Differential and Integral Cross Sections of the (p, α) and (d, α) Reactions on some Light Nuclei

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Alpha emitting reactions induced by protons and deuterons were investigated in our laborabory since 1960. Protons with energy near 7.5 MeV and deuterons with energy near 15 MeV were produced by the Kyoto University cyclotron. Alpha particles leaving the residual nuclei in their ground or low-lying excited states were detected by a proportional counter, a scintillation counter and later by a solid state detector.

Differential and integrated cross sections are given in tabullar forms for the following reactions; (p, α) reactions on F^{19}, Na^{23}, Al^{27}, P^{31} and K^{39}, (d, α) reactions on C^{12}, N^{14}, O^{16}, F^{19}, Ne^{20}, Al^{27}, P^{31} and S^{32}.

1. INTRODUCTION

When the nucleus is struck by high speed protons, deuterons or other particles, many types of nuclear reaction occur if energetically possible. Among those reactions, alpha particle emitting reactions are interesting from the following standpoints.

1) Alpha particle energy is determined more precisely than other particles such as protons or deuterons, so that to detect and analyze the emitted alpha particle energy is a convenient method to determine the energy levels of the residual nucleus.

2) Whether the alpha particle emitting state is a compound nucleus or not is interesting from the standpoint of reaction mechanism.

3) From the standpoint of surface direct reaction, it is interesting to inquire whether the (p, α) and (d, α) reactions come from the nucleons pick-up or α-cluster knock-out processes.

4) If the above mentioned knock-out process is dominant, there will be fair variation of the reaction cross sections from nucleus to nucleus, *i, e.*, the type of 4n nucleus will give larger values of cross sections than others.

5) If alpha-clustering in the target nucleus is assumed, the angular distributions of alpha particles resulting from the (p, α) reaction may have some re-

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lation to the free proton-alpha scattering and some relation will hold between the (d, α) reaction and the free deuteron-alpha scattering.

6) Since deuteron and alpha particles have zero isobaric spin, it is possible to check the isobaric spin conservation rule in the (d, α) reaction when the target and the residual nucleus have different iso-spin quantum number.

In the following, results obtained in our laboratory for the (p,α) reactions on F^{19}, Na^{23}, Al^{27}, P^{31} and K^{39}, and for the (d, α) reactions on C^{12}, N^{14}, O^{16}, F^{19}, Ne^{20}, Al^{27}, P^{31} and S^{32} are given in tabullar forms. Abbreviations used in these tables are,

α_0, : alpha particles leaving the residual nucleus in its ground state.

α_1,etc: alpha particles leaving the residual nucleus in its first excited state and so on.

E_p: incident proton kinetic energy in the laboratory system.

E_d: incident deuteron kinetic energy in the laboratory system.

$\theta_{C.M.}$: angle between the direction of the detected alpha particle and the direction of the incident beam in the center of mass system.

$(d\sigma/d\Omega)_{C.M.}$: differential cross sections in the center of mass system.

Error: essentially statistical error + back ground subtraction error.

2. EXPERIMENTAL METHODS AND RESULTS

2-1. F^{19} (p, α) O^{16} Reaction[2)]

The 7.4 MeV protons were extracted from the Kyoto University cyclotron and focused on a teflon film of 0.6 mg/cm² thick at the centre of a scattering chamber. Proton energies were changed from 7.4 MeV to 6.9, 6.5 and 6.0 MeV by passing through the aluminum foil of suitable thickness.

Alpha particle detection was done by a counter telescope consisting from a thin proportional counter in conjunction with a CaI scintillation counter. Alpha particles leaving the residual nucleus in its ground state were selected. The results obtained are listed in Table 1. Integrated cross sections calculated from these differential cross sections are given in Table 6.

Detailed description of the experimental procedures is given in reference (2).

2-2. Na^{23} (p, α) Ne^{20} Reaction[5)]

Thin layer of about 1 mg/cm² of the Na_2CO_3 fine powder was used as a Na^{23} target. Proton beam handling is the same as above 2-1. Proton energies were 7.3 MeV, 7.1 MeV and 6.9 MeV. Alpha particles leaving the residual Ne^{20} nucleus in its ground and first excited states were detected with a p-n junction type solid counter. Results sre listed in Table 2. Integrated cross sections calculated from these results are listed in Table 6. Detailed description of the experimental procedures are given in reference (5).

2-3. Al^{27} (p, α) Mg^{24} Reaction[2)]

A commercial aluminum foil of 0.2 mg/cm² was used as a Al^{27} target. Proton energies were changed from 7.4 MeV to 7.0, 6.5 MeV by the stacked foil method.

Alpha particles leaving the residual nucleus Mg^{24} in its ground and first excited states were counted with a single proportional counter of 10 cm effective length.

Differential cross sections of these reactions are listed in Table 3, and the calculated integral cross sections are given in Table 6.

2-4. P^{31} (p, α) Si^{28} Reaction[2)]

Proton energies used were 7,4, 7.0, 6.5 and 6.1 MeV. P^{31} target were prepared by red phosphorous fine powder deposited on a 0.25 mil mylar sheet. The target thickness was 0.3 mg/cm^2 for P^{31}. Alpha particles leaving the Si^{28} nucleus in its ground and first excited states were detected with a single proportional counter described in 2-3 and in reference (2).

Differential cross sections for this reaction are given in Table 4, and the calculated integral cross sections are listed in Table 6.

2-5. K^{39} (p, α) A^{36} Reaction[5)]

Proton energies were changed from 7.3 MeV to 7.1 and 6.9 MeV. Thin layer of K_2CO_3 fine powder deposited on a 0.25 mil mylar sheet was used as a K^{39} target. Target thickness was about 1 mg/cm^2.

Alpha particles leaving the residusl A^{36} nucleus in its ground and first excited states were detected with a p-n junction type solid state counter. Differential cross sections for this reaction are listed in Table 5, and the integral cross sections calculated from these results are given in Table 6.

2-6. C^{12} (d, α) B^{10} Reaction[1)]

Deuteron energy was 14.7 MeV. Polystyrene film of 0.2 mg/cm^2 thickness was used as a C^{12} target. Alpha Particle detection was done with a proportional counter whose gas pressure was controled from outside the scattering chamber. Detailed description of the experimental procedure is given in reference (1).

