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CROSS SECTIONS FOR CHARGE TRANSFERS OF HIGHLY IONIZED IONS IN HYDROGEN ATOMS (UP-DATED VERSION OF IPPJ-AM-15)

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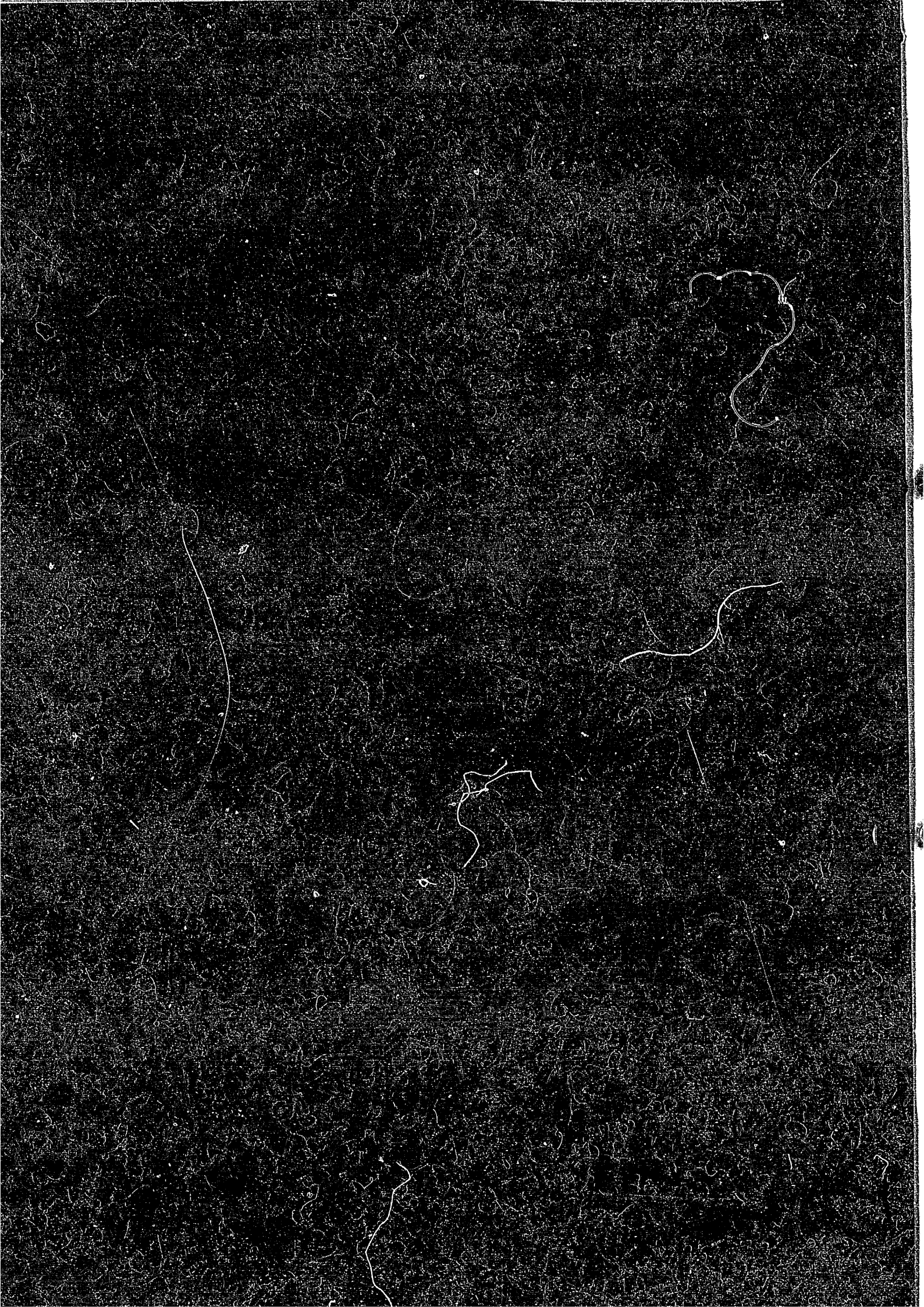

CROSS SECTIONS FOR CHARGE TRANSFERS OF HIGHLY IONIZED IONS IN HYDROGEN ATOMS

(Up-dated version of IPPJ-AM-15 by Y. Kaneko, T. Arikawa Y. Itikawa, T. Iwai, T. Kato, M. Matsuzawa, Y. Nakai K. Okuno, H. Ryufuku, H. Tawara and T. Watanabe)

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Abstract

Experimental data through mid 1983 are compiled on the total cross sections for the electron capture processes of highly ionized ions in collisions with hydrogen atoms. The results are shown in figures as a function of the collision energy. Also are shown the cross sections for some related processes including the electron detachment (or stripping) and excitation. This is the first up-dated version of a previous compilation published as IPPJ-AM-15.

I. INTRODUCTION

Since the publication of our previous compilation, IPPJ-AM-15[1], entitled "Cross sections for charge transfer collisions involving hydrogen atoms" by Y. Kaneko *et al.*, a series of the experiments[2] have confirmed the importance of the electron capture processes involving highly ionized impurity ions in diagnostics and evaluation of high temperature Tokamak plasmas. In such an electron capture process of highly ionized ions A^{q+} in collisions with hydrogen atoms at low energies, the electron is preferentially captured into the excited states of the ion which is immediately decayed into the ground state by emitting a photon in most cases; that is,

$$\begin{array}{l} A^{q+} + H \rightarrow A^{(q-1)+*}(n, l) + H^{+} \\ \qquad\qquad\quad \downarrow \\ \qquad\qquad\quad A^{(q-1)+}(g.s.) + h\nu \end{array} \qquad (1)$$

Therefore, this process results in significant energy loss from high temperature plasmas. Over the past year, some experimental results on the (n, l) distribution of the electron-captured ions in process (1) have been reported and found to give some detailed insight in understanding the electron capture process of highly ionized ions.[3] However, such data are still too few to compile and evaluate.

In the present report are compiled the experimental data on the total cross sections of the electron transfer processes of highly stiripped ions in collisions with hydrogen atoms published through mid 1983. A list of the compiled processes is given in section II. The references are listed in section III. The compiled data for electron capture are shown in figures (Fig. 1 through Fig. 152) in section IV in the increasing order of the atomic number of ions (section II-1). The cross sections are presented in the unit of cm^2/atom and the collision energy in keV/amu (*e.i.*, the energy in the abcissa being equivalent to the kinetic energy of atomic hydrogen). In section V are shown the experimental results on some related processes in Fig. A1 through Fig. A20,

including the electron excitation and detachment or stripping, listed in section II-2. The present compilation is intended to be served as the first up-dated version of the previous compilation, IPPJ-AM-15. New data are indicated with square marks in figures. A numerical database of these compiled data is now being developed for future data retrieval system.

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II. LIST OF PROCESSES SHOWN IN FIGURES

1) Electron Capture

Fig. No.	Processes	References
1.	$\underline{H}^+ + H \rightarrow \underline{H}$	2, 34, 36, 37
	$\underline{H}^+ + H \rightarrow \underline{H} + H^+$	29, 30, 38, 42, 73, 76
	$\underline{D}^+ + D \rightarrow \underline{D} + D^+$	38
	$H^+ + D \rightarrow H + D^+$	73
2.	$\underline{H}^+ + H \rightarrow \underline{H}(2s) + H^+$	23, 42, 43, 45, 47
	$\underline{D}^+ + H \rightarrow \underline{D}(2s) + H^+$	23
3.	$\underline{H}^+ + H \rightarrow \underline{H}(2p) + H^+$	33, 43, 45
	$\underline{D}^+ + H \rightarrow \underline{D}(2p) + H^+$	45
4.	$^4He^{2+} + H \rightarrow He^+$	4, 76
	$^3He^{2+} + H \rightarrow He^+$	2, 6, 11, 12
5.	$^3He^{2+} + H \rightarrow He^+(2s)$	11
	$^4He^{2+} + H \rightarrow He^+(2s)$	4
6.	$^4He^+ + H \rightarrow He$	6, 76
7.	$^7Li^+ + H \rightarrow Li$	10
8.	$^7Li^{2+} + H \rightarrow Li^+$	10, 72
9.	$^7Li^{3+} + H \rightarrow Li^{2+}$	10, 72
10.	$^{11}B^+ + H \rightarrow B$	26
11.	$^{11}B^{2+} + H \rightarrow B^+$	26, 54
	$B^{2+} + H \rightarrow B^+$	16, 25
12.	$^{11}B^{3+} + H \rightarrow B^{2+}$	26
	$B^{3+} + H \rightarrow B^{2+}$	16, 54
13.	$B^{4+} + H \rightarrow B^{3+}$	16, 26, 54
14.	$B^{5+} + H \rightarrow B^{4+}$	16
	$^{11}B^{5+} + H \rightarrow B^{4+}$	26
15.	$C^+ + H \rightarrow C^0$	13, 18, 26

Fig. No.	Processes	References
16.	$C^{2+} + H \rightarrow C^{+}$	9, 13, 26, 54
17.	$C^{3+} + H \rightarrow C^{2+}$	13, 16, 26, 54, 74
18.	$C^{4+} + H \rightarrow C^{3+}$	13, 16, 26, 54, 74, 82
19.	$C^{5+} + H \rightarrow C^{4+}$	26, 74, 82
20.	$C^{6+} + H \rightarrow C^{5+}$	26, 74, 82
21.	$N^{+} + H \rightarrow N^{0}$	1, 13, 18
22.	$N^{2+} + H \rightarrow N^{+}$	13, 54, 72, 79
23.	$N^{3+} + H \rightarrow N^{2+}$	13, 16, 54, 72, 79
24.	$N^{4+} + H \rightarrow N^{3+}$	13, 16, 54, 72
25.	$N^{5+} + H \rightarrow N^{4+}$	13, 54, 72, 82
26.	$N^{6+} + H \rightarrow N^{5+}$	82
27.	$N^{7+} + H \rightarrow N^{6+}$	26, 82
28.	$O^{+} + H \rightarrow O^{0}$	1, 2, 13
29.	$O^{2+} + H \rightarrow O^{+}$	13, 54, 74
30.	$O^{3+} + H \rightarrow O^{2+}$	13, 17, 54, 74
31.	$O^{4+} + H \rightarrow O^{3+}$	13, 17, 54, 74
32.	$O^{5+} + H \rightarrow O^{4+}$	13, 16, 17, 54, 74
33.	$O^{6+} + H \rightarrow O^{5+}$	16, 17, 74, 82
34.	$O^{7+} + H \rightarrow O^{6+}$	17, 82
35.	$O^{8+} + H \rightarrow O^{7+}$	17, 82
36.	$Ne^{2+} + H \rightarrow Ne^{+}$	65
37.	$Ne^{3+} + H \rightarrow Ne^{2+}$	65, 72
38.	$Ne^{4+} + H \rightarrow Ne^{3+}$	65, 72
39.	$Ne^{5+} + H \rightarrow Ne^{4+}$	72
40.	$Ne^{8+} + H \rightarrow Ne^{7+}$	82
41.	$Ne^{9+} + H \rightarrow Ne^{8+}$	82
42.	$Ne^{10+} + H \rightarrow Ne^{9+}$	82
43.	$Na^{2+} + H \rightarrow Na^{+}$	79

Fig. No.	Processes	References
44.	$Na^{3+} + H \rightarrow Na^{2+}$	79
45.	$Na^{4+} + H \rightarrow Na^{3+}$	79
46	$Mg^{2+} + H \rightarrow Mg^{+}$	25
47.	$Si^{2+} + H \rightarrow Si^{+}$	14
48.	$Si^{3+} + H \rightarrow Si^{2+}$	14
49.	$Si^{4+} + H \rightarrow Si^{3+}$	14, 17
50.	$Si^{5+} + H \rightarrow Si^{4+}$	14, 17
51.	$Si^{6+} + H \rightarrow Si^{5+}$	14, 17
52.	$Si^{7+} + H \rightarrow Si^{6+}$	14, 17
53.	$Si^{8+} + H \rightarrow Si^{7+}$	17
54.	$Si^{9+} + H \rightarrow Si^{8+}$	17
55.	$Ar^{2+} + H \rightarrow Ar^{+}$	50, 65, 79
56.	$Ar^{3+} + H \rightarrow Ar^{2+}$	50, 65, 79
57.	$Ar^{4+} + H \rightarrow Ar^{3+}$	50, 65, 79
58.	$Ar^{5+} + H \rightarrow Ar^{4+}$	50
59.	$Ar^{6+} + H \rightarrow Ar^{5+}$	50, 65, 79
60.	$Ar^{7+} + H \rightarrow Ar^{6+}$	50, 79
61.	$Ar^{8+} + H \rightarrow Ar^{7+}$	50
62.	$Ar^{9+} + H \rightarrow Ar^{8+}$	50
63.	$Ti^{2+} + H \rightarrow Ti^{+}$	25
64.	$Fe^{3+} + H \rightarrow Fe^{2+}$	81
65.	$Fe^{4+} + H \rightarrow Fe^{3+}$	5, 17, 81
66.	$Fe^{5+} + H \rightarrow Fe^{4+}$	5, 17, 50, 81
67.	$Fe^{6+} + H \rightarrow Fe^{5+}$	5, 17, 50, 81
68.	$Fe^{7+} + H \rightarrow Fe^{6+}$	5, 17, 81
69.	$Fe^{8+} + H \rightarrow Fe^{7+}$	5, 17, 81
70.	$Fe^{9+} + H \rightarrow Fe^{8+}$	5, 17, 81
71.	$Fe^{10+} + H \rightarrow Fe^{9+}$	5, 17, 81

Fig. No.	Processes	References
72.	$Fe^{11+} + H \rightarrow Fe^{10+}$	5, 17, 81
73.	$Fe^{12+} + H \rightarrow Fe^{11+}$	5, 17, 81
74.	$Fe^{13+} + H \rightarrow Fe^{12+}$	5, 17, 81
75.	$Fe^{14+} + H \rightarrow Fe^{13+}$	17, 81
76.	$Fe^{15+} + H \rightarrow Fe^{14+}$	17
77.	$Zn^{2+} + H \rightarrow Zn^{+}$	25
78.	$Kr^{2+} + H \rightarrow Kr^{+}$	25, 78
79.	$Kr^{3+} + H \rightarrow Kr^{2+}$	78
80.	$Kr^{4+} + H \rightarrow Kr^{3+}$	78
81.	$Kr^{5+} + H \rightarrow Kr^{4+}$	78
82.	$Kr^{6+} + H \rightarrow Kr^{5+}$	78
83.	$Mo^{4+} + H \rightarrow Mo^{3+}$	17
84.	$Mo^{5+} + H \rightarrow Mo^{4+}$	17
85.	$Mo^{6+} + H \rightarrow Mo^{5+}$	17
86.	$Mo^{7+} + H \rightarrow Mo^{6+}$	17
87.	$Mo^{8+} + H \rightarrow Mo^{7+}$	17
88.	$Mo^{9+} + H \rightarrow Mo^{8+}$	17
89.	$Mo^{10+} + H \rightarrow Mo^{9+}$	17
90.	$Mo^{11+} + H \rightarrow Mo^{10+}$	17
91.	$Mo^{12+} + H \rightarrow Mo^{11+}$	17
92.	$Mo^{13+} + H \rightarrow Mo^{12+}$	17
93.	$Mo^{14+} + H \rightarrow Mo^{13+}$	17
94.	$Mo^{15+} + H \rightarrow Mo^{14+}$	17
95.	$Mo^{16+} + H \rightarrow Mo^{15+}$	17
96.	$Mo^{17+} + H \rightarrow Mo^{16+}$	17
97.	$Mo^{18+} + H \rightarrow Mo^{17+}$	17
98.	$Cd^{2+} + H \rightarrow Cd^{+}$	25
99.	$Xe^{2+} + H \rightarrow Xe^{+}$	50

Fig. No.	Processes	References
100.	$Xe^{3+} + H \rightarrow Xe^{2+}$	50
101.	$Xe^{4+} + H \rightarrow Xe^{3+}$	50
102.	$Xe^{5+} + H \rightarrow Xe^{4+}$	50
103.	$Xe^{6+} + H \rightarrow Xe^{5+}$	50
104.	$Xe^{7+} + H \rightarrow Xe^{6+}$	50
105.	$Xe^{8+} + H \rightarrow Xe^{7+}$	50
106.	$Xe^{9+} + H \rightarrow Xe^{8+}$	50
107.	$Xe^{10+} + H \rightarrow Xe^{9+}$	50
108.	$Xe^{11+} + H \rightarrow Xe^{10+}$	50
109.	$Xe^{12+} + H \rightarrow Xe^{11+}$	50
110.	$Ba^{2+} + H \rightarrow Ba^{+}$	25
111.	$Ta^{3+} + H \rightarrow Ta^{2+}$	17
112.	$Ta^{4+} + H \rightarrow Ta^{3+}$	17
113.	$Ta^{5+} + H \rightarrow Ta^{4+}$	17
114.	$Ta^{6+} + H \rightarrow Ta^{5+}$	17
115.	$Ta^{7+} + H \rightarrow Ta^{6+}$	17
116.	$Ta^{8+} + H \rightarrow Ta^{7+}$	17
117.	$Ta^{9+} + H \rightarrow Ta^{8+}$	17
118.	$Ta^{10+} + H \rightarrow Ta^{9+}$	17
119.	$Ta^{11+} + H \rightarrow Ta^{10+}$	17
120.	$Ta^{12+} + H \rightarrow Ta^{11+}$	17
121.	$Ta^{13+} + H \rightarrow Ta^{12+}$	17
122.	$Ta^{14+} + H \rightarrow Ta^{13+}$	17
123.	$Ta^{15+} + H \rightarrow Ta^{14+}$	17
124.	$Ta^{16+} + H \rightarrow Ta^{15+}$	17
125.	$Ta^{17+} + H \rightarrow Ta^{16+}$	17
126.	$Ta^{18+} + H \rightarrow Ta^{17+}$	17
127.	$Ta^{19+} + H \rightarrow Ta^{18+}$	17

Fig. No.	Processes	References
128.	$W^{4+} + H \rightarrow W^{3+}$	17
129.	$W^{5+} + H \rightarrow W^{4+}$	17
130.	$W^{6+} + H \rightarrow W^{5+}$	17
131.	$W^{7+} + H \rightarrow W^{6+}$	17
132.	$W^{8+} + H \rightarrow W^{7+}$	17
133.	$W^{9+} + H \rightarrow W^{8+}$	17
134.	$W^{10+} + H \rightarrow W^{9+}$	17
135.	$W^{11+} + H \rightarrow W^{10+}$	17
136.	$W^{12+} + H \rightarrow W^{11+}$	17
137.	$W^{13+} + H \rightarrow W^{12+}$	17
138.	$W^{14+} + H \rightarrow W^{13+}$	17
139.	$W^{15+} + H \rightarrow W^{14+}$	17
140.	$Au^{5+} + H \rightarrow Au^{4+}$	17
141.	$Au^{6+} + H \rightarrow Au^{5+}$	17
142.	$Au^{7+} + H \rightarrow Au^{6+}$	17
143.	$Au^{8+} + H \rightarrow Au^{7+}$	17
144.	$Au^{9+} + H \rightarrow Au^{8+}$	17
145.	$Au^{10+} + H \rightarrow Au^{9+}$	17
146.	$Au^{11+} + H \rightarrow Au^{10+}$	17
147.	$Au^{12+} + H \rightarrow Au^{11+}$	17
148.	$Au^{13+} + H \rightarrow Au^{12+}$	17
149.	$Au^{14+} + H \rightarrow Au^{13+}$	17
150.	$Au^{15+} + H \rightarrow Au^{14+}$	17
151.	$Au^{16+} + H \rightarrow Au^{15+}$	17
152.	$Tl^{2+} + H \rightarrow Tl^{+}$	25

2) Related Processes

Fig. No.	Processes	References
A1.	$\underline{H^+} + H \rightarrow \underline{H^+} + H(2p)$	33, 43, 45
	$\underline{D^+} + H \rightarrow \underline{D^+} + H(2p)$	45
A2.	$\underline{H^+} + H \rightarrow \underline{H^+} + H(2s)$	43, 47
A3.	$\underline{H^+} + H \rightarrow \underline{H^+} + H(n=2)$	52
A4.	$\underline{H^+} + H \rightarrow \underline{H^+} + H(n=3)$	52
A5.	$\underline{H^+} + H \rightarrow \underline{H^+} + H(n=4)$	52
A6.	$\underline{H^+} + H \rightarrow \underline{H^+} + H^+ + e$	30, 32, 46, 68
A7.	$\underline{H} + H \rightarrow \underline{H^+}$	39, 40, 77
A8.	$\underline{H} + H \rightarrow \underline{H}(2s)$	44
	$\underline{H}(1s) + H(1s) \rightarrow \underline{H}(2s)$	24
A9.	$\underline{H} + H \rightarrow \underline{H}(2p)$	44
A10.	$\underline{H} + H \rightarrow \underline{H^-} + H^+$	40
A11.	$\underline{H^-} + H \rightarrow \underline{H}$	48, 77
	$\underline{H^-} + H \rightarrow \underline{H} + H^-$	31
A12.	$\underline{H^-} + H \rightarrow \underline{H^+}$	48
A13.	$^4He^+ + H \rightarrow He^{2+}$	8, 77
A14.	$^4He^+ + H \rightarrow He^+ + H(2p)$	27
A15.	$^3He^+ + H \rightarrow He^+(2s)$	11
A16.	$^4He + H \rightarrow He^+$	77
A17.	$^4He^- + H \rightarrow He$	77
A18.	$C^+ + H \rightarrow C^{2+}$	26
A19.	$C^{2+} + H \rightarrow C^{3+}$	26
A20.	$C^{3+} + H \rightarrow C^{4+}$	26

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IV. FIGURES OF CROSS SECTIONS FOR $A^{q+} + H \rightarrow A^{(q-1)+} + H^+$ COLLISIONS

