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Report

ATOMIC COLLISION PROCESSES IN PLASMA PHYSICS EXPERIMENTS

Analytic expressions for selected cross-sections and Maxwellian rate coefficients

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1974

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Analytic expressions for selected cross-sections and Maxwellian rate coefficients

R L Freeman, E M Jones

ABSTRACT

Convenient analytic expressions have been obtained for the cross-sections and the Maxwellian rate coefficients for electron ionisation, proton ionisation, and proton charge exchange. These expressions were obtained for atomic and molecular hydrogen, the alkali metals, the rare gases, calcium and magnesium. The rates for these same processes have been evaluated for 5 and 10 keV atomic hydrogen beams in atomic hydrogen.

The experimental values for the ionisation and charge exchange cross-sections were fitted either by the analytic expressions of Gryzinski[1] or by a polynomial, and these analytic expressions were then used for integration over a Maxwellian velocity distribution. The values of the rate coefficients were fitted in selected cases with a polynomial and the coefficients for this polynomial are tabulated. Plots of the analytic fits to the experimental cross-sections and the Maxwellian rate coefficients are given in each case.

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May 1974

SBN: 85311 027 1

INTRODUCTION

The cross-sections and rate coefficients presented in this report have been collected during studies of plasma diagnostic techniques using atom beams, and from the development of zero and one-dimensional codes to follow plasma behaviour.

Such codes require the inclusion of basic ionisation and charge transfer processes in the form of rate coefficients. To eliminate the time consuming process of integrating the cross-sections over a Maxwellian distribution function at each time step in the code it was decided to evaluate the coefficient as a function of energy and fit a polynomial to the resulting curve.

The analytic forms derived by Gryzinski are simple and give reasonable agreement with the practical data for electron and proton ionisation cross-sections, but a polynomial fit was used for the charge exchange cross-sections because the Gryzinski expressions do not fit the experimental data.

1. GRYZINSKI EXPRESSIONS

The Gryzinski analytic form used for single ionisation by an electron was:

$$\sigma = \frac{\sigma_o}{u_i^2} \; g_i(x)$$

where $$g_i(x) = \frac{1}{x}\left(\frac{x-1}{x+1}\right)^{3/2}\left(1 + \frac{2}{3}\left(1 - \frac{1}{2x}\right) \ell n(2.7 + (x-1)^{\frac{1}{2}})\right),$$

and x is the ratio of the kinetic energy of the bombarding electron to the binding energy of the orbital electron ($x = E_i/u_i$), and $\sigma_o = 6.56 \times 10^{-14} Z^2$ eV^2 cm^2 .

The form for single ionisation by protons was

$$\sigma = \frac{\sigma_o}{u_i^2} \; G_i \; (v_q/v_i)$$

$$\text{where} \quad G_i = \frac{32}{15}\left(\frac{v_q}{v_i}\right)^4 \left(1 - \frac{19x^2}{12} - \frac{x^4}{24} + \frac{5x^6}{16(1-x^2)^{\frac{1}{2}}} \ln\left(\frac{1+(1-x^2)^{\frac{1}{2}}}{1-(1-x^2)^{\frac{1}{2}}}\right)\right)(1-x^2)^{\frac{1}{2}}$$

below the apparent threshold ($v_q < 0.224\ v_i$) (NB. change in threshold from Gryzinski [1c])

$$\text{and} \quad G_i = \left(\frac{v_i}{v_q}\right)^2 \left(\frac{v_q^{\,2}}{v_q^{\,2}+v_i^{\,2}}\right)^{3/2} \left(\frac{v_q^{\,2}}{v_q^{\,2}+v_i^{\,2}} + \frac{2}{3}\left(1+\frac{1}{\alpha}\right)\ln\left[2.7+\frac{v_q}{v_i}\right]\right)\left(1-\frac{1}{\alpha}\right)\left[1-\left(\frac{1}{\alpha}\right)^{\left(1+\frac{v_q}{v_i}\right)}\right]$$

$$\alpha = 4\left(\frac{v_q}{v_i}\right)^2\left(1+\frac{v_i}{v_q}\right), \quad x = \frac{E_{thr}}{E_q}, \quad E_{thr} = \frac{u_i}{2}\left(\frac{m_q}{m_i}+1\right)\left(\frac{m_q\, e}{m_e\, q}\right)^{\frac{1}{2}}$$

v_q = the velocity of the target proton

$v_i = \sqrt{\dfrac{2u_i}{m_e}}$ the velocity of an electron corresponding to the ionization potential

Both forms are summed over the number of shells to obtain the total contribution. The shell edge potentials used to describe each shell were taken from Mordberg[2], Slater[3], Bearden[4] and Hill[5], and are listed in Table 1.

2. FIT TO EXPERIMENTAL DATA OF THE GRYZINSKI ANALYTIC FORM

2.1 Electron ionisation cross-sections

The analytic forms of the cross-sections and some experimental data are presented in graphical form in Figs 1 to 28.

Figs 1 and 2 show the analytic cross-sections for ionisation of atomic and molecular hydrogen. The agreement is good in both cases, with the maximum deviation from the practical data being 12% for atomic and 20% for molecular hydrogen.

For helium (Fig 3) the agreement is good at high energies (maximum error of 14% between 500 and 10^4eV), but below 500 eV the error can be as large as 27%. The agreement between the analytic form and the experimental data for neon (Fig 4) is non-existent; at low energies the analytic form is a factor of 4 too large.

The curves for argon, krypton and xenon, show better agreement. At low energies the argon curve (Fig 5) matches one set of data, but at high energies it is up to 30% too low. The krypton curve (Fig 6) is within 26% of the experimental results below 200 eV, but the agreement deteriorates steadily above this energy and the curve is 50% low at 10^4 eV. Xenon (Fig 7) shows similar defects being within 20% at worst below 200 eV, but becoming 30% too low at 10^4 eV.

In the cases of the alkali metals (Figs 8-12) the errors in the experimental data are larger, but agreement with the analytic form is good. For lithium (Fig 8) the largest error is at the peak of the curve ($\sim$ 27%).

At high energies the sodium experimental data (Fig 9) spans the curve, while at low energies the error decreases from 60% at 7 eV to 14% at 30 eV. The potassium data (Fig 10) shows a similar effect, though not so marked. The rubidium curve (Fig 11) lies midway between the two sets of data at high energies, while at low energies the error decreases from 50% at 5 eV to 10% at 10 eV.

The experimental data for caesium (Fig 12) is a good fit up to 10 eV, in the range 10-100 eV the maximum error is 23%, but from 100 eV upwards the data and curve fit exactly.

In the cases of magnesium and calcium the analytic form is a very bad fit. The fit could be improved slightly by multiplying the analytic values by 2.2 for magnesium, and 1.4 for calcium.

2.2 Proton ionisation cross-sections

The Gryzinski expression for proton ionisation is a poorer fit to the practical data than the electron ionisation model.

The hydrogen, helium and neon data, shown in Figs 15-18 have polynomial fits (dashed curve) as well as the Gryzinski curves (solid line). The polynomial fitting procedure will be discussed in the next section.

In the cases of atomic hydrogen (Fig 15) the Gryzinski curve and data match above 2×10^4 eV (maximum error 10%), but at low energies the analytic form drops off too slowly. Similarly for molecular hydrogen (Fig 16) the fit is good above 5 x 10^4eV but below this level the curve exceeds the data by some 50% at 10^4eV, and the curve then drops away too quickly. Helium (Fig 17) shows the same behaviour as molecular hydrogen, while the neon data and curve again bear no relation to each other.

Both argon and krypton show some 30% deviation from the practical data, and no experimental data has been collected for the remaining curves.

3. POLYNOMIAL FITS

In cases of special interest for the computer codes the agreement between practical data and the Gryzinski analytic form for proton ionisation could be improved.

In these cases (H, H_2 and He) a polynomial of the form

$$\ell n \ \sigma = \sum_{i=o}^{n} A_i \ (\ell n \ E)^i$$

was fitted to the practical data and is plotted on the graphs (Figs 15-17) as a dashed curve. The same form of polynomial was used to fit the charge exchange data.

4. CHARGE EXCHANGE

The Gryzinski analytic form for charge exchange cross-sections is extremely poor when compared to the practical data. To have some expression for this cross-section a polynomial of the form previously mentioned was fitted to the practical data.

In the cases of molecular hydrogen, krypton, xenon and magnesium, the odd points below the maxima at the low energy side were assumed to indicate that the cross-section had passed its maximum and would decrease. The curves have been fitted accordingly.

The coefficients of the polynomial fits for the proton ionisation and the charge exchange cross-sections are listed in Table 2, along with their ranges of validity.

5. RATE COEFFICIENTS

Rate coefficients $\sigma.v$ (cross-sections at a given energy multiplied by electron or proton velocity at the same energy) and rate coefficients evaluated over a Maxwellian velocity distribution $\langle\sigma.v\rangle$ have been evaluated for all three processes. In the cases where a polynomial fit has been obtained for the cross-section this was used in preference to the Gryzinski form in the integration routines, and the results are shown graphically in Figs 37-50. For the Maxwellian rate coefficients the energy scale gives the temperature of the Maxwellian distribution. The resulting rate coefficients for several cases have been fitted with polynomials and the coefficients and ranges of validity are given in Table 3.

6. IONISATION OF ENERGETIC ATOMIC BEAMS

Maxwellian rate coefficients for ionisation by electrons and ionisation and charge exchange of protons with energetic atomic hydrogen beams of energy 5 keV and 10 keV have been evaluated. Polynomials have been fitted to the curves, and the coefficients and ranges of validity are given in Table 4.

The curves are shown in Figs 51-53, and are of particular interest in the study of neutral injection in the levitron.

SUMMARY

It can be seen that the Gryzinski form for both electron and proton ionisation gives a useful estimate of the cross-sections (with the exception of neon). If a more accurate value is needed a polynomial fit is necessary.

No attempt has been made in this note to give comprehensive data for the cases considered, or to judge the accuracy of the experimental data.