Alpha particles leaving the B^{10} nucleus in its ground and first excited states were selected. The numerical values of the differential cross sections are listed in Table 7, and the integrated cross sections calculated from these values are given in Table 15.

2-7. N^{14} (d, α) C^{12} Reaction[1)]

Natural nitrogen gas was used as a N^{14} target. Alpha particle detection was done by a thin proportional counter in conjunction with a CsI scintillation counter. Detailed description of the experimental procedures is given in reference (1). The incident deuteron energy was 14.7 MeV, but the energy loss in the gas target was about 200 KeV, so the effective energy was about 14.6 MeV. Alpha particles leaving the C^{12} nucleus in its ground and first excited states were selected. Differential cross sections for this reaction are given in Table 8, and the integrated cross sections are listed in Table 15.

2-8. O^{16} (d, α) N^{14} Reaction[1),3)]

This reaction was investigated in two stages. First, a mylar film of about 0.8 mg/cm^2 was used as a O^{16} target, and the alpha particle detection was done by a thin proportional counter in conjunction with a CsI scintilation counter. Deuteron energy was 14.7 MeV in this stage. Second, natural oxygen gas was used as a O^{16} target, and the alpha particles were detected with a p-n junction semiconductor counter. Deuteron energy was 14.5 MeV in the second stage. Detailed descriptions are given in references (1) and (3).

Numerical values of the differential cross sections are given in Table 9, and the integrated cross sections are listed in Table 15.

2-9. F^{19} (d, α) O^{17} Reaction[4]

A thin film of 0.8 mg/cm² thick teflon was used as a F^{19} target. Alpha particles leaving the O^{17} nucleus in its ground, first, second, third and fourth excited states were resolved with a semiconductor detector, whose reverse bias voltage was adjusted to fit the range of alpha particles. Deuteron energy was 14.7 MeV. Detailed description of the experimental procedure is given in reference (4).

Numerical values of the differential cross sections for this reaction corresponding to each O^{17} state described above are given in Table 10. Integrated cross sections are listed in Table 15.

2-10. Ne^{20} (d, α) F^{18} Reaction[4]

Natural neon gas was used as a Ne^{20} target. The gas pressure was about 30 cm Hg. Alpha particles were detected with a semiconductor detector. Alpha particle groups corresponding to the ground, fifth, sixth and seventh excited states of the F^{18} nucleus were resolved by this detector, but alphas corresponding to the first, second, third and fourth excited states of the residual nucleus were not resolvable. So the differntial cross sections for these states are summed values of each reaction channel. Deuteron energy was 14.7 MeV. Detailed description of the experimental procedure is given in reference (4).

In Table 11, the numerical values of the differential cross sections for this reaction are given. Integrated cross sections are listed in Table 15.

2-11. Al^{27} (d, α) Mg^{25} Reaction[6]

A commercial aluminum foil of 0.2 mg/cm² thick was used as a Al^{27} target. Alpha particle detection was done with a p-n junction type semiconductor detector. α_0, α_1, α_2, α_3, α_4 and α_8 groups leading to the ground, first, second, third, fourth and eighth excited states of the Mg^{25} nucleus were resolved by this detection system, but alpha groups corresponding to the fifth, sixth and seventh excited states of the Mg^{25} nucleus were observed as one group. Detailed description of the experimental procedure is given in reference (6).

Numerical values of the cross sections for this reaction are given in Table 12, and the integral cross sections are listed in Table 15.

2-12. P^{31} (d, α) Si^{29} Reaction[4]

Fine powder of red phosphor deposited onto thin mylar film (0.9 mg/cm²) was used as a P^{31} target. Phosphor thickness of 2.7 mg/cm² and 0.6 mg/cm² were used alternatively. Alpha particle detection was done with a semiconductor detector. Only the alpha group corresponding to the ground state of Si^{29} was resolvable. Detailed description of the experimental procedure is given in reference (4).

Numerical values of the differential cross sections for this reaction is given in Table 13, and the integral cross section is listed in Table 15.

2-13. S^{32} $(d.\alpha)$ P^{30} Reaction[4)]

Hydrogen sulfide gas was used as a S^{32} target. The gas pressure was about 30 cm Hg. Alpha particle detection was done with a semiconductor detector. α_0, α_3, and α_4 groups corresponding to the ground, third and fourth excited states of the P^{30} nucleus were resolved. Alpha groups leaving the residual P^{30} nucleus in its first and second excited states were counted as one group. From α_5 to α_9 groups were also unresolvable. Detailed description of the experimental procedure is given in reference (4).

Numerical values of the differential cross sections are given in Table 14, and the integral cross sections are listed in Table 15.

Table 1. Numerical values of differential cross sections for F^{19} (p, α) O^{16} reaction.

F^{19} (p, α) O^{16} g'nd

$E_p=7.4$ MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.6	1.67	5.3
32.3	1.43	2.8
42.9	1.00	4.3
53.5	0.99	4.2
63.9	1.51	2.9
74.2	1.58	2.9
84.4	1.26	3.3
94.5	0.50	5.4
104.4	0.12	8.3
114.2	0.12	13
123.9	0.56	5.5
133.5	0.95	4.1
142.9	1.32	3.5
152.2	1.71	4.1
161.5	2.09	3.6

$E_p=6.9$ MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.5	0.772	6.3
32.2	0.760	4.3
42.9	0.645	7.7
53.4	0.642	3.6
63.8	0.610	4.4
74.2	0.659	4.4
84.4	0.487	5.3
94.4	0.284	6.7
104.4	0.181	10
114.2	0.244	8.1
123.8	0.533	5.8
133.4	0.983	5.0
142.8	1.27	4.0
152.2	1.64	4.8
161.5	2.13	3.0

$E_p=6.5$ MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.5	0.621	6.6
32.2	0.683	6.8
42.8	0.556	6.8
53.3	0.514	6.8
63.8	0.575	6.3
74.1	0.582	6.9
84.3	0.630	6.5
94.4	0.494	7.7
104.8	0.246	11
114.1	0.197	12
123.8	0.430	8,5
133.3	1.04	5.5
142.8	1.80	4.2
152.2	2.27	3.7
161.5	2.40	3.0