Fig.1 $H^+ + H \rightarrow H$

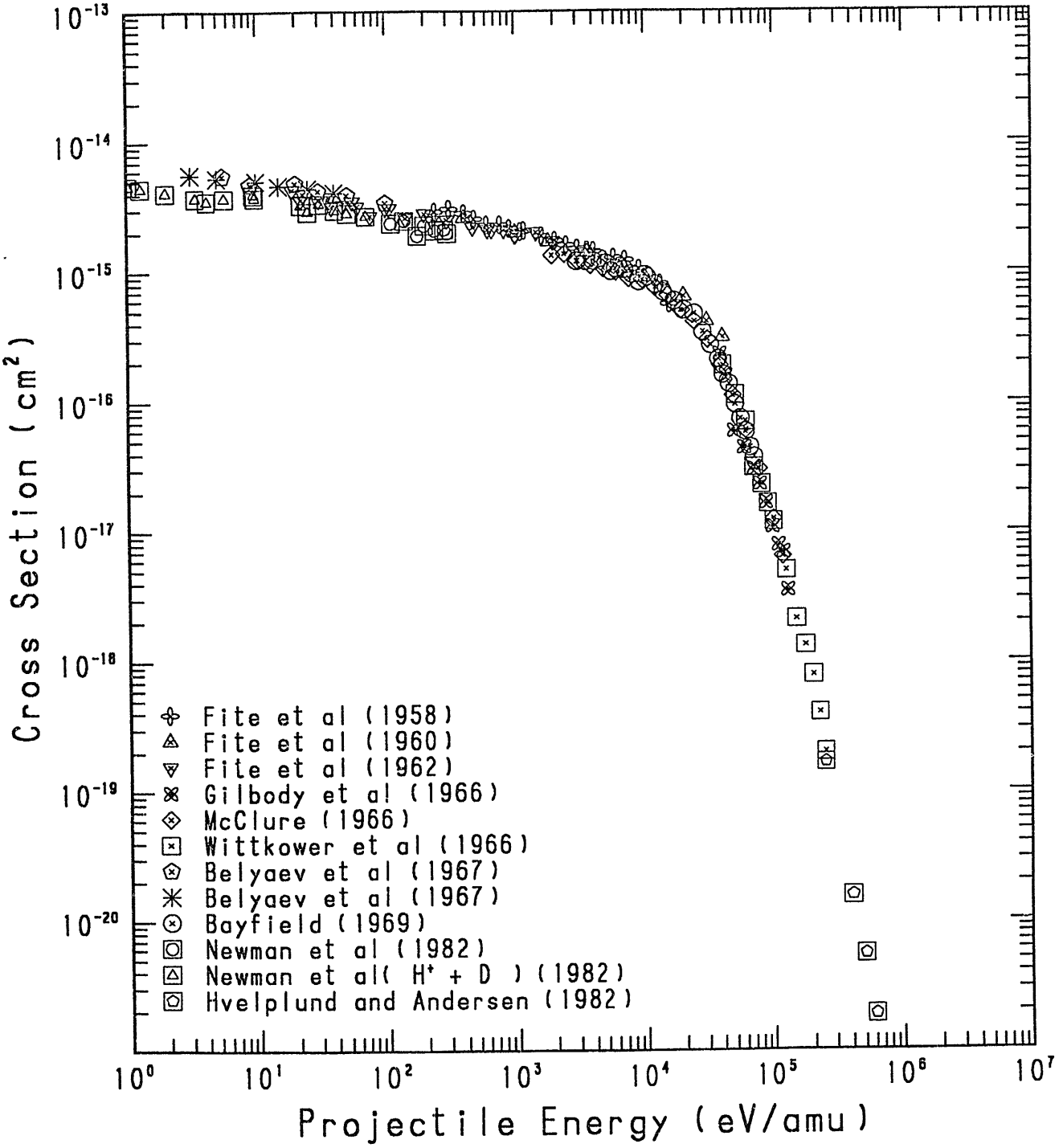


Fig.2 $H^+ + H \rightarrow H(2s)$

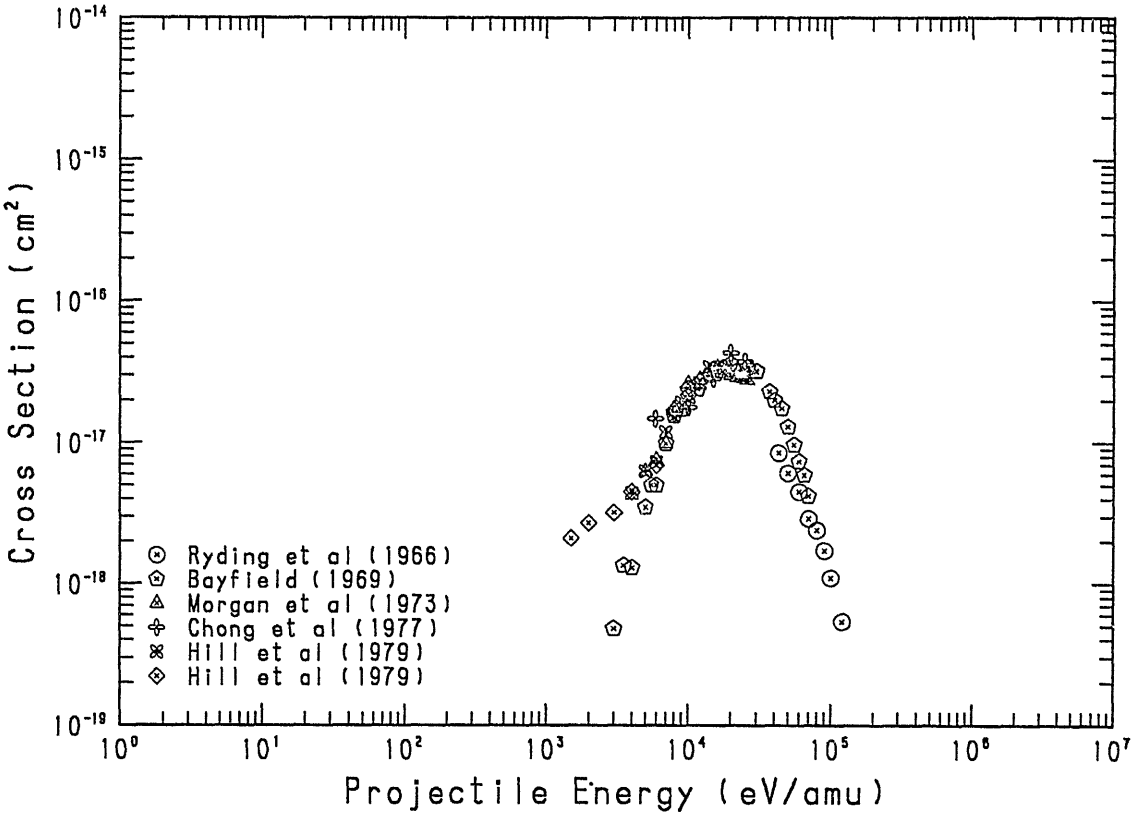


Fig.3 $H^+ + H \rightarrow H(2p)$

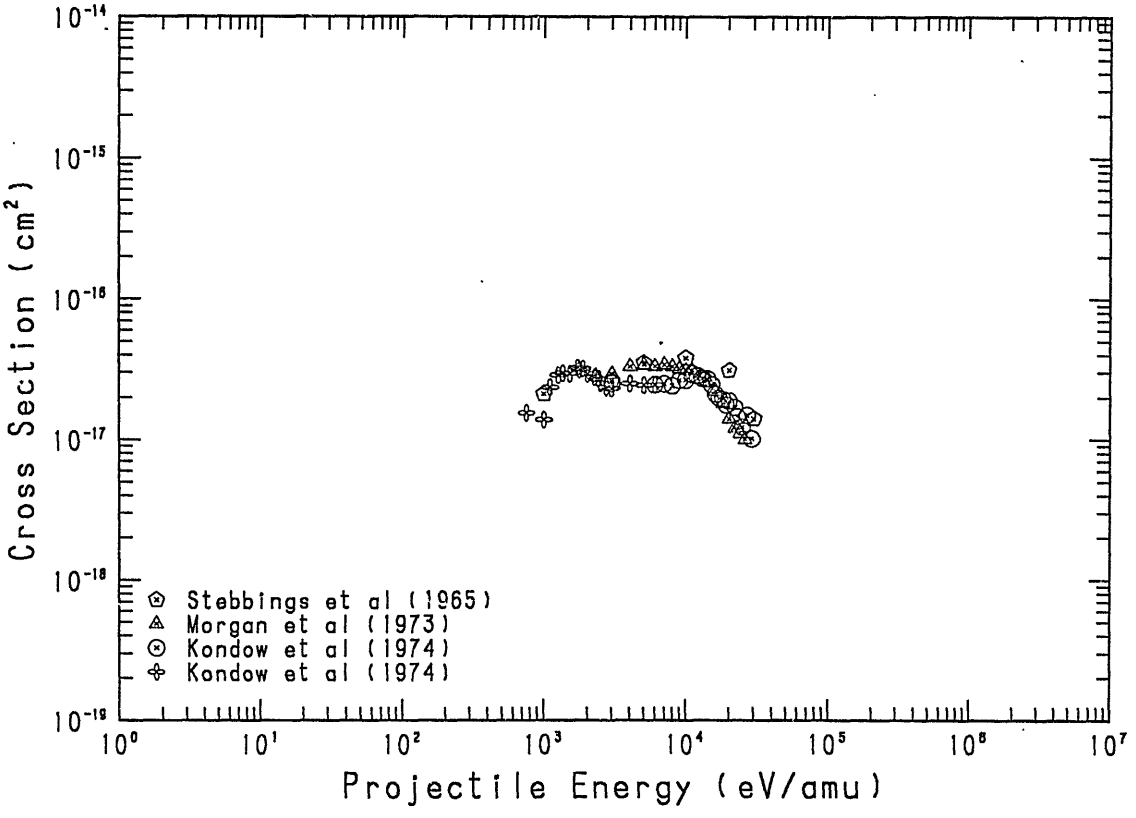


Fig.4 $He^{2+} + H \rightarrow He^{+}$

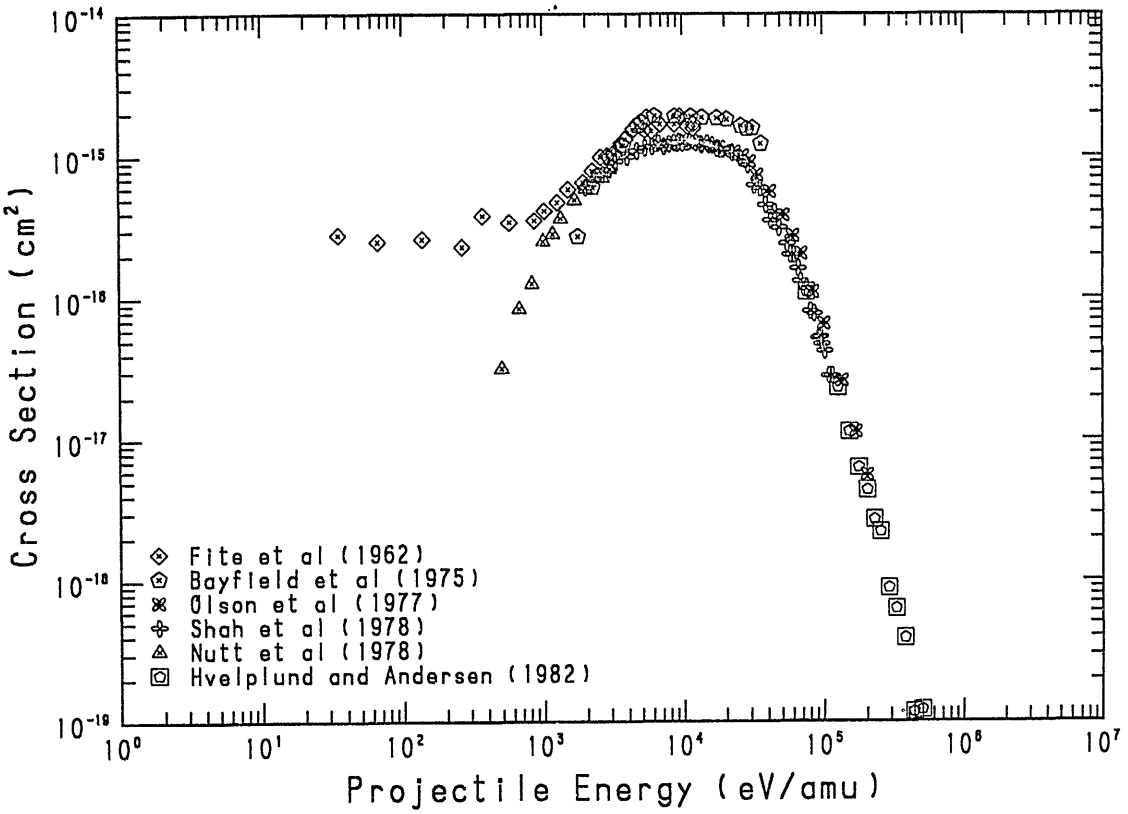


Fig.5 $He^{2+} + H \rightarrow He^{+}(2s)$

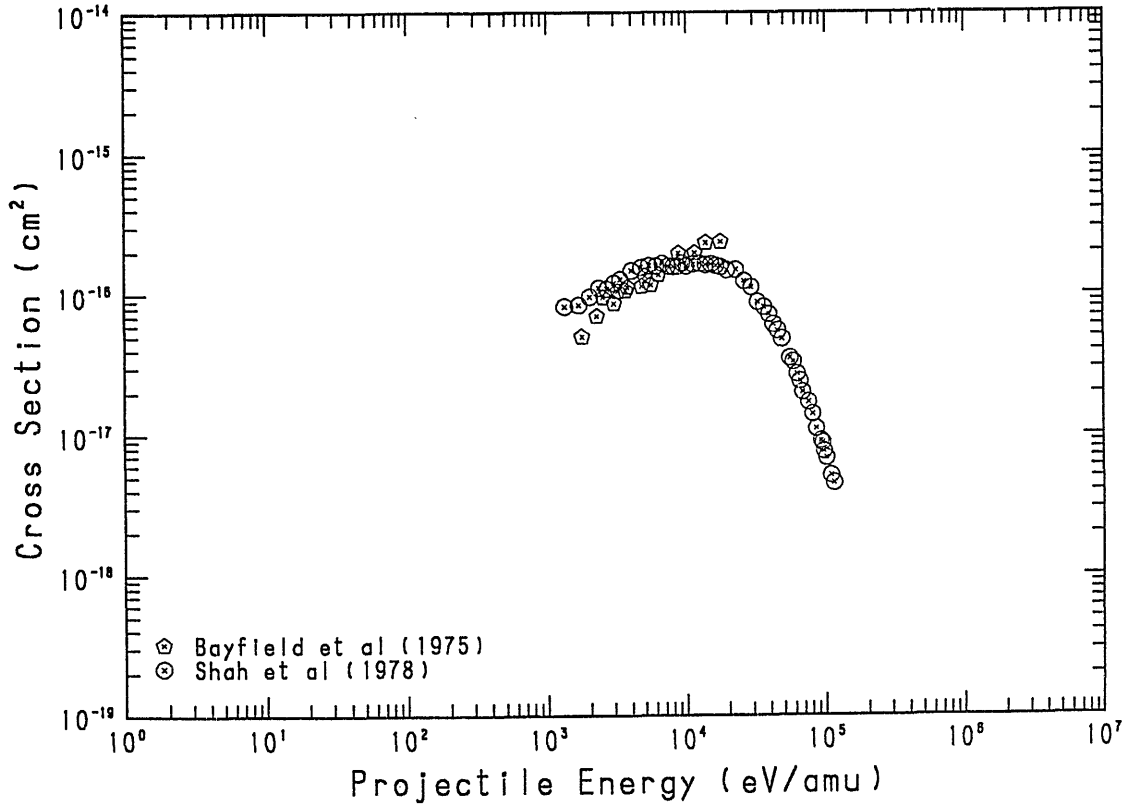


Fig.6 $He^+ + H \rightarrow He$

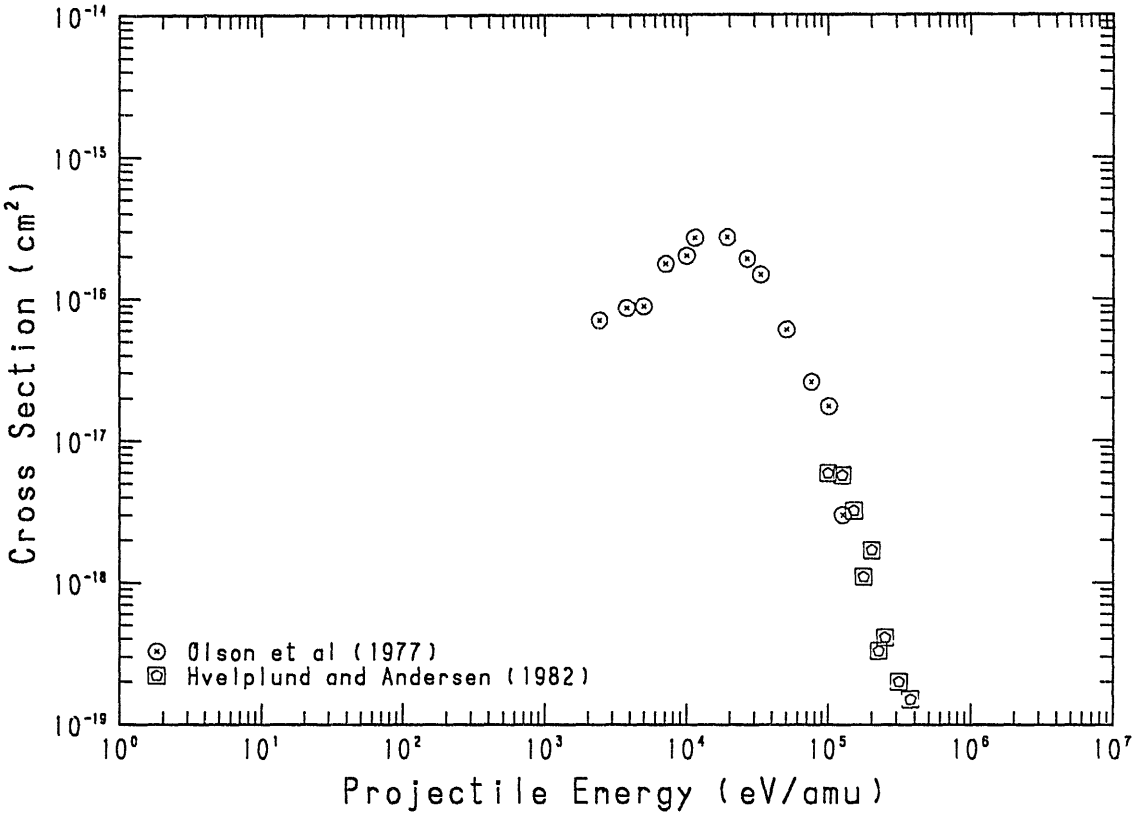


Fig.7 $Li^+ + H \rightarrow Li$

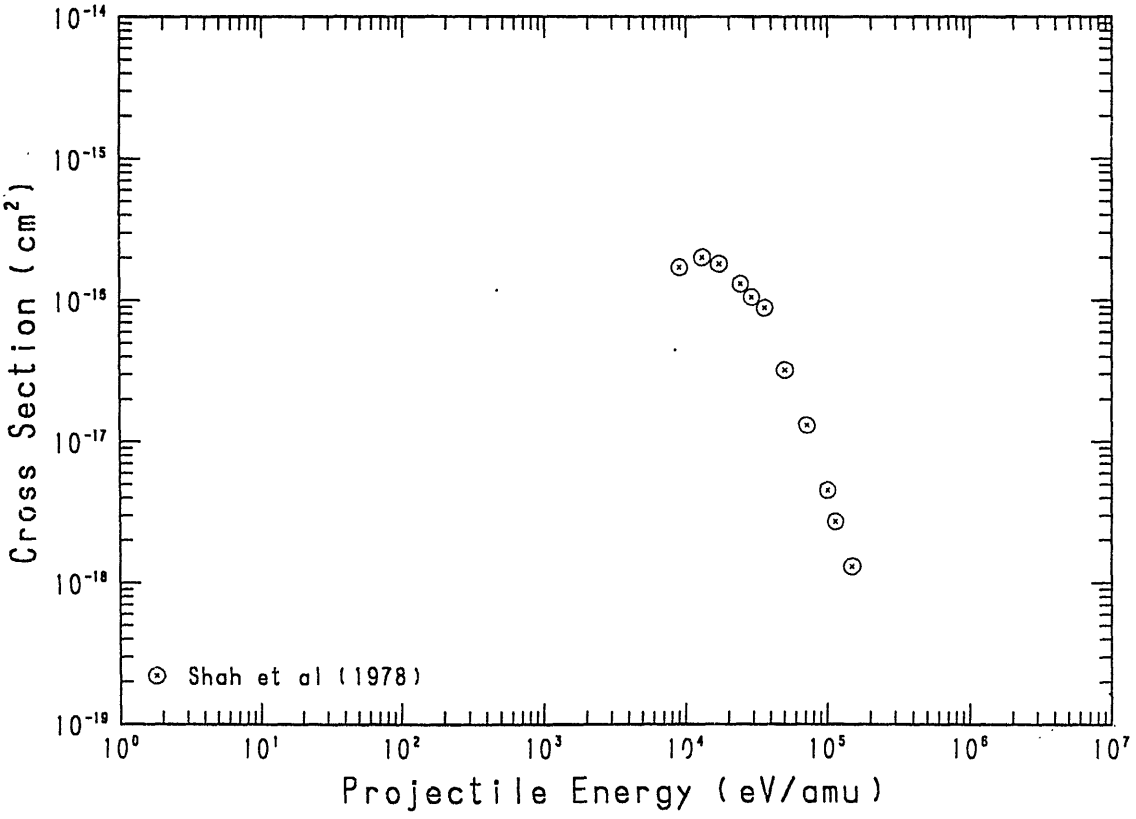


Fig.8 $Li^{2+} + H \rightarrow Li^{+}$

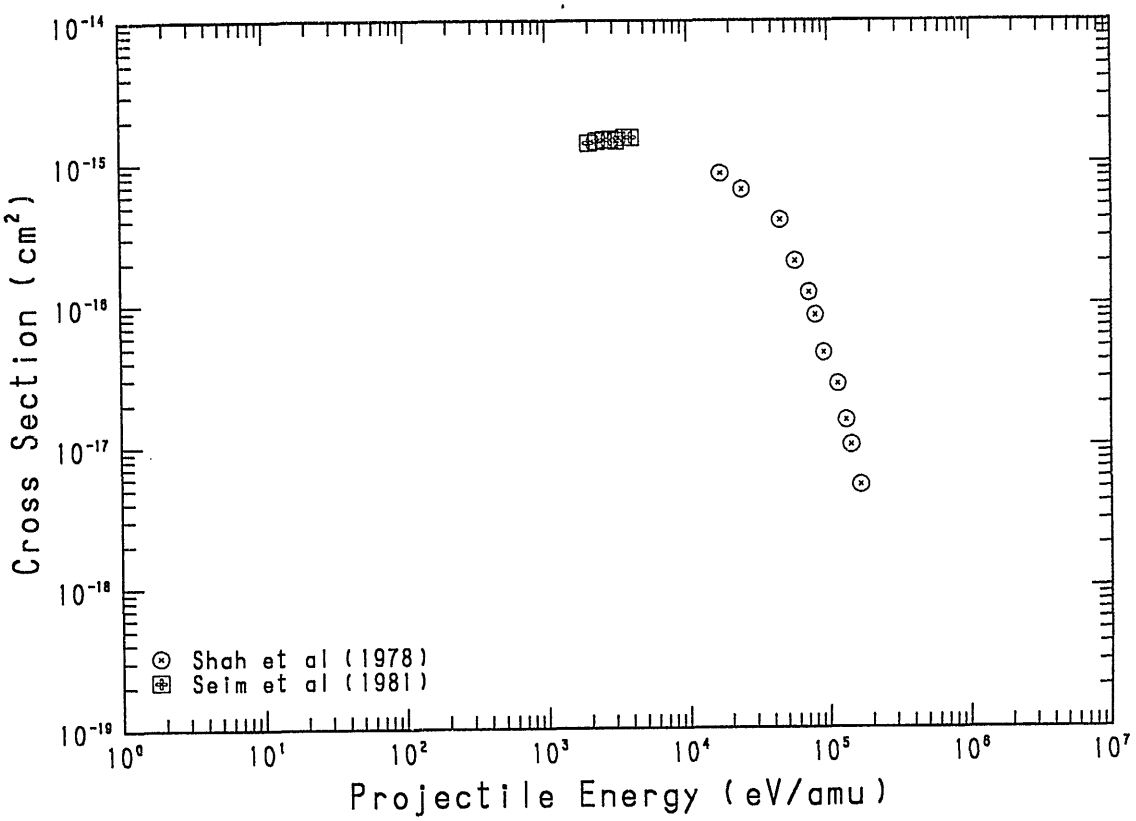


Fig.9 $Li^{3+} + H \rightarrow Li^{2+}$

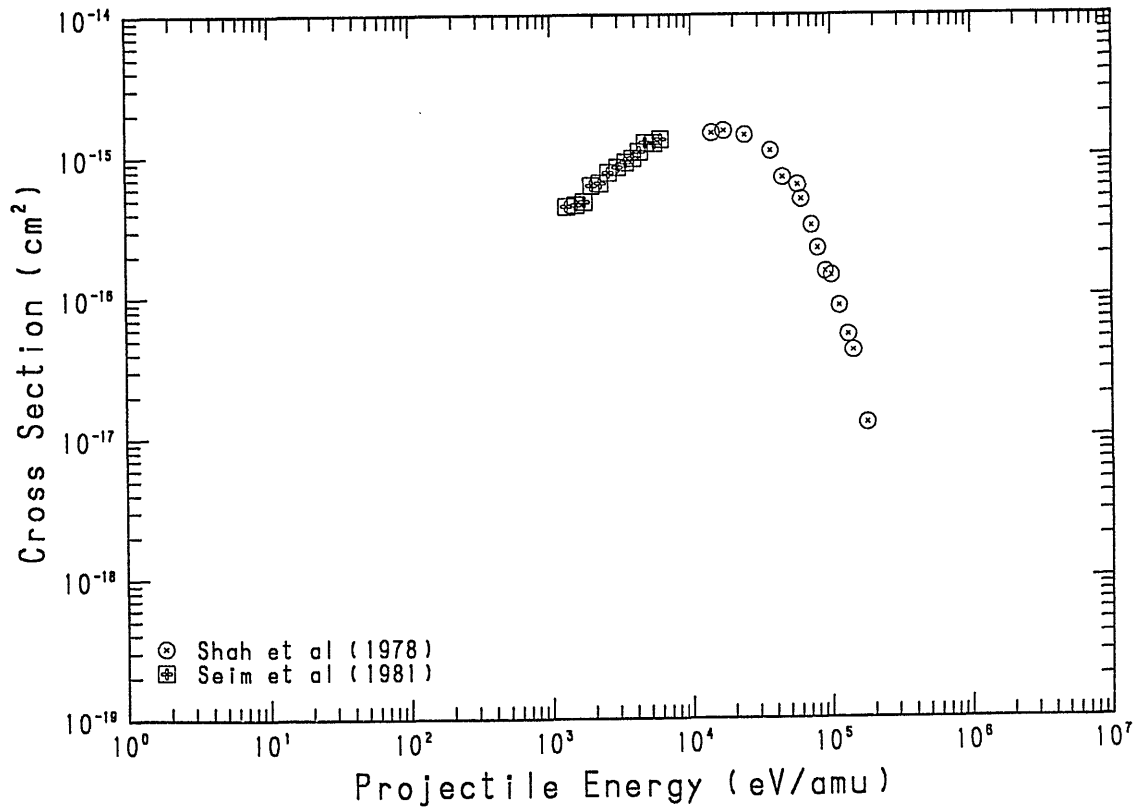


Fig.10 $B^{+} + H \rightarrow B$

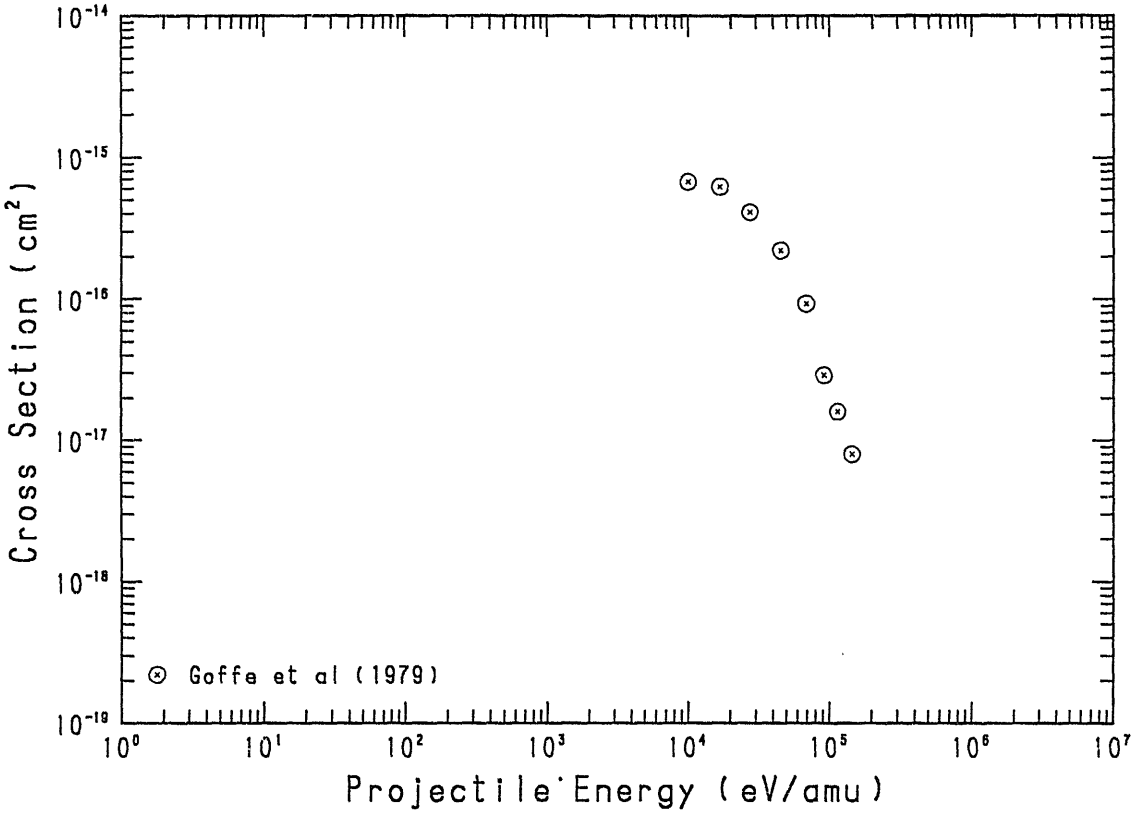


Fig.11 $B^{2+} + H \rightarrow B^{+}$

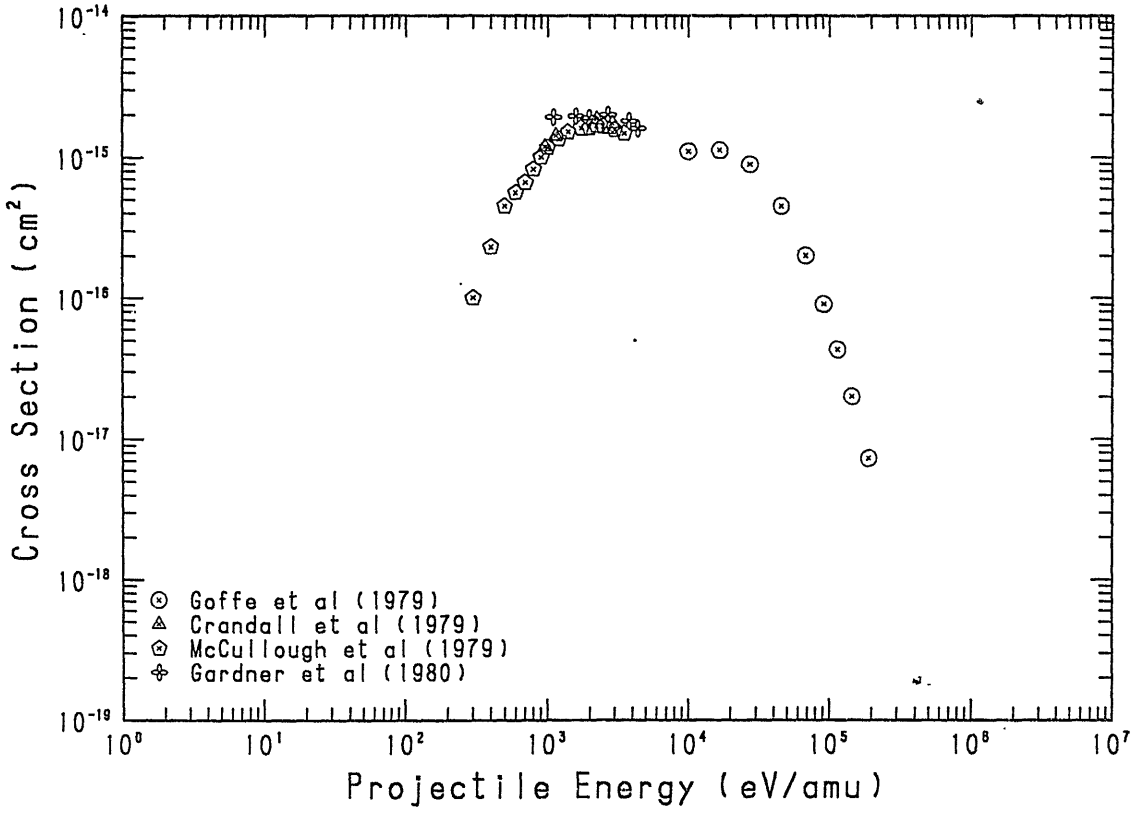


Fig.12 $B^{3+} + H \rightarrow B^{2+}$

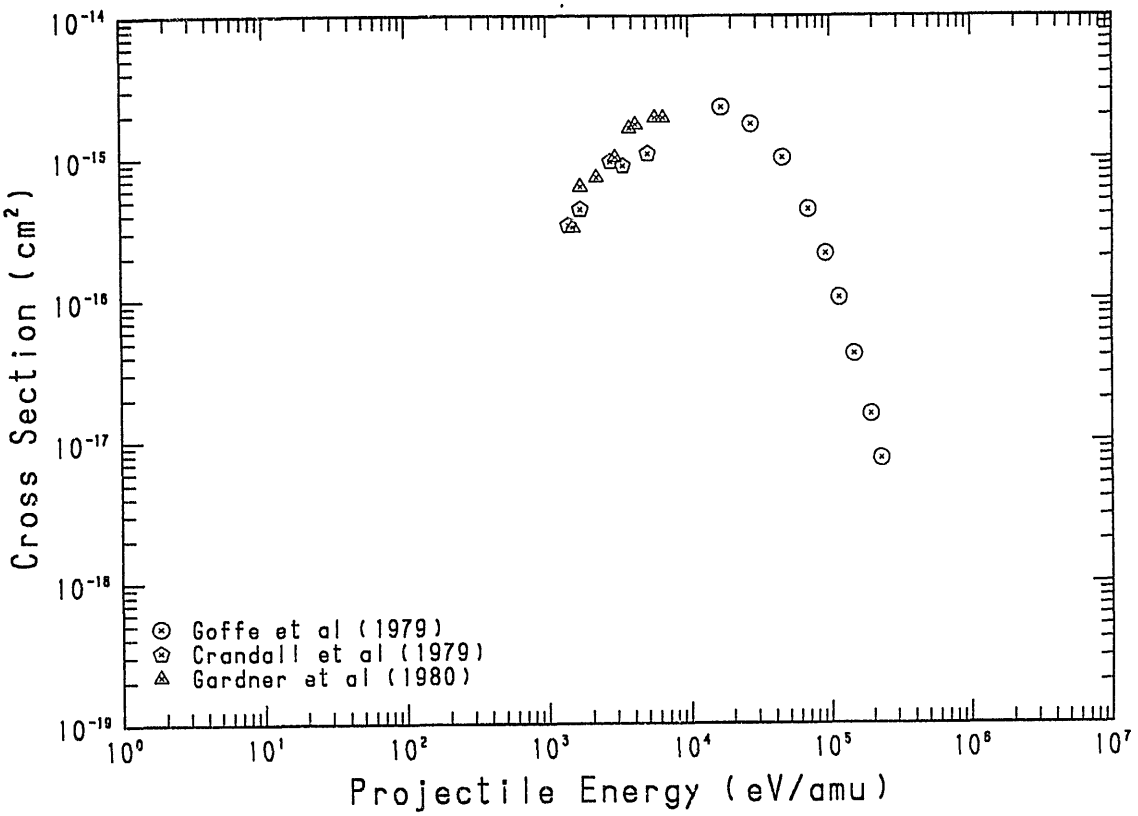


Fig.13 $B^{4+} + H \rightarrow B^{3+}$

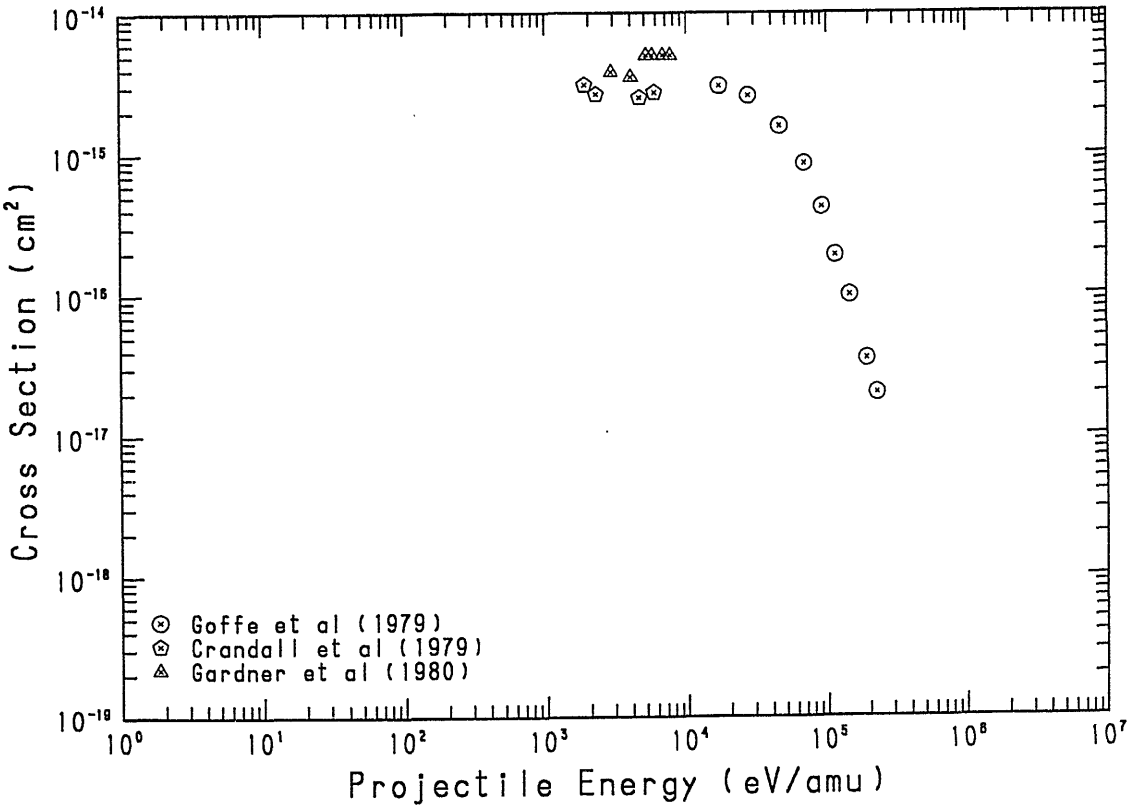


Fig.14 $B^{5+} + H \rightarrow B^{4+}$

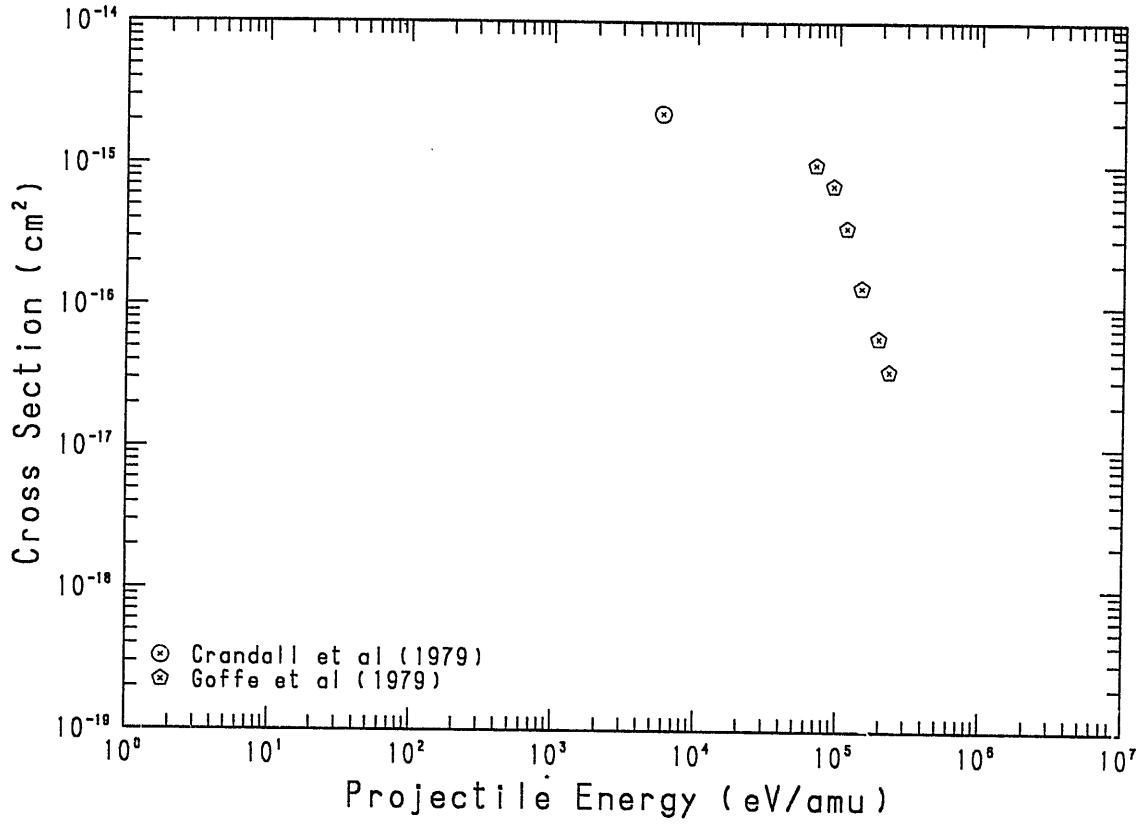


Fig.15 $C^{+} + H \rightarrow C$

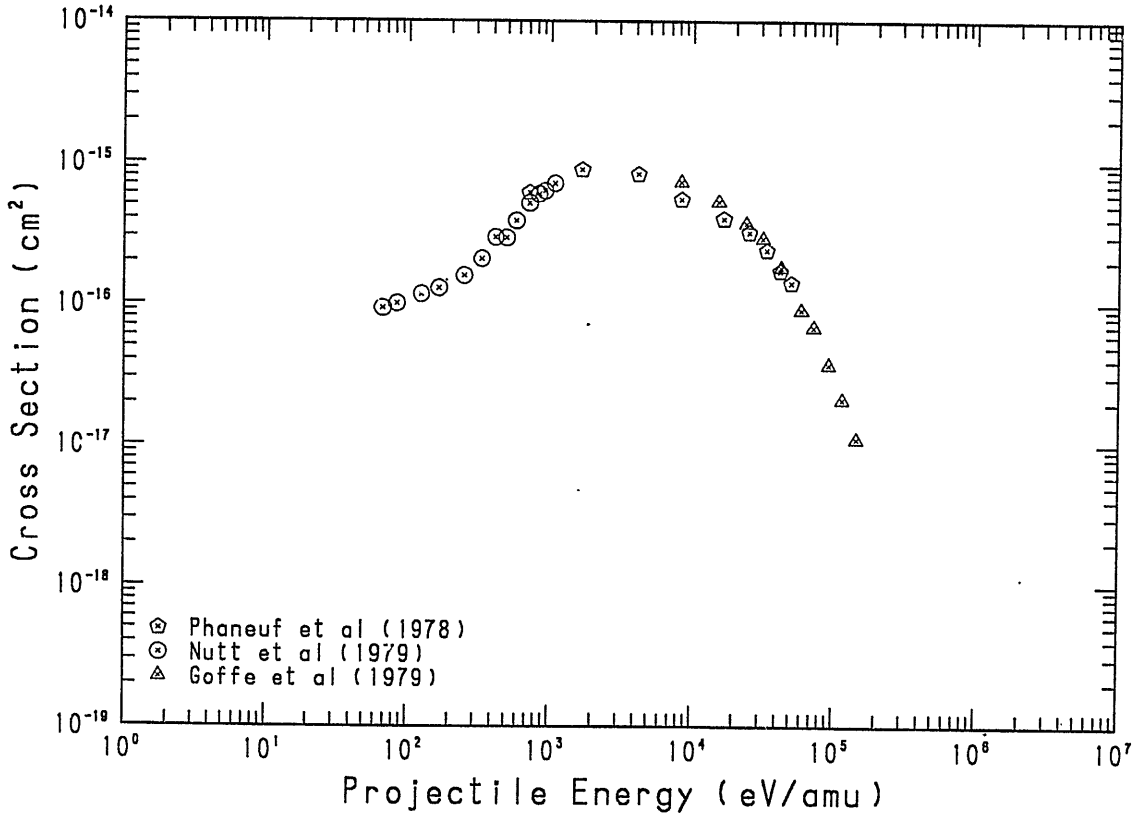


Fig.16 $C^{2+} + H \rightarrow C^{+}$

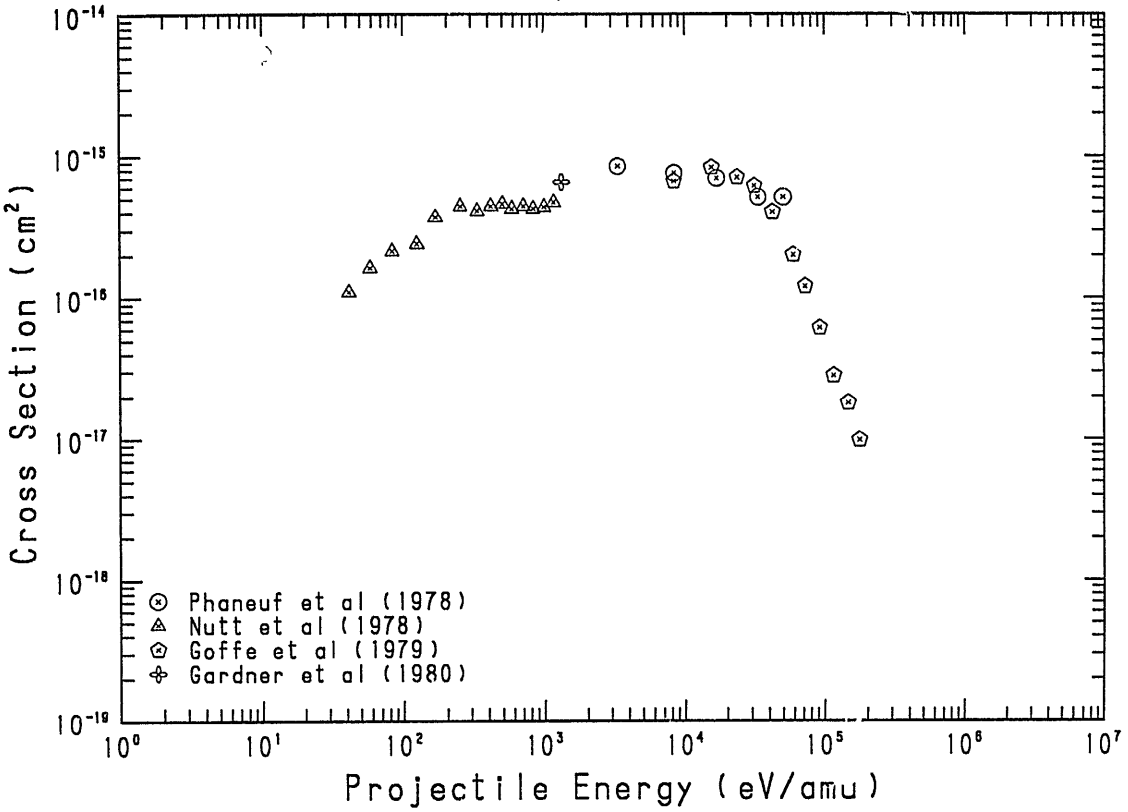


Fig.17 $C^{3+} + H \rightarrow C^{2+}$

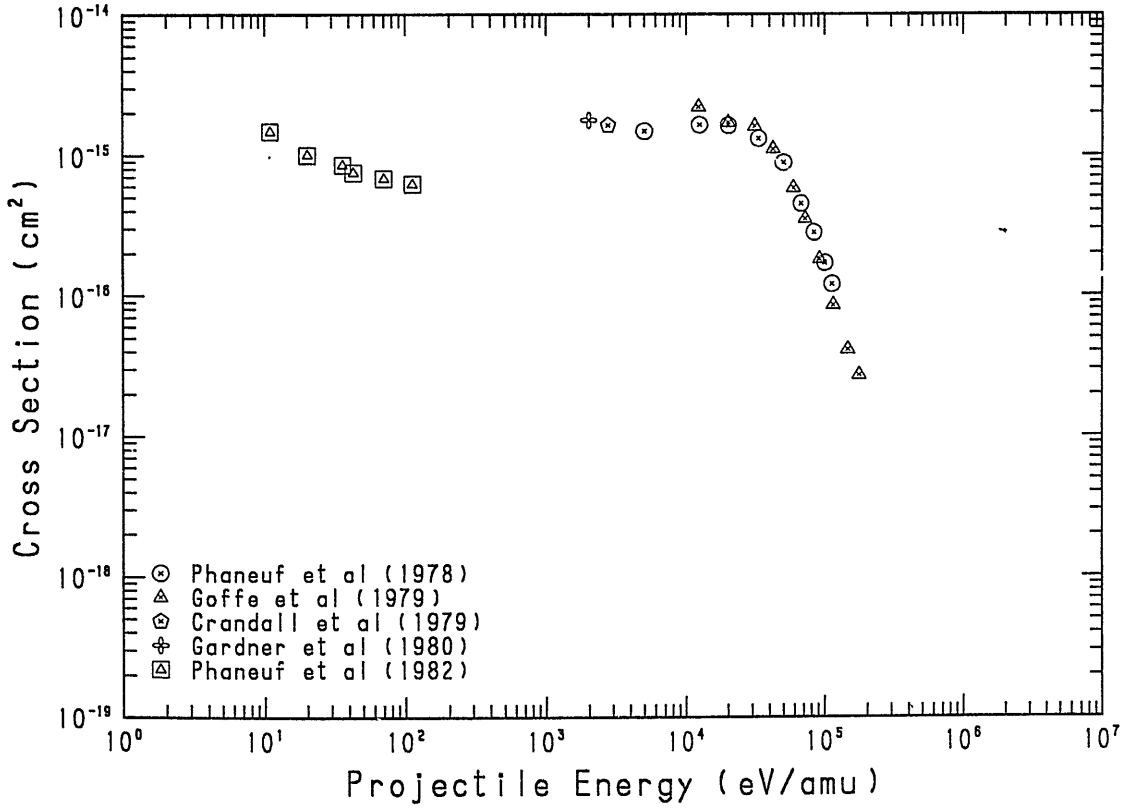


Fig.18 $C^{4+} + H \rightarrow C^{3+}$

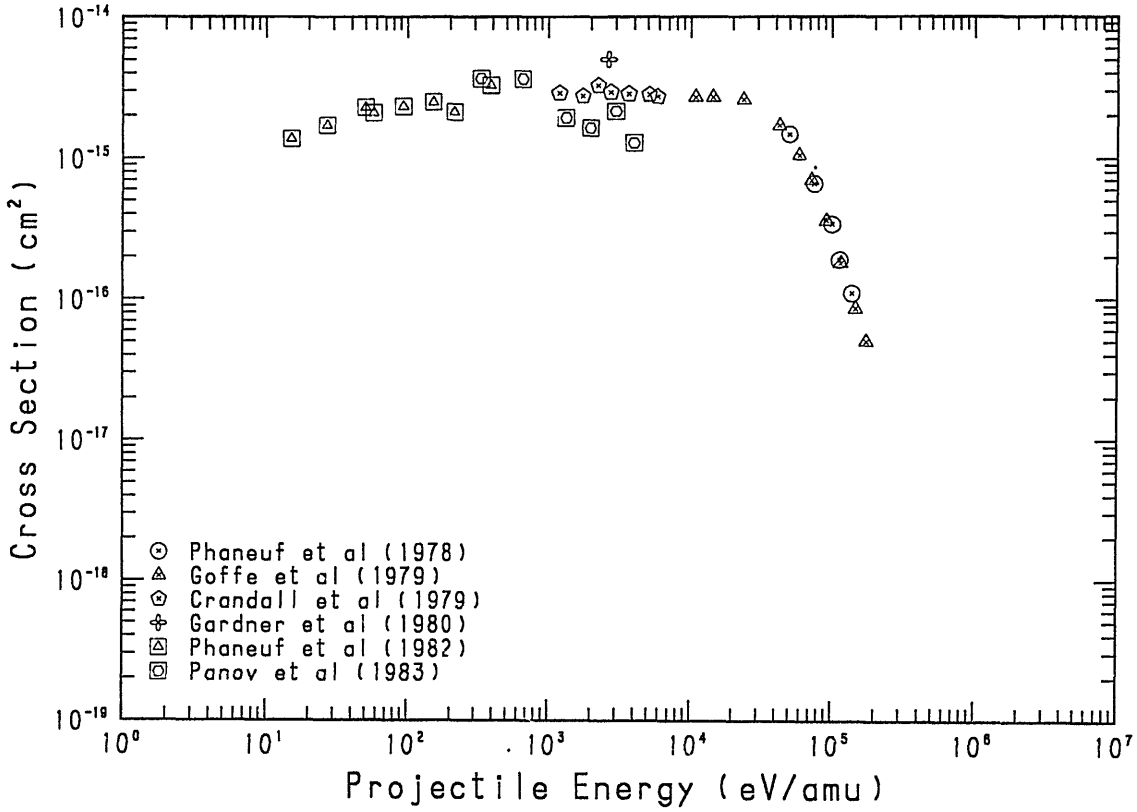


Fig.19 $C^{5+} + H \rightarrow C^{4+}$

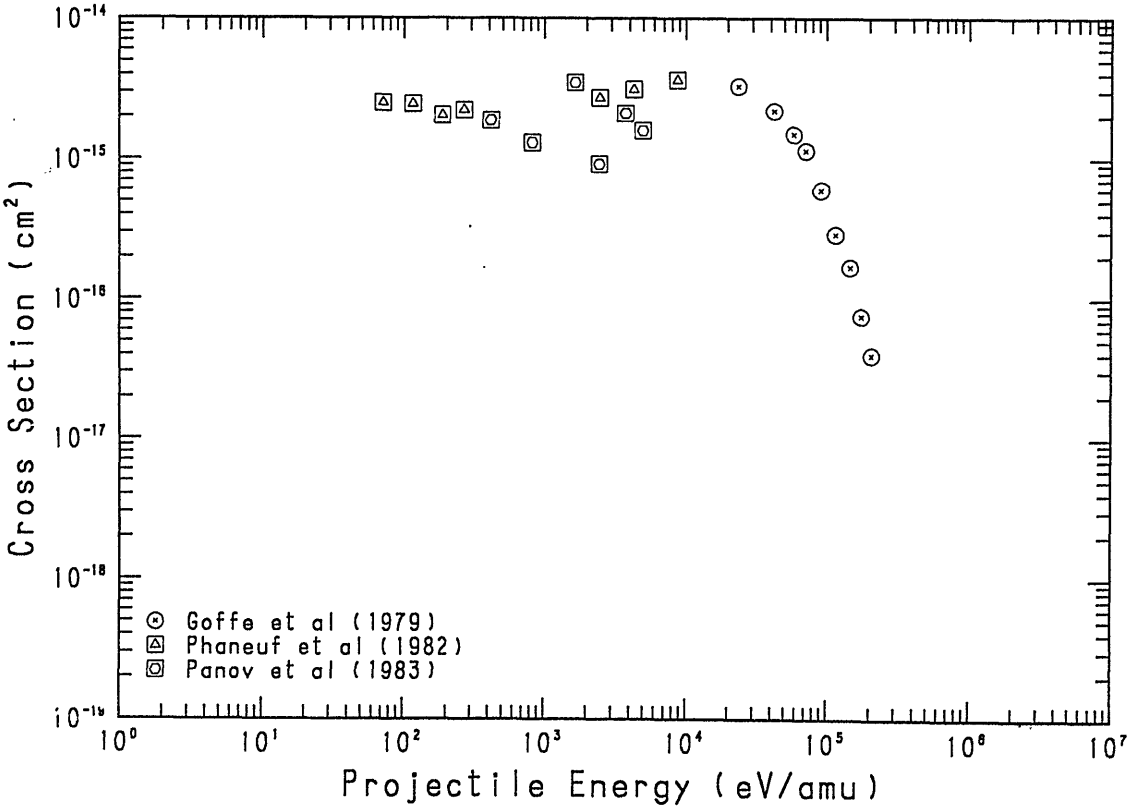


Fig.20 $C^{6+} + H \rightarrow C^{5+}$

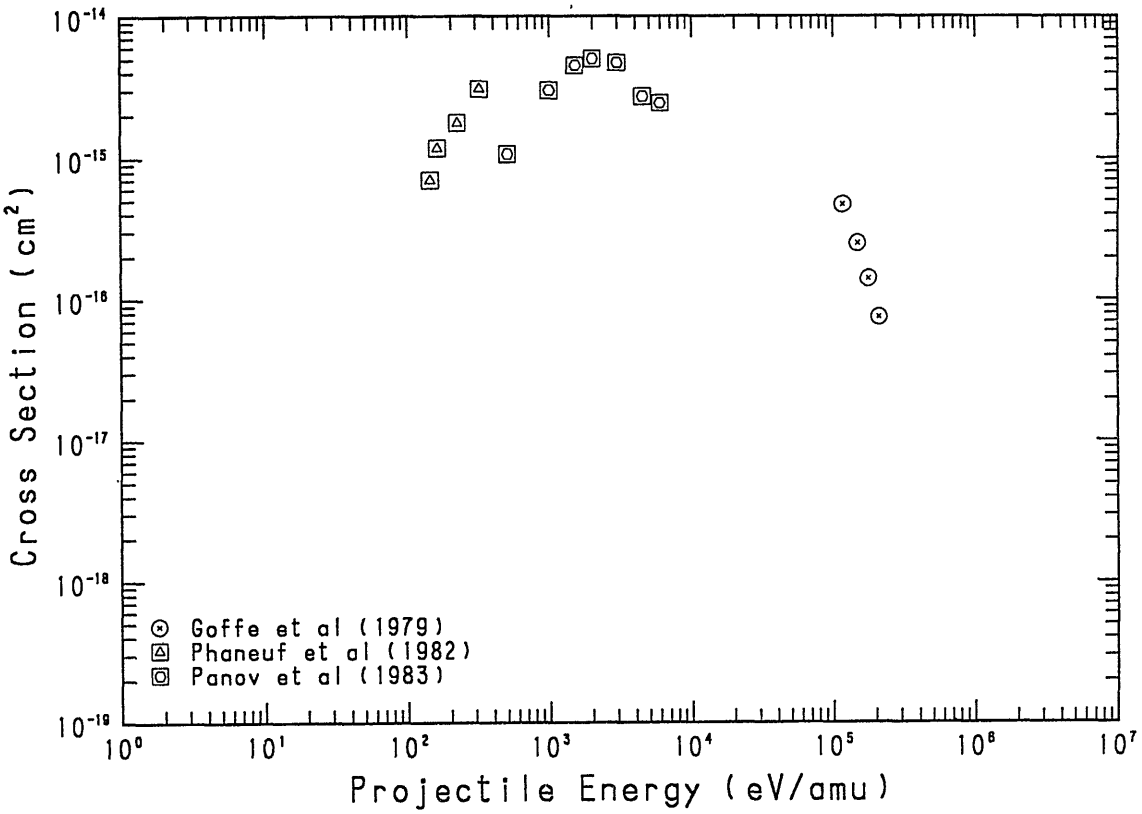


Fig.21 $N^+ + H \rightarrow N$

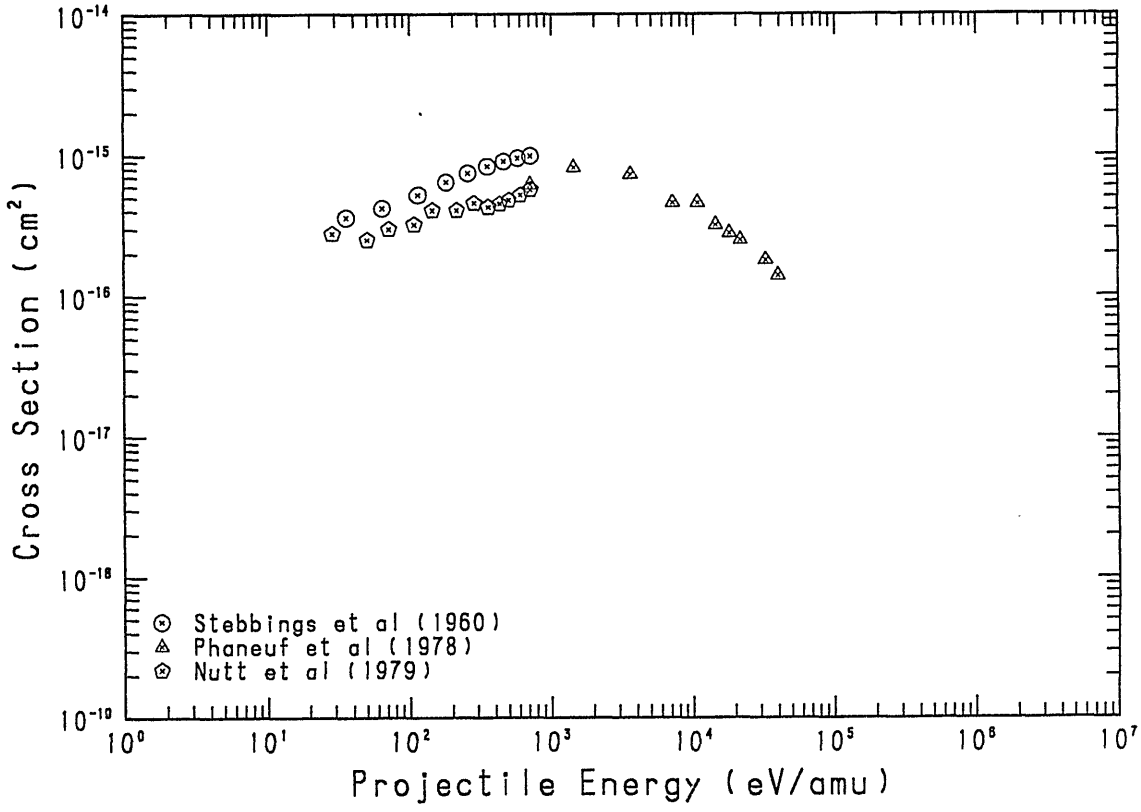


Fig.22 $N^{2+} + H \rightarrow N^{+}$

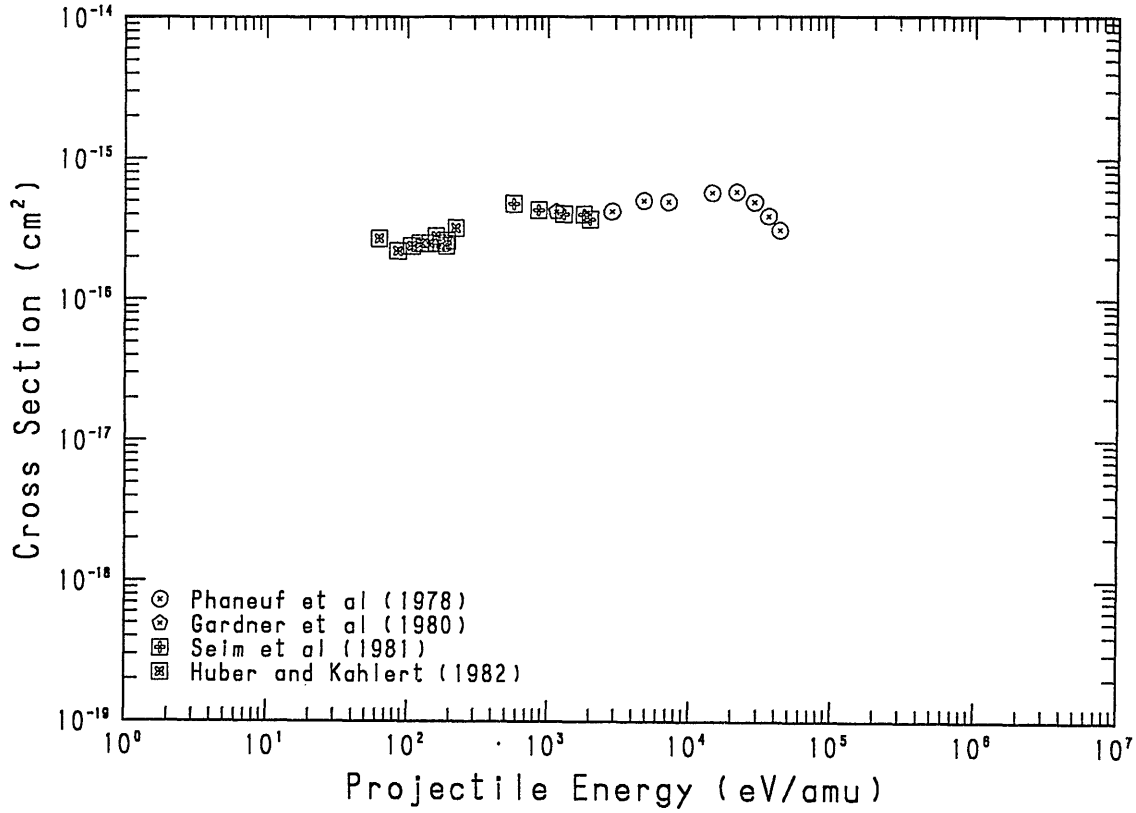


Fig.23 $N^{3+} + H \rightarrow N^{2+}$

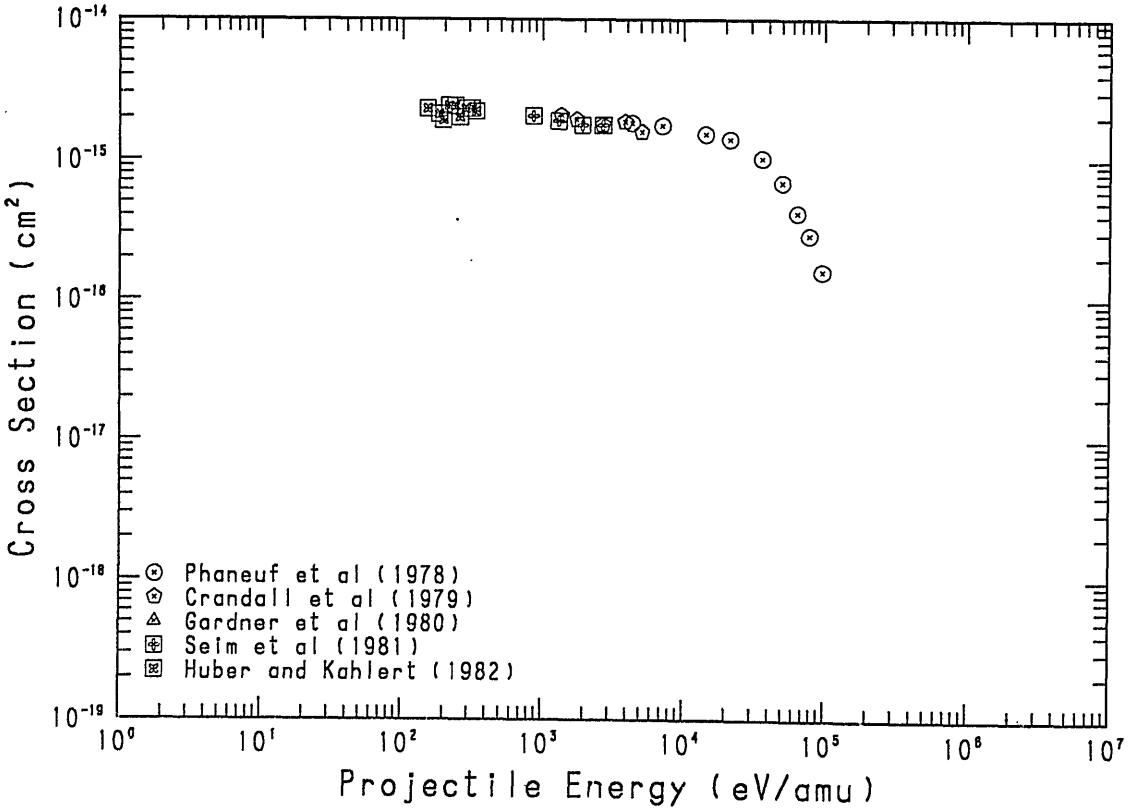


Fig.24 $N^{4+} + H \rightarrow N^{3+}$

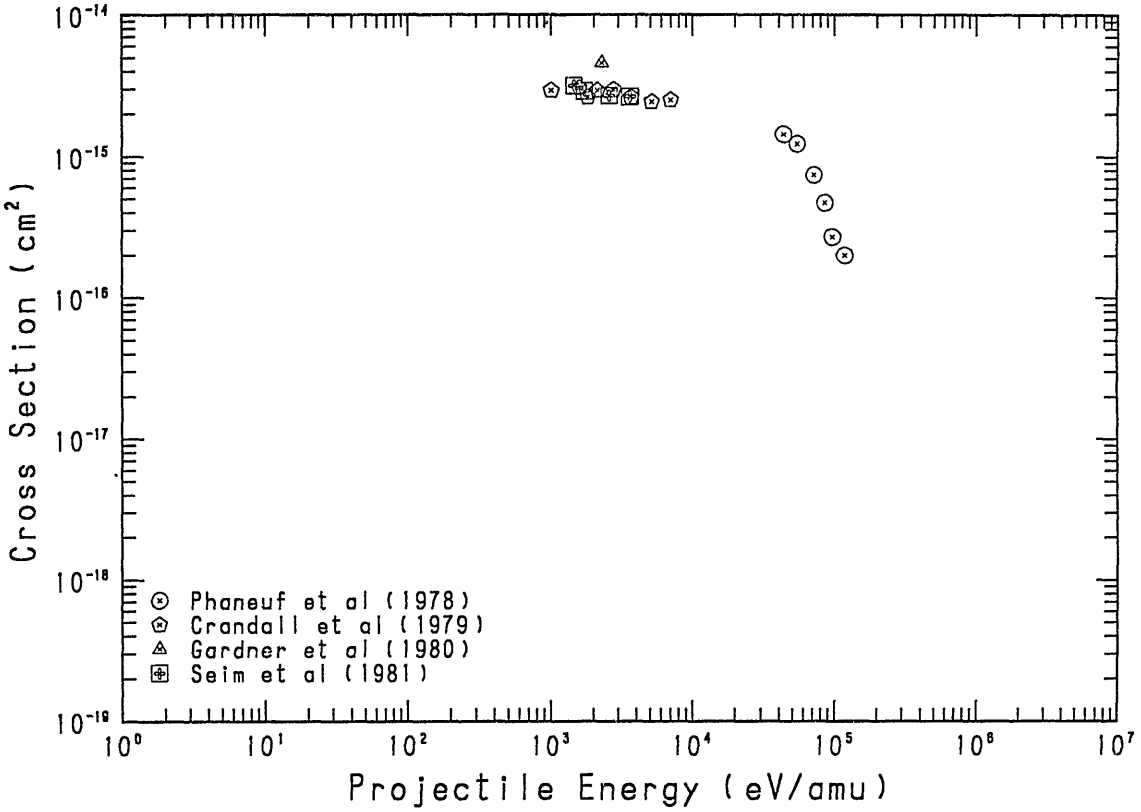


Fig.25 $N^{5+} + H \rightarrow N^{4+}$

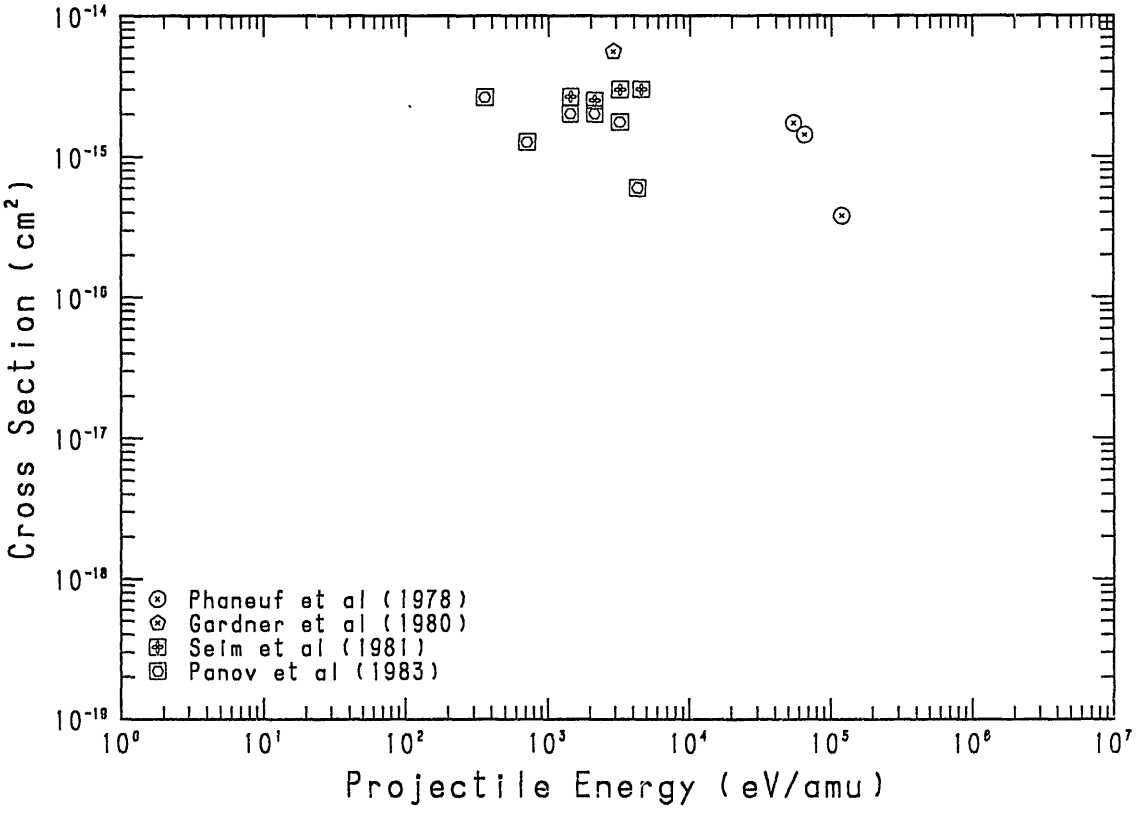


Fig.26 $N^{6+} + H \rightarrow N^{5+}$

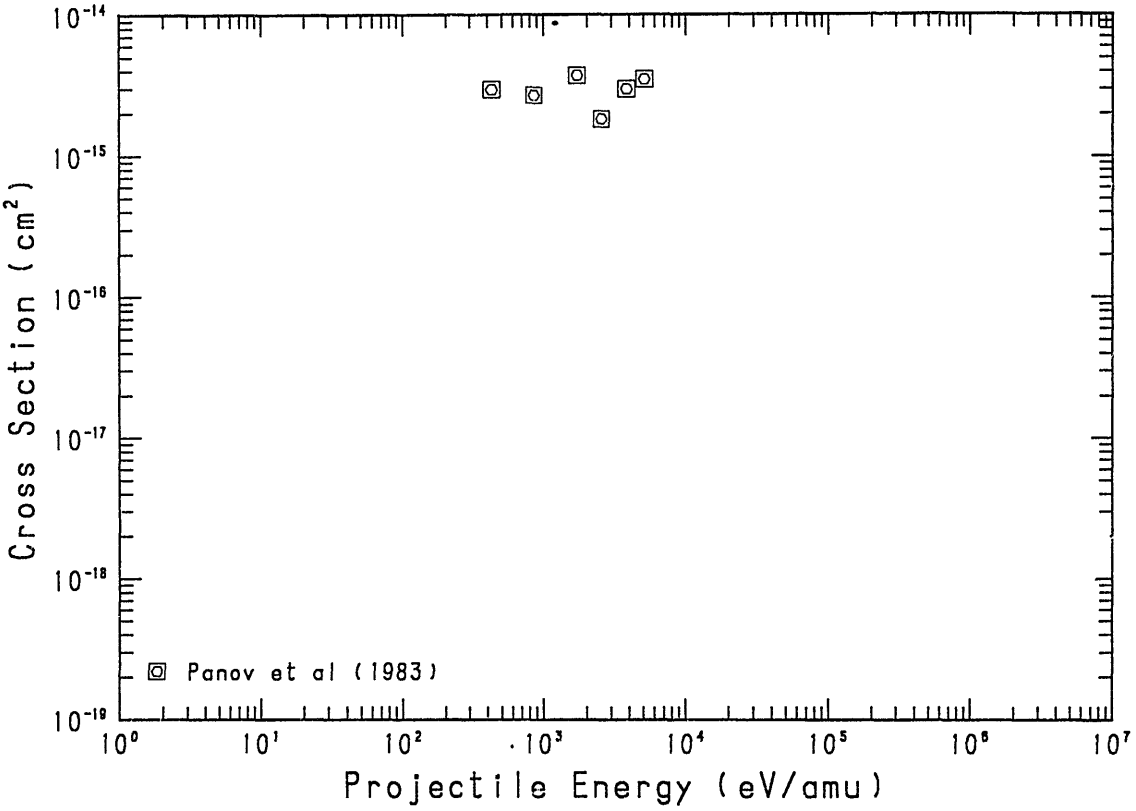


Fig.27 $N^{7+} + H \rightarrow N^{6+}$

