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LOW ENERGY CHARGE EXCHANGE BETWEEN Nq^+ , Neq^+ AND Arq^+ WITH Cs

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Resumé :

Les ions multichargés Nq^+ ($q=5$), Neq^+ ($q=5,8$) et Arq^+ ($q=8,9$) ont été étudiés par spectroscopie optique lors de la collision d'échange de charge avec une vapeur de Caesium. Les états de Rydberg sont peuplés par capture électronique. Les transitions entre états de Rydberg doublement excités $1s^2 2s^2 2p^5 3s n\ell 4L_J - 1s^2 2s^2 2p^5 3s n'\ell' 4L'_J$ with $n=7, \dots, 12$ et $\ell=6, \dots, 11$ ont été observées par double collision avec Ar^{9+} .

Abstract

Optical spectroscopy studies have been performed with Nq^+ ($q=5$), Neq^+ ($q=5,8$) and Arq^+ ($q=8,9$) multicharged ions. Rydberg states were populated by electron capture from Caesium. Doubly excited $1s^2 2s^2 2p^5 3s n\ell 4L_J - 1s^2 2s^2 2p^5 3s n'\ell' 4L'_J$ with $n=7, \dots, 12$ and $\ell=6, \dots, 11$ Rydberg transitions of Ar VIII have been observed by double collision with Ar^{9+} .

Electron capture with $Xq^+ + H_2$ (He) collisions have been extensively studied by Ultra violet and X spectroscopy. The capture levels with this targets are low $n=3, 4, 5$. To obtain higher levels $n=9, 10, 11, 12$ we have used atomic alkaline vapor target. $\Delta n=1$ and $\Delta n=2$ transitions from these levels are situated in the visible and near Ultra violet range. In this paper we report our studies of these transitions between single and doubly excited states.

Nq^+ ($q=5$), Neq^+ ($q=5,8$) et Arq^+ ($q=8,9$) beams ($E=10$ q.keV) issued from an E.C.R. source and magnetically analysed are sent through an atomic caesium vapor produced in a cell

maintained at a constant temperature of 70 or 90°C corresponding to a pressure of about 8×10^{-5} and 3×10^{-4} mb, respectively. Photons originating from $X^{q+} + \text{Cs}$ collisions are observed at 90° to the beam axis and focused onto the entrance slit of a 0.6 m Czerny-Turner spectrometer, equipped with a 1200 ℓ/mm grating blazed at 300 nm. A photomultiplier is used as detector covering a spectral range from 200 to 650 nm.

Figures 1, 2 and 3 show typical spectra obtained with N, Ne and Ar beams at low spectral resolution ($\text{FWHM} \approx 0.9$ nm) and low pressure ($T = 70^\circ\text{C}$) together with their identifications. The relative intensities of the lines observed are consistent with the predominant population of the $n=11, 12$, the $n=10, 11$, $n=9, 10$, $n=8, 9$ and $n=7, 8$ manifolds after single capture into $q=9, 8, 7, 6, 5$ charges states respectively. This is in good agreement with the classical barrier model [2] which yields $n=11.5$, $n=10.4$, $n=9.4$, $n=8.2$ and $n=7.1$ respectively. The reaction windows (figure 4) calculated with the model of Niehaus (3) are in good agreement with the intensity of observed lines.

Fig.1. Spectrum of Rydberg transitions of N V following electron capture into 80 keV N^{5+} by collision in caesium at 70°C.

Tables 1, 2, 3 give the results of the wavelength measurements which are compared with the computed hydrogenic values. The agreement is relatively good because the core polarizations and penetration effects are small for the Rydberg states with high orbital momentum.

Fig.2. a) Spectrum of Rydberg transitions of Ne V following electron capture into 80 keV Ne⁵⁺ by collision in caesium at 70°C.
b) Spectrum of Rydberg transitions of Ne VII and Ne VIII following electron capture into 80 keV Ne⁸⁺ by collision in caesium at 90°C.

Fig.3. a) Spectrum of Rydberg transitions of Ar VIII following electron capture into 80 keV Ar⁸⁺ by collision in caesium at 70°C.
b) Spectrum of Rydberg transitions with $\Delta n=1$ and $\Delta n=2$ of Ar IX following capture into 90 keV Ar⁹⁺ by the caesium at 70°C. Ar VIII lines are weak and broadened.

After Ar⁹⁺-Cs collisions weak and broadened lines occur in Fig.3b close to wavelengths where the strong Ar VIII 7-8 and 8-9 transitions are observed after Ar⁸⁺-Cs collisions in Fig.3a. These two spectral regions have therefore been remeasured with better resolution (FWHM $\approx$ 0.15 nm). This allows to resolve new lines appearing close to the Ar VIII 7i-8k and 8k-9l transitions in Fig.5. They are identified as 7i-8k and 8k-9l transitions between Ar VIII 1s² 2s² 2p⁵ 3sn² ⁴L doubly excited terms. These quartet terms may be populated by capture of an electron into the metastable Ar⁸⁺ 1s² 2s² 2p⁵ 3s ³P_{0,2}-ions with lifetimes $\tau \approx 0.5$ ms which have been created either in ion-source or by a first capture of an electron into Ar⁹⁺ which cascades down to the 2p⁶ and 2p⁵ 3s terms under emission of the spectrum in Fig.3a. The fact that these quartet transitions are more intense with an incident Ar⁹⁺ beam than with a Ar⁸⁺ beam is interpreted by two successive electron captures into Ar⁹⁺ in the Cs vapor. This process has already been observed in Li-like ions [4]. The double collision is confirmed by the quadratic

intensity variation of these lines with pressure. When neglecting core-changing collisions this also indicates that the metastable fraction in the Ar^{8+} beam from the ECR-source is very weak (<3%), in agreement with Defrance et al. [5].