$E_p=6.0$ MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.5	2.27	3.6
32.1	1.45	5.1
42.7	0.797	6.7
53.3	0.398	7.4
63.7	0.252	9.8
74.0	0.493	7.0
84.2	0.657	5.9
94.3	0.548	7.1
104.2	0.500	7.7
114.0	0.481	7.6
123.7	0.483	8.0
133.3	0.869	6.0
142.7	1.45	4.6
152.1	2.05	3.1
161.5	2.60	3.3

Table 2. Numerical values of differential cross sections for Na^{23} (p,α) Ne^{20} reaction

(a) Na^{23} (p, α_0) Ne^{20} g'nd

E_p=7.3 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
32.3	1.13	14
43.0	1.05	11
53.5	0.89	7.9
64.0	0.89	9.1
74.3	0.66	9.8
84.6	0.60	8.8
94.6	0.76	8.6
104.6	0.81	6.5
114.3	0.98	8.5
124.0	1.14	7.5
133.5	1.42	7.2
143.0	1.62	6.0
152.3	2.20	5.5
161.6	2.44	4.1

E_p=7.1 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
32.3	1.41	11
43.0	0.95	14
53.5	1.01	11
64.0	0.72	11
74.3	0.54	15
84.6	0.29	24
94.6	0.34	18
104.6	0.33	18
114.3	0.40	18
124.0	0.50	15
133.5	0.94	10
143.0	1.05	9
152.3	1.24	9
161.6	1.55	6

E_p=6.9 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
32.3	1.02	17
43.0	0.75	18
53.5	0.96	13
64.0	0.74	16
74.3	0.62	19
84.6	0.70	14
94.6	0.80	14
104.6	0.91	13
114.3	0.80	16
124.0	0.91	15
133.5	0.91	17
143.0	1.19	14
152.3	1.33	14
161.6	1.16	13

Table 2. (continued)

(b) Na^{23} (p,α_1) Ne^{20} 1st

E_p=7.3 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
32.6	5.49	6.1
43.3	5.44	5.4
53.9	4.73	3.4
64.4	3.93	4.3
74.8	3.67	4.2
85.1	3.16	3.7
95.1	2.65	4.6
105.1	2.67	3.6
114.8	3.18	4.8
124.4	3.99	4.0
133.9	4.67	4.0
143.3	5.65	3.5
152.6	6.45	3.3
161.8	7.45	2.4

E_p=7.1 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
32.6	6.28	5
43.3	5.19	6
53.9	4.78	5
64.4	4.05	5
74.8	3.31	6
85.1	2.39	8
95.1	2.21	7
105.1	2.65	6
114.8	3.41	6
124.4	3.83	6
133.9	4.46	5
143.3	5.55	4
152.6	6.23	4
161.8	7.79	3

E_p=6.9 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
32.6	7.95	6.3
43.3	6.92	5.9
53.9	5.92	5.5
64.4	4.97	6.1
74.8	3.95	7.4
85.1	3.57	6.4
95.1	2.68	7.4
105.1	2.51	7.9
114.8	2.91	8.2
124.4	3.70	7.3
133.9	4.26	7.8
143.3	4.73	7.1
152.6	5.79	6.5

Table 3. Numerical values of differential cross sections for Al^{27} (p,α) Mg^{24} reaction

(a) Al^{27} (p,α_0) Mg^{24} g'nd

E_p=7.4 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.4	0.769	14
26.7	0.772	7.8
32.1	0.817	4.8
42.6	0.917	4.5
53.2	0.785	4.6
63.5	0.737	5.1
73.9	0.687	5.4
84.0	0.697	4.5
94.1	0.713	4.2
104.1	0.696	6.8
113.9	0.761	3.6
123.6	0.769	3.3
133.1	1.13	3.9
142.6	1.50	2.4
152.1	2.11	2.3
161.4	2.70	2.1

E_p=7.0 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Errer %
21.4	1.24	5.5
26.7	1.15	4.5
32.0	1.31	5.6
42.6	1.30	5.3
53.1	1.26	4.9
63.5	1.23	5.2
73.8	0.892	5.2
84.0	0.628	7.7
94.1	0.599	8.7
104.0	0.518	7.8
113.8	0.617	8.4
123.5	0.771	7.7
133.1	0.967	6.8
142.6	0.903	7.5
152.0	0.876	6.2
161.4	0.784	7.9

E_p=6.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.4	2.46	3.8
26.7	2.78	5.9
32.0	2.58	4.0
42.6	2.73	3.4
53.1	2.45	4.3
63.5	1.79	4.7
73.8	1.58	5.4
84.0	1.13	7.9
94.1	1.05	6.6
104.0	0.992	7.1
113.8	1.08	8.3
123.5	1.29	6.9
133.1	1.64	6.6
142.6	1.87	6.6
152.0	1.83	7.8
161.4	2.07	6.3

E_p=6.1 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.4	3.15	6.6
32.0	3.33	5.2
42.6	3.37	5.9
53.1	3.49	5.5
63.5	2.58	4.8
73.8	2.17	7.2
84.0	1.65	11
94.0	1.44	7.5
104.0	1.54	10
113.8	1.27	12
123.5	1.88	14
133.1	2.59	8.8
142.6	2.41	9.6
152.0	2.15	9.5
161.4	1.96	11

Table 3. (continued)

(b) Al^{27} (p,α_1) Mg^{24} 1st

E_p=7.4 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.5	5.82	4.9
26.9	5.76	2.8
32.2	4.89	2.0
42.9	3.93	2.2
53.4	3.41	2.3
63.9	3.41	2.4
74.2	3.64	2.3
84.4	3.92	1.9
94.5	3.94	1.8
104.4	4.03	2.8
114.2	4.41	1.5
123.9	5.43	1.2
133.4	6.92	1.6
142.4	8.62	1.0
152.2	8.87	1.2
161.5	8.55	1.2

E_p=7.0 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/aterad	Error %
21.5	8.45	2.1
26.9	8.97	1.6
32.2	8.80	2.2
42.9	8.53	2.1
53.4	7.68	2.0
63.9	6.34	2.5
74.2	5.81	2.2
84.4	5.16	2.7
94.5	4.99	3.2
104.4	5.08	2.5
114.2	5.37	2.9
123.9	6.18	2.8
133.4	6.75	2.6
142.9	7.09	2.7
152.2	7.25	2.2
161.6	7.16	2.7