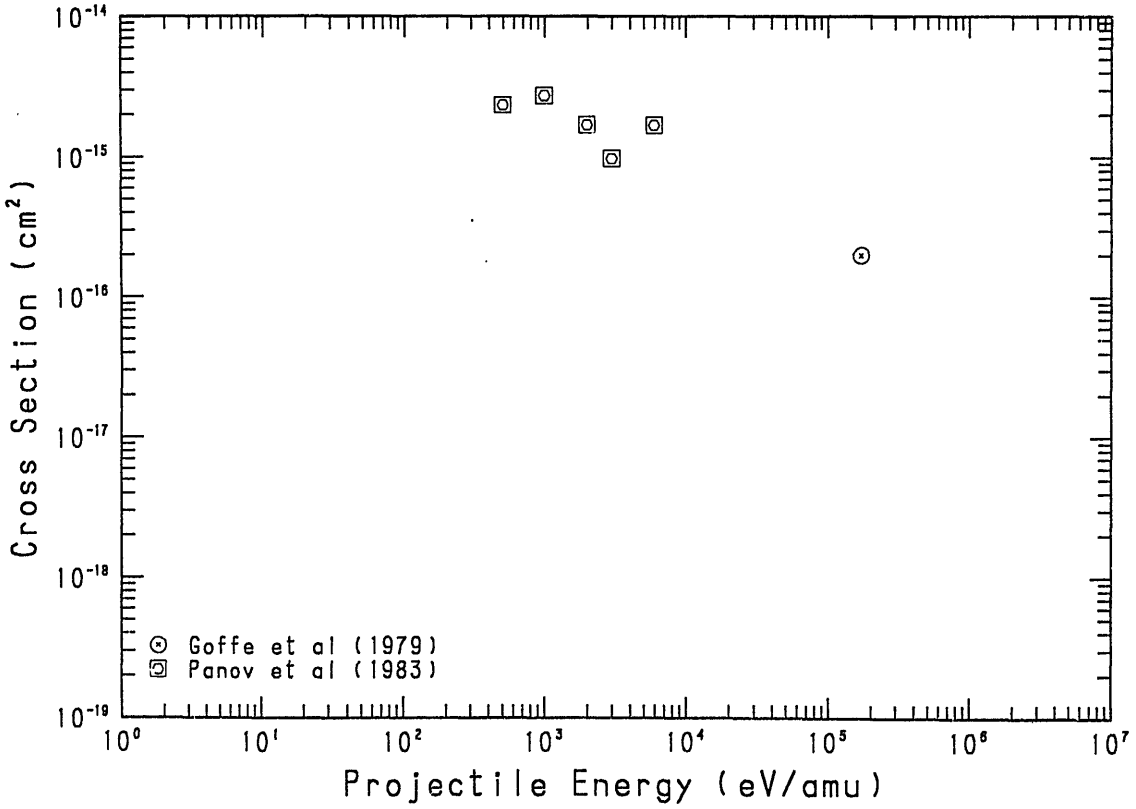


Fig.28 $O^+ + H \rightarrow O$

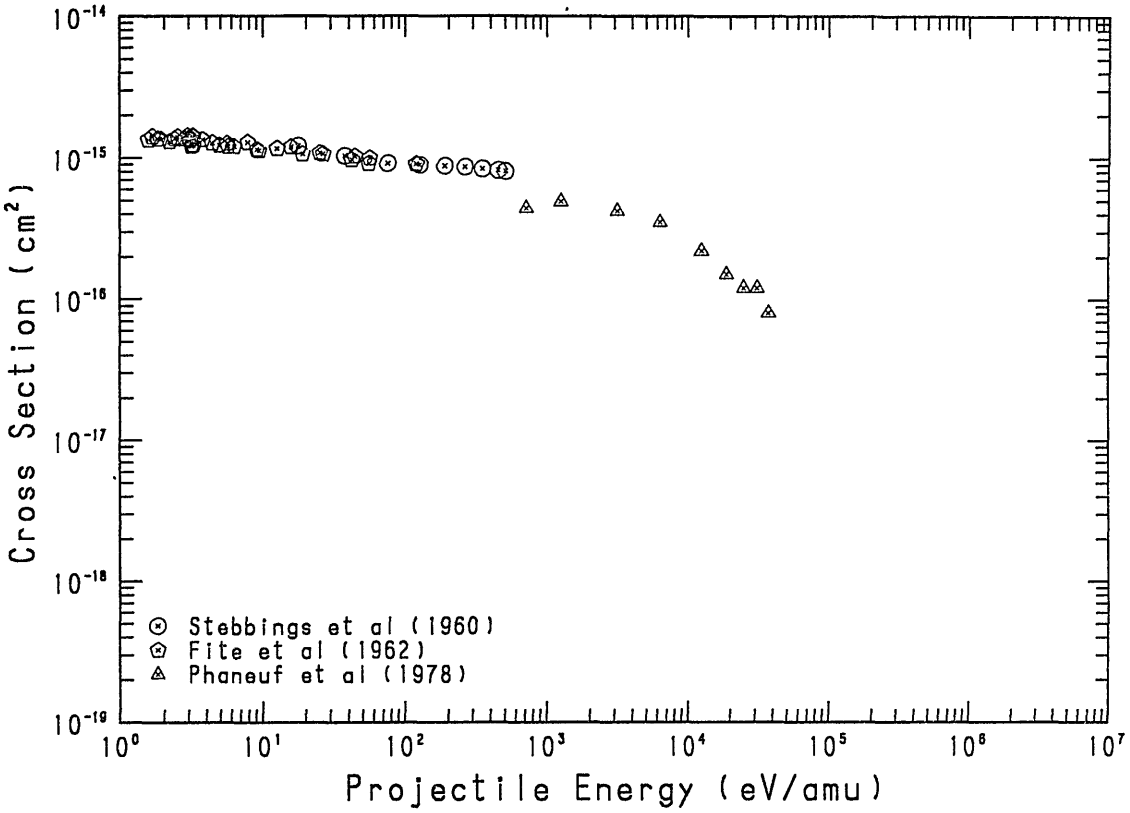


Fig.29 $O^{2+} + H \rightarrow O^+$

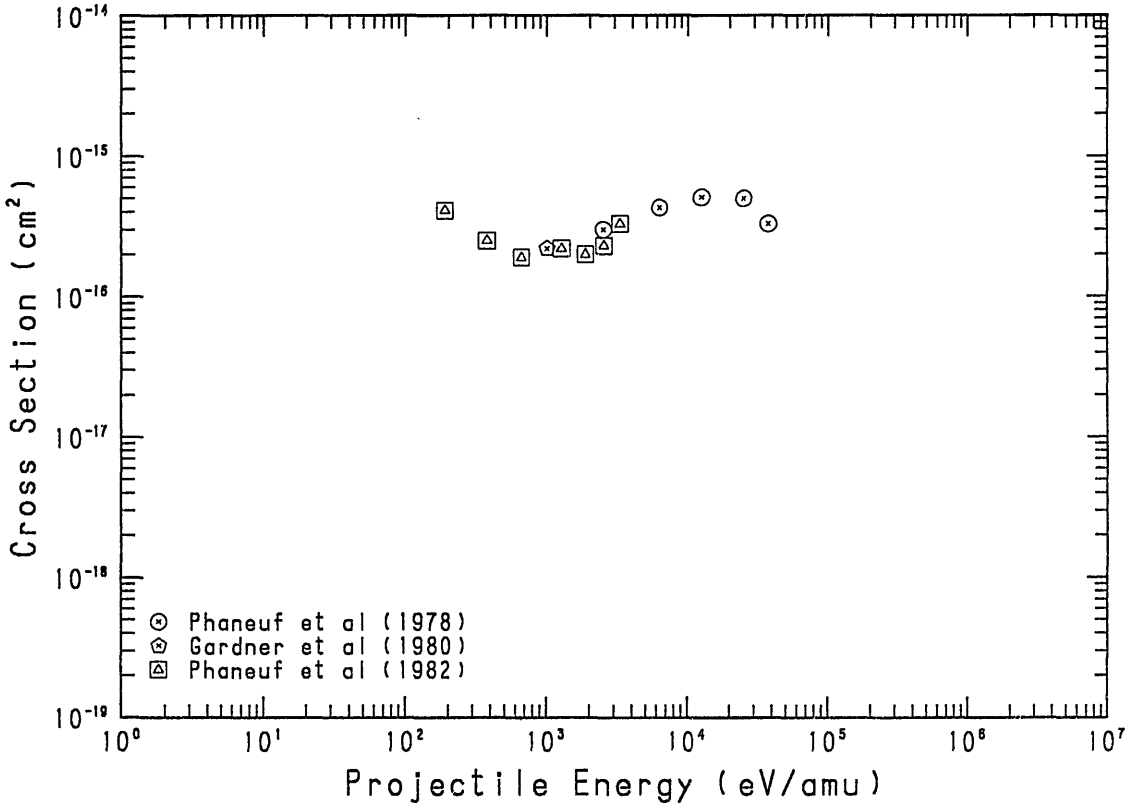


Fig.30 $O^{3+} + H \rightarrow O^{2+}$

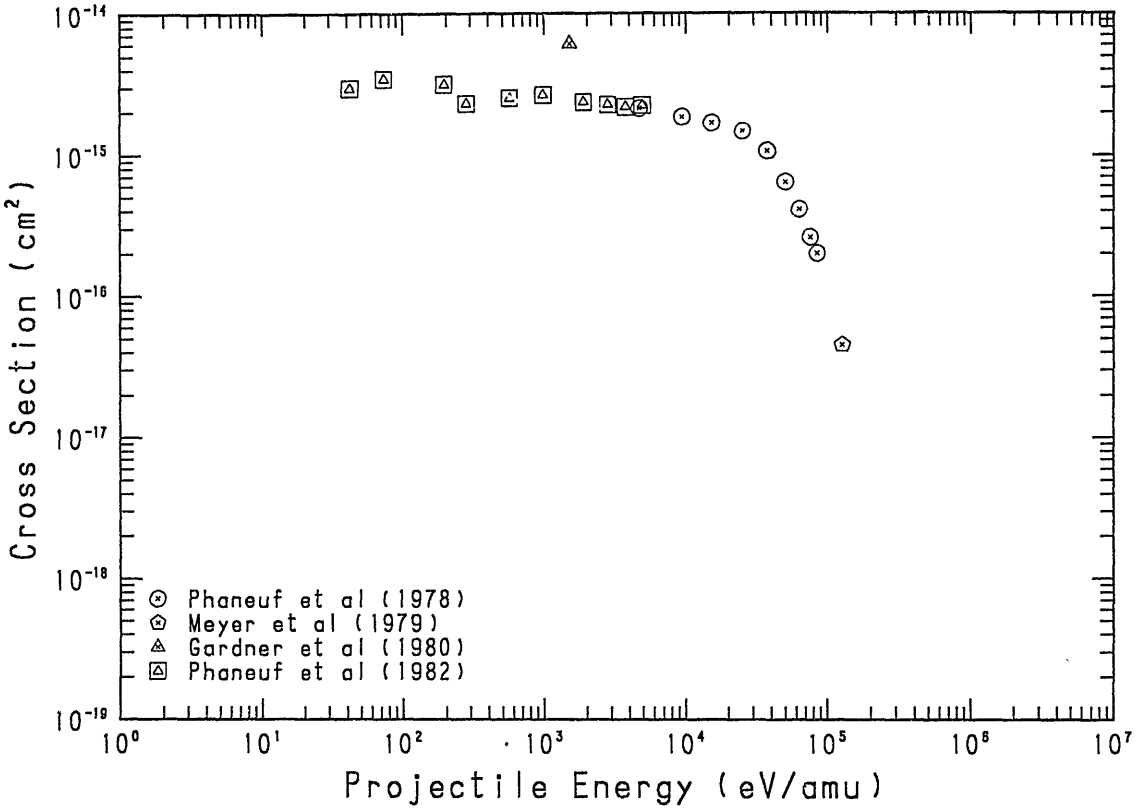


Fig.31 $O^{4+} + H \rightarrow O^{3+}$

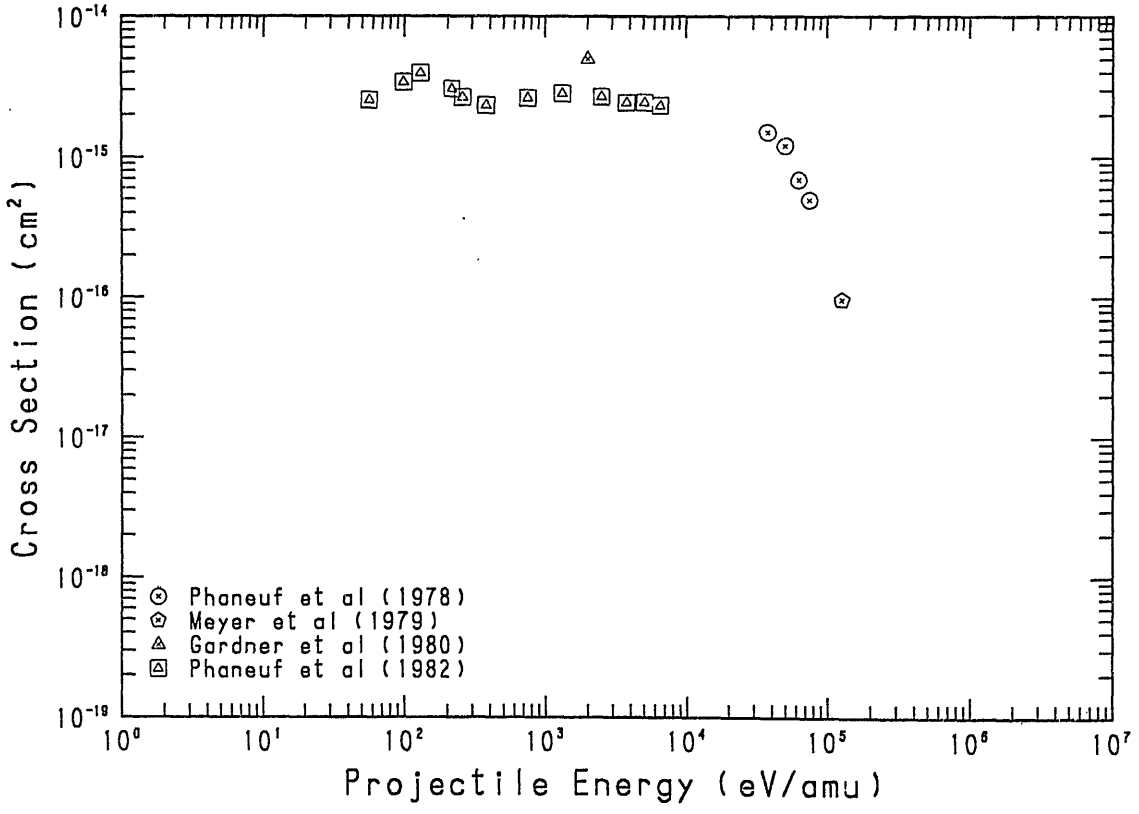


Fig.32 $O^{5+} + H \rightarrow O^{4+}$

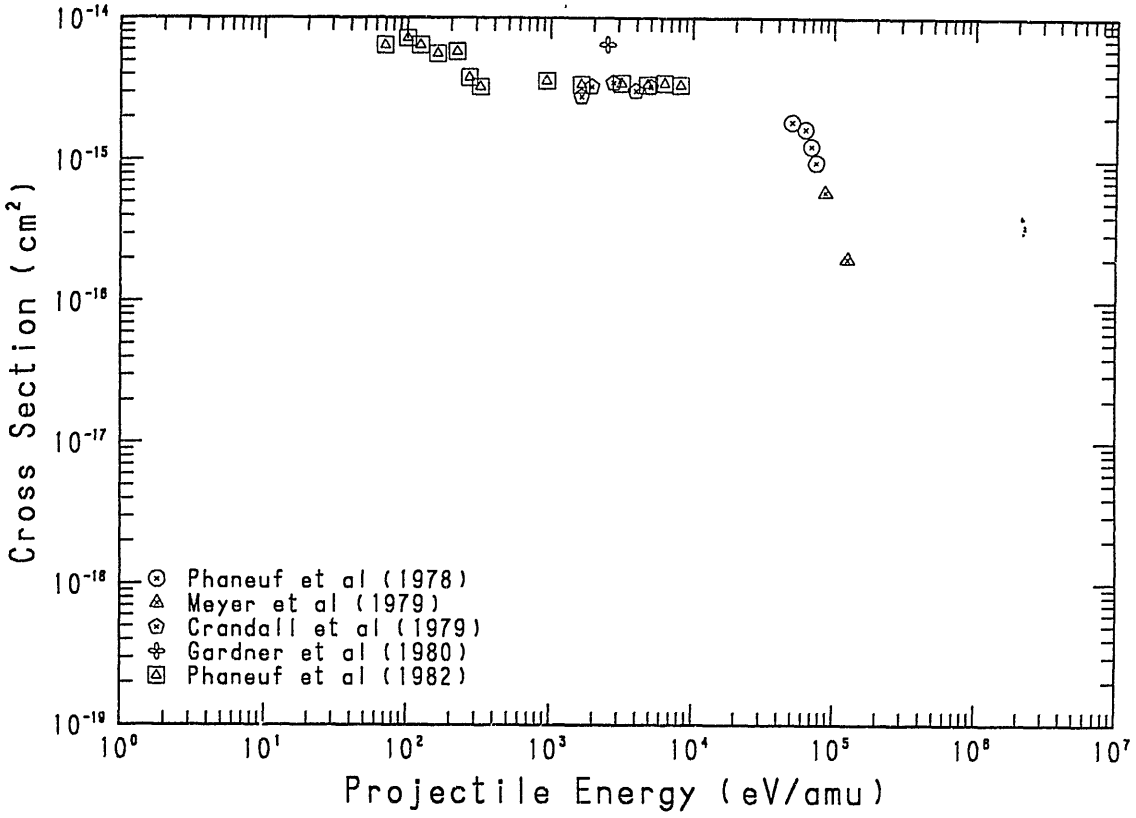


Fig.33 $O^{6+} + H \rightarrow O^{5+}$

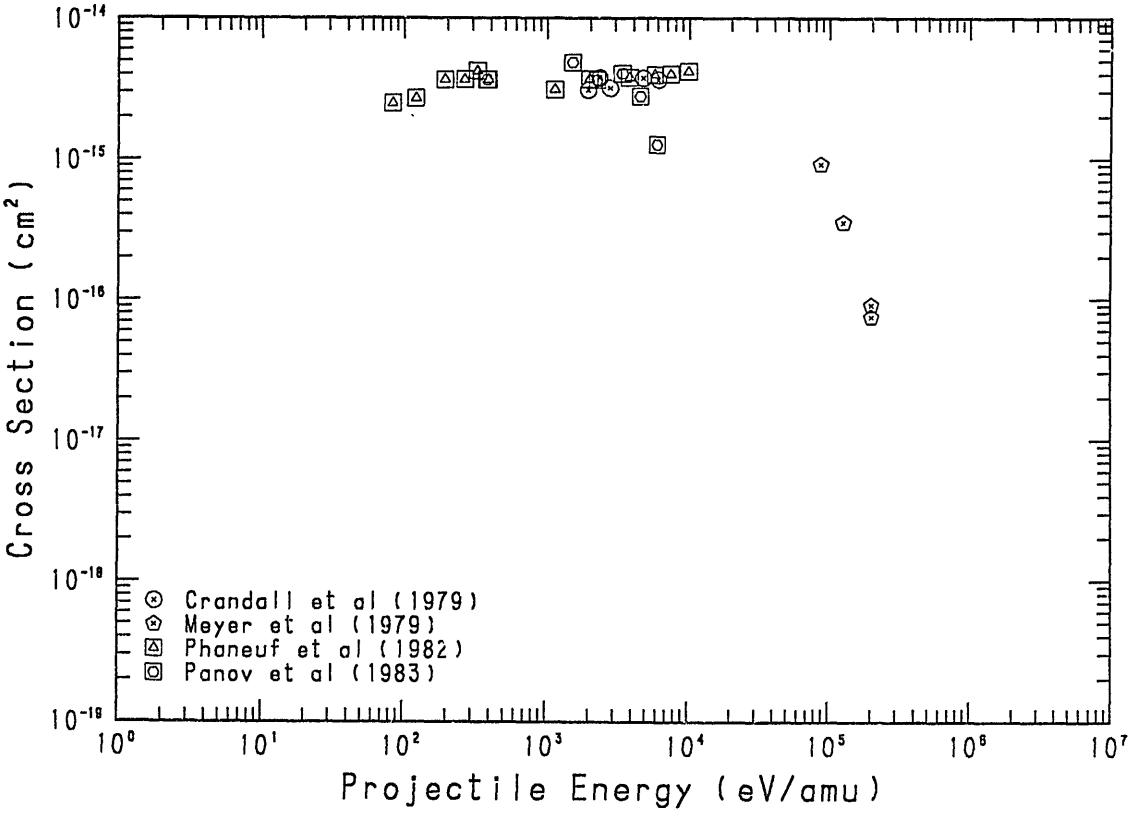


Fig.34 $O^{7+} + H \rightarrow O^{6+}$

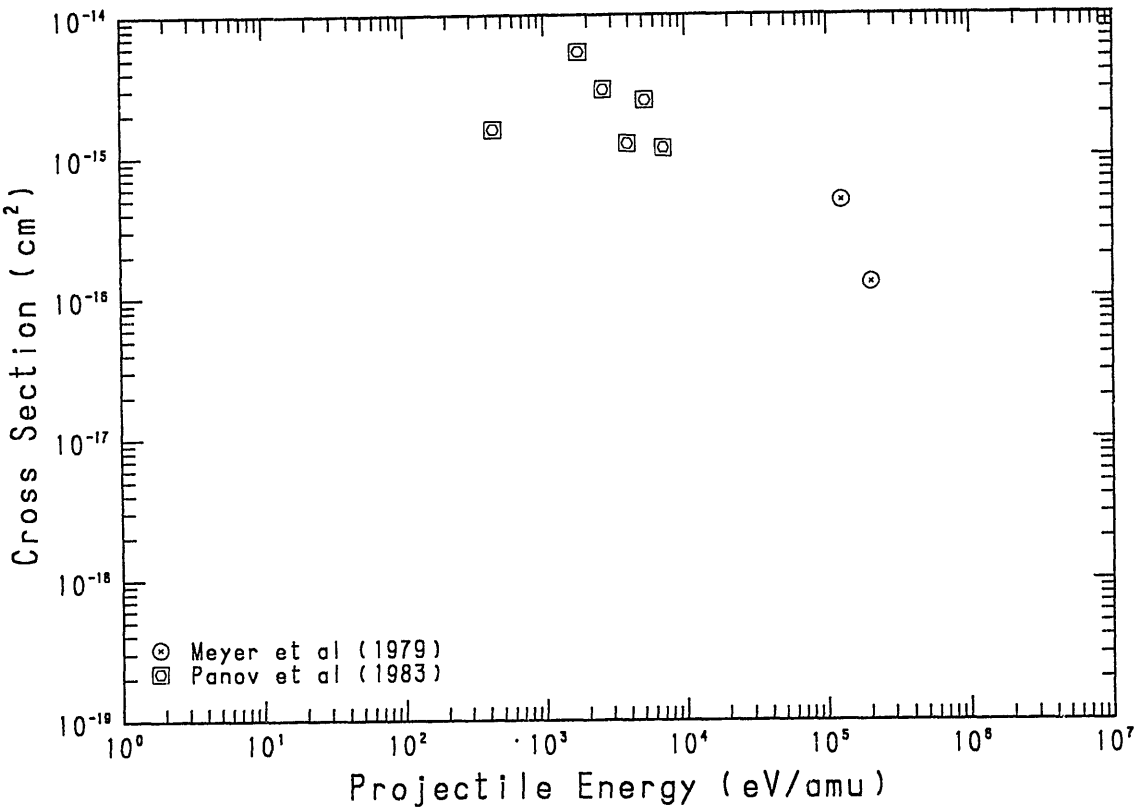


Fig.35 $O^{8+} + H \rightarrow O^{7+}$

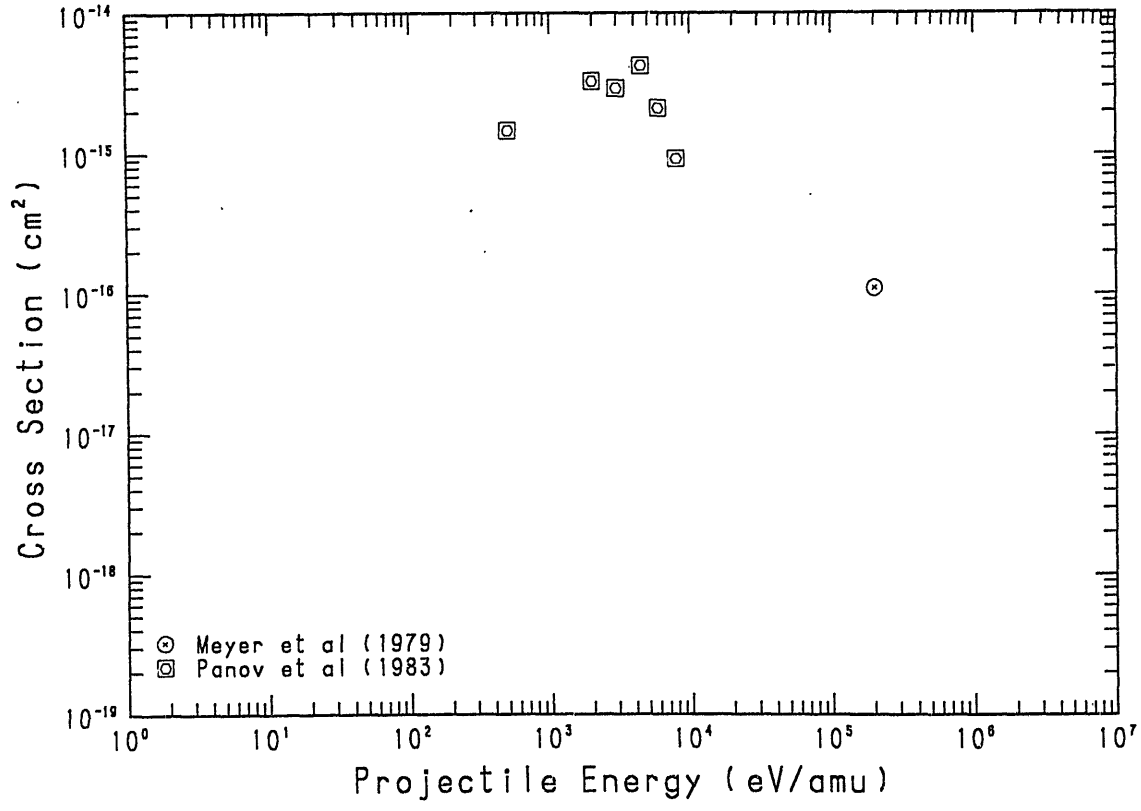


Fig.36 $Ne^{2+} + H \rightarrow Ne^{+}$

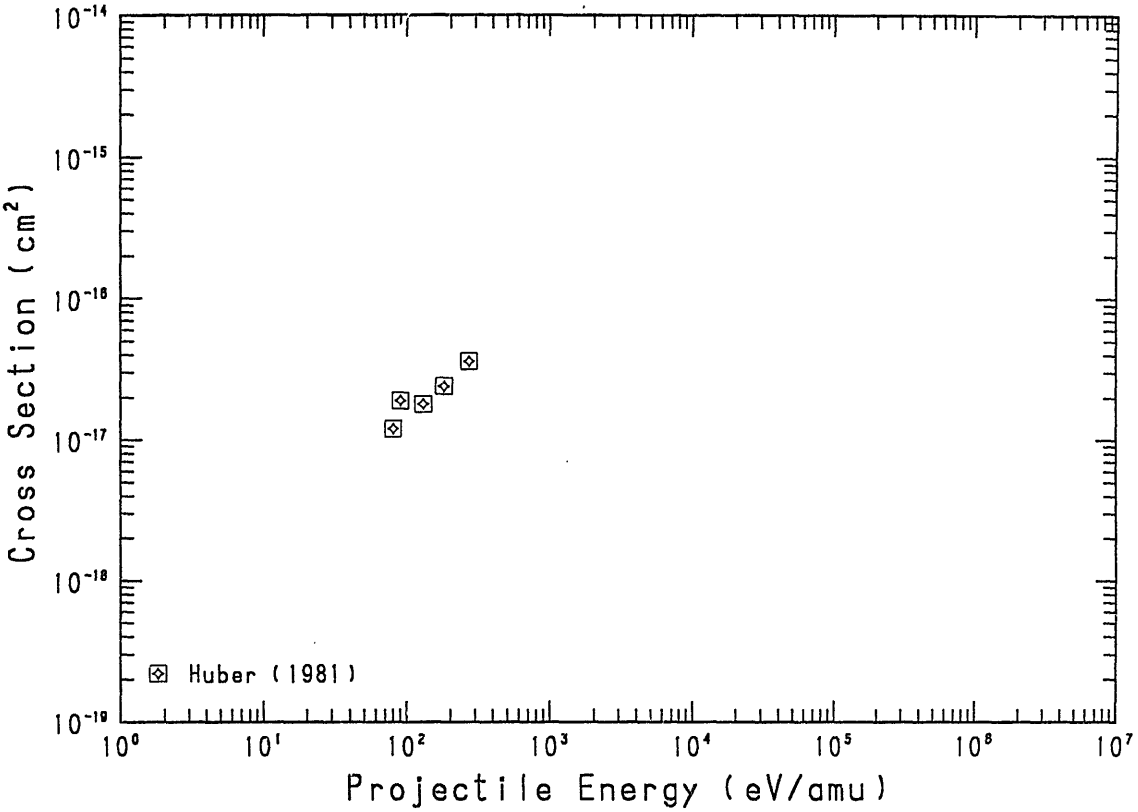


Fig.37 $Ne^{3+} + H \rightarrow Ne^{2+}$

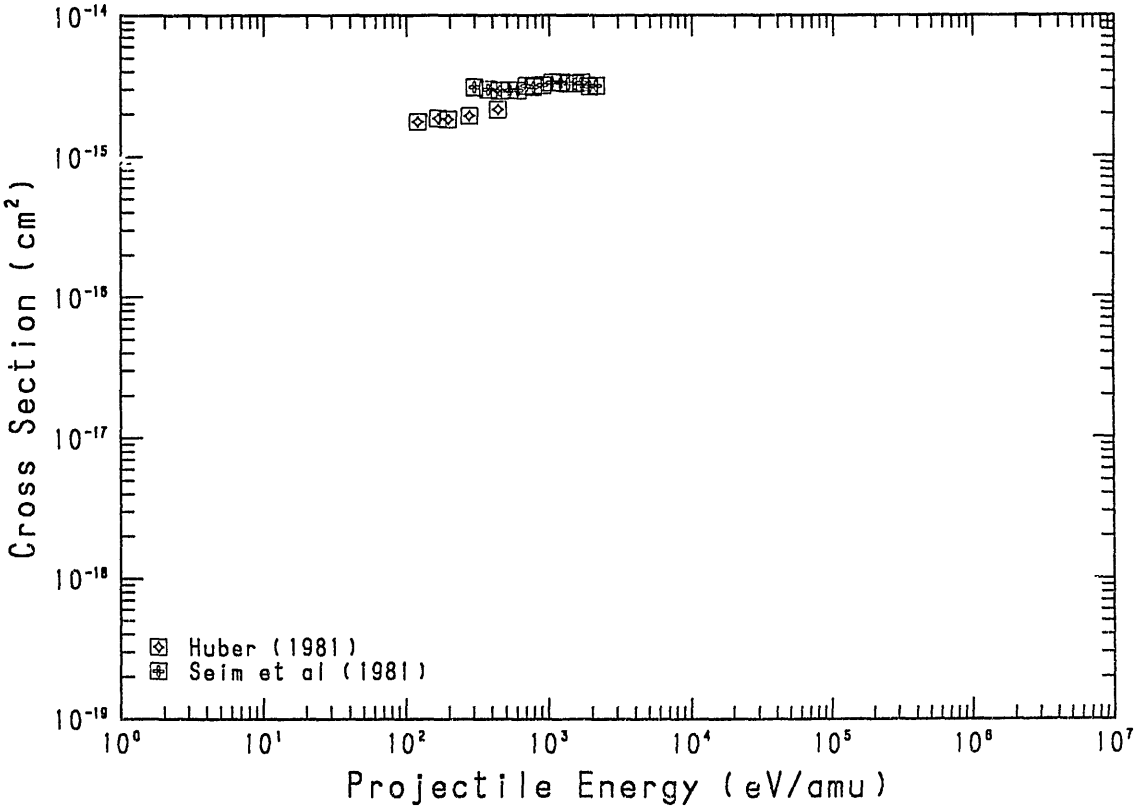


Fig.38 $Ne^{4+} + H \rightarrow Ne^{3+}$

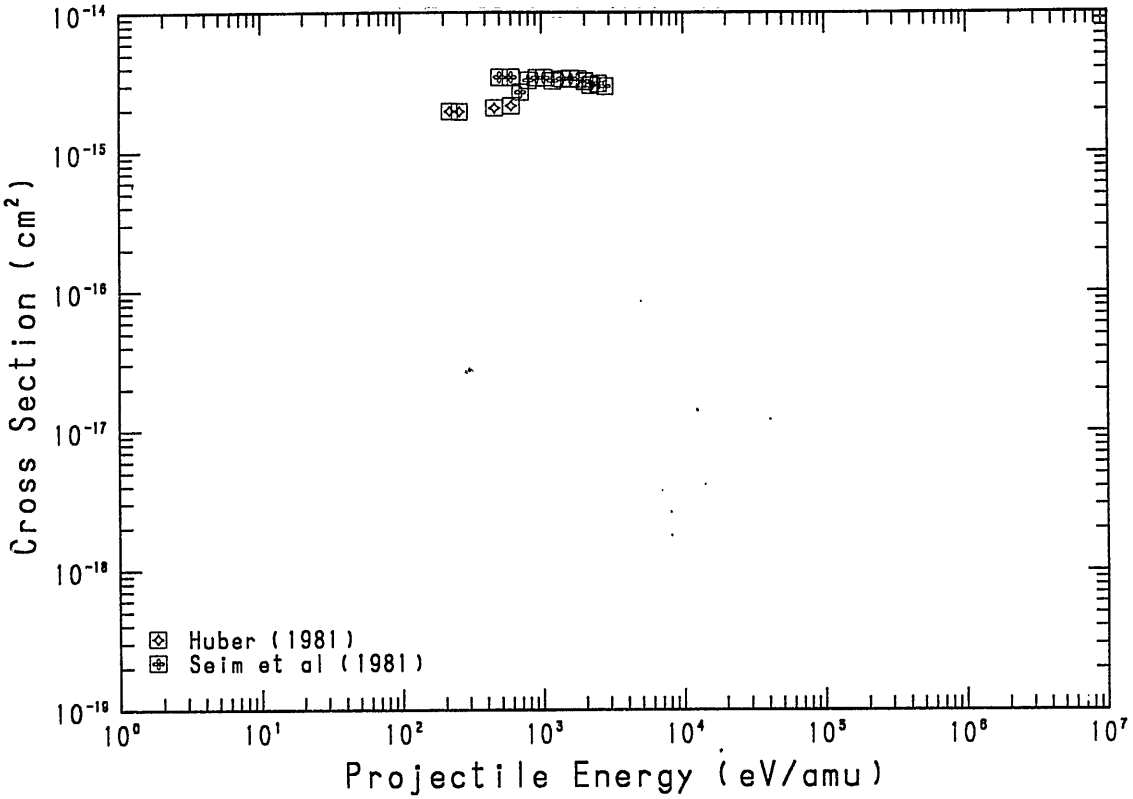


Fig.39 $Ne^{5+} + H \rightarrow Ne^{4+}$

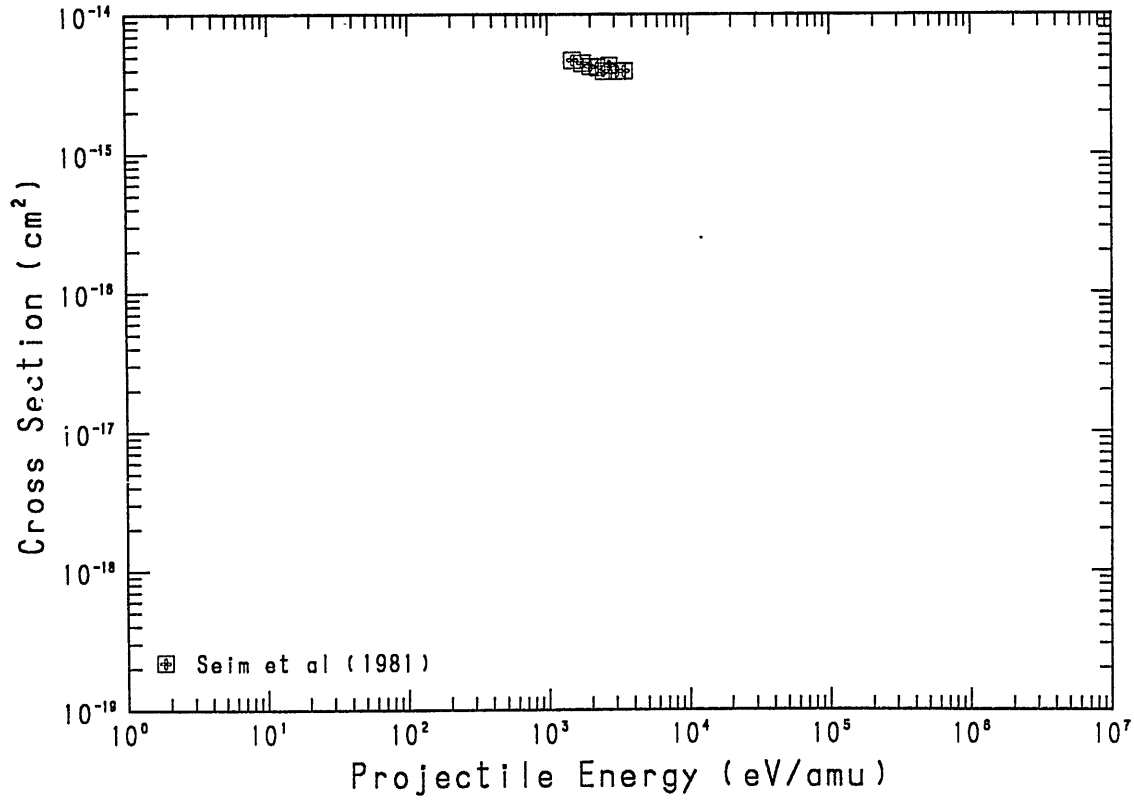


Fig.40 $Ne^{8+} + H \rightarrow Ne^{7+}$

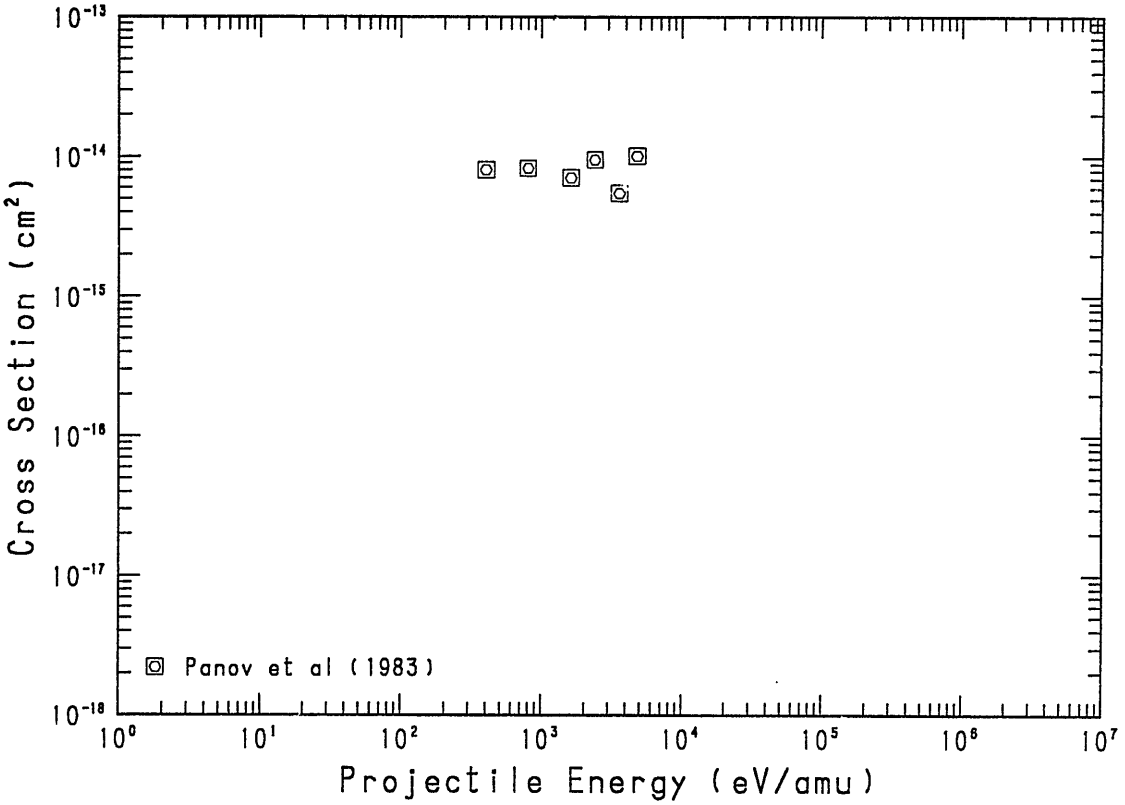


Fig.41 $Ne^{9+} + H \rightarrow Ne^{8+}$

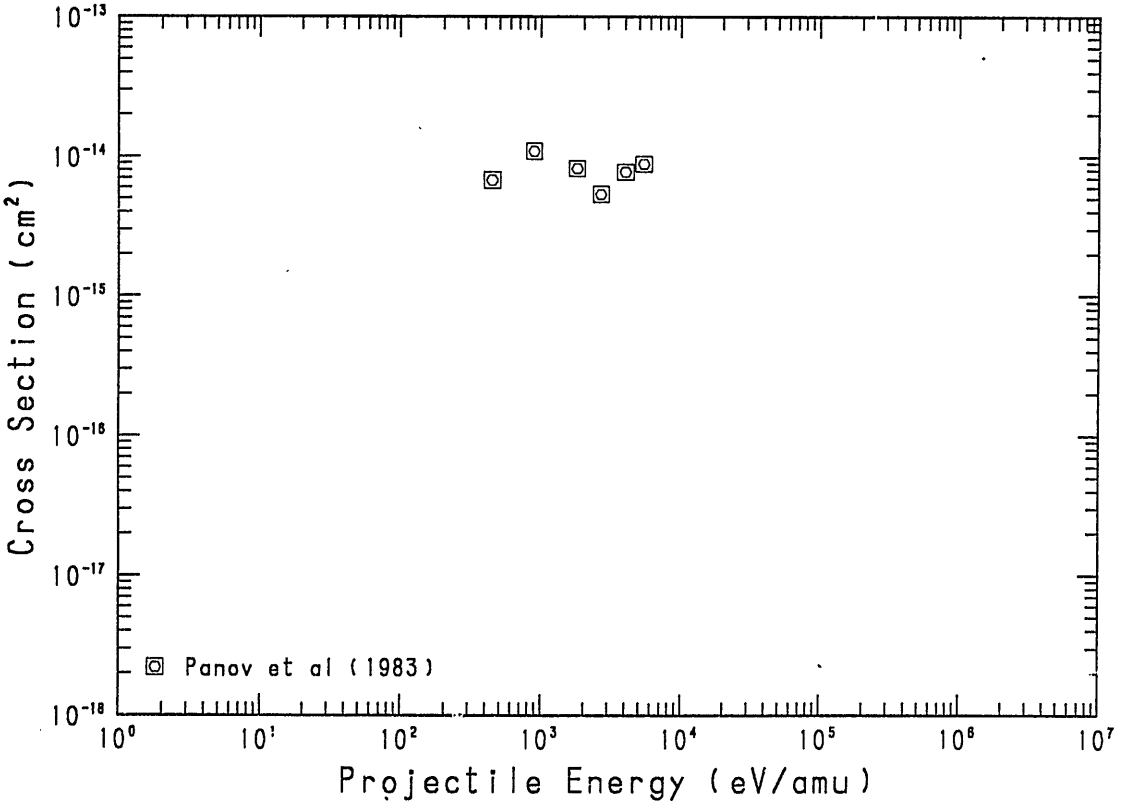


Fig.42 $Ne^{10+} + H \rightarrow Ne^{9+}$

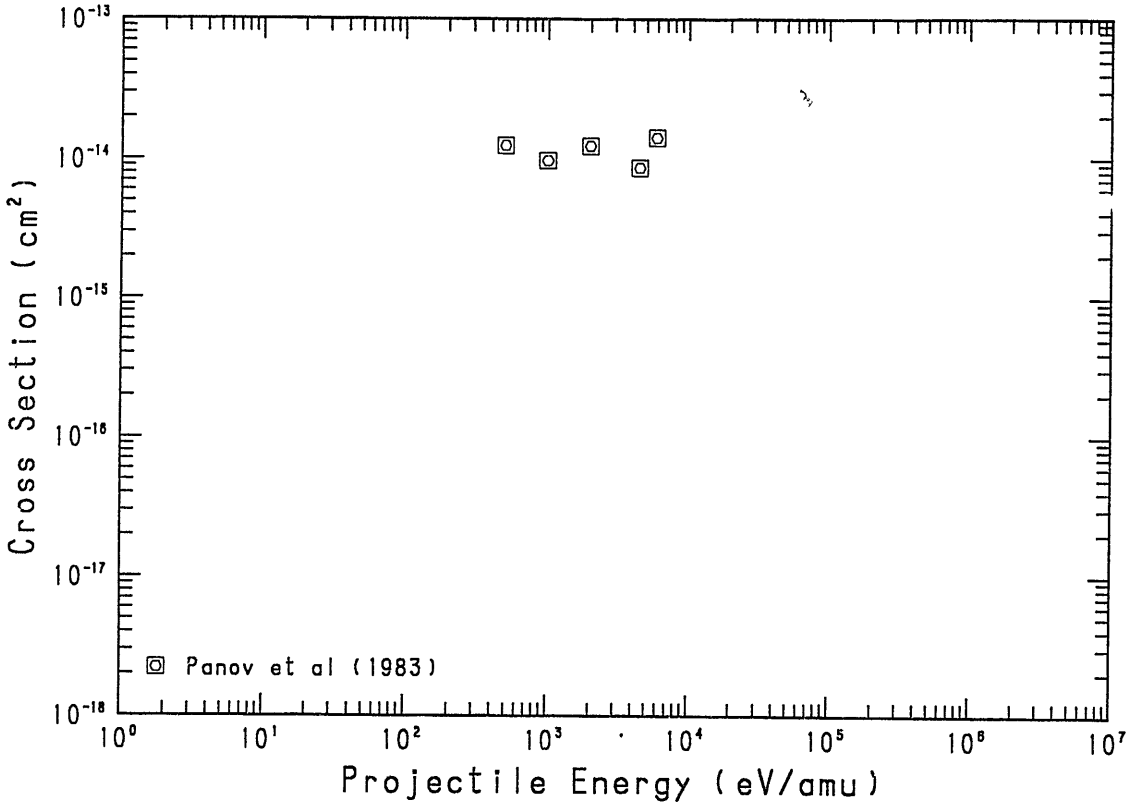


Fig.43 $Na^{2+} + H \rightarrow Na^{+}$

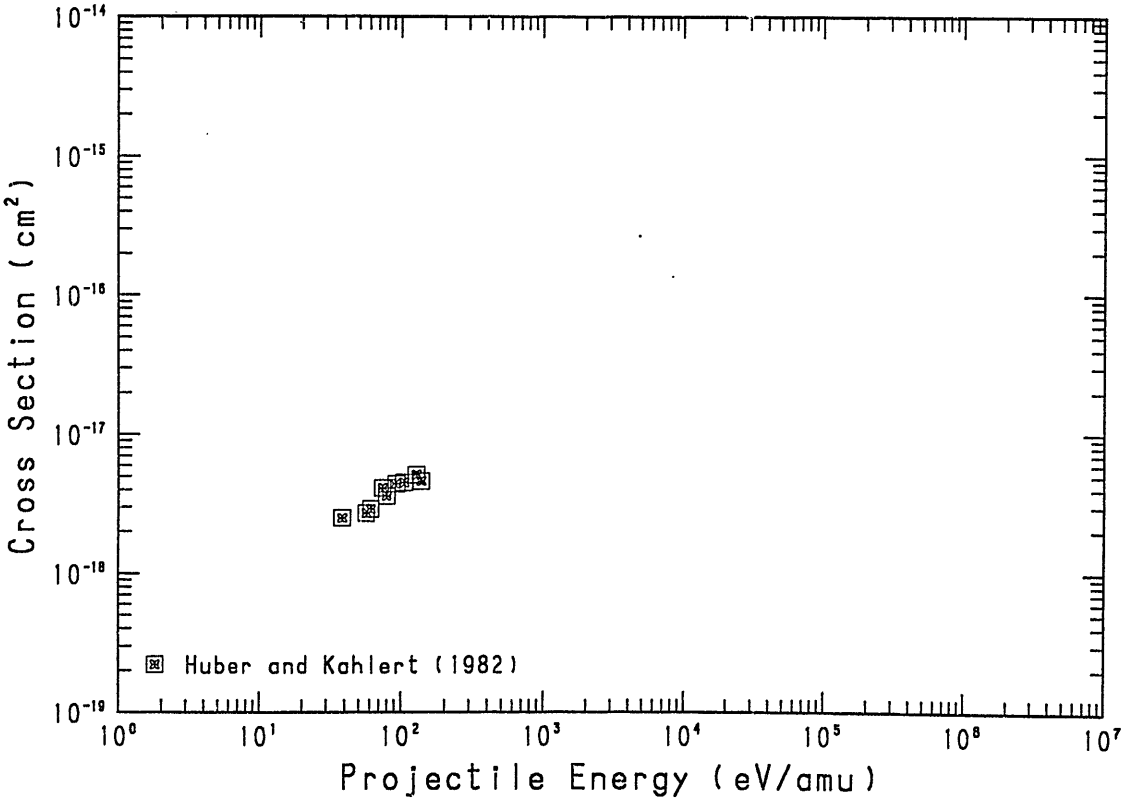


Fig.44 $Na^{3+} + H \rightarrow Na^{2+}$

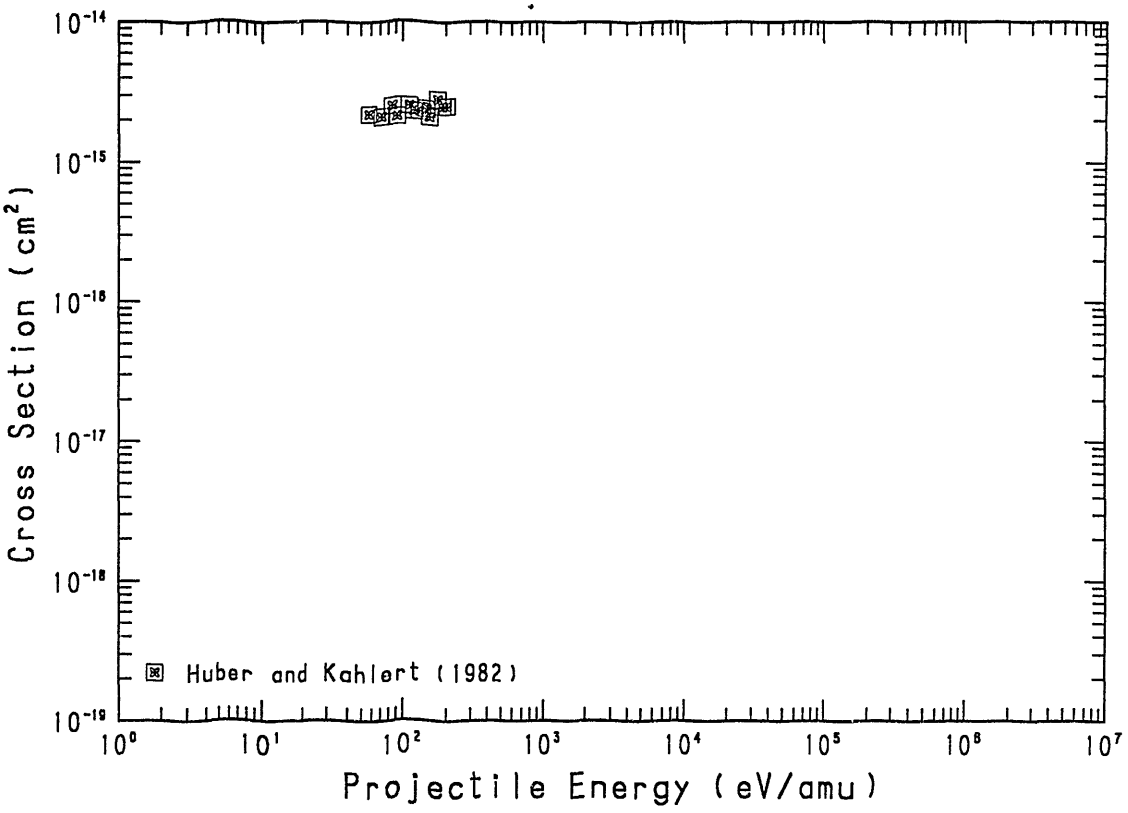


Fig.45 $Na^{4+} + H \rightarrow Na^{3+}$

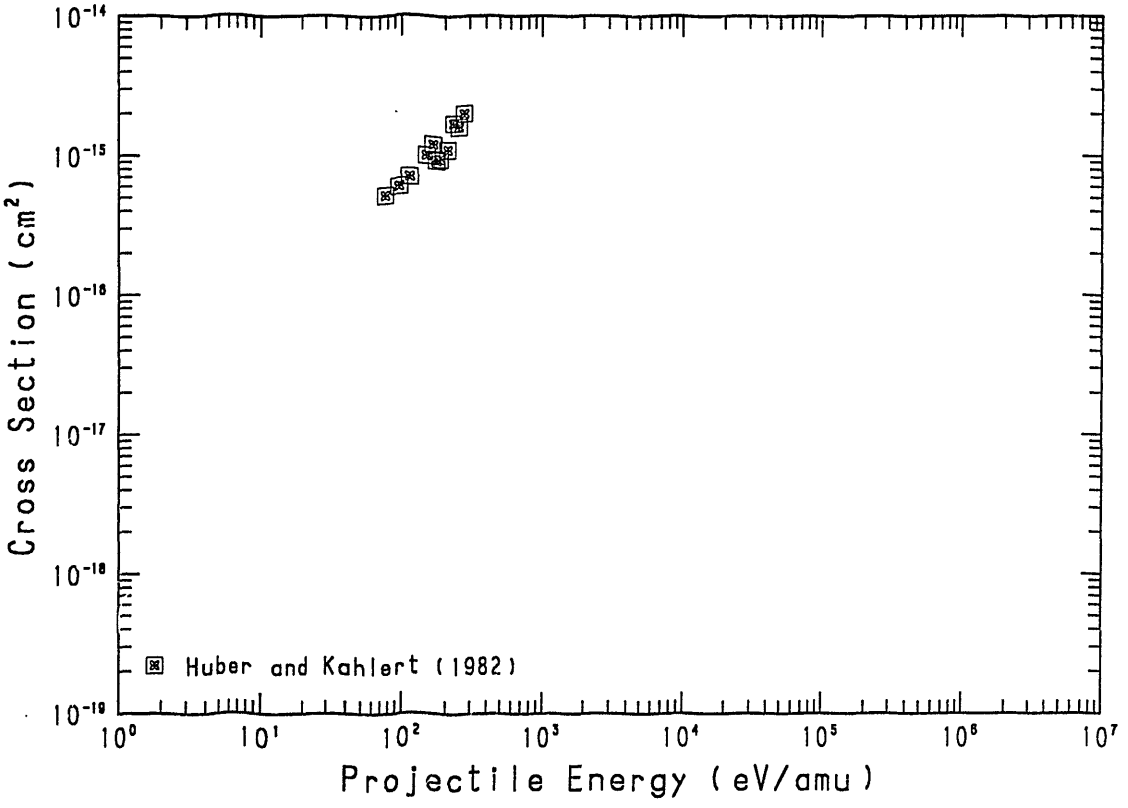


Fig.46 $Mg^{2+} + H \rightarrow Mg^{+}$

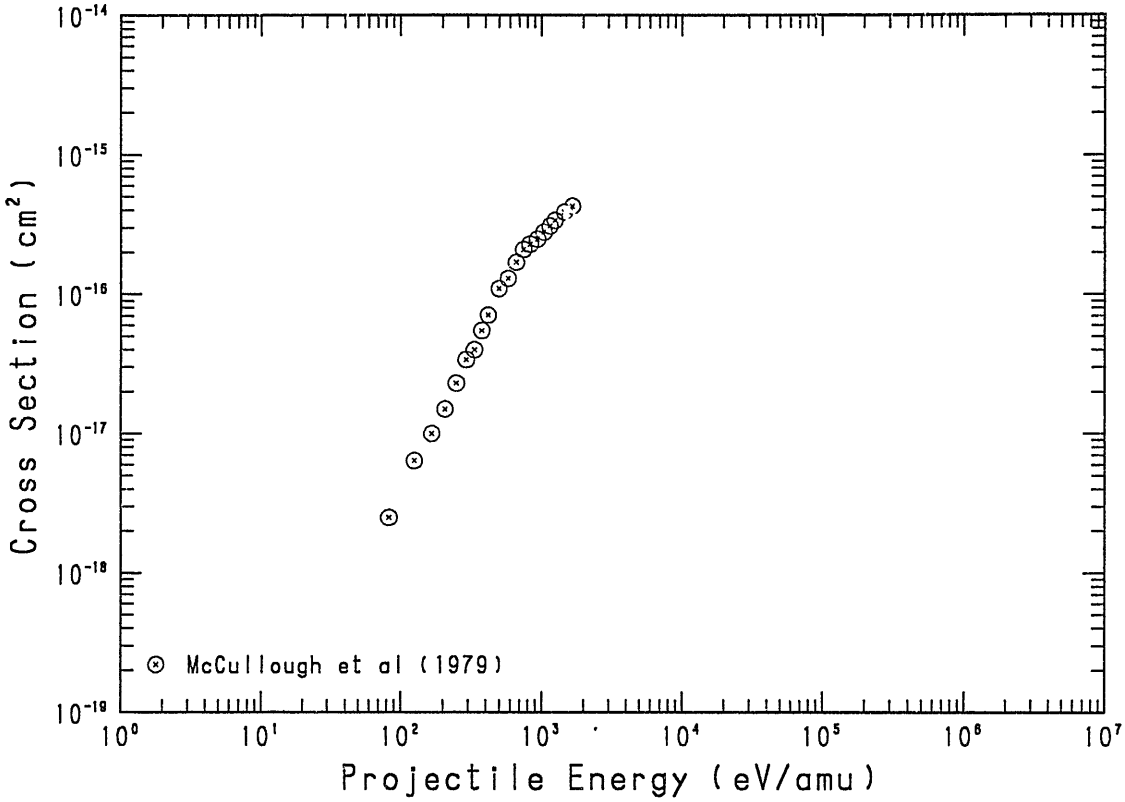


Fig.47 $Si^{2+} + H \rightarrow Si^{+}$

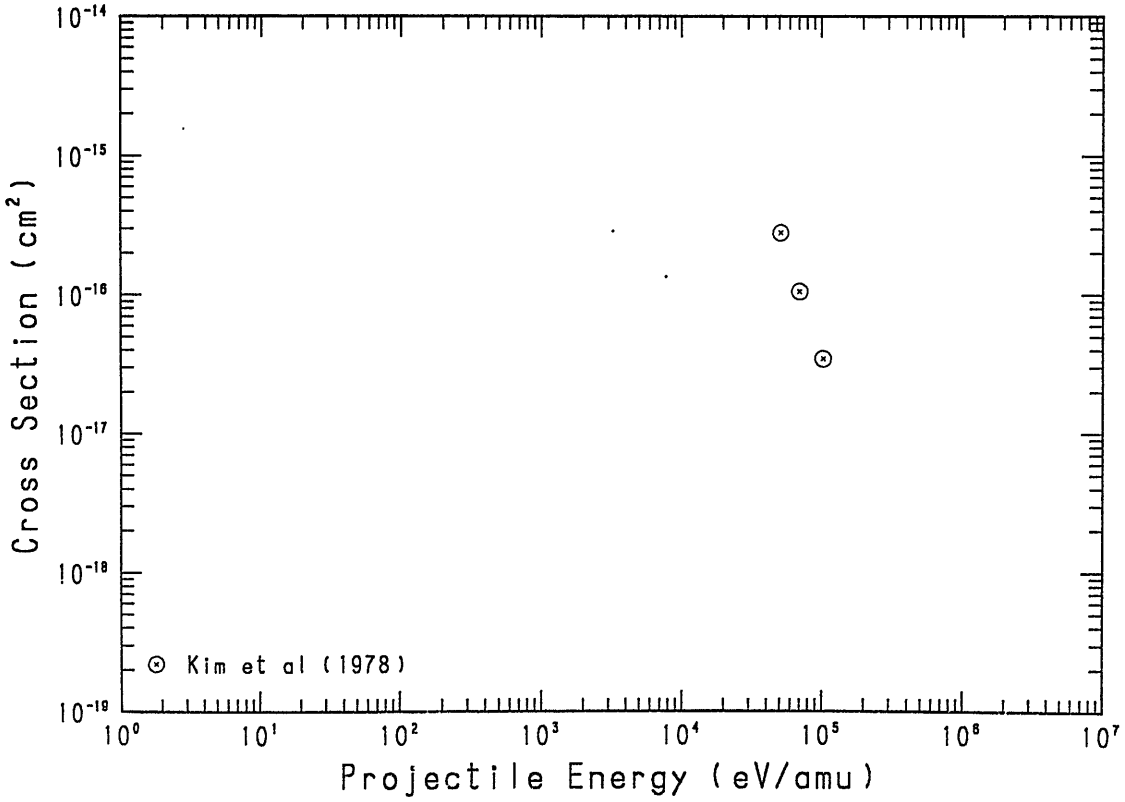


Fig.48 $Si^{3+} + H \rightarrow Si^{2+}$

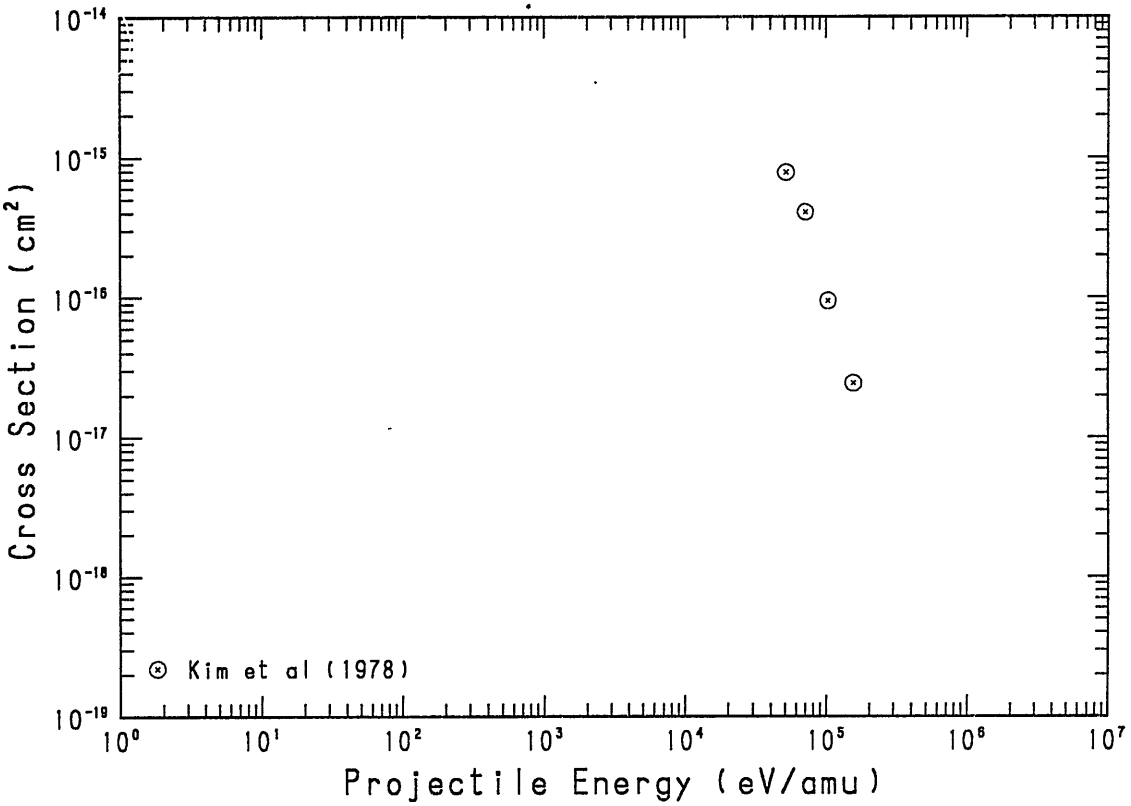


Fig.49 $Si^{4+} + H \rightarrow Si^{3+}$

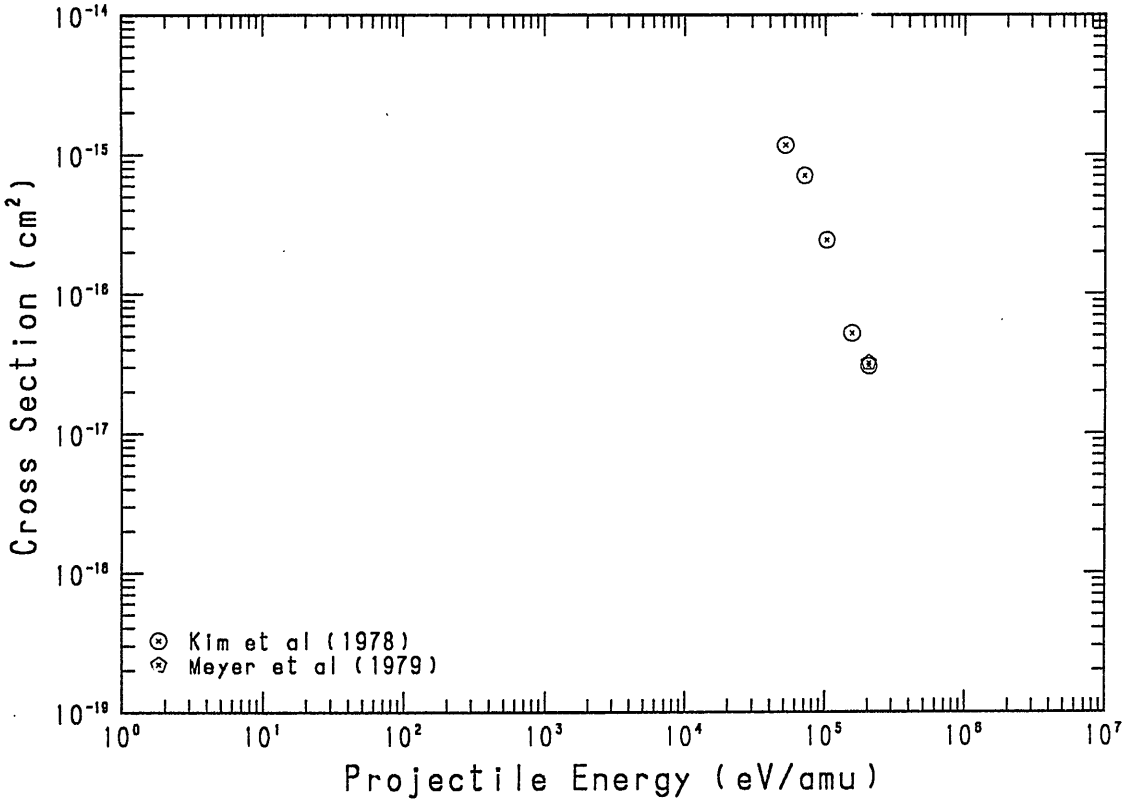


Fig.50 $Si^{5+} + H \rightarrow Si^{4+}$

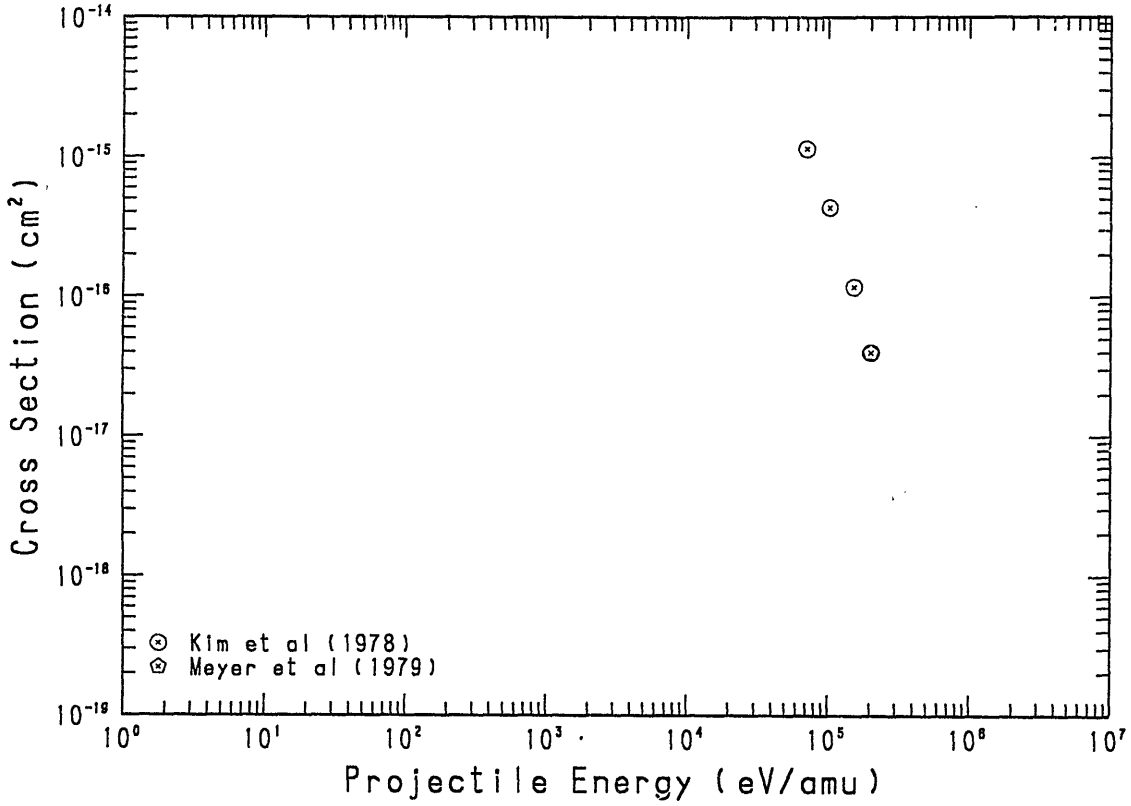


Fig.51 $Si^{6+} + H \rightarrow Si^{5+}$

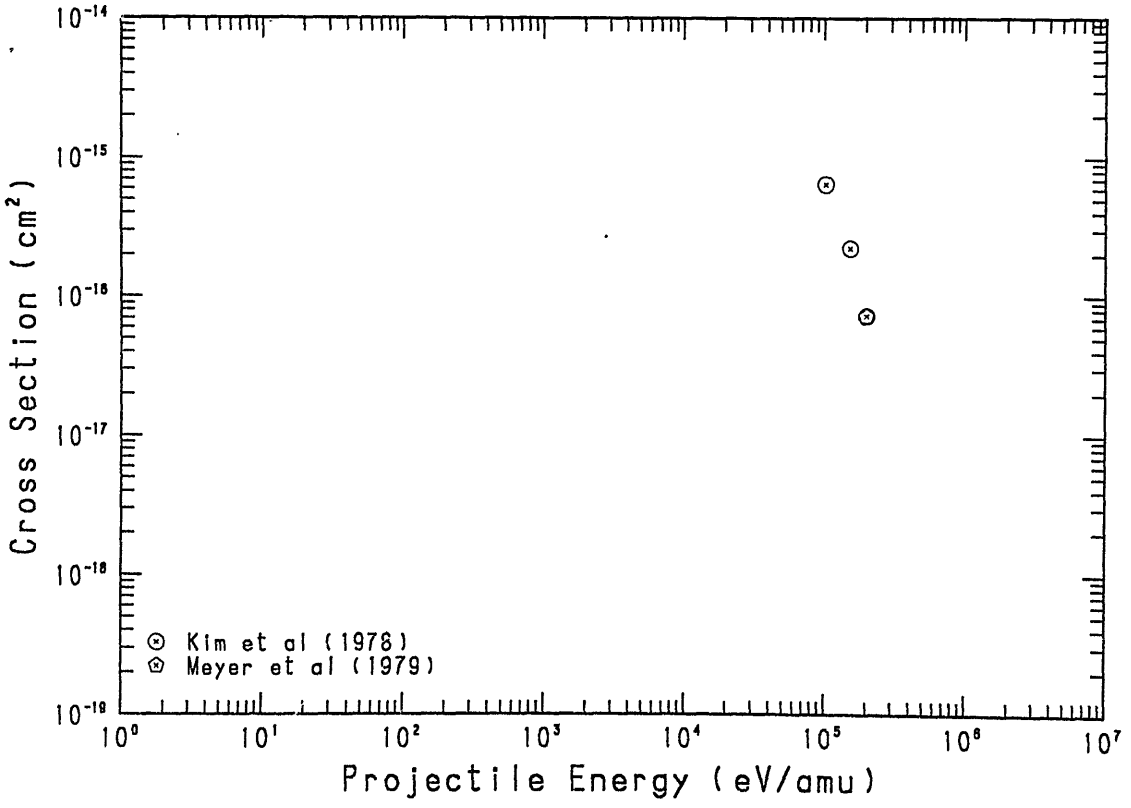


Fig.52 $Si^{7+} + H \rightarrow Si^{6+}$

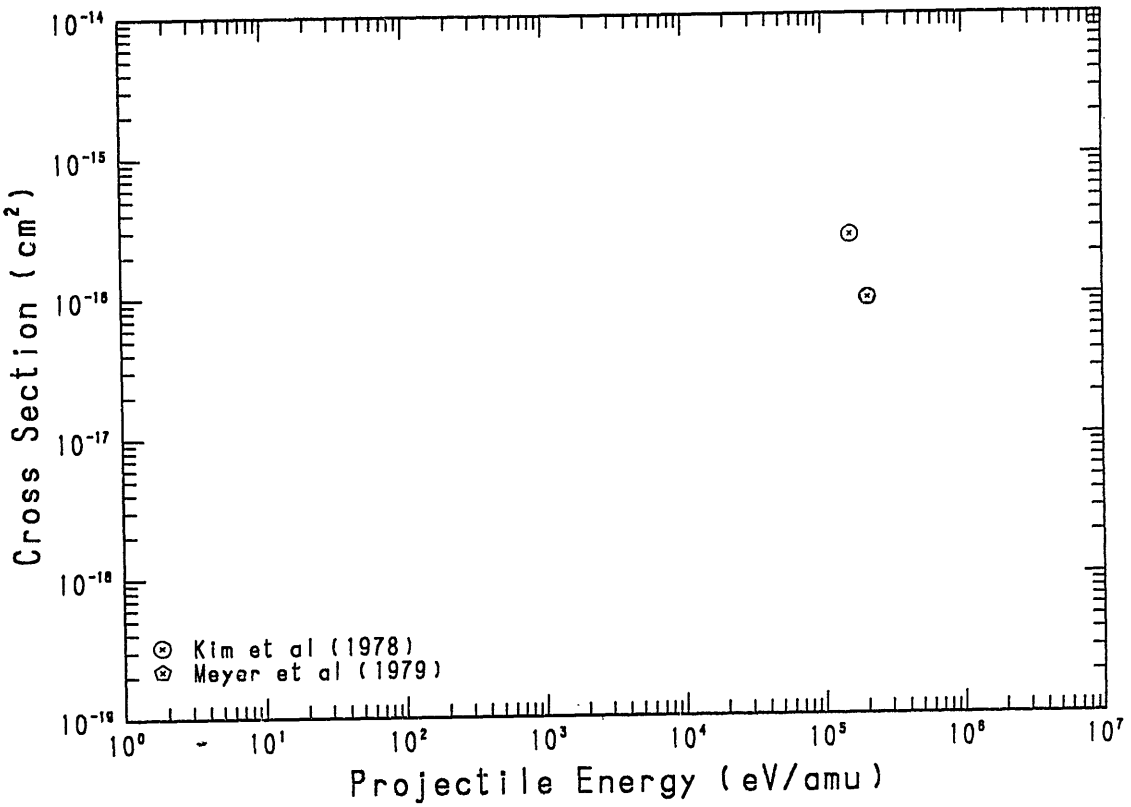


