FR 8002373

Meeting on atomic and molecular data for fusion.
Fontenay-aux-Roses, France, May 19 - 22, 1980.
CEA - CONF 5282

CHARGE CHANGING COLLISION CROSS SECTIONS OF ATOMIC IONS

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ABSTRACT -

A device has been built to measure charge changing cross sections of atomic ions. It consists of an E.C.R. ion source (Micromafios) that delivers oxygen ions up to charge + 8, argon ions up to charge + 13. The ion source potential may be varied from 1 up to 10 kVolts. A first magnet is used to charge analyze the extracted beam. For a given charge state, the ion beam is passed in a collision cell whose pressure may be varied. The ions undergoing collisions on the target are analyzed by a second magnet and collected.

The single collision condition is checked. Different collisions are considered :

1- Charge exchange collisions of argon ions with charge $2 \leq Z \leq 12$ on argon. Cross sections for capture of 1, 2 and 3 electrons are given.
2- Stripping of argon ions ($1 \leq Z \leq 4$) on argon atoms.
3- Charge exchange of oxygen ions ($2 \leq Z \leq 8$) colliding on deuterium. One and two electron capture cross sections are presented.

I - INTRODUCTION -

During these last years a renewed interest in the physics of highly charged ions has been observed. Presently, data related to different processes such as ionization, charge exchange and stripping are urgently needed in order to understand physical phenomena in fusion and astrophysical plasmas. It became possible to start work on data acquisition on some of the mentionned phenomena when an device became available at this laboratory.

II - EXPERIMENTAL DEVICE - Data evaluationprocedure -

2.1. Experimental device -

Fig. 1 represents the device. The main elements are as follows : the ion source -1- is an E.C.R. source (Micromafios). It delivers highly charged ion currents in sufficient amounts Table I summarizes for different ion species charge and currents (μA) delivered at 7 kV [1]. The source is at a positive potential which may be varied from 1 to 10 kVolts.

TABLE I

	1	2	3	4	5	6	7	8	9	10	11	12	13	15	17
12 C^6					5	0,2									
15 N^7					20	3	0,1								
18 O^8	more				25	15	3	0,1							
20Ne^{10}		than				20	10	2	<0,1						
40 A^{18}			30 μA						10	3	<1	<0,3	<0,1		
84Kr^{36}	20	20	20	12	12	12	11	11	11	10	6	6	2	0,2	0,05

Two identical analyzing 167° magnets are used : the first -5- to charge analyze and separate a given charge to mass ratio among the ions extracted from the source ; the second -6- to separate the collision products. Gas is feed to the collision chamber -5- using an automated pressure regulated leak. A first diaphragm with provision for suppressing secondary electrons -3- is used for beam shaping before the gas cell entrance. A Faraday Cup -4- is used to measure incident ion current. Collision products are collected on the measuring Faraday Cup -7- Its insulation resistance is 10^{15} Ω.

2.2. Data evaluation procedure -

The projectile energy range extends from 1 Z to 10 Z keV where Z is the incident ion charge.

When the single collision condition is ascertained, it is possible to deduce the concerned collision cross section from current measurements. If I_b is the incident beam current, the current of formed ions I_f produced in path length is given approximately by :

$$I_b = I_f N \sigma$$

where N is the target thickness = $n\ell$ (n neutral gas number density, ℓ target length).

In fact, the cross section is associated to the current collected in the analyzing magnet acceptance angle (± 3° with respect to the incident ion trajectory).

III- RESULTS - DISCUSSION -

Three types of collisions are considered.

3.1. Charge exchange of Ar ions [2][3][4] in argon. In Fig.2 are given the electron capture cross section of argon ions at constant energy as function of the incident argon ion charge $2 \leq Z \leq 12$ ($Ar^{Z+} + Ar \rightarrow Ar^{(Z-k)+} + Ar^{k+}$).