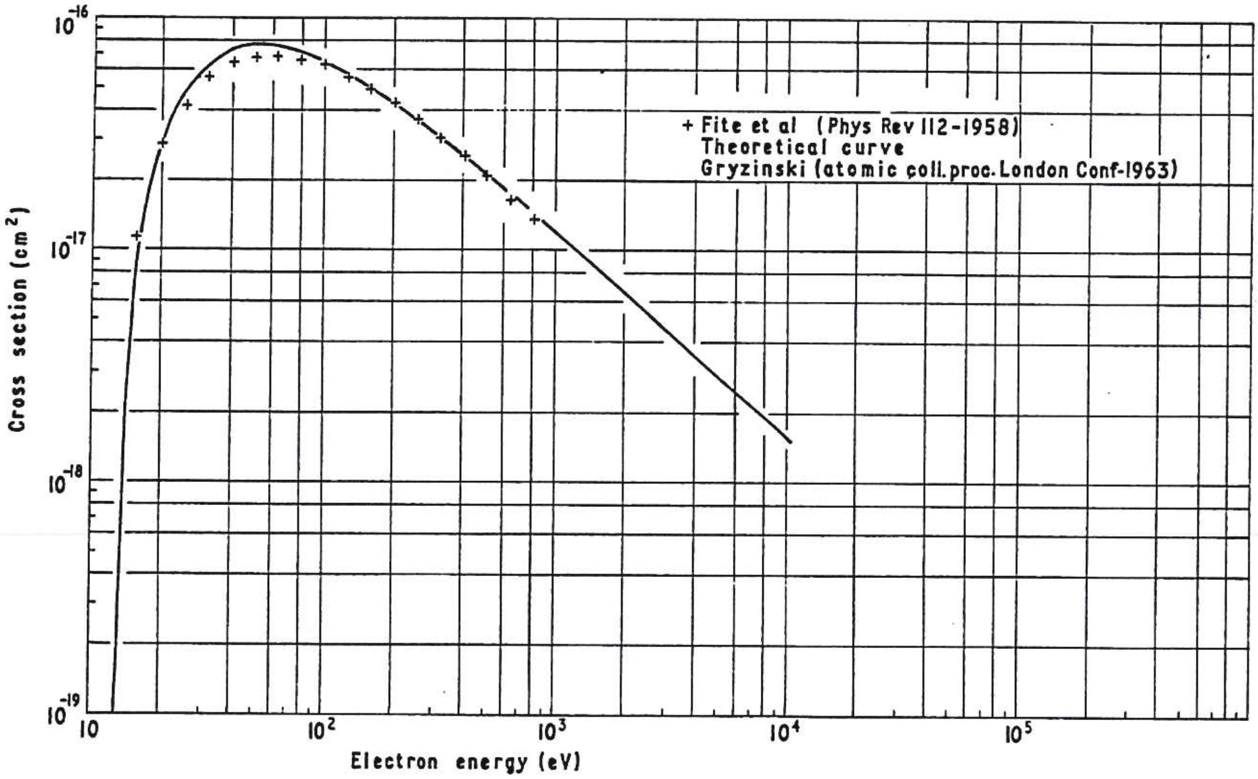

Fig.1 Ionisation of atomic hydrogen by electrons

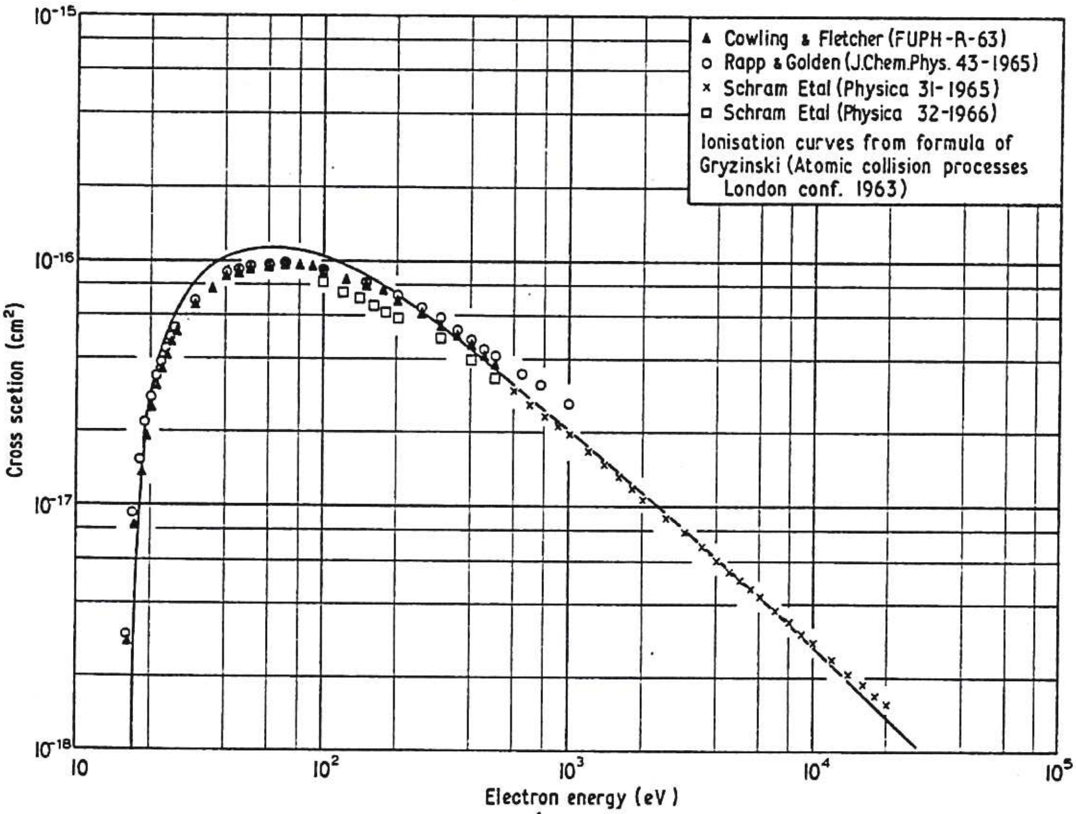

Fig.2 Ionisation of molecular hydrogen by electrons

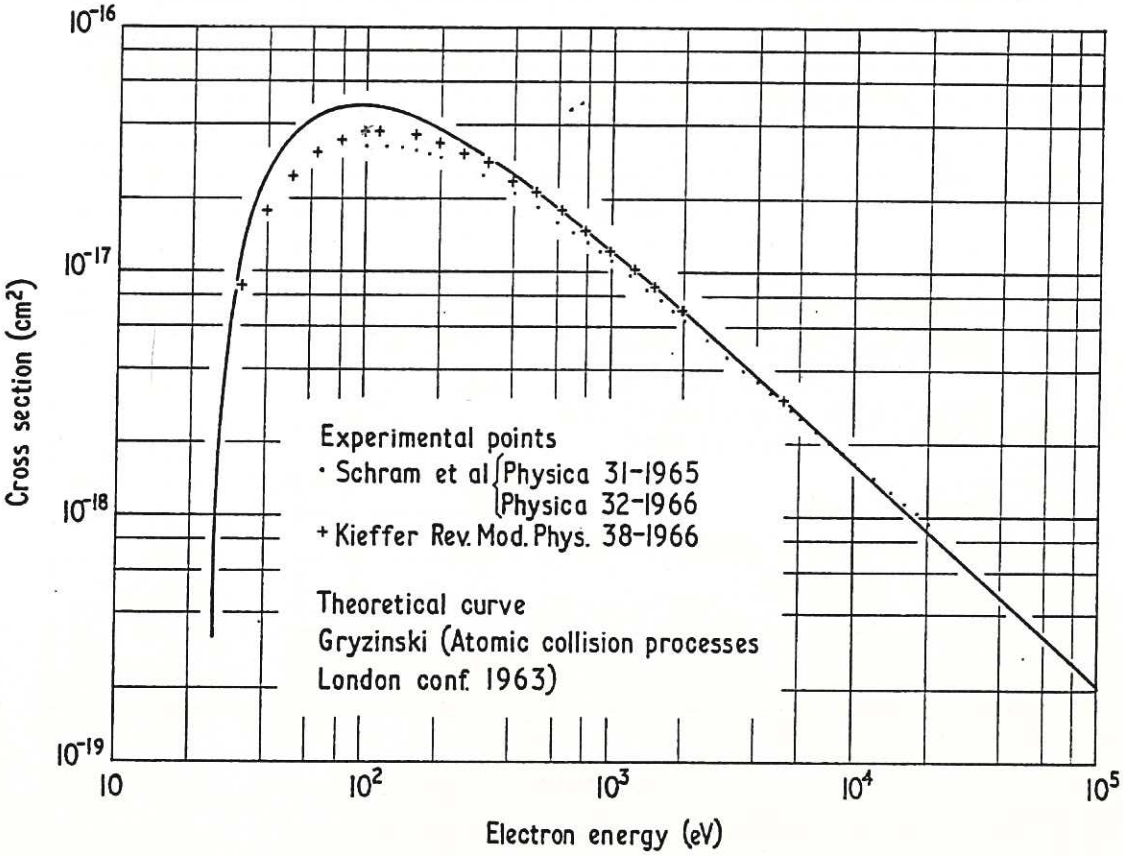

Fig.3 Ionisation of helium by electrons

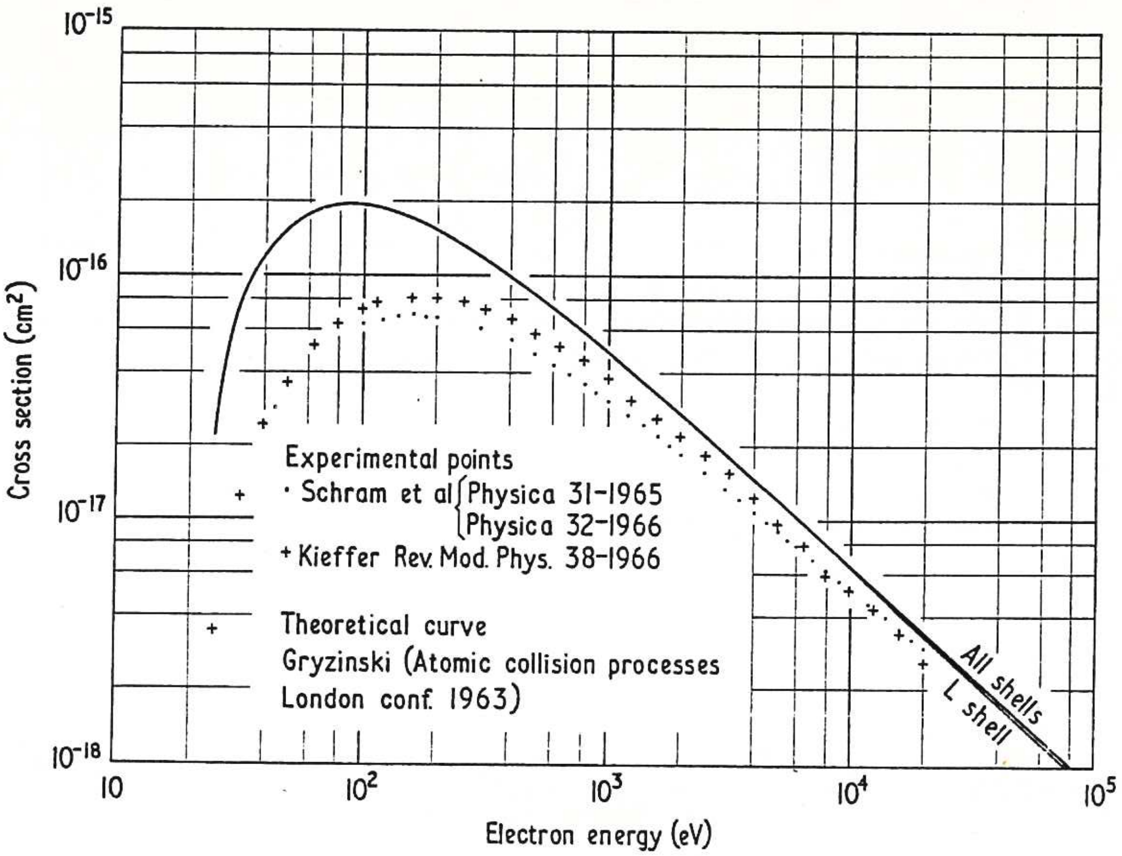

Fig.4 Ionisation of neon by electrons

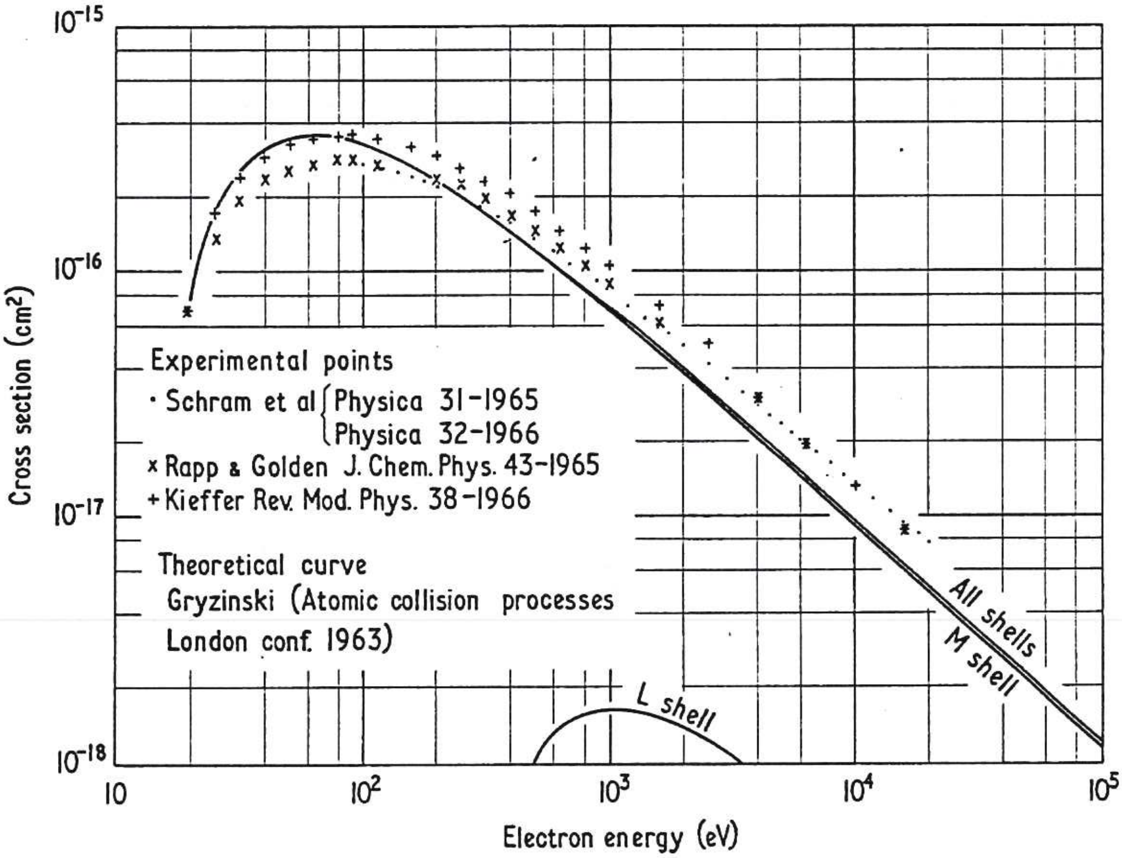

Fig.5 Ionisation of argon by electrons

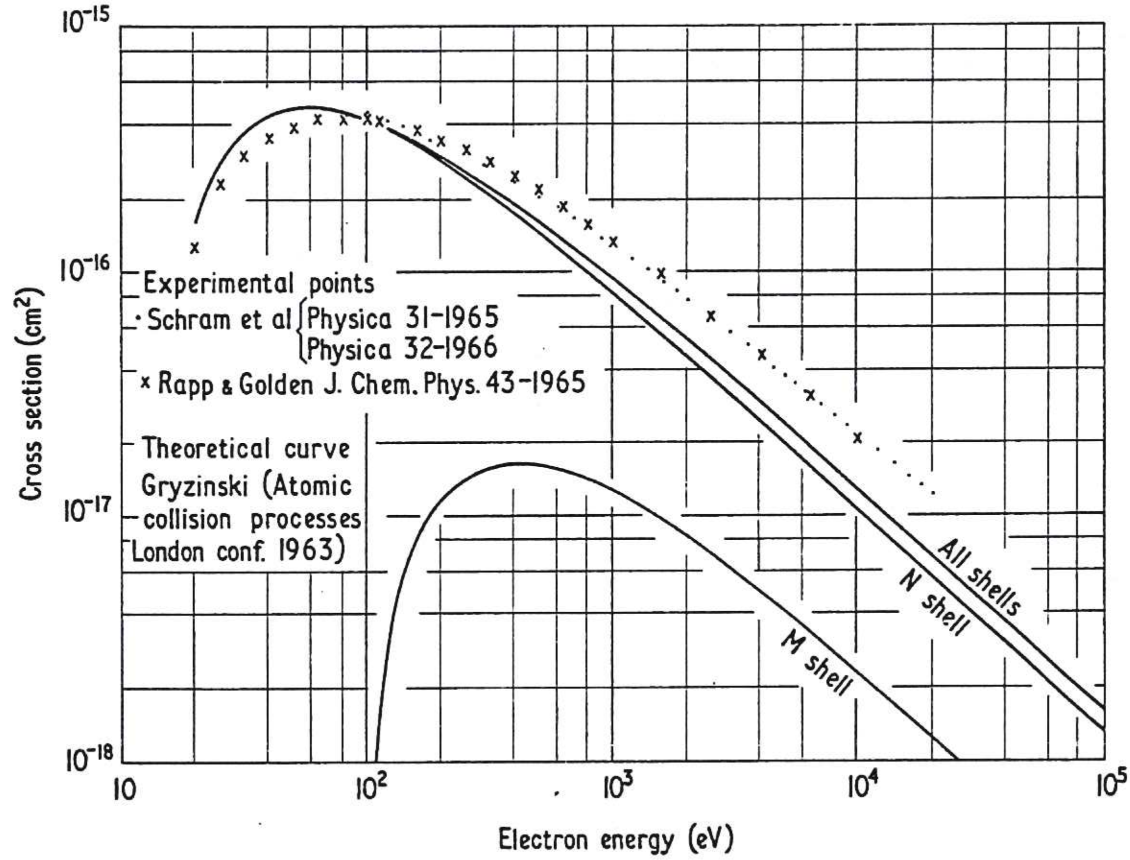

Fig.6 Ionisation of krypton by electrons

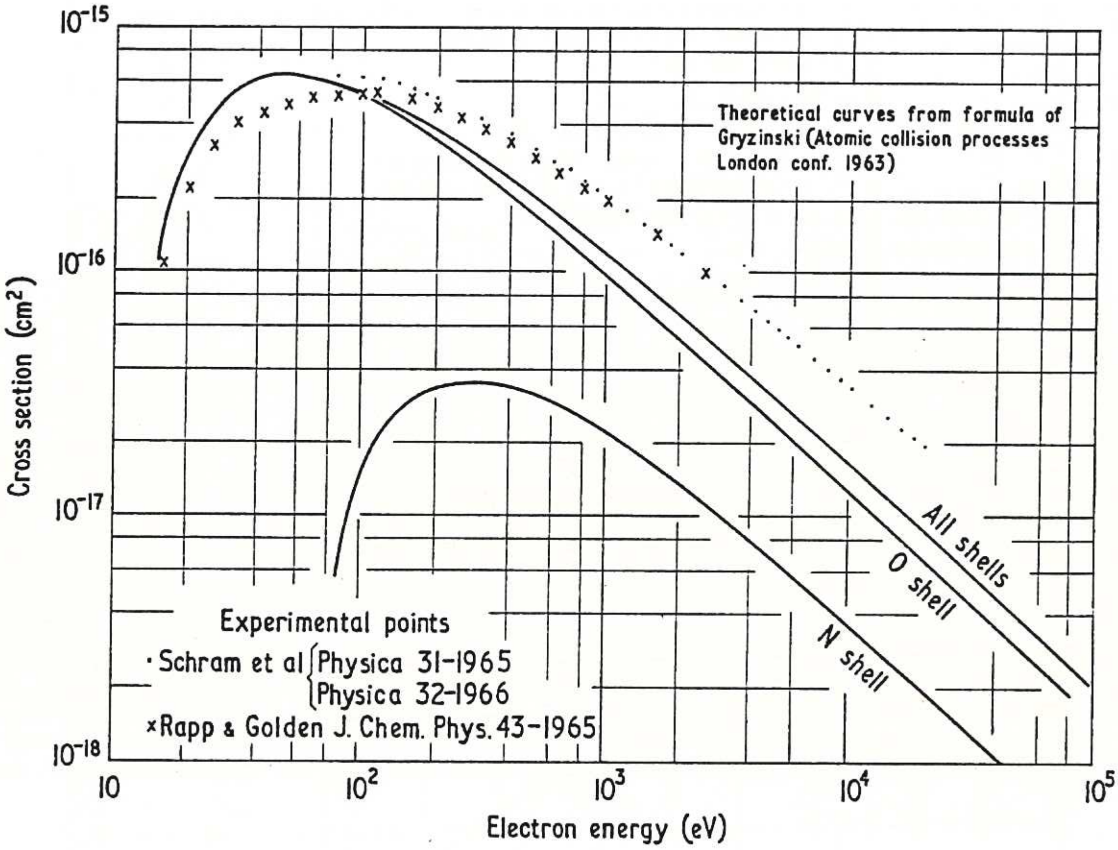

Fig.7 Ionisation of xenon by electrons

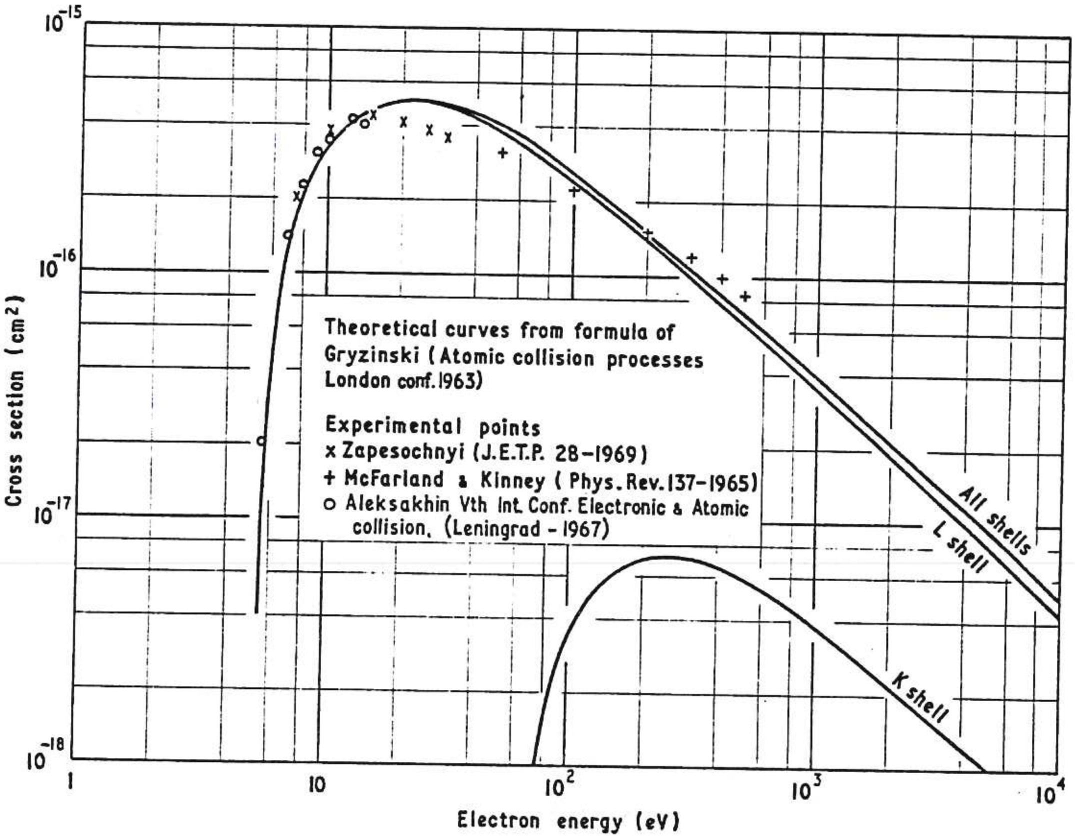