Fig.53 $Si^{8+} + H \rightarrow Si^{7+}$

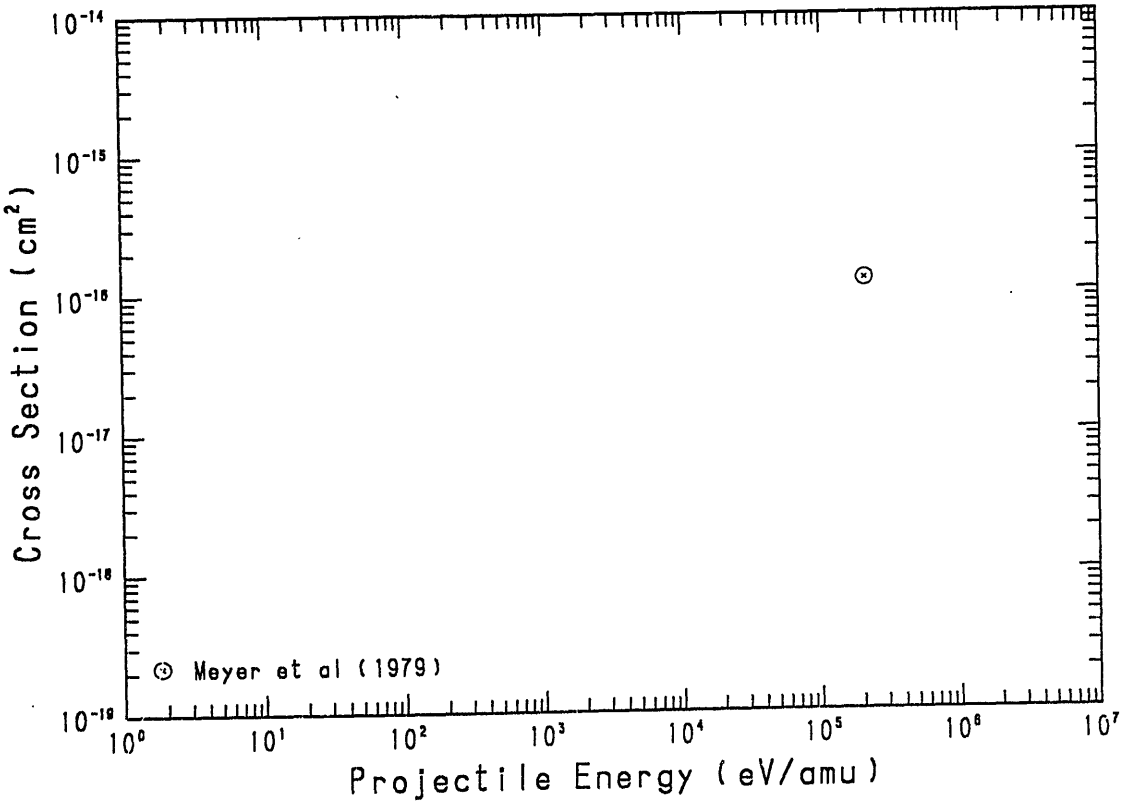


Fig.54 $Si^{9+} + H \rightarrow Si^{8+}$

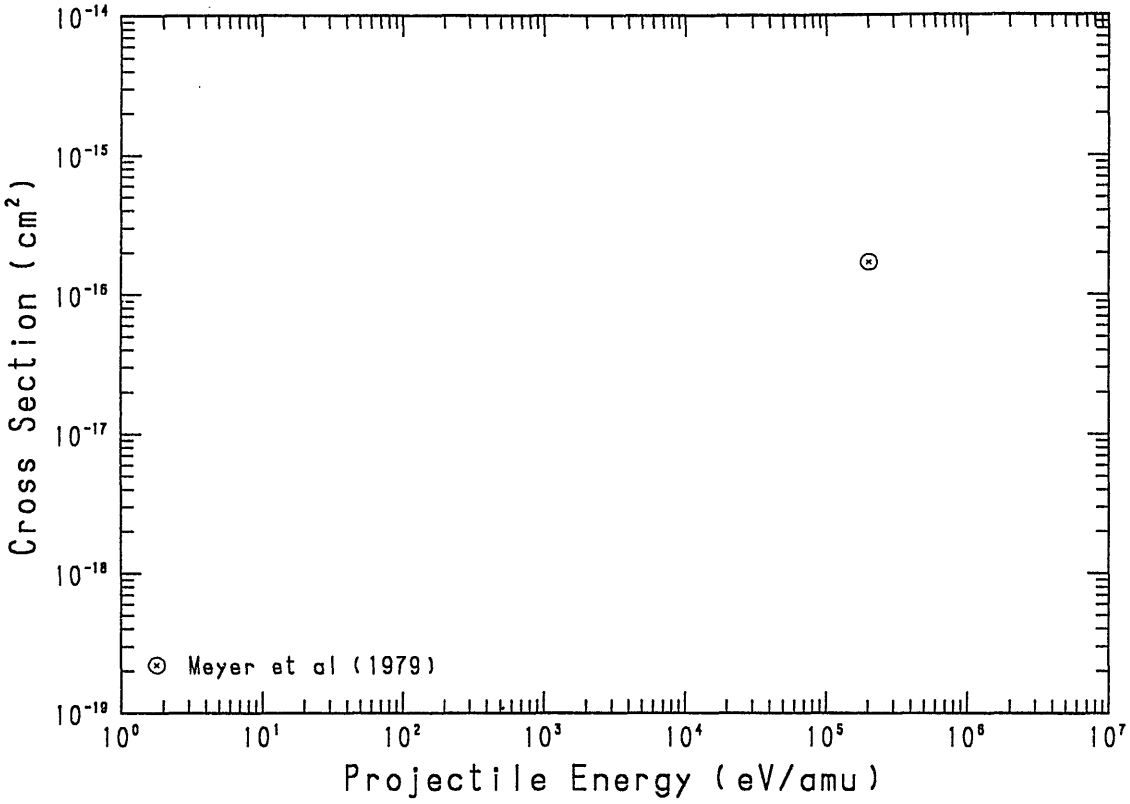


Fig.55 $Ar^{2+} + H \rightarrow Ar^{+}$

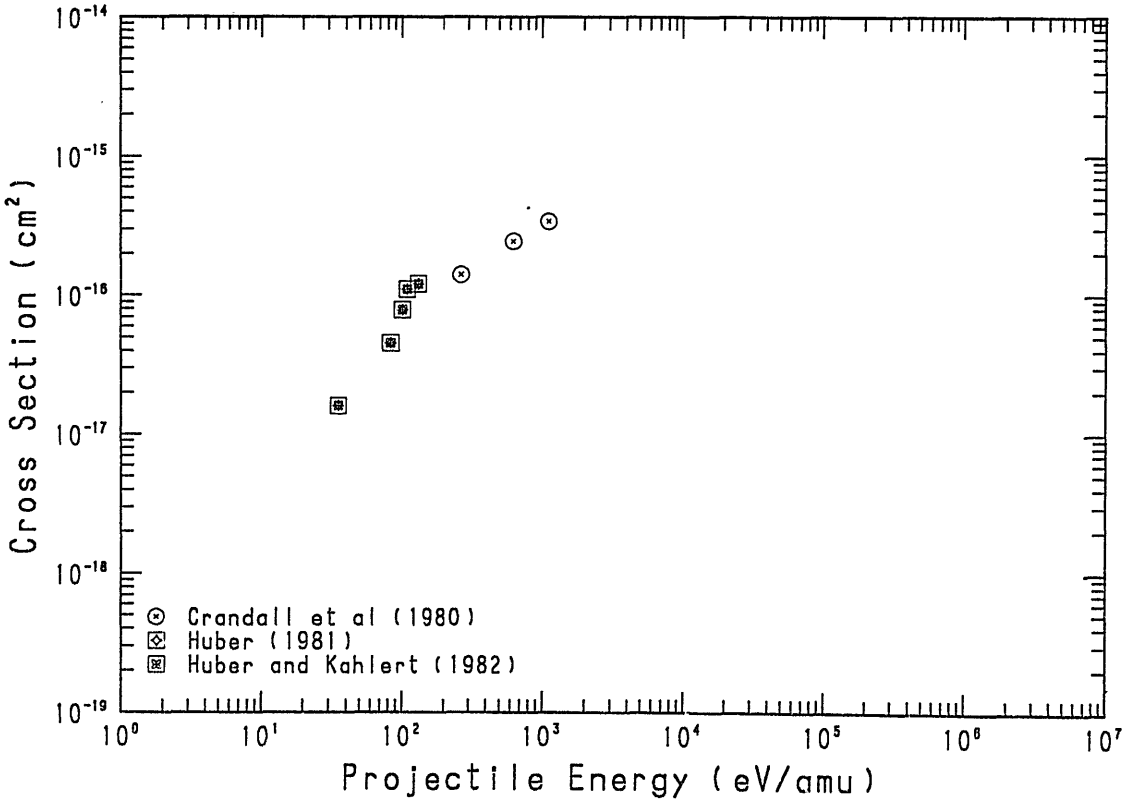


Fig.56 $Ar^{3+} + H \rightarrow Ar^{2+}$

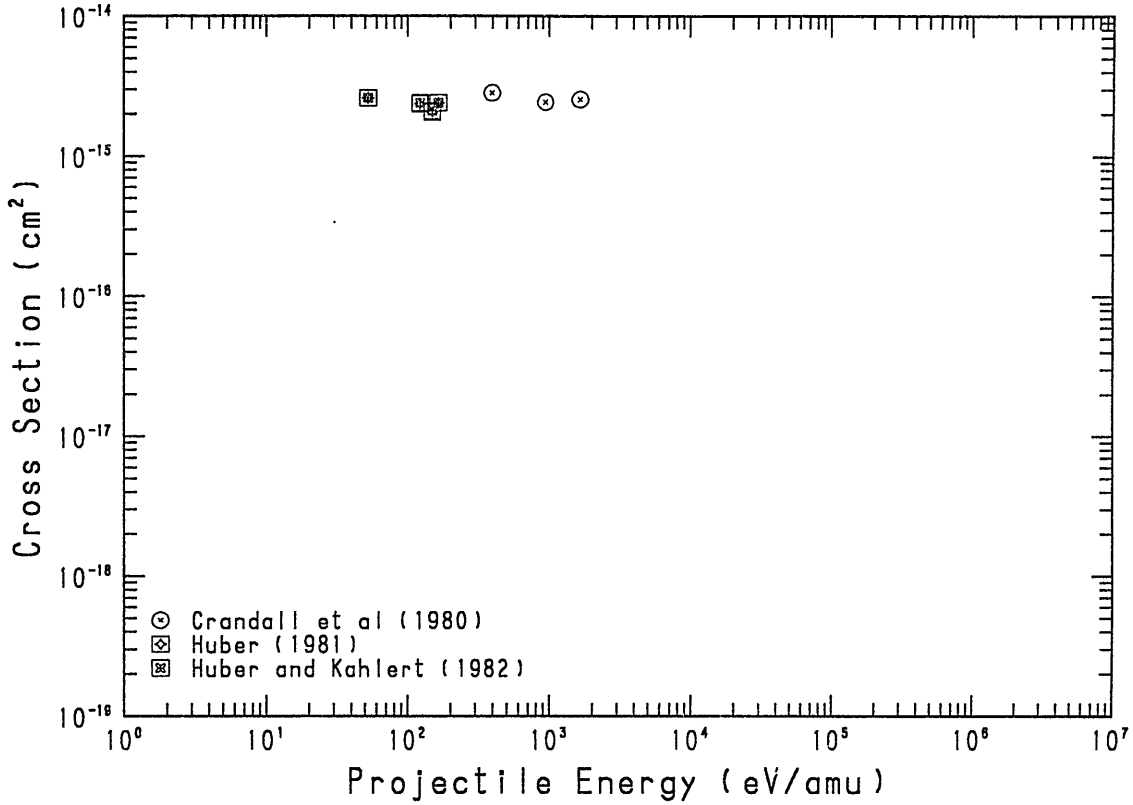


Fig.57 $Ar^{4+} + H \rightarrow Ar^{3+}$

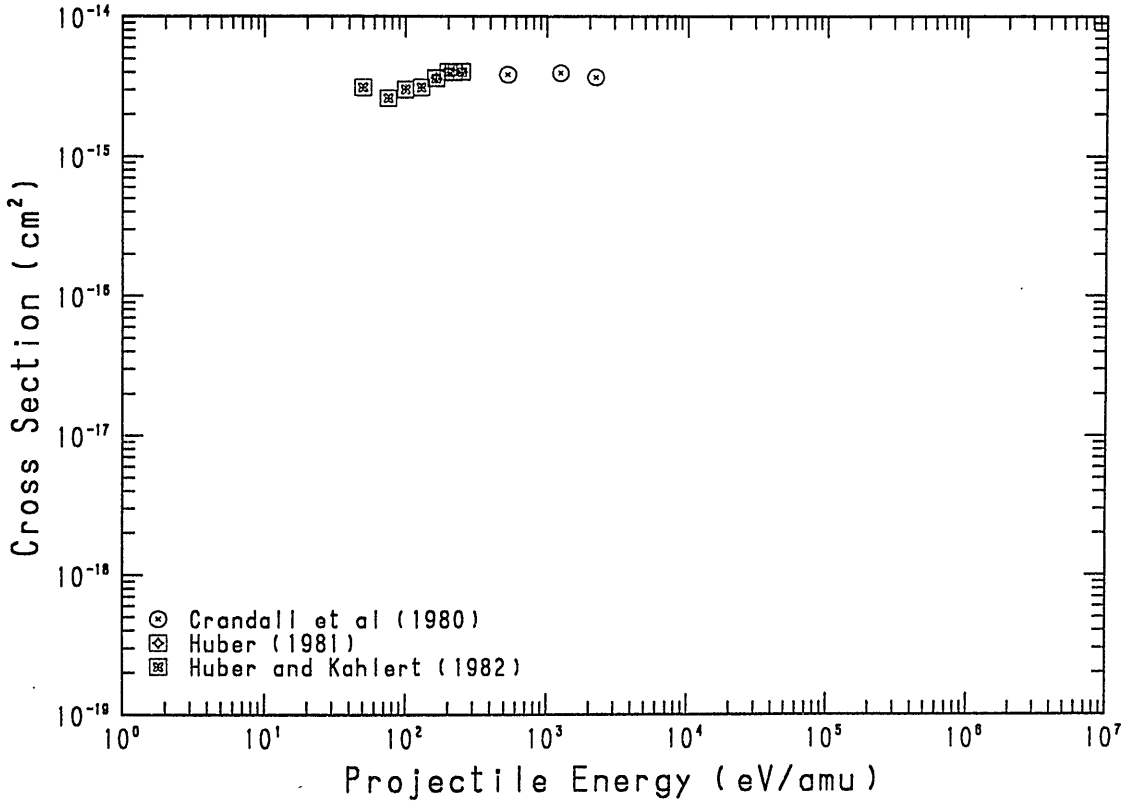


Fig.58 $Ar^{5+} + H \rightarrow Ar^{4+}$

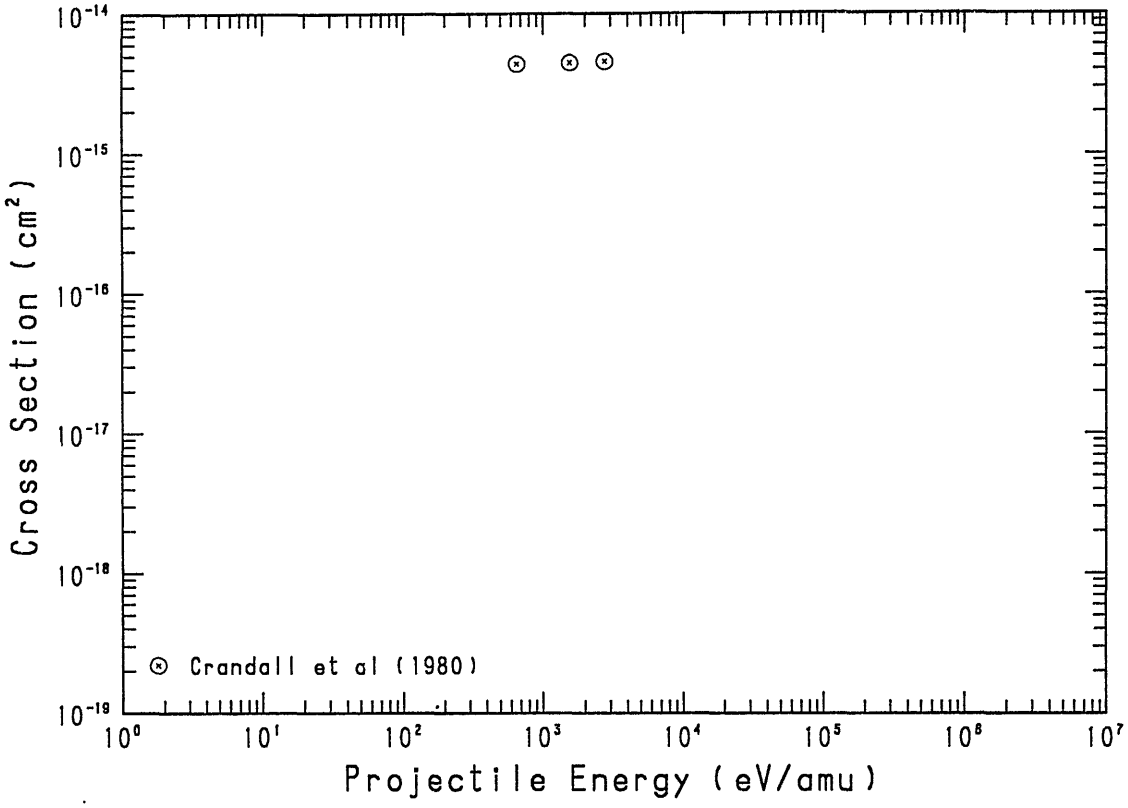


Fig.59 $Ar^{6+} + H \rightarrow Ar^{5+}$

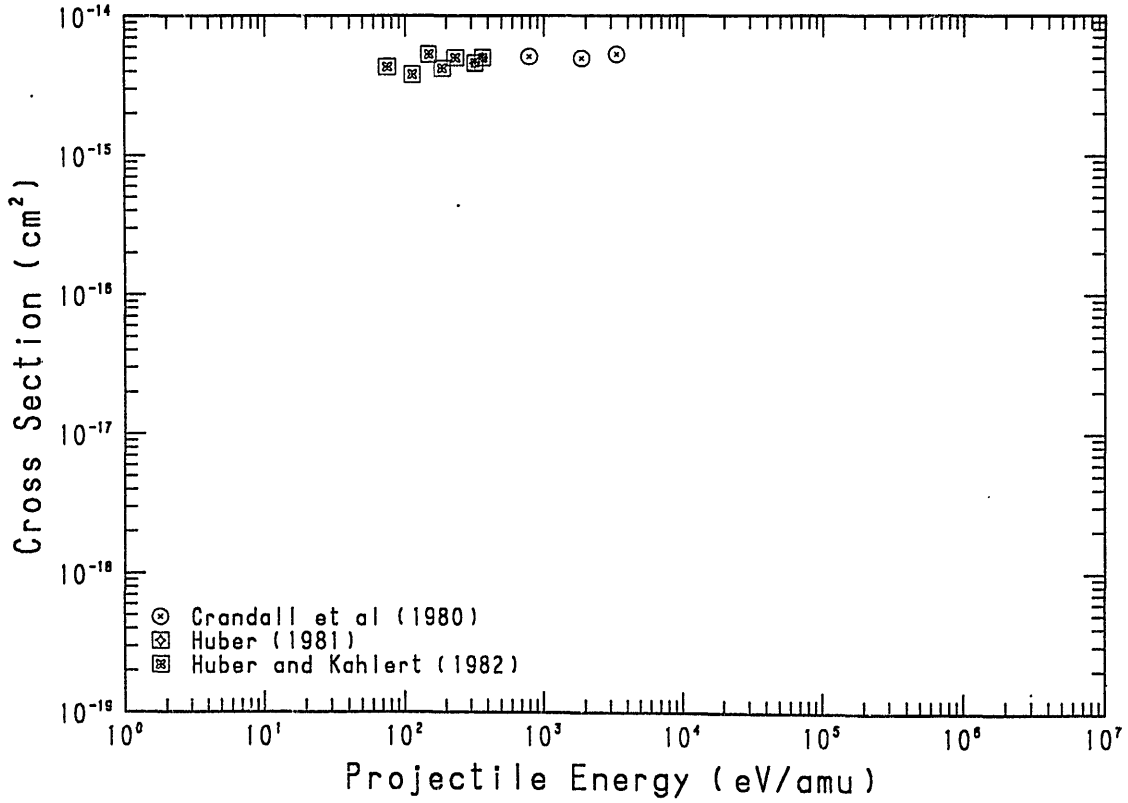


Fig.60 $Ar^{7+} + H \rightarrow Ar^{6+}$

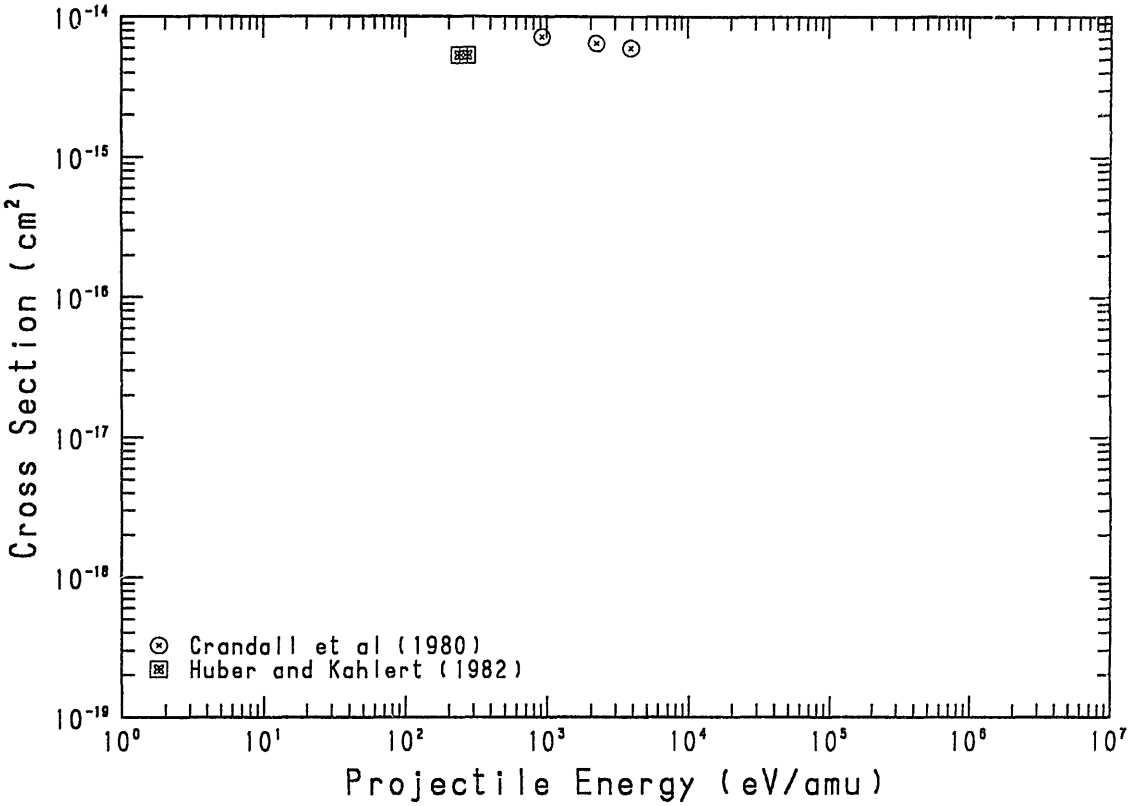


Fig.61 $Ar^{8+} + H \rightarrow Ar^{7+}$

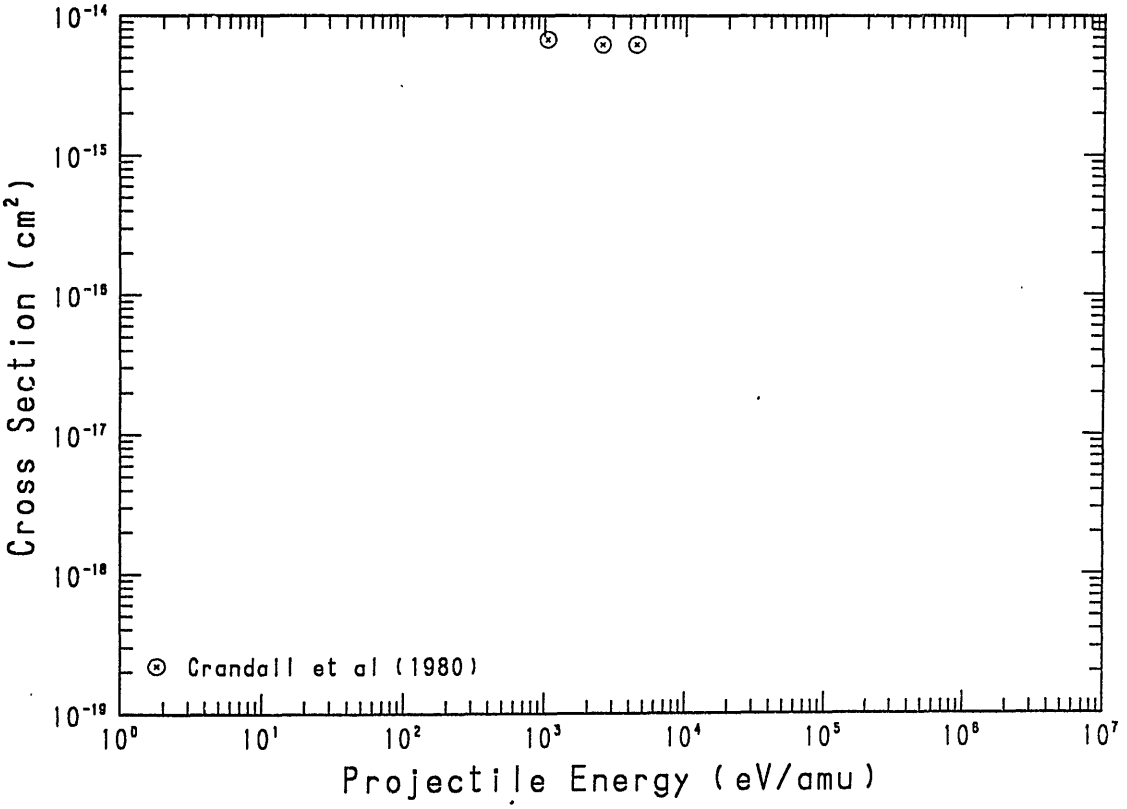


Fig.62 $Ar^{9+} + H \rightarrow Ar^{8+}$

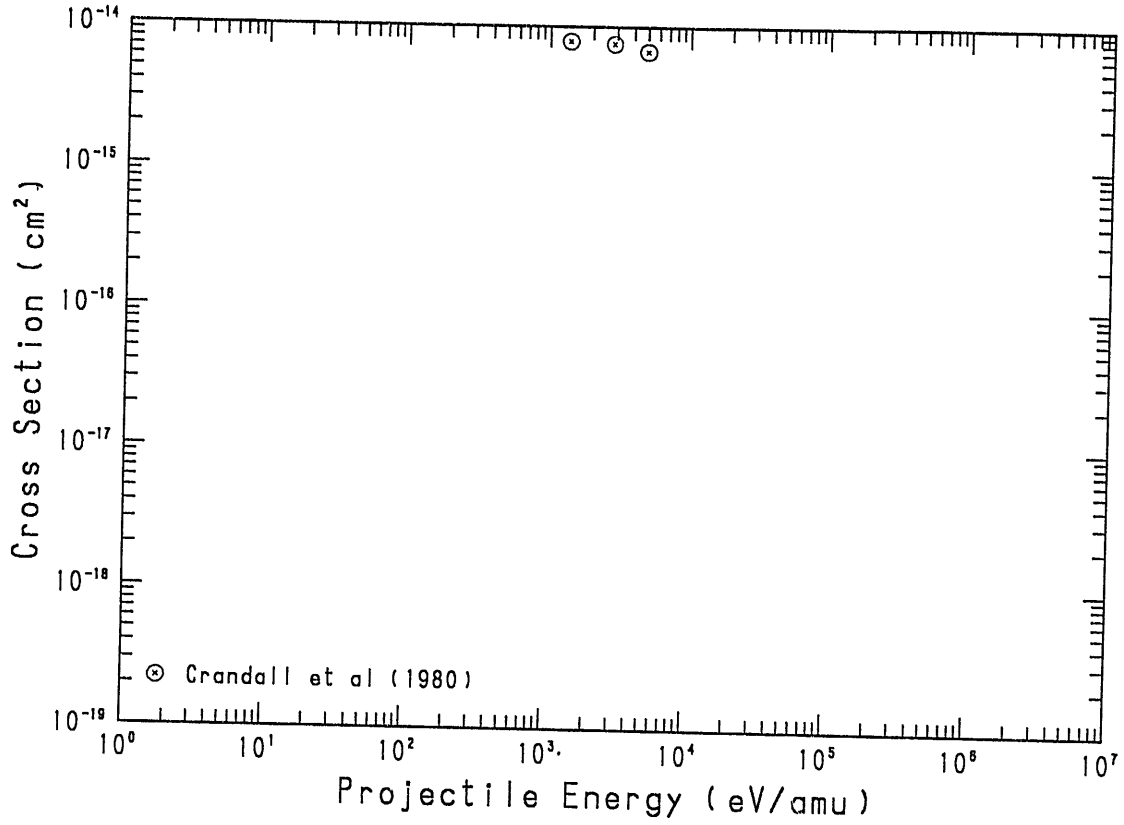


Fig.63 $Ti^{2+} + H \rightarrow Ti^{+}$

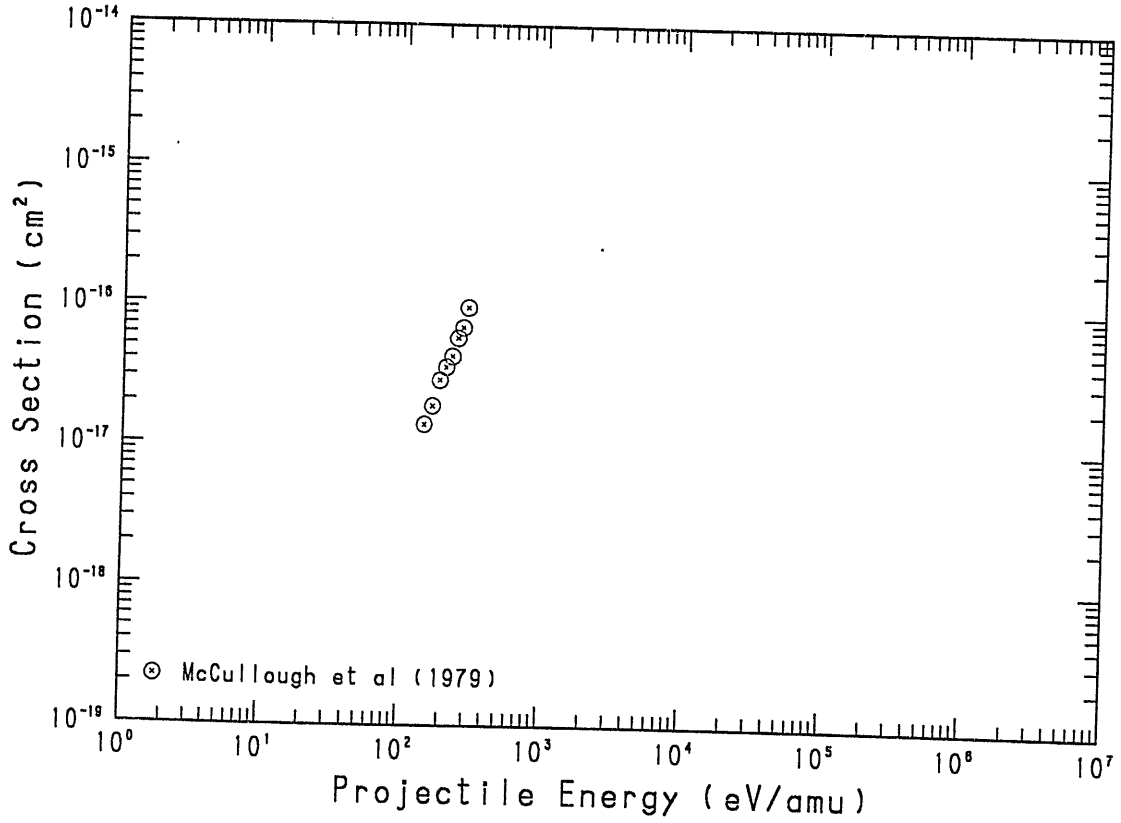


Fig.64 $Fe^{3+} + H \rightarrow Fe^{2+}$

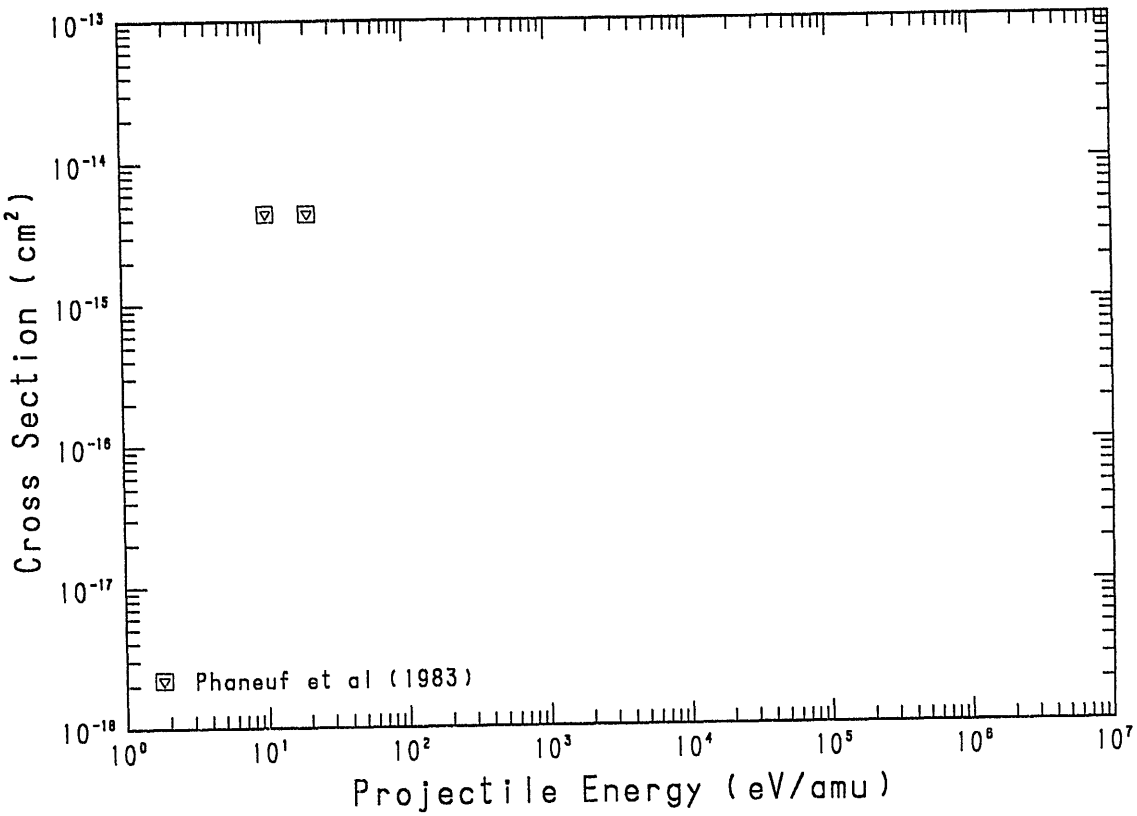


Fig.65 $Fe^{4+} + H \rightarrow Fe^{3+}$

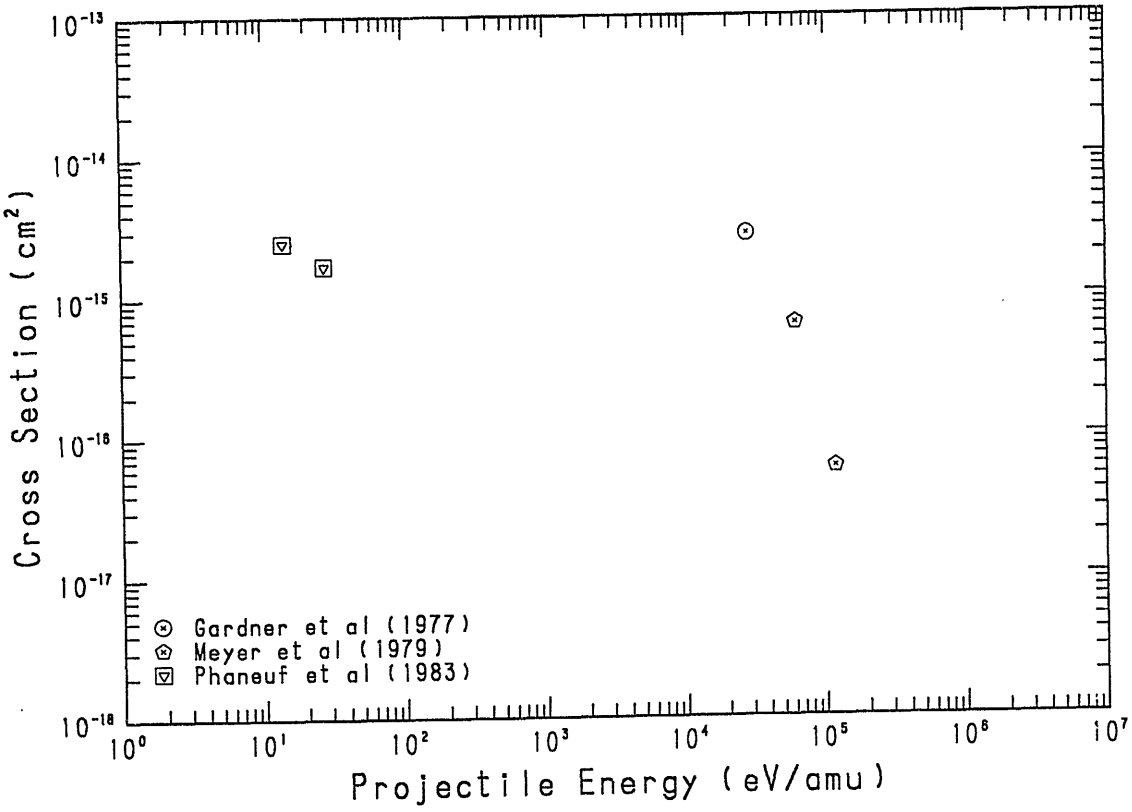


Fig.66 $Fe^{5+} + H \rightarrow Fe^{4+}$

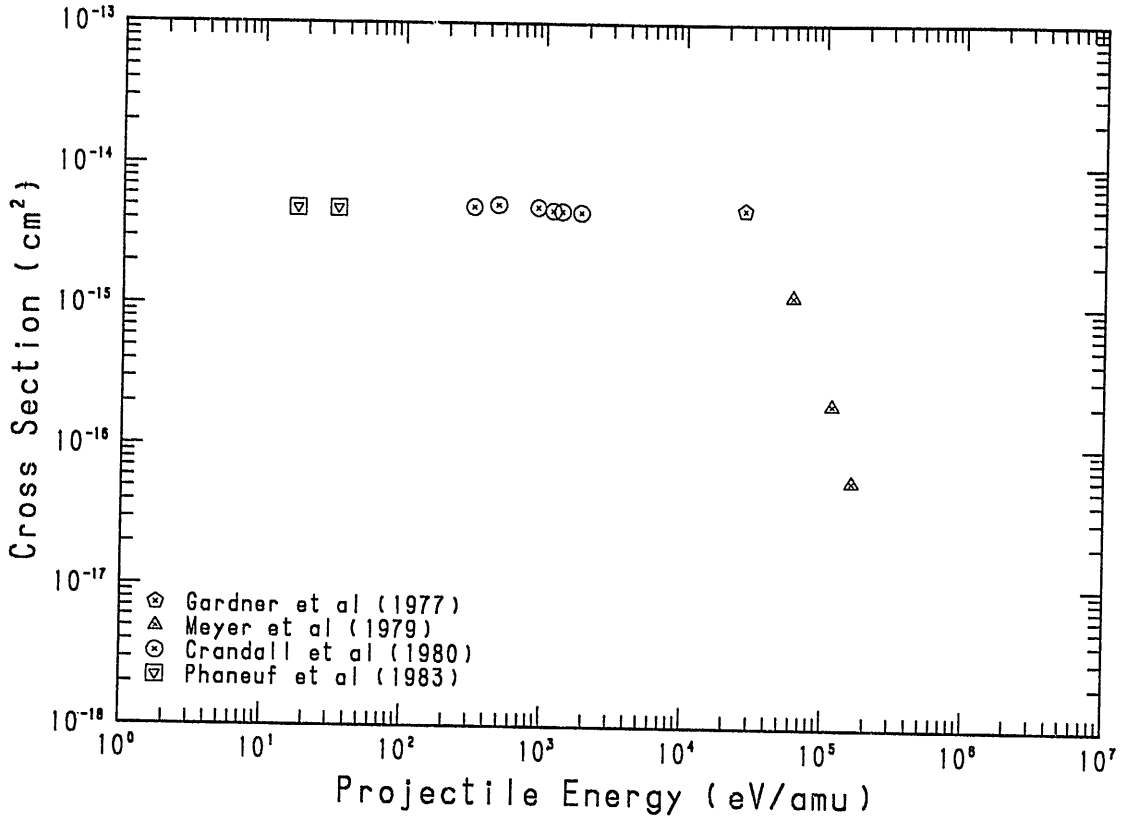


Fig.67 $Fe^{6+} + H \rightarrow Fe^{5+}$

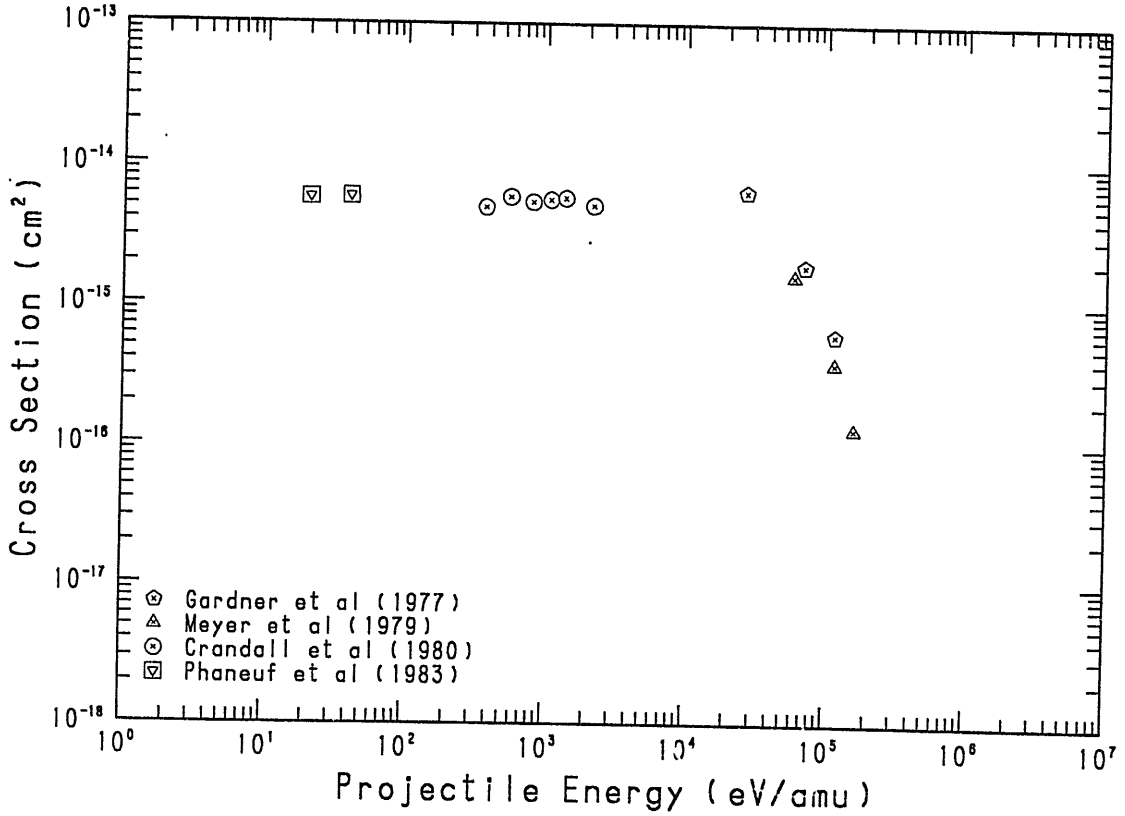


Fig.68 $Fe^{7+} + H \rightarrow Fe^{6+}$

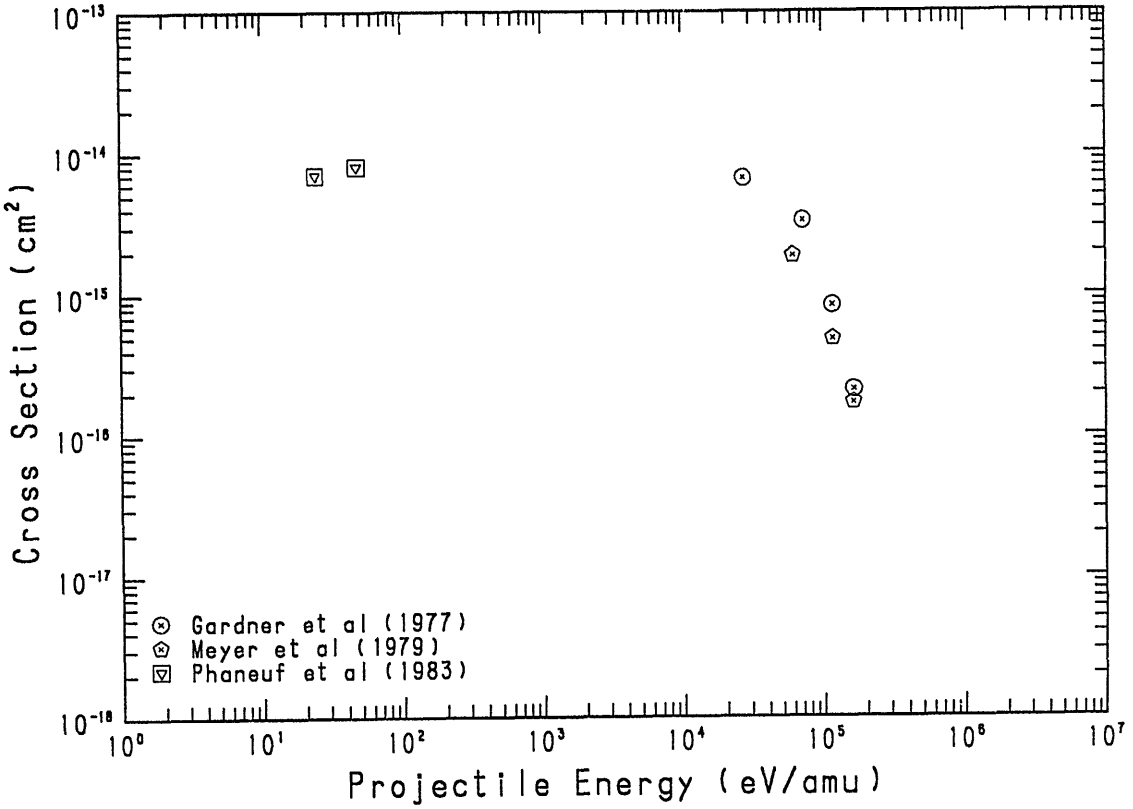


Fig.69 $Fe^{8+} + H \rightarrow Fe^{7+}$

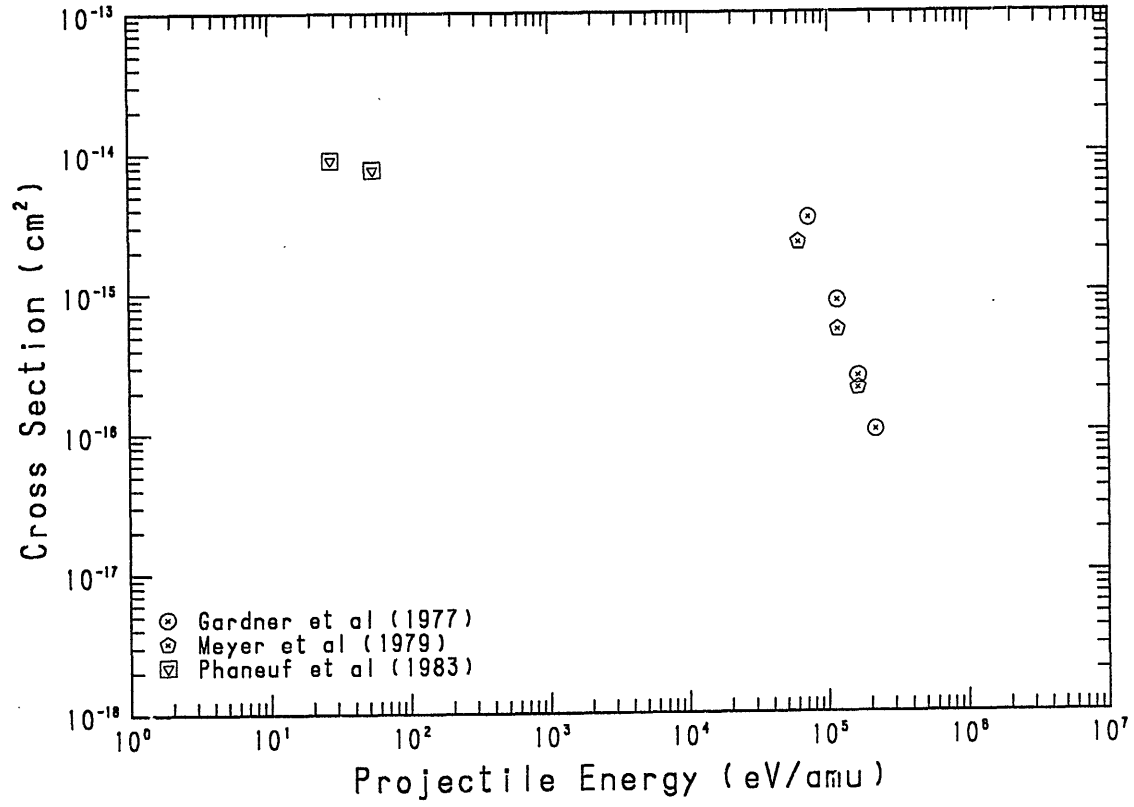


Fig.70 $Fe^{9+} + H \rightarrow Fe^{8+}$

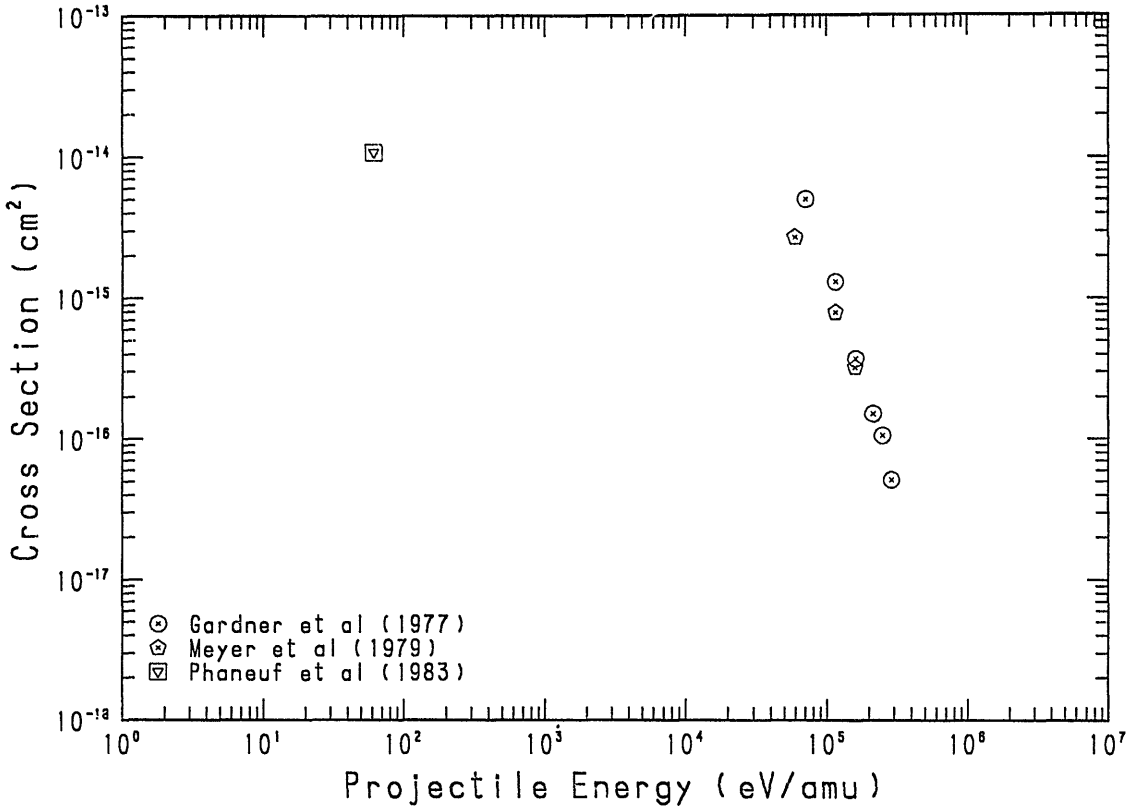


Fig.71 $Fe^{10+} + H \rightarrow Fe^{9+}$

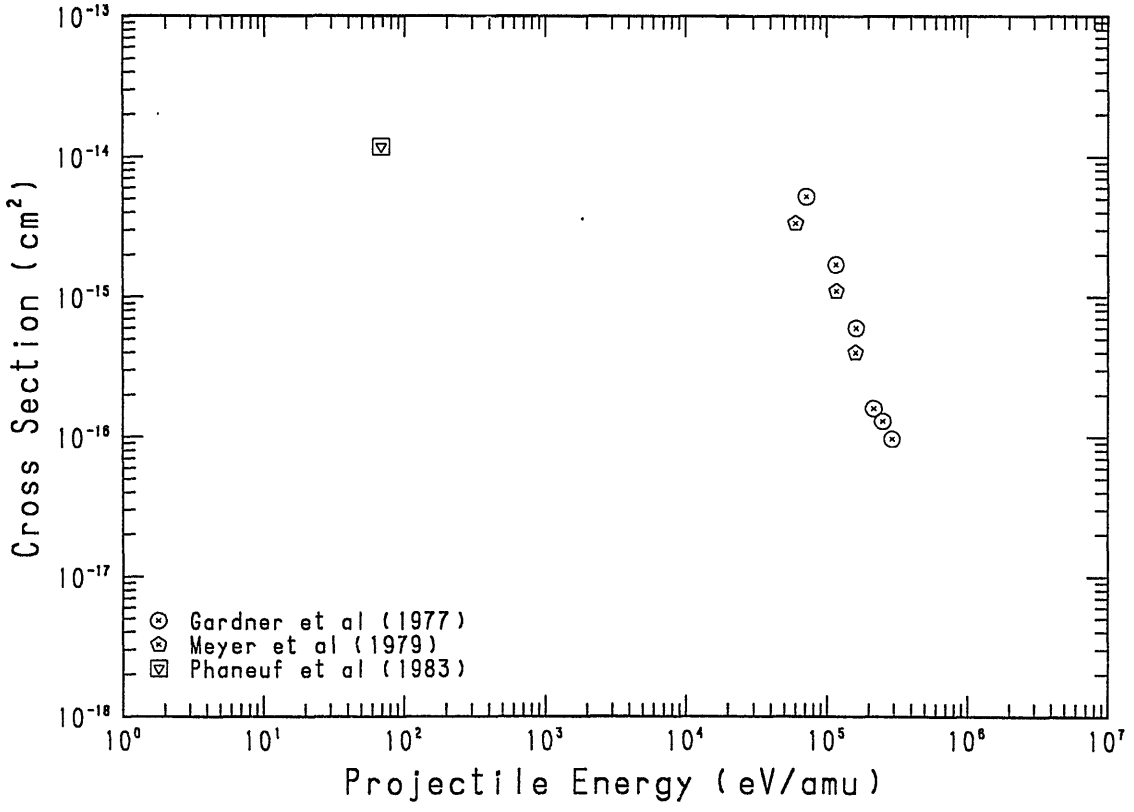


Fig.72 $Fe^{11+} + H \rightarrow Fe^{10+}$

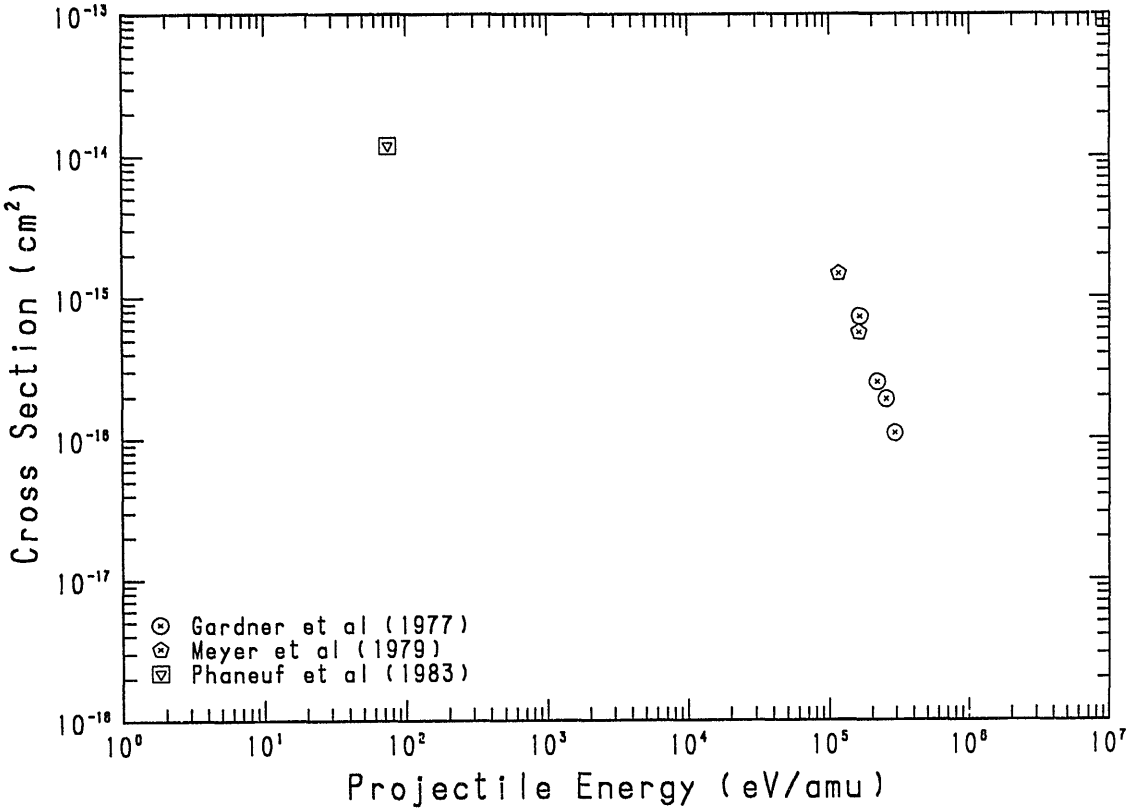


Fig.73 $Fe^{12+} + H \rightarrow Fe^{11+}$

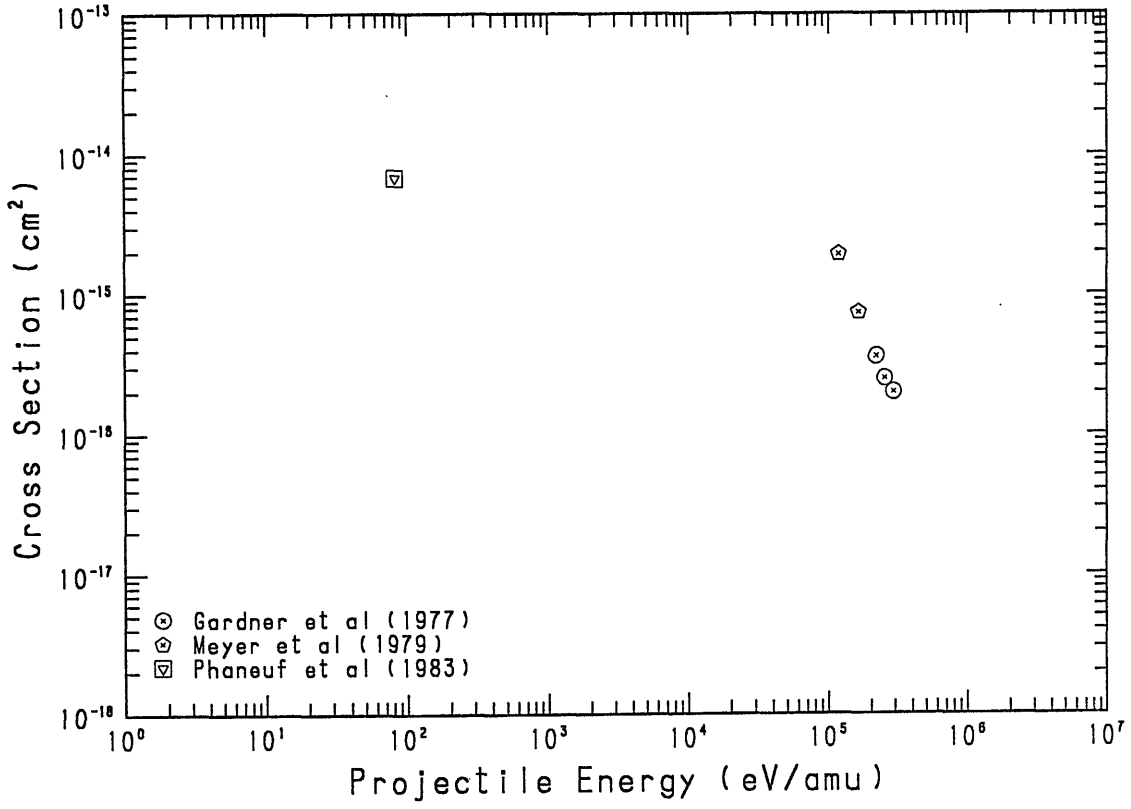


Fig.74 $Fe^{13+} + H \rightarrow Fe^{12+}$

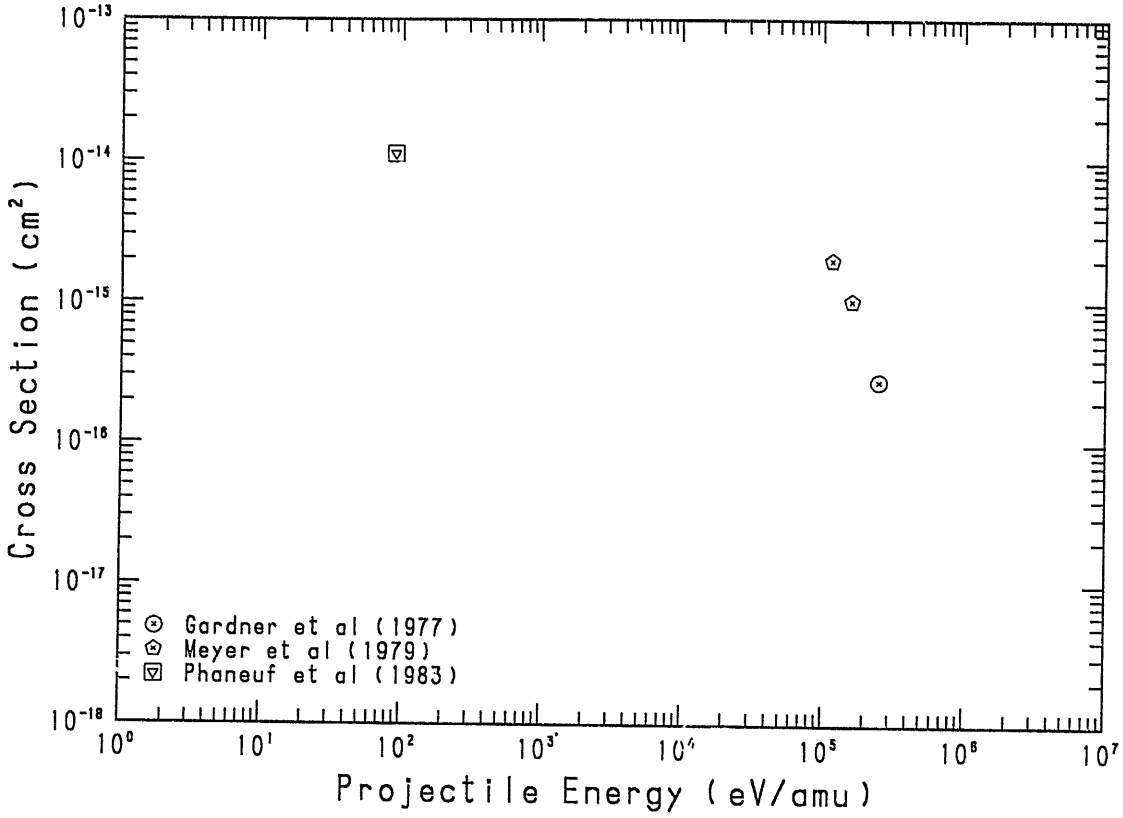


Fig.75 $Fe^{14+} + H \rightarrow Fe^{13+}$

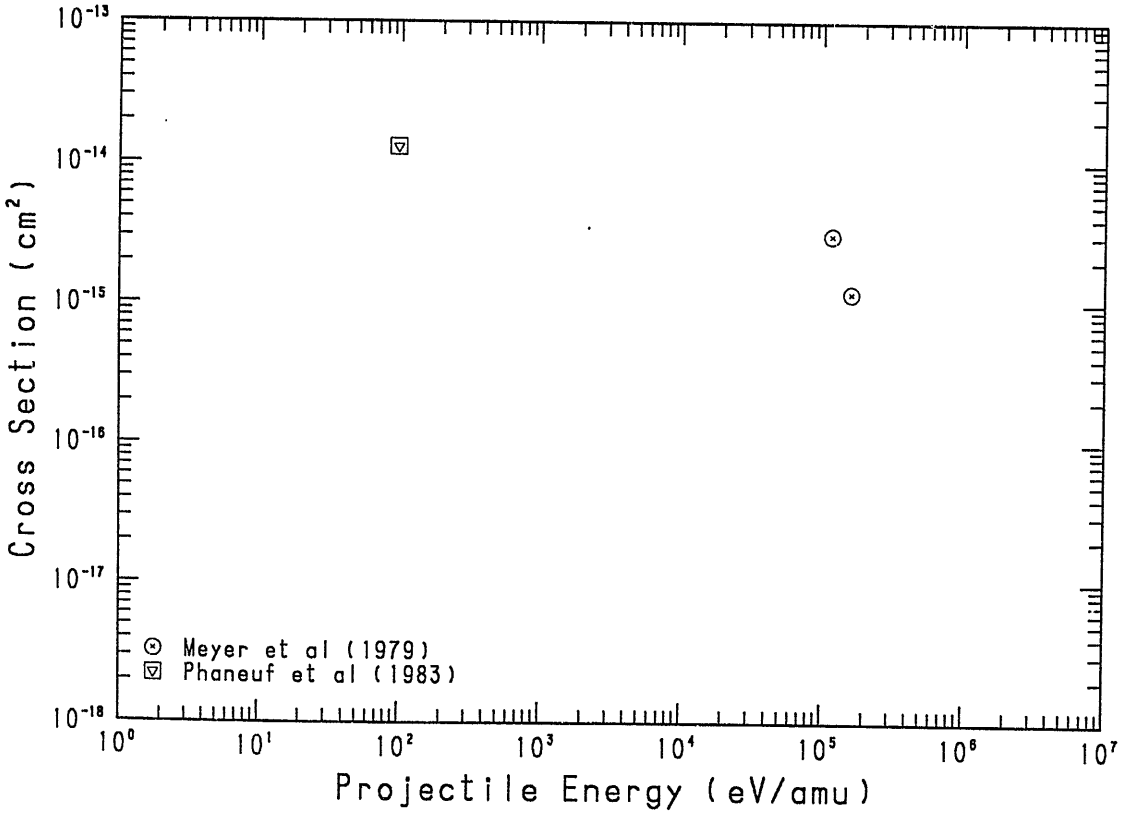


Fig.76 $Fe^{15+} + H \rightarrow Fe^{14+}$

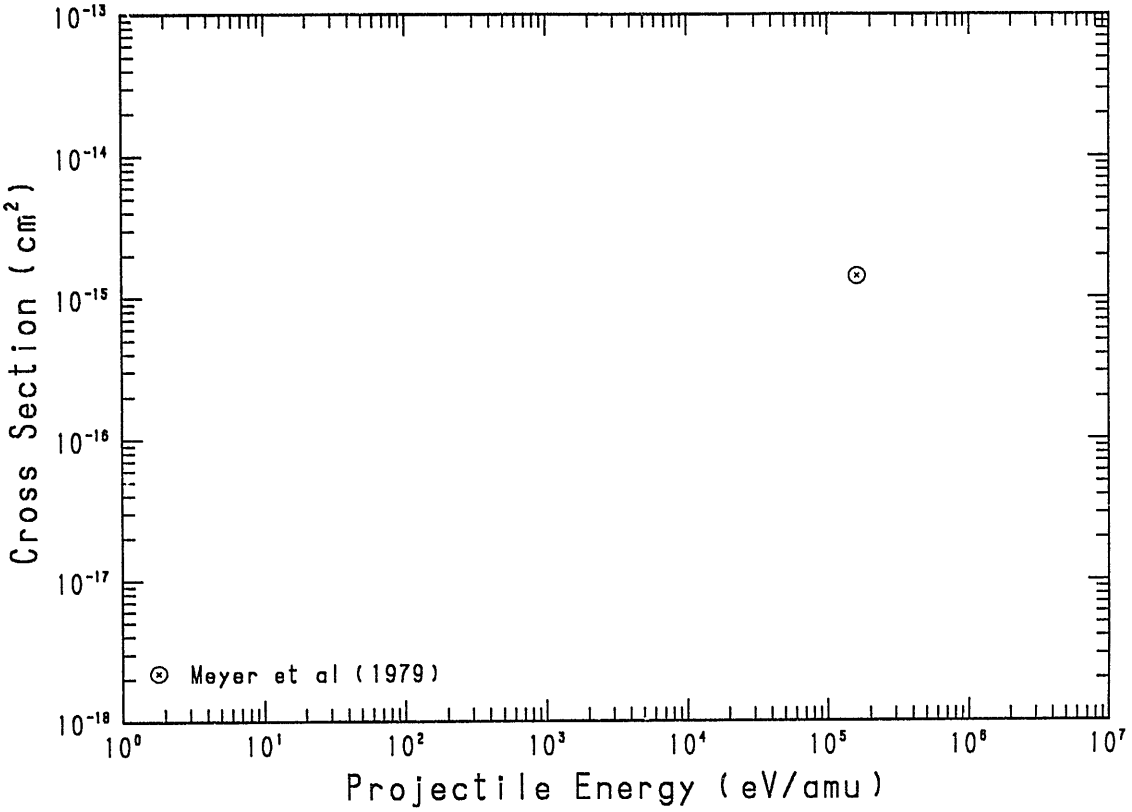


Fig.77 $Zn^{2+} + H \rightarrow Zn^{+}$

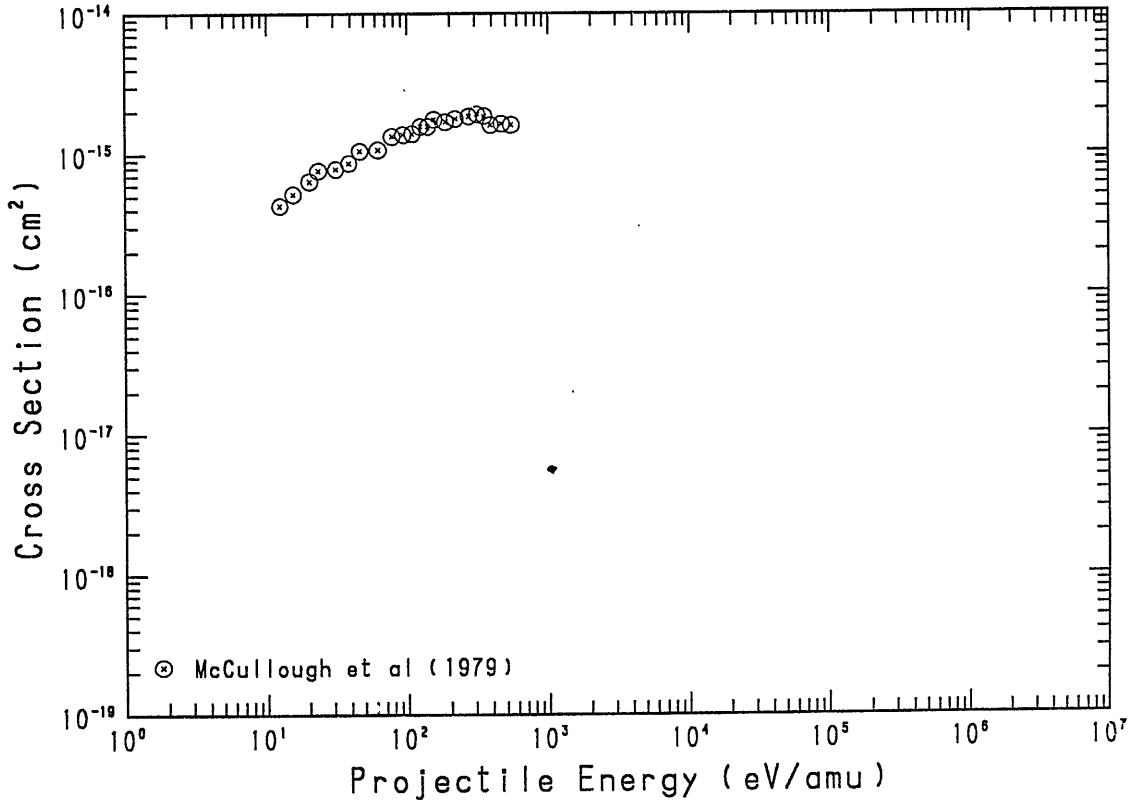


