2. Conference on low energy beams - LEIB 2.
Bath, GB, April 14 - 17, 1980.
CEA - CONF 5209

FR8002026

CHARGE TRANSFER CROSS-SECTIONS of ARGON IONS COLLIDING ON ARGON ATOMS

J. AUBERT, S. BLIMAN, N. CHAN-TUNG, R. GELLER, B. JACQUOT

and D. VAN HOUTTE

Département de Recherches sur la Fusion Contrôlée

Service IGn - Centre d'Etudes Nucléaires

85 X - 38041 GRENOBLE CEDEX (France)

ABSTRACT

A device has been built to measure charge changing cross-sections of Argon ions colliding on argon atoms. It consists of an E. C.R. ion source (Micromafios) that delivers 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 separated 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 pressure is varied in the collision cell in order to check that the single collision condition is satisfied. It is shown that the ions do two types of collisions: charge exchange and stripping whose cross-sections are measured. Interpretation of charge exchange is proposed along yet classic theoretical approaches. As to stripping no available theory allows interpretation.

I. INTRODUCTION

During these last years a reviewed 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 data acquisition on some of the mentionned phenomena when an ion source developped in this laboratory was available [S.BLIMAN and al (1978), J. DELERNARDI and al (1979) paper 57 this Conference].

2 . EXPERIMENTAL DEVICE - DATA EVALUATION PROCEDURE.

2.1. Experimental device.

Fig. 1 represents the device. The main elements are as follows : the ion source -1- is at positive potential : varied from 1 to 10 kVolts. A first analyzing 170° magnet -2- allows selection of the desired charge to mass ratio. A first diaphragm with provision for suppressing secondary electrons -3- is used for ion beam shaping before the gas cell entrance. A rotatable Faraday Cup -4- is used to measure the selected incident ion beam. The collision cell-5- is connected to a regulated leak. When gas is admitted to the collision cell, the flow is pressure regulated. A second analyzing magnet -6- identical to the first one allows separation of collision products. These are collected on the measuring Faraday Cup -7- its insulation resistance is 10^{15} Ω allowing minute current measurements.

Fig. 2 gives a schematic representation of the measurement device. According to the amplitude of currents to be measured, a high gain amplifier (band width: 1MHz, noise limit 10^{-11} Amp) or a vibrating reed electrometer is used.

2.2. Data evaluation procedure.

At a given setting of the source potential $V_{extraction}$ a given charge to mass ratio is selected using magnet 1. The ion trajectory mean radius is constant (0.5 m). Beam shaping is performed before entrance in the collision chamber. In the chamber incident current is measured. It is then checked that 100 % transmission is obtained to the Faraday cup at the second magnet exit.

Then, target gas is fed to the collision chamber. When considering charge exchange, the formed ions are selected with the second magnet (magnetic field is increased from the initial value) and measured. When stripping collisions are considered, the ions are selected lowering the magnetic field from its initial value.

The projectile energy range extends from 1 to 10 keV times the ion initial charge.

To obtain the cross section values, one has to ascertain that the single collision condition is satisfied. If I_b is the incident beam current, the current of formed ions I_f produced in path length is given approximately by

$$I_f = I_b \, N \, \sigma$$

Where σ is the concerned collision cross section, and N the target thickness $= \ell \, n$ (ℓ target length, n neutral gas number density).

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

3. RESULTS - DISCUSSION.

Argon gas is injected in the collision chamber. The base pressure is lower than 10^{-6} Torr. The pressure is increased up to 5×10^{-4} Torr. Over approximately two orders of magnitude in pressure variation, the I_f/I_b ratio as function of N is a straight line. Departure from linear may be interpreted as multiple collisions occuring in path length.

Two types of collisions have been considered :

3.1. Stripping collisions :

The collision cross sections given in Fig. 3 are associated to the reaction :

$$Ar^{Z+} + Ar \rightarrow Ar^{Z+1} + e + Ar.$$

Where Z+ denotes the initial charge ion.

