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A. Salmoun, T. Bouchama, S. Martin, M. Druetta. SUBSHELL SELECTIVE ELECTRON CAPTURE IN COLLISION OF $O4+$ WITH $H2$ AT 40 keV. Journal de Physique Colloques, 1989, 50 (C1), pp.C1-353-C1-356. 10.1051/jphyscol:1989140 . jpa-00229338

HAL Id: jpa-00229338

<https://hal.science/jpa-00229338>

Submitted on 1 Jan 1989

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SUBSHELL SELECTIVE ELECTRON CAPTURE IN COLLISION OF O^{4+} WITH H_2 AT 40 keV

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Résumé :

La collision d'échange de charge entre des ions O^{4+} de 40 keV et de l'hydrogène moléculaire a été observée par spectroscopie optique dans l'ultraviolet. En plus des transitions entre états doublets avec coeur $1s^2 2s^2$, les transitions entre états doublets et quadruplets avec coeur $1s^2 2s 2p$ ont été observées. Les niveaux $n=3$ de OIV sont préférentiellement peuplés. Les sections efficaces absolues ont été mesurées.

Abstract :

u.v. photon spectroscopy of charge exchange collision between O^{4+} (40 keV) ions and H_2 has been observed. In addition to the transitions between doublet states with $1s^2 2s^2$ core, transitions between doublet and quartet states with $1s^2 2s 2p$ core have been observed $n=3$ levels of O IV are selectively populated. Absolute cross sections have been measured.

Collision between O^{4+} and H_2 has been analysed by photon spectroscopy

The experimental apparatus has been described in previous papers (1) (2). The O^{4+} ion beam extracted from the electron cyclotron resonance source is charge and mass analysed by two bending magnets and finally sent into a gas cell with a 8 mm diameter entrance hole. The pressure is kept at 5×10^{-5} mbar and typical beam intensity is 8 μA at 40 keV energy.

Light emitted during the collision is observed at 25° of the beam direction with a grazing incidence spectrometer equipped with a 600 lines/mm grating blazed at 25.6 nm. The photon detection is made by MgF_2 coated microchannels plates (MCP).

The absolute cross-section calibration of our experimental set-up has been realized in-situ with the three C IV lines ($\lambda=31.2$ nm $2s^2 S-3p^2 P^o$, $\lambda=38.4$ nm $2p^2 P^o-3d^2 D$, $\lambda=41.9$ nm $2p^2 P^o-3s^2 S$) obtained by the $C^{4+} + H_2$ collision at 40 keV and for which the emission cross-sections have been measured (3). By this method we only have measure the ion beam currents in the vacuum. During the experiment we have only to take into account the small instabilities of the ion current (after passage through the gas). We also use as secondary etalons, collisions like N^{6+} , O^{6+} , N^{5+} , $N^{6+} + He(H_2)$ for which emission cross-sections have been measured and which cover a wide spectral range. A conservative value of the error bar on emission cross-sections may be then evaluated to 30%. Of course for intense lines where the photon statistic is good, this error bar may be better. This estimated error bar does not include any possible polarization effect of the emitted radiations.

A typical spectrum recorded during the $O^{4+} + H_2$ collision at 40 keV is displayed on figure 1. 0 IV lines belong to transitions with the upper state either in the $1s^2 2s^2 n\ell$ configuration or in the $1s^2 2s 2p n'\ell'$ configuration. They are interpreted as the result of the single electron charge exchange collision between O^{4+} in the fundamental $1s^2 2s^2 {}^1S$ state or in the metastable $1s^2 2s 2p$ state and H_2 . The $1s^2 2s 2p$ state has a lifetime of 0.51 ns (4) compatible with the time of flight of the ions from the ECR source to the observation cell. Brazuk et al. (5) have measured by a method of beam attenuation the metastable O^{4+} beam fraction in an ECR source. Their value of 42% will be taken in our work in order to determine the cross-section values. Two weak lines at 62.9 and 77.96 nm may be interpreted as the $2s 2p^2 {}^4P - 2p^3 {}^4S^\circ$ and $2s 2p^2 {}^2D - 2p^3 {}^2D^\circ$ transitions. We also observe the λ 55.4 nm $2s^2 2p^2 P^\circ - 2s 2p^2 {}^2P$, λ 60.8 nm $2s^2 2p^2 P^\circ - 2s 2p^2 {}^2S$, λ 78.7-79.0 nm $2s^2 2p^2 P^\circ - 2s 2p^2 {}^2D$ transitions.