Fig.78 $Kr^{2+} + H \rightarrow Kr^{+}$

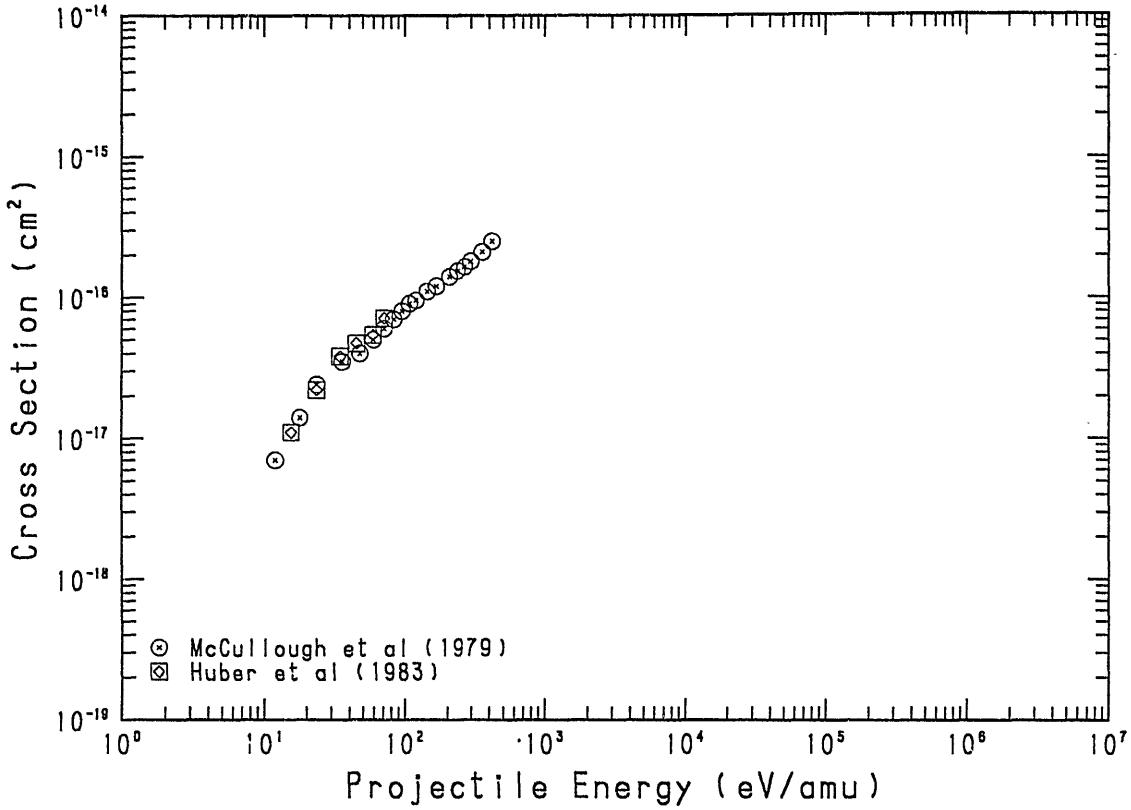


Fig.79 $Kr^{3+} + H \rightarrow Kr^{2+}$

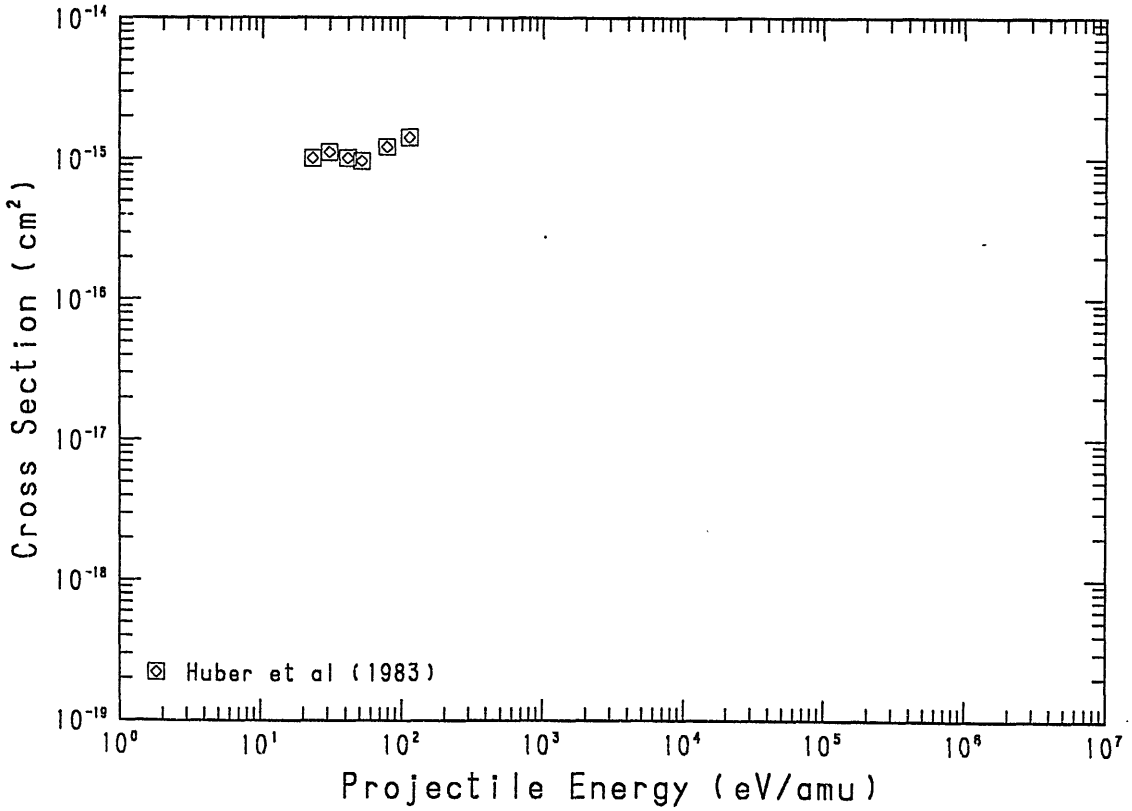


Fig.80 $Kr^{4+} + H \rightarrow Kr^{3+}$

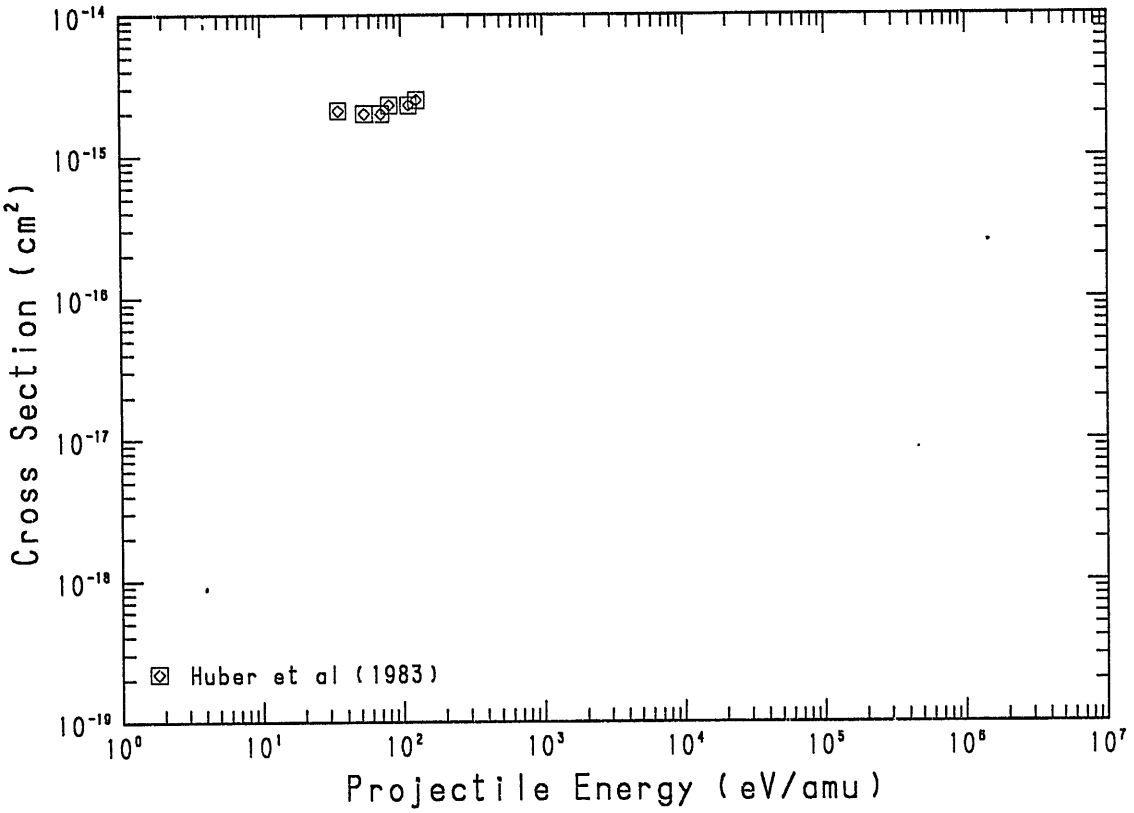


Fig.81 $Kr^{5+} + H \rightarrow Kr^{4+}$

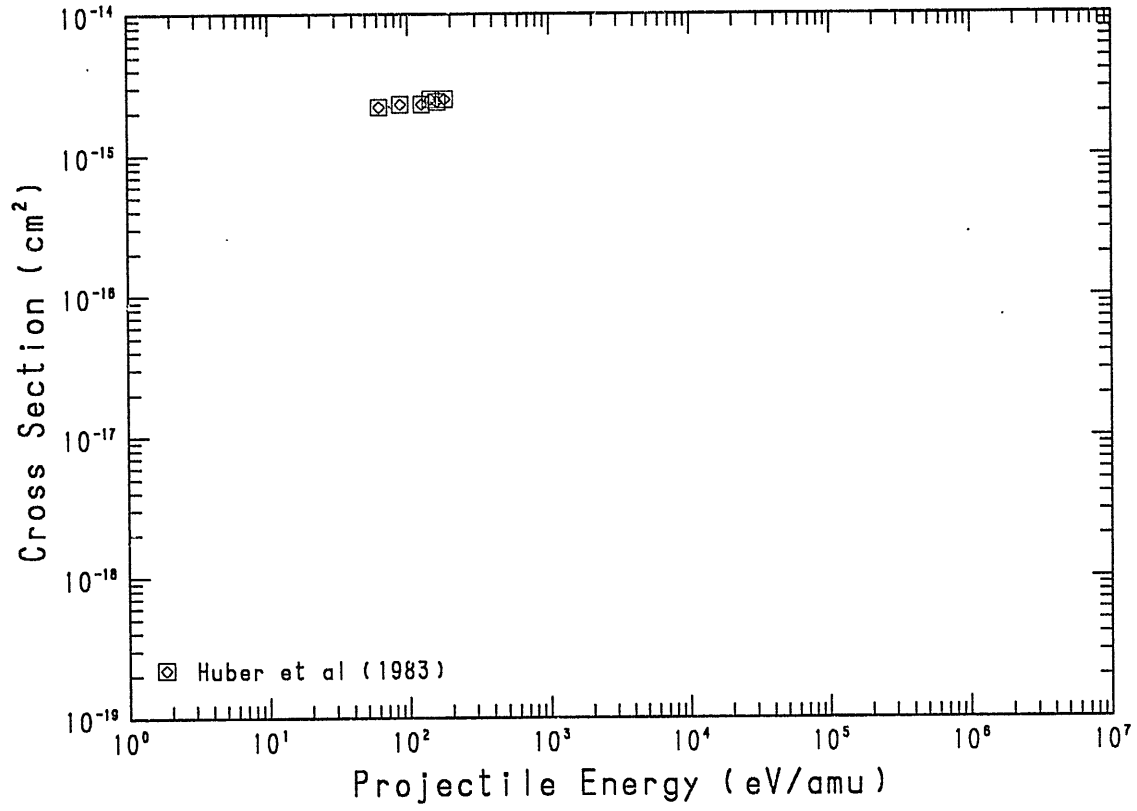


Fig.82 $Kr^{6+} + H \rightarrow Kr^{5+}$

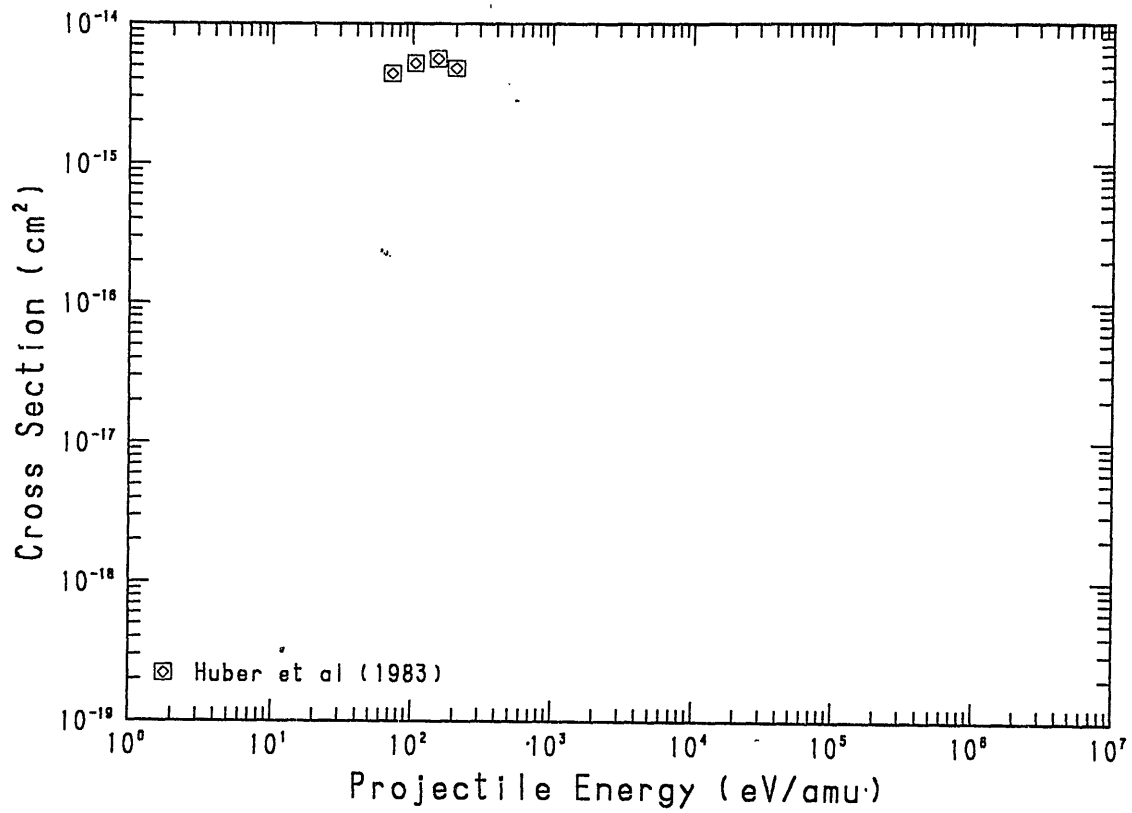


Fig.83 $Mo^{4+} + H \rightarrow Mo^{3+}$

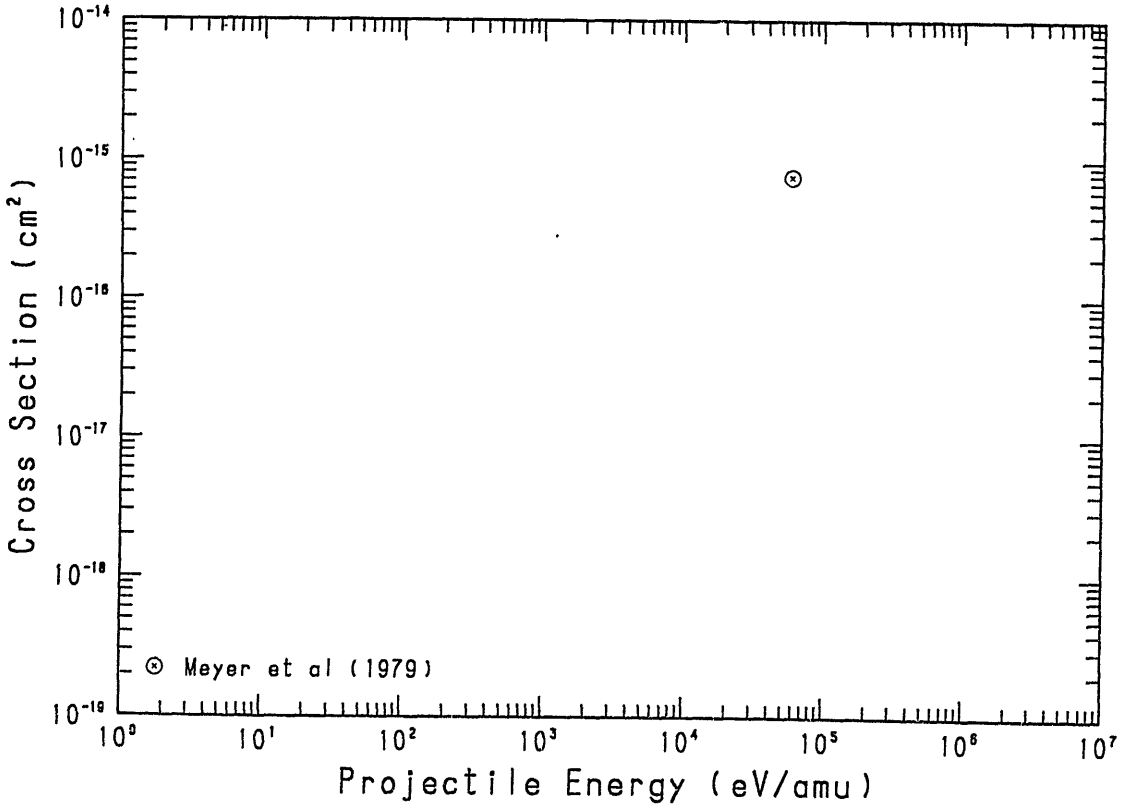


Fig.84 $Mo^{5+} + H \rightarrow Mo^{4+}$

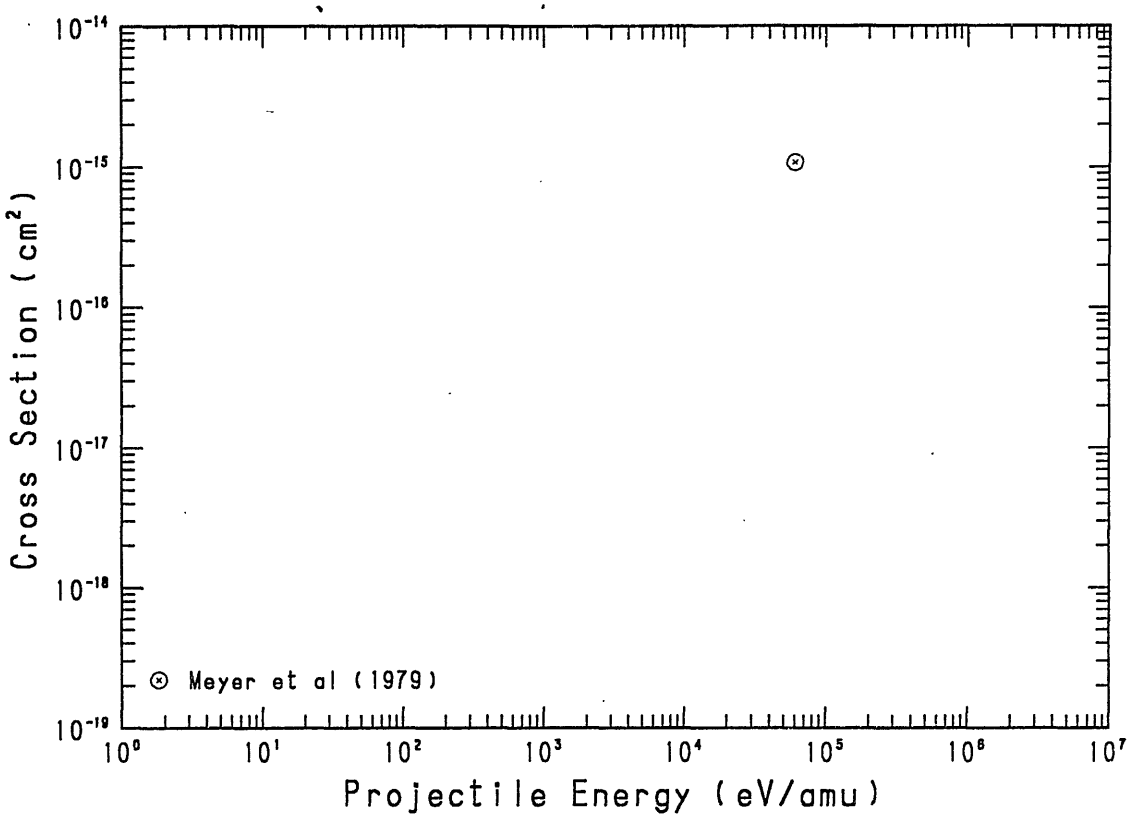


Fig.85 $Mo^{6+} + H \rightarrow Mo^{5+}$

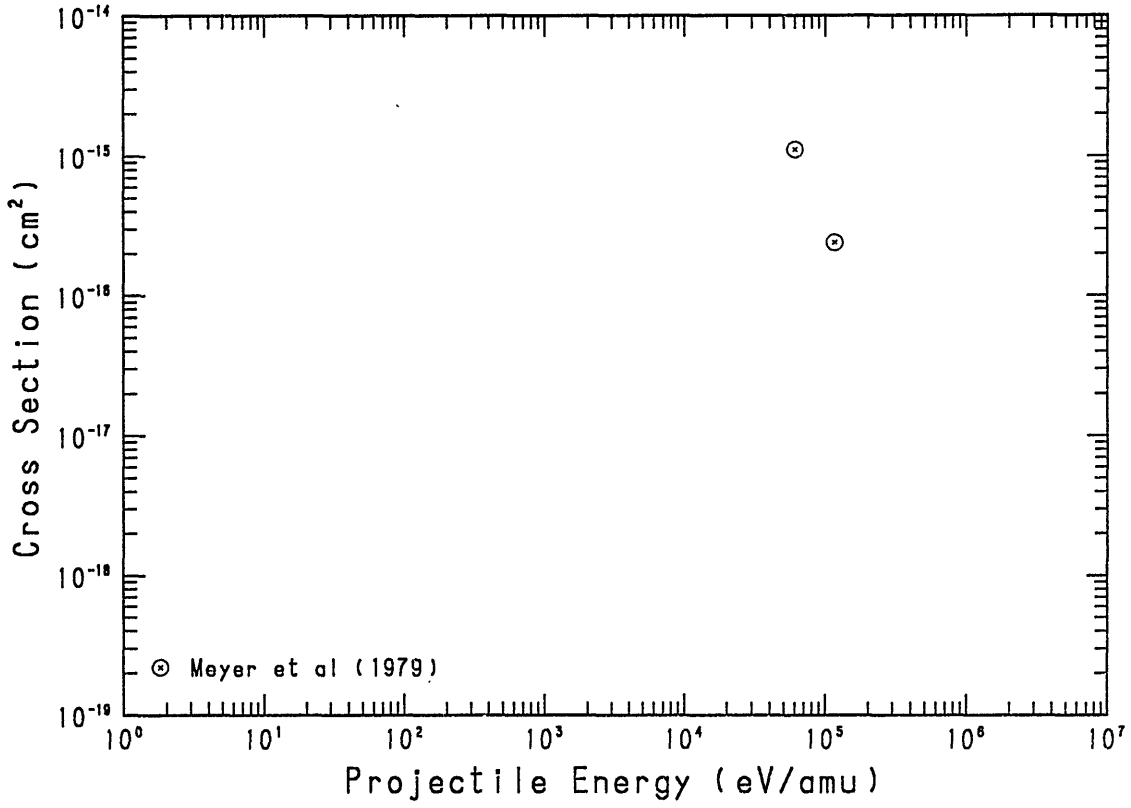


Fig.86 $Mo^{7+} + H \rightarrow Mo^{6+}$

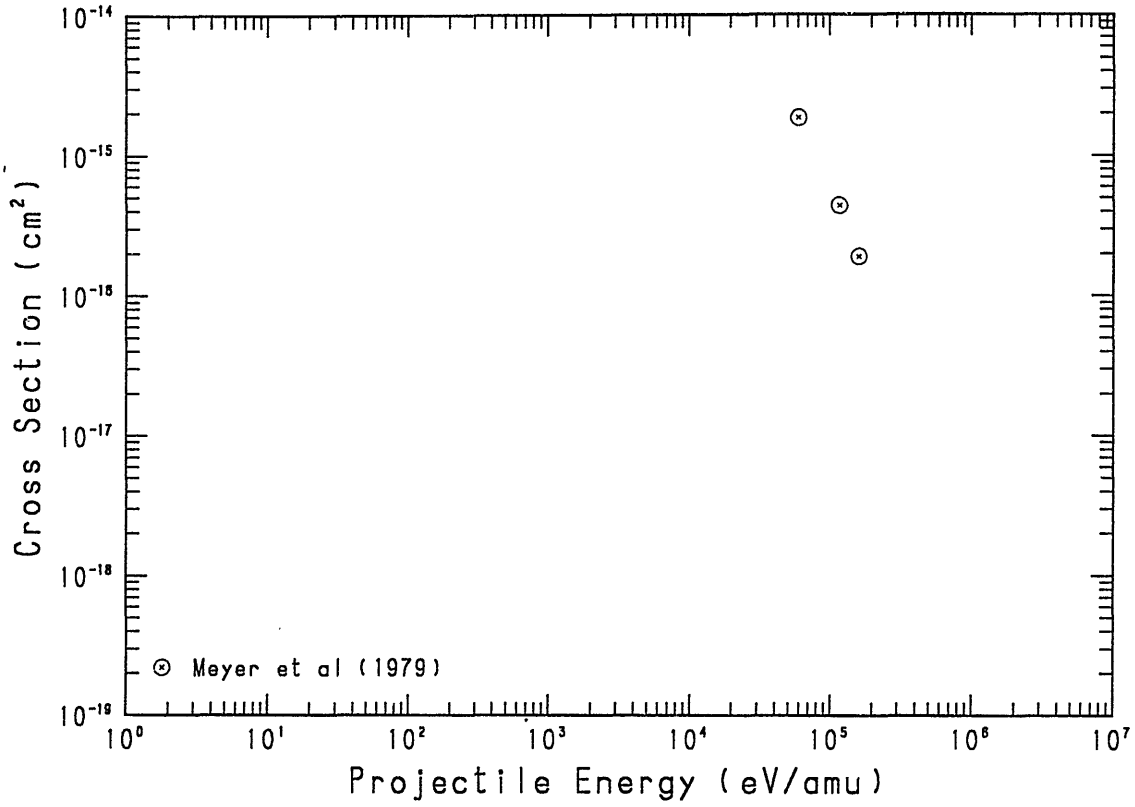


Fig.87 $Mo^{8+} + H \rightarrow Mo^{7+}$

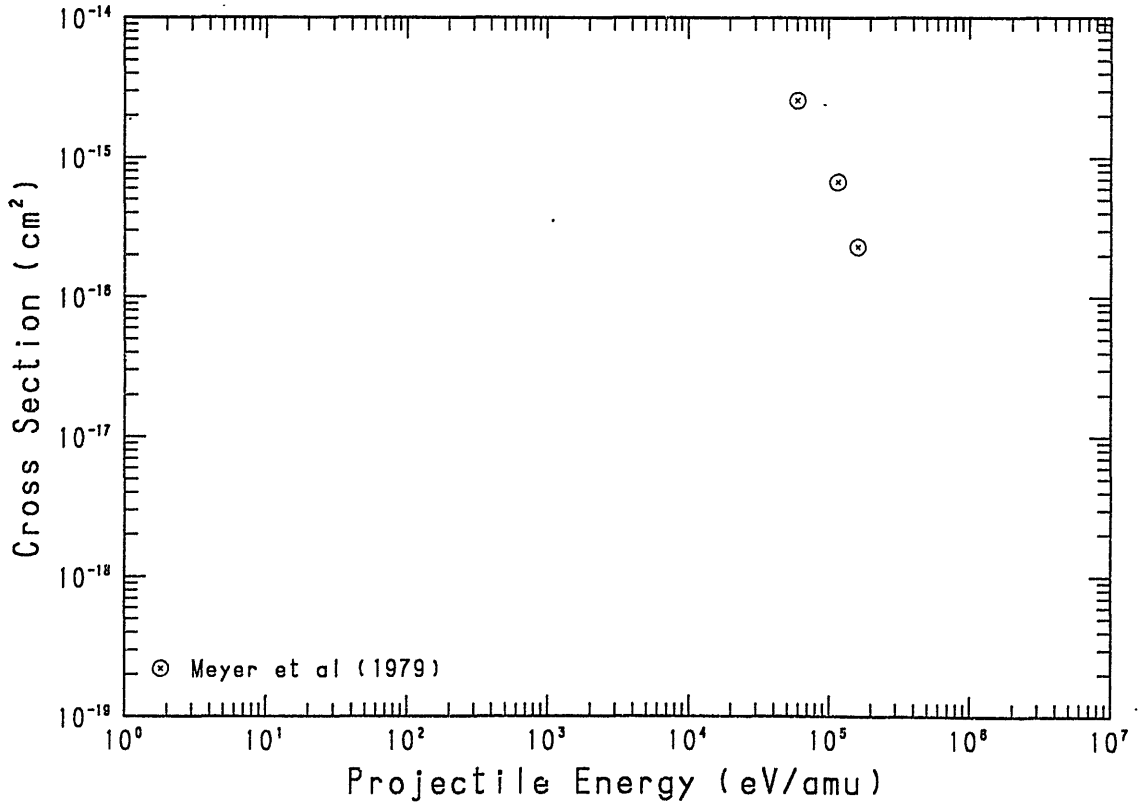


Fig.88 $Mo^{9+} + H \rightarrow Mo^{8+}$

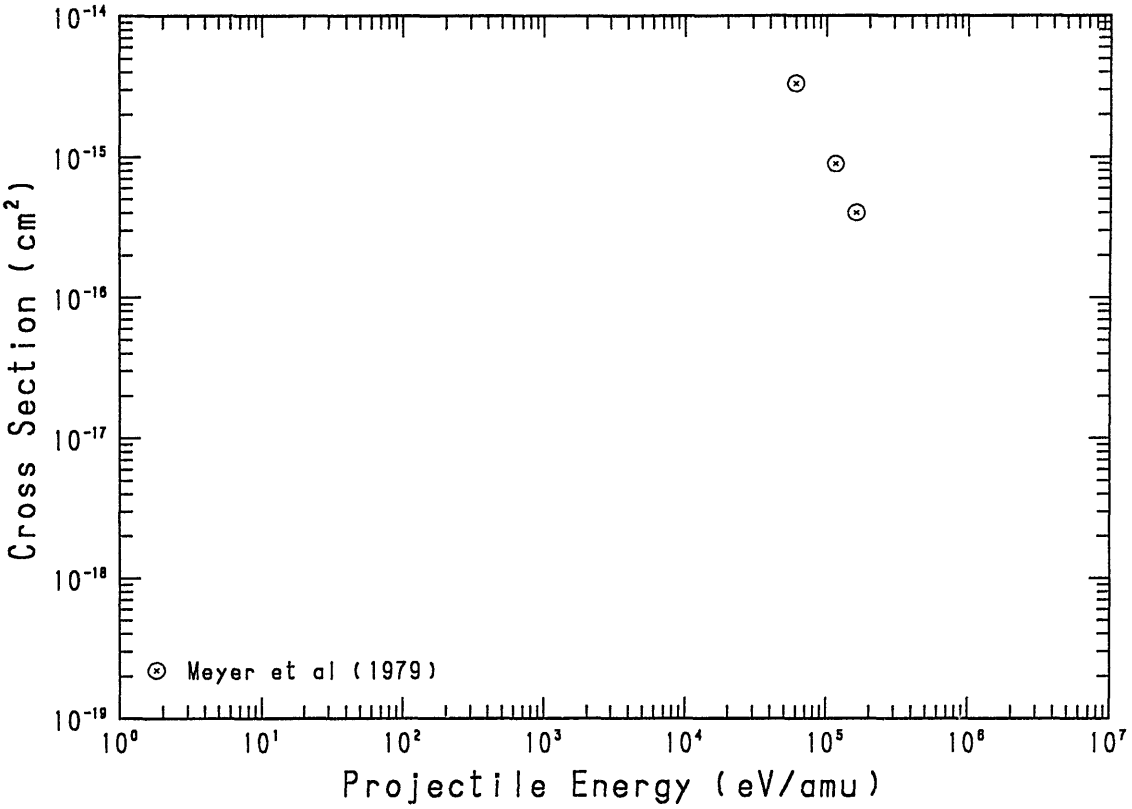


Fig.89 $Mo^{10+} + H \rightarrow Mo^{9+}$

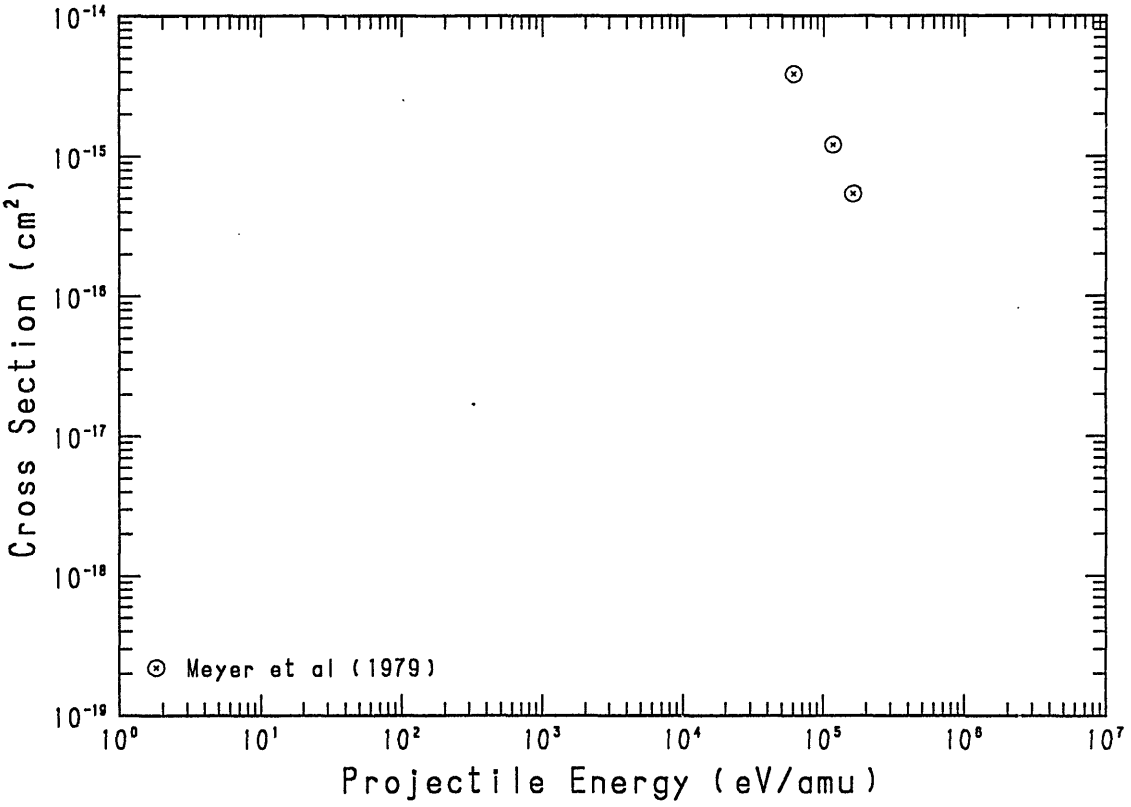


Fig.90 Mo^{11+} + H → Mo^{10+}

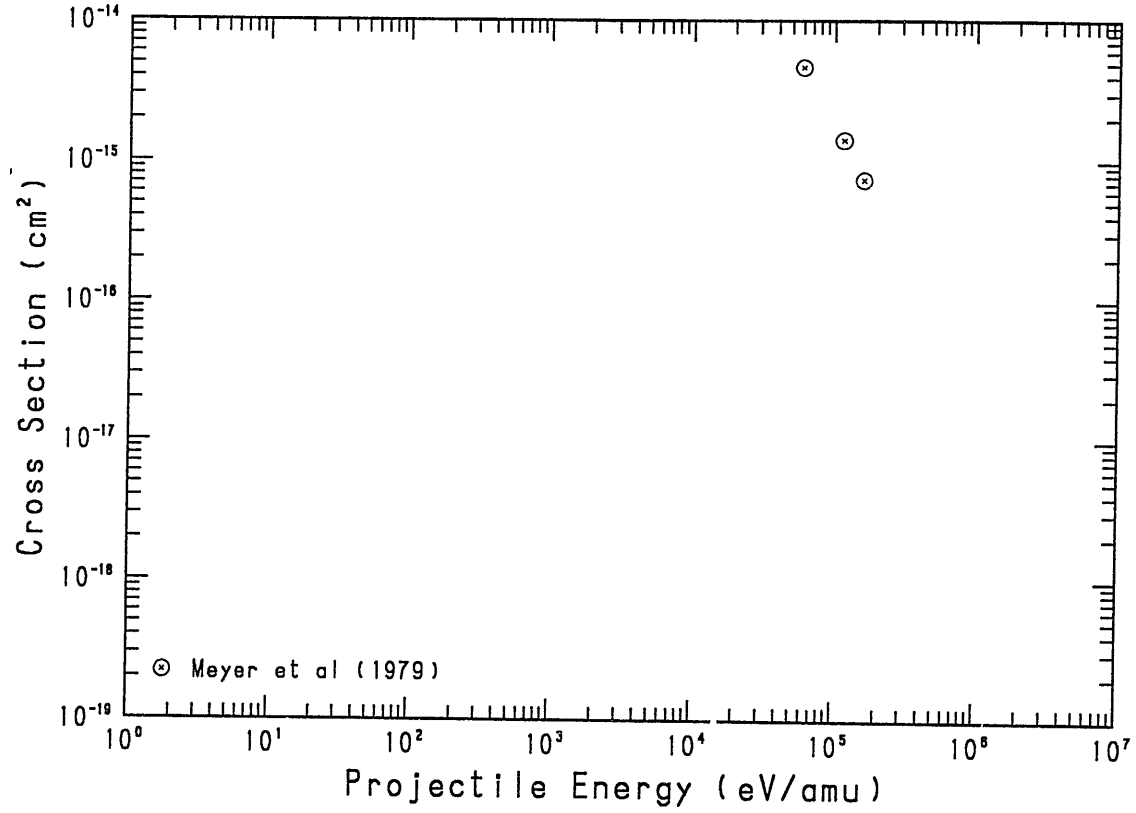


Fig.91 Mo^{12+} + H → Mo^{11+}

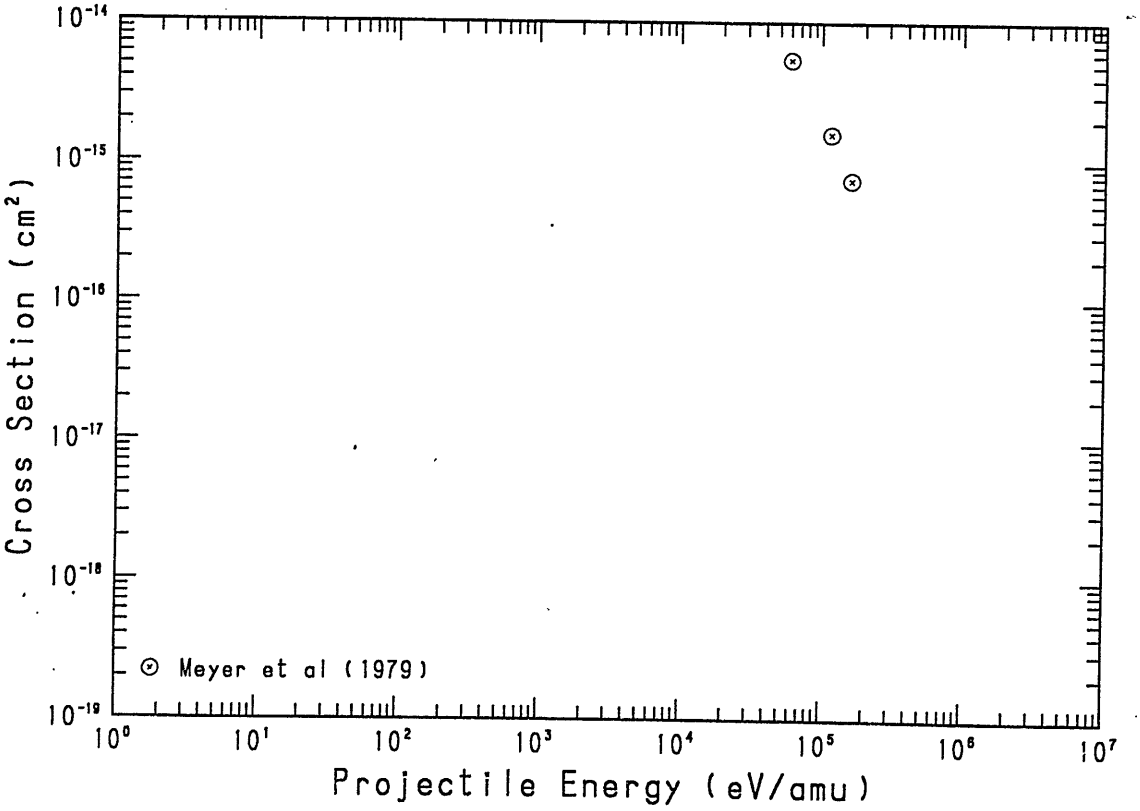


Fig.92 $Mo^{13+} + H \rightarrow Mo^{12+}$

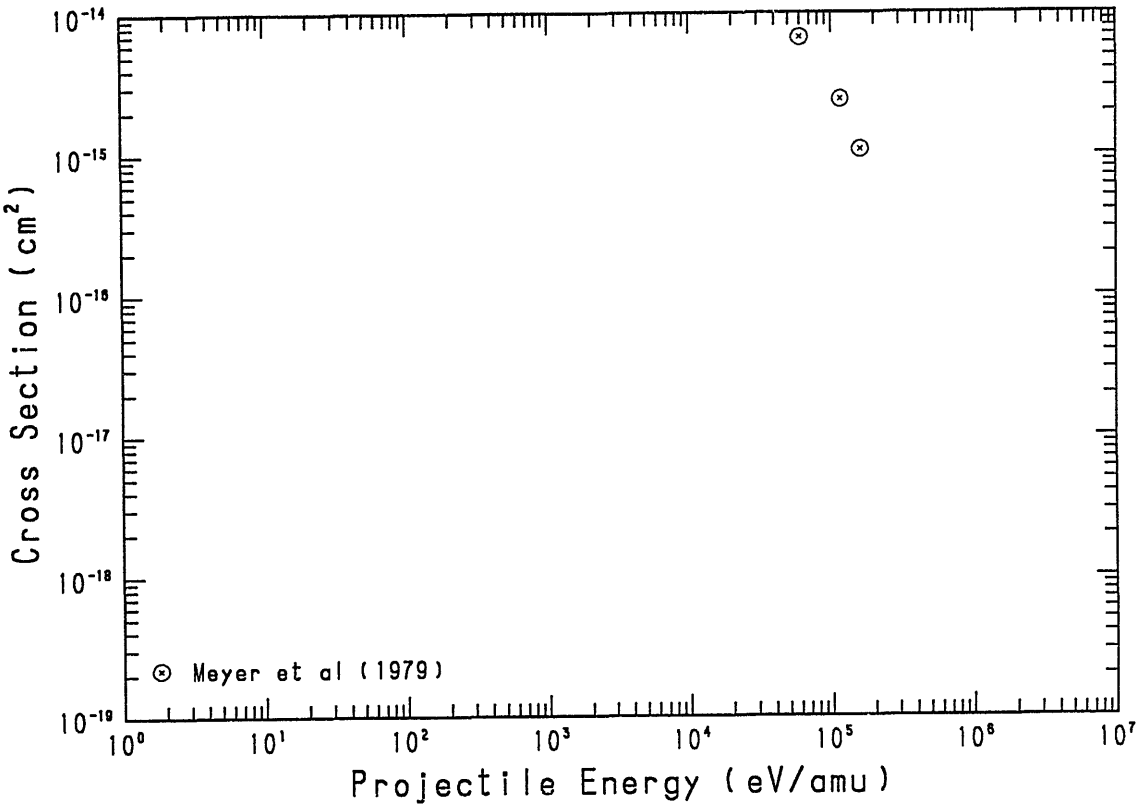


Fig.93 $Mo^{14+} + H \rightarrow Mo^{13+}$

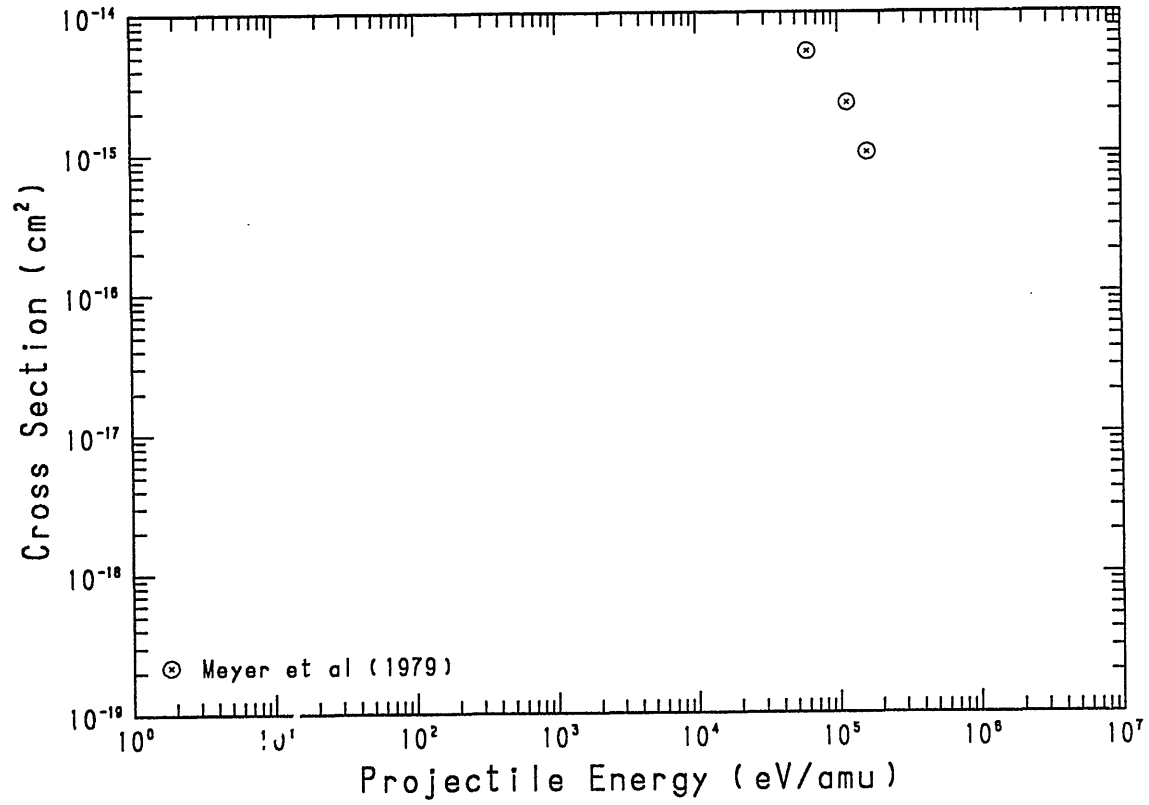


Fig.94 $Mo^{15+} + H \rightarrow Mo^{14+}$

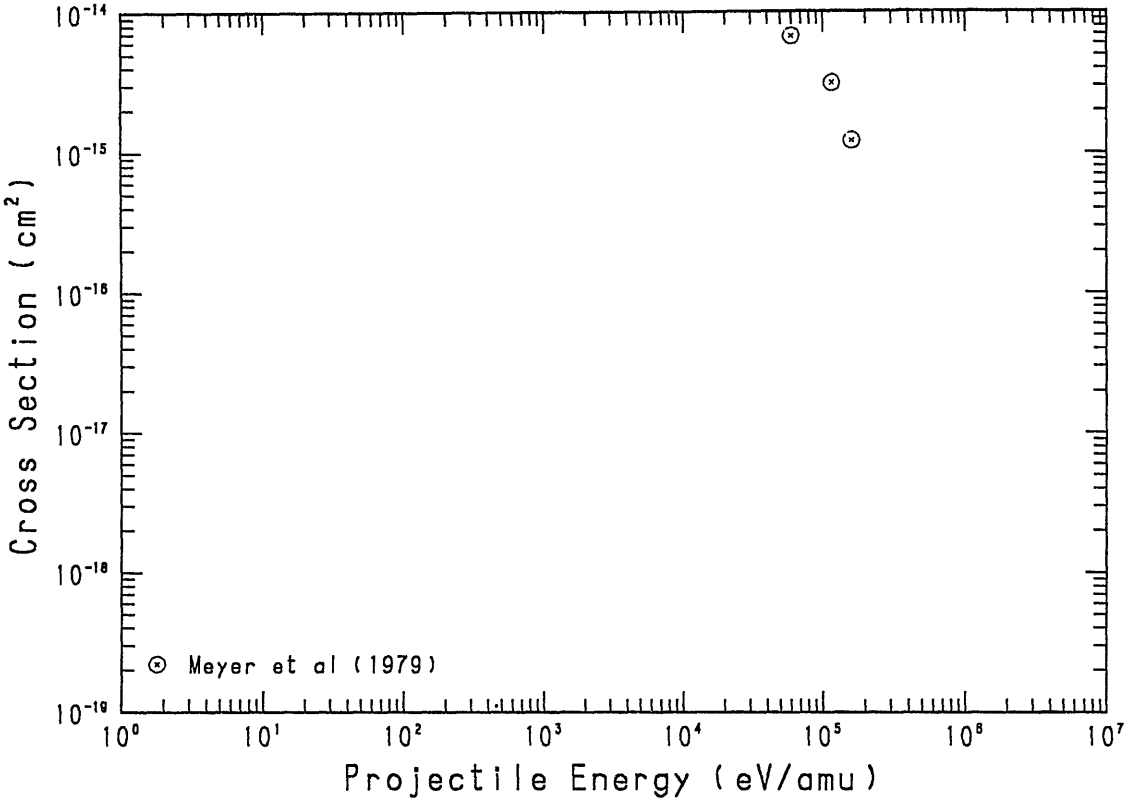


Fig.95 $Mo^{16+} + H \rightarrow Mo^{15+}$

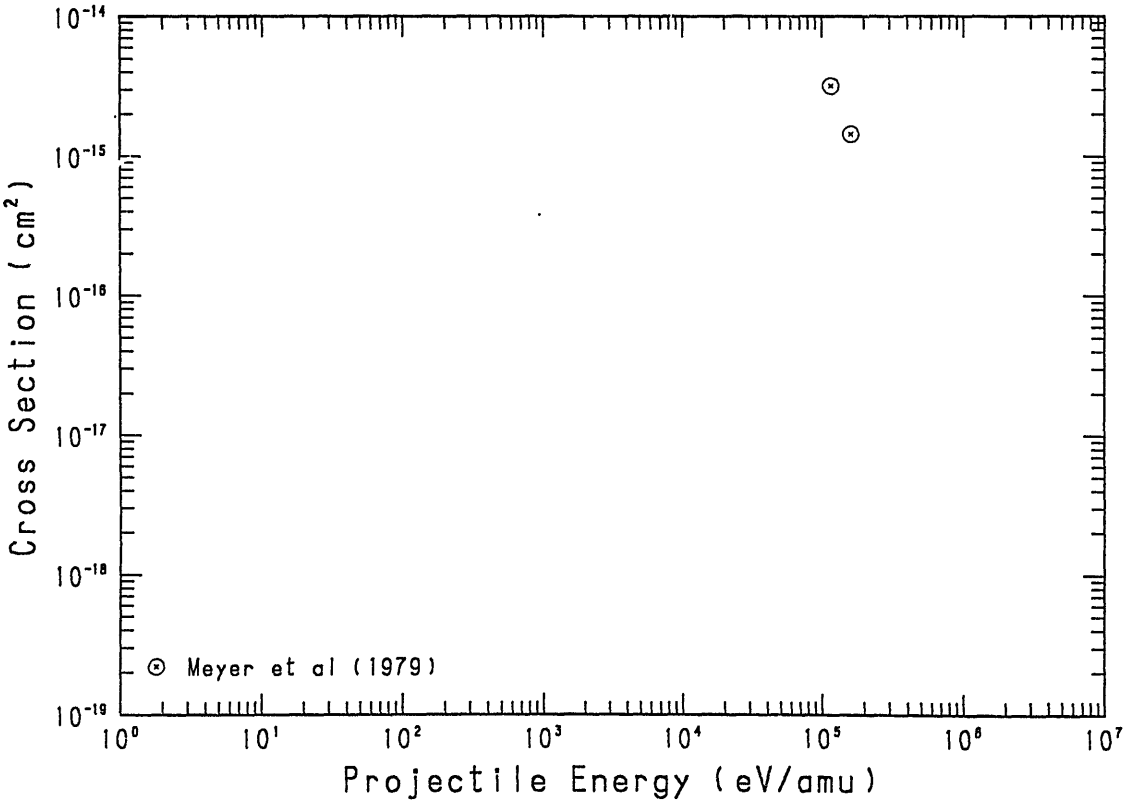


Fig.96 $Mo^{17+} + H \rightarrow Mo^{16+}$

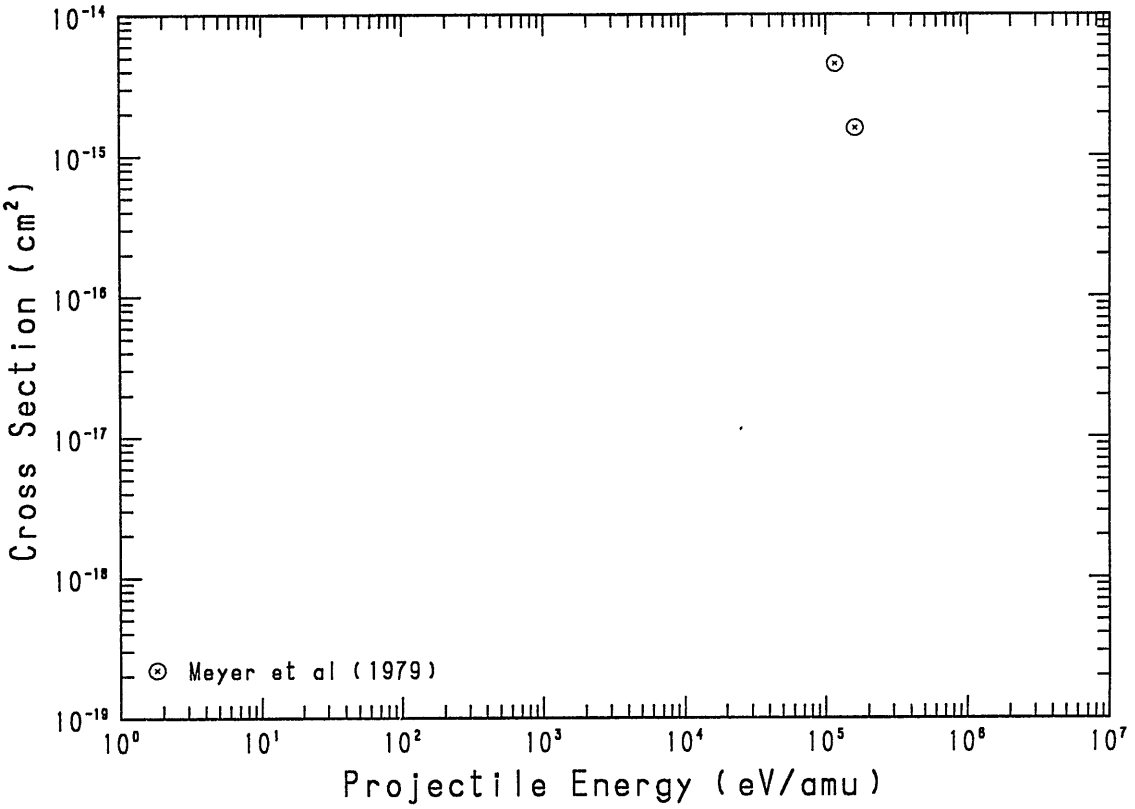


Fig.97 $Mo^{18+} + H \rightarrow Mo^{17+}$

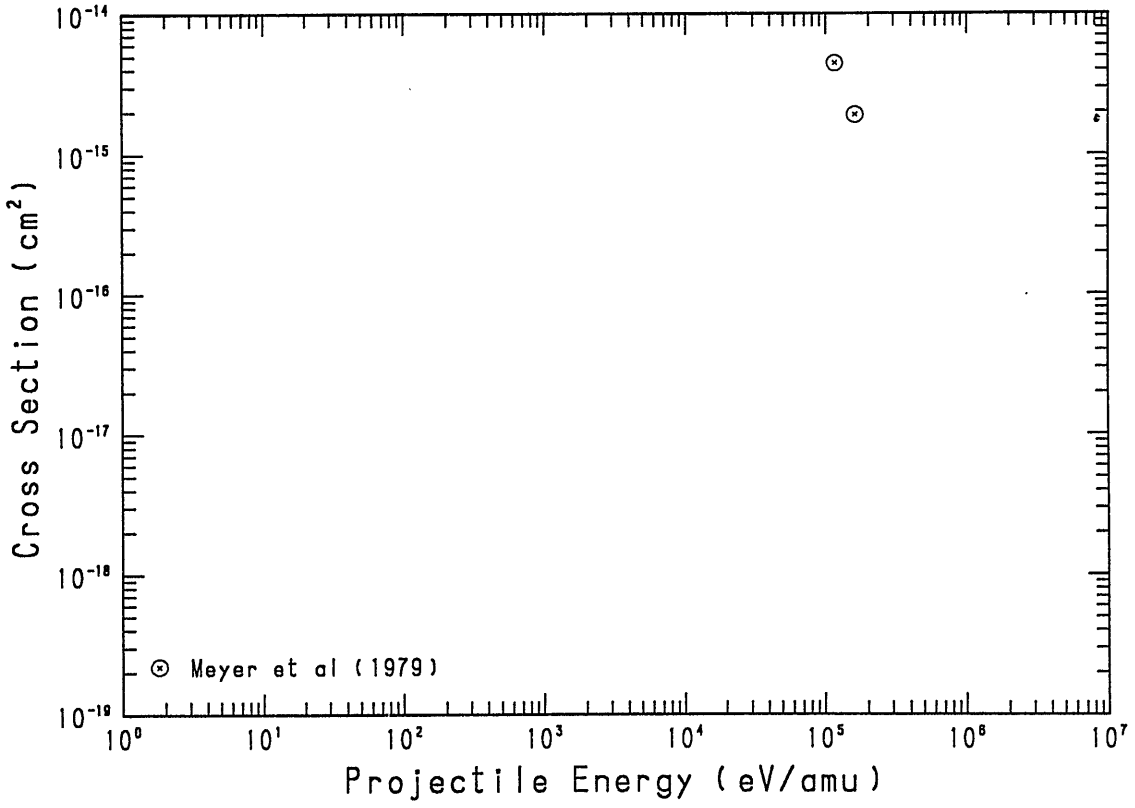


Fig.98 $Cd^{2+} + H \rightarrow Cd^{+}$

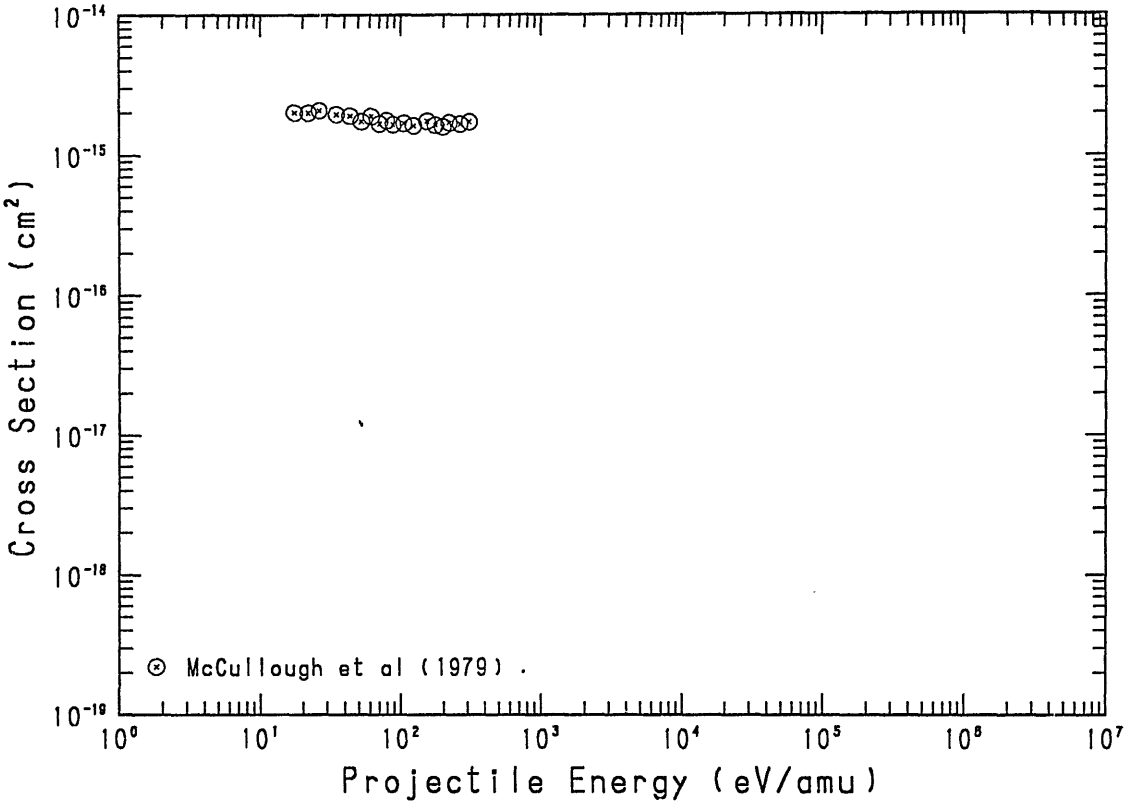


Fig.99 $Xe^{2+} + H \rightarrow Xe^{+}$

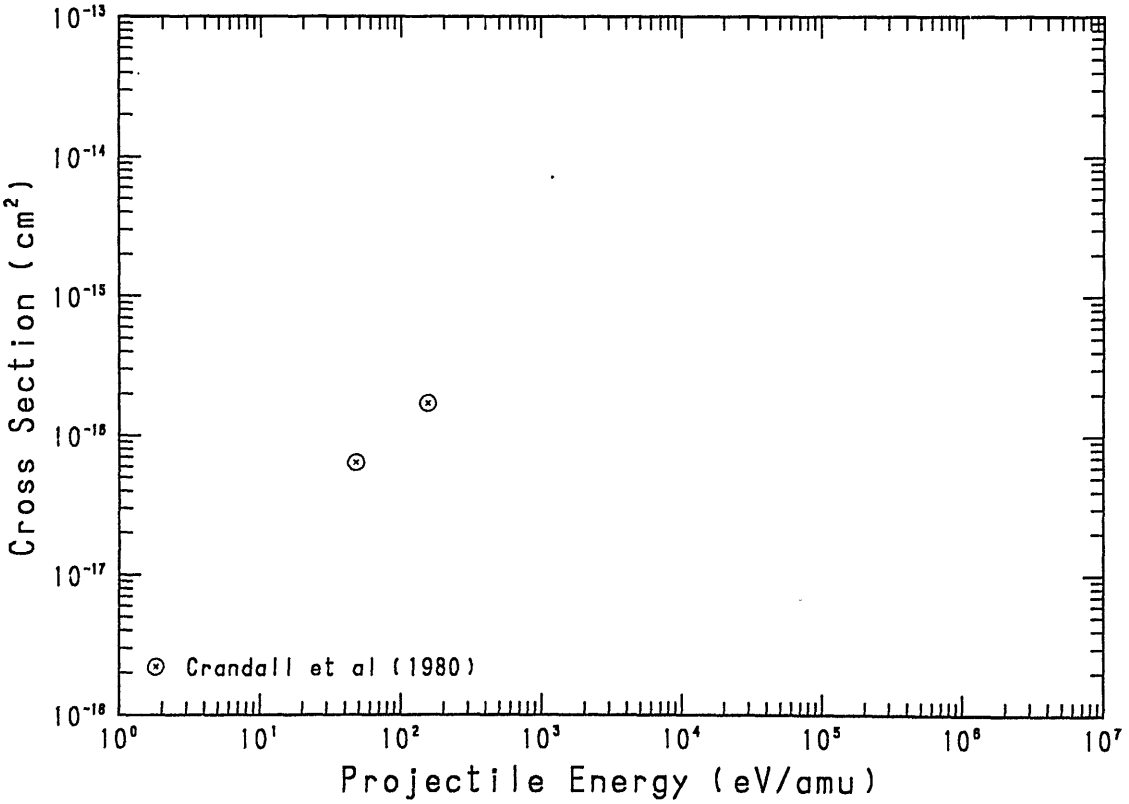


Fig.100 $Xe^{3+} + H \rightarrow Xe^{2+}$

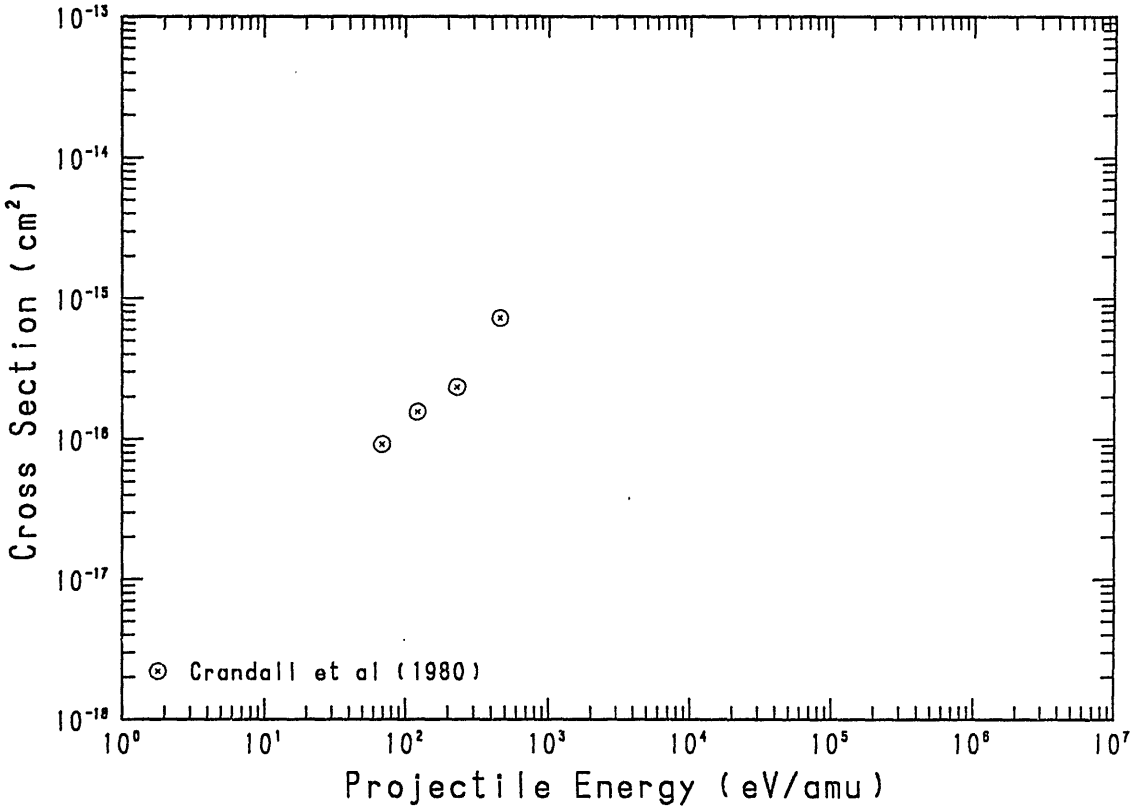


Fig.101 $Xe^{4+} + H \rightarrow Xe^{3+}$

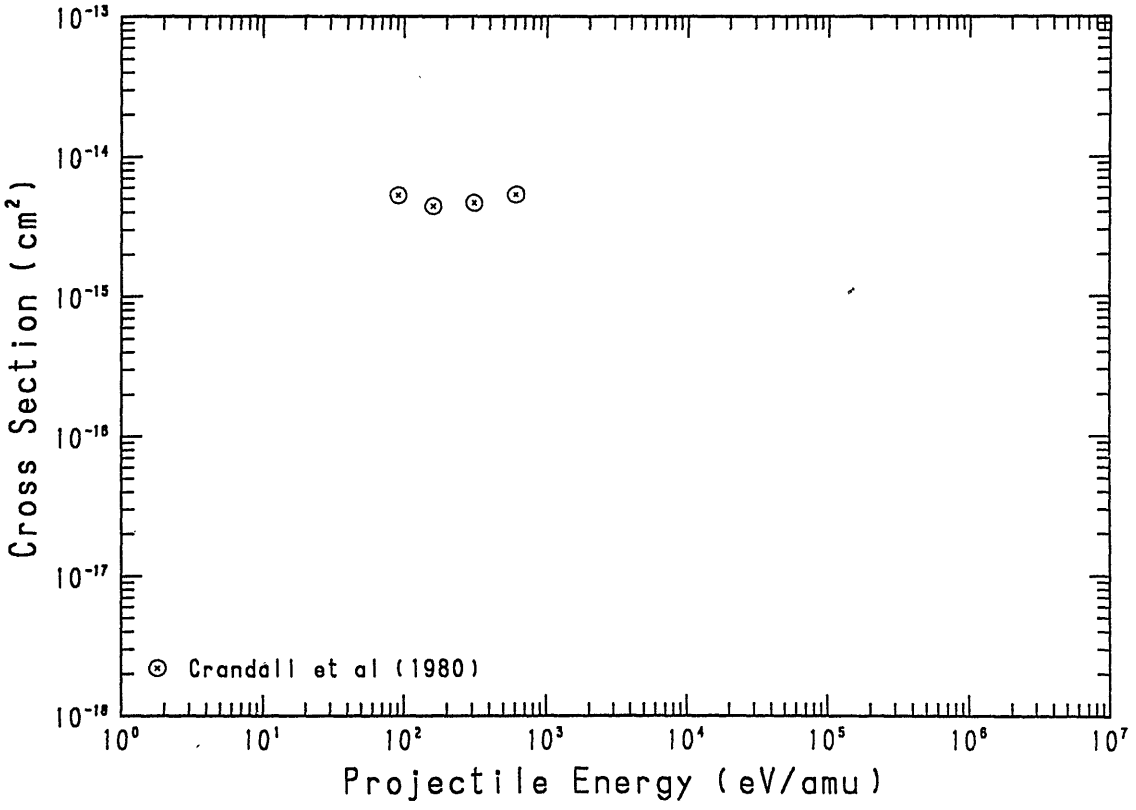


Fig.102 $Xe^{5+} + H \rightarrow Xe^{4+}$

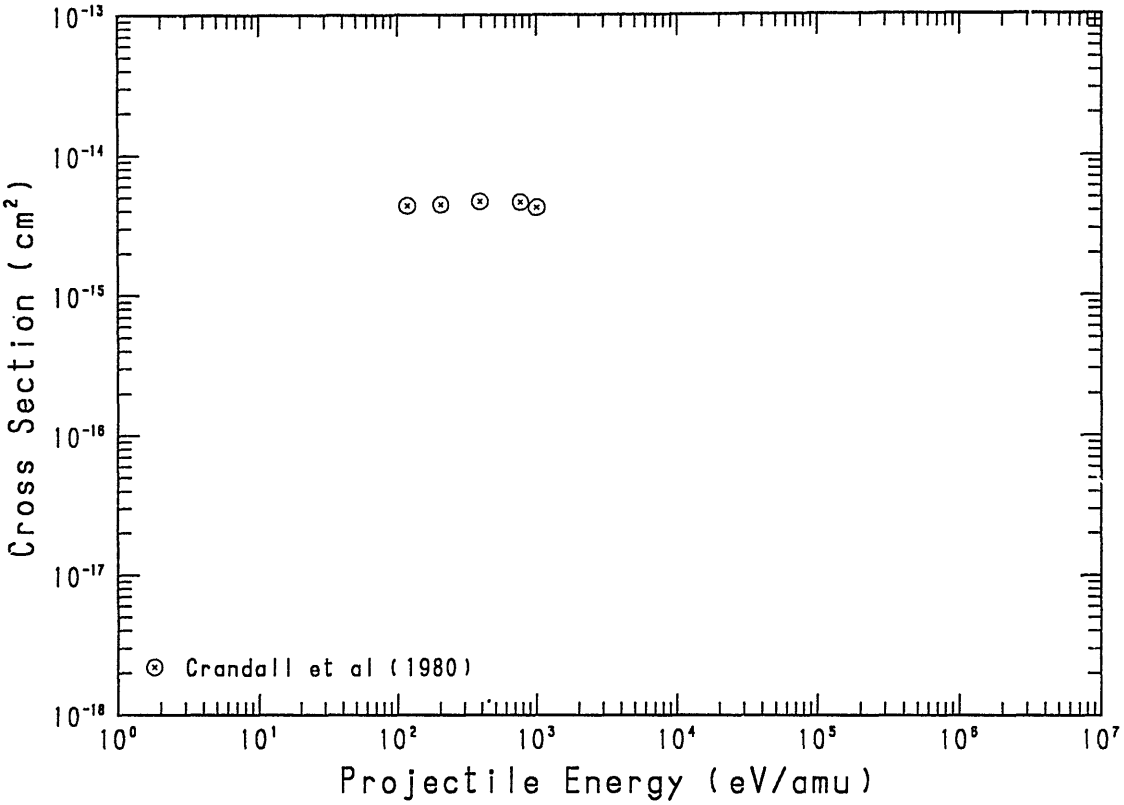


