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BEAM-FOIL SPECTROSCOPY OF CHLORINE AND SULFUR IONS

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BEAM-FOIL SPECTROSCOPY OF CHLORINE AND SULFUR IONS

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RESUME

Nous présentons les spectres d'ions fortement ionisés de chlore et de soufre dans les domaines d'énergies, respectivement, 2900 - 3500 eV et 2300 - 2600 eV. Ces spectres ont été obtenus après excitation d'un faisceau d'ions traversant une cible mince de carbone. Le rayonnement X émis par le faisceau émergent est analysé avec un spectromètre à cristal courbe du type Johann. L'angle d'observation par rapport à l'axe du faisceau est de 54°. La construction d'un spectre théorique à partir des résultats obtenus avec une méthode multiconfigurations Dirac-Fock permet d'interpréter l'énergie et l'intensité des raies observées. Toutes les raies correspondent à des transitions 2p - 1s (spectre Kα) d'ions excités ayant des structures hydrogénoides, héliumoide, lithiumoide, bérylliumoide, et boroides.

ABSTRACT

We report on the measurement of spectra of highly stripped chlorine and sulfur ions in the energy ranges of, respectively, 2900 - 3500 eV and 2300 - 2600 eV. The spectra have been obtained after excitation of ions travelling through a thin carbon foil. X-rays emitted by the emerging beam are analyzed with a Johann-type bent crystal spectrometer. The observation angle with respect to the beam axis is 54°. The interpretation of the spectra is performed by comparing experimental results with Multiconfiguration Dirac-Fock (MCDF) calculated energies and intensities. All the lines are interpreted by 2p - 1s transitions (Kα - spectrum) in excited ions with, respectively, H-, He-, Li-, Be- and B-like electron structures.

INTRODUCTION

Experimental and theoretical studies of the spectra of highly charged ions are of prime interest in astrophysics and plasma physics. The beam-foil method [1-5] is a powerful tool for this purpose ; it allows investigation of a large range of atomic numbers and also, by varying the beam energy, of different degrees of ionization.

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EXPERIMENTAL SET-UP

The 7 MV HVEC tandem accelerator of the Centre d'Etudes de Bruyères-le-Châtel, equipped with a Middleton-type sputtering source, supplies a beam of 45 MeV S^{8+} ions (40 MeV Cl^{7+} ions). This beam is directed through a 1.5 mm diameter collimator and focused on a thin (5 µg/cm^2) self-supported carbon foil positioned at 90° with respect to the beam axis.