E_p=6.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.5	9.08	2.0
26.9	9.13	3.2
32.2	8.12	2.2
49.9	6.77	2.1
53.4	6.30	2.7
63.9	5.53	2.7
74.2	5.61	3.0
84.4	5.52	3.6
94.5	4.91	3.0
104.4	4.63	3.3
114.2	4.72	4.0
123.9	5.13	3.5
133.4	5.55	3.6
142.9	5.89	3.7
152.2	6.09	4.3
161.6	6.03	3.7

E_p=6.1 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.5	8.53	4.0
32.2	7.68	3.4
42.9	6.37	4.3
53.4	6.31	4.0
63.9	6.05	3.1
74.2	6.60	4.1
84.4	5.92	5.5
94.5	6.87	3.4
104.4	6.91	5.1
114.2	6.69	5.4
123.9	7.46	6.8
133.4	7.37	5.3
142.9	6.76	5.5
152.5	8.06	4.9
161.6	7.45	9.4

Table 4. Numerical values of differential cross sections for P^{31} (p,α) Si^{28} reaction

(a) P^{31} (p,α_0) Si^{28} g'nd

E_p=7.4 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.2	3.78	6.1
26.5	3.26	2.8
31.7	4.27	2.5
42.2	3.76	1.0
52.7	2.47	2.5
63.0	1.33	3.1
73.3	0.95	5.2
83.4	0.69	5.6
93.5	0.59	5.7
103.4	0.92	4.6
113.3	0.91	4.5
123.0	0.92	4.1
132.7	1.22	4.3
142.2	1.42	4.0
151.7	1.71	3.0
161.2	1.96	3.3

E_p=7.0 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.2	3.47	4.2
26.5	2.56	4.6
31.7	2.44	4.3
42.2	1.48	4.3
52.7	1.08	6.1
63.0	0.93	6.6
73.3	0.75	6.4
83.4	0.43	11
93.5	0.66	9.5
103.4	1.31	5.0
113.3	1.97	5.2
123.0	1.97	4.5
132.7	1.34	6.2
142.2	1.19	6.2
151.7	2.52	3.8
161.2	4.95	2.2

E_p=6.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.2	7.48	3.9
26.4	5.62	3.8
31.7	4.44	4.1
42.2	2.27	3.1
52.6	1.25	5.6
62.9	1.00	4.5
73.2	0.80	9.5
83.4	1.06	6.6
93.4	0.66	7.8
103.4	1.31	6.1
113.2	1.74	7.6
122.9	2.44	8.6
132.6	3.10	6.7
142.2	3.54	6.3
151.7	3.84	4.8
161.2	4.47	5.2

E_p=6.1 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.2	1.81	5.3
26.4	1.61	5.0
31.7	1.15	4.5
42.2	0.87	7.7
52.6	0.70	8.2
62.9	0.76	5.2
73.2	0.97	5.5
83.4	1.13	6.2
93.4	0.96	6.5
103.4	1.19	5.8
113.2	1.24	6.5
122.9	1.56	6.0
132.6	1.78	5.6
142.2	2.54	4.6
151.7	2.76	3.6
161.2	2.73	4.1

Table 4. (continued)

(b) P^{31} (p,α_1) Si^{28} 1st

E_p=7.4 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.3	8.40	4.1
26.6	7.54	1.9
31.9	8.10	1.9
42.5	7.41	0.7
53.0	6.78	1.6
63.4	5.52	1.6
73.6	5.93	1.7
83.8	6.39	1.9
93.9	5.98	1.8
103.8	5.92	1.9
113.6	4.83	2.1
123.4	5.08	1.8
133.0	5.41	2.0
142.5	6.24	1.9
151.9	7.52	1.5
161.3	6.73	1.8

E_p=7.0 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.3	8.52	2.5
26.6	8.31	2.4
31.9	7.74	2.3
42.5	7.29	1.9
53.0	6.17	2.4
63.4	5.85	2.6
73.6	4.92	2.5
83.8	4.46	3.5
93.9	4.19	3.8
103.8	4.16	2.9
113.6	4.47	3.5
123.4	5.18	2.9
133.0	4.29	3.6
142.5	3.20	4.0
151.9	2.46	4.1
161.3	2.64	3.3

E_p=6.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.3	11.1	3.2
26.6	10.6	2.7
31.9	10.8	2.6
42.5	10.5	1.4
53.0	9.53	2.0
63.4	8.55	2.8
73.6	7.13	3.2
83.8	5.49	2.9
93.9	3.54	3.4
103.8	4.28	3.4
113.6	4.85	4.6
123.4	5.80	5.6
133.0	6.90	4.3
142.5	6.90	4.5
151.9	6.67	3.7
161.3	5.03	4.9

E_p=6.1 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
21.3	7.83	2.5
26.6	7.68	2.3
31.9	7.58	1.7
42.5	7.28	2.6
53.0	6.20	2.7
63.4	5.08	2.0
73.6	4.62	2.5
83.8	4.15	3.3
93.9	3.67	3.4
103.8	4.26	3.1
113.6	3.96	3.7
123.4	4.33	3.6
133.0	4.39	3.5
142.5	4.36	3.5
151.9	4.62	2.8
161.3	4.90	3.1

Table 5. Numerical values of differential cross sections for K^{39} (p,α) A^{36} reaction.