In the low energy limit, scattering in the collision is estimated. Extrapolating from P.R. Jones and al (1959), and from C.H. Lane and al (1960), a superior limit to the cross section is ascertained (broken-curve), the solid curve corresponding to the measured points. The available theories for interpretation are for $\sigma_{1.2}$ these of O.B. Firsov (1959) and H.M. Fleischmann (1972). The first one gives a general expression for the cross section. The fit to experimental points is generally good at energies greater than 200 keV. Our $\sigma_{1.2}$ points fit to the Fleischmann's calculated values :

$$\delta_{T.M.} (t) \approx 3.2 \times 10^{-14} \left[\frac{\varepsilon}{\varepsilon^{2/3} + 30^{2/3}} \right]^{1.2}$$

Where $\varepsilon = \dfrac{E}{M E_i^2 R_t^2}$; in ε, E is the projectile energy, M the atomic mass number of the projectile, E_i the ionization energy of the projectile and R_t the target radius. For the other values $\sigma_{2.3}$, $\sigma_{3.4}$, $\sigma_{4.5}$ there is no theory available for interpretation at this time. These phenomena are certainly of importance in the early transport stages of medium energy accelerators.

3.2. Electron capture.

In Fig. 4 are given the cross sections associated to the general charge exchange collision

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

where $Z+$ denotes the projectile initial charge.

In the energy range considered that is 1 to 10 keV times the incident ion charge it may be noted that the cross sections increase with Z. The cross sections are quasi energy independant except for the $\sigma_{1\cdot 2}$ at the lowest energy where scattering takes surely place. The cross sections may be compared to the theoretical prediction of L.P. Presniakov and al (1975) :

$$\sigma_{Z,Z-1} = \pi a_0^2 \frac{Z^2}{\left[I_{Ar} / Ry\right]^2} . f(v/v_0) \text{ cm}^2$$

Where : $f(v/v_0) \simeq 1$ for $v < v_0$, a_0 is the first Bohr radius, $Ry = 13.6$ eV and $I_{Ar} = 16$ eV first Argon Ionization Potential v_0 is the atomic unit of velocity.

It is seen that all our values are larger by approximately a factor of 2 than predicted.

Another comparison may be made with a general formula obtained by E. Salzborn and al (1979) :

$$\sigma_{Z,Z-1} = 1.43\ 10^{-12} .\ Z^{1.17} \left(I_{Ar}(\text{eV}) \right)^{-2.76} \text{ cm}^2 .$$

It appears that our experimental values are smaller than should be from this formula. However considering the uncertainty on our measurements, their values are within the error bar of the Salzborn estimate ..

4. CONCLUSION.

Stripping and electron capture cross sections have been obtained in the energy range 1 - 10 keV times the incident ion charge. For the stripping their is no theoretical results available for comparison. For electron capture, it is seen that the measured values agree quite well with the semi experimental prediction of E. Salzborn.

REFERENCES

[1] S. BLIMAN, S. DOUSSON, R. GELER
Nucl. Inst. Meth. 148 (1978), 213

[2] J. DEBERNARDI, R. GELLER, B. JACQUOT, C. JACQUOT
Rapport EUR-CEA-FC 1026 - Nov. (1979)

[3] O.B. FIRSOV
Zh. Eksp. Teor. Fiz 36 (1959), 1517
(Sov. Phys. JETP 9, 1959, 1076)

[4] H.H. FLEISCHMANN, R.C. DEHMEL, S.K. LEE
Phys. Rev. A5 (1972), 1784

[5] P.R. JONES, F.P. ZIEMBA, H.A. MOSES, E. EVERHART
Phys. Rev. 113 (1959), 182

[6] C.H. LANE, E. EVERHART
Phys. Rev. 120 (1960), 2064

[7] L.P. PRESNYAKOV, A.D. ULANTSEV
Sov. J. Quant. Electronics, 4 (1975), 1320

[8] E. SALZBORN, A. MULLER
Electronic and Atomic Collisions Invited papers 11th ICPEAC
Ed^{r} N. ODA, K. TAKAYANAGI
North Holland Pub. Cy 1980, p. 407

CAPTION OF FIGURES

Fig. 1 : Experimental device.

1. ion source 2. First analyzing magnet
3. beam shaping diaphragm 4. rotatable collector
5. collision chamber 6. second analyzing magnet
7. Faraday cup.

Fig. 2 : Instrumentation.