Fig. 4. Reaction windows for $Z = 5, \dots, 9$ with Caesium

Fig. 5. a) Spectrum of Ar VIII following single collision into Ar^{8+} .
b) Spectrum of Ar VIII following double collision into Ar^{9+} . 71-8k and 8k-9l doubly excited transitions of Ar

Fig. 6. Experimental shift in function of the $\Delta\langle r^{-4} \rangle$ hydrogenic values

The results on the quartet transitions are displayed in Table 4. The observed lines are identified as transitions between states with highest values of L and J because they decay only radiatively (no autoionization). The other quartet levels with lower values of L and J are strongly mixed with doublet continuum levels and are thus autoionized very rapidly.

The shift between $1s^2 2s^2 2p^5 3s 7i \ ^4K_{17/2} - 1s^2 2s^2 2p^5 3s 8k \ ^4L_{19/2}$ and $1s^2 2s^2 2p^6 7i \ ^2I_J - 1s^2 2s^2 2p^6 8k \ ^2K_J$ transitions of Ar VIII is due to the long range forces. For these levels with $n \gg l \gg 6$, the penetration contributions which we have calculated using a Dirac-Fock method [11] are very low [$\Delta p = 9.6 \text{ cm}^{-1}$ for $2p^5 3s 7i \ ^4K_{17/2} - 2p^5 3s 8k \ ^4L_{19/2}$]. Using the experimental shift as a function of the $\Delta \langle r^{-4} \rangle$ hydrogenic values display in figure 6, we obtained a value of the dipole polarizability of $1.4 \pm 0.2 \text{ a}_0^3$ for the $1s^2 2s^2 2p^5 3s$ core polarizability of Ar VIII.

Table I Rydberg transitions observed in $N^{5+} + Cs(70^\circ C)$

Transitions	Experimental values (nm)	Hydrogenic values (nm)
<i>N V</i> 5-6	298.2 ± 0.3	298.2
<i>N V</i> 6-8	300.1 ± 0.3	299.9
<i>N V</i> 6-7	494.5 ± 0.3	494.6

Table II.b Rydberg transitions observed in $Ne^{5+} + Cs(70^\circ C)$

Transitions	Experimental values (nm)	Hydrogenic values (nm)
<i>Ne V</i> 5-6	296.8 ± 0.3	298.2
<i>Ne V</i> 6-8	299.3 ± 0.3	299.9
<i>Ne V</i> 6-7	493.8 ± 0.3	494.6

Table II.a Rydberg transitions observed in $Ne^{8+} + Cs(90^\circ C)$

Transitions	Experimental values (nm)	Hydrogenic values (nm)
<i>Ne VII</i> 7-9	230.5 ± 0.3	230.7
<i>Ne VII</i> 6-7	251.5 ± 0.3	252.4
<i>Ne VII</i> 8-10	330.7 ± 0.3	330.7
<i>Ne VII</i> 7-8	388.4 ± 0.3	388.9
<i>Ne VIII</i> 6-10	253.1 ± 0.3	253.3
<i>Ne VIII</i> 9-12	263.5 ± 0.3	263.6
<i>Ne VIII</i> 7-8	297.6 ± 0.3	297.7
<i>Ne VIII</i> 9-11	348.3 ± 0.3	348.9
<i>Ne VIII</i> 8-9	434.0 ± 0.3	434.2
<i>Ne VIII</i> 10-12	465.3 ± 0.3	466.0

TABLE III. Rydberg transitions observed in $\text{Ar}^{9+} + \text{Cs}$ (70°C) (a) and in $\text{Ar}^{8+} + \text{Cs}$ (70°C) (b).

Transitions	Experimental values (nm)	Hydrogenic values (nm)
a) Ar IX 7i-8k	235.16 ± 0.15	235.2
Ar IX 8k-9l	343.01 ± 0.15	343.07
Ar IX 9l-10m	479.55 ± 0.15	479.61
Ar IX 9l-11m	275.70 ± 0.15	275.66
Ar IX 10m-12n	368.20 ± 0.15	368.19
b) Ar VIII 7i-8k	297.58 ± 0.15	297.68
Ar VIII 8k-9l	434.16 ± 0.15	434.19
Ar VIII 8k-10l	253.03 ± 0.15	253.13
Ar VIII 9l-11m	348.89 ± 0.15	348.88

TABLE IV. Doubly excited Rydberg transitions observed in $\text{Ar}^{9+} + \text{Cs}$ (90°C).

Transitions	Experimental values (nm)
$1s^2 2s^2 2p^5 3s 7i \ 4K_{17/2}$	296.58 ± 0.15
$1s^2 2s^2 2p^5 3s 8k \ 4L_{19/2}$	
$1s^2 2s^2 2p^5 3s 8k \ 4L_{19/2}$	433.60 ± 0.15
$1s^2 2s^2 2p^5 3s 9l \ 4M_{21/2}$	
$1s^2 2s^2 2p^5 3s 9l \ 4M_{21/2}$	348.66 ± 0.15
$1s^2 2s^2 2p^5 3s 11m \ 4N_{23/2}$	

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