It is seen from this figure that the one electron capture cross sections $\sigma_{Z,Z-1}$ shows from our results a charge dependance which writes $\sigma_{Z,Z-1} \sim 6\ 10^{-16}\ Z\ cm^2$.

In the case of argon ion collision on argon atom it appears that our experimental values are slightly lower than predicted from Salzborn scaling rule [5]

$$\sigma_{Z,Z-1} \simeq 1.43\ 10^{-12}\ Z^{1.17}\ (16)^{-2.76}\ cm^2$$

and slightly larger than theoretically predicted by Presniakov [6]

$$\sigma_{Z,Z-1} \simeq \pi\ a_o^2\ \frac{Z^2}{(16/13.6)^2}\ f\left(\frac{v}{v_o}\right)\ cm^2$$

where $f\left(\frac{v}{v_0}\right) \simeq 1$ for $v < v_o$

The two and three electron capture cross sections show as the one electron capture an oscillating behavior. At Z = 8, the ion configuration is Ne-like. The single capture cross section decrease could be associated to a nuclear potential screened by the remaining electron configuration (two closed shells).

3.2. Stripping of Ar ions in argon [2][7][8] . The collision cross sections given in Fig.3 are associated to the reaction :

$$Ar^{Z+} + Ar \rightarrow Ar^{(Z+1)+} + Ar + e^-$$

where Z+ denotes the initial ion charge. In the low energy limit where scattering is important, extrapolating from P.R. Jones [9] an estimate is made of the current scattered out of the analyzing magnet's acceptance. This allows an upper limit (broken line) to be given to the measured cross sections (solid curve).

There exists only one semi-empirical treatment (H.M. Fleischmann et al.[10]) to which the $\sigma_{1,2}$ curve may be compared. At this time, in the energy range considered there is no theory available for interpretation of $\sigma_{2,3}$, $\sigma_{3,4}$, $\sigma_{4,5}$.

3.3. Electron capture cross sections of oxygen ions colliding deuterium gas (D_2) [11]. The one and two electron capture cross sections of oxygen ions in collision on deuterium targets have been measured. The cross sections are associated with the general collision

$$O^{Z+} + D_2 \rightarrow O^{(Z-1)+} + D_2^+$$

$$O^{Z+} + D_2 \rightarrow O^{(Z-2)+} + D^+ + D^+$$

where $2 \leq Z \leq 8$.

The one electron capture cross section in the actual energy range shows a variation as function of the ion initial charge as predicted by L.P. Presnyakov [6] $\sigma_{Z,Z-1} \propto Z^2$.

This is shown on Fig. .

IV - CONCLUSION -

Charge changing collision cross sections of different ions on gas targets have been presented. The energy range is 1Z - 10Z keV where Z is the incident ion charge. The cross sections are generally in the range of a few 10^{-15} cm^2. Since the electron capture is made on an excited level, line radiation follows. Since transition probabilities for spontaneous emission are Z^6 dependant and radiation occurs in the V.U.V. and X-ray energy range, the impurity problem should receive great attention.