Some weak lines of OIII (λ 22.8-29.5-35.9-37.4-39.6 nm) are also observed. They are due to double collision or/and double capture process.

The emission cross-sections σ_{em} of the observed O IV lines are reported in Table I and II. Capture from the $O^{4+} 1s^2 2s^2$ core is selective on the $n=3$ doublets levels. With the $O^{4+} 1s^2 2s 2p$ core the capture is also selective on the $n=3$ doublet and quadruplet levels. These results are in agreement with the results of the reaction window of the Extended Classical Barrier Model (ECBM) (6).

The total $\sum \sigma(n\ell)$ excitation cross-section ($\pm 30\%$) is found $317 \times 10^{-17} \text{ cm}^2$ for the $n\ell$ $1s^2 2s^2$ core, and $280 \times 10^{-17} \text{ cm}^2$ for the $1s^2 2s 2p$ core. These values are to be compared to the $\sigma_{q \rightarrow q-1}$ (298 ± 4) 10^{-17} cm^2 of Phaneuf et al. obtained with a PIG source, at the same energy, but without discrimination against the metastable beam fraction. These results seem to prove that the capture cross-section from the metastable state is of the same magnitude than the capture cross-section from the fundamental state.

This experiment was carried out at the LAGRIPPA, CEA-CNRS.

Table I - Emission cross-sections σ_{em} (10^{-17} cm^2) for the O^{4+} ($1s^2 2s^2$) + $H_2 \rightarrow O^{3+}$ ($1s^2 2s^2 n\ell$) + H_2^+ collision (40 keV) (error bar $\pm 30\%$)

$\lambda \text{ nm}$	transition	σ_{em}
19.5	$2s \ 2p^\circ - 4d \ 2D$	2.6
23.8	$2p \ 2p^\circ - 3d \ 2D$	66
27.9	$2p \ 2p^\circ - 3s^2 S$	102
37.9	$2s 2p^2 \ 2D - 3p \ 2p^\circ$	120
44.2	$2s 2p^2 \ 2S - 3p \ 2p^\circ$	26
	$\sigma(3s) \ 102 \ \sigma(3p) \ 146 \ \sigma(3d) \ 66$	
	$\sum \sigma(n\ell) \ 317$	
	$n\ell$	

Table II - Emission cross-sections σ_{em} (10^{-17}cm^2) for the $O^{4+} (1s^2 2s 2p)$
 $+ H_2 \rightarrow O^{3+} (1s^2 2s 2p n l) + H_2^+$ collision (40 keV) (error bar $\pm 30\%$)

λnm	transition	σ_{em}
20.10	$2s 2p^2 \ ^4P - 4s \ ^4P$	2.8
20.29	$2s^2 2p^2 p^{\circ} - 3p^2 S$	4.7
20.73	$2s^2 2p^2 p^{\circ} - 3p^2 D$	47
21.41	$2s^2 2p^2 p^{\circ} - 3p^2 P$	24
23.11	$2s^2 \ ^4P - 3d^4 p^{\circ}$	8.3
23.35	$2s 2p^2 \ ^4P - 3d^4 D^{\circ}$	16
26.05	$2s 2p^2 \ ^2D - 3d^2 F^{\circ}$	7.4
26.68	$2s 2p^2 \ ^2D - 3d^2 D^{\circ}$	5.8
27.22	$2s 2p^2 \ ^4P - 3s^4 p^{\circ}$	131
28.58	$2s 2p^2 \ ^2S - 3d^2 p^{\circ}$	1.8
29.92	$2s 2p^2 \ ^2P - 3d^2 p^{\circ}$	0.2
30.68	$2s 2p^2 \ ^2D - 3s^2 p^{\circ}$	21
31.16	$2s 2p^2 \ ^2P - 3s^2 p^{\circ}$	2
34.65	$2s 2p^2 \ ^2S - 3s^2 p^{\circ}$	7.4
36.72	$2s 2p^2 \ ^2P - 3s^2 p^{\circ}$	2
55.36	$2s^2 2p^2 p^{\circ} - 2s 2p^2 P$	12

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Fig. 1 - $O^{4+} + H_2$

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