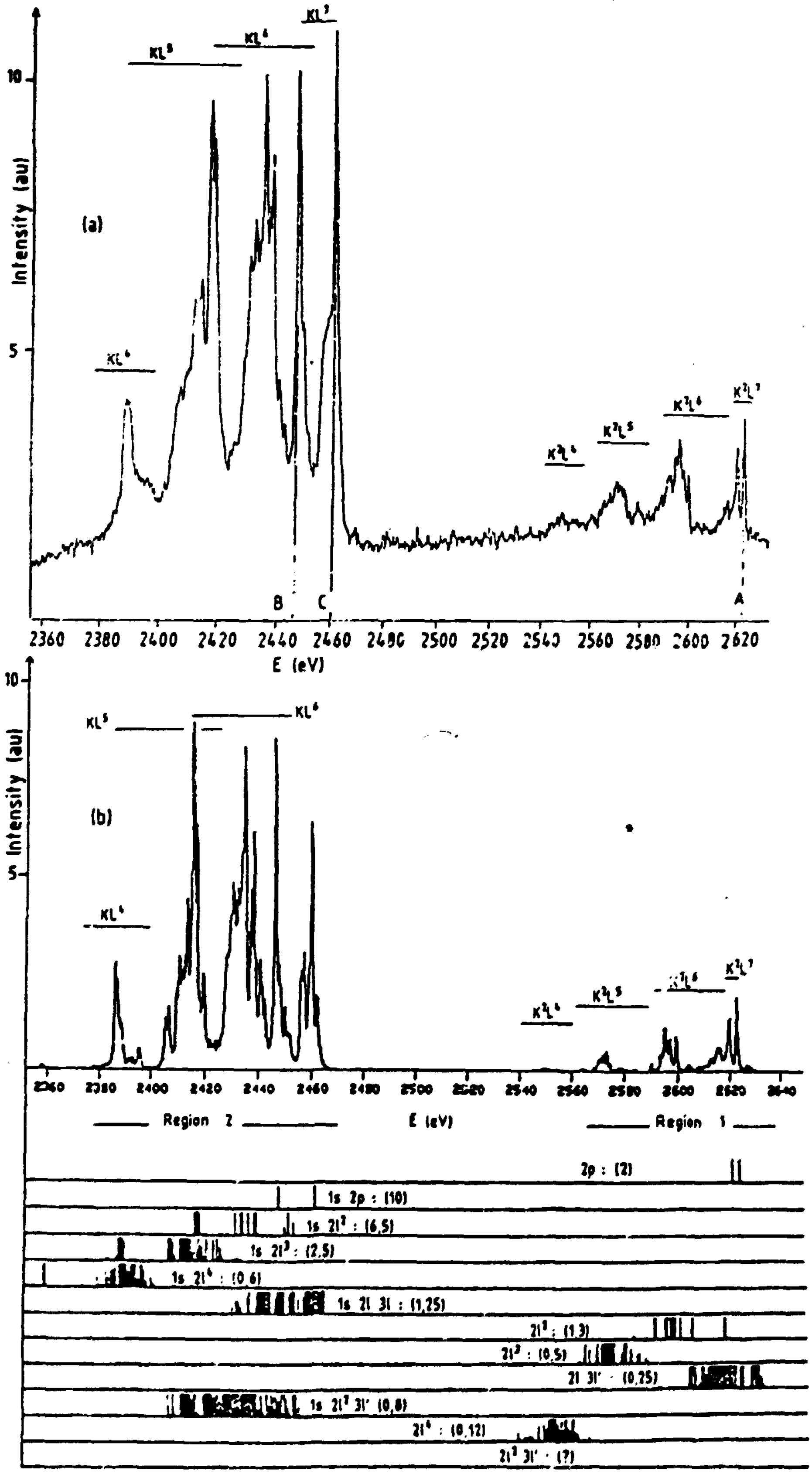

Figure 1a

Kα satellite and hypersatellite spectrum obtained after excitation of a 45 MeV S^{8+} beam through a 5 µg/cm^2 carbon foil and analyzed with a (10$\bar{1}$0) quartz crystal in the first order.

Figure 1b

Kα satellite spectrum simulated by MCDF calculations.
The H-like lines, their hypersatellites, in the energy range 2620 - 2540 eV and the He-like lines, their satellites, in the energy range 2450 - 2380 eV are shown in region 1 and region 2, respectively.

X-rays emitted by the emerging beam are analyzed with a 0.25 m Johann-type bent crystal spectrometer over a 5 mm path length starting at the foil. The detector is a Kodak SA3 photographic emulsion for which the response function is known in a given range of optical density.

ENERGY CALIBRATION OF THE SPECTRA

A removable X-ray tube located inside the interaction chamber [6,7] is used for the calibration of the spectra by superimposing characteristic X-ray lines upon the beam foil spectrum which is to be analyzed. Because of the Doppler shift the absolute energy calibration requires, above all, that a reference line must be chosen among those emitted by the beam. Our measurements enable us to take as a reference line the well resolved 2 $p_{3/2}$ component of the Lyman α doublet. Relative positions of Ly α and intercombination lines also provide the exact observation angle of 54°.

RESULTS AND DISCUSSION

Figures 1 and 2 present the variation of optical density with energy, corrected for Doppler shift ; they give a general survey of the 2p – 1s transition lines.

The observation of the X-ray spectra is made in an area where no populating processes of excited states exist (except in particular cases for which cascades occur). Thus, the photon number in each line can be written as:

$$I_{ij} = p\, g_i\, R_{ij}$$

where p is the statistical population of the initial state, g_i is its degeneracy and R_{ij} is the yield of the initial state into the $i \to j$ transition. The latter is defi-