Fig.103 $Xe^{6+} + H \rightarrow Xe^{5+}$

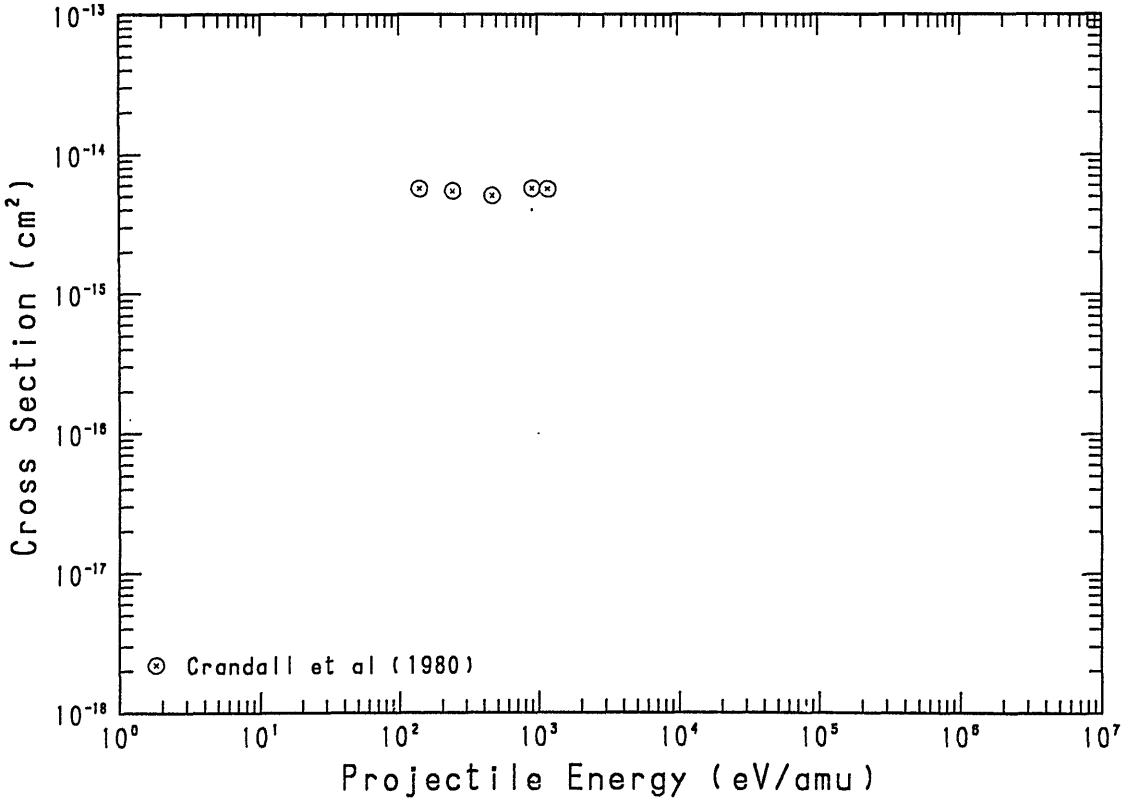


Fig.104 $Xe^{7+} + H \rightarrow Xe^{6+}$

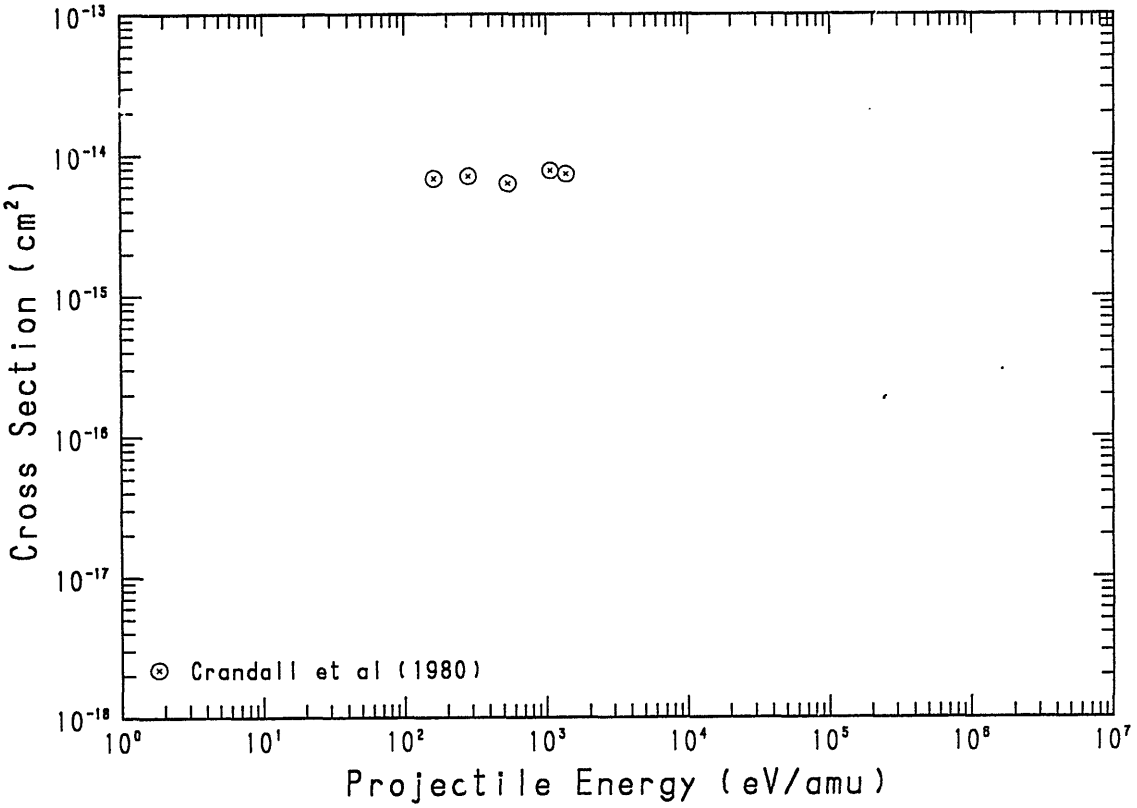


Fig.105 $Xe^{8+} + H \rightarrow Xe^{7+}$

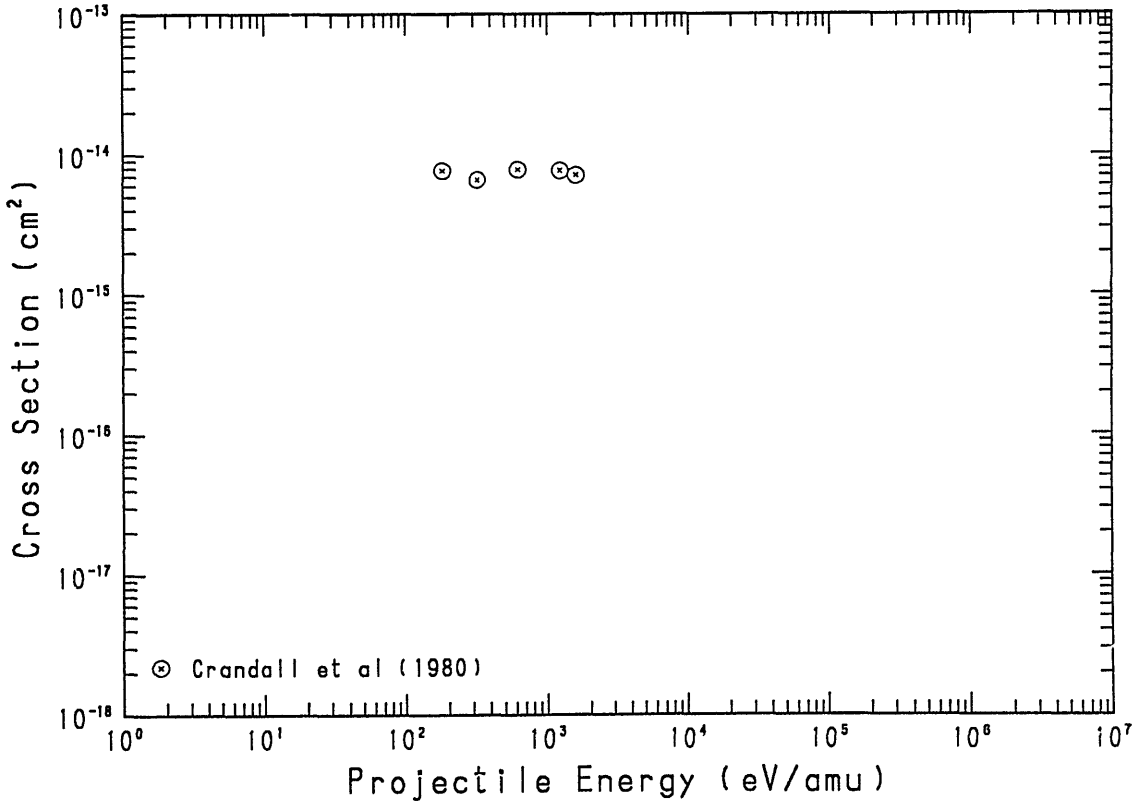


Fig.106 $Xe^{9+} + H \rightarrow Xe^{8+}$

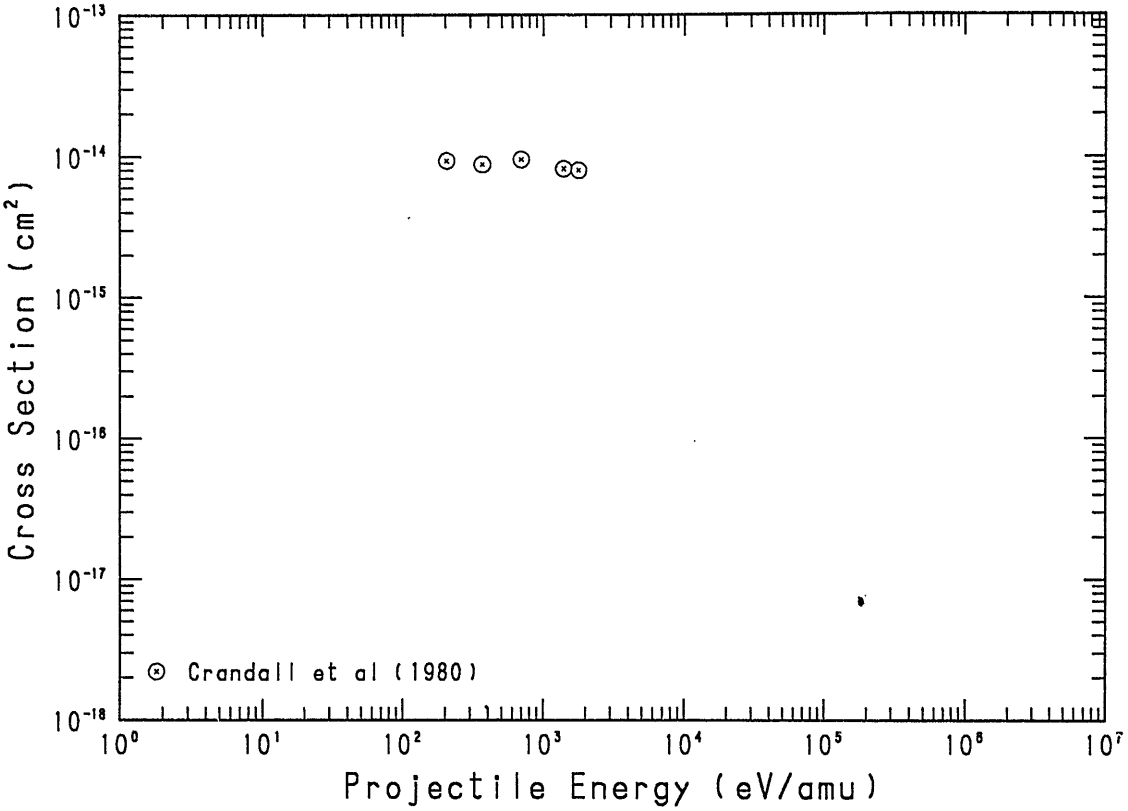


Fig.107 $Xe^{10+} + H \rightarrow Xe^{9+}$

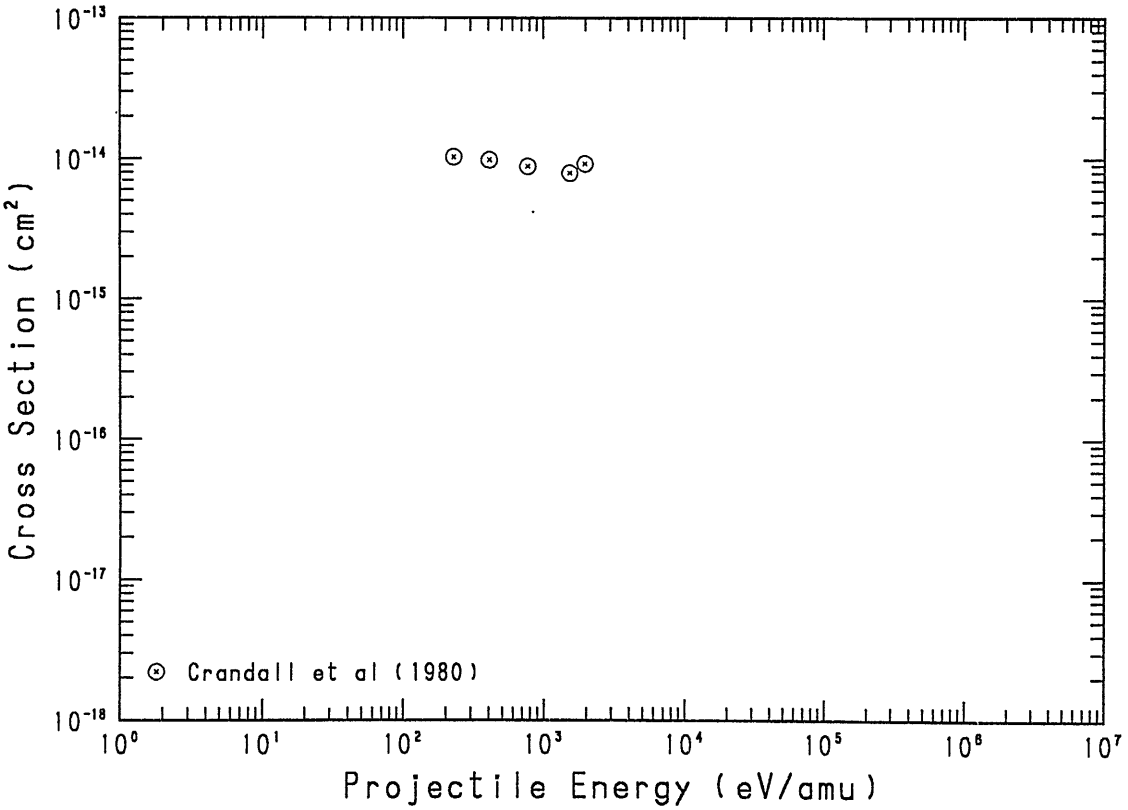


Fig.108 $Xe^{11+} + H \rightarrow Xe^{10+}$

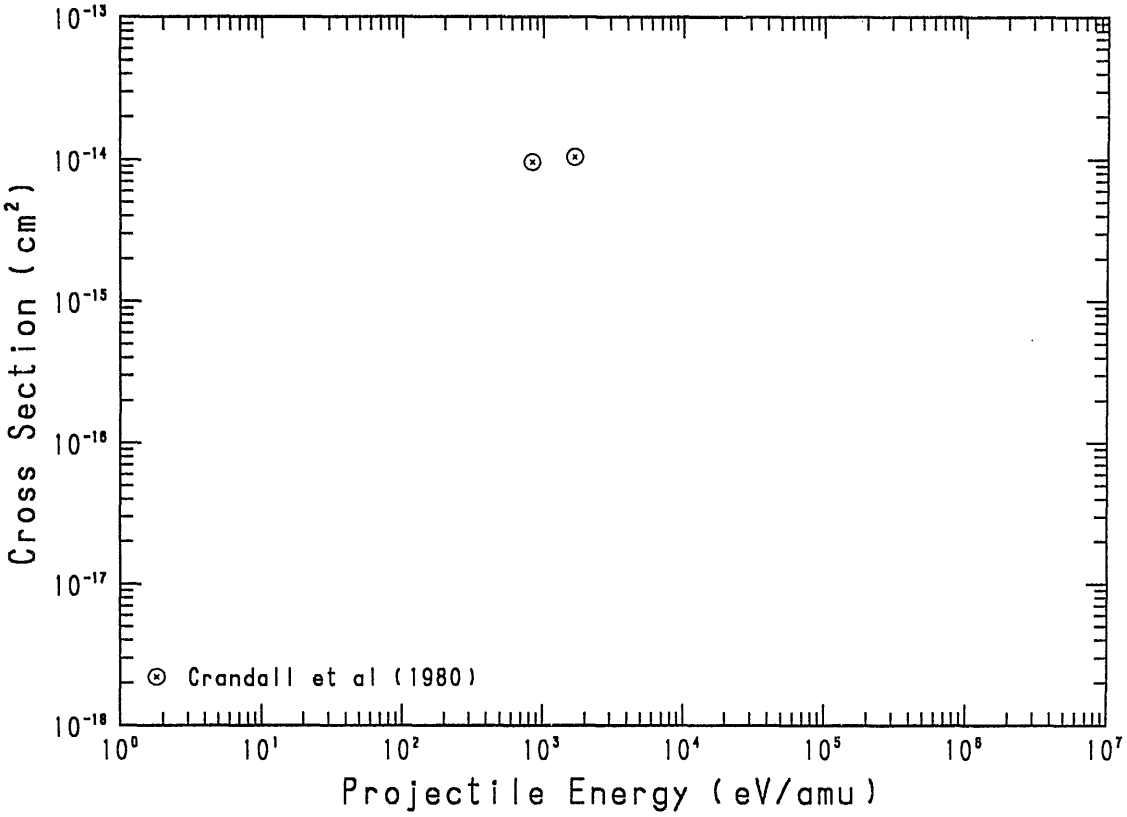


Fig.109 $Xe^{12+} + H \rightarrow Xe^{11+}$

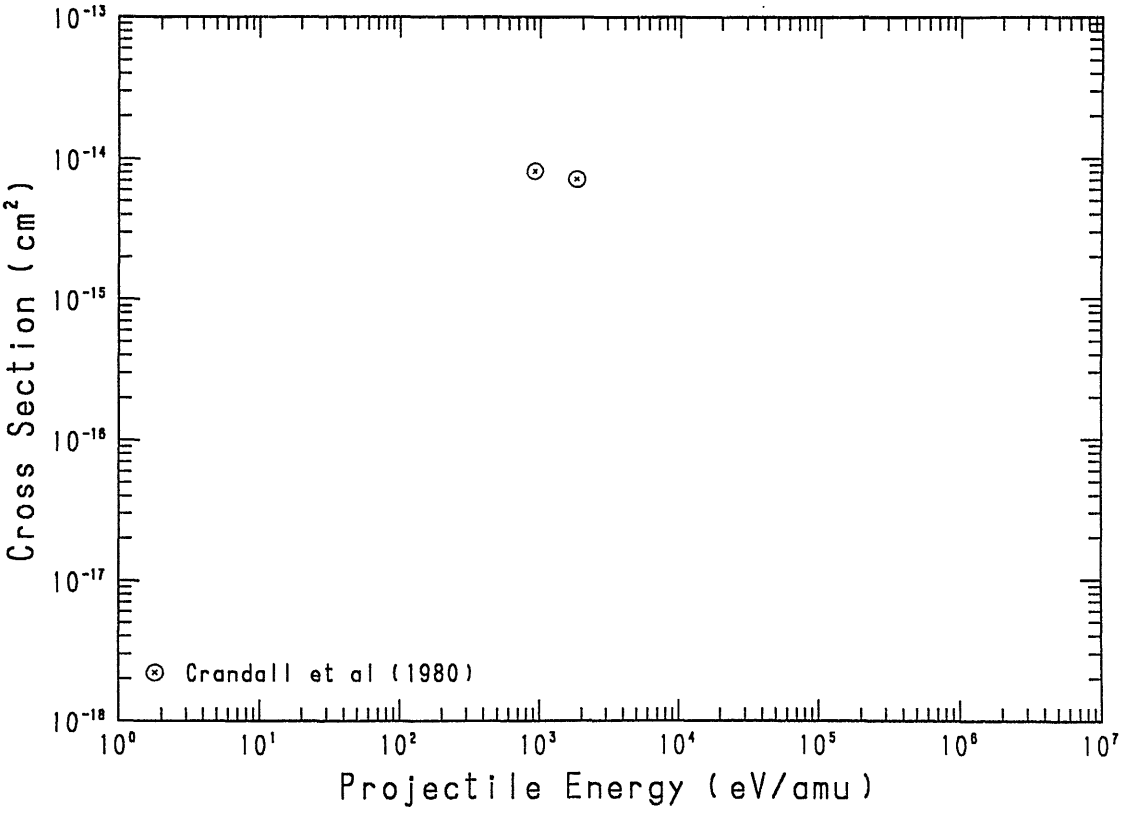


Fig.110 $Ba^{2+} + H \rightarrow Ba^{+}$

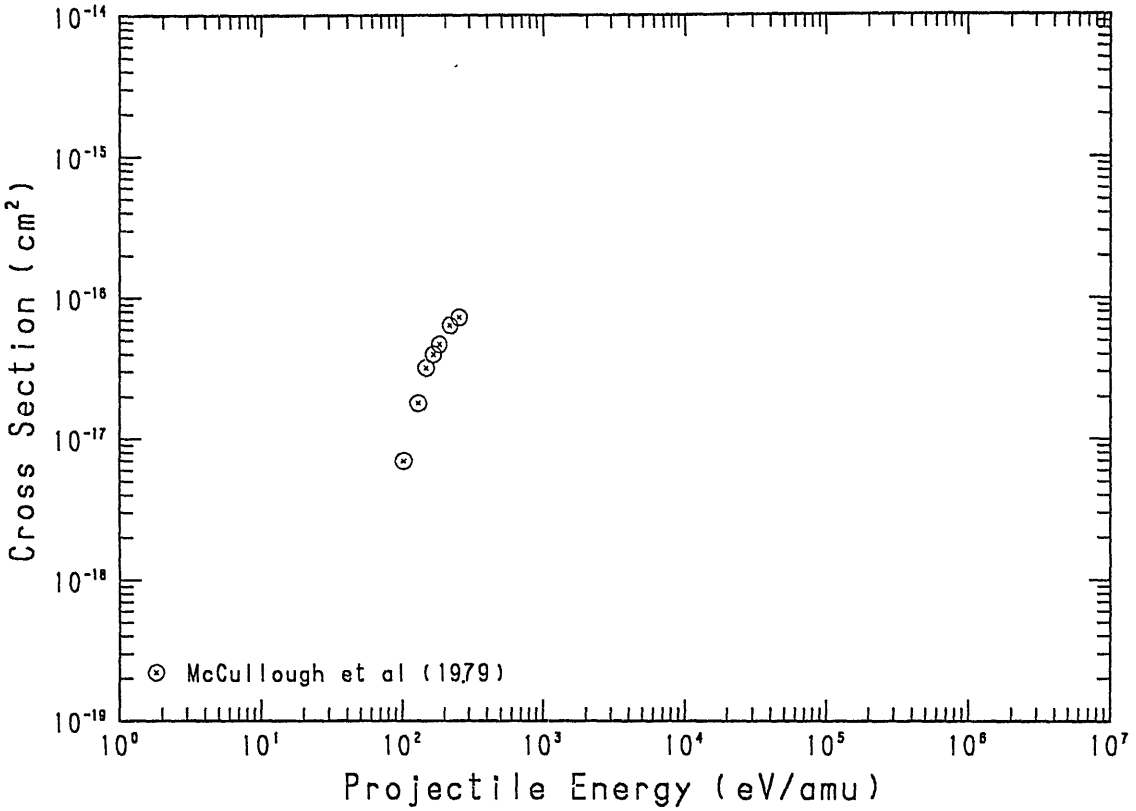


Fig.111 $Ta^{3+} + H \rightarrow Ta^{2+}$

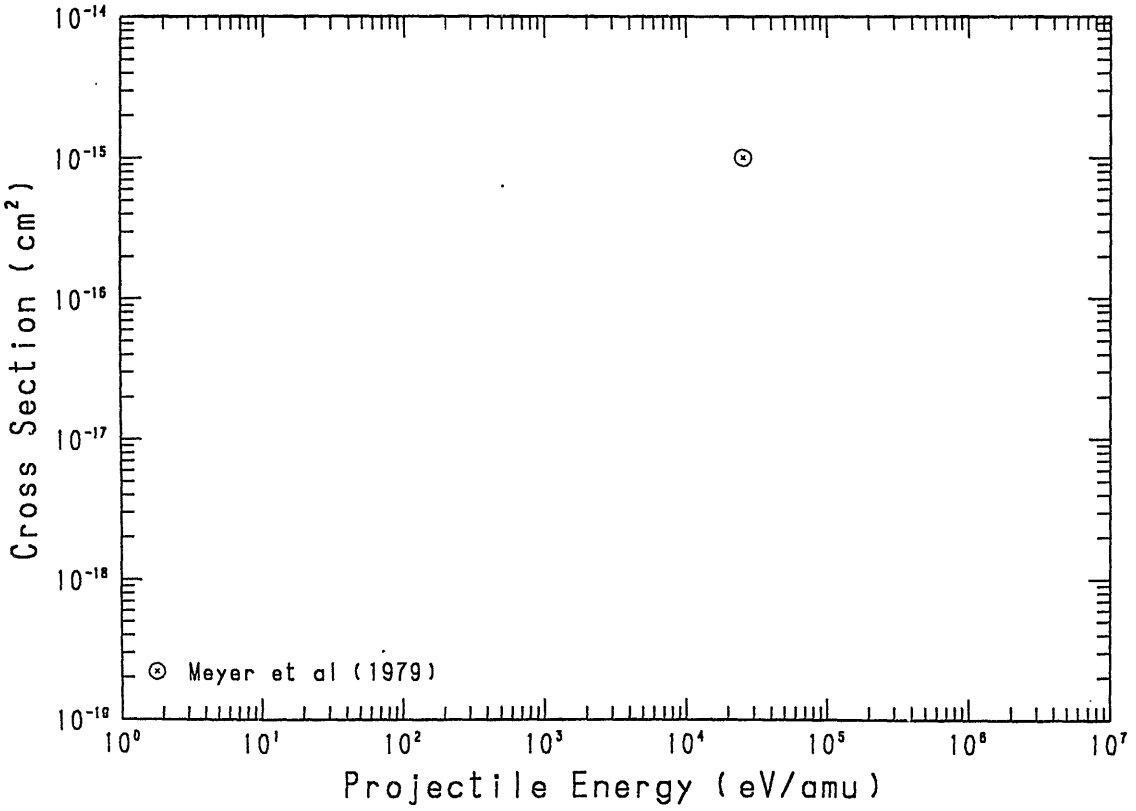


Fig.112 $Ta^{4+} + H \rightarrow Ta^{3+}$

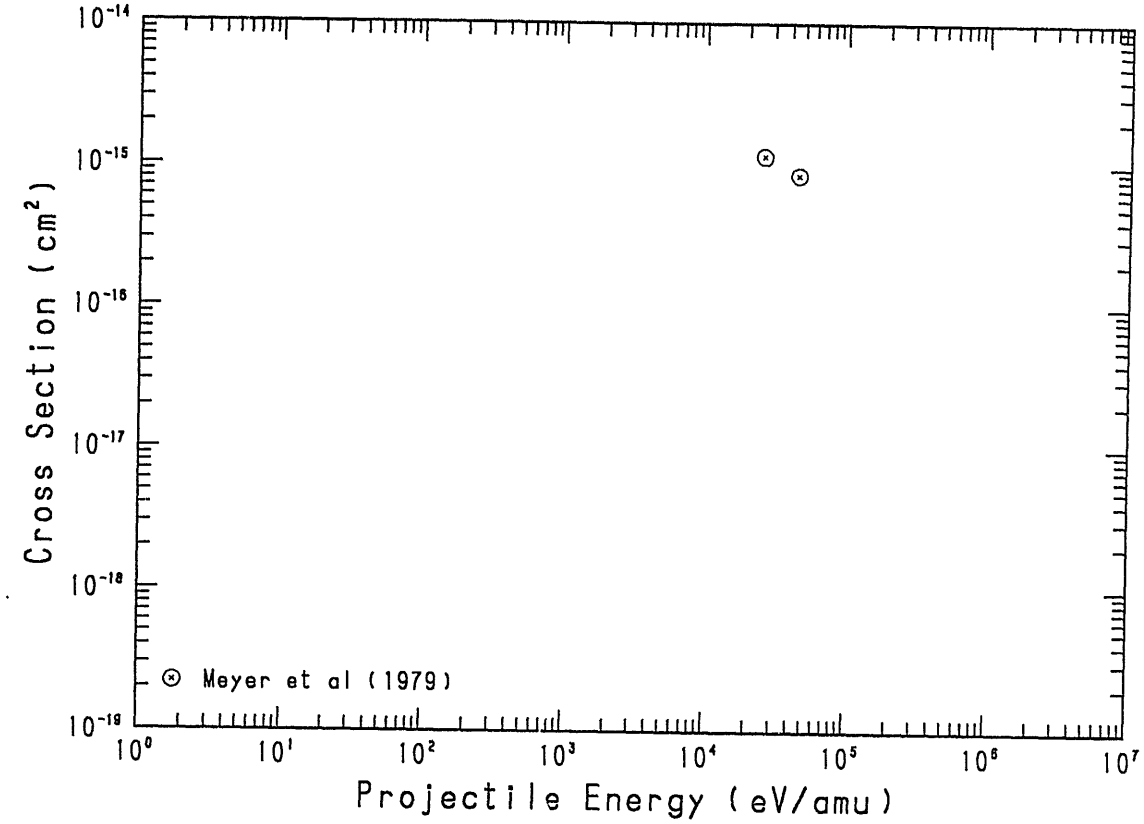


Fig.113 $Ta^{5+} + H \rightarrow Ta^{4+}$

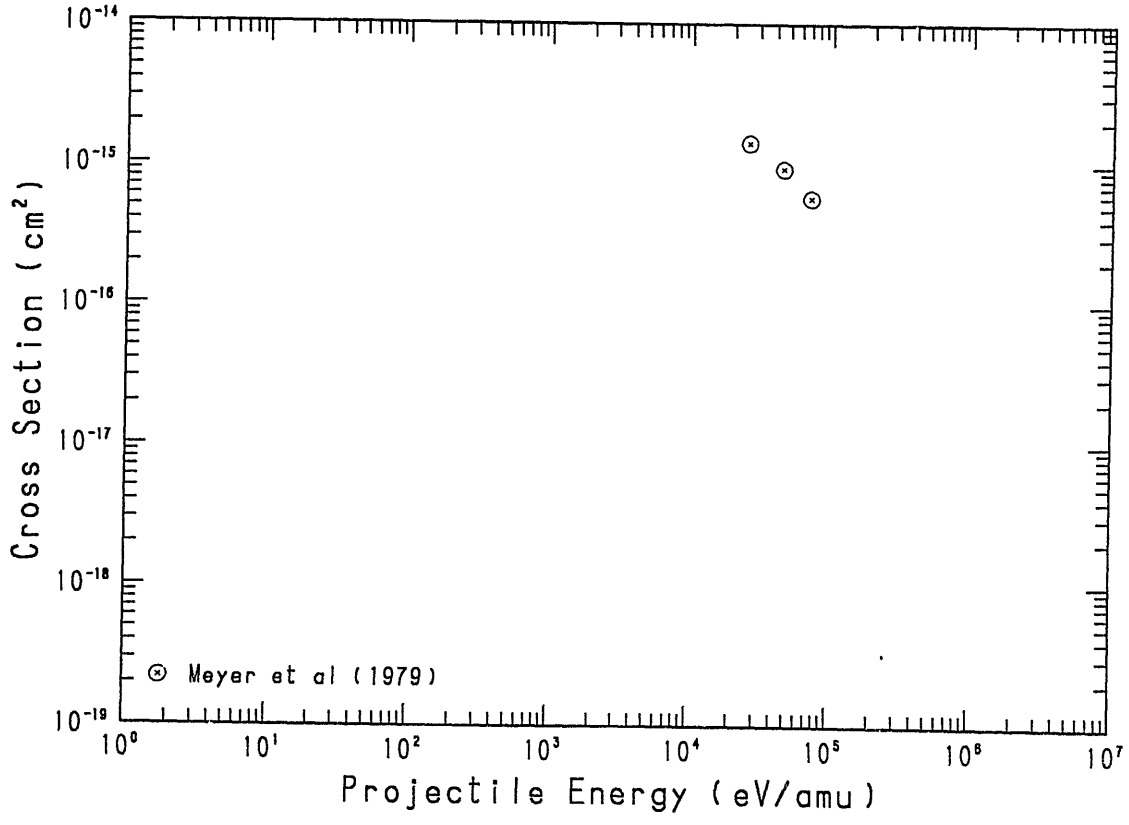


Fig.114 $Ta^{6+} + H \rightarrow Ta^{5+}$

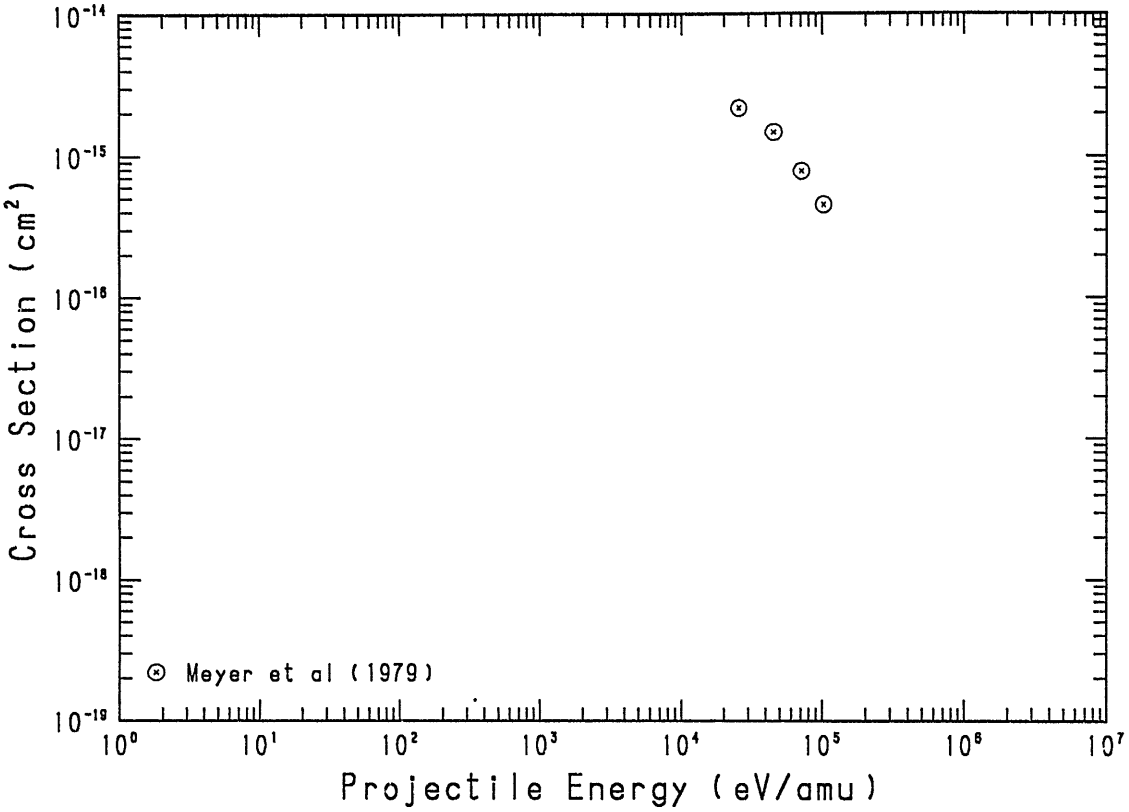


Fig.115 $Ta^{7+} + H \rightarrow Ta^{6+}$

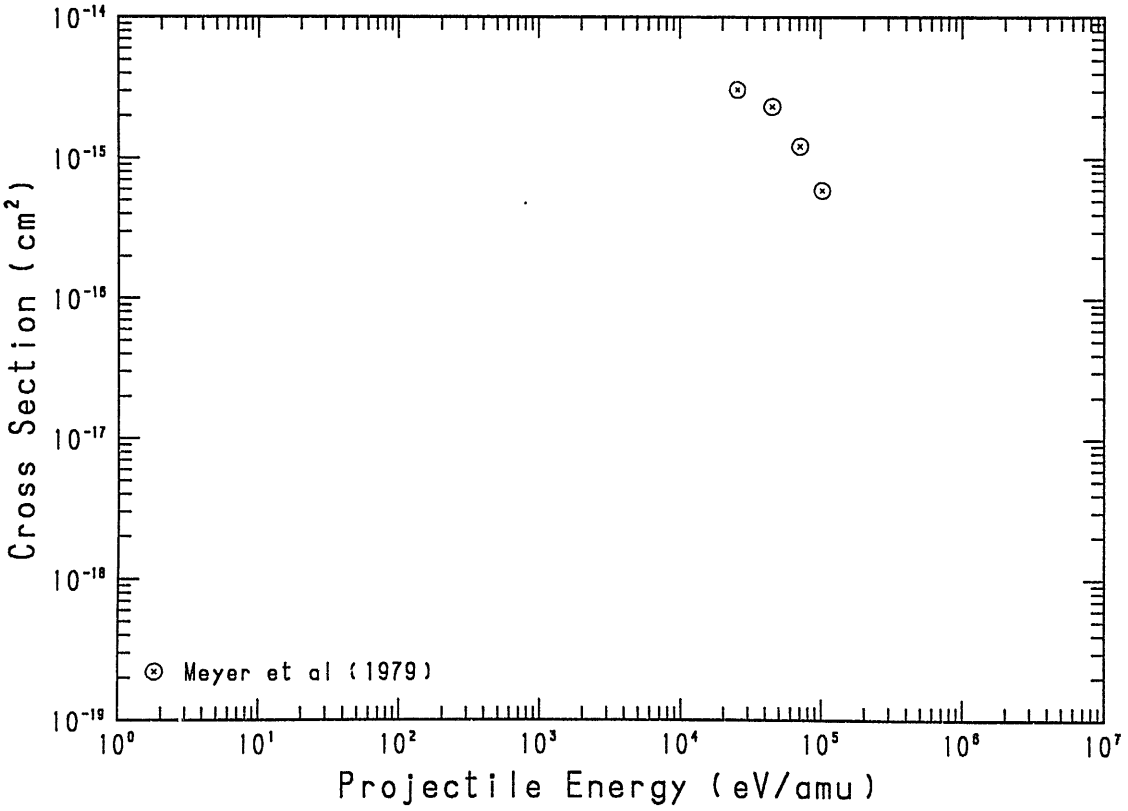


Fig.116. $Ta^{8+} + H \rightarrow Ta^{7+}$

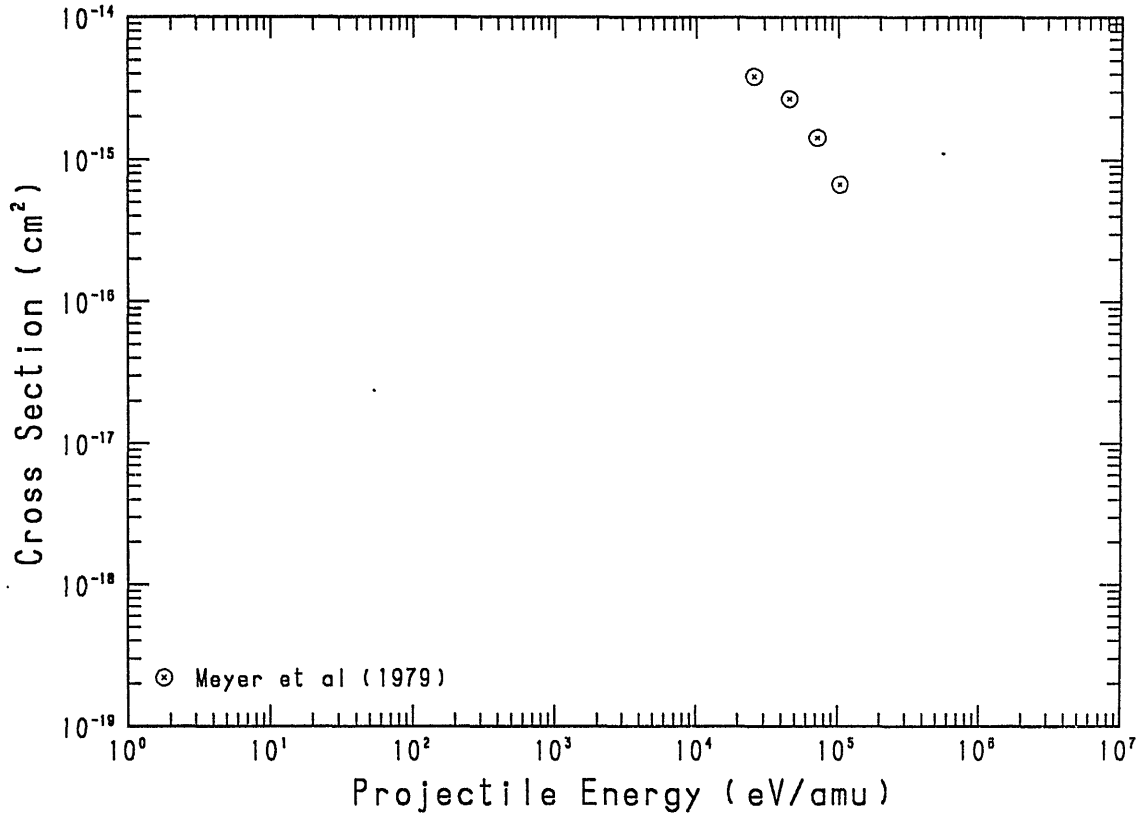


Fig.117 $Ta^{9+} + H \rightarrow Ta^{8+}$

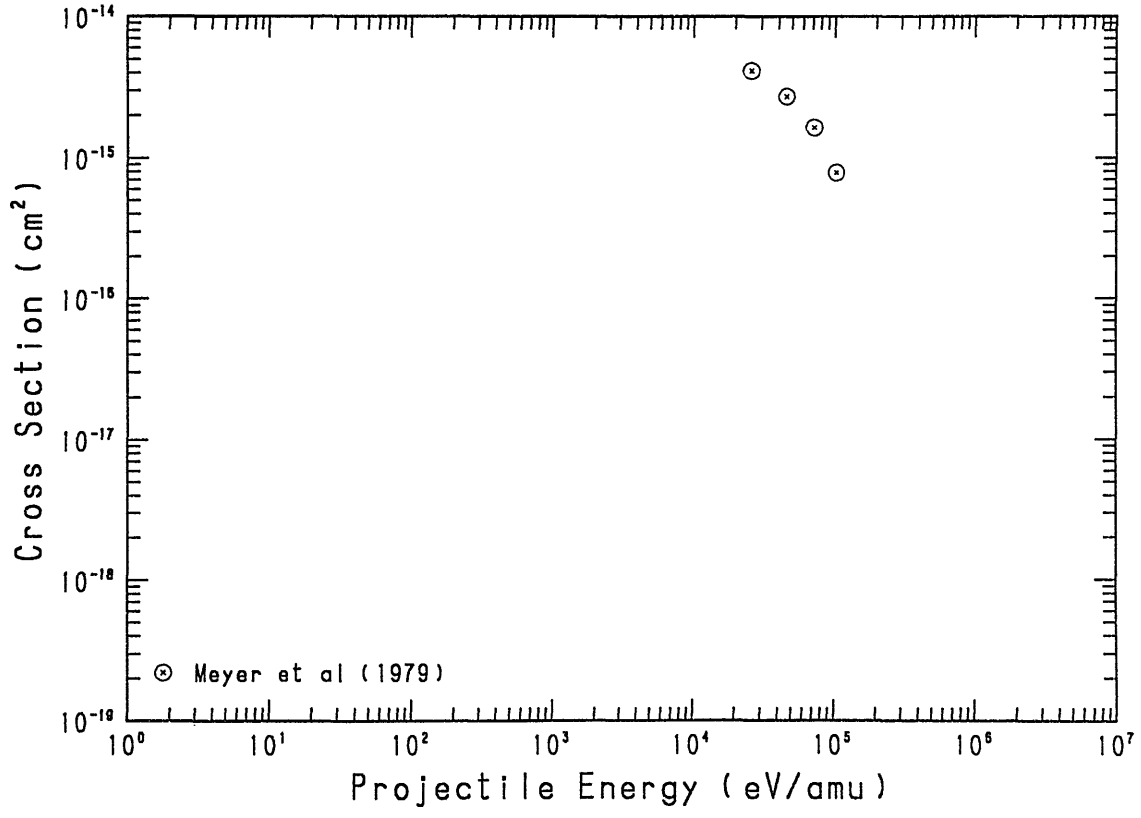


Fig.118 $Ta^{10+} + H \rightarrow Ta^{9+}$

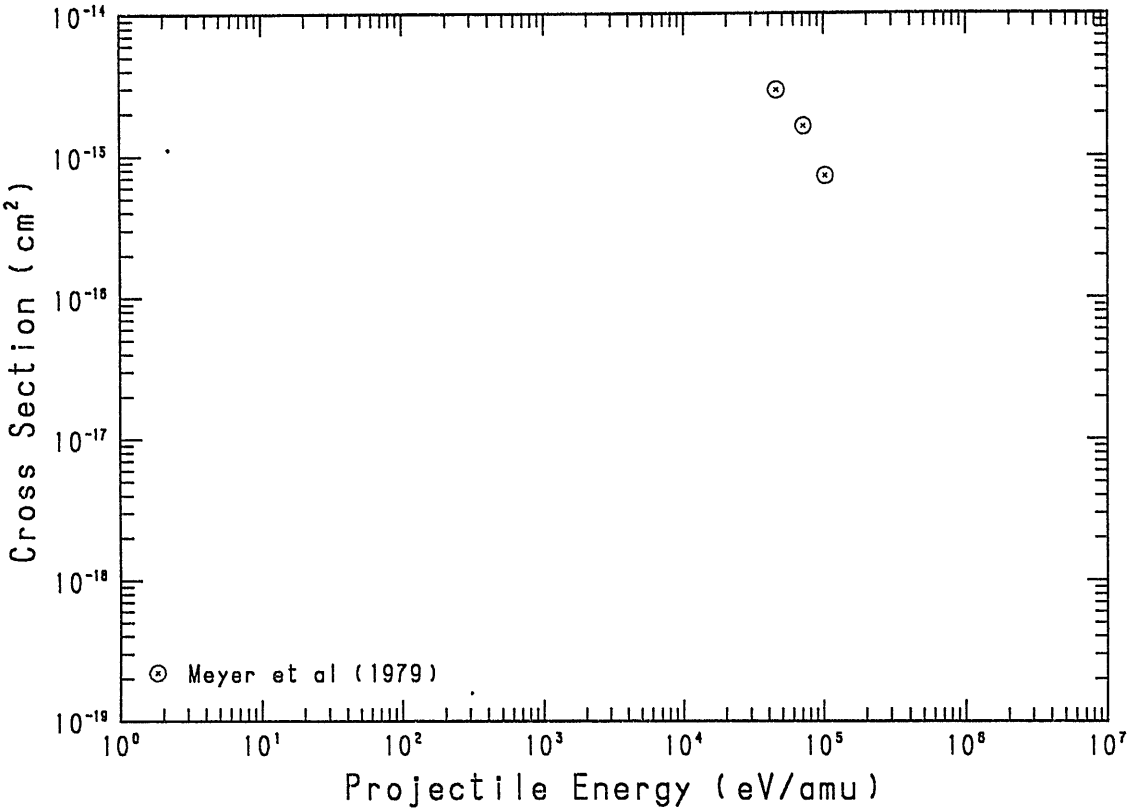


Fig.119 $Ta^{11+} + H \rightarrow Ta^{10+}$

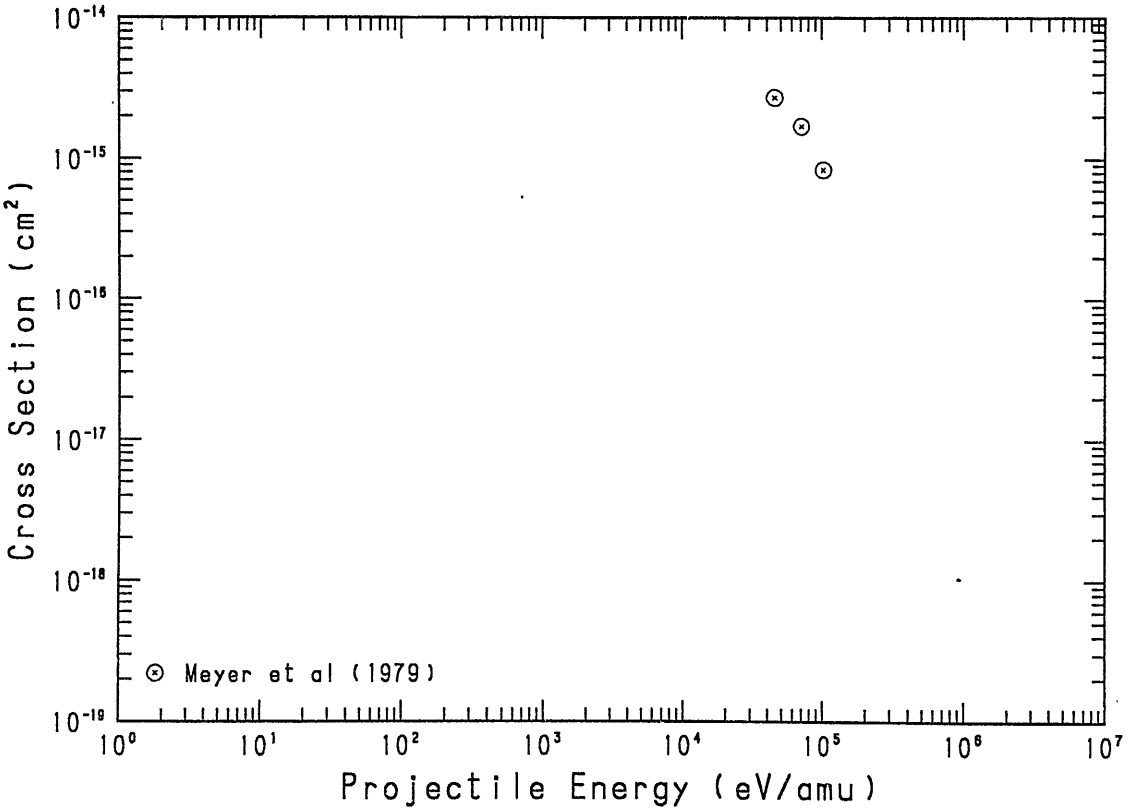


Fig.120 $Ta^{12+} + H \rightarrow Ta^{11+}$

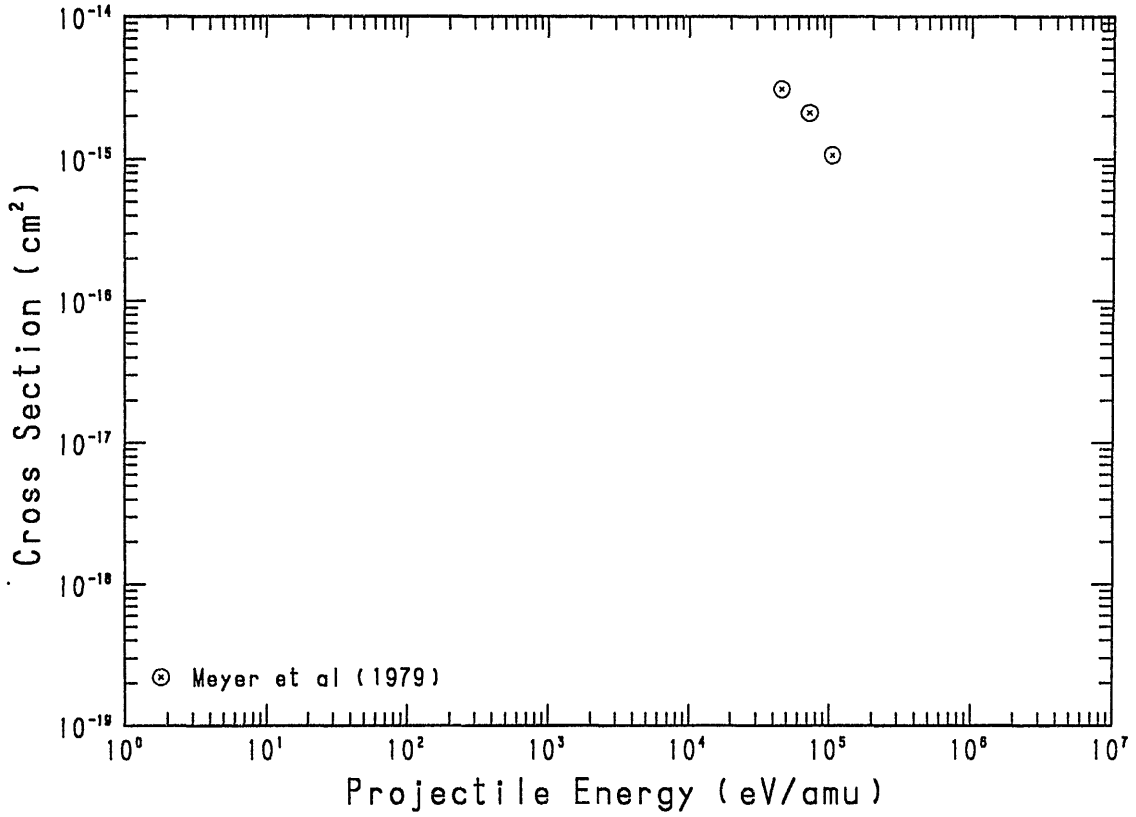


Fig.121 $Ta^{13+} + H \rightarrow Ta^{12+}$

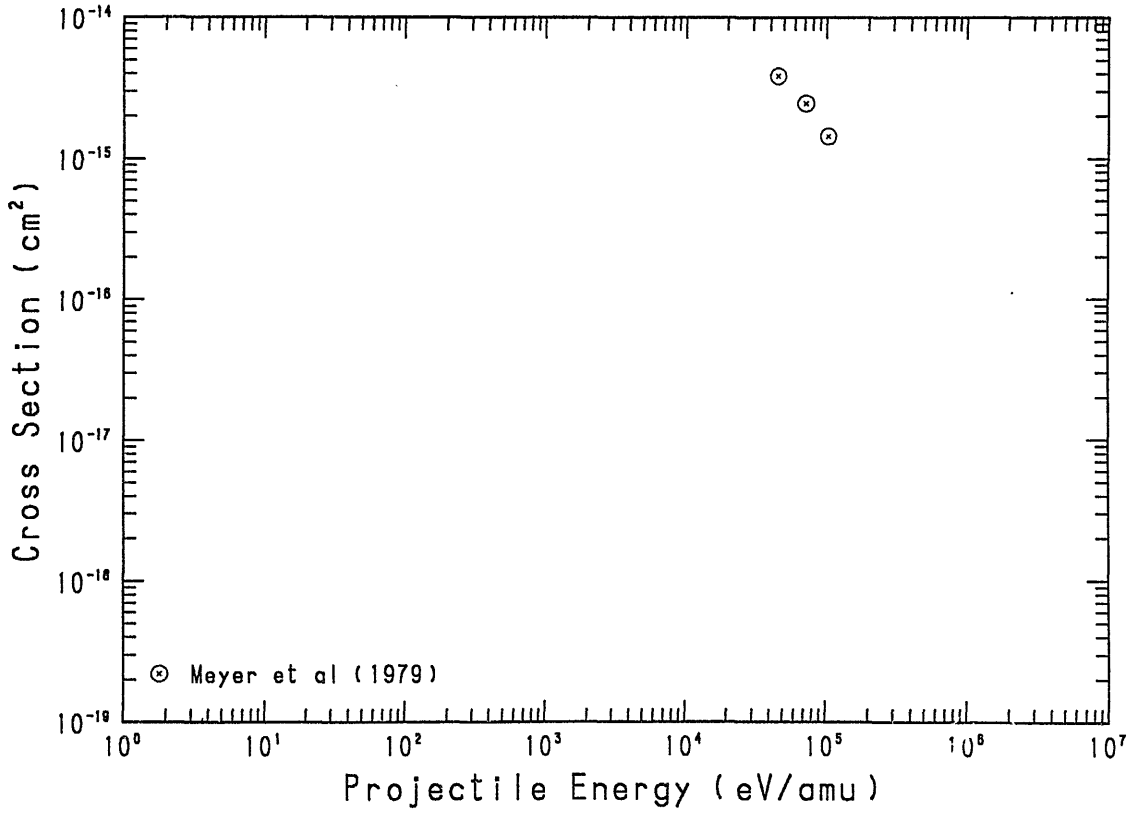


Fig.122 $Ta^{14+} + H \rightarrow Ta^{13+}$

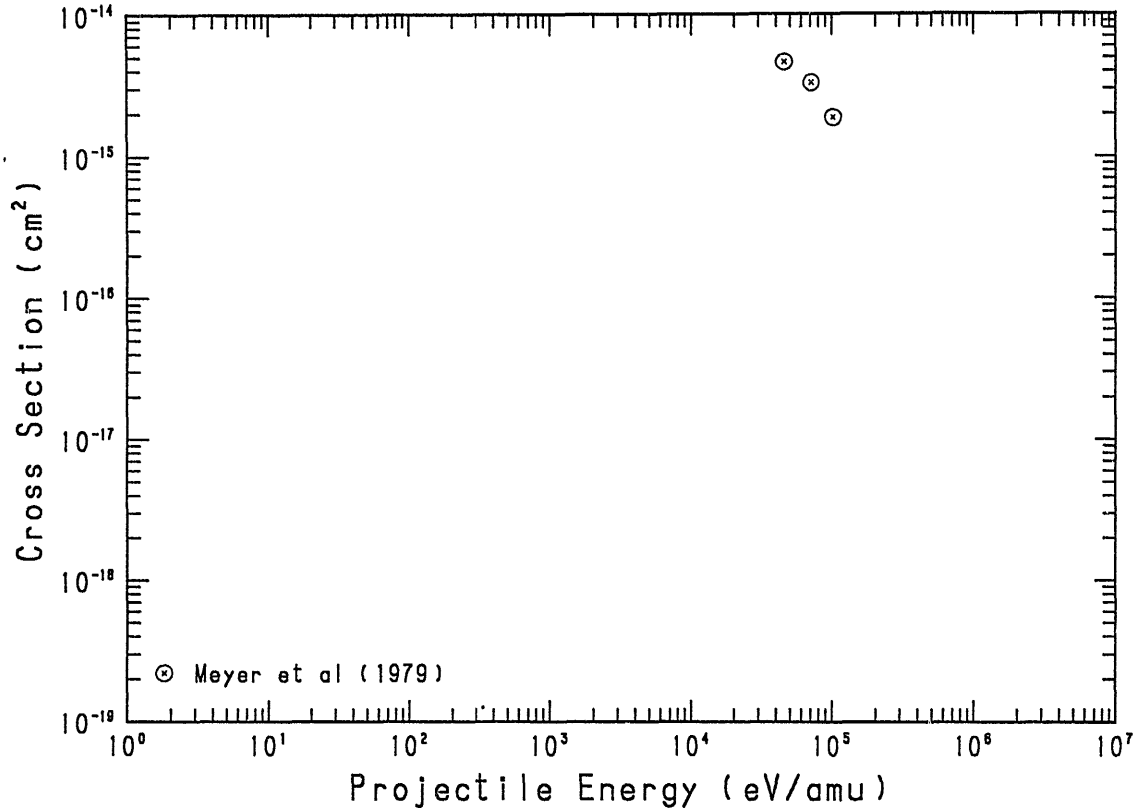


Fig.123 $Ta^{15+} + H \rightarrow Ta^{14+}$

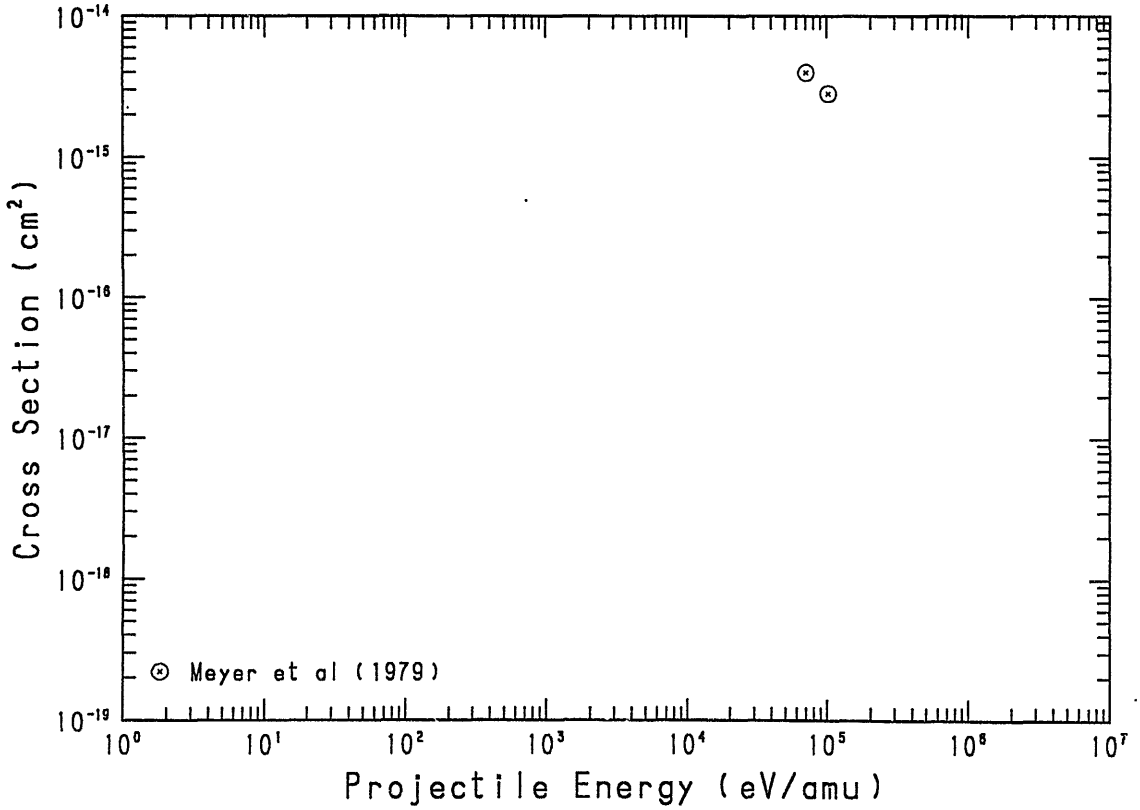


Fig.124 $Ta^{16+} + H \rightarrow Ta^{15+}$

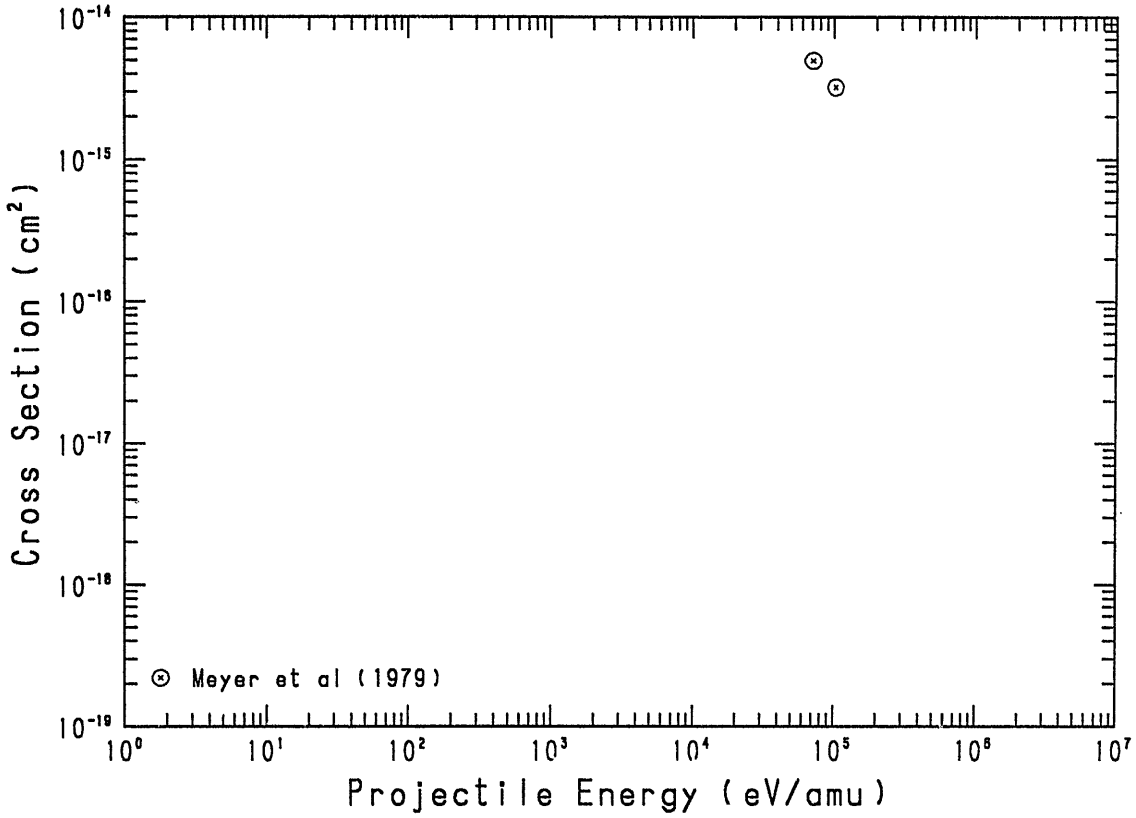


Fig.125 $Ta^{17+} + H \rightarrow Ta^{16+}$

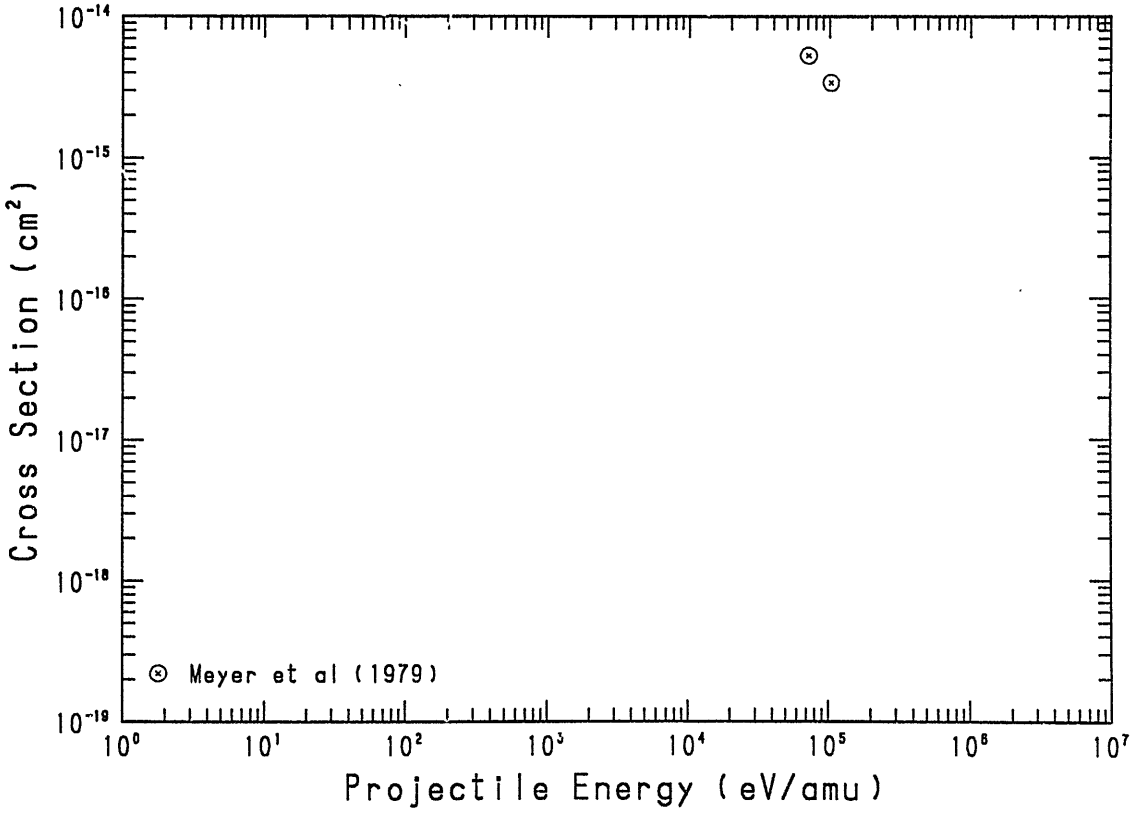


Fig.126 $Ta^{18+} + H \rightarrow Ta^{17+}$

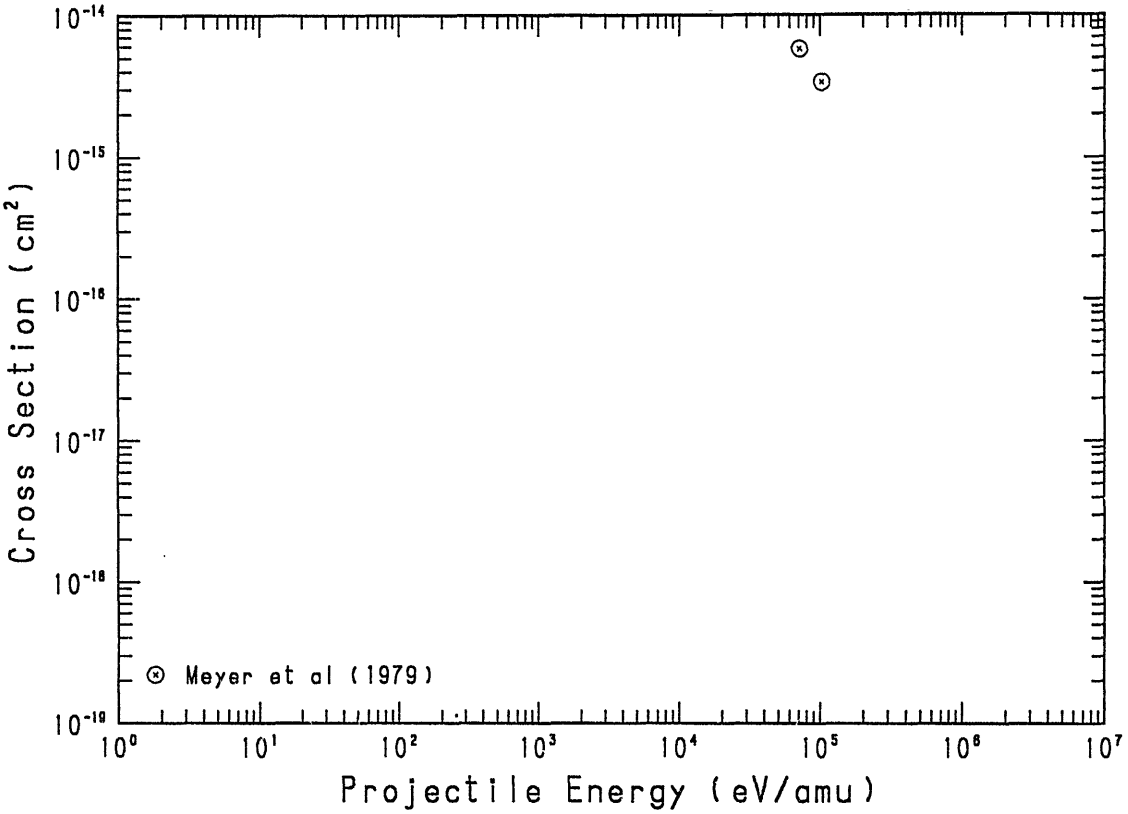


Fig.127 $Ta^{19+} + H \rightarrow Ta^{18+}$