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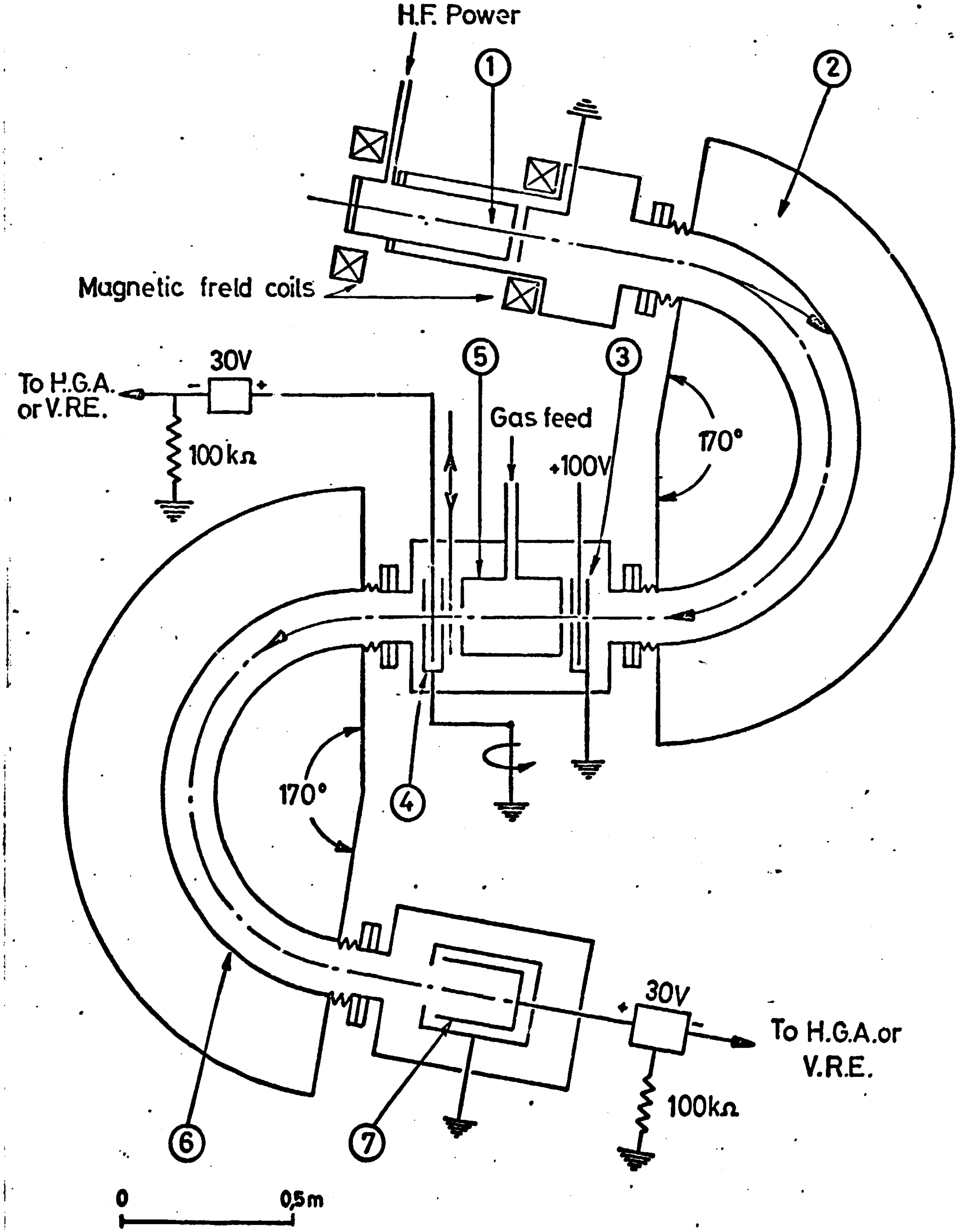
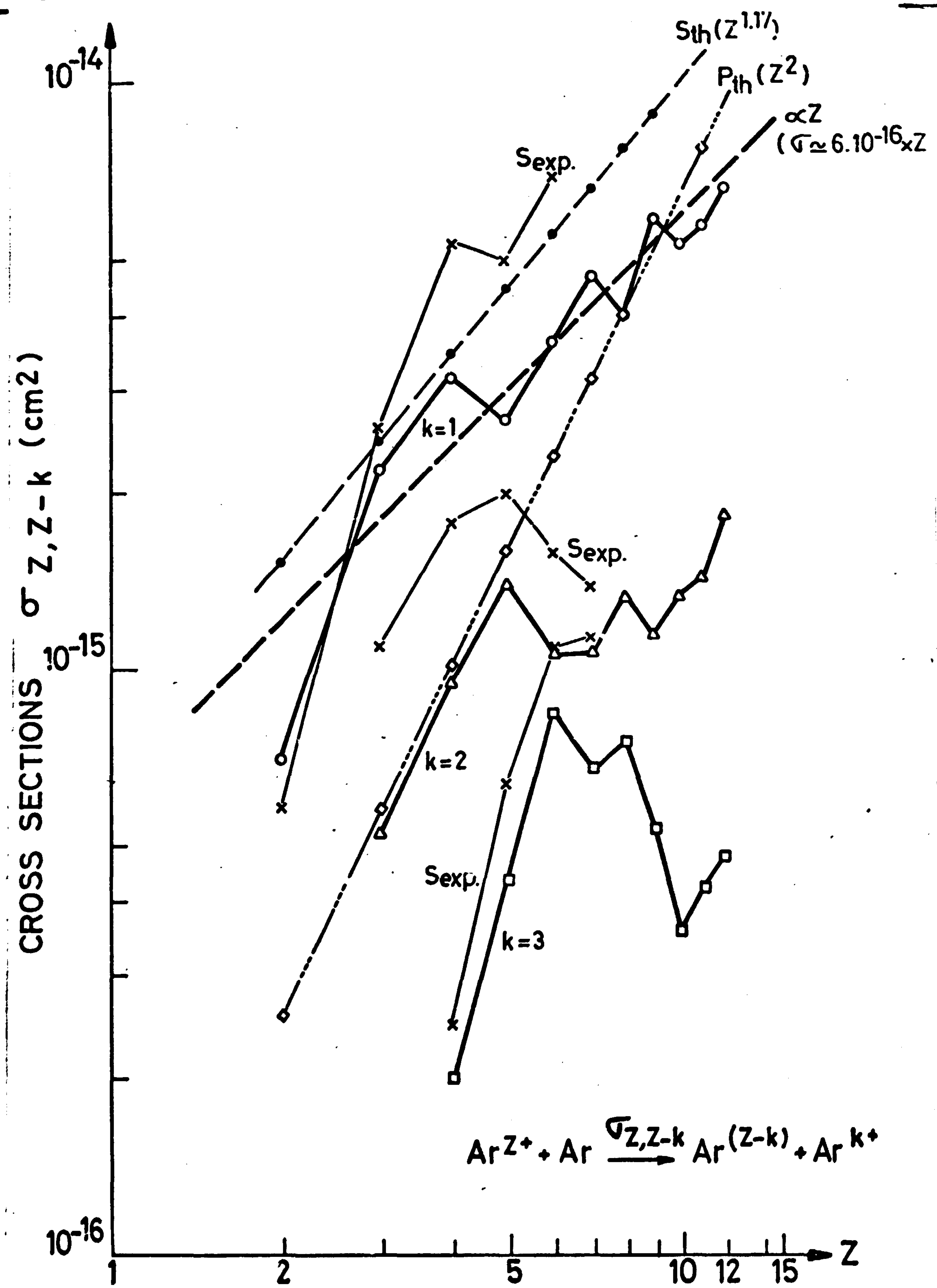