Fig.8 Ionisation of lithium by electrons

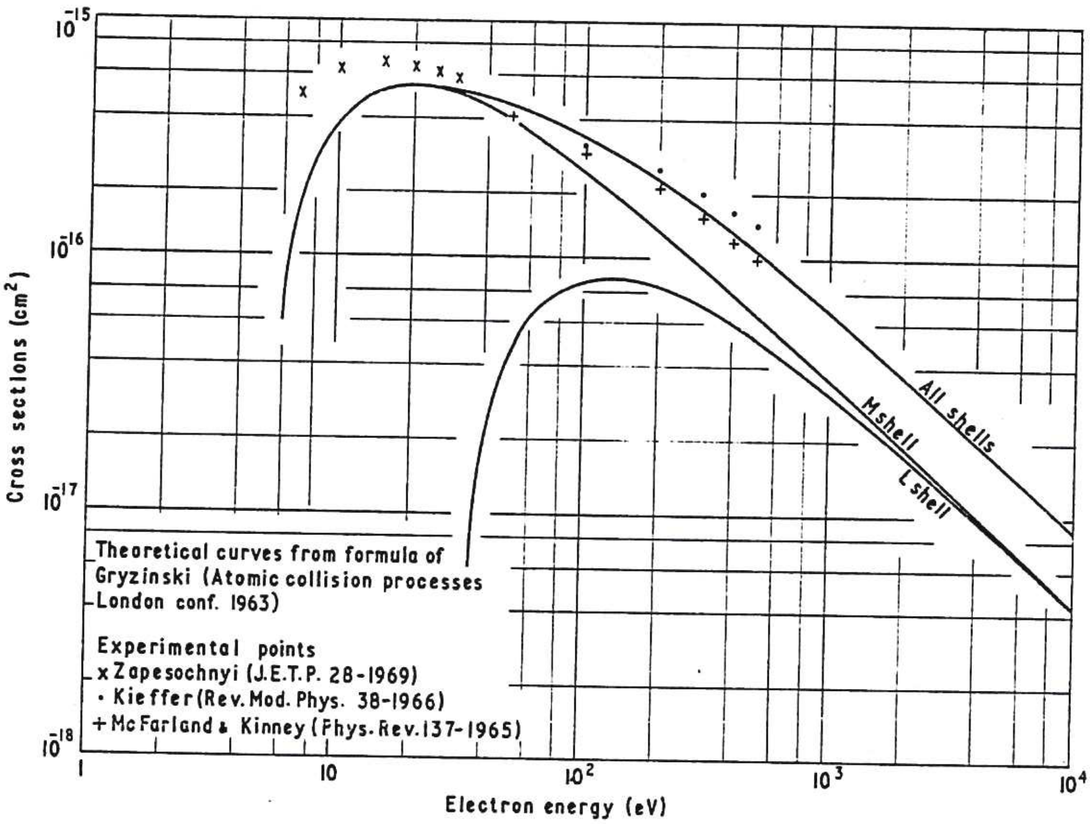

Fig.9 Ionisation of sodium by electrons

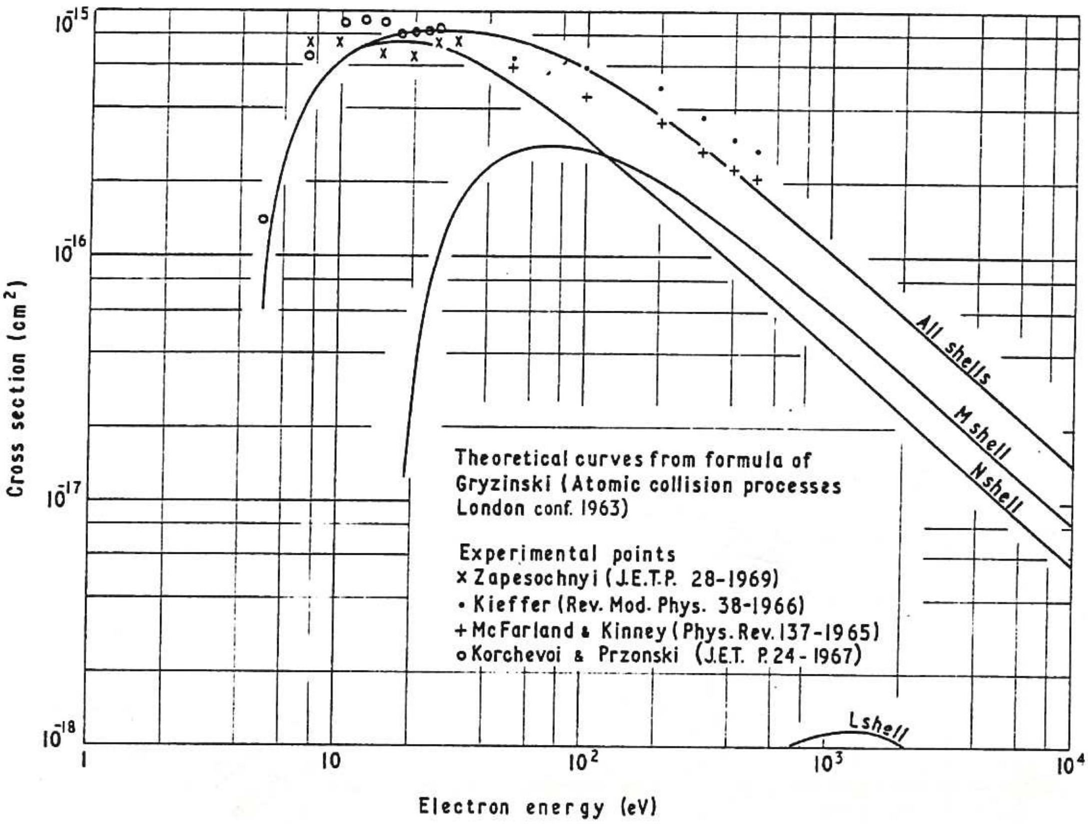

Fig.10 Ionisation of potassium by electrons

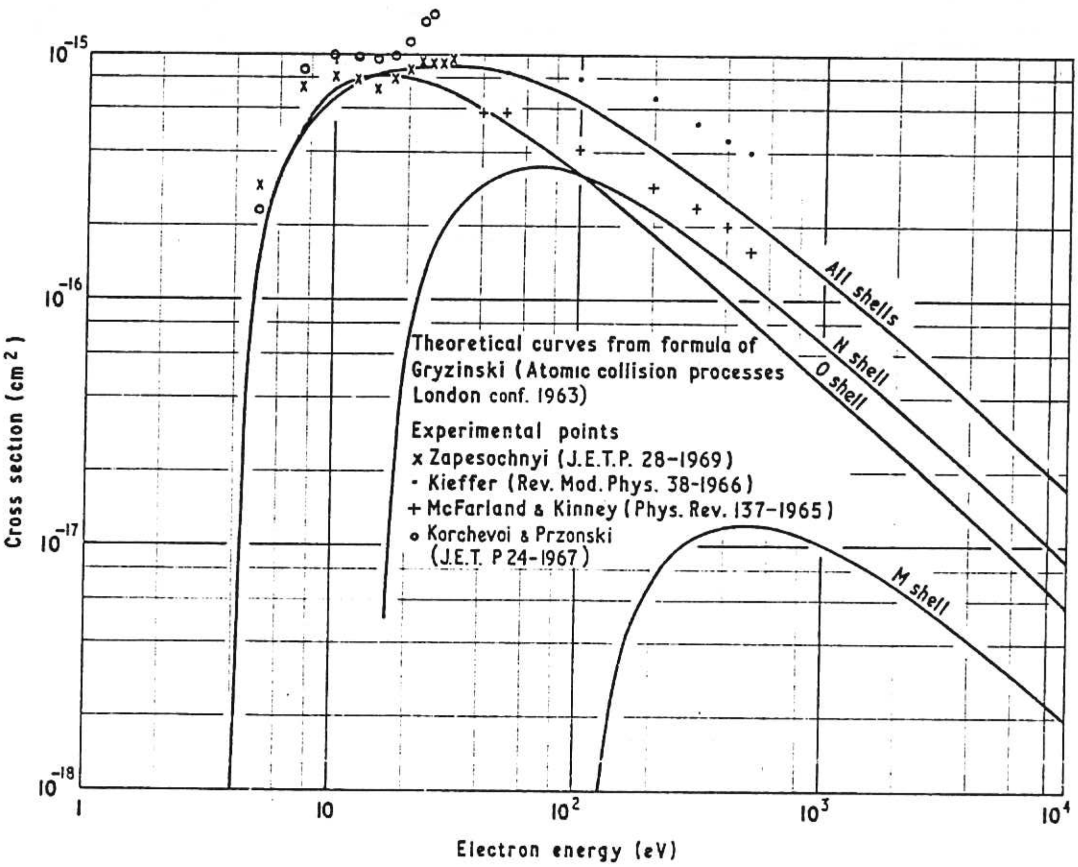

Fig.11 Ionisation of rubidium by electrons

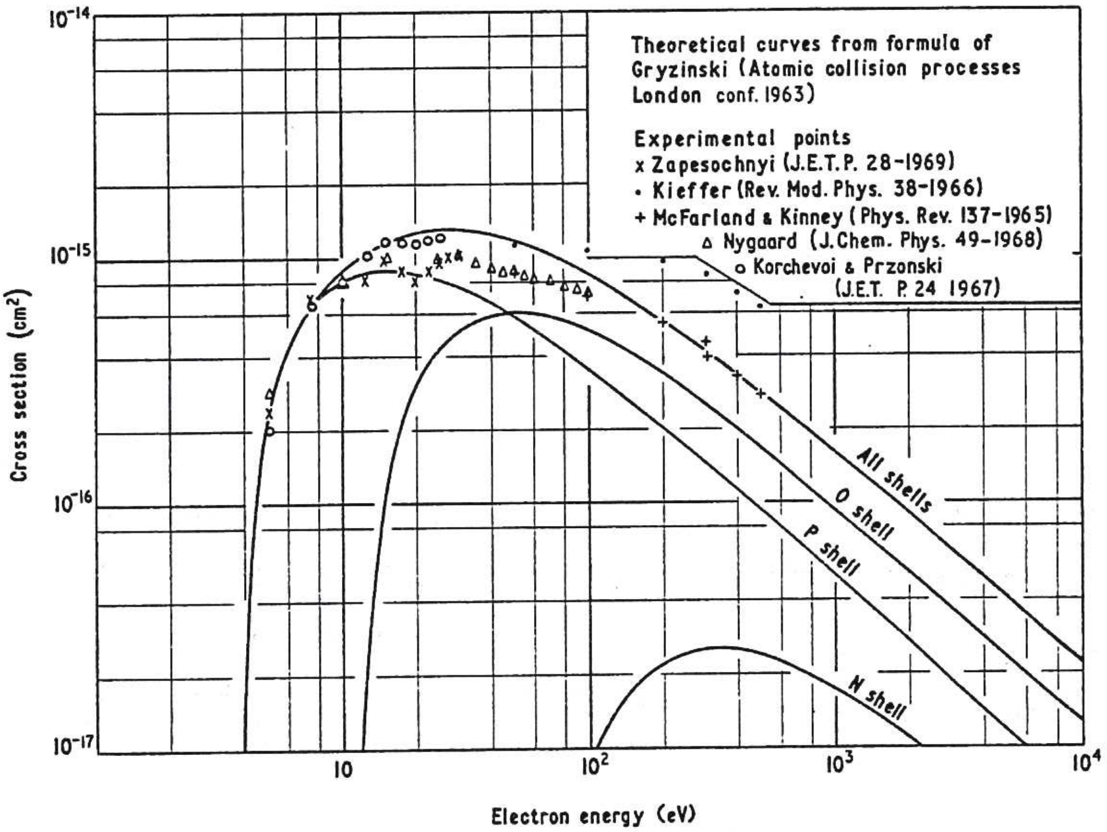

Fig.12 Ionisation of caesium by electrons

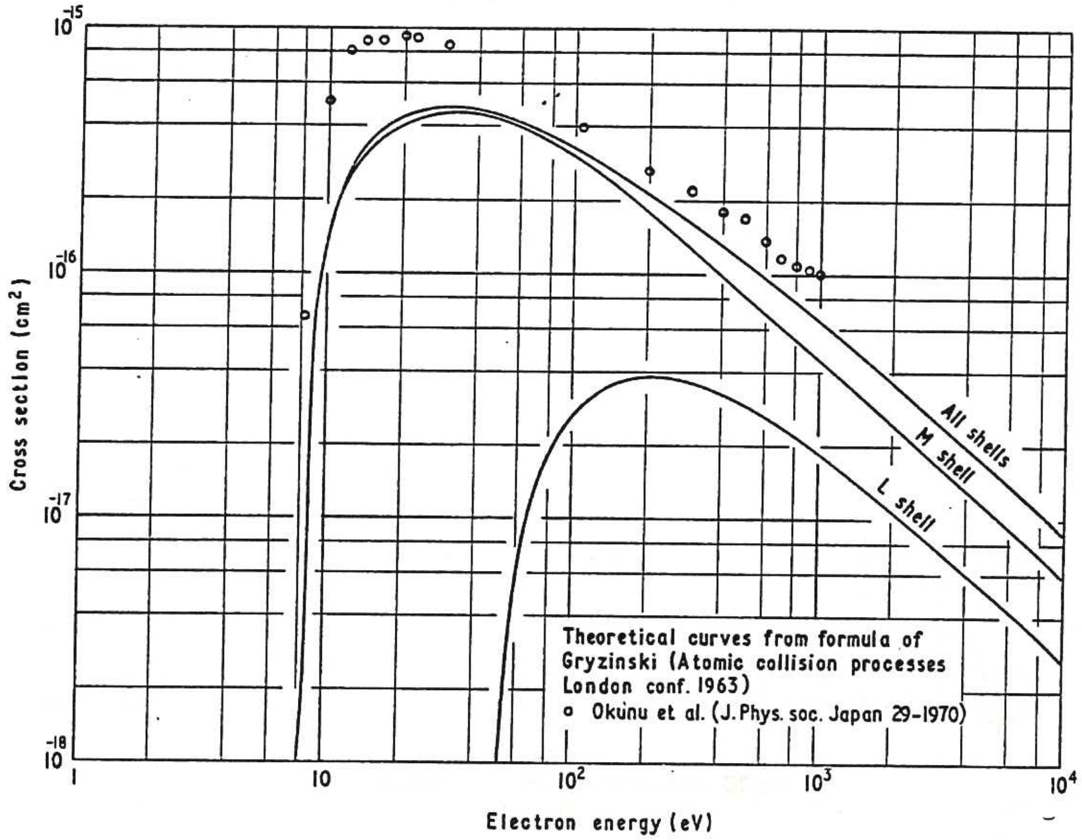

Fig.13 Ionisation of magnesium by electrons

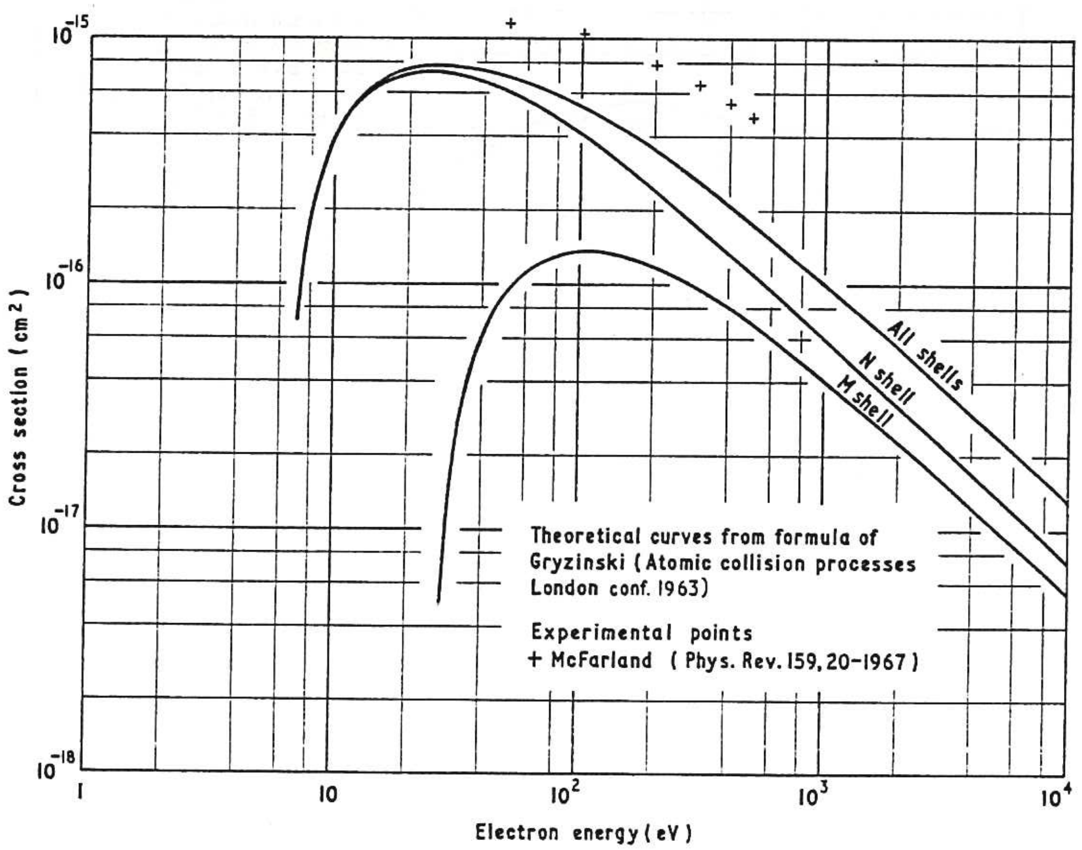

Fig.14 Ionisation of calcium by electrons

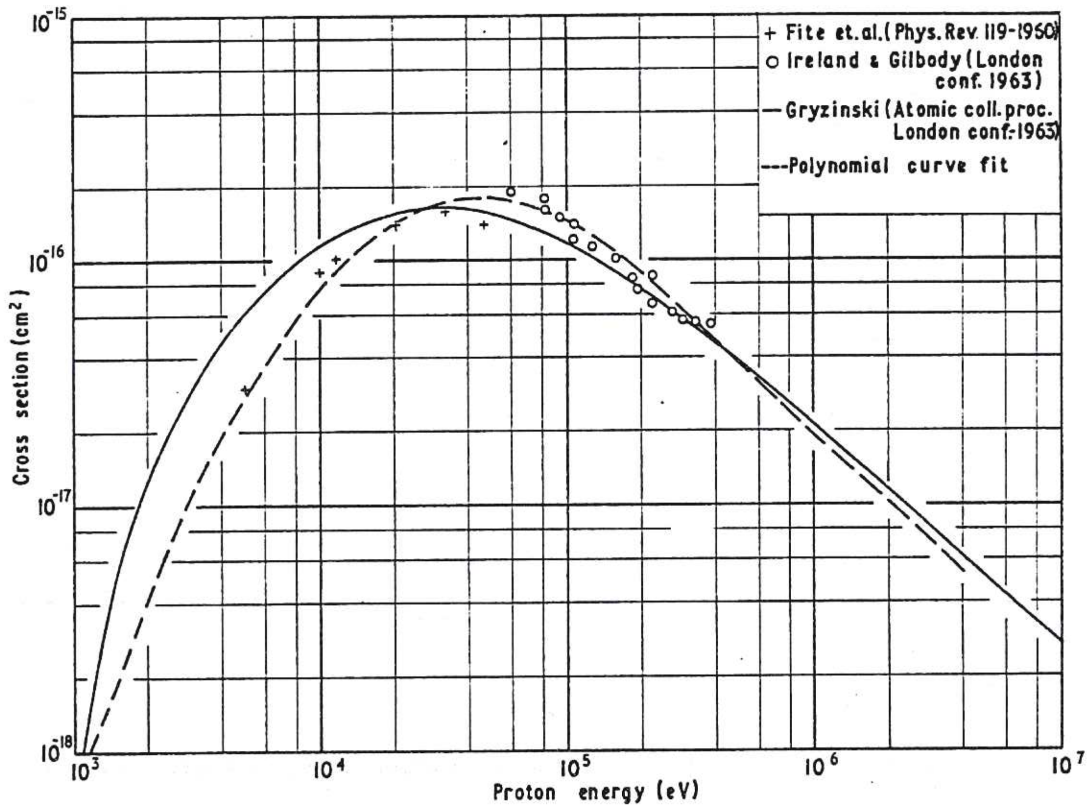

Fig.15 Ionisation of atomic hydrogen by protons

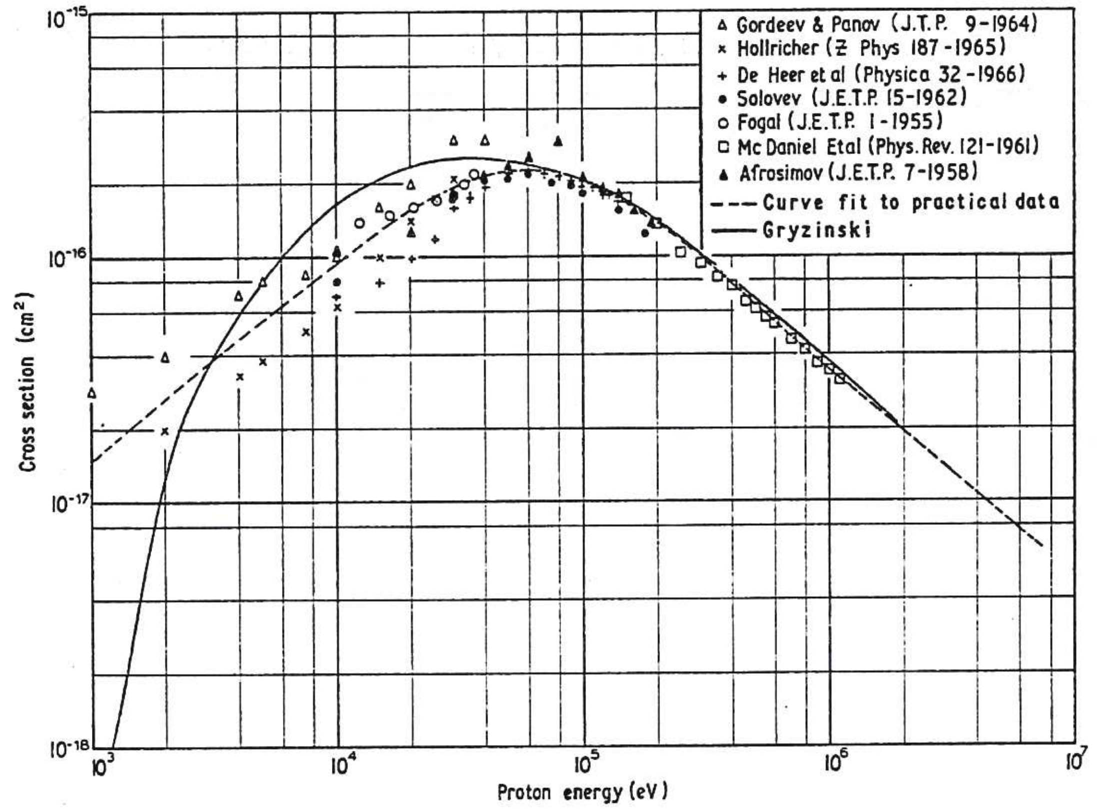