(a) K^{39} (p,α_0) A^{36} g'nd

$E_p=7.3$ MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
31.4	3.09	6.1
41.8	2.50	4.9
52.2	2.31	4.4
62.4	1.68	3.8
72.6	1.45	4.5
82.8	1.26	4.3
92.8	1.02	3.2
102.8	1.30	3.9
112.6	1.72	3.3
122.4	1.85	3.7
132.2	2.25	3.5
141.8	2.49	3.9
151.4	2.94	3.4
161.0	4.02	2.7

$E_p=7.1$ MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
31.4	2.65	9.0
41.8	2.28	6.1
52.2	1.99	5.7
62.4	1.84	5.3
72.6	1.92	4.8
82.8	1.59	5.4
92.8	1.54	5.8
102.8	1.61	5.3
112.6	1.79	5.6
122.4	2.09	5.0
132.2	2.51	5.5
141.8	3.08	4.7
151.4	3.54	7.6
161.0	3.61	1.1

$E_p=6.9$ MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
31.4	4.14	5.4
41.8	3.65	5.4
52.2	3.16	3.6
62.4	2.50	5.0
72.6	2.44	5.0
82.8	2.03	7.3
92.8	2.32	6.8
102.8	2.22	5.5
112.6	2.31	6.4
122.4	2.77	6.1
132.2	3.49	5.9
141.8	3.72	5.4
151.4	4.71	5.7
161.0	4.81	3.7

Table 5. (continued)

(b) K^{39} (p,α_1) A^{36} 1st

E_p=7.3 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
31.6	4.15	5.7
42.1	3.58	4.1
52.5	3.47	3.6
62.8	4.10	2.4
73.1	3.71	2.9
83.2	3.96	2.4
93.2	3.98	1.6
103.2	3.89	2.3
113.1	4.63	2.0
122.8	5.25	2.2
132.5	5.20	2.3
142.1	5.37	2.7
151.6	5.18	2.6
161.1	5.59	2.3

E_p=7.1 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
31.6	4.08	7.2
42.1	3.41	5.0
52.5	3.72	4.2
62.8	3.80	3.7
73.1	3.96	3.4
83.2	3.40	3.7
93.2	3.50	3.8
103.2	3.50	3.6
113.1	3.82	3.9
122.8	4.18	3.6
132.5	4.90	4.0
142.1	4.81	3.8
151.6	4.56	6.7
161.1	4.66	3.2

E_p=6.9 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
31.6	4.03	5.5
42.1	3.85	5.3
52.5	3.79	3.3
62.8	3.91	4.0
73.1	3.86	4.0
83.2	3.49	5.6
93.2	3.55	5.5
103.2	3.37	4.0
113.1	3.37	5.3
122.8	3.43	5.5
132.5	3.52	5.9
142.1	3.65	5.4
151.6	4.80	5.7
161.1	4.97	3.7

Table 6. Integral Cross Sections for the (p, α) Reaction

Reaction	E_p (MeV)	Integral Cross Section (mb)
F^{19} (p, α_0) O^{16} g'nd	7.4	13.2
	6.9	8.6
	6.5	9.3
	6.0	11.1
Na^{23} (p, α_0) Ne^{20} g'nd	7.3	13.3
	7.1	9.4
	6.9	10.1
Na^{23} (p, α_1) Ne^{20} lst	7.3	53.2
	7.1	52.3
	6.9	57.3
Al^{27} (p,α_0) Mg^{24} g'nd	7.4	11.9
	7.0	21.1
	6.5	11.4
	6.1	28.2
Al^{27} (p, α_1) Mg^{24} lst	7.4	61.6
	7.0	80.9
	6.5	73.2
	6.1	87.2
P^{31} (p, α_0) Si^{28} g'nd	7.4	20.0
	7.0	19.6
	6.5	27.9
	6.1	18.0
P^{31} (p, α_1) Si^{28} lst	7.4	78.2
	7.0	61.1
	6.5	86.2
	6.1	62.7
K^{39} (p,α_0) A^{36} g'nd	7.3	25.1
	7.1	27.0
	6.9	37.6
K^{39} (p, α_1) A^{36} lst	7.3	54.2
	7.1	49.4
	6.9	47.1

Table 7. Numerical values of differential cross sections for C^{12} (d, α) B^{10} reaction

(a) C^{12} (d, α_0) B^{10} g'nd

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
24.6	2.64	14
30.9	6.27	5.3
37.2	5.85	3.3
49.6	4.56	5.2
61.1	2.21	5.4
72.5	1.88	4.6
83.6	2.15	4.4
94.2	1.59	3.6
104.3	1.04	6.8
114.0	1.67	4.4
123.3	2.98	4.7
132.2	2.65	4.7
140.7	2.27	5.8
148.9	2.72	5.3
156.9	4.31	4.9
165.2	5.31	4.9

(b) C^{12} (d,α_1) B^{10} 1st

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
25.6	5.02	12
31.9	7.26	5.0
38.2	6.69	3.6
50.5	3.50	5.6
62.5	1.25	7.0
74.2	1.67	4.8
85.5	2.30	4.4
96.2	2.65	3.1
106.5	2.64	4.8
116.2	3.81	3.3
125.4	4.54	4.4
134.2	3.41	4.7
142.5	2.34	7.3
150.5	3.42	6.0
158.2	4.75	5.9
165.6	6.86	5.9

Table 8. Numerical values of differential cross sections for N^{14} (d, α) C^{12} reaction

(a) N^{14} (d, α_0) C^{12} g'nd

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.0	0.956	1.9
28.7	0.535	3.5
34.3	0.174	3.2
45.5	0.036	16
56.7	0.237	5.0
67.7	0.337	4.7
78.2	0.218	6.2
88.5	0.164	7.7
98.8	0.187	5.5
108.7	0.189	9.8
118.3	0.110	14
127.5	0.102	9.3
136.7	0.105	16
145.3	0.083	14
154.2	0.127	16
162.8	0.286	5.0

(b) N^{14} (d, α_1) C^{12} 1st

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.5	1.43	1.5
29.2	1.36	2.2
35.0	1.15	1.2
46.3	0.871	3.3
57.5	0.698	2.9
68.5	0.632	3.4
79.0	0.640	3.6
89.3	0.505	4.4
99.5	0.551	3.2
110.0	0.655	5.3
119.0	0.593	6.0
128.5	0.505	4.2
137.3	0.486	7.6
146.0	0.643	5.1
154.8	0.802	4.3
163.3	0.947	2.9

Table 9. Numerical values of differential cross sections for O^{16} (d, α) N^{14} reaction.