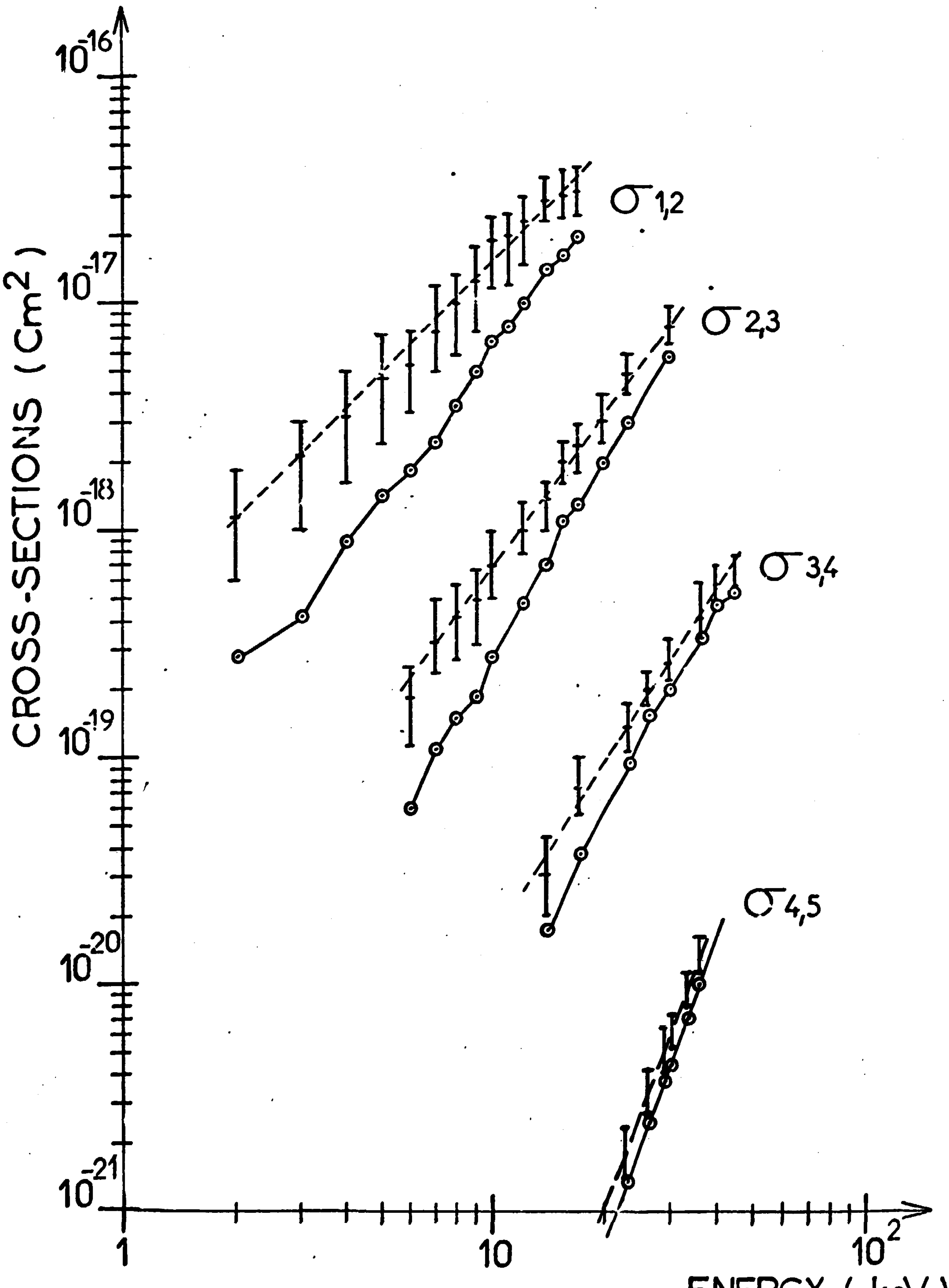


