	***(rr)***
2.520	0.1055	9.99	3.294	0.0499	8.07	3.869	0.2713	60.55
2.531	0.1066	10.19	3.308	0.0499	8.14	3.884	0.2796	62.91
2.537	0.0983	9.43	3.313	0.0503	8.23	3.900	0.2644	59.98
2.547	0.0957	9.26	3.325	0.0469	7.74	3.914	0.2066	47.21
2.560	0.0920	8.99	3.333	0.0442	7.31	3.922	0.1639	37.59
2.574	0.0900	8.89	3.344	0.0434	7.24	3.929	0.1467	33.77
2.585	0.0915	9.12	3.358	0.0405	6.81			
2.604	0.0880	8.89	3.370	0.0366	6.20			
2.618	0.0852	8.71	3.377	0.0329	5.59			
2.634	0.0841	8.70	3.384	0.0294	5.02			
2.652	0.0837	8.78	3.385	0.0225	3.85			
2.684	0.0806	8.65	3.393	0.0194	3.33			
2.695	0.0798	8.65	3.397	0.0176	3.02			
2.717	0.0782	8.60	3.404	0.0240	4.15			
2.732	0.0778	8.66	3.411	0.0338	5.87			
2.745	0.0778	8.74	3.415	0.0471	8.20			
2.771	0.0752	8.61	3.422	0.0564	9.84			
2.781	0.0752	8.67	3.424	0.0638	11.14			
2.801	0.0737	8.62	3.435	0.0695	12.23			
2.816	0.0754	8.92	3.441	0.0734	12.95			
2.832	0.0743	8.89	3.454	0.0808	14.36			
2.849	0.0713	8.63	3.464	0.0808	14.45			
2.869	0.0713	8.76	3.468	0.0887	15.91			
2.888	0.0713	8.87	3.484	0.0891	16.12			
2.899	0.0719	9.01	3.494	0.0863	15.71			
2.919	0.0747	9.49	3.509	0.0876	16.09			
2.940	0.0704	9.08	3.525	0.0891	16.51			
2.956	0.0710	9.25	3.537	0.0915	17.06			
2.983	0.0693	9.20	3.552	0.0911	17.14			
2.993	0.0695	9.28	3.571	0.0915	17.39			
3.019	0.0699	9.49	3.589	0.0893	17.15			
3.050	0.0710	9.85	3.605	0.0915	17.73			
3.080	0.0710	10.04	3.621	0.0941	18.39			
3.106	0.0710	10.21	3.639	0.0955	18.87			
3.123	0.0708	10.29	3.662	0.0994	19.88			
3.142	0.0723	10.63	3.679	0.0968	19.55			
3.163	0.0752	11.22	3.691	0.1003	20.38			
3.170	0.0830	12.43	3.702	0.1029	21.03			
3.177	0.0904	13.60	3.718	0.1057	21.78			
3.184	0.1124	16.99	3.738	0.1096	22.83			
3.196	0.2397	36.50	3.749	0.1151	24.13			
3.204	0.1129	17.29	3.760	0.1173	24.74			
3.211	0.0636	9.78	3.782	0.1288	27.47			
3.216	0.0553	8.52	3.796	0.1393	29.94			
3.226	0.0523	8.11	3.819	0.1648	35.85			
3.241	0.0523	8.19	3.825	0.1791	39.06			
3.261	0.0523	8.29	3.835	0.1935	42.42			
3.273	0.0521	8.32	3.847	0.2164	47.77			
3.287	0.0506	8.16	3.857	0.2404	53.34			