The extent of current measurement covers the range from 10^{-6} to 10^{-14} Amperes.

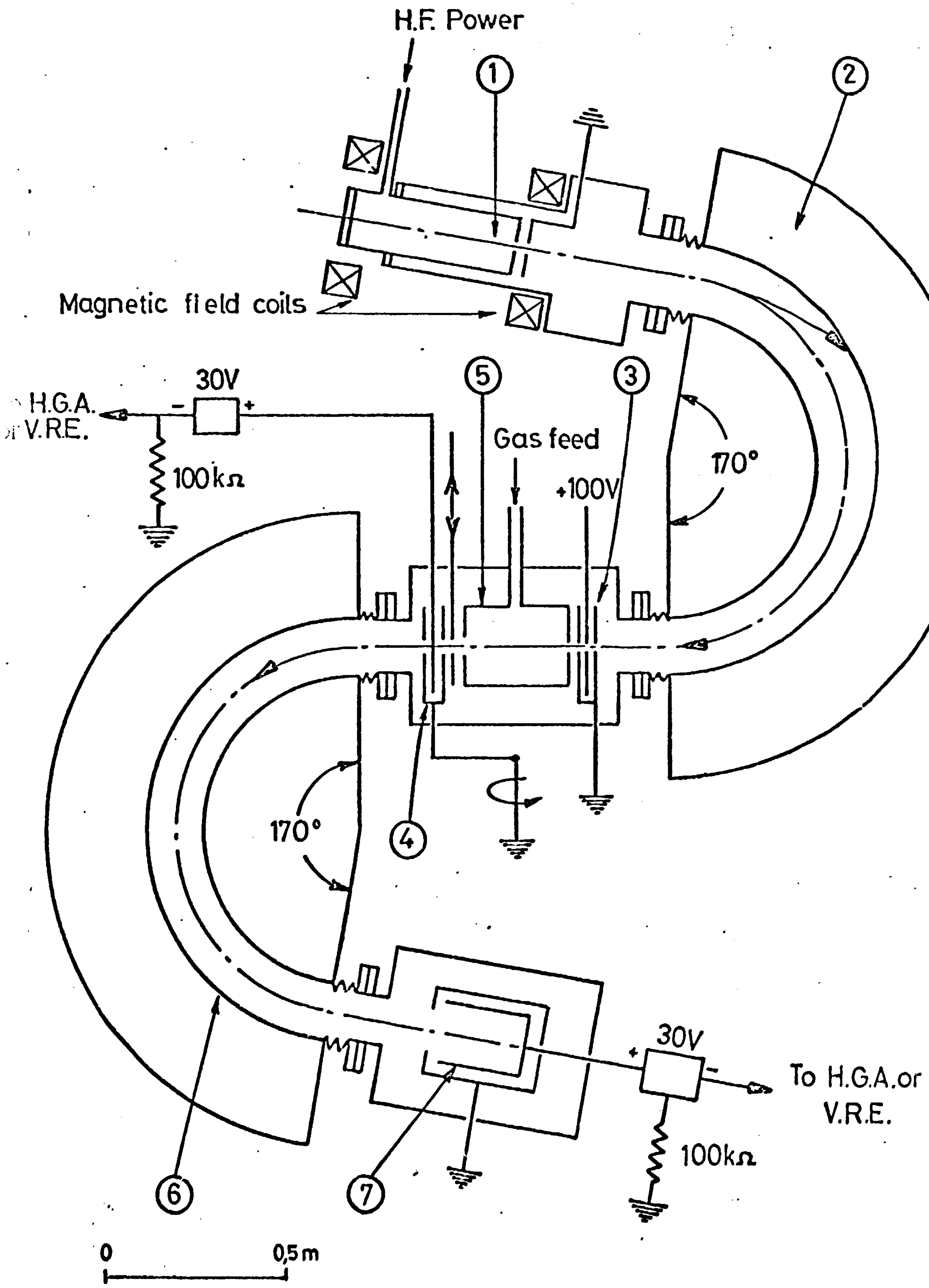
Vibrating reed electrometer : V.R.E. High gain amplifier : H.G.A.