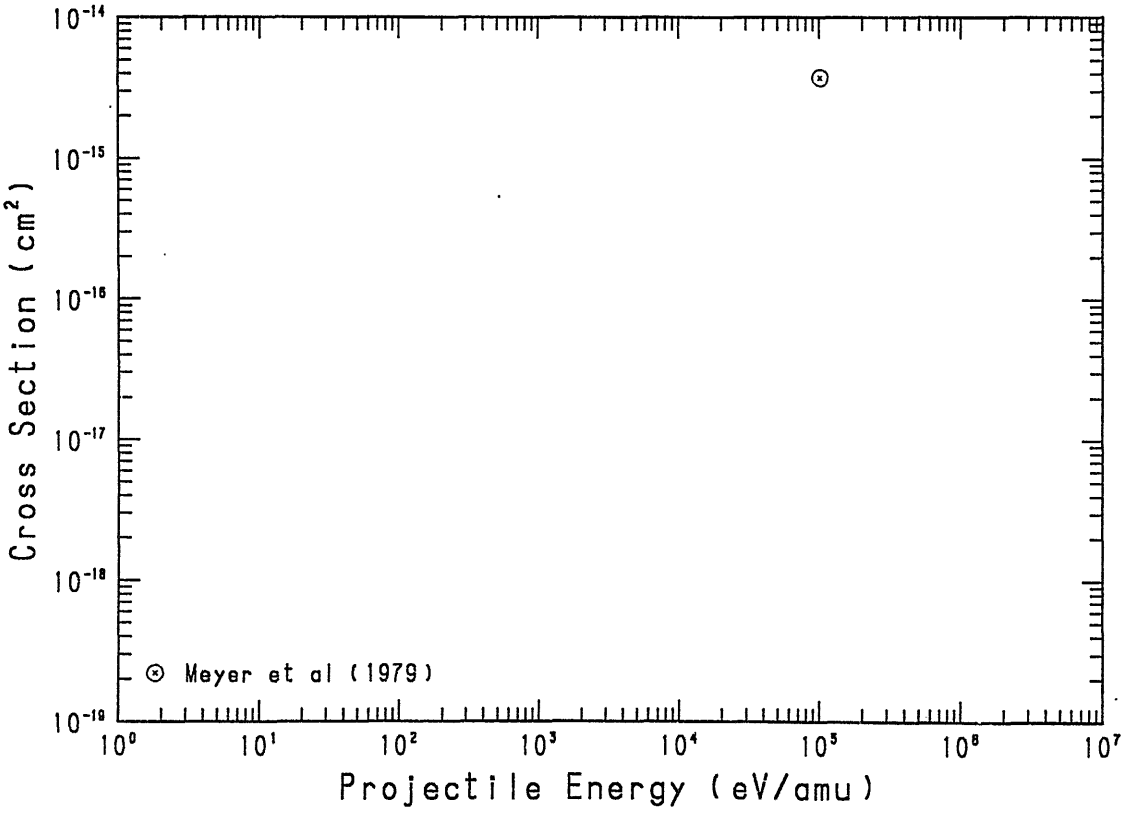


Fig.128 $W^{4+} + H \rightarrow W^{3+}$

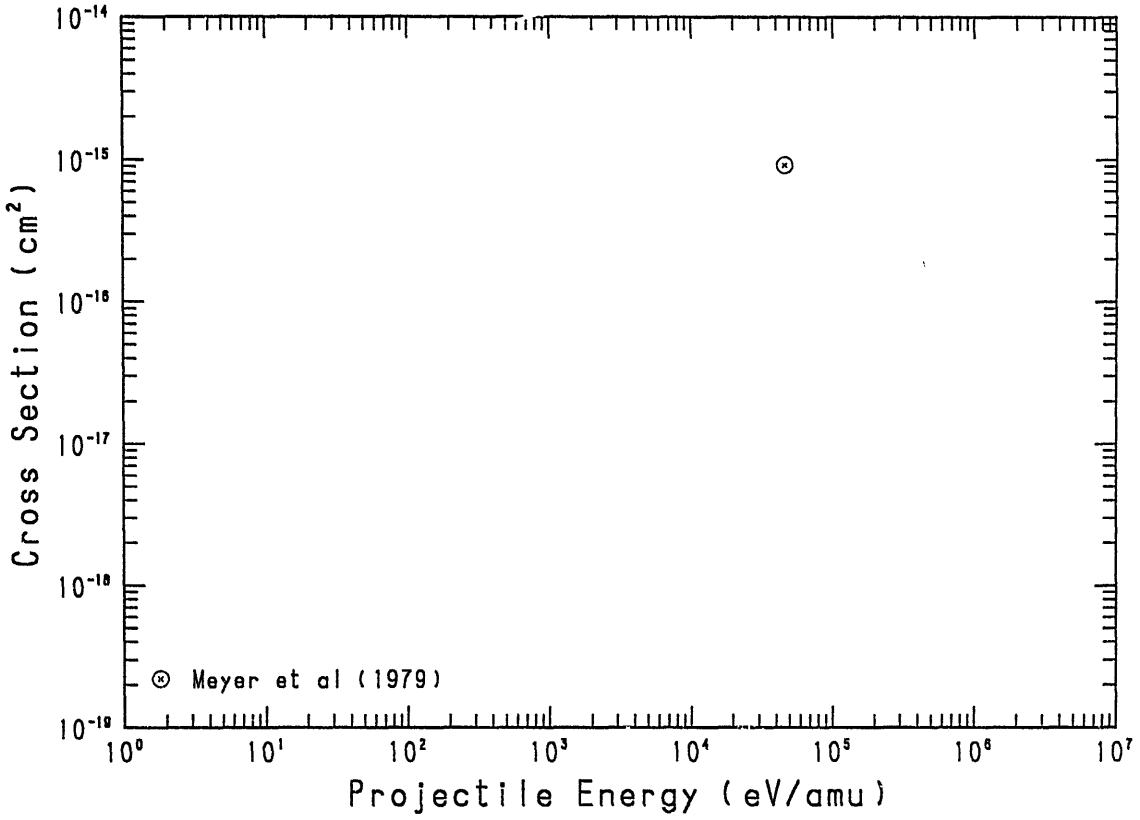


Fig.129 $W^{5+} + H \rightarrow W^{4+}$

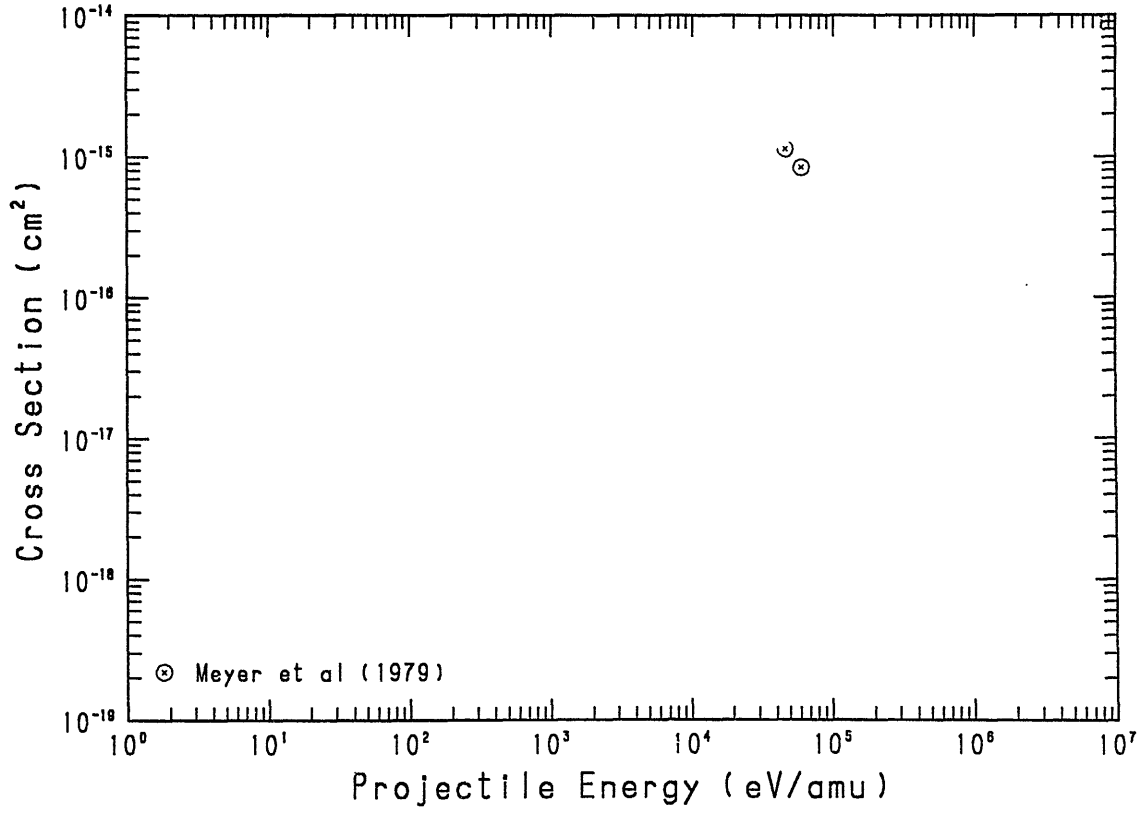


Fig.130 $W^{6+} + H \rightarrow W^{5+}$

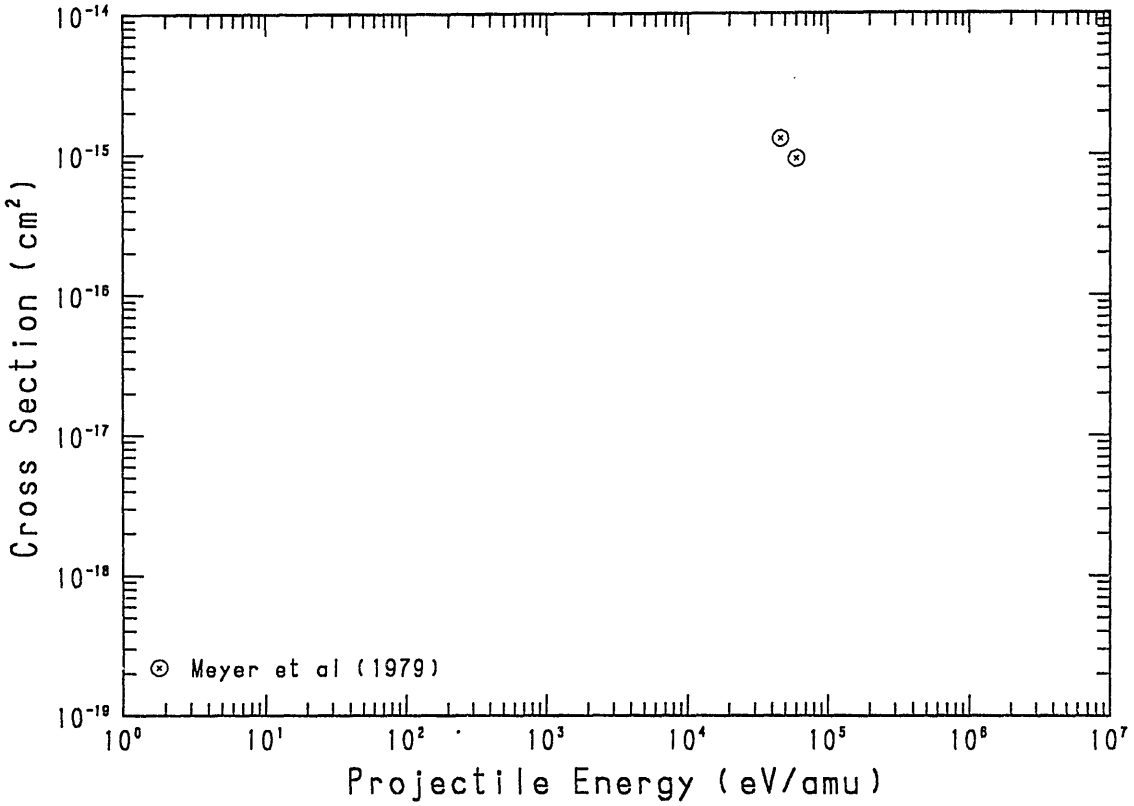


Fig.131 $W^{7+} + H \rightarrow W^{6+}$

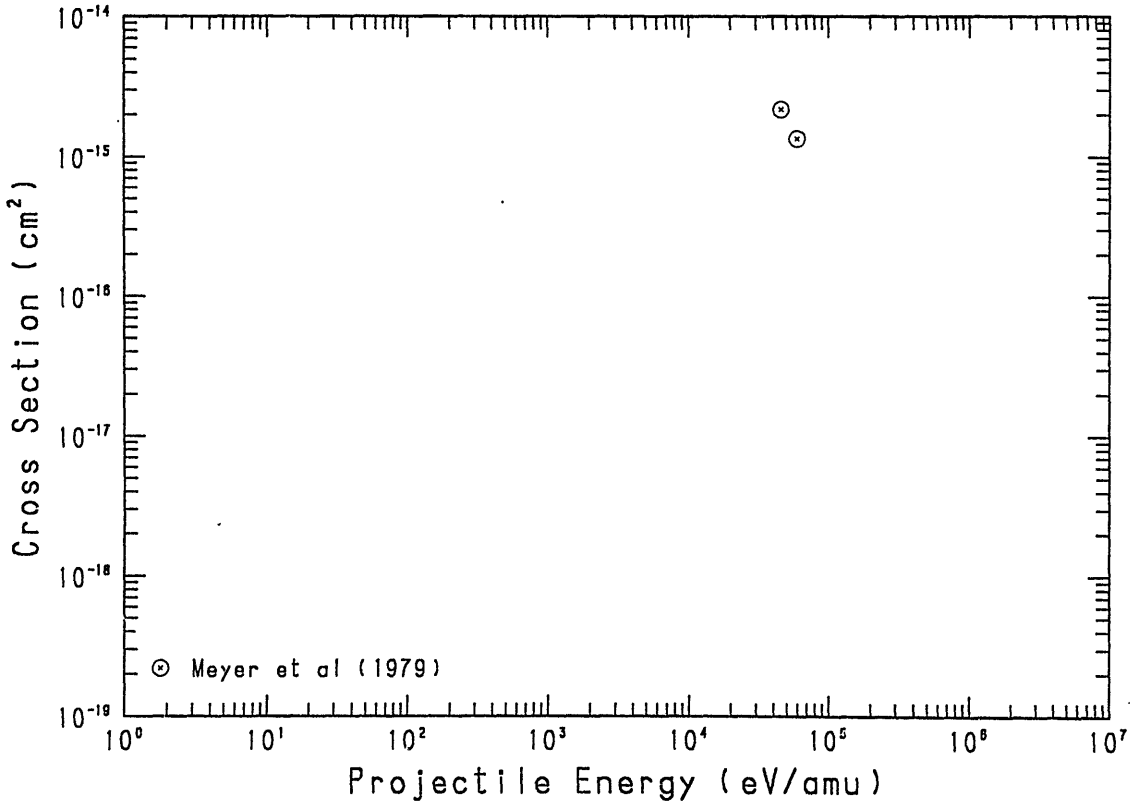


Fig.132 $W^{8+} + H \rightarrow W^{7+}$

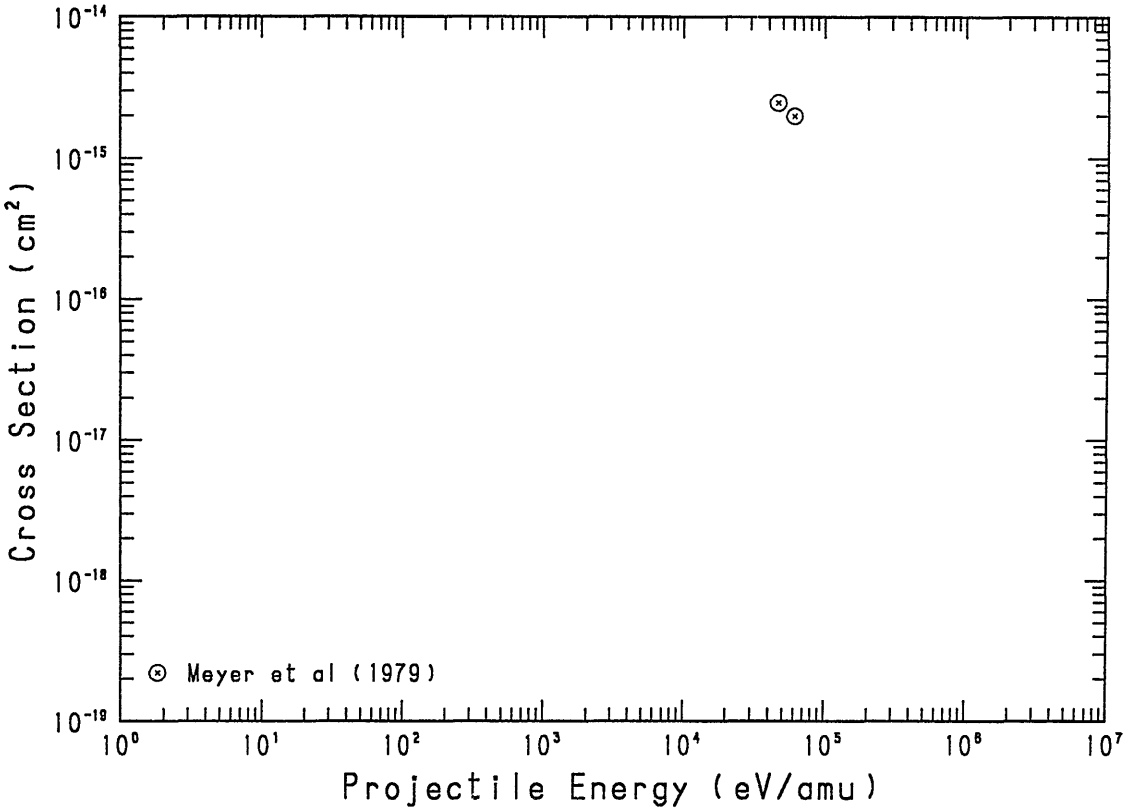


Fig.133 $W^{9+} + H \rightarrow W^{8+}$

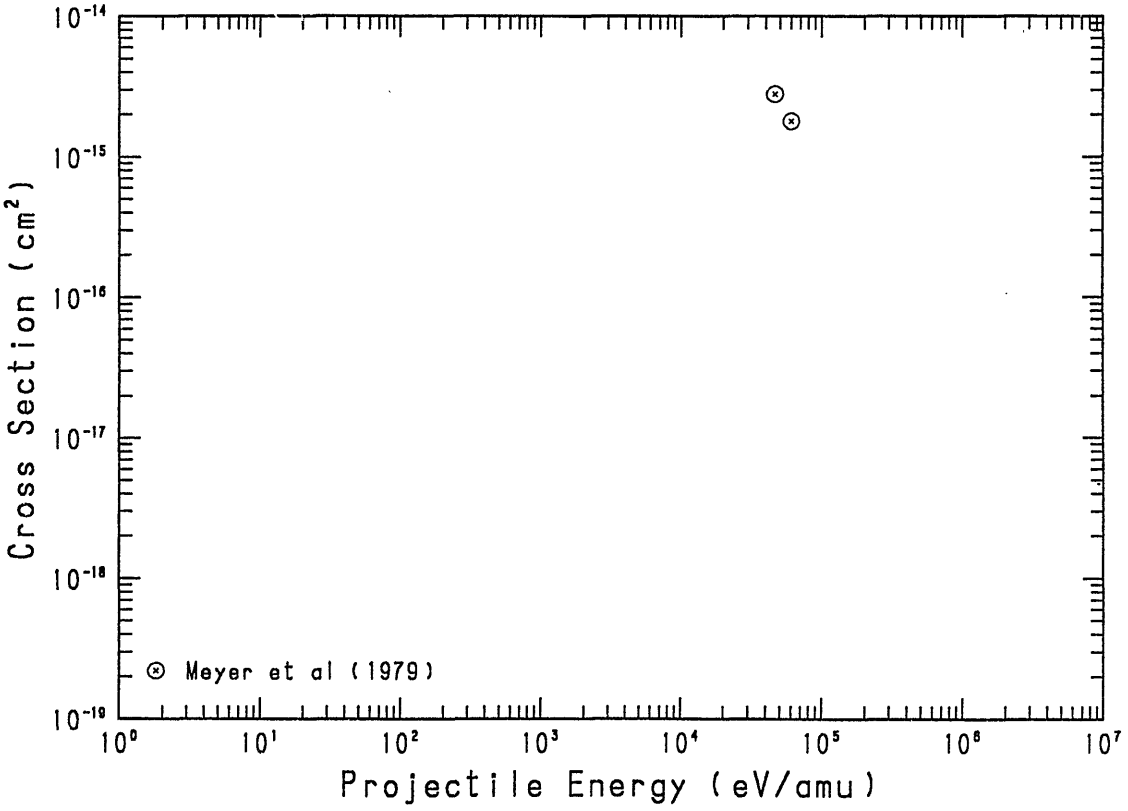


Fig.134 $W^{10+} + H \rightarrow W^{9+}$

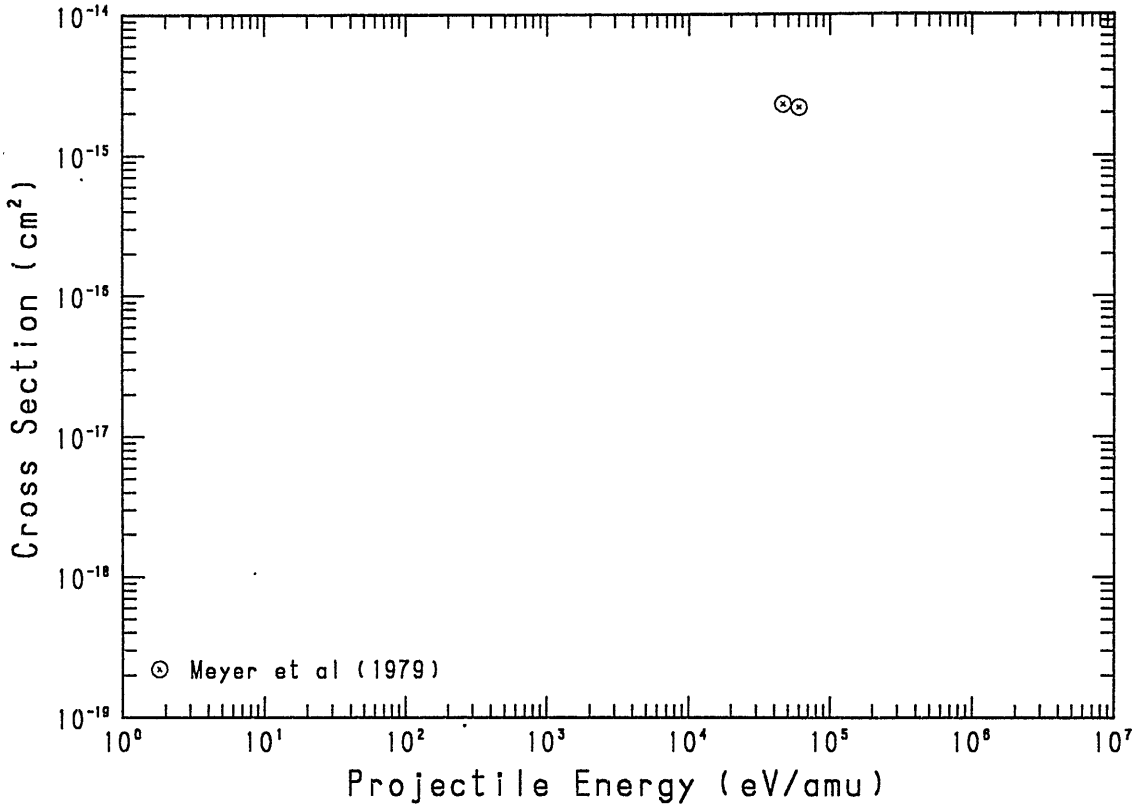


Fig.135 $W^{11+} + H \rightarrow W^{10+}$

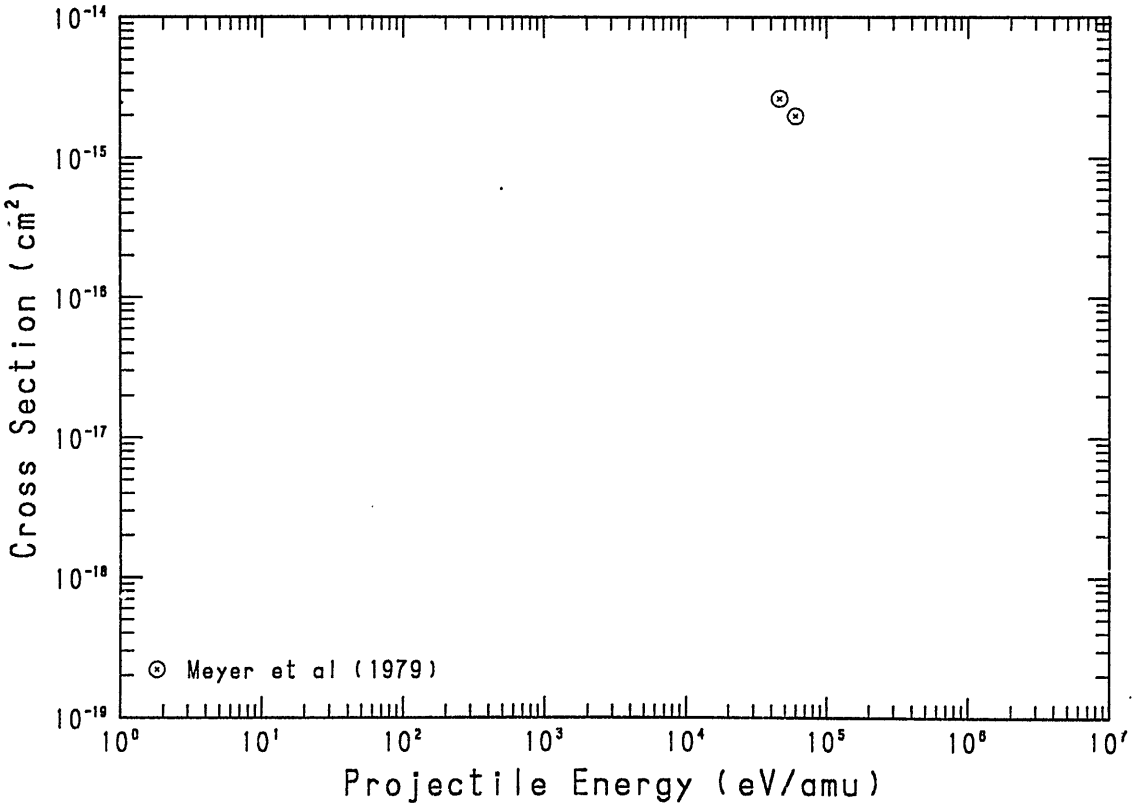


Fig.136 $W^{12+} + H \rightarrow W^{11+}$

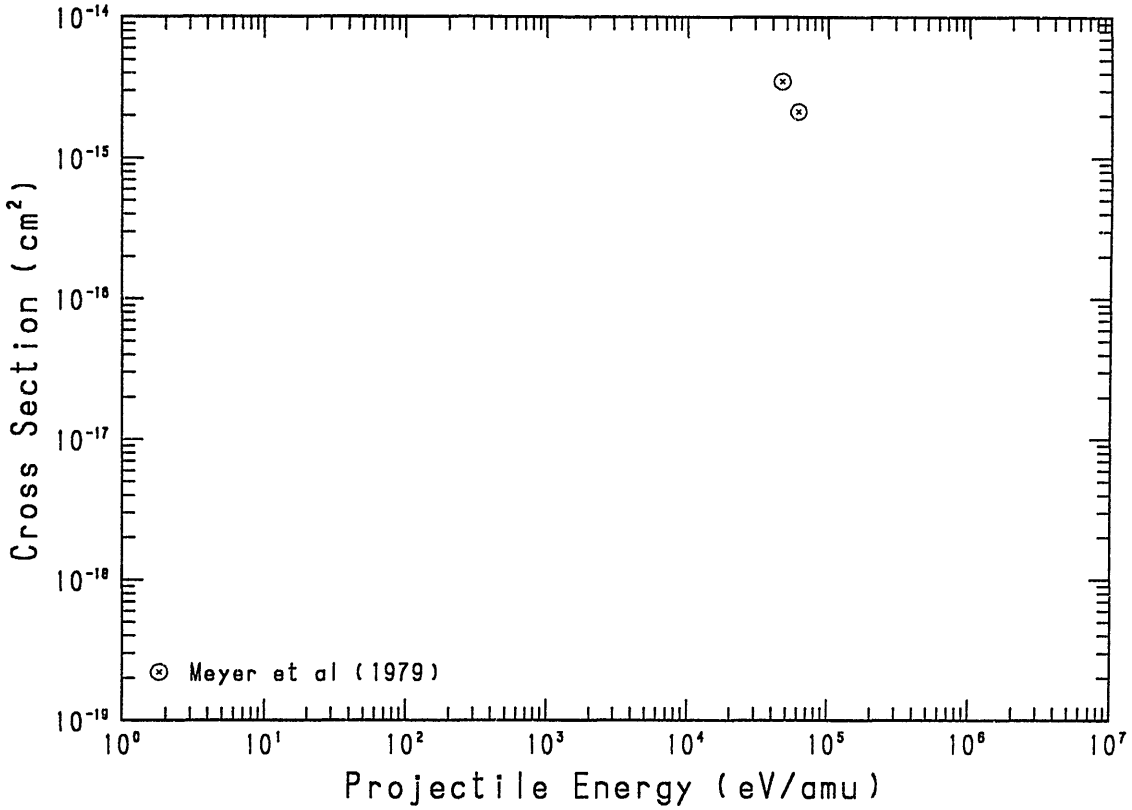


Fig.137 $W^{13+} + H \rightarrow W^{12+}$

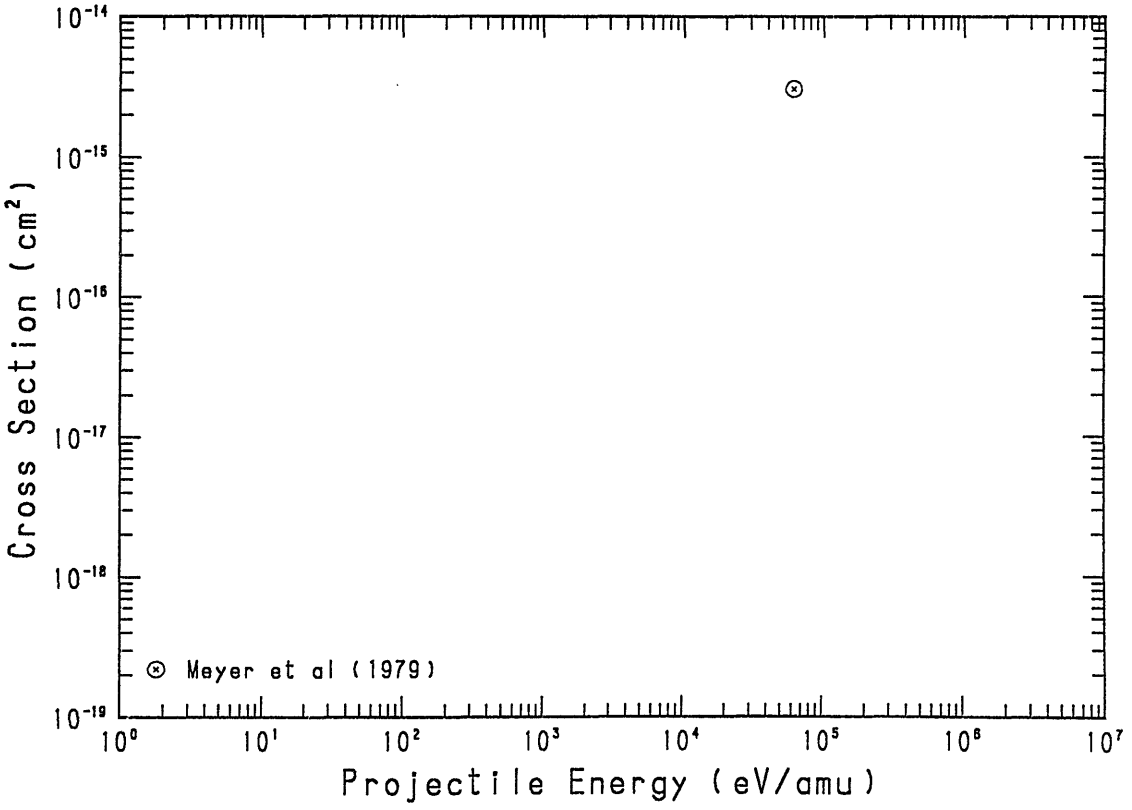


Fig.138 $W^{14+} + H \rightarrow W^{13+}$

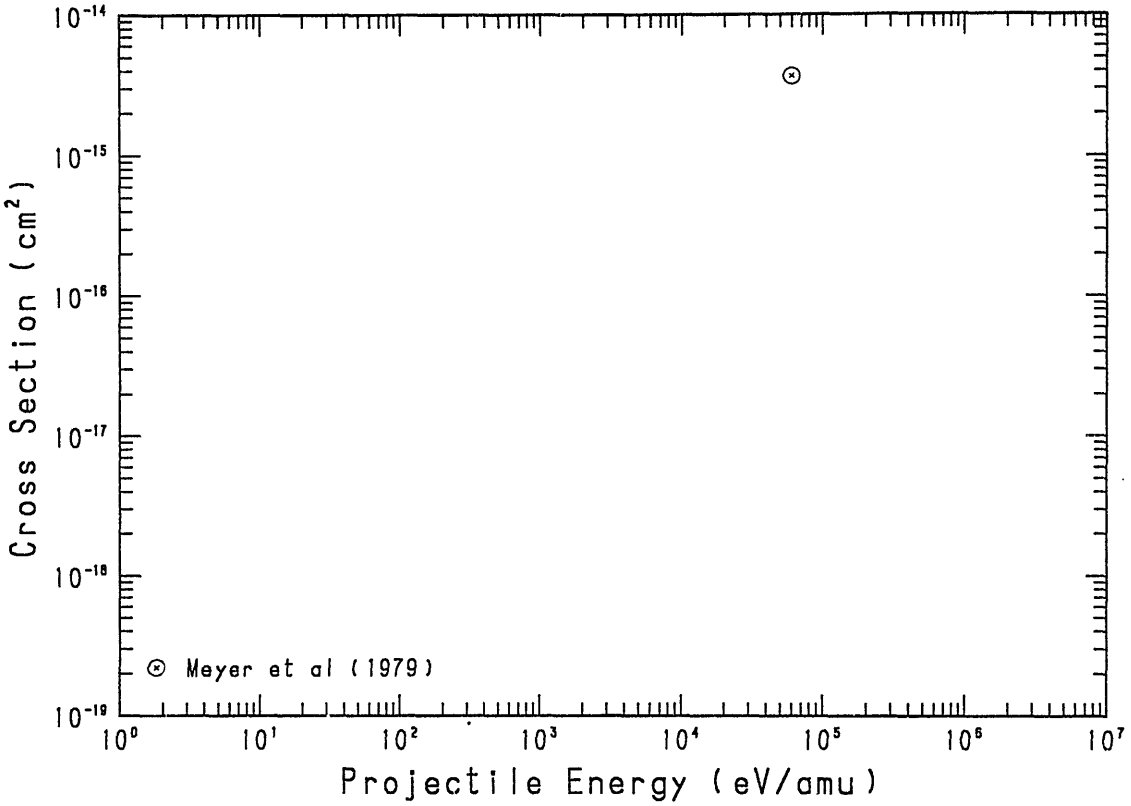


Fig.139 $W^{15+} + H \rightarrow W^{14+}$

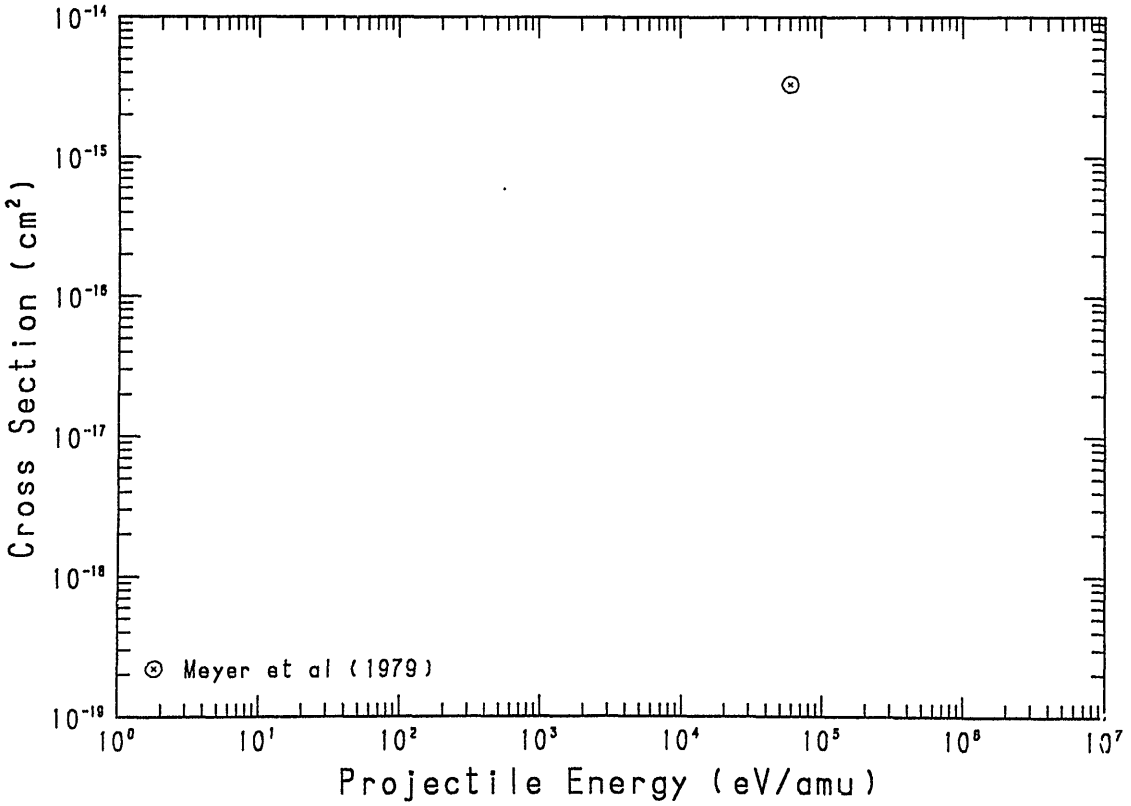


Fig.140 $Au^{5+} + H \rightarrow Au^{4+}$

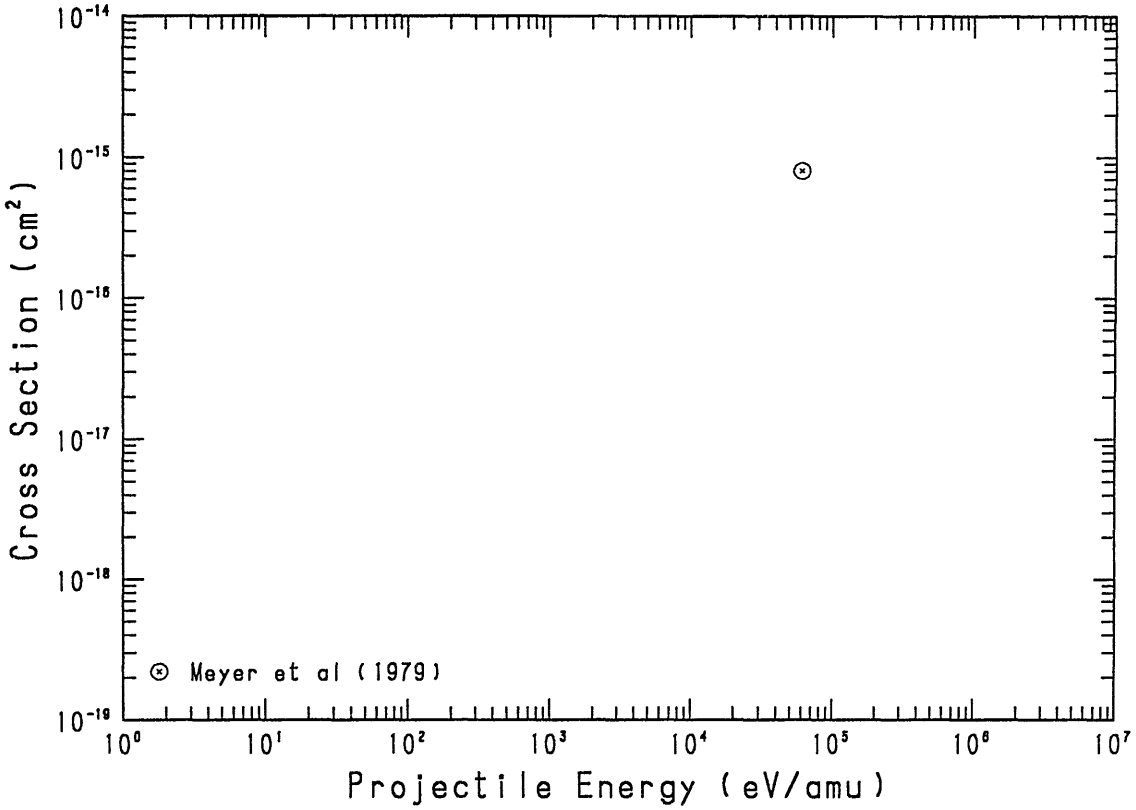


Fig.141 $Au^{6+} + H \rightarrow Au^{5+}$

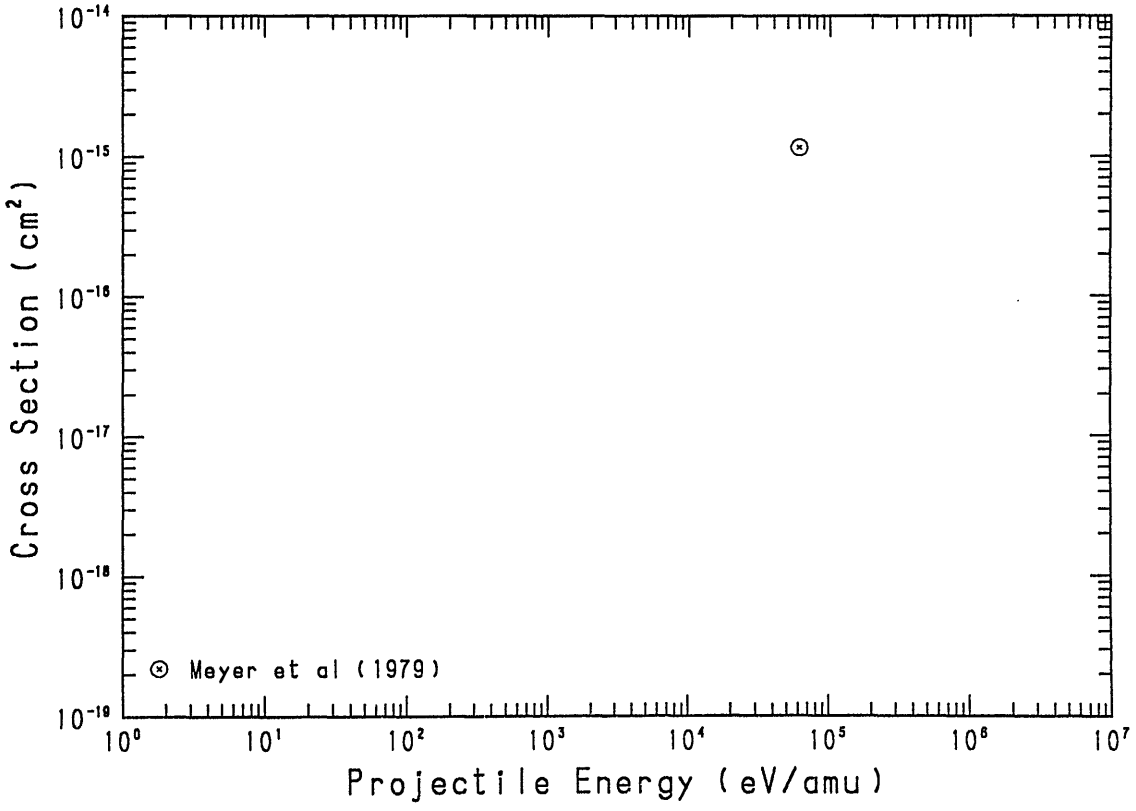


Fig.142 $Au^{7+} + H \rightarrow Au^{6+}$

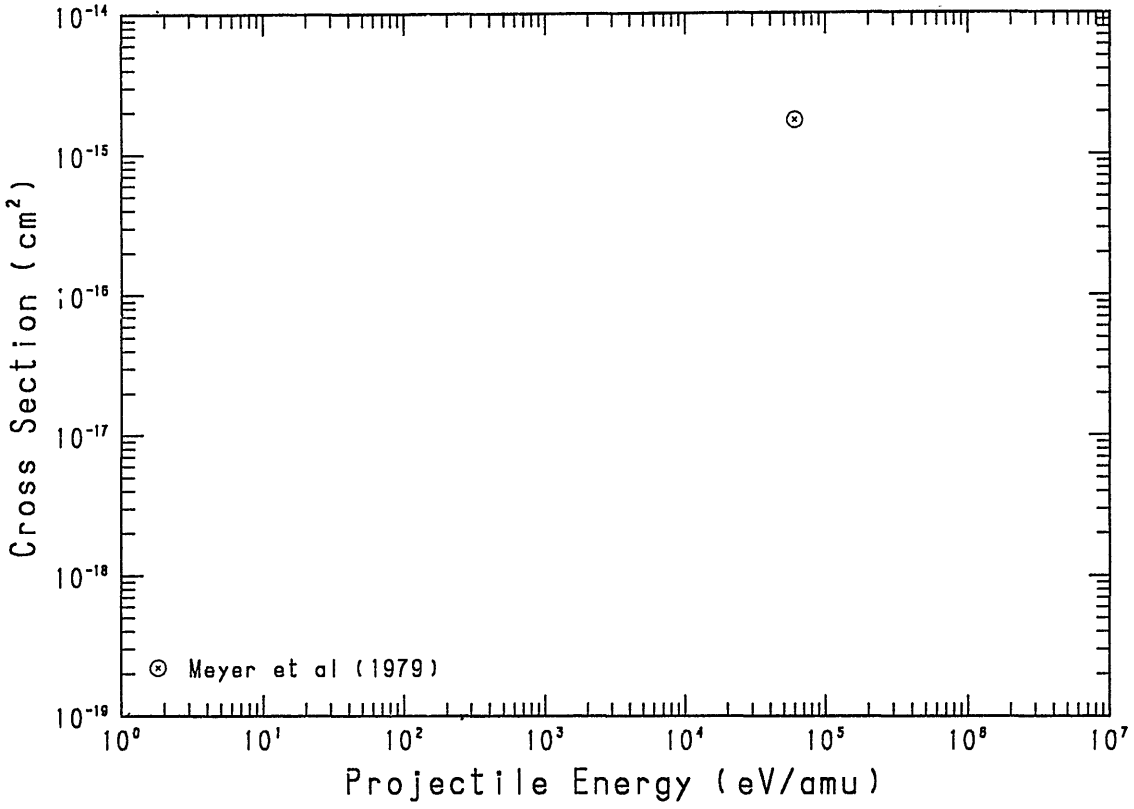


Fig.143 $Au^{8+} + H \rightarrow Au^{7+}$

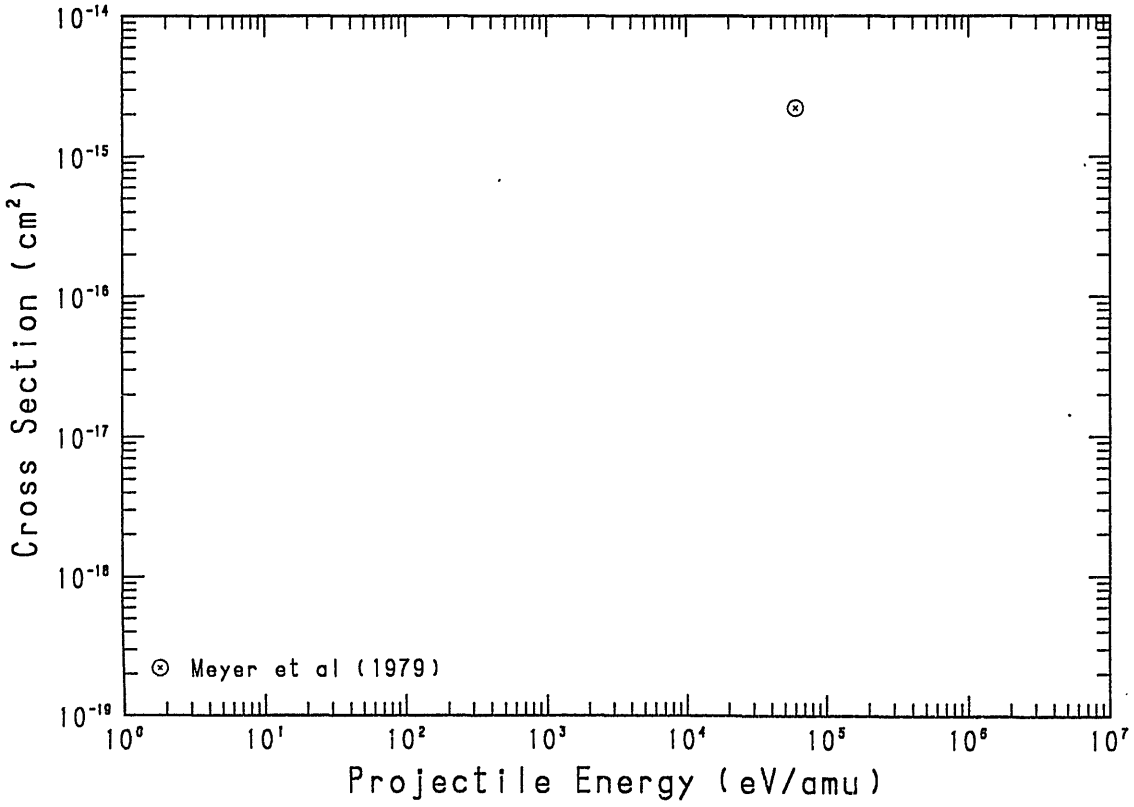


Fig.144. $Au^{9+} + H \rightarrow Au^{8+}$

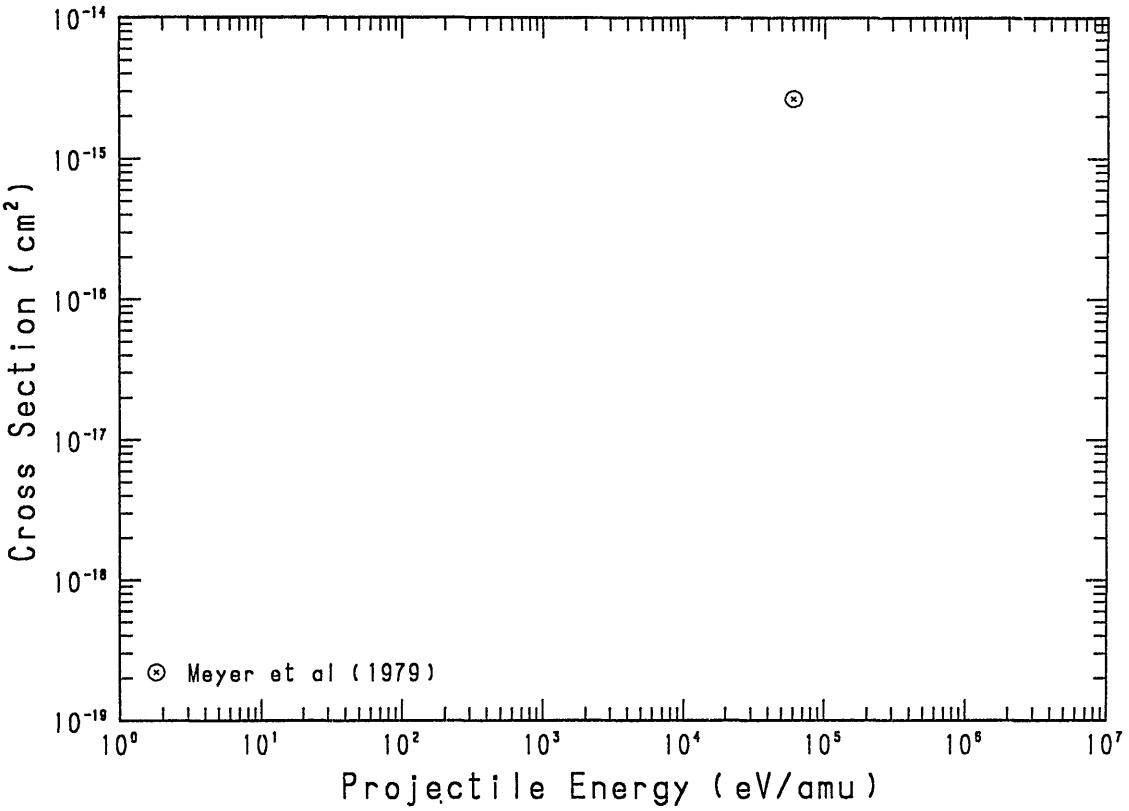


Fig.145 $Au^{10+} + H \rightarrow Au^{9+}$

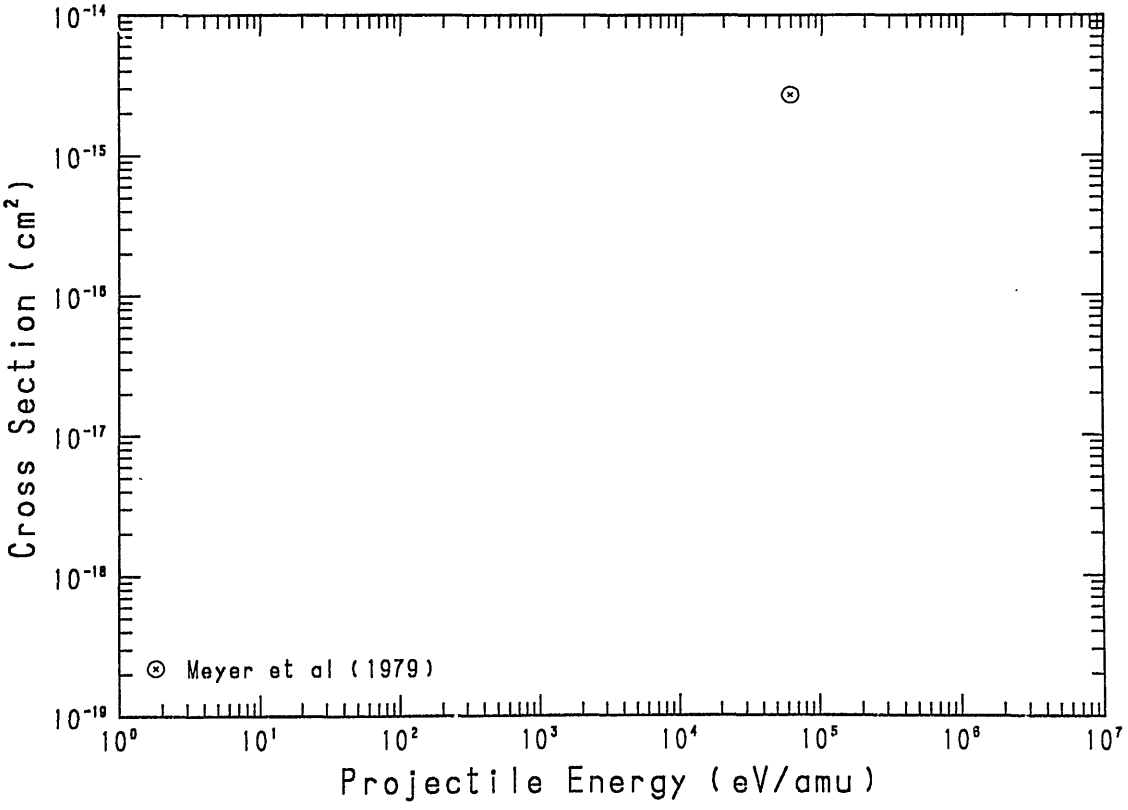


Fig.146 $Au^{11+} + H \rightarrow Au^{10+}$

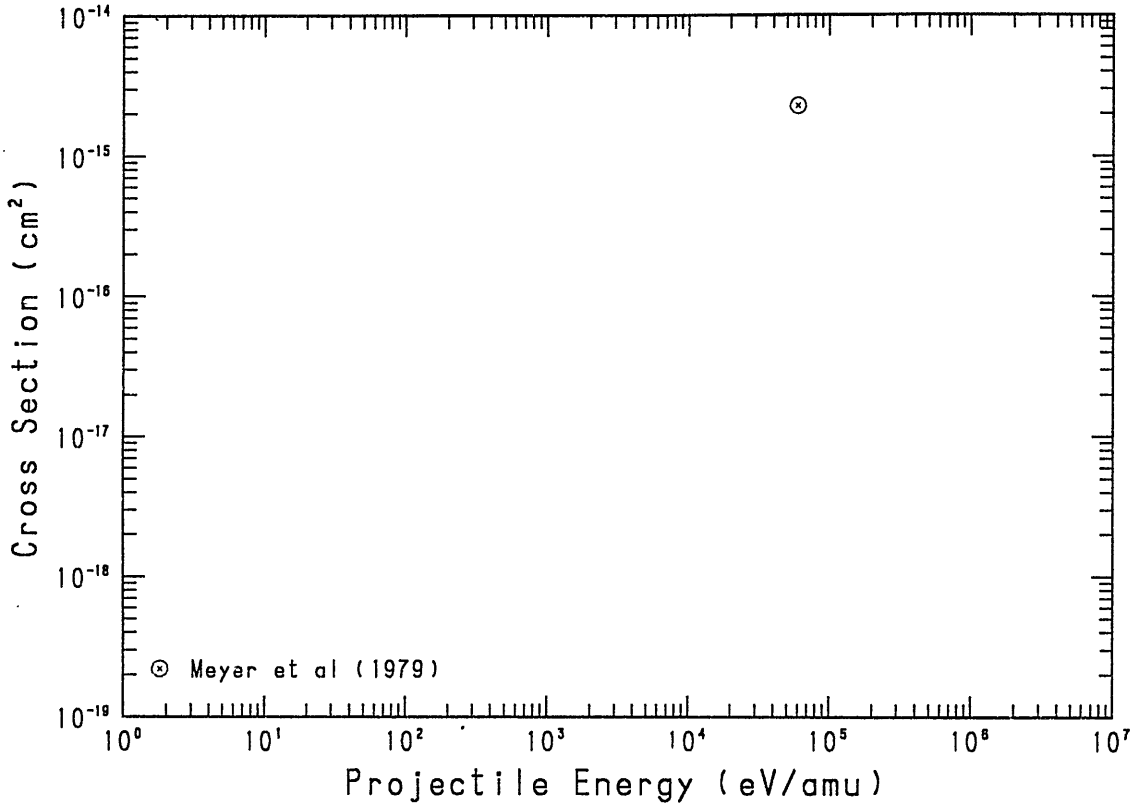


Fig.147 $Au^{12+} + H \rightarrow Au^{11+}$

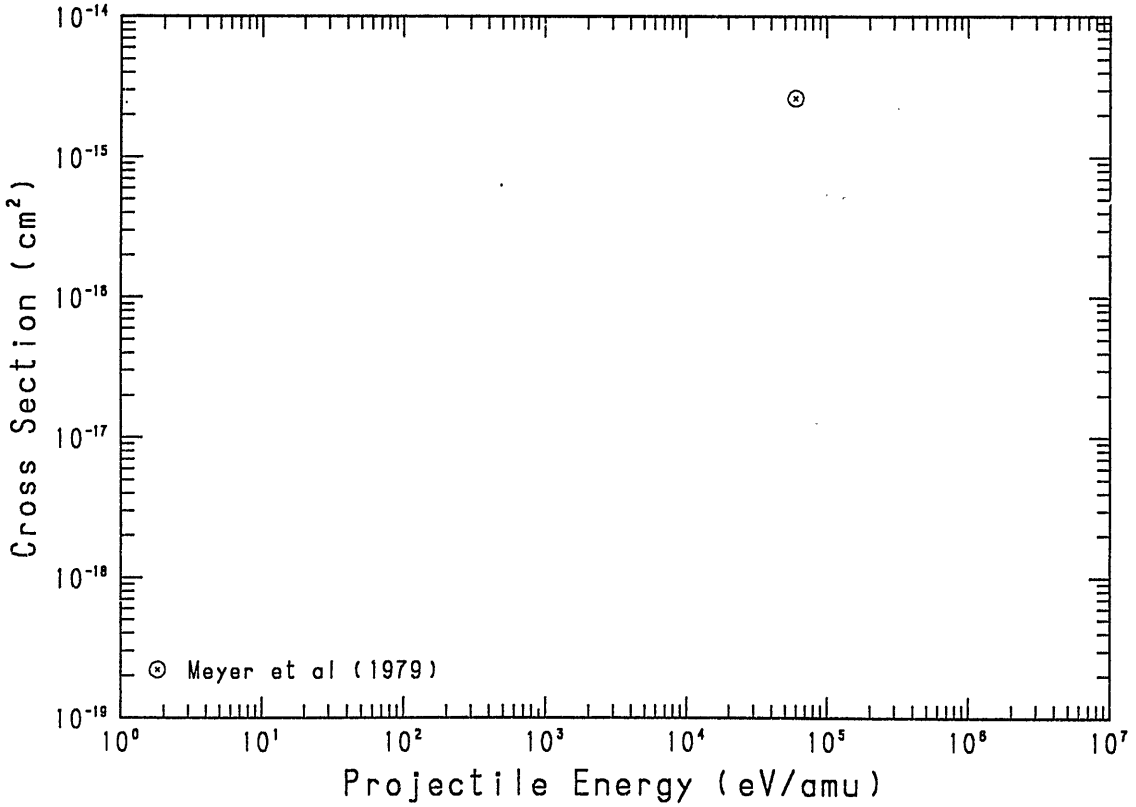


Fig.148 $Au^{13+} + H \rightarrow Au^{12+}$

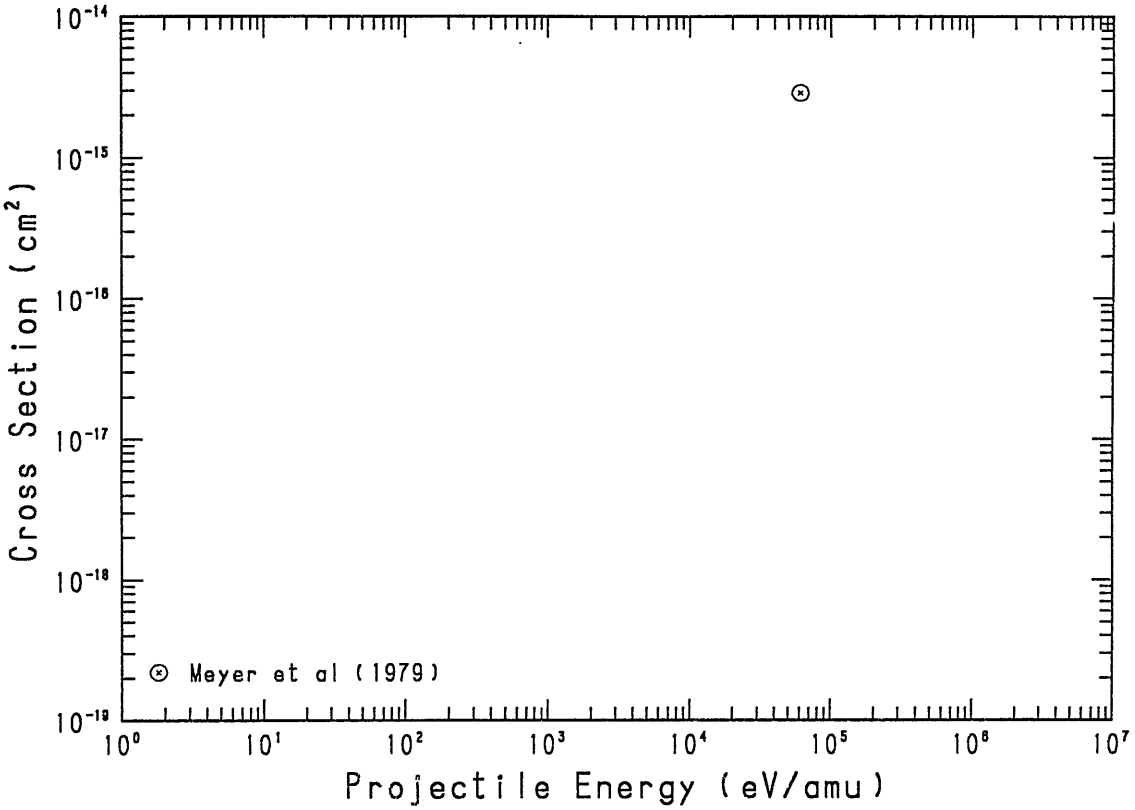


Fig.149 $Au^{14+} + H \rightarrow Au^{13+}$

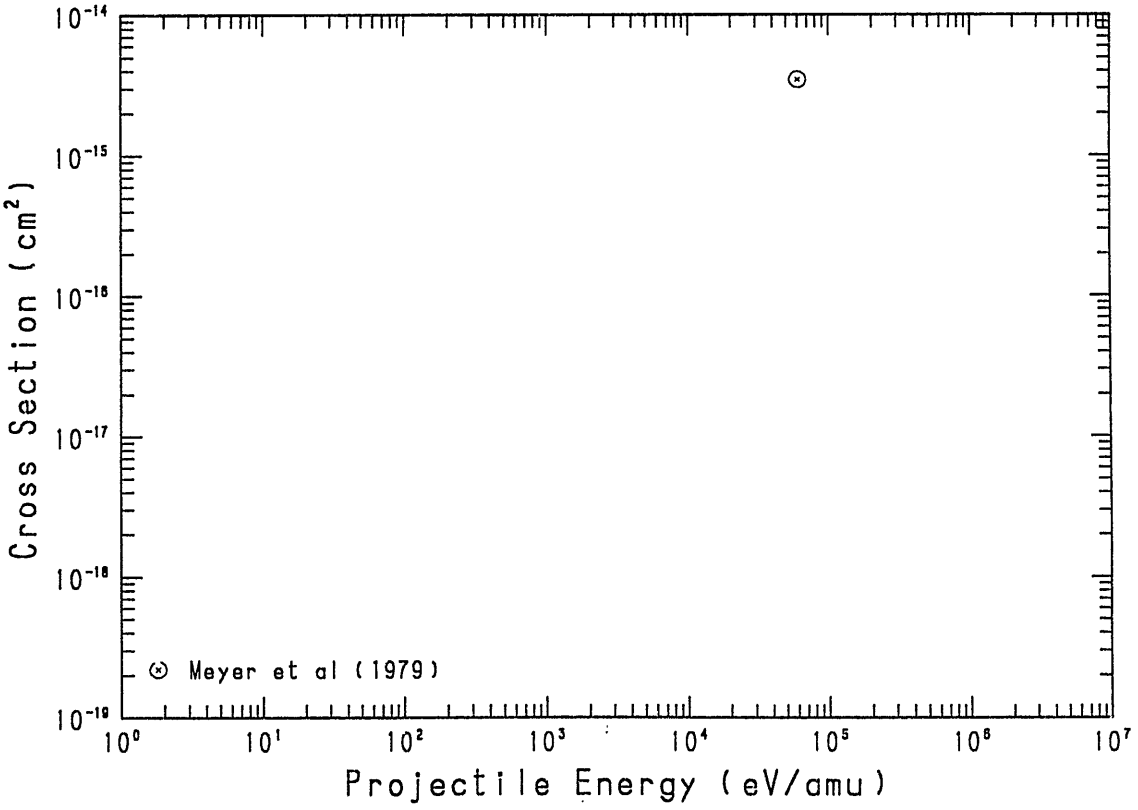


Fig.150 $Au^{15+} + H \rightarrow Au^{14+}$

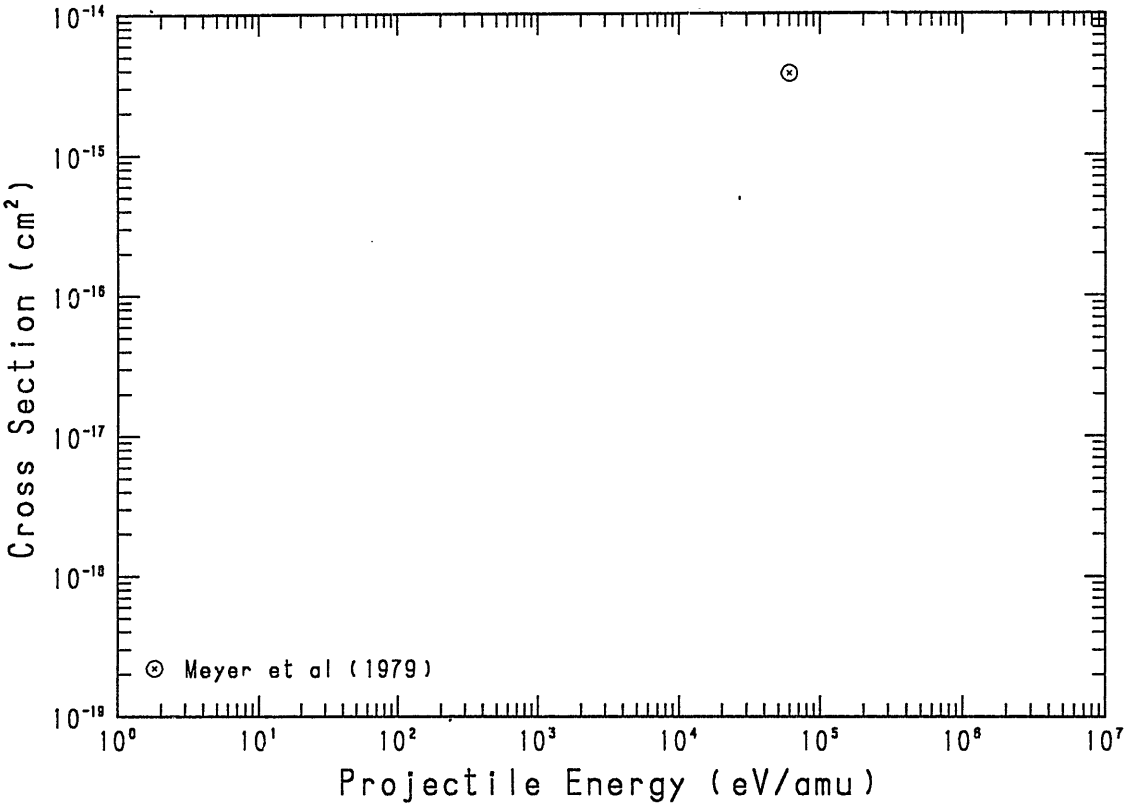


Fig.151 $Au^{16+} + H \rightarrow Au^{15+}$

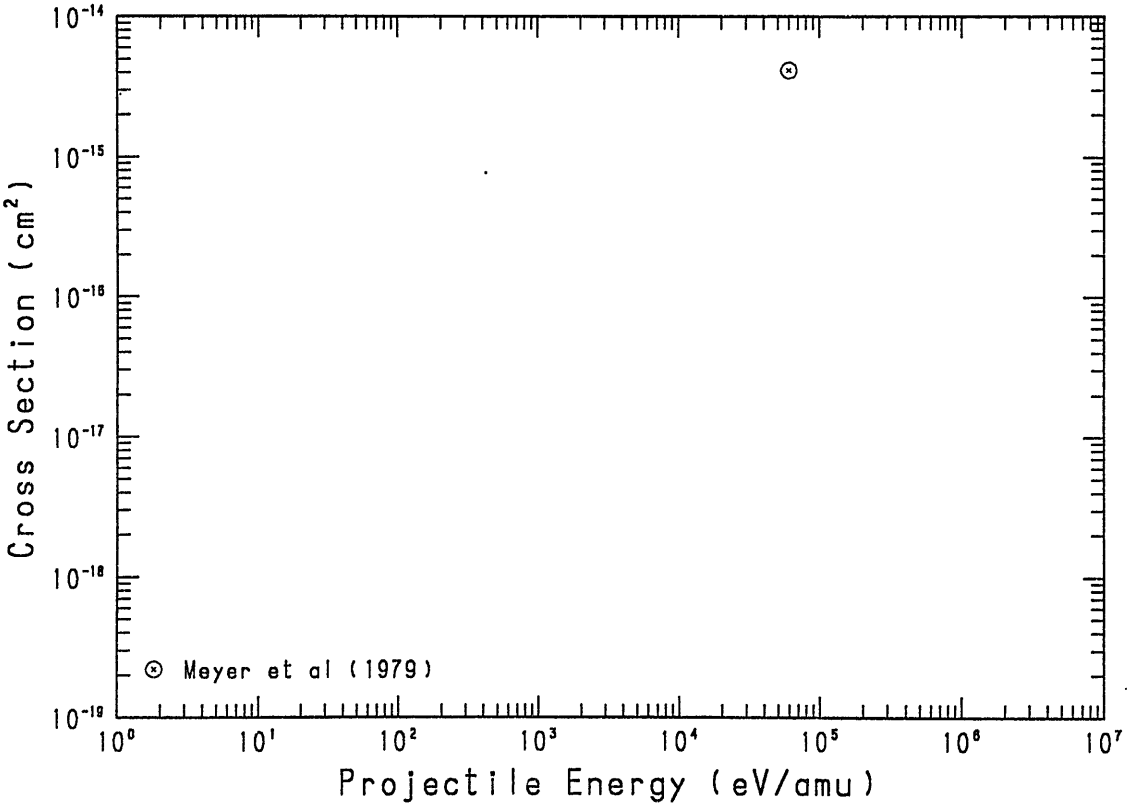
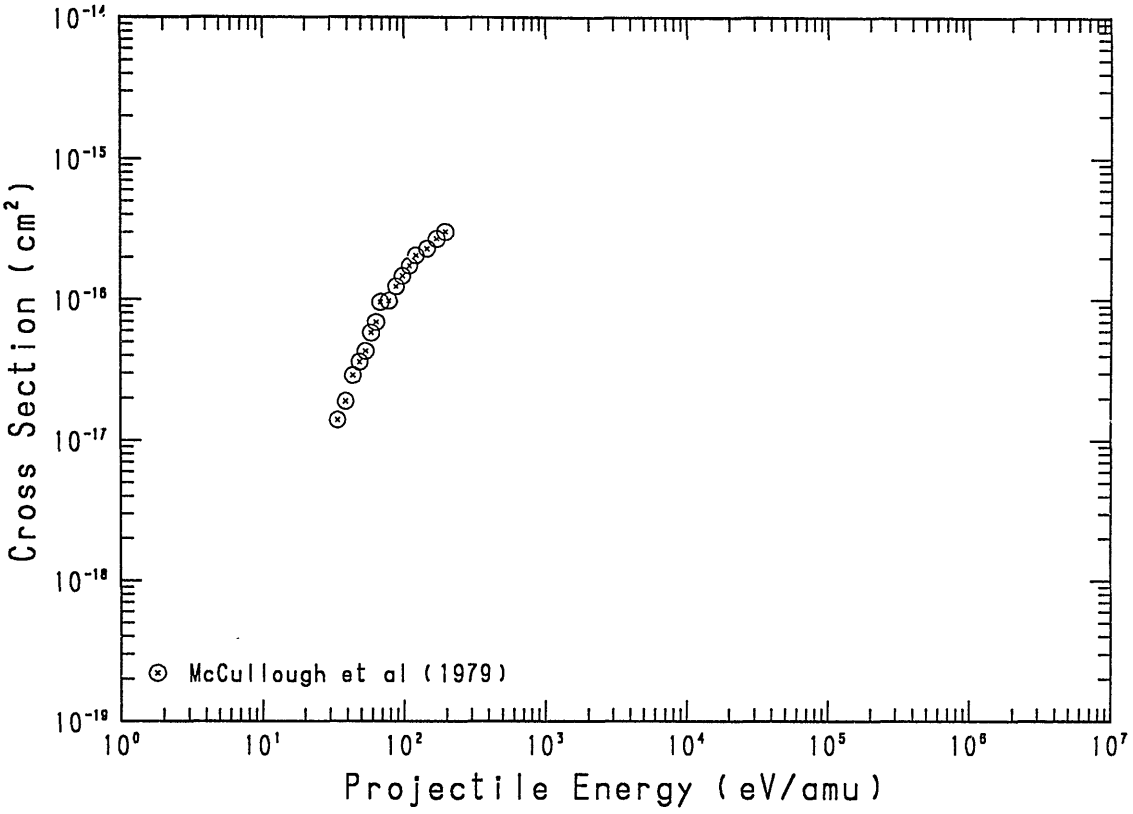