(a) O^{16} (d, α_0) N^{14} g'nd

E_d=14.7 MeV			E_d=14.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %	$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.3	1.30	3.1	23.3	1.15	1
29.1	0.922	3.2	29.1	1.23	1
34.9	1.21	4.0	34.9	1.33	1
46.3	1.44	2.6	40.6	1.45	1
57.5	0.647	4.2	46.3	1.26	2
68.5	0.427	4.7	57.5	0.622	2
79.2	0.203	4.1	68.5	0.356	3
89.7	0.233	6.4	79.2	0.293	3
99.8	0.430	3.8	89.6	0.255	4
109.7	0.521	4.5	99.8	0.276	4
119.2	0.513	4.7	109.6	0.266	4
128.5	0.437	5.4	119.2	0.374	3
137.5	1.37	3.4	128.5	0.334	3
146.3	1.70	3.2	137.5	0.549	2
154.9	2.13	3.4	146.3	1.20	3
163.3	1.39	4.2	154.9	1.42	2
			163.3	1.09	1

(b) O^{16} (d, α_1) N^{14} 1st

E_d=14.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.6	0.036	6
29.5	0.025	6
35.3	0.012	12
41.1	0.012	10
46.8	0.014	14
58.1	0.019	12
69.2	0.011	13
80.0	0.005	23
90.5	0.010	20

(c) O^{16} (d, α_2) N^{14} 2nd

Ed=14.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ mb/sterad	Error %
23.8	1.64	1
29.7	2.49	1
35.6	3.09	1
41.4	2.05	1
47.2	0.784	2
58.6	0.403	3
69.7	0.580	2
80.6	0.928	2
91.1	1.05	2
101.3	0.826	2
111.1	0.597	3
120.6	0.763	2
129.7	1.33	5
138.6	1.12	10
147.2	0.789	10
155.6	1.39	10
163.8	1.93	10

Table 10. Numerical values of differential cross sections for F^{19} (d, α) O^{17} reaction

(a) F^{19} (d, α_0) O^{17} g'nd

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
22.4	535	2.0
33.4	255	3.7
44.4	216	3.3
55.3	72.9	6.2
65.9	58.7	7.3
76.4	87.1	6.4
86.8	87.0	7.0
96.9	63.0	6.6
106.3	69.1	7.3
116.4	82.8	6.6
125.9	87.7	6.9
135.3	58.8	8.0
144.4	78.2	7.0
153.4	104	4.8
162.4	90.6	5.6

(b) F^{19} (d, α_1) O^{17} 1st

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
22.4	131	4.1
33.5	74.1	5.6
44.5	46.7	7.2
55.4	58.7	6.8
66.0	43.0	8.7
76.6	27.0	12
86.9	39.5	10
97.0	42.8	7.8
106.9	34.4	12
116.6	22.1	13
126.0	34.4	11
135.4	59.1	8.0
144.5	31.4	11
153.5	49.4	7.0
162.4	87.0	5.8

(c) F^{19} (d, α_2) O^{17} 2nd

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
22.5	36.2	7.8
33.6	40.7	8.1
44.7	22.8	17
55.6	16.9	28
66.3	13.9	26
76.8	9.7	28
87.2	11.1	29
97.3	18.3	30
107.2	14.7	25
116.8	13.1	25
126.3	8.1	35
135.6	10.6	30
144.7	24.6	20
153.6	37.7	15
162.5	38.3	16

(d) F^{19} (d, α_3) O^{17} 3rd

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
22.6	132	4.1
33.7	92.2	5.4
44.8	50.2	12
55.7	71.4	14
66.5	46.2	14
77.0	41.3	13
87.4	41.4	15
97.5	38.2	21
107.4	13.8	26
117.0	23.2	19
126.5	14.2	27

Table 10. (continued)

(e) F^{19} (d, α_4) O^{17} 4th

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
22.6	53.0	6.5
33.9	35.3	8.6
45.0	45.9	12
55.9	25.8	22
66.7	22.2	20
77.2	25.9	17
87.6	21.2	21
97.7	14.9	33
107.6	21.1	21
126.7	23.6	21

Table 11. Numerical values of differential cross sections for Ne^{20} (d, α) F^{18} reaction

(a) Ne^{20} (d, α_0) F^{18} g'nd

E_d=14.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
22.7	1268	1.0
33.9	671	1.4
45.0	171	4.0
56.0	128	4.4
66.8	195	3.0
77.4	196	4.4
87.7	111	5.5
92.8	177	6.8
97.8	246	4.2
187.7	202	4.5
117.4	131	6.2
126.8	70	5.8
136.0	99	7.0
145.0	216	4.9
153.9	249	2.5
162.7	435	2.0
167.0	600	1.6

(b) Ne^{20} $(d,\alpha_{1,2,3,4})$ F^{18} 1st, 2nd, 3rd and 4th.

E_d=14.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
22.8	2429	0.7
34.0	1487	0.9
45.2	1153	1.6
56.2	1047	1.6
67.0	529	4.4
77.0	689	2.3
88.0	744	2.5
93.1	747	3.3
98.1	770	2.4
108.0	931	2.1
117.6	977	2.3
127.0	973	1.6
136.2	1407	1.8
145.2	1550	1.8
154.0	1403	1.1
162.8	1696	1.0
167.1	2069	0.9

Table 11. (continued)

(c) Ne^{20} (d, α_5) F^{18} 5th

E_d=14.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
22.8	458	12
34.2	336	12
45.3	270	13
56.4	270	13
67.2	127	14
77.8	138	15
88.2	136	15
93.3	136	22
98.3	119	16
108.2	136	16
117.8	134	16
127.2	95	16
136.4	106	17
145.3	170	16
154.2	234	13
162.8	361	13
167.2	345	12

(d) Ne^{20} (d, α_6) F^{18} 6th

E_d=14.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
22.9	628	11
34.3	373	12
45.5	253	13
56.5	167	14
67.4	213	13
78.0	75	17
88.4	115	15
93.5	206	20
98.5	173	15
108.4	127	16
118.0	148	16
127.4	157	14
136.5	255	14
145.5	244	15
154.3	256	13
162.9	275	13
167.2	315	12

(e) Ne^{20} (d, α_7) F^{18} 7th

E_d=14.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
22.9	438	12
34.3	182	13
45.5	130	15
56.5	71	16
67.4	74	15
78.0	65	18
88.4	96	16
93.5	81	25
98.5	81	17
108.4	89	17
118.0	131	16
127.4	150	15
136.5	78	18
145.5	110	17
154.3	184	13
162.9	200	13
167.2	249	13