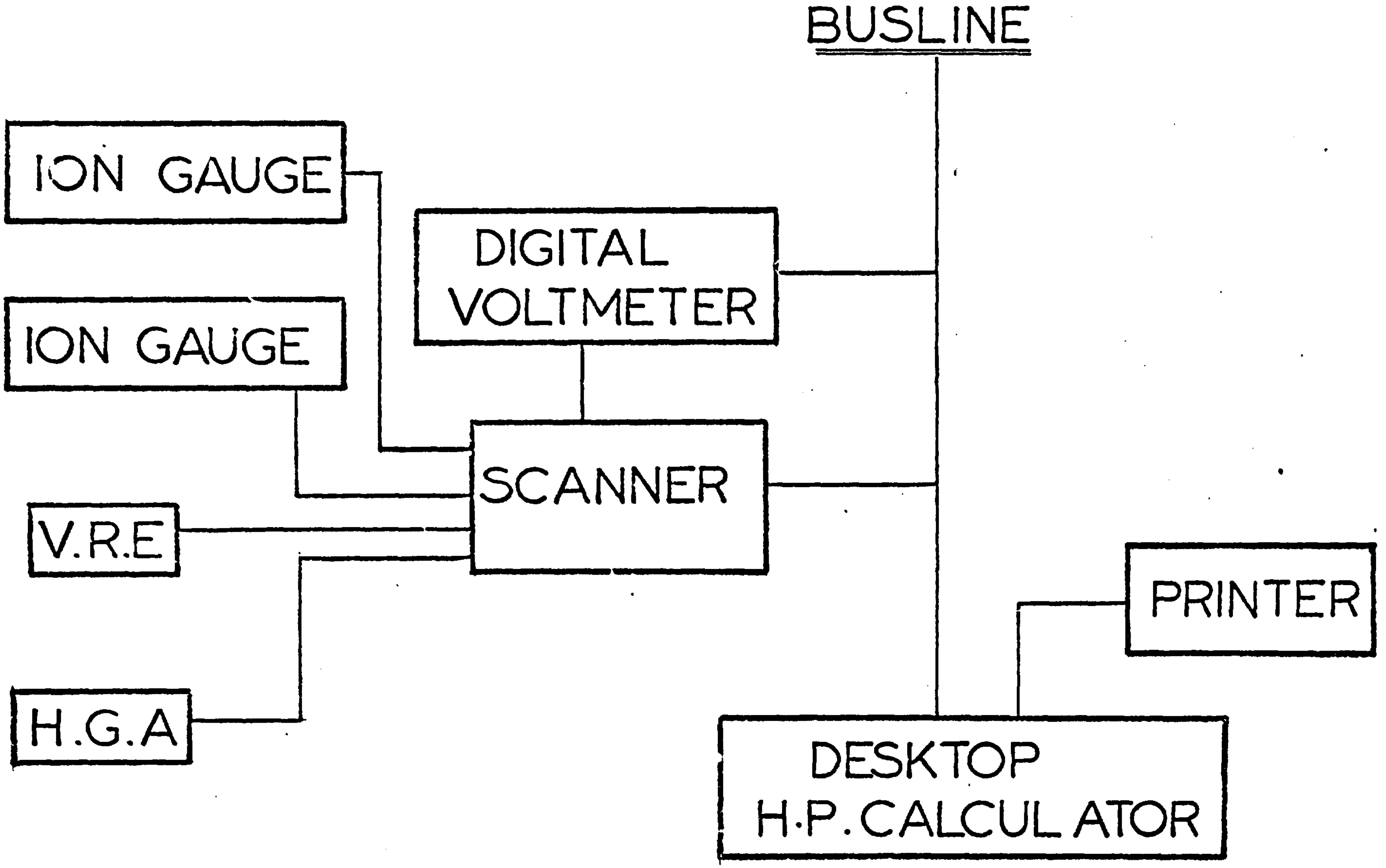
Fig. 3 : Measured stripping cross sections as function of incident ion energy