Fig.16 Ionisation of molecular hydrogen by protons

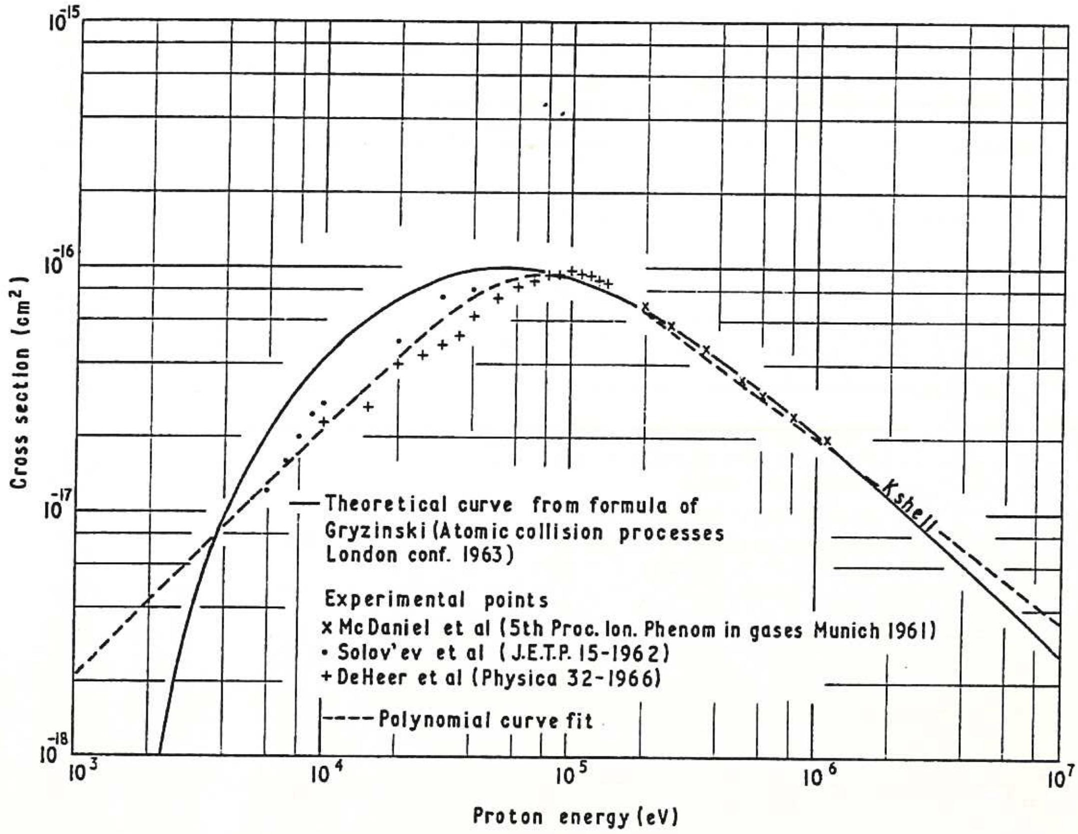

Fig.17 Ionisation of helium by protons

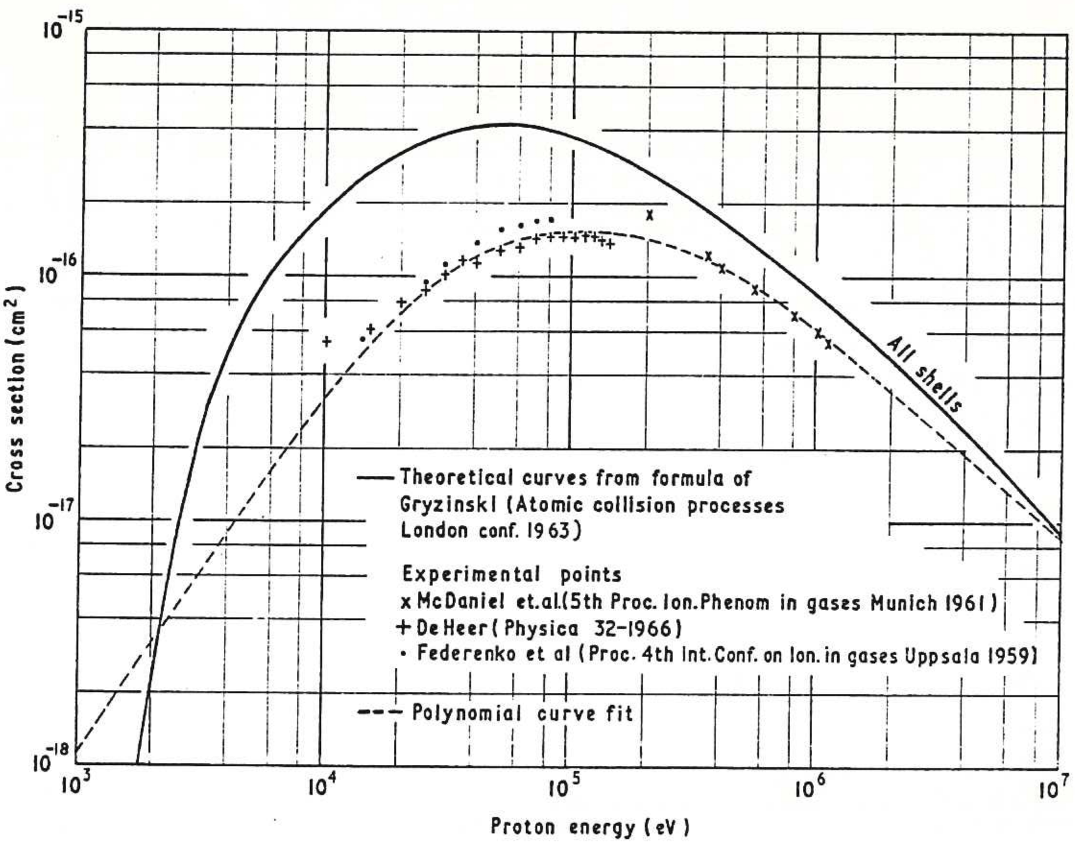

Fig.18 Ionisation of neon by protons

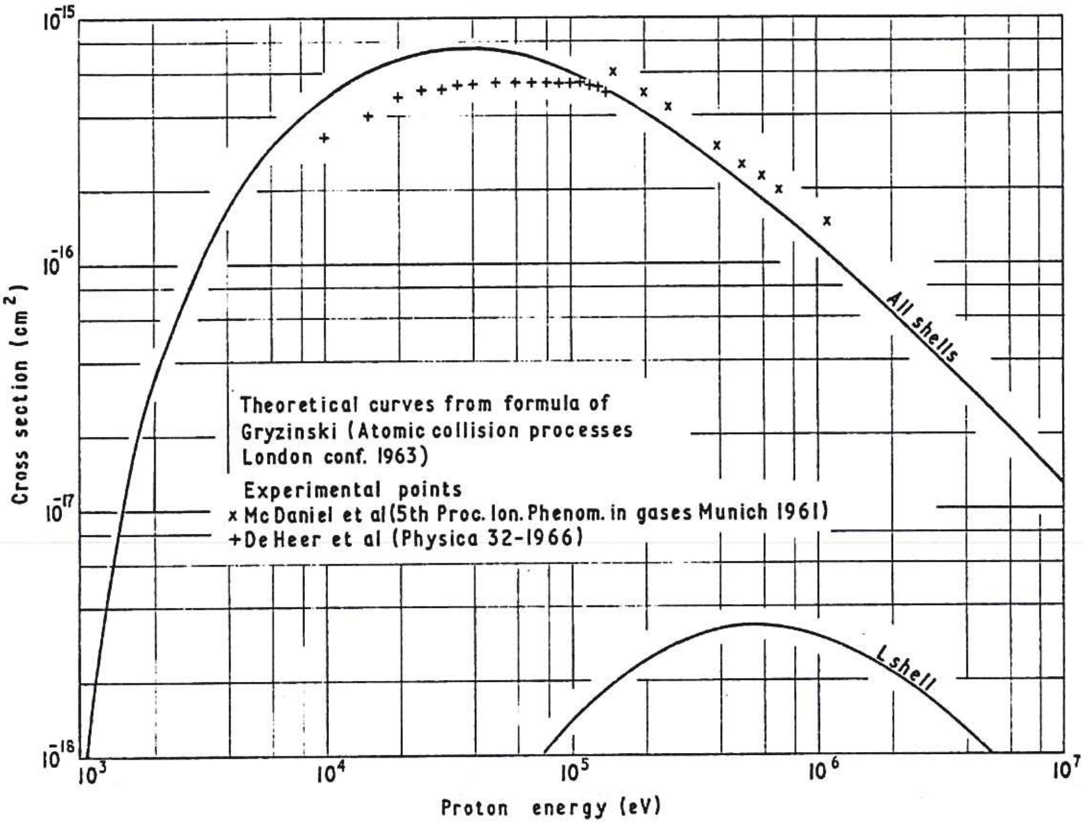

Fig.19 Ionisation of argon by protons

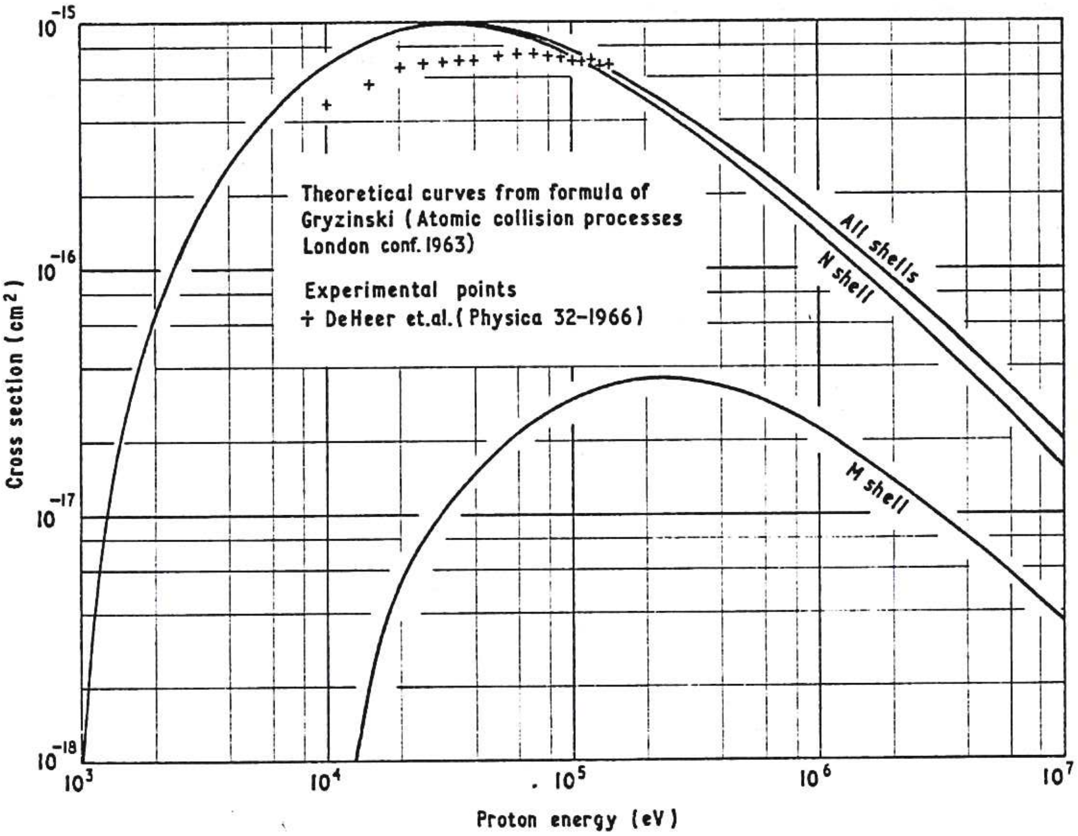

Fig.20 Ionisation of krypton by protons

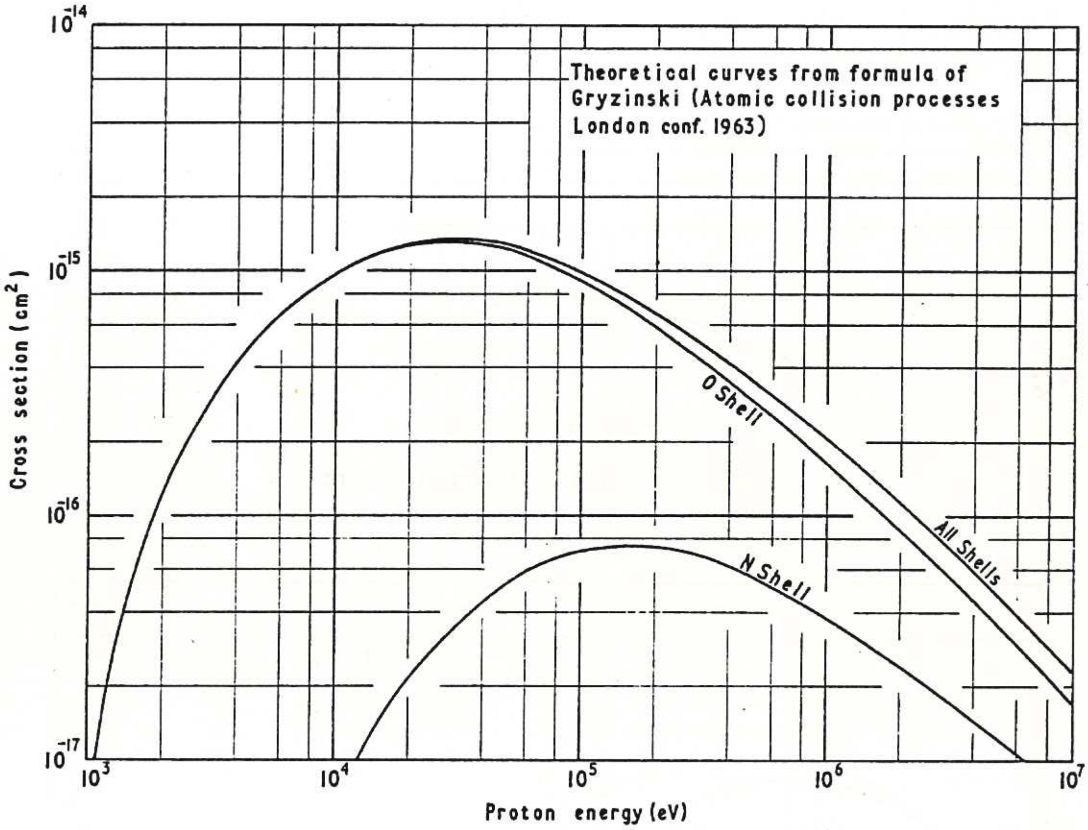

Fig.21 Ionisation of xenon by protons

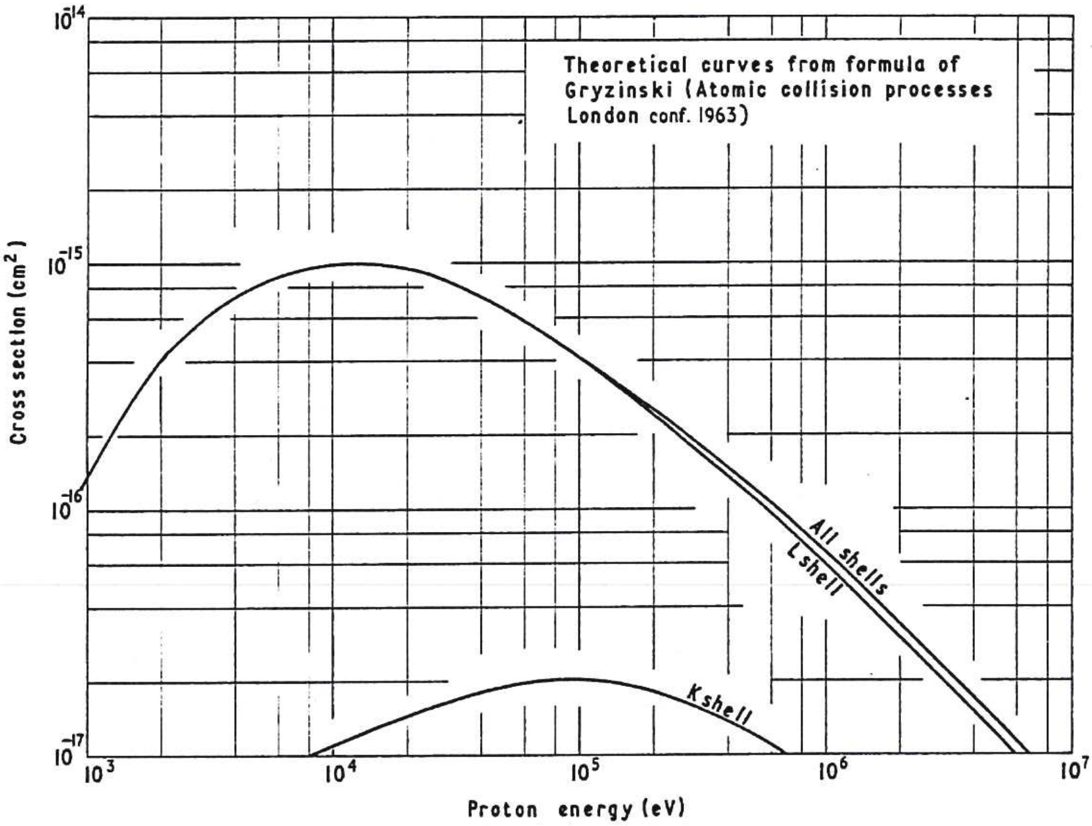

Fig.22 Ionisation of lithium by protons

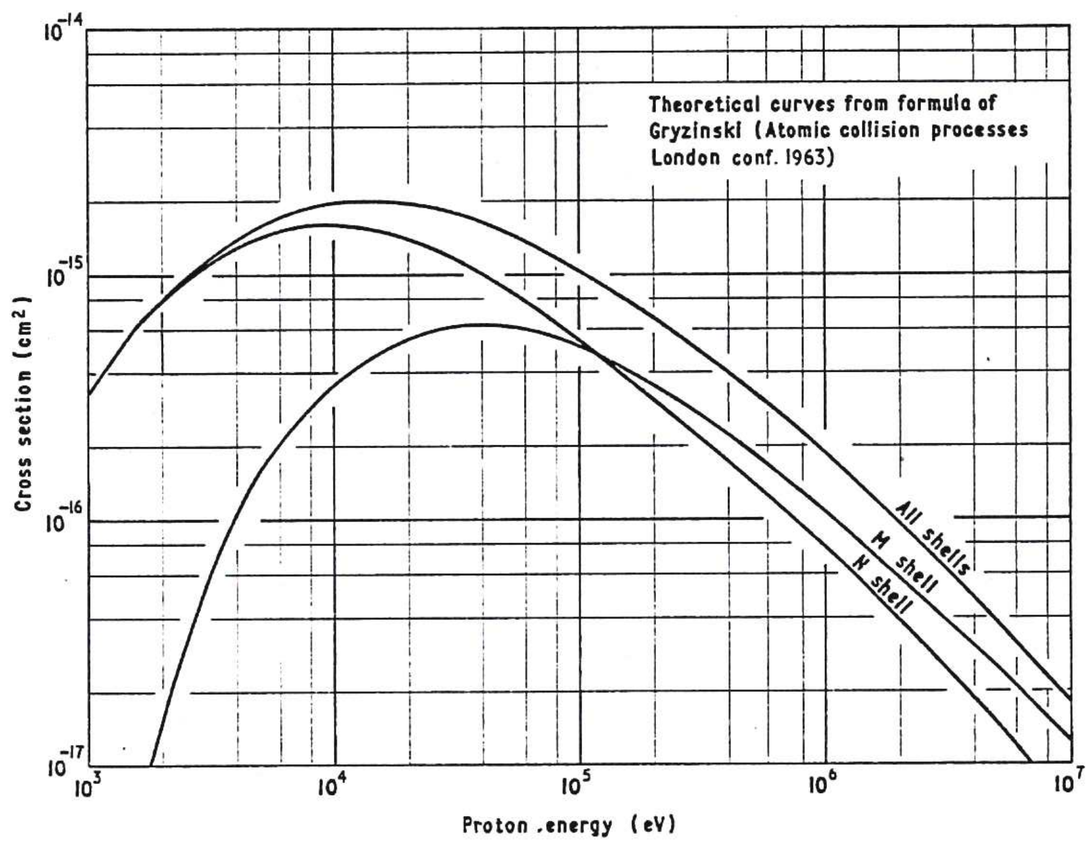

Fig.23 Ionisation of potassium by protons