H.F. Power
1
2
Magnetic freld coils
30V
To H.G.A. or V.RE.
100 kΩ
5
3
Gas feed
+100V
170°
170°
4
30V
To H.G.A.or V.R.E.
100kΩ
6
7
0
0,5m

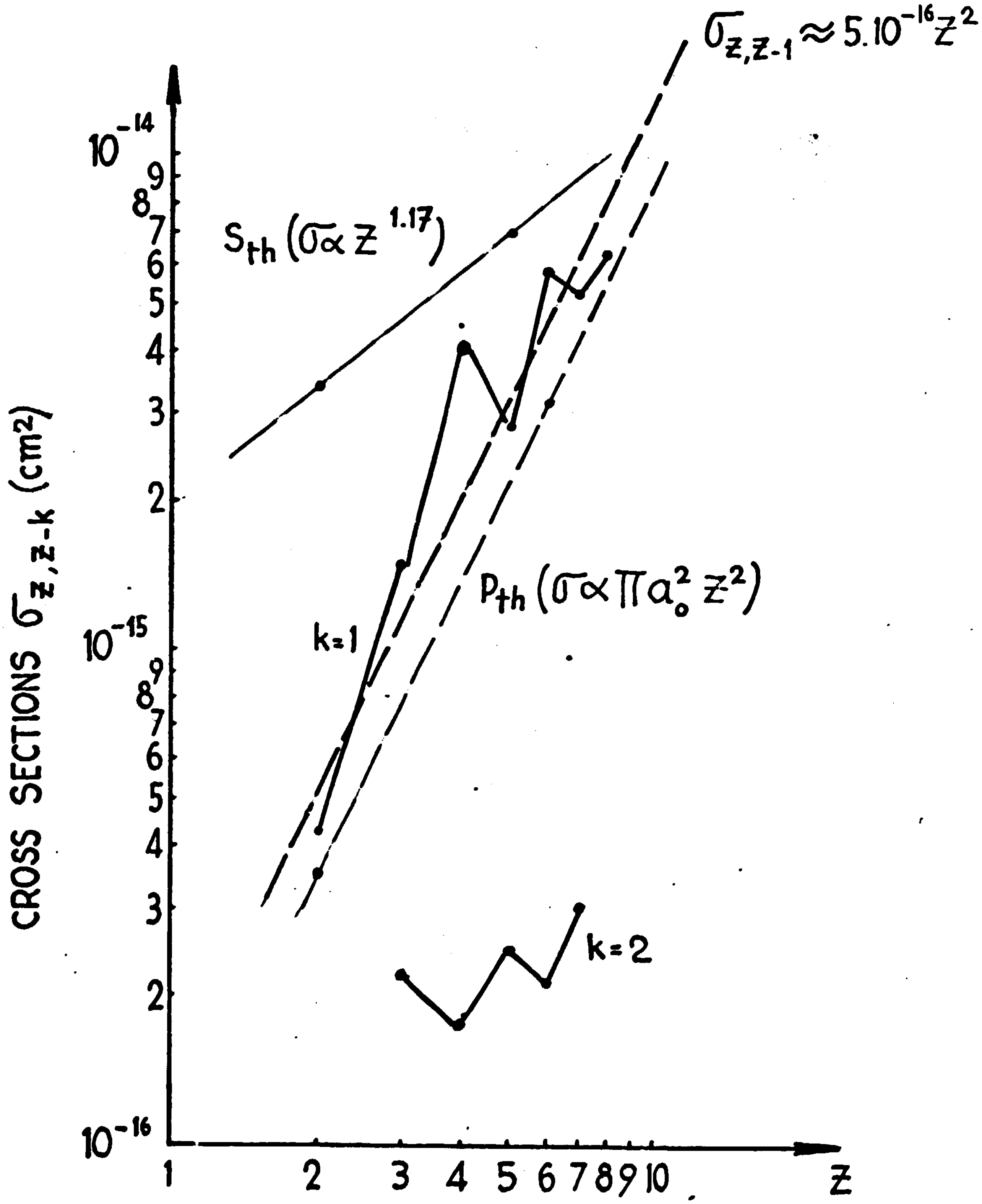
Fig : 1



CROSS SECTIONS σ Z,Z-k (cm2)
10-14
10-15
10-16
Sth(Z1.17)
Pth(Z2)
∝Z
(σ ≃ 6.10-16xZ
Sexp.
k=1
Sexp.
k=2
Sexp.
k=3
Ar Z+ + Ar σZ,Z-k Ar(Z-k) + Ar k+
1
2
5
10
12
15
Z



CROSS-SECTIONS (Cm^2)
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
$\sigma_{1,2}$
$\sigma_{2,3}$
$\sigma_{3,4}$
$\sigma_{4,5}$
1
10
10^2
ENERGY (keV)



$$O^{Z+} + D^2 \longrightarrow O^{(Z-1)+} + D_2^+$$
$$\longrightarrow O^{(Z-2)+} + D^+ + D^+$$