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

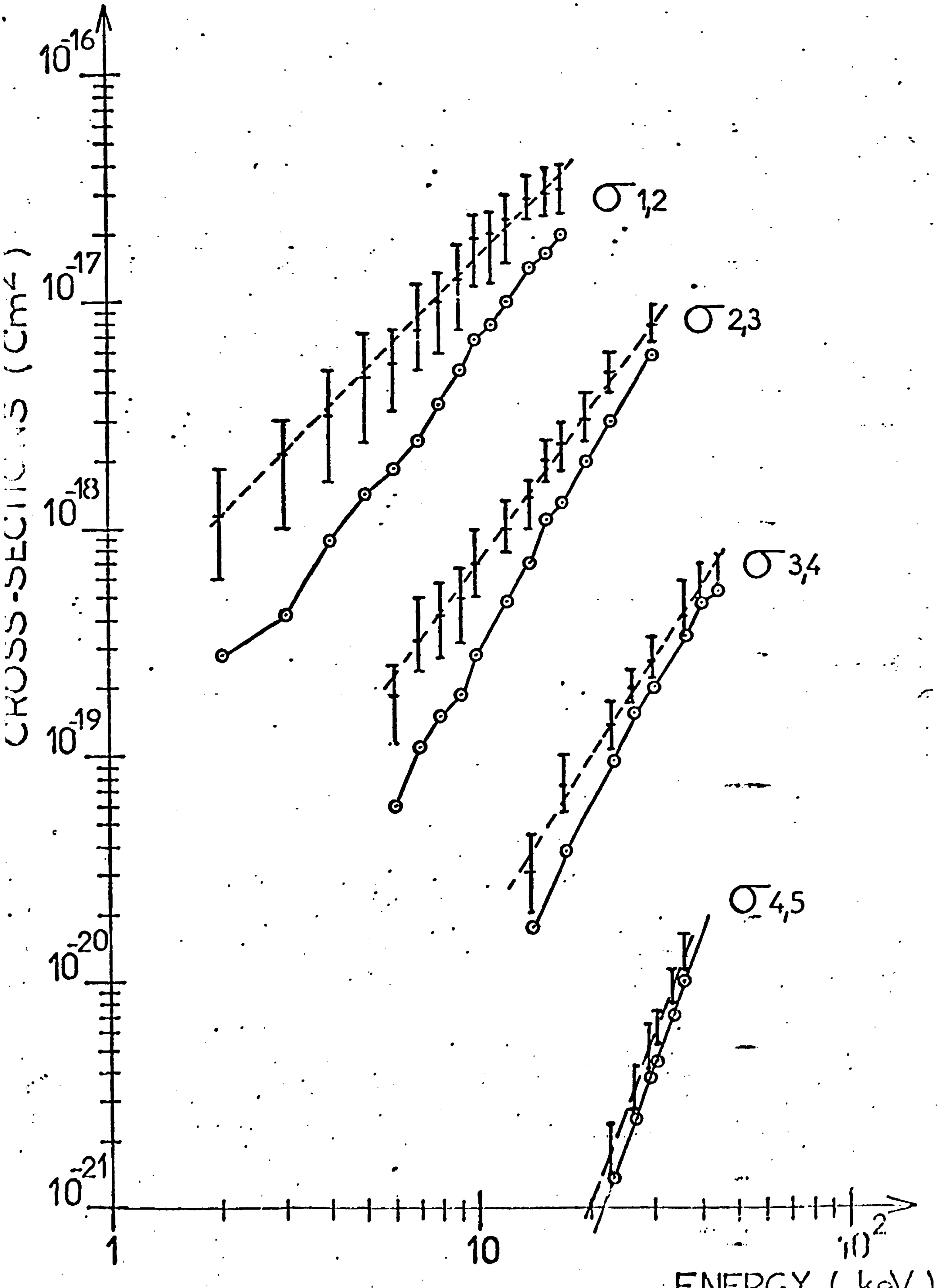
Fig. 4 : Measured electron capture cross sections as function of incident ion energy