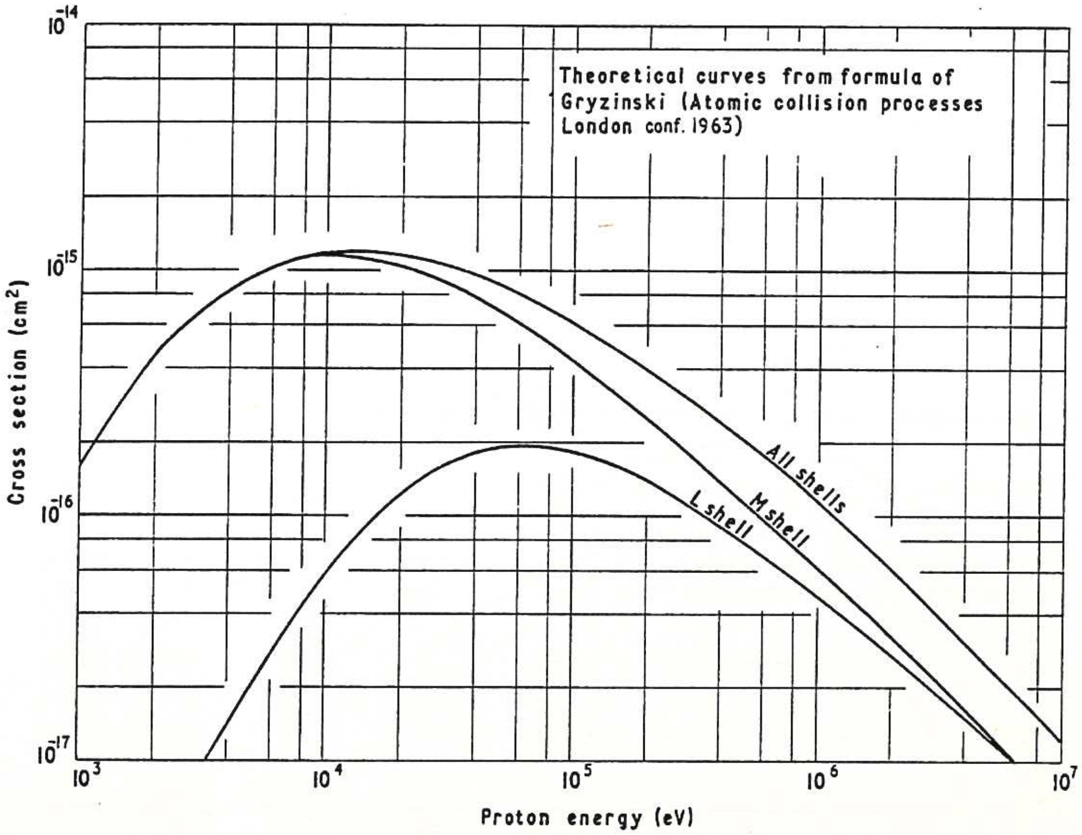

Fig.24 Ionisation of sodium by protons

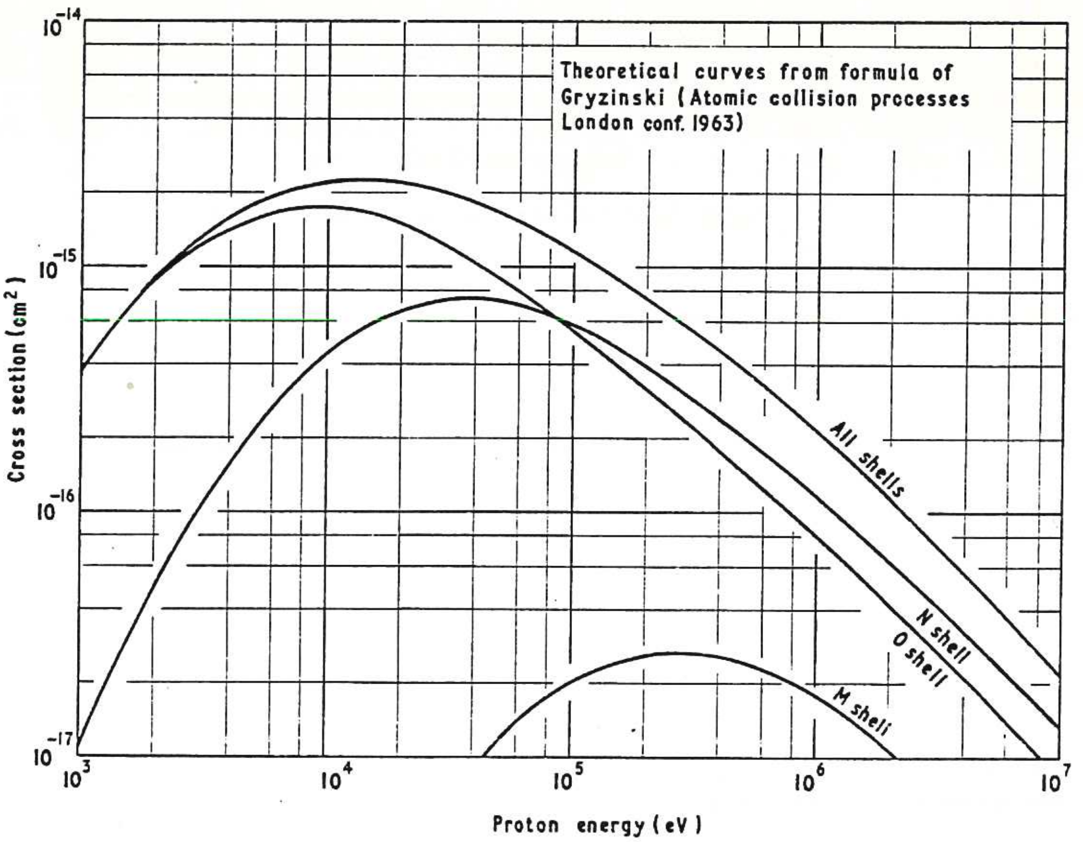

Fig.25 Ionisation of rubidium by protons

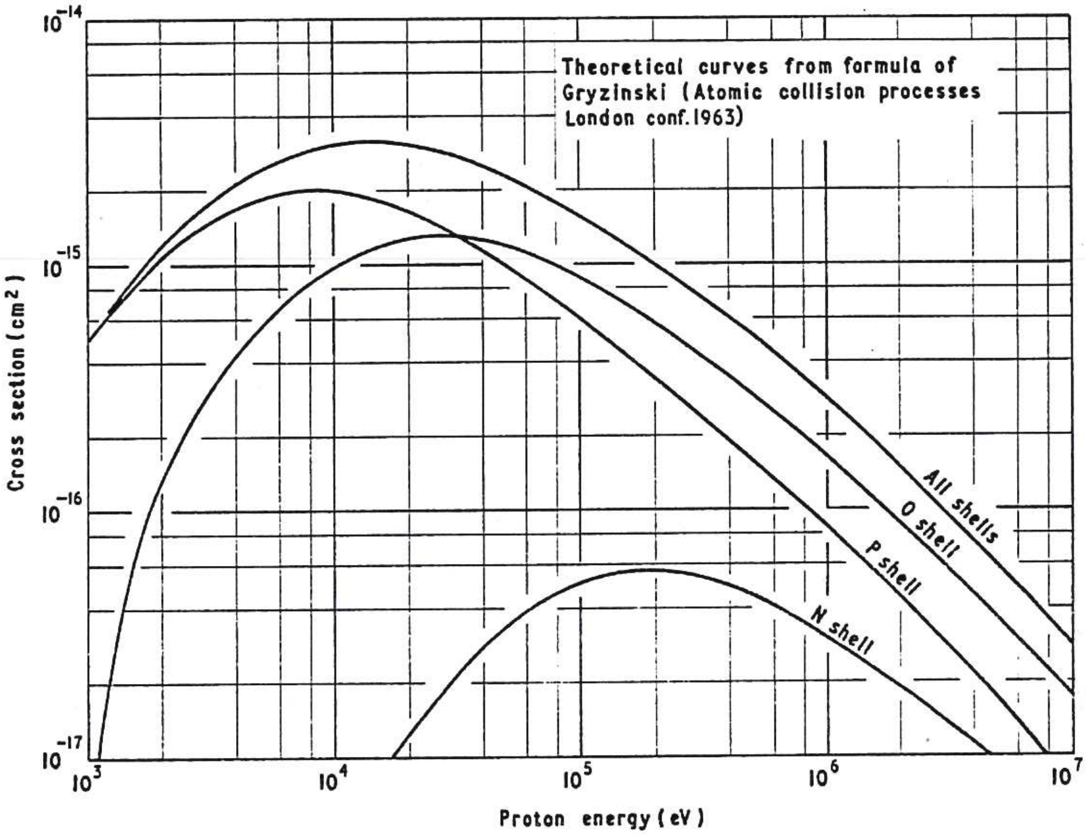

Fig.26 Ionisation of caesium by protons

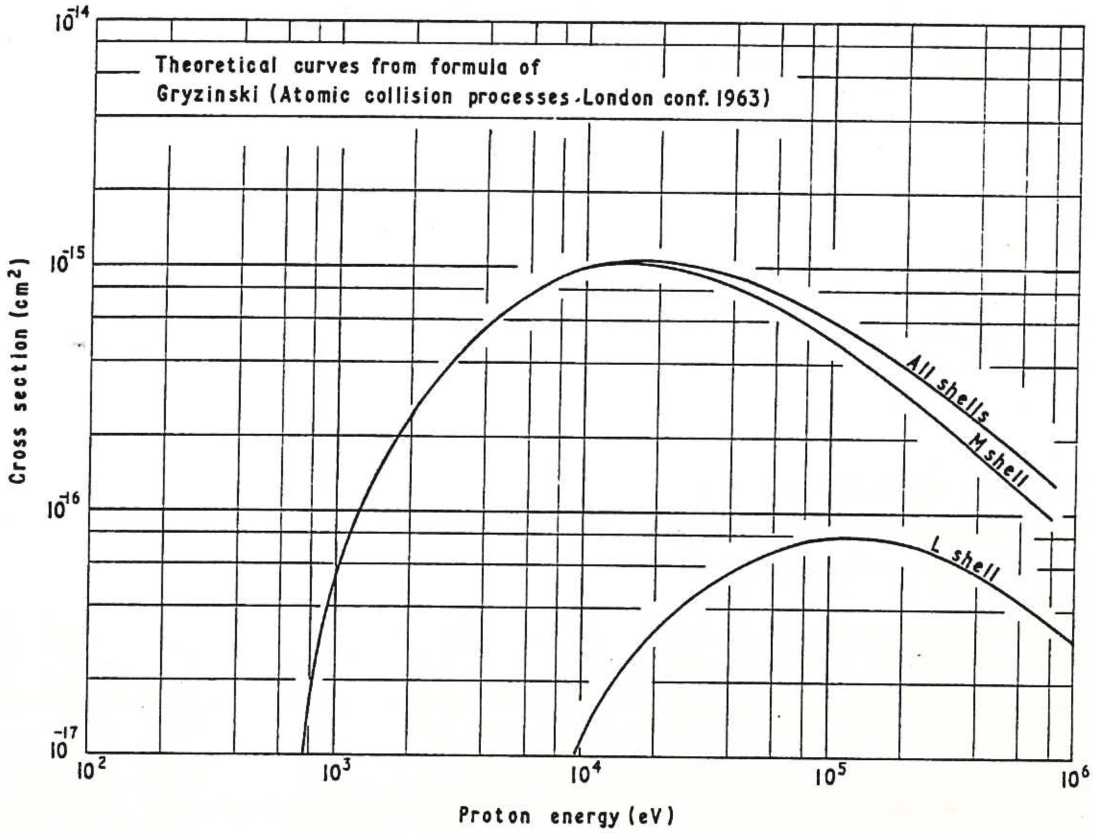

Fig.27 Ionisation of magnesium by protons

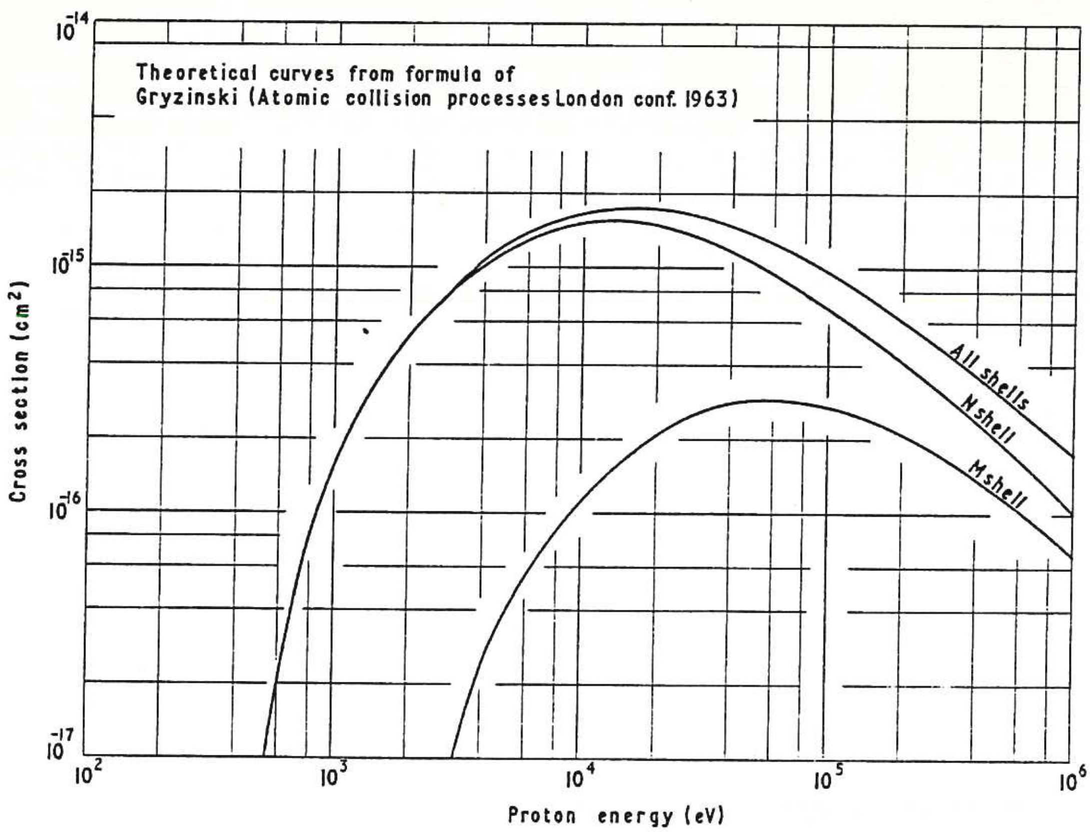

Fig.28 Ionisation of calcium by protons

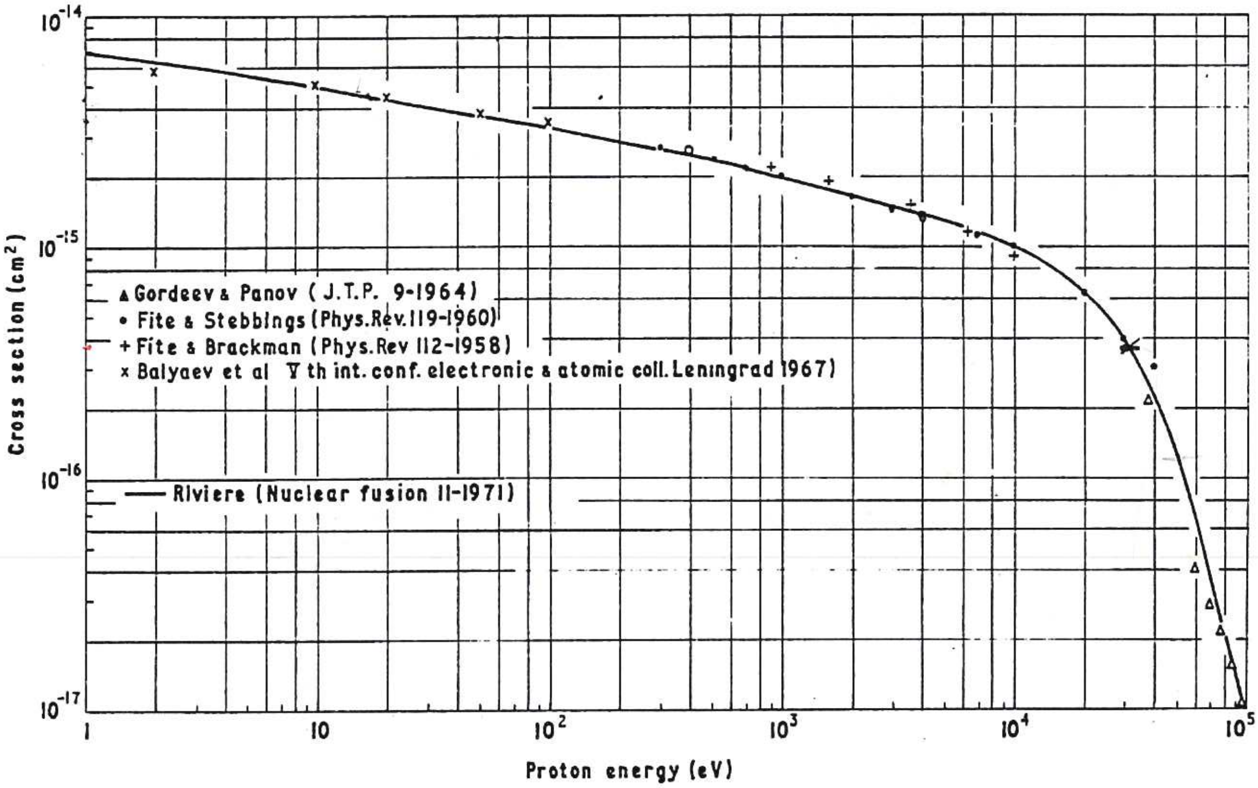

Fig.29 Charge exchange cross-section protons on atomic hydrogen

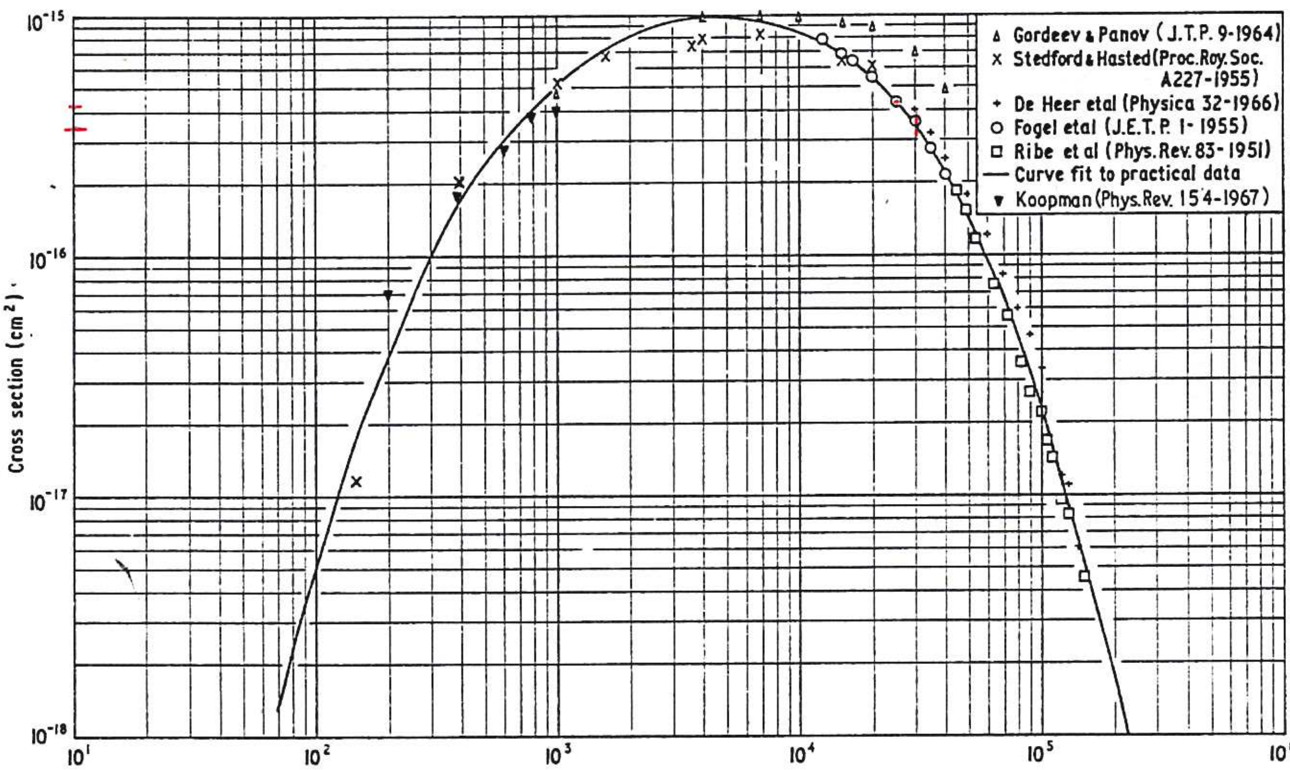

Fig.30 Charge exchange cross-section for molecular hydrogen ($H^+ + H_2 \rightarrow H_2^+ + H$)