Fig.152. $Tl^{2+} + H \rightarrow Tl^{+}$



V. FIGURES OF CROSS SECTIONS FOR RELATED PROCESSES

Fig.A1 $H^+ + H \rightarrow H^+ + H(2p)$

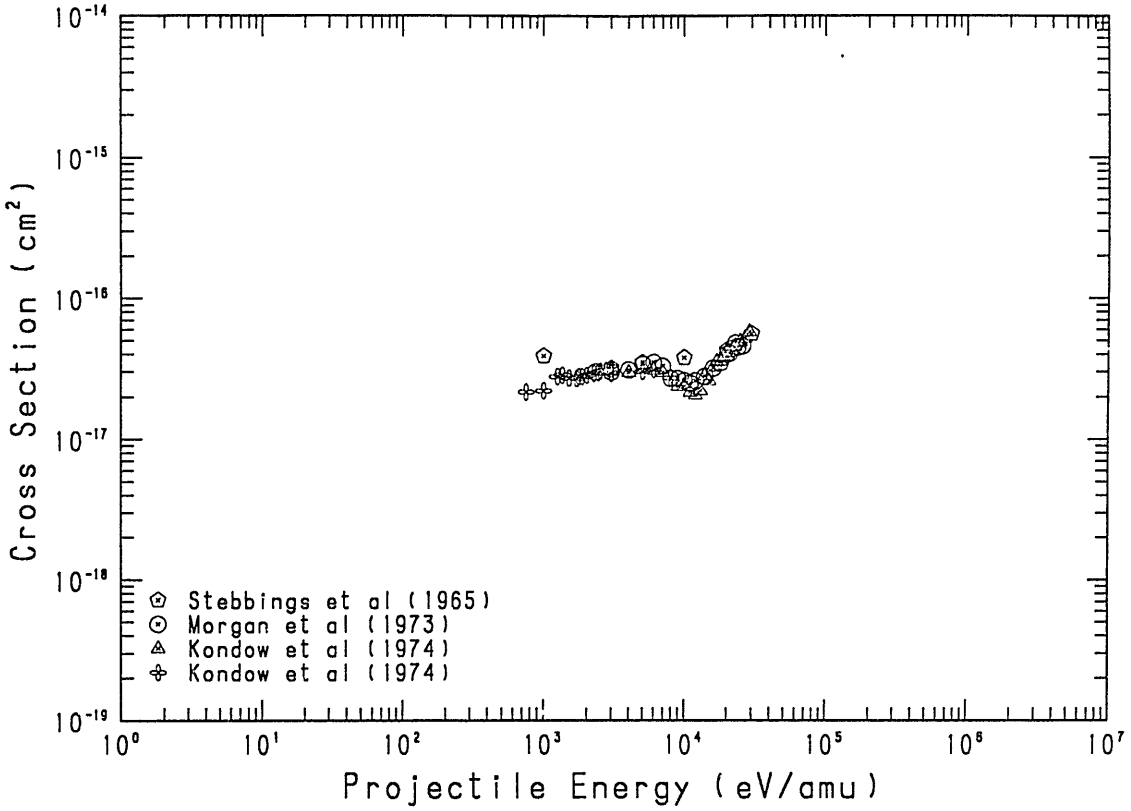


Fig.A2 $H^+ + H \rightarrow H^+ + H(2s)$

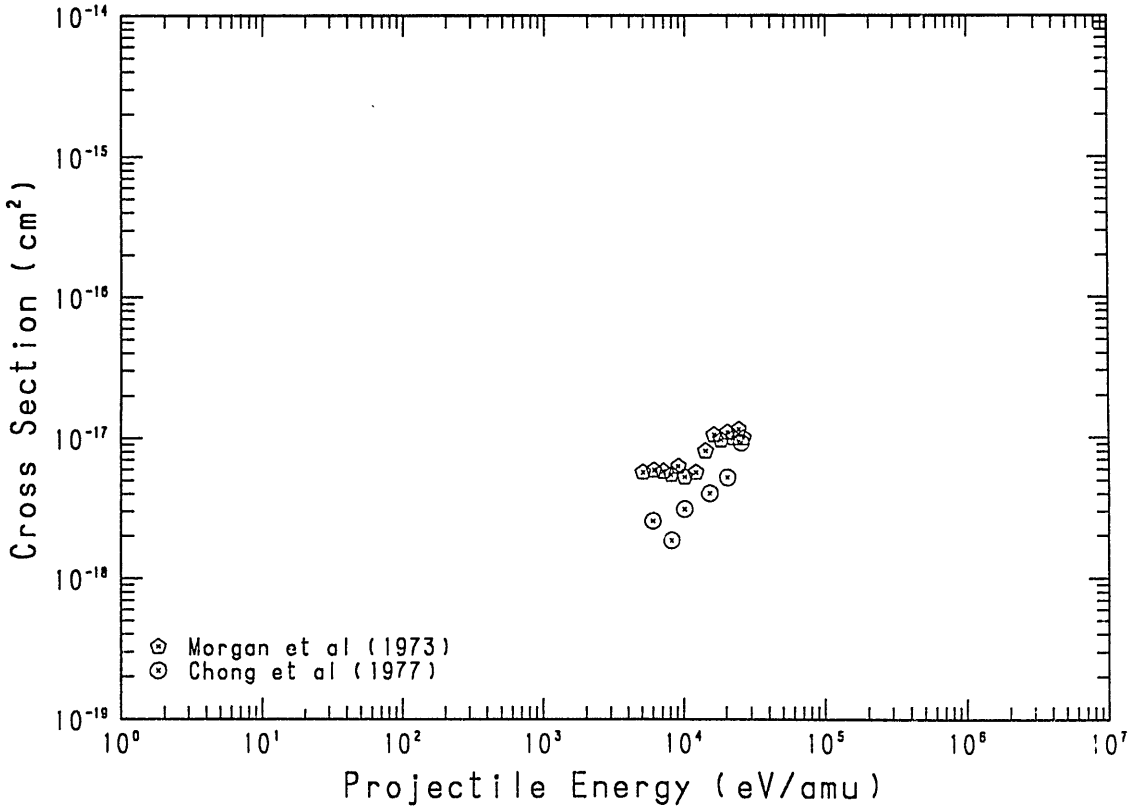


Fig.A3 $H^+ + H \rightarrow H^+ + H(n=2)$

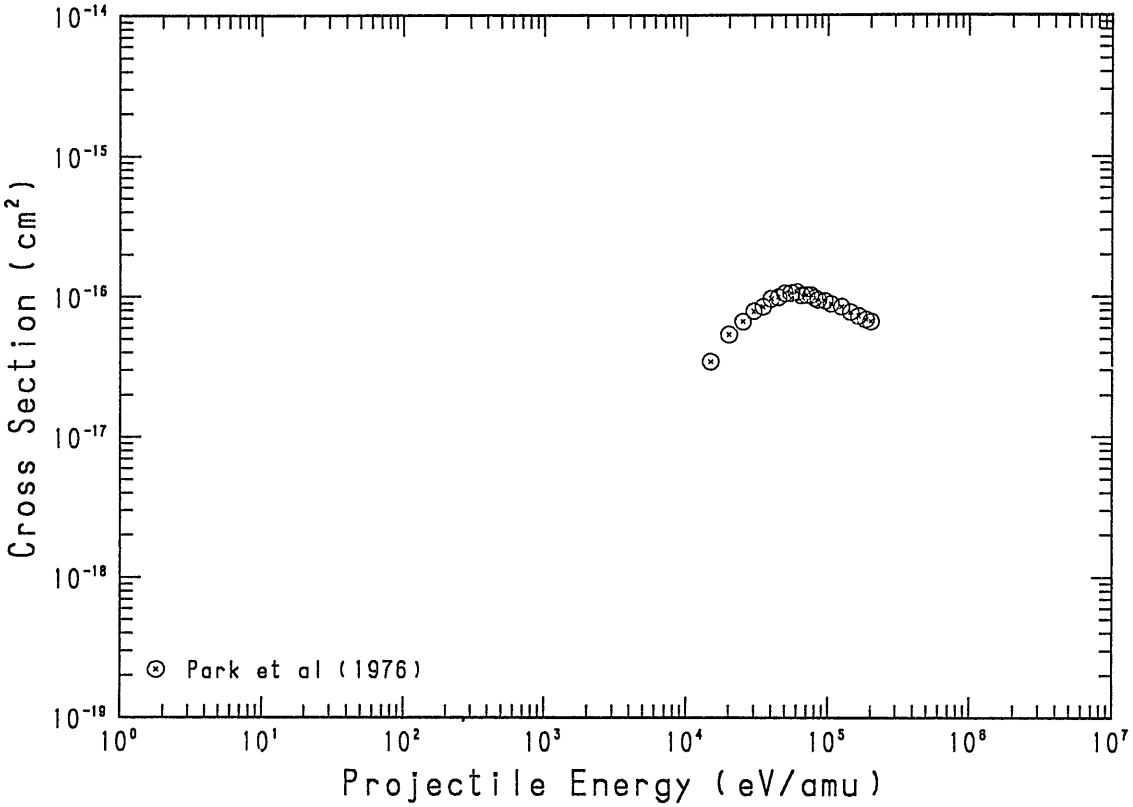


Fig.A4 $H^+ + H \rightarrow H^+ + H(n=3)$

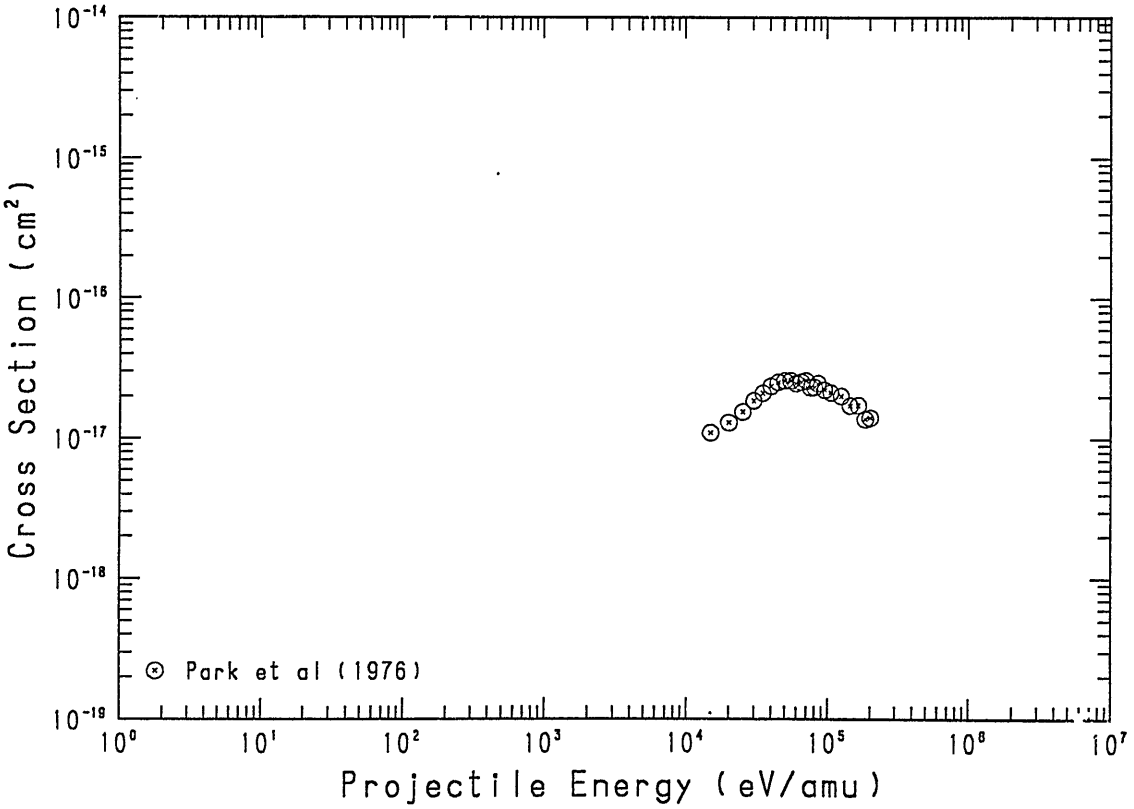


Fig.A5 $H^+ + H \rightarrow H^+ + H(n=4)$

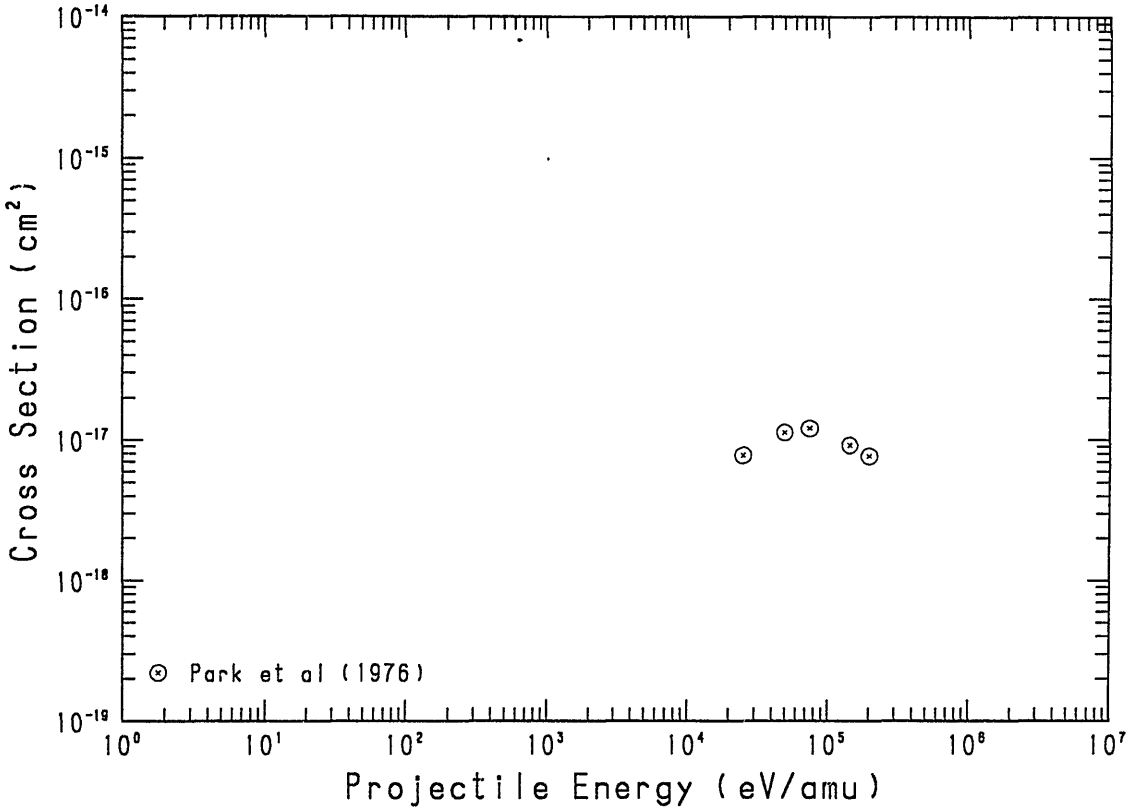


Fig.A6 $H^+ + H \rightarrow H^+ + H^+ + e$

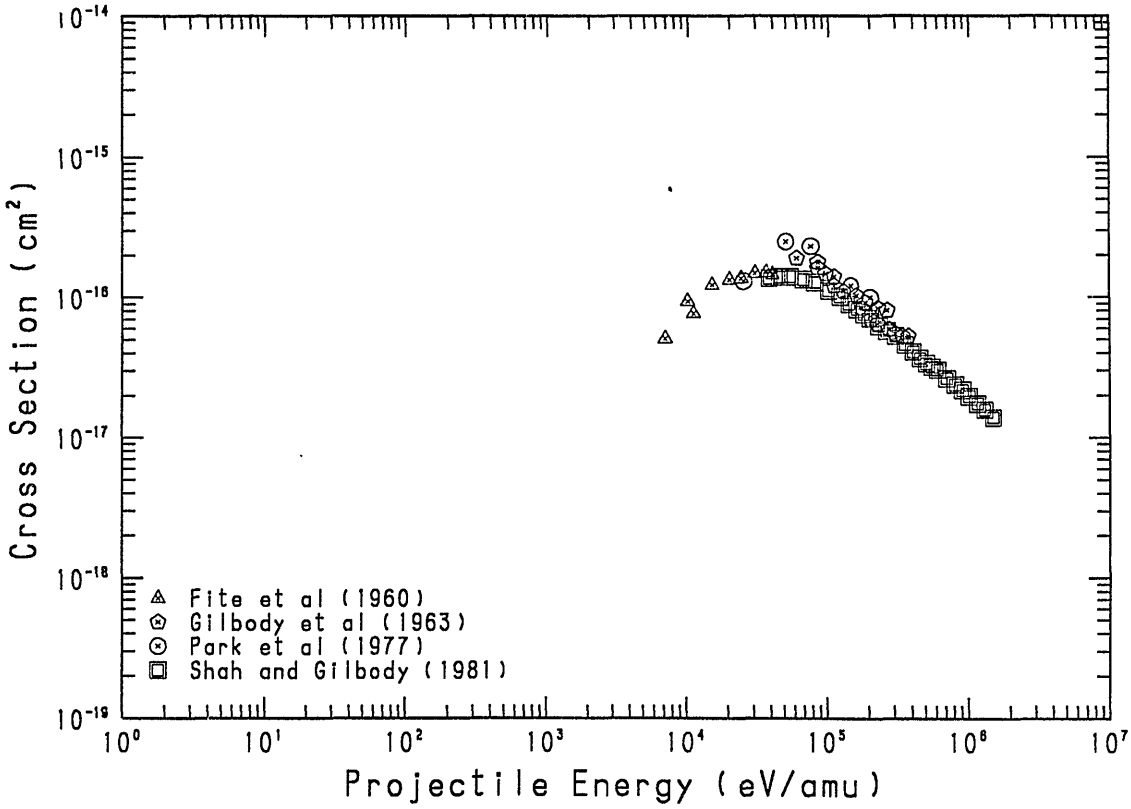


Fig.A7 H + H → H^+

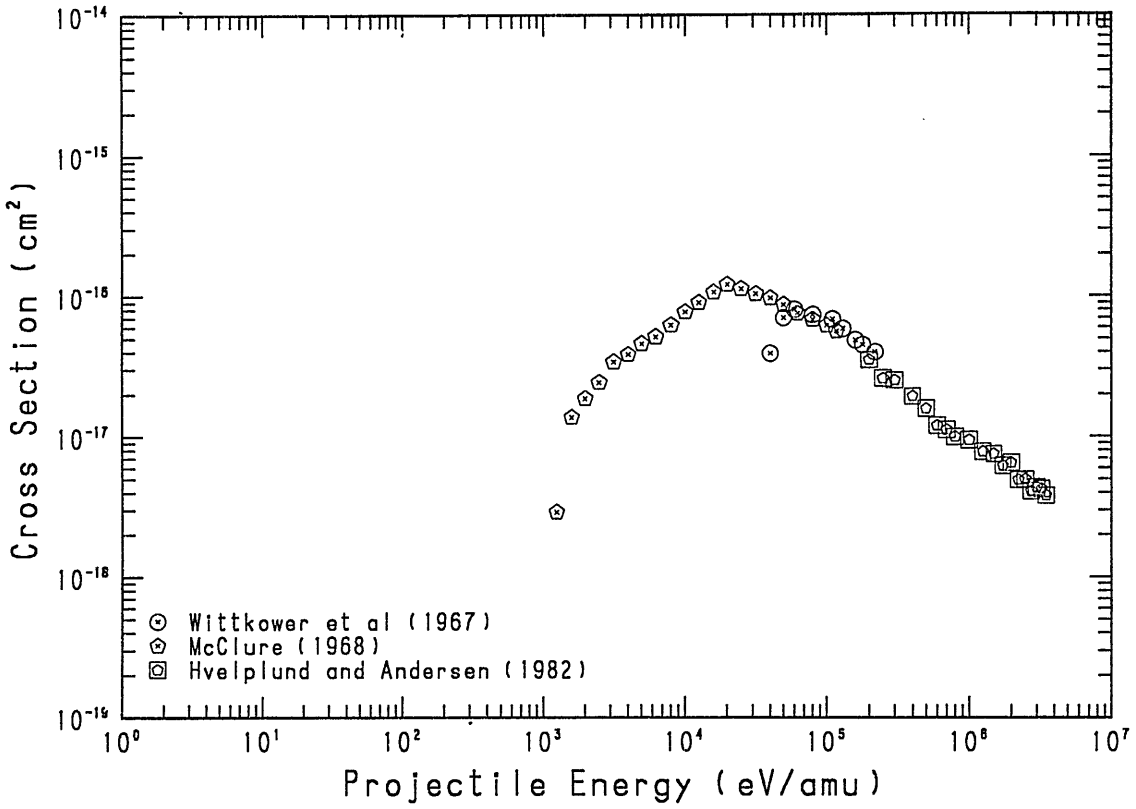


Fig.A8 H + H → H(2s)

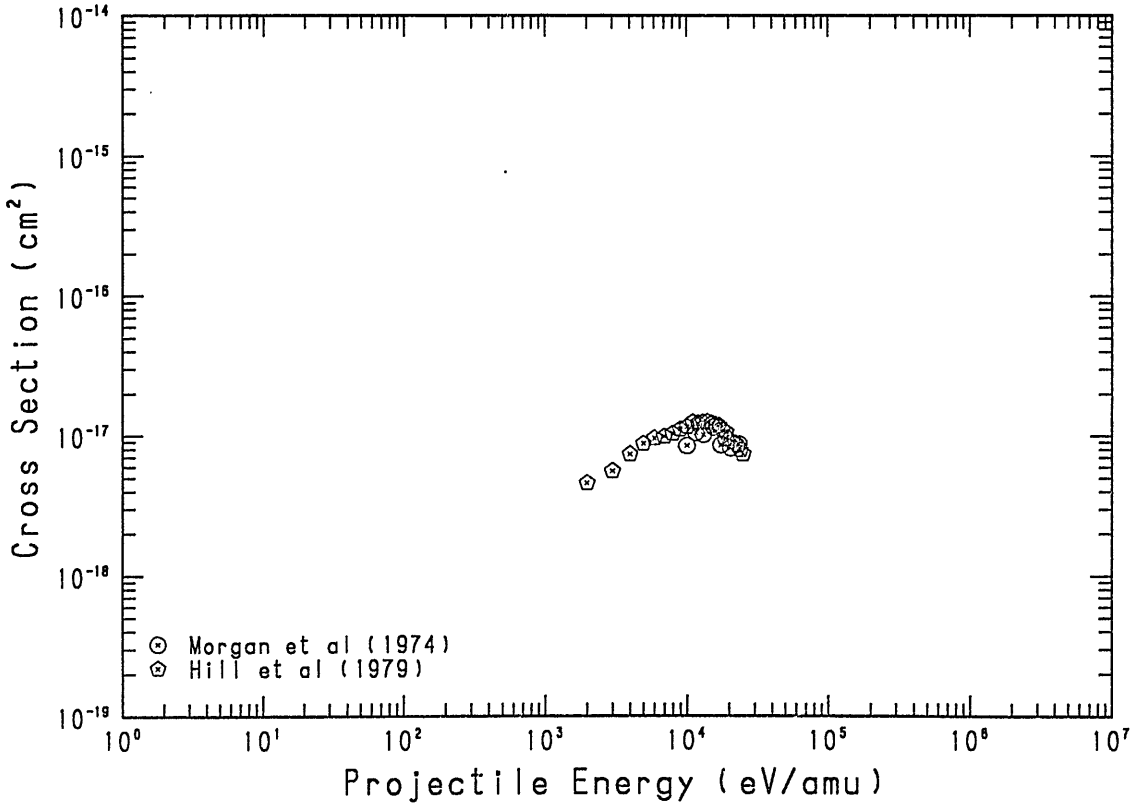


Fig.A9 H + H → H(2p)

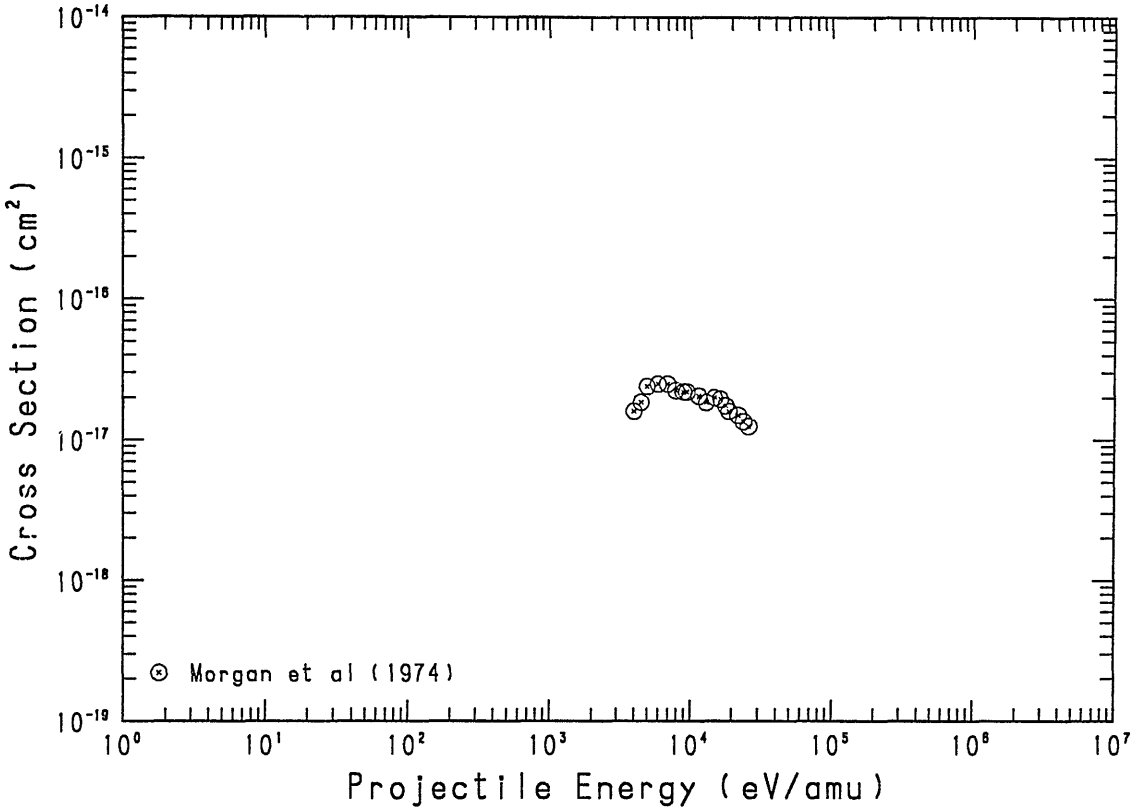


Fig.A10 H + H → H⁻ + H⁺

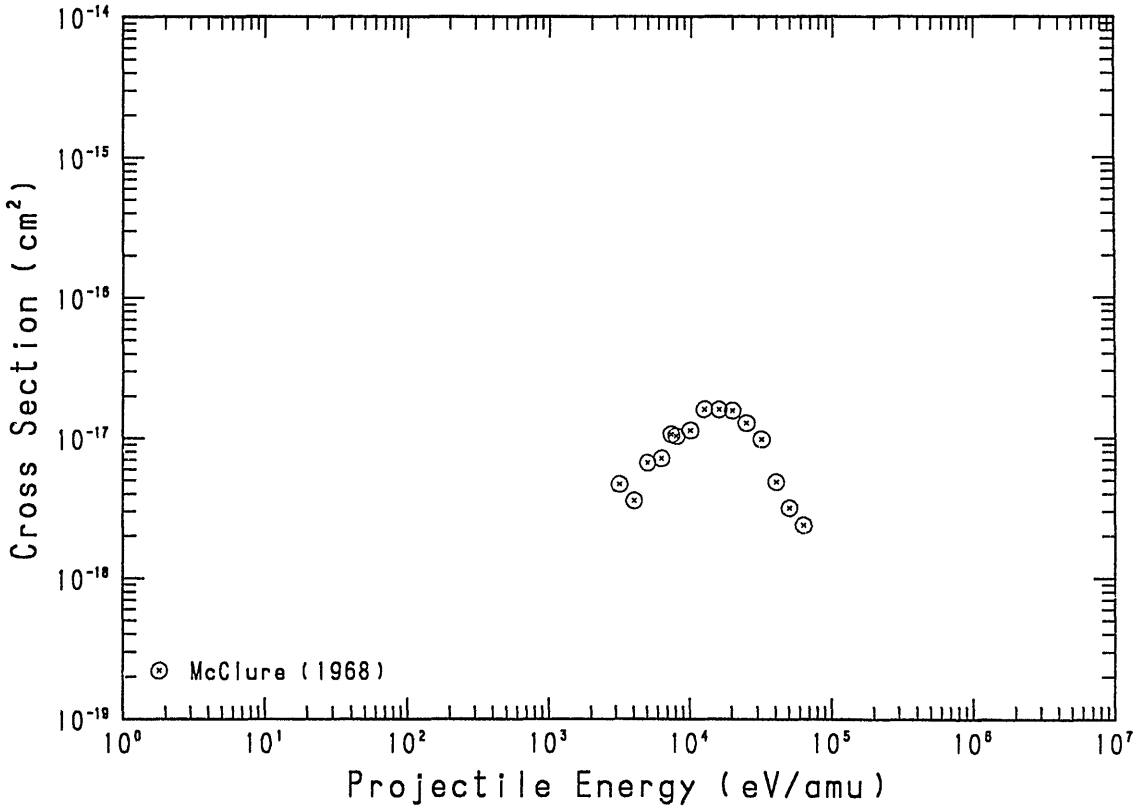


Fig.A11 $H^- + H \rightarrow H$

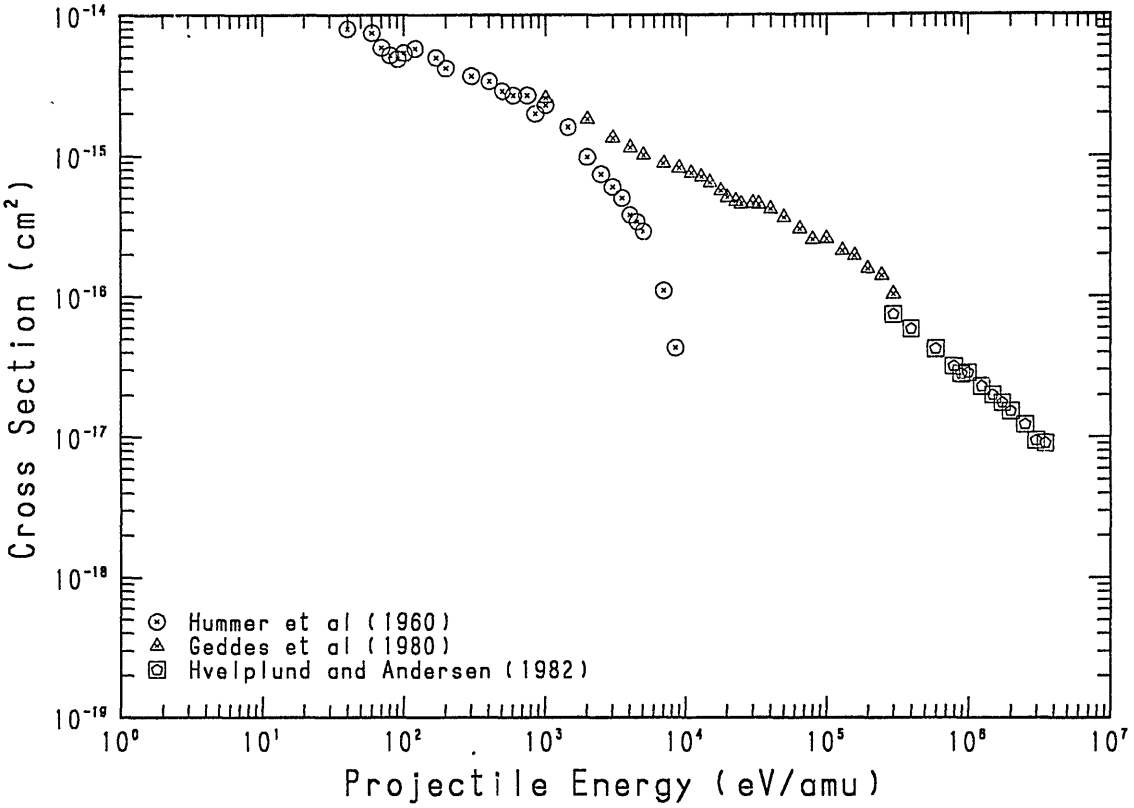


Fig.A12 $H^- + H \rightarrow H^+$

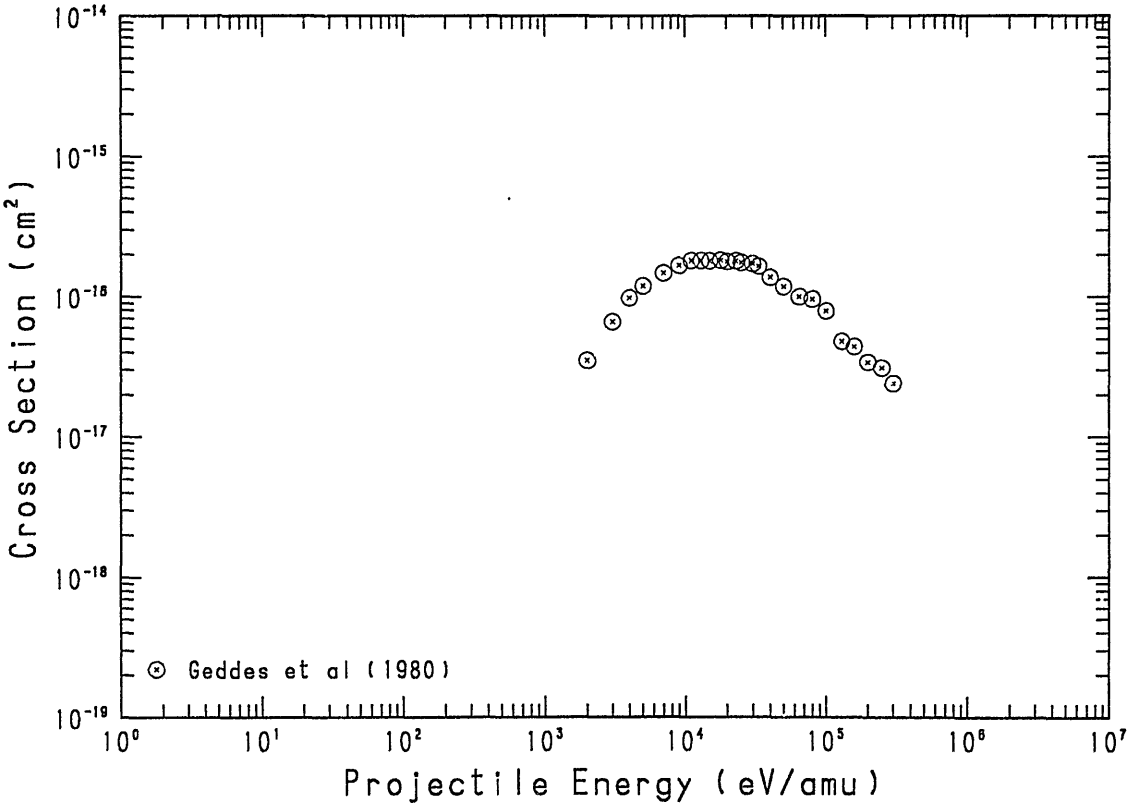


Fig.A13 $He^+ + H \rightarrow He^{2+}$

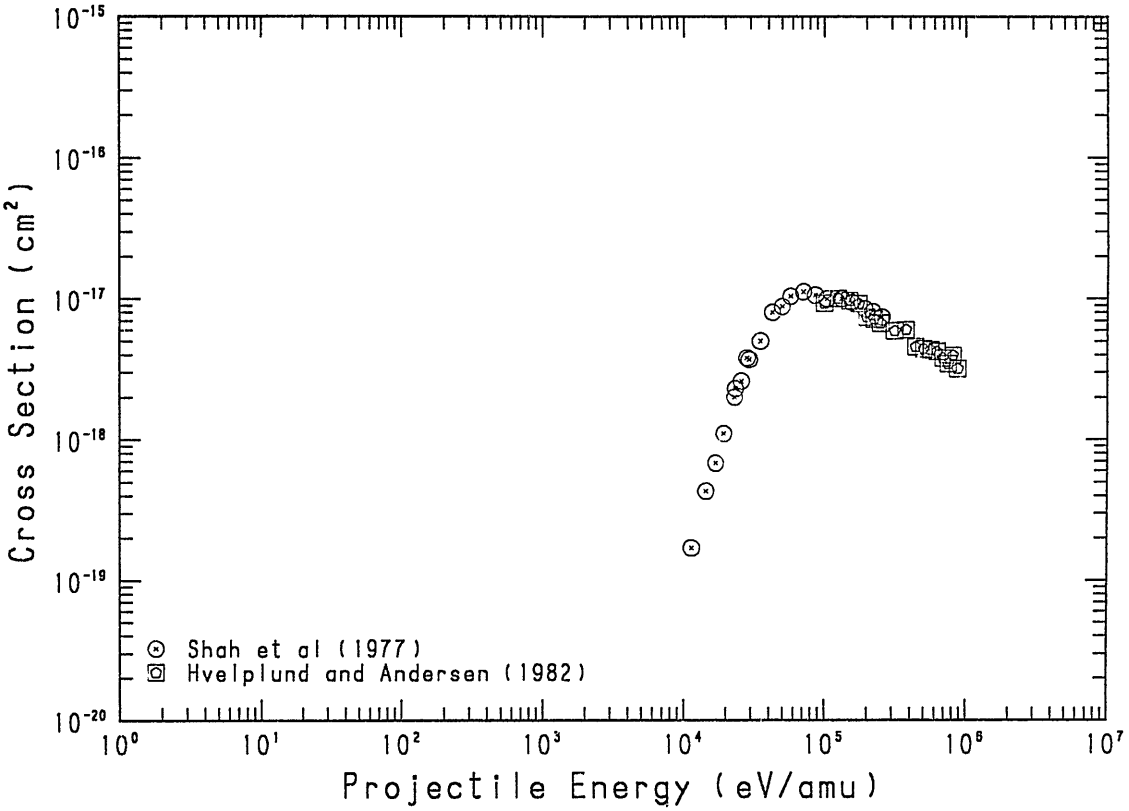


Fig.A14 $He^+ + H \rightarrow He^+ + H(2p)$

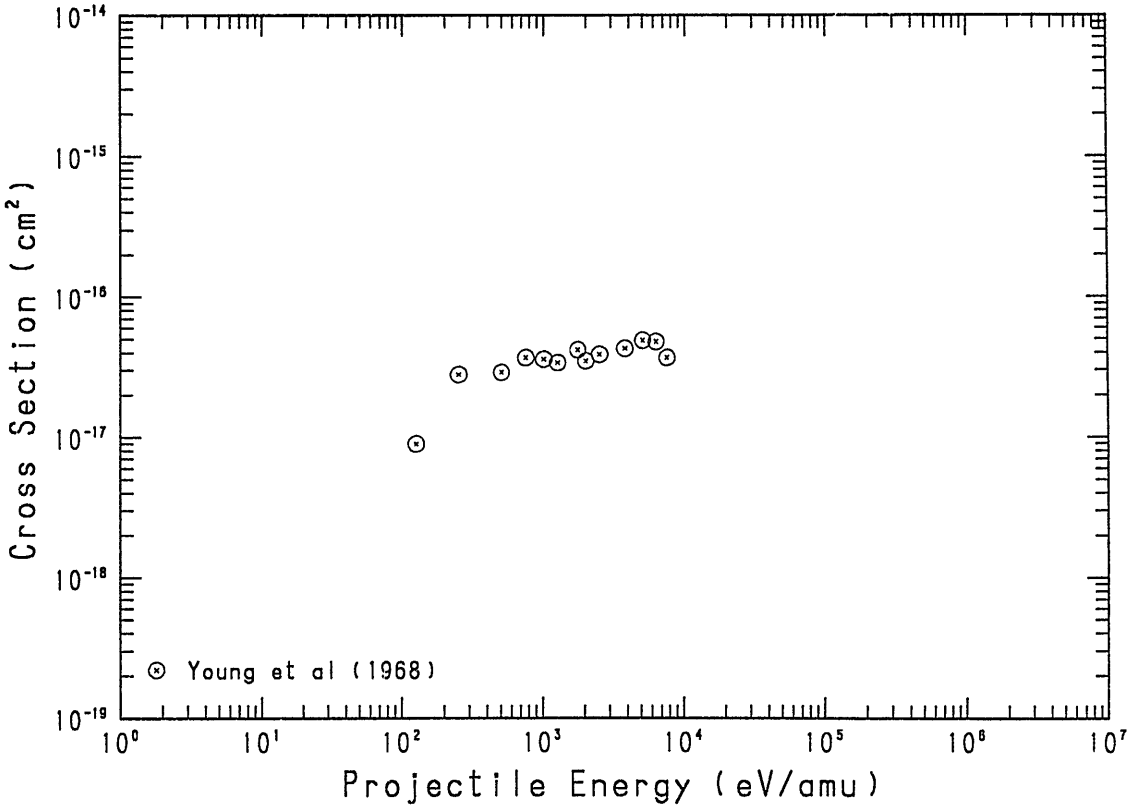


Fig.A15 $He^+ + H \rightarrow He^+(2s)$

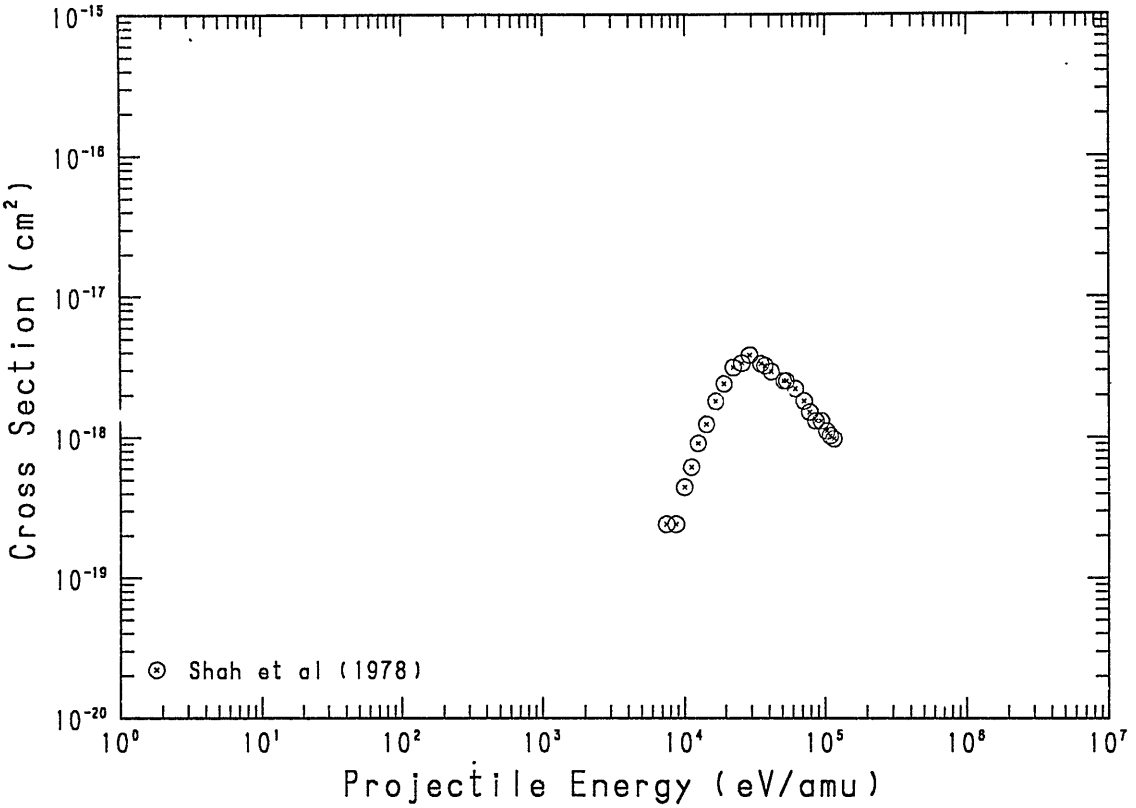


Fig.A16 $He + H \rightarrow He^+$

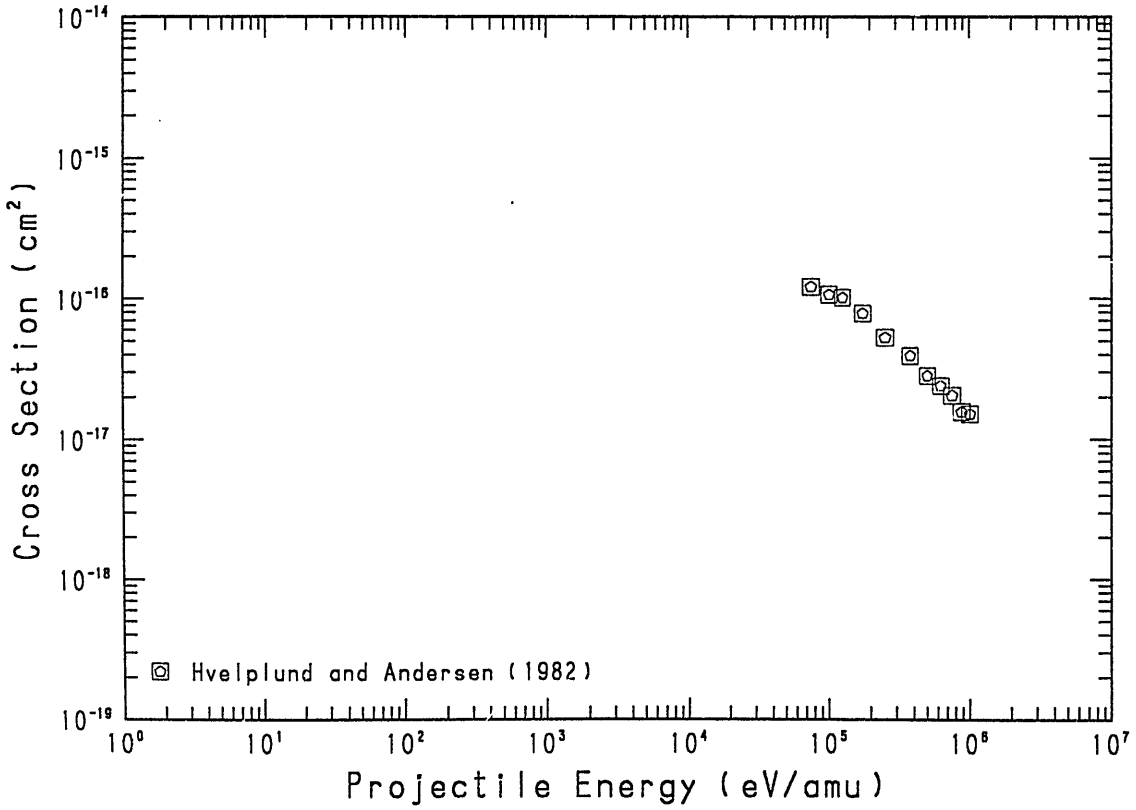


Fig.A17 $He^- + H \rightarrow He$

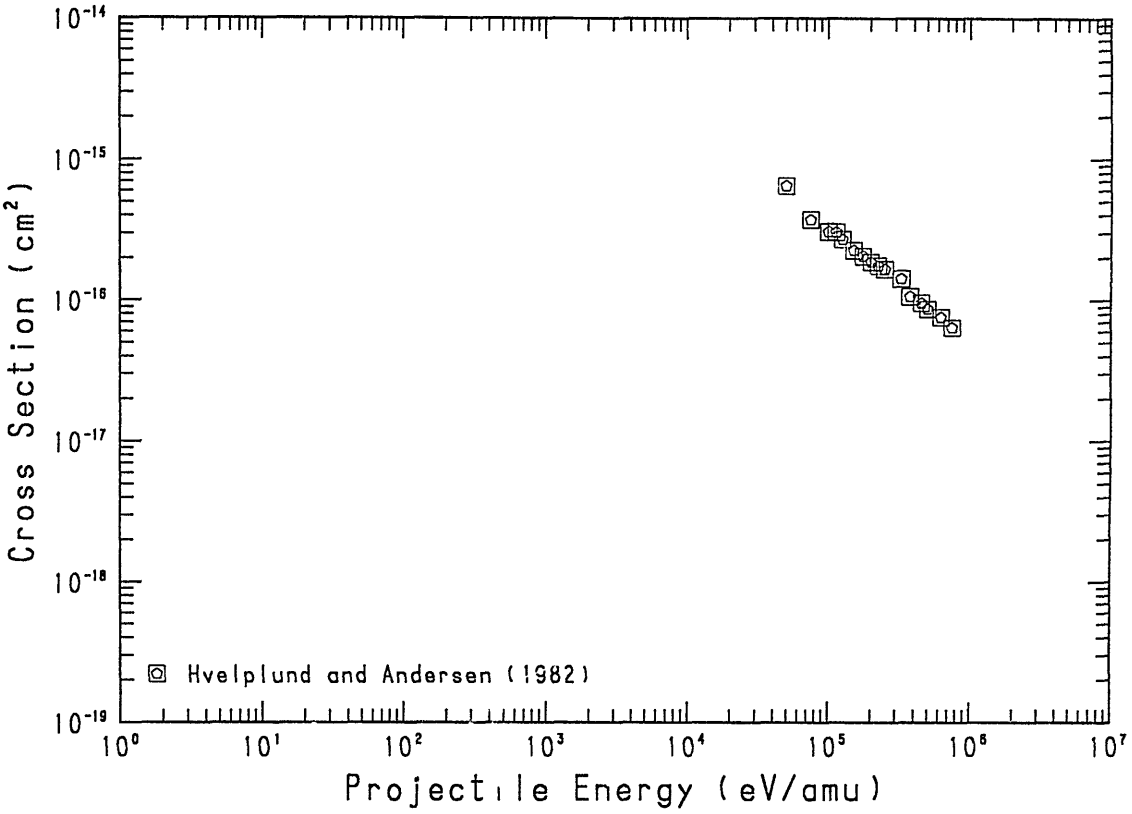


Fig.A18 $C^+ + H \rightarrow C^{2+}$

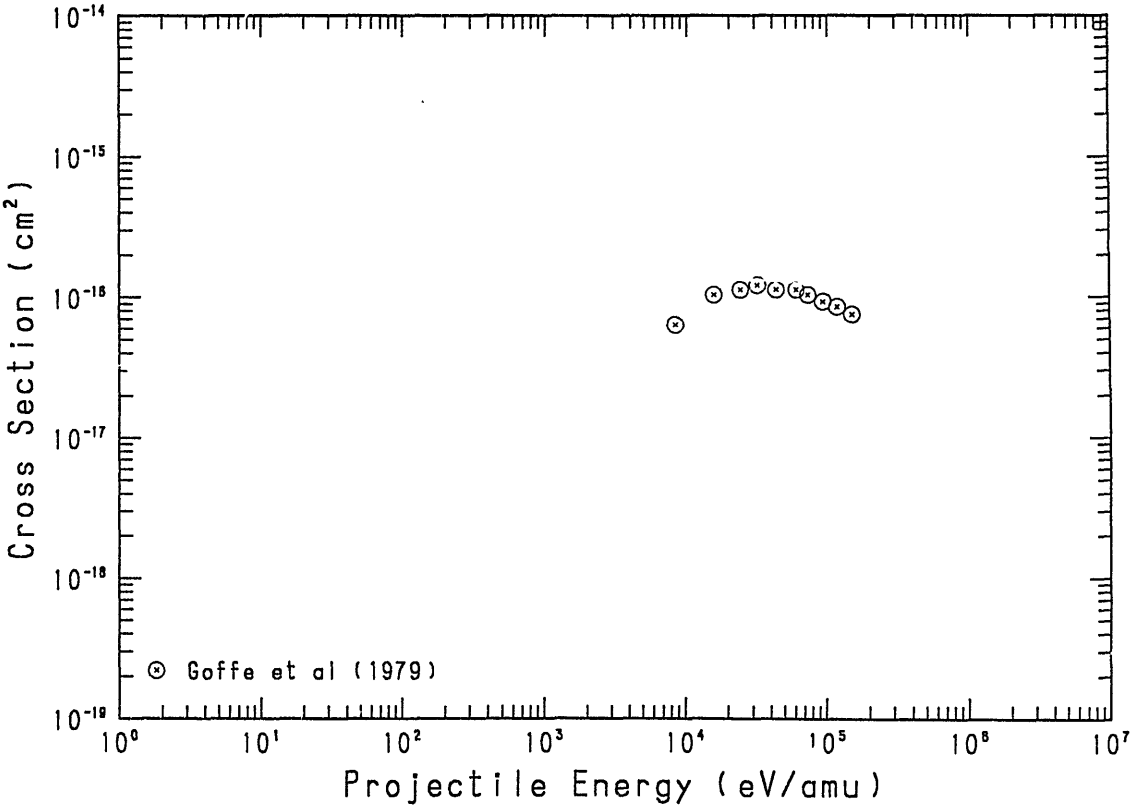


Fig.A19 $C^{2+} + H \rightarrow C^{3+}$

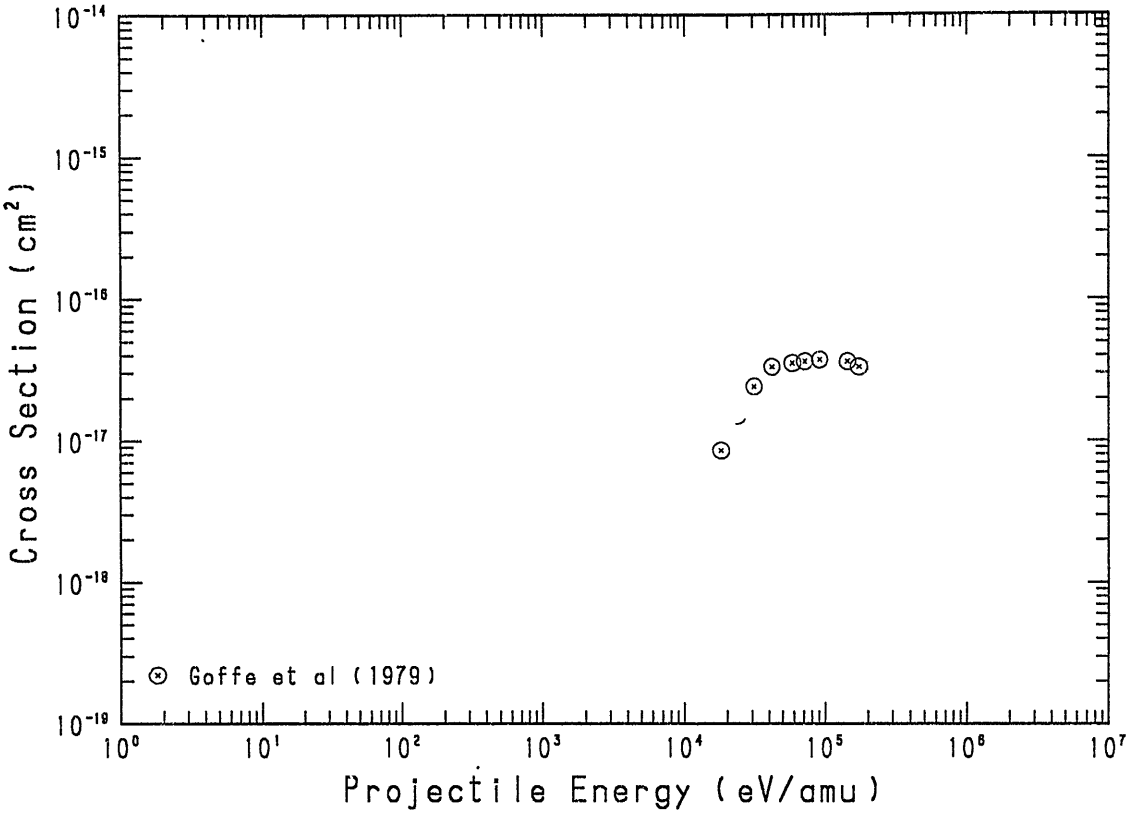
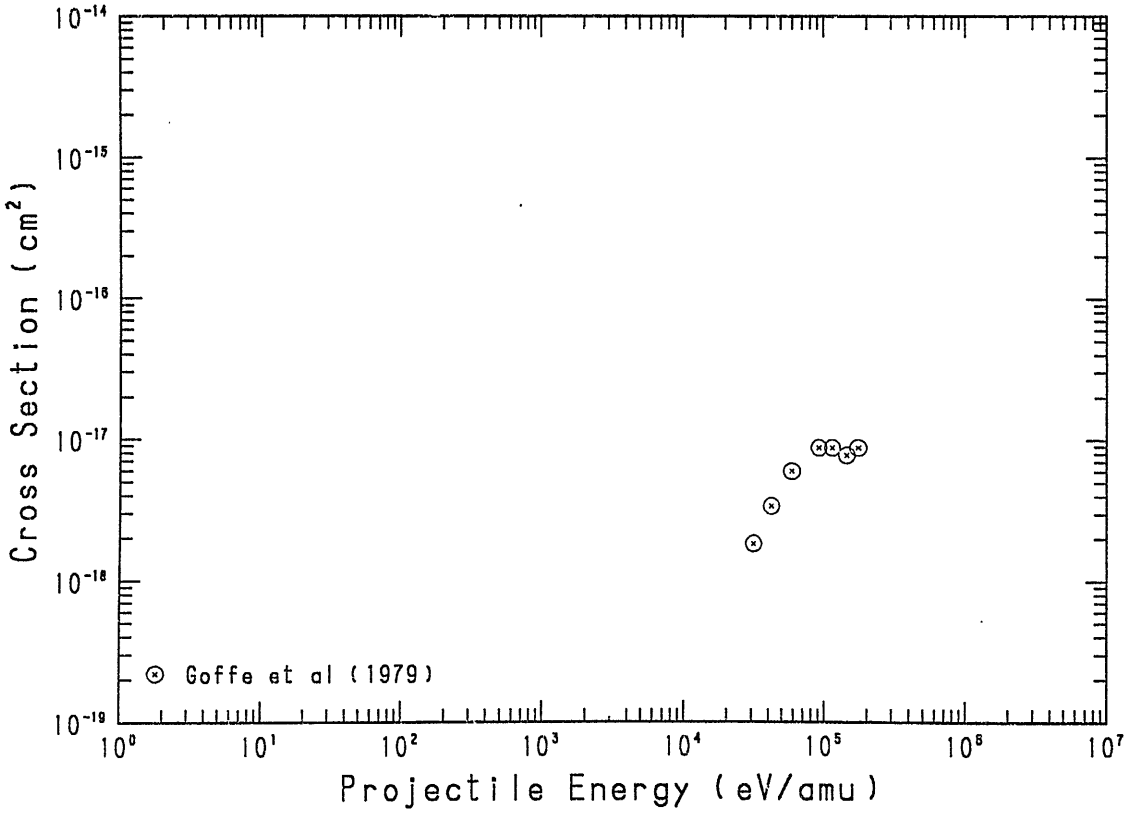


Fig.A20 $C^{3+} + H \rightarrow C^{4+}$



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