Table 12. Numerilcal values of differential cross sections for Al^{27} (d,α) Mg^{25} reaction

(a) Al^{27} (d, α_0) Mg^{25} g'nd

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
21.8	276	3.3
32.6	203	3.7
43.3	109	4.7
53.9	93.3	3.9
64.5	77.3	4.7
74.8	57.2	4.9
85.1	62.5	4.0
95.1	59.0	3.7
105.1	36.3	7.0
114.8	38.4	6.9
124.5	31.6	8.8
133.9	32.7	8.6
143.3	39.3	8.0
152.6	52.2	6.9
161.8	48.7	6.1

(b) Al^{27} (d, α_1) Mg^{25} 1st

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
21.8	36.3	9
32.6	18.7	13
43.3	16.2	14
54.0	8.3	16
64.5	10.1	13
74.9	9.5	12
85.1	7.4	12
95.2	5.1	14
105.1	8.7	14
114.9	6.9	16
124.5	8.7	17
134.0	10.5	15
143.3	11.9	14
152.6	15.6	13
161.8	22.3	9

(c) Al^{27} (d, α_2) Mg^{25} 2nd

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
21.8	43.7	8
32.6	23.9	11
43.4	21.4	12
54.0	21.0	10
64.5	14.6	11
74.9	11.1	11
85.2	10.8	10
95.3	11.4	9
105.2	14.2	11
114.9	9.9	13
124.5	12.1	14
134.0	19.4	11
143.4	20.9	11
152.6	20.7	11
161.8	24.7	9

(d) Al^{27} (d, α_3) Mg^{25} 3rd

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
21.8	268	3.3
32.7	172	4.1
43.4	118	5.0
54.1	84.0	4.9
64.6	80.4	4.6
75.0	76.3	4.2
85.3	64.5	3.9
95.3	65.7	3.8
105.3	49.8	6.0
115.0	42.2	6.5
124.6	53.9	6.9
134.1	43.2	7.5
143.4	49.5	6.9
152.7	49.8	7.0
161.8	87.8	4.6

Table 12. (continued)

(e) Al^{27} (d, α_4) Mg^{25} 4th

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
21.8	833	6.6
32.7	555	7.1
43.5	568	7.2
54.1	466	6.5
64.7	333	7.1
75.1	208	8.0
85.3	259	6.2
95.4	277	5.8
105.3	174	10
115.1	147	11
124.7	302	9.0
134.1	326	8.5
143.5	327	8.5
152.7	350	8.4
161.8	330	7.5

(f) Al^{27} $(d, \alpha_{5,6,7})$ Mg^{25} 5,6 and 7th

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
21.9	168	4.1
32.7	84.4	5.8
43.5	78.3	6.1
54.2	88.3	4.8
64.8	76.9	4.7
75.2	57.8	4.8
85.4	51.3	4.4
95.5	49.6	4.3
105.4	58.4	5.5
115.2	61.2	5.4
124.8	51.3	6.9
134.2	62.4	6.2
143.5	66.4	6.0
152.7	79.1	5.6
161.9	84.1	4.7

(g) Al^{27} (d, α_8) Mg^{25} 8th

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
21.9	222	3.6
32.8	165	4.1
43.6	122	4.9
54.3	106	4.3
64.9	72.1	4.8
75.3	60.3	4.7
85.5	63.3	3.9
95.6	59.9	3.9
105.5	64.6	5.2
115.3	62.6	5.4
124.9	60.7	6.4
134.3	74.1	5.7
143.6	80.0	5.5
152.8	89.2	5.3
161.9	94.5	4.4

Table 13. Numerical values of differential cross sections for P^{31} (d, α) Si^{29} reaction

P^{31} (d, α_0) Si^{29} g'nd

E_d=14.7 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
21.5	156	4.6
32.2	59.4	3.9
37.5	42.9	8.0
42.8	61.0	6.5
48.1	71.9	7.0
53.2	72.6	6.3
63.7	28.1	7.1
68.9	19.0	13
74.0	24.1	11
79.2	23.4	9.9
84.2	25.1	11
94.3	12.9	24
114.0	15.3	22
123.7	7.0	32
133.3	8.3	30
142.8	6.9	33
152.2	16.6	20
161.5	19.9	9.5

Table 14. Numerical values of differential cross sections for S^{32} (d, α) P^{30} reaction

(a) S^{32} (d, α_0) P^{30} g'nd

E_d=14.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
21.5	293	2.2
26.9	176	2.5
32.2	135	3.0
42.8	145	3.4
53.4	93.8	5.5
63.8	70.7	6.4
74.1	73.9	6.1
84.3	75.4	7.1
94.4	32.0	9.1
104.3	56.4	7.0
114.1	72.5	7.1
123.8	40.1	9.2
133.5	42.3	9.0
142.8	48.0	7.4
152.2	50.6	6.7
161.5	71.0	4.9

(b) S^{32} $(d,\alpha_{1,2})$ P^{30} 1st and 2nd

E_d=14.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
21.5	261	2.3
26.9	156	2.7
32.3	92.5	3.5
42.9	98.3	4.1
53.4	49.3	7.5
63.9	36.3	8.9
74.2	36.8	8.6
84.4	46.1	9.0
94.5	30.9	9.2
104.4	26.7	10
114.2	22.4	13
123.9	23.2	13
133.4	9.5	18
142.9	25.2	10
152.3	34.3	8.0
161.5	25.2	8.2

Table 14. (continued)

(c) S^{32} (d, α_3) P^{30} 3rd

E_d=14.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
21.6	94.6	3.8
26.9	88.5	3.5
32.3	59.7	4.6
42.9	32.7	7.2
53.5	27.7	10
64.0	26.8	10
74.3	11.8	15
84.5	16.5	15
94.6	23.2	11
104.5	16.4	13
114.3	7.7	22
124.0	24.2	12
133.5	14.8	14
142.9	34.2	8.7
152.3	67.5	5.8
161.6	55.4	5.6