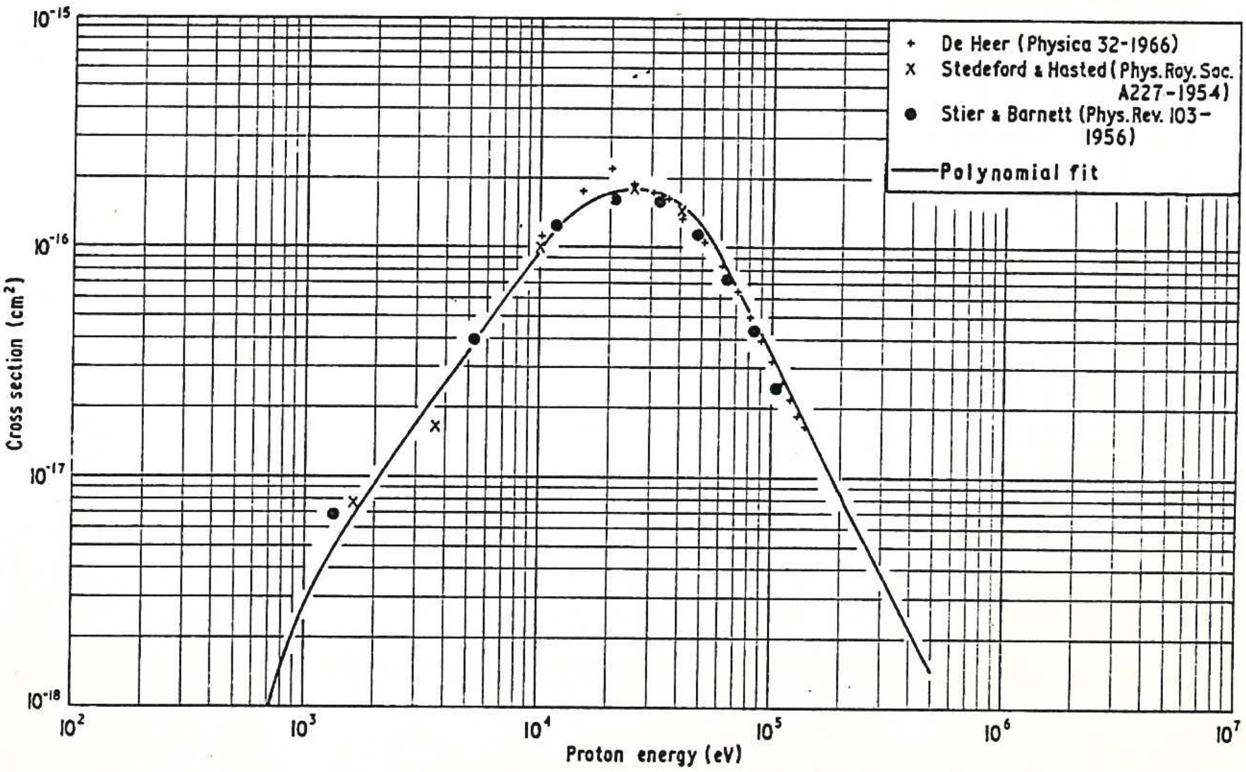

Fig.31 Charge exchange cross-section for helium

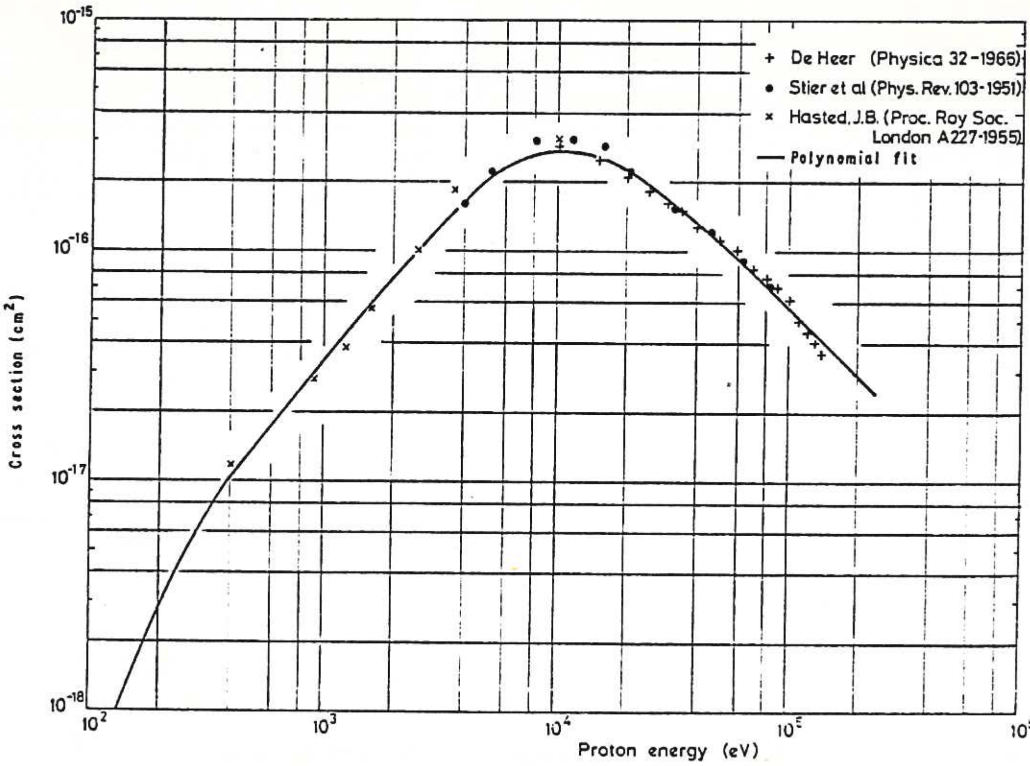

Fig.32 Charge exchange cross-section for neon

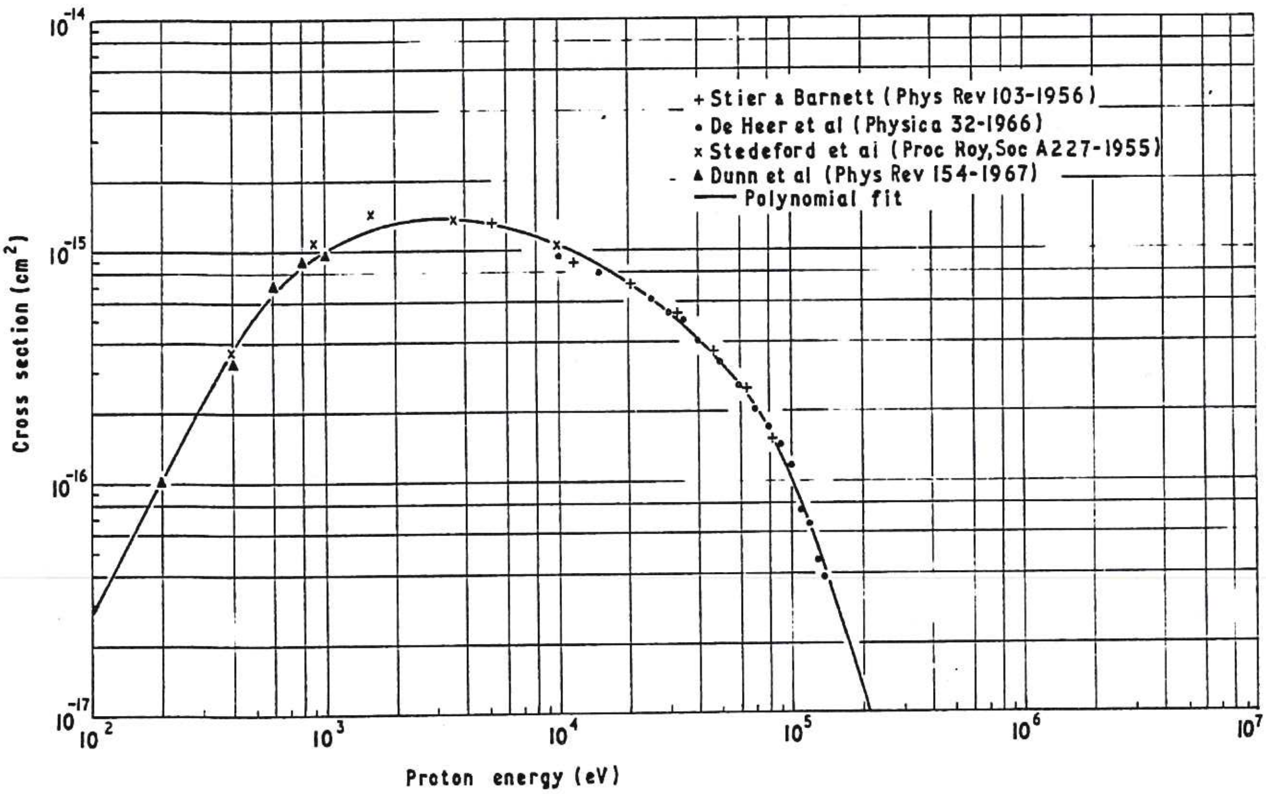

Fig.33 Charge exchange cross-section for argon

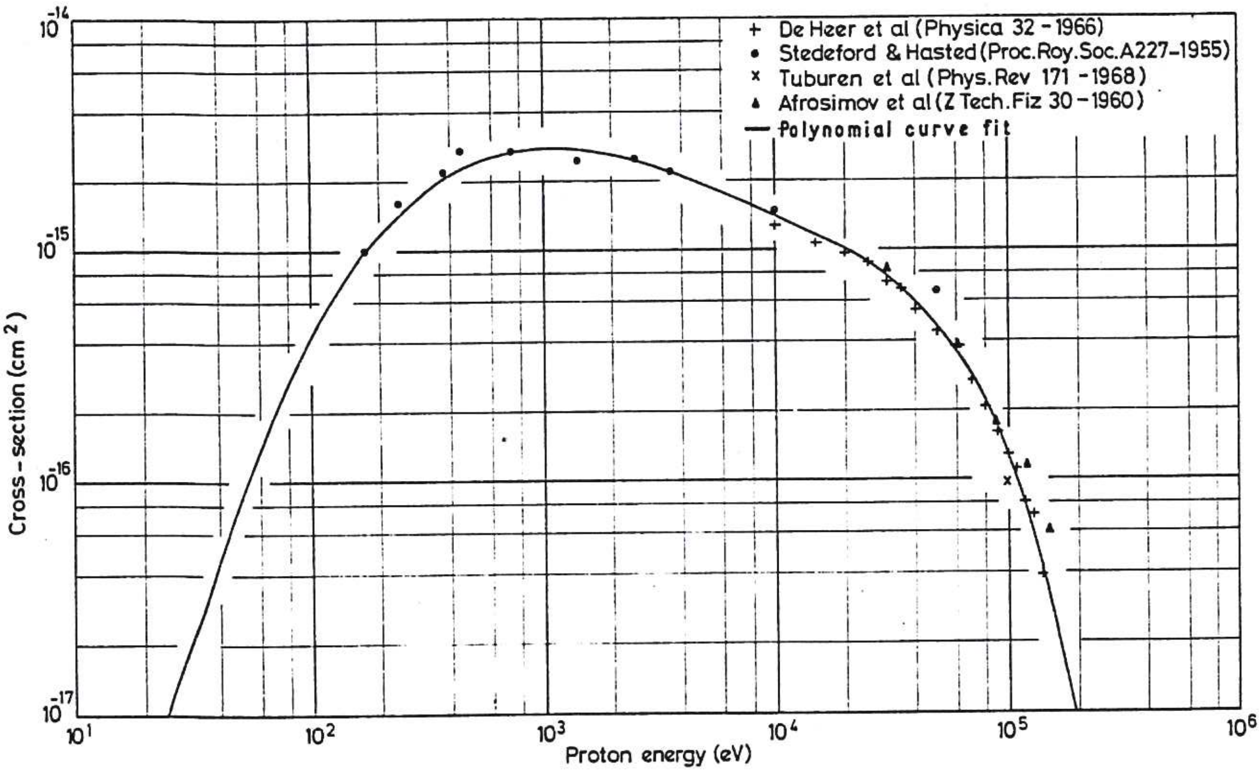

Fig.34 Charge exchange cross-section for krypton

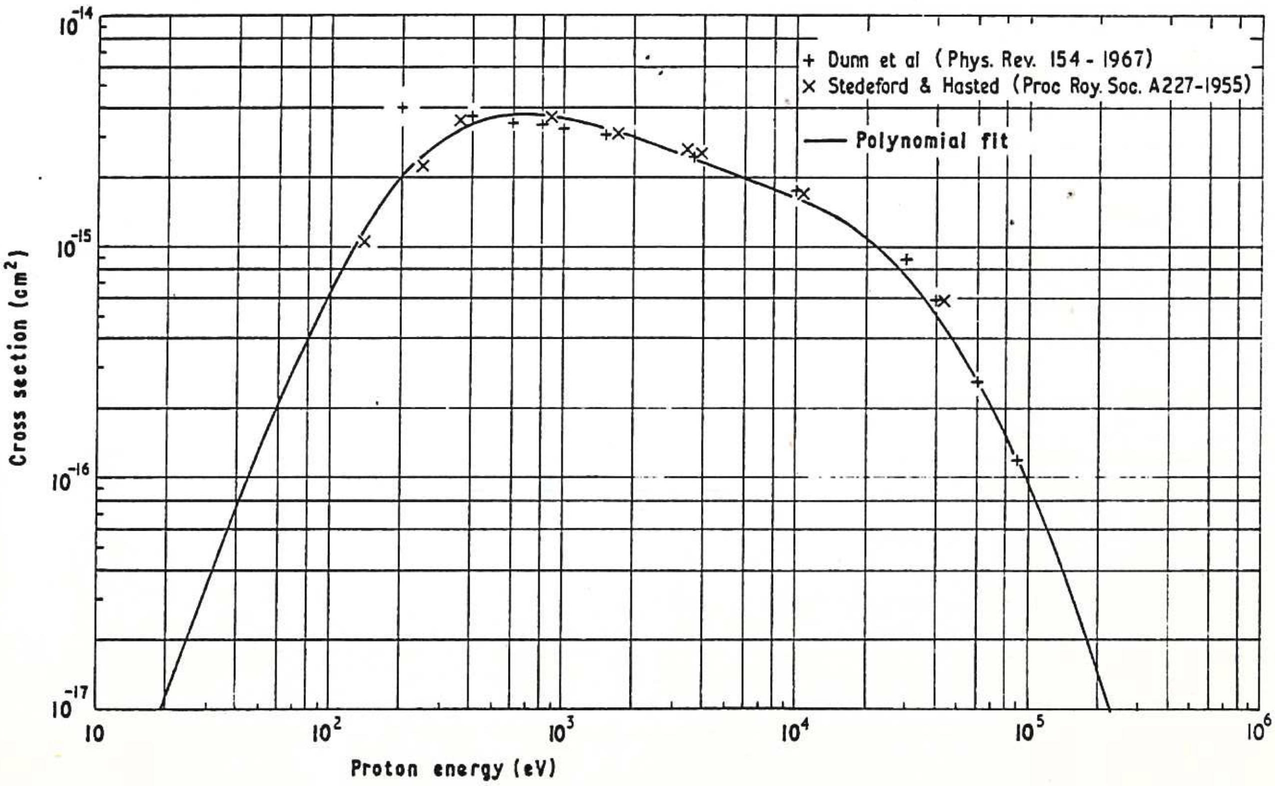

Fig.35 Charge exchange cross-section for xenon

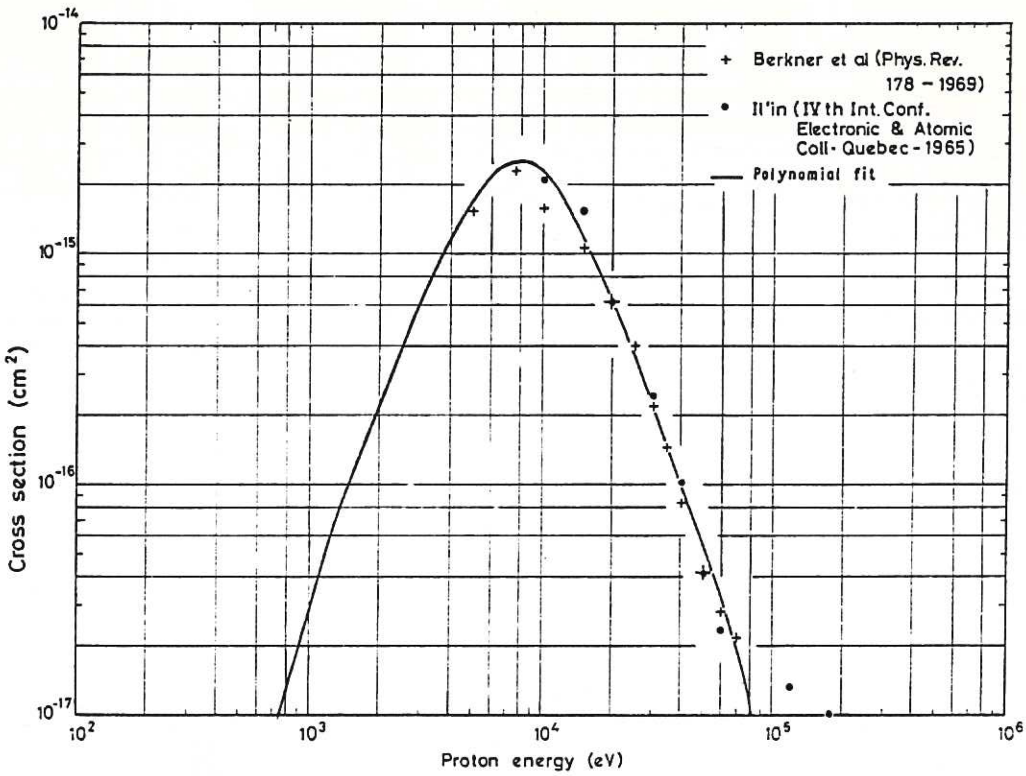

Fig.36 Charge exchange cross-section for magnesium

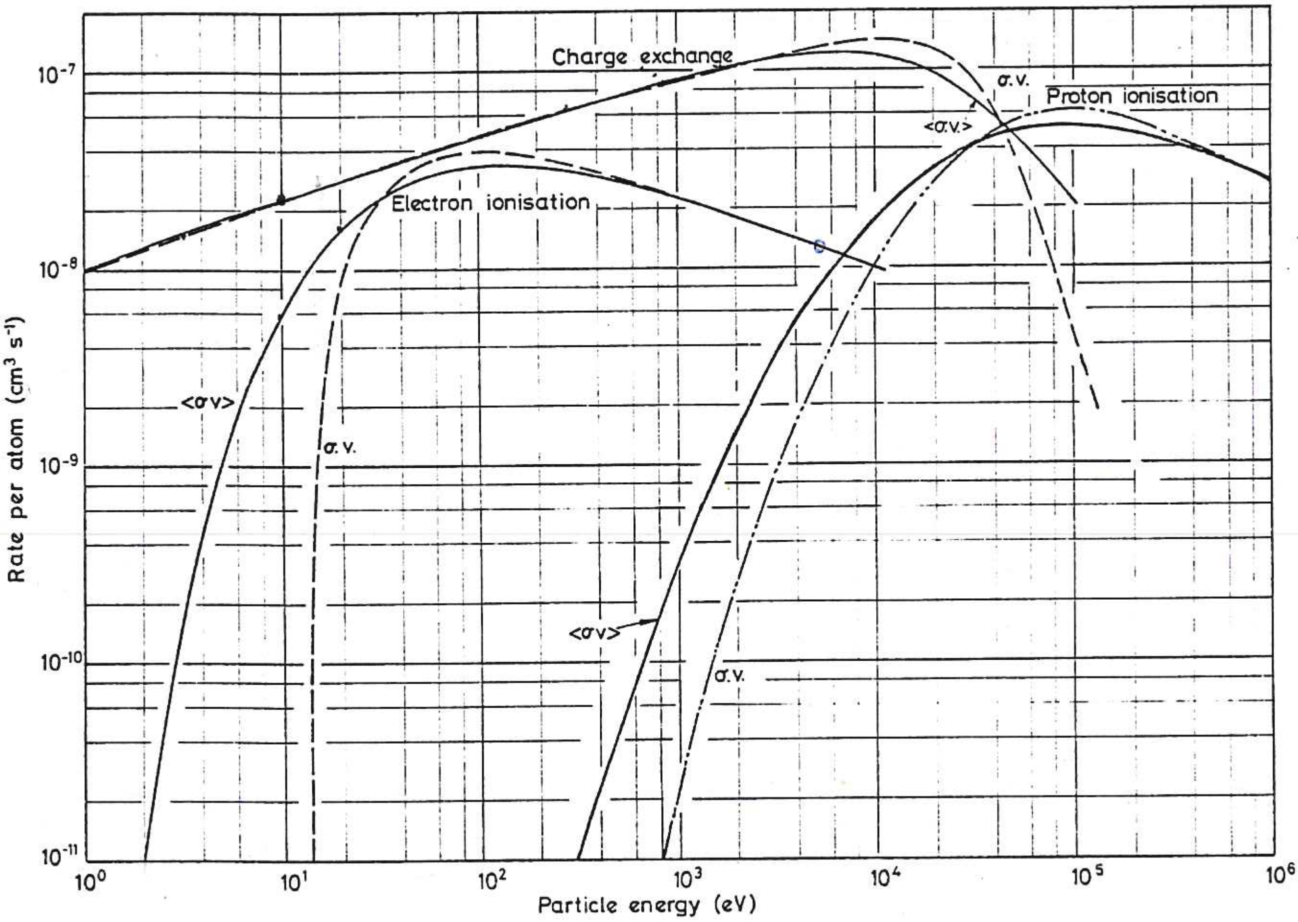

Fig.37 Rate coefficient for atomic hydrogen

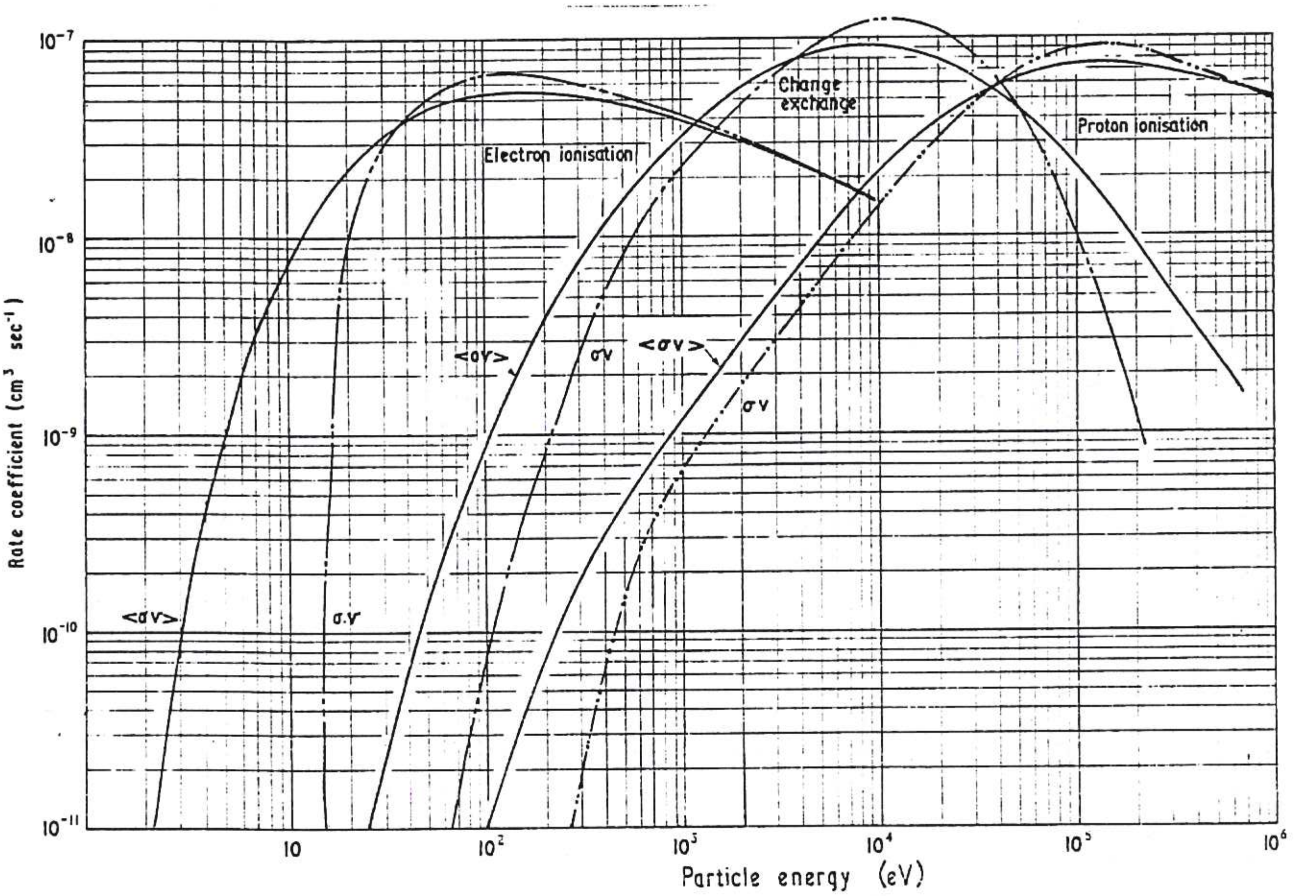

Fig.38 Rate coefficients for molecular hydrogen

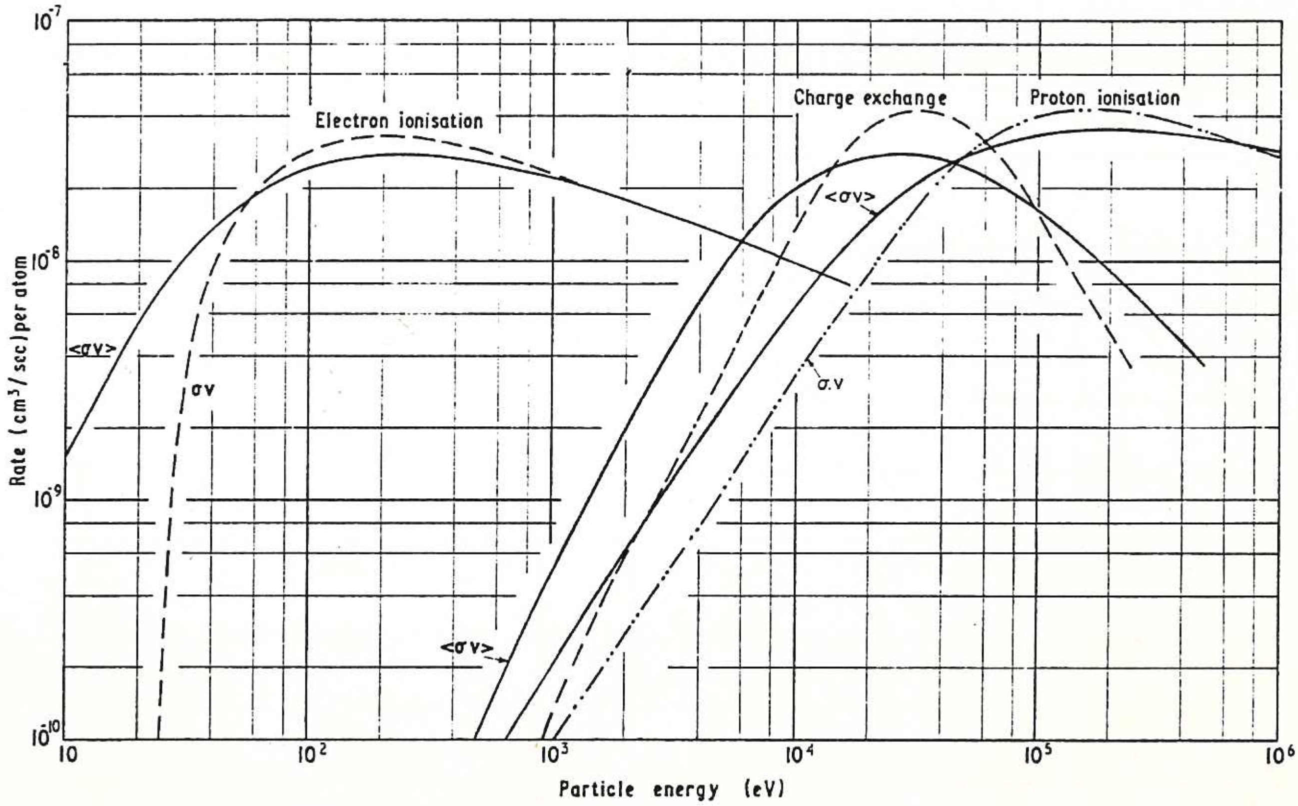

Fig.39 Rate coefficients for helium

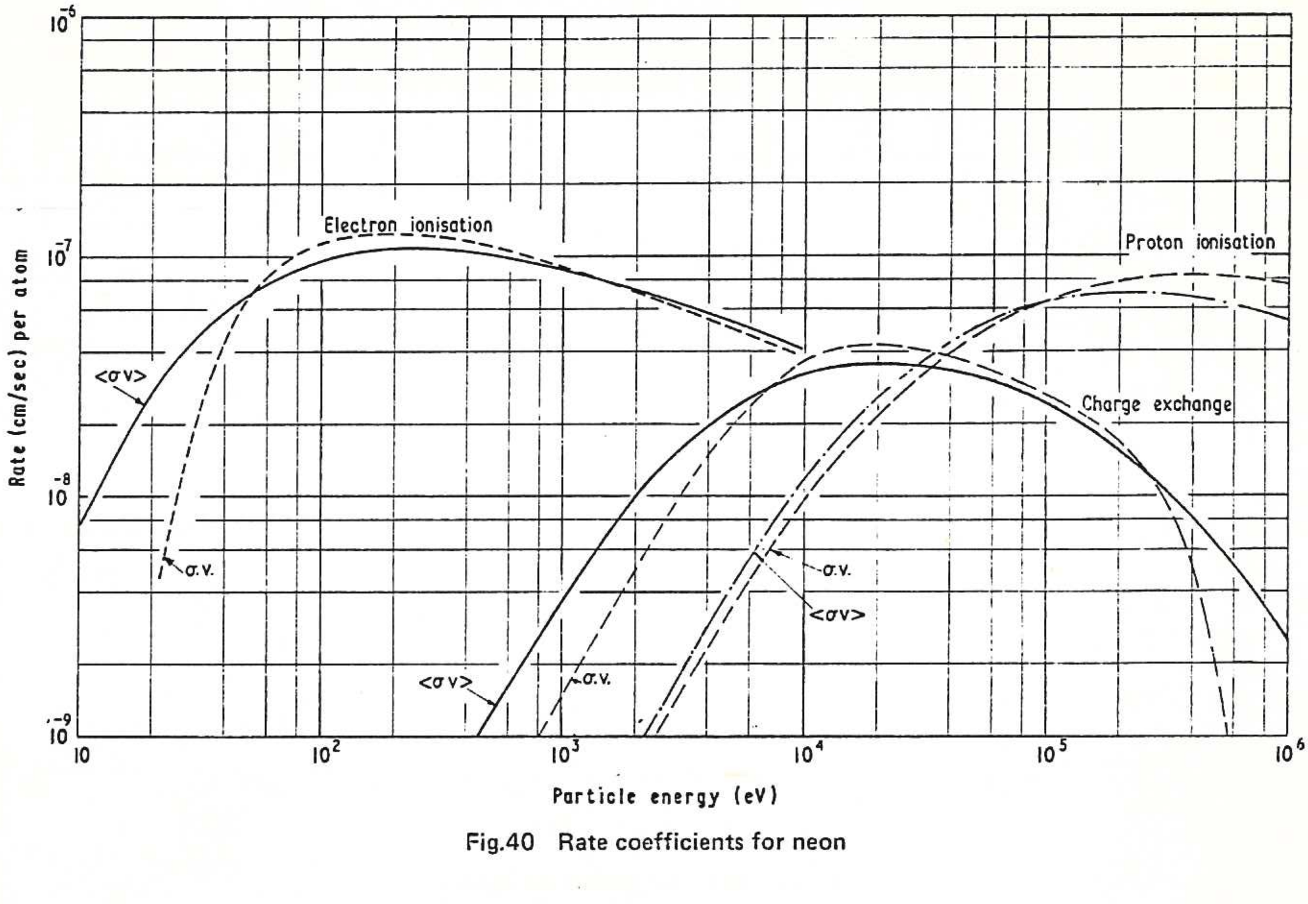

Fig.40 Rate coefficients for neon

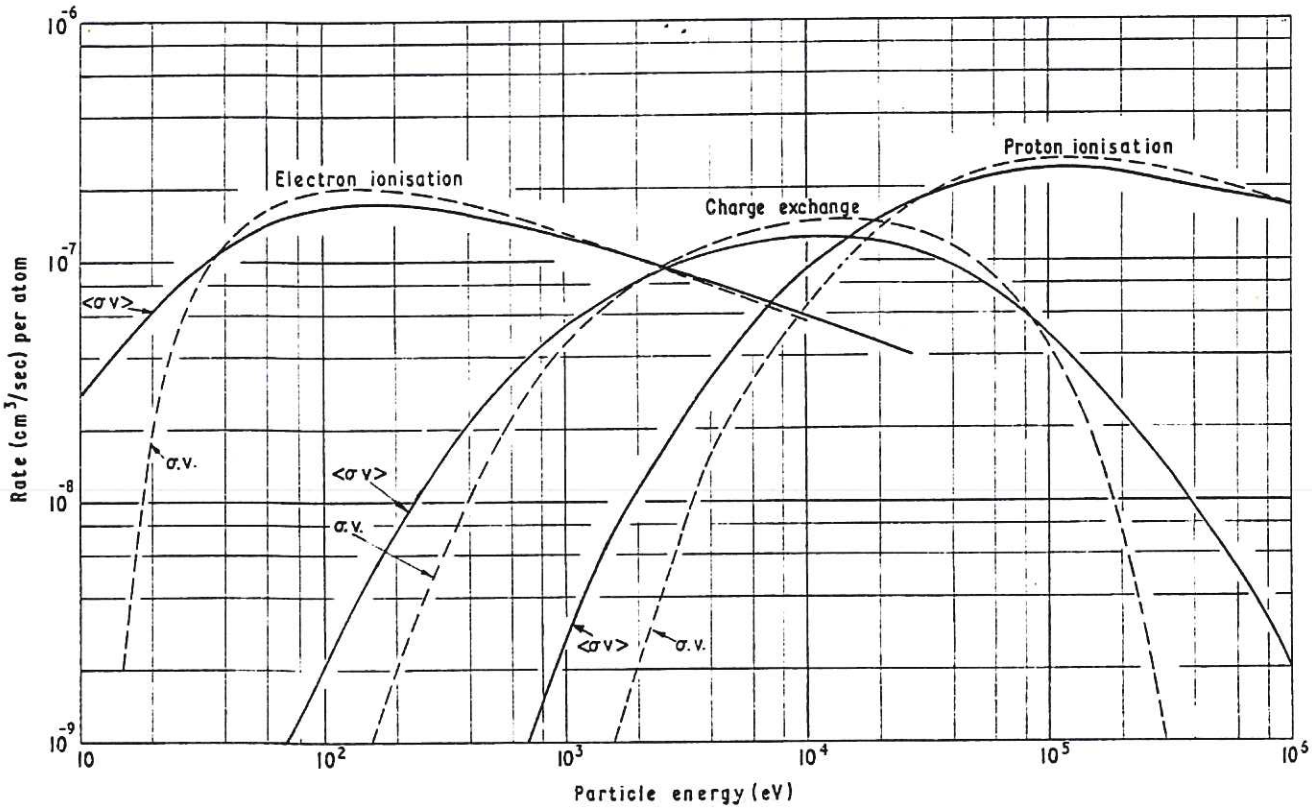

Fig.41 Rate coefficients for argon

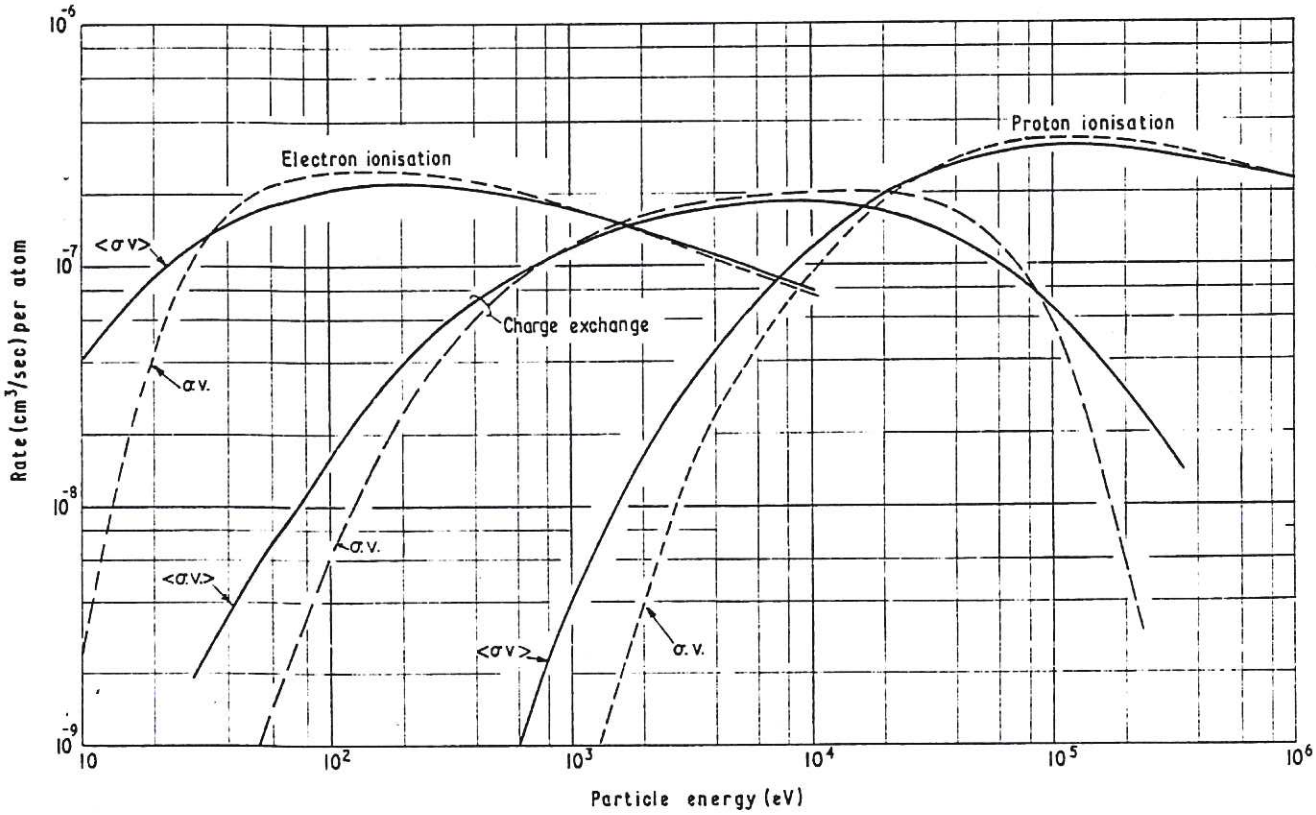

Fig.42 Rate coefficients for krypton

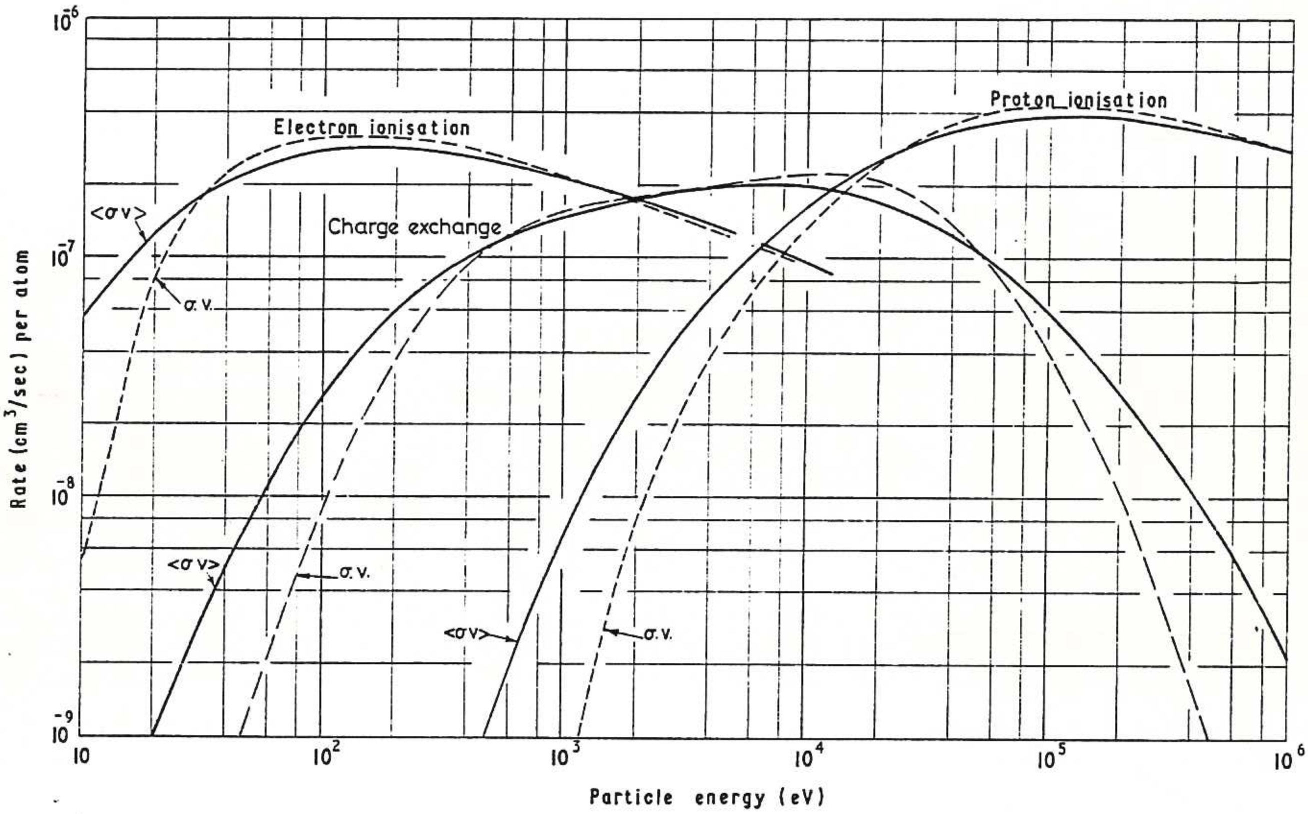

Fig.43 Rate coefficients in xenon

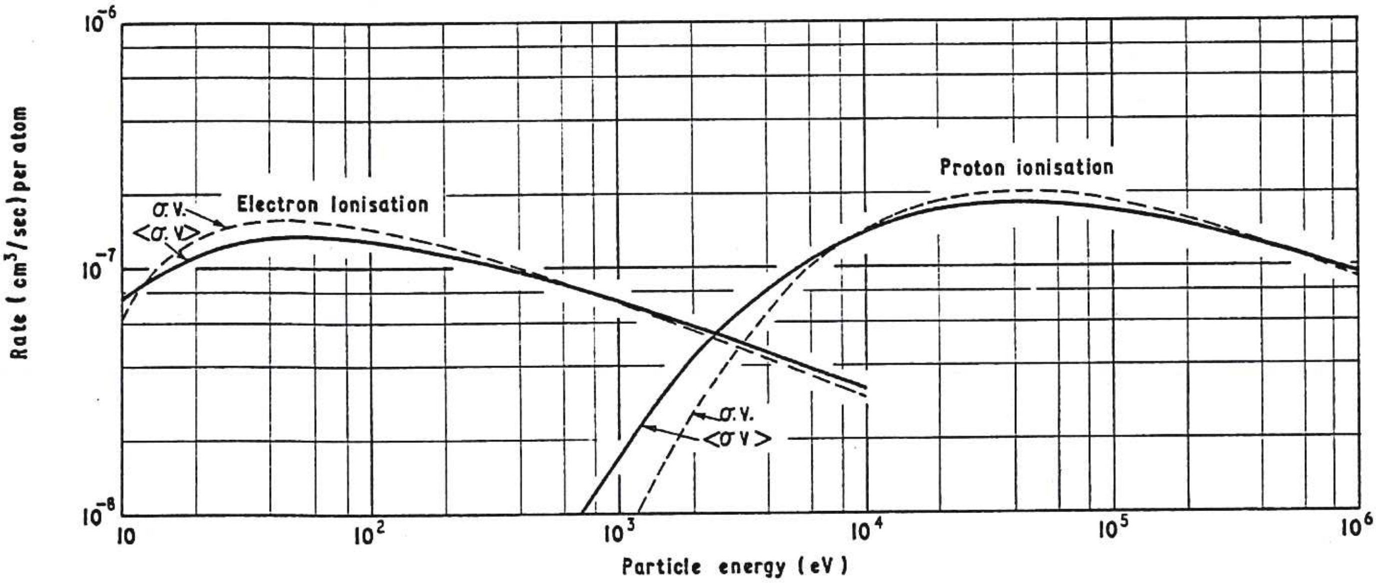

Fig.44 Rate coefficients for lithium

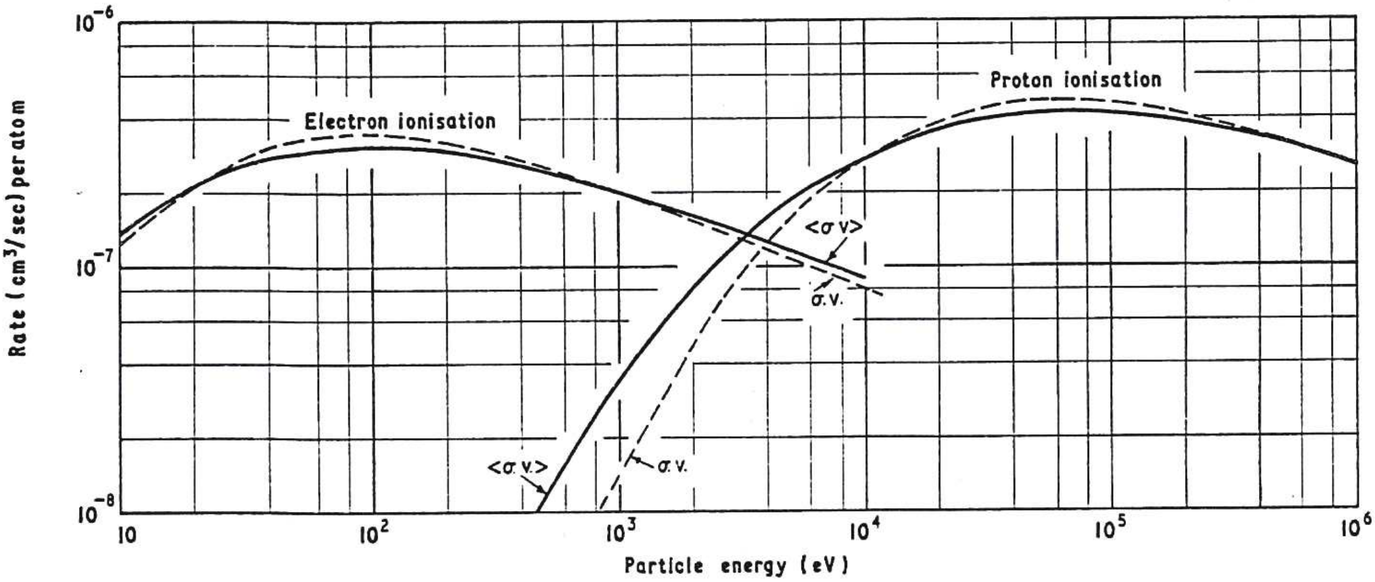

Fig.45 Rate coefficients for potassium

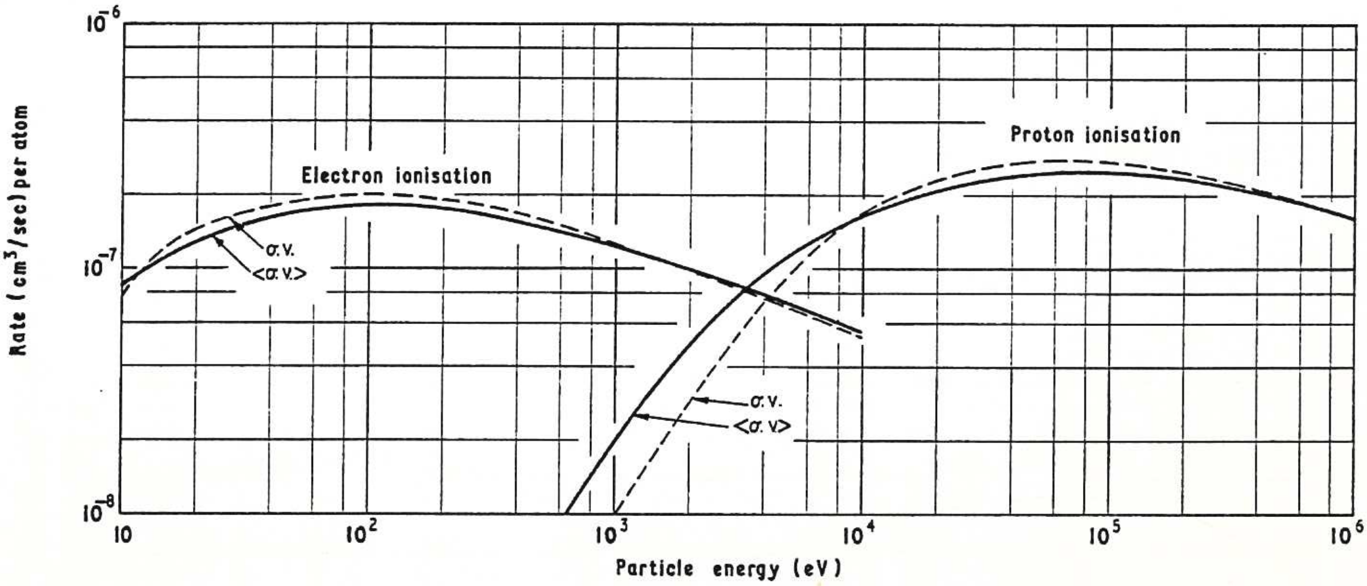

Fig.46 Rate coefficients for sodium

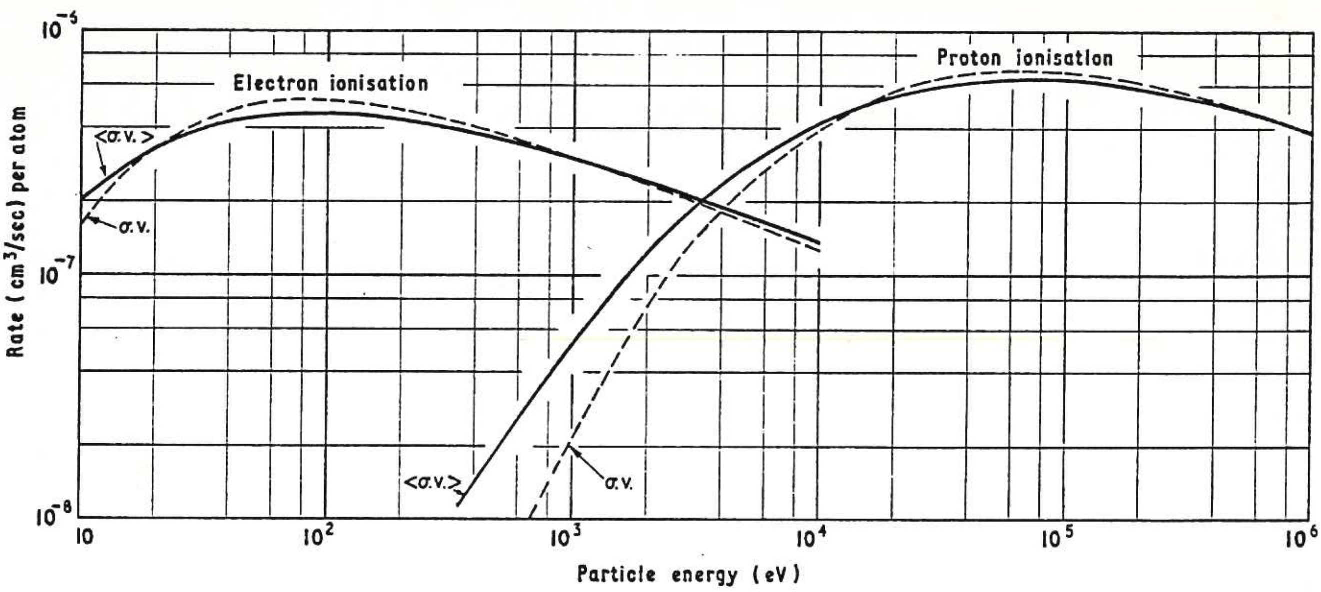

Fig.47 Rate coefficients for caesium

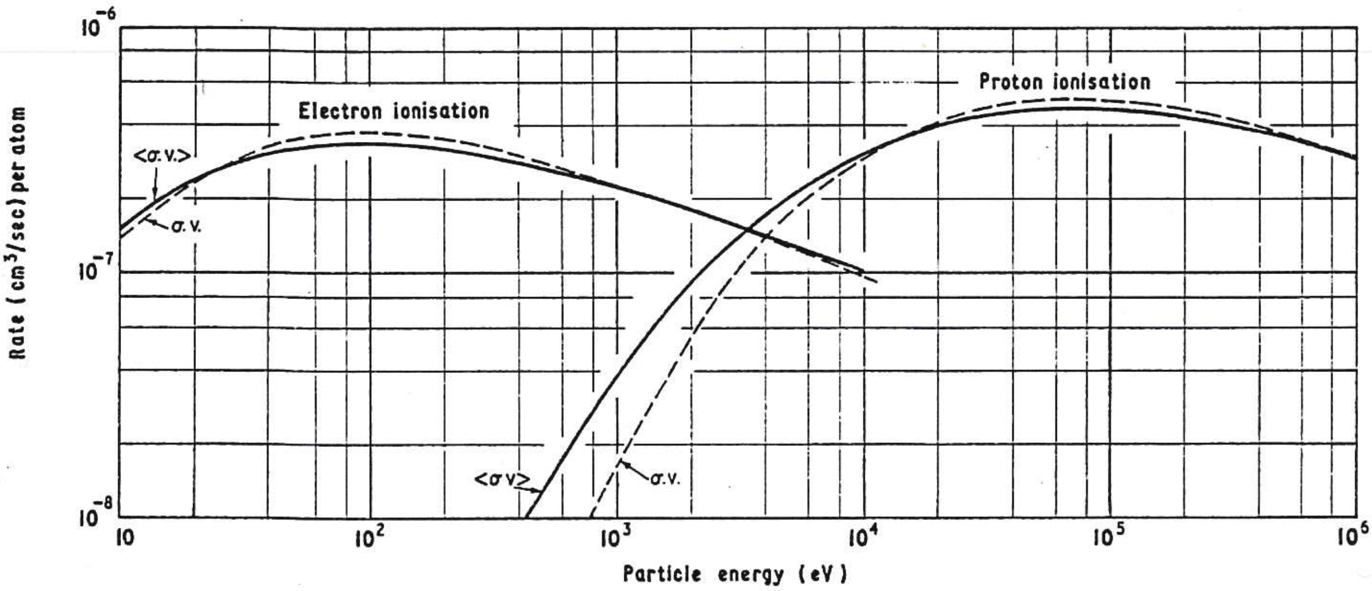

Fig.48 Rate coefficients for rubidium

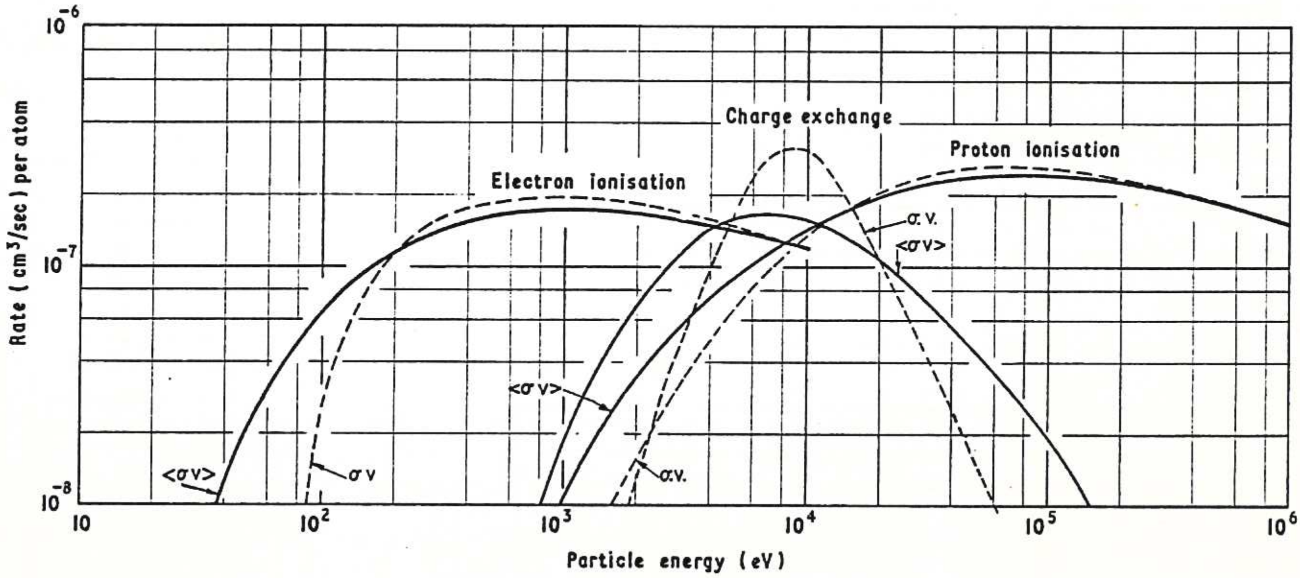

Fig.49 Rate coefficients for magnesium

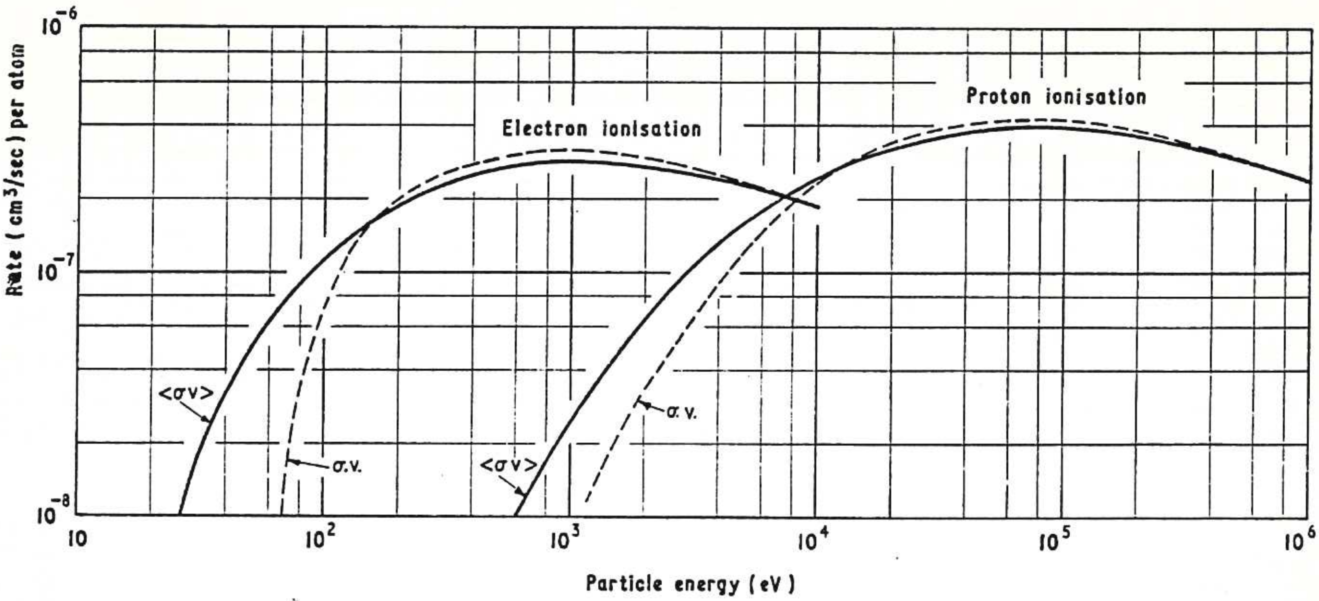

Fig.50 Rate coefficients for calcium

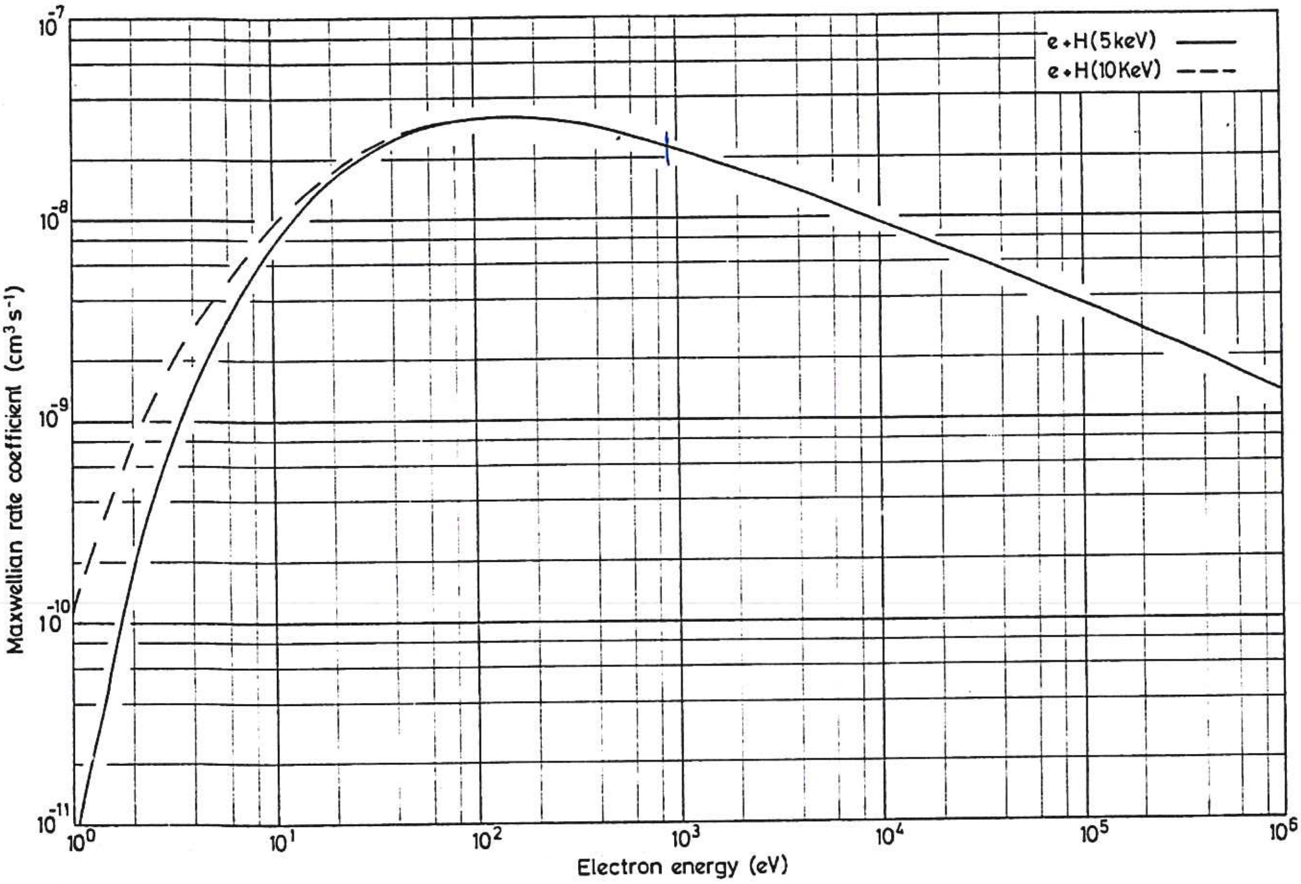

Fig.51 Maxwellian rate coefficient for electron ionisation of energetic hydrogen atoms

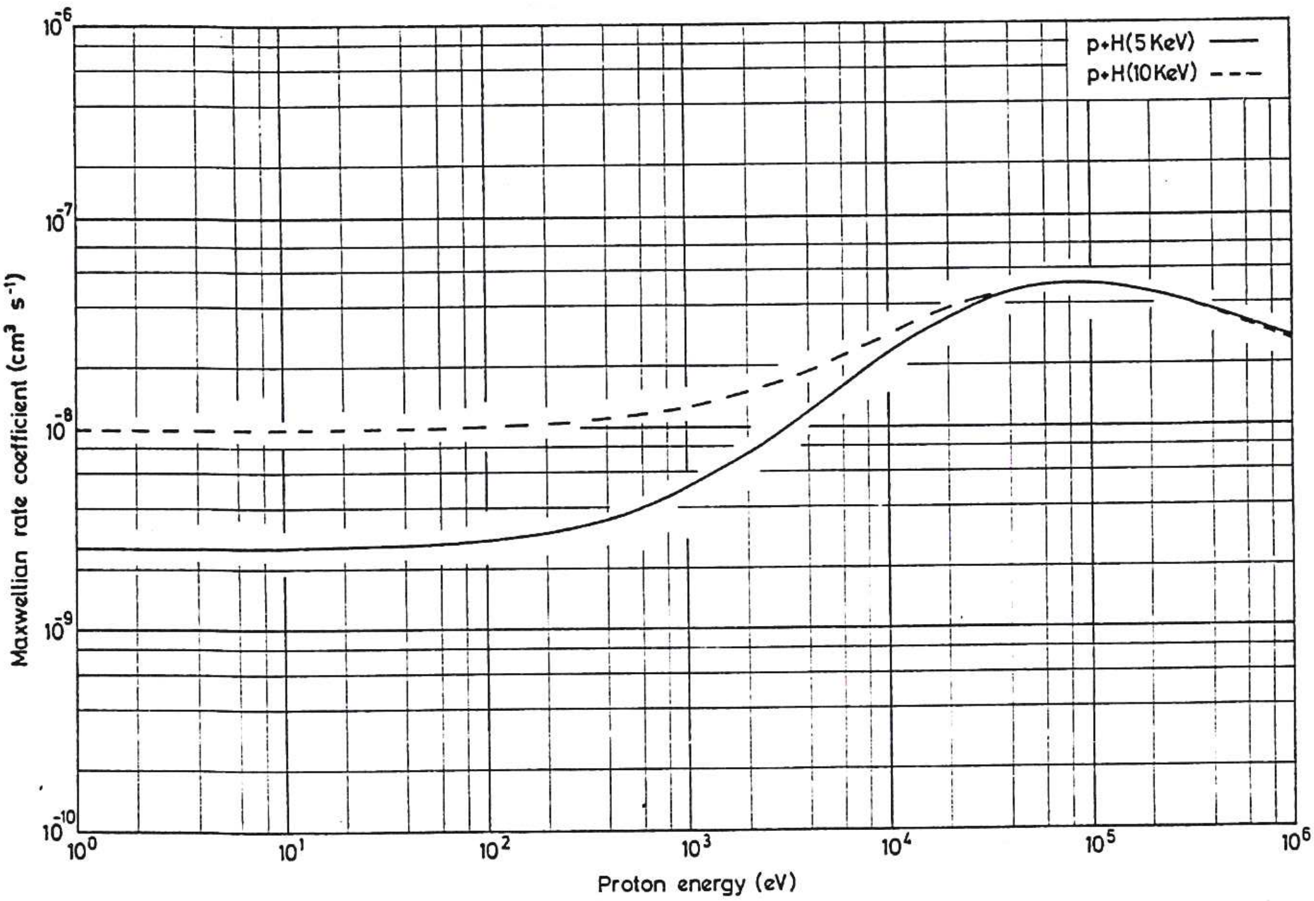

Fig.52 Maxwellian rate coefficient for proton ionisation of energetic hydrogen atoms

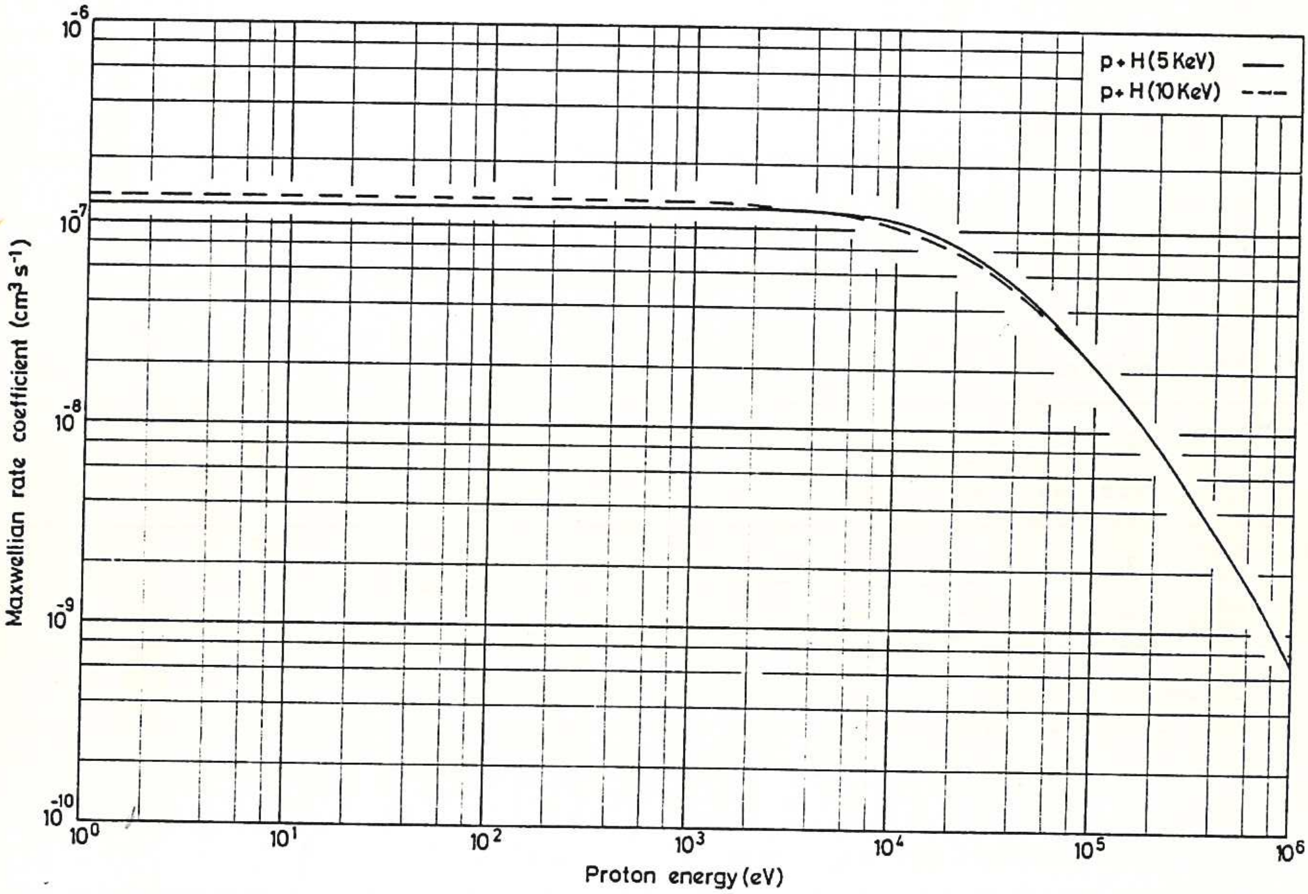

Fig.53 Maxwellian rate coefficient for charge exchange of protons on energetic hydrogen atoms

TABLE 1

ELEMENT \ SHELL NOTATION		K	LI	LII	LIII	MI	MII	MIII	MIV	MV	NI	NII	NIII	NIV	NV	NVI	NVII	OI	OII	OIII	OIV	OV	PI
HYDROGEN	No of Electrons	1																					
	Shell Energy	13.598																					
MOLECULAR HYDROGEN	No of Electrons	2																					
	Shell Energy	15.427																					
HELIUM	No of Electrons	2																					
	Shell Energy	24.46																					
LITHIUM	No of Electrons	2	1																				
	Shell Energy	54.42	5.363																				
NEON	No of Electrons	2	2	3	3																		
	Shell Energy	866.9	45.0	21.47																			
SODIUM	No of Electrons	2	2	3	3	1																	
	Shell Energy	1073.4	63.3	31.29		5.12																	
MAGNESIUM	No of Electrons	2	2	3	3	2																	
	Shell Energy	1306.0	89.4	48.98		7.61																	
ARGON	No of Electrons	2	2	3	3	2	3	3															
	Shell Energy	3206.7	322.4	251.6		35.0	15.68																
POTASSIUM	No of Electrons	2	2	3	3	2	3	3			1												
	Shell Energy	3614.85	377.1	297.95	293.87	34.01	17.69				4.318												