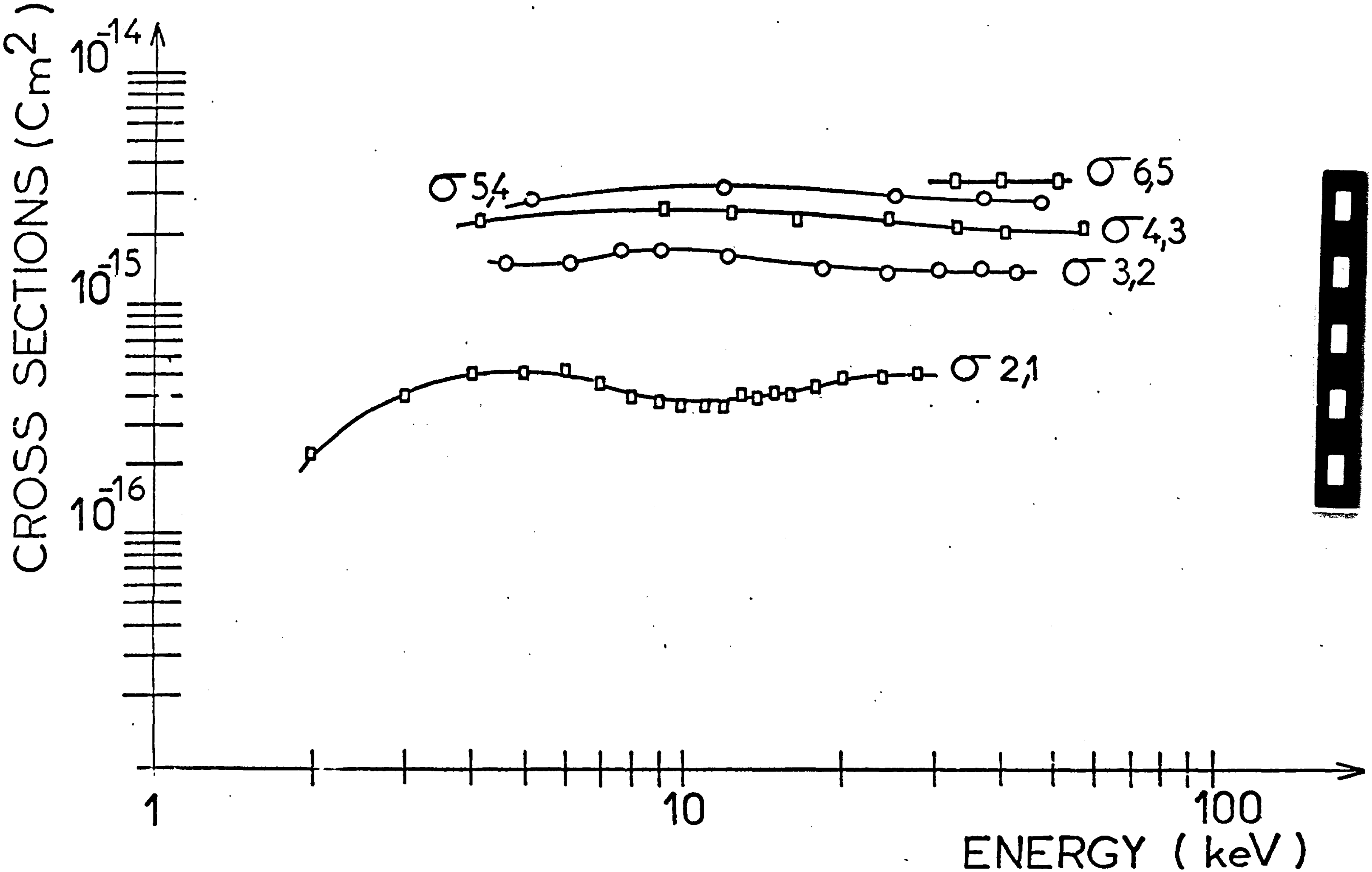
$$Ar^{Z+} + Ar \rightarrow Ar^{(Z-1)+} + Ar^+$$


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


BUSLINE
ION GAUGE
DIGITAL VOLTMETER
ION GAUGE
SCANNER
V.R.E
PRINTER
H.G.A
DESKTOP H.P. CALCULATOR

-FIG -2 -


CROSS-SECTIONS (Cm²)
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)


CROSS SECTIONS (Cm^2)
10^{-14}
10^{-15}
10^{-16}
σ 5,4
σ 6,5
σ 4,3
σ 3,2
σ 2,1
1
10
100
ENERGY (keV)

-FIG-4-