(d) S^{32} (d, α_4) P^{30} 4th

E_d=14.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
21.6	783	1.3
27.0	493	1.5
32.3	380	1.8
43.0	201	2.9
53.6	151	4.3
64.0	163	4.2
74.4	152	4.2
84.6	102	6.0
94.6	99.6	5.1
104.6	93.8	5.4
114.4	75.7	6.9
124.0	55.8	7.8
133.6	56.6	7.4
143.0	60.9	6.5
152.3	43.5	7.2
161.6	48.2	6.0

(e) S^{32} $(d, \alpha_{5\sim9})$ P^{30} 5～9th

E_d=14.5 MeV		
$\theta_{C.M.}$ degree	$(d\sigma/d\Omega)_{C.M.}$ μb/sterad	Error %
21.6	1108	1.1
27.0	881	1.1
32.4	558	1.4
43.0	502	1.8
53.6	389	2.7
64.1	370	2.8
74.5	303	3.0
84.6	172	4.7
94.7	222	3.4
104.6	201	3.7
114.5	179	4.5
124.1	205	4.0
133.6	220	3.7
143.0	291	2.9
152.4	281	2.8
161.6	285	2.4

Table 15. Integral Cross Sections for the (d, α) reaction

reaction	E_d (MeV)	Integral Cross Section (mb)
C^{12} (d, α_0) Be^8 g'nd	14.7	34
C^{12} (d, α_1) Be^8 1st	14.7	42
N^{14} (d, α_0) C^{12} g'nd	14.7	3.2
N^{14} (d, α_1) C^{12} 1st	14.7	9.1
O^{16} (d, α_0) N^{14} g'nd	14.7	9.9
	14.5	7.9
O^{16} (d, α_2) N^{14} 2nd	14.5	13.3
F^{19} (d, α_0) O^{17} g'nd	14.7	1.3
F^{19} (d, α_1) O^{17} 1st	14.7	0.6
F^{19} (d, α_2) O^{17} 2nd	14.7	0.2
F^{19} (d, α_3) O^{17} 3rd	14.7	0.5
F^{19} (d, α_4) O^{17} 4th	14.7	0.4
Ne^{20} (d, α_0) F^{18} g'nd	14.5	2.8
Ne^{20} $(d, \alpha_{1+2+3+4})$ F^{18}	14.5	(13.9)
Ne^{20} (d, α_5) F^{18} 5th	14.5	2.4
Ne^{20} (d, α_6) F^{18} 6th	14.5	2.7
Ne^{20} (d, α_7) F^{18} 7th	14.5	1.6
Al^{27} (d, α_0) Mg^{25} g'nd	14.7	1
Al^{27} (d, α_1) Mg^{25} 1st	14.7	0.1
Al^{27} (d, α_2) Mg^{25} 2nd	14.7	0.2
Al^{27} (d, α_3) Mg^{25} 3rd	14.7	1
Al^{27} (d, α_4) Mg^{25} 4th	14.7	0.6
Al^{27} (d, α_{5+6+7}) Mg^{25}	14.7	(0.9)
Al^{27} (d, α_8) Mg^{25} 8th	14.7	1
P^{31} (d, α_0) Si^{29} g'nd	14.7	0.3
S^{32} (d, α_0) P^{30} g'nd	14.5	0.9
S^{32} (d, α_{1+2}) P^{30}	14.5	(0.5)
S^{32} (d, α_3) P^{30} 3rd	14.5	0.3
S^{32} (d, α_4) P^{30} 4th	14.5	1.6
S^{32} $(d, \alpha_{5\sim9})$ P^{30}	14.5	(3.7)

3. DISCUSSION

Discussions on each reaction are given in references (1) to (6). Here we discuss the qualitative natures of the (p,α) and (d,α) reactions.

In general, it is believed that when the incident particle has high energy, and the emitted particle corresponds to the ground or lower excited states of the residual nucleus, reactions occur mainly through surface direct interaction[7]. Characteristics of this surface direct reaction are larger yield than expected from the compound nucleus process, and the angular distribution is resembled by suitable summation of $|j_l(QR)|^2$, where j_l is the l-th order spherical Bessel function, Q is the momentum transfer between the incident and emitted particles and R is the interaction radius. This means, in the surface direct reaction, the angular distribution show foward peaking and diffraction-like pattern.

In our experiment, 15 MeV deuteron has very larger momentum than 7.5 MeV proton, so behaviours of the surface direct reaction are expected more likely to appear in the (d,α) reaction than in the (p,α) reaction. It is true in our cases that almost all of the alpha particle angular distributions of the (d,α) reaction exhibited pronounced foward peaking and diffraction-like pattern, but on the contrary, the (p,α) reaction showed no distinct foward peaking so far investigated. There remain, some characteristics which can not be simply explained by the surface direct reaction. First of all is the backward peacking observed in the (p,α) reaction on F^{19} and in the (d,α) reaction on C^{12}, O^{16} and Ne^{20}. Moreover, as was pointed out by Takamatsu[4], the integral cross sections for the (d,α) reaction on C^{12}, O^{16}, Ne^{20}, Mg^{24} and S^{32} are about three times larger than the ones on neighbouring odd-A and odd-odd nuclei, *i. e.* N^{14}, F^{19} and P^{31}. This even-odd effect was observed also in the (p,α) reaction by Bayman *et al*[8] and by Kumabe *et al*[9].

Second, the strong energy dependence of the angular distributions found in the (p,α) reaction on F^{19}, Al^{27} and P^{31} cannot be well explained by a simple direct reaction theory.

Since the system F^{19}, Al^{27} and P^{31} plus proton have excitation energies 13 MeV, 12 MeV and 9 MeV respectively, the intermediate states between the single level compound system and the complete statistical state are formed when these nuclides are struck by 7 MeV protons. In these cases, as was pointed out by Ericson,[10] fluctuations can occur on the shape of angular distributions and on the integral cross sections.

Differential cross sections and integrated cross sections on various nuclei show us that, the (p,α) and (d,α) reactions are not so simple that simple compound or direct reaction theory can give complete explanation. It may be suggested that, the intermediate system whose life time is about 10^{-21} sec[11], shorter than the life time of the compound nucleus and longer than the time required for the incident particle to pass through the target nucleus, may play an important role and moreover, the alpha particle clustering in the target or in the intermediate system has essential effect on such reaction.

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