CALCIUM	No of Electrons	2	2	3	3	2	3	3			2												
	Shell Energy	4046.1	437.8	351.0	346.9	43.54	25.85				6.09												
KRYPTON	No of Electrons	2	2	3	3	2	3	3	5	5	2	3	3										
	Shell Energy	14325.0	1926.5	1730.6	1678.9	295.2	217.68	209.5	96.5		27.2	13.93											
RUBIDIUM	No of Electrons	2	2	3	3	2	3	3	5	5	2	3	3					1					
	Shell Energy	15200	1874.5			325.2	250.3	240.8	114.3	112.9	31.33	16.33						4.159					
XENON	No of Electrons	2	2	3	3	2	3	3	5	5	2	3	3	5	5			2	3	3			
	Shell Energy	34570	5243.0		4782.0	1140.0	961.5		679.0		208.0	153.0		65.5				22.7	12.08				
CAESIUM	No of Electrons	2	2	3	3	2	3	3	5	5	2	3	3	5	5			2	3	3			1
	Shell Energy	35980.0	5317.8			1217.1	1065.0	997.6	732.5		230.8	166.9		77.65				22.7	13.1	11.4			3.87

TABLE 2
CROSS-SECTION

REACTION	A_0	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	RANGE (eV)	UNITS of $(\ell nE)^i$
PROTON IONISATION											
p + H	-0.4203309×10^{2}	0.3557321×10^{1}	-0.1045134×10^{1}	0.3139238	-0.7454475×10^{-1}	0.8459113×10^{-2}	-0.3495444×10^{-3}	-	-	$100\rightarrow5\times10^{6}$	keV
p + H_2	-0.3878836×10^{2}	0.1117867×10^{1}	-0.5450406	0.3420528	-0.9266296×10^{-1}	0.1017394×10^{-1}	-0.3923876×10^{-3}	-	-	$100\rightarrow10^{7}$	keV
p + He	-0.4075642×10^{2}	0.1556363×10^{1}	-0.8902739	0.5443478	-0.1435057	0.1590320×10^{-1}	-0.6330861×10^{-3}	-	-	$100\rightarrow10^{7}$	keV
p + Ne	-0.4134772×10^{2}	0.1744445×10^{1}	-0.5750752	0.5236317	-0.2288208	0.4959978×10^{-1}	-0.5871520×10^{-2}	0.3651439×10^{-3}	-0.9343662×10^{-5}	$10^{3}\rightarrow10^{7}$	keV
CHARGE EXCHANGE											
p + H	$\sigma = \dfrac{0.6937\times10^{-14}\,(1-0.155\log_{10}E)^2\ \text{cm}^2}{1+0.1112\times10^{-14}\,E^{3.3}}$				-	-	-	-	-	$1\rightarrow10^{5}$	eV
p + H_2	-0.1955178×10^{2}	-0.3676721×10^{2}	0.1651920×10^{2}	-0.3261031×10^{1}	0.3312837	-0.1695712×10^{-1}	0.3439524×10^{-3}	-	-	$30\rightarrow5\times10^{5}$	eV
p + He	-0.4040162×10^{2}	0.2307004×10^{1}	-0.1713230×10^{1}	0.1351025×10^{1}	-0.4566584	0.6353690×10^{-1}	-0.3139240×10^{-2}	-	-	$10\rightarrow10^{6}$	keV
p + Ne	-0.7602588×10^{3}	0.5200924×10^{3}	-0.1545427×10^{3}	0.2410828×10^{2}	-0.2074846×10^{1}	0.9335632×10^{-1}	-0.1717926×10^{-2}	-	-	$10\rightarrow10^{6}$	eV
p + A	-0.4101956×10^{3}	0.4139650×10^{3}	-0.1987734×10^{3}	0.5309073×10^{2}	-0.8574027×10^{1}	0.8580034	-0.5211295×10^{-1}	0.1762754×10^{-2}	-0.2552401×10^{-4}	$1\rightarrow10^{7}$	eV
p + Kr	0.2236134×10^{2}	-0.9536137×10^{2}	0.5545670×10^{2}	-0.1680554×10^{2}	0.3037309×10^{1}	-0.3402141	0.2314875×10^{-1}	-0.8746496×10^{-3}	0.1402600×10^{-4}	$50\rightarrow10^{5}$	eV
p + Xe	-0.5950850×10^{2}	0.2961736×10^{2}	-0.2072167×10^{2}	0.7935097×10^{1}	-0.1691107×10^{1}	0.2081319	-0.1474035×10^{-1}	0.5577909×10^{-3}	-0.8738234×10^{-5}	$1\rightarrow10^{6}$	eV
p + Mg	-0.3810777×10^{2}	0.3985107×10^{1}	-0.3662240×10^{1}	0.4221167×10^{1}	-0.2258339×10^{1}	0.5018420	-0.3975168×10^{-1}	-	-	$100\rightarrow10^{6}$	keV

TABLE 3
MAXWELLIAN RATE COEFFICIENTS

REACTION	A_0	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	RANGE (eV)	UNITS of $(\ell nE)^i$
IONISATION											
p + H	-0.1490861×10^{3}	0.7592575×10^{2}	-0.2209281×10^{2}	0.3909709×10^{1}	-0.4402168	0.3209047×10^{-1}	-0.1493409×10^{-2}	0.4094151×10^{-4}	-0.5069777×10^{-6}	$100\rightarrow10^{7}$	eV
p + H_2	-0.5600788×10^{2}	-0.7573652×10^{1}	0.1324987×10^{2}	-0.4482919×10^{1}	0.7492077	-0.7071952×10^{-1}	0.3827517×10^{-2}	-0.1107900×10^{-3}	0.1323309×10^{-5}	$100\rightarrow10^{7}$	eV
p + He	0.5737904×10^{1}	-0.8085855×10^{2}	0.4680503×10^{2}	-0.1272666×10^{2}	0.1954478×10^{1}	-0.17884228	0.9668473×10^{-2}	-0.2852063×10^{-3}	0.3540439×10^{-5}	$100\rightarrow10^{7}$	eV
e + H	-0.3173850×10^{2}	0.1143818×10^{2}	-0.3833998×10^{1}	0.7046692	-0.7431486×10^{-1}	0.4153749×10^{-2}	-0.9486967×10^{-4}	-	-	$1\rightarrow10^{5}$	eV
e + H_2	-0.3265772×10^{2}	0.1233251×10^{2}	-0.4059211×10^{1}	0.7328010	-0.7596204×10^{-1}	0.4181685×10^{-2}	-0.9427185×10^{-4}	-	-	$1\rightarrow10^{6}$	eV
e + He	-0.4450917×10^{2}	0.2442968×10^{2}	-0.1025714×10^{2}	0.2470931×10^{1}	-0.3426362	0.2505100×10^{-1}	-0.7438675×10^{-3}	-	-	$25\rightarrow10^{4}$	eV
CHARGE EXCHANGE											
p + H	-0.1841757×10^{2}	0.528295	-0.2200477	0.9750192×10^{-1}	-0.1749183×10^{-1}	0.4954298×10^{-3}	0.2174910×10^{-3}	-0.2530205×10^{-4}	0.8230751×10^{-6}	$1\rightarrow10^{5}$	eV
p + H_2	0.4393093×10^{1}	-0.4673875×10^{2}	0.2555619×10^{2}	-0.6928134×10^{1}	0.1099433×10^{1}	-0.1066905	0.6229316×10^{-2}	-0.2011935×10^{-3}	0.2764444×10^{-5}	$10\rightarrow10^{6}$	eV
p + He	-0.5088878×10^{3}	0.3429709×10^{2}	-0.9992931×10^{2}	0.1493233×10^{2}	-0.1116296×10^{-1}	0.2363328×10^{-1}	0.2149761×10^{-2}	-0.1518706×10^{-3}	0.2909627×10^{-5}	$100\rightarrow10^{6}$	eV

TABLE 4
MAXWELLIAN RATE COEFFICIENTS FOR BEAMS IN ATOMIC HYDROGEN (5 keV + 10 keV)

REACTION	A_0	A_1	A_2	A_3	A_4	A_5	A_6	RANGE	UNITS of $(\ell nE)^i$
IONISATION									
p + H (5 keV)	-0.2513477×10^{2}	0.3664119×10^{1}	-0.8144032	0.3948899×10^{-1}	0.8507599×10^{-2}	-0.1028873×10^{-2}	0.3112871×10^{-4}	$1\text{ eV}\rightarrow40\text{ eV} = 2.55\times10^{-9}$ $40\text{ eV}\rightarrow10^{5}\text{ eV}$	eV
e + H (5 keV)	-0.2554387×10^{2}	0.5393130×10^{1}	-0.1460947×10^{1}	0.2220500	-0.2054505×10^{-1}	0.1040474×10^{-2}	-0.2176789×10^{-4}	$1\text{ eV}\rightarrow10^{5}\text{ eV}$	eV
p + H (10 keV)	-0.1840003×10^{2}	0.2622242	0.2558553	-0.9019891×10^{-1}	0.1395841×10^{-1}	-0.9317183×10^{-3}	0.2214643×10^{-4}	$1\text{ eV}\rightarrow100\text{ eV} = 9.79\times10^{-9}$ $100\text{ eV}\rightarrow10^{6}\text{ eV}$	eV
e + H (10 keV)	-0.2294140×10^{2}	0.3209821×10^{1}	-0.7180771	0.9188585×10^{-1}	-0.8202399×10^{-2}	0.4398966×10^{-3}	-0.1002732×10^{-4}	$1\text{ eV}\rightarrow10^{5}\text{ eV}$	eV
CHARGE EXCHANGE									
p + H (5 keV)	-0.1595881×10^{2}	0.9086215×10^{-1}	-0.5516096×10^{-2}	-0.1702348×10^{-1}	0.4813597×10^{-2}	-0.4474338×10^{-3}	0.1284692×10^{-4}	$1\text{ eV}\rightarrow5\times10^{3}\text{ eV} = 1.226\times10^{-7}$ $5\times10^{3}\text{ eV}\rightarrow10^{6}\text{ eV}$	eV
p + H (10 keV)	-0.1584099×10^{2}	0.2862118×10^{-1}	0.2378704×10^{-1}	-0.2012109×10^{-1}	0.4563415×10^{-2}	-0.4002690×10^{-3}	0.1122735×10^{-4}	$1\text{ eV}\rightarrow1\times10^{3}\text{ eV const} = 1.354\times10^{-7}$ $1\times10^{3}\text{ eV}\rightarrow10^{6}\text{ eV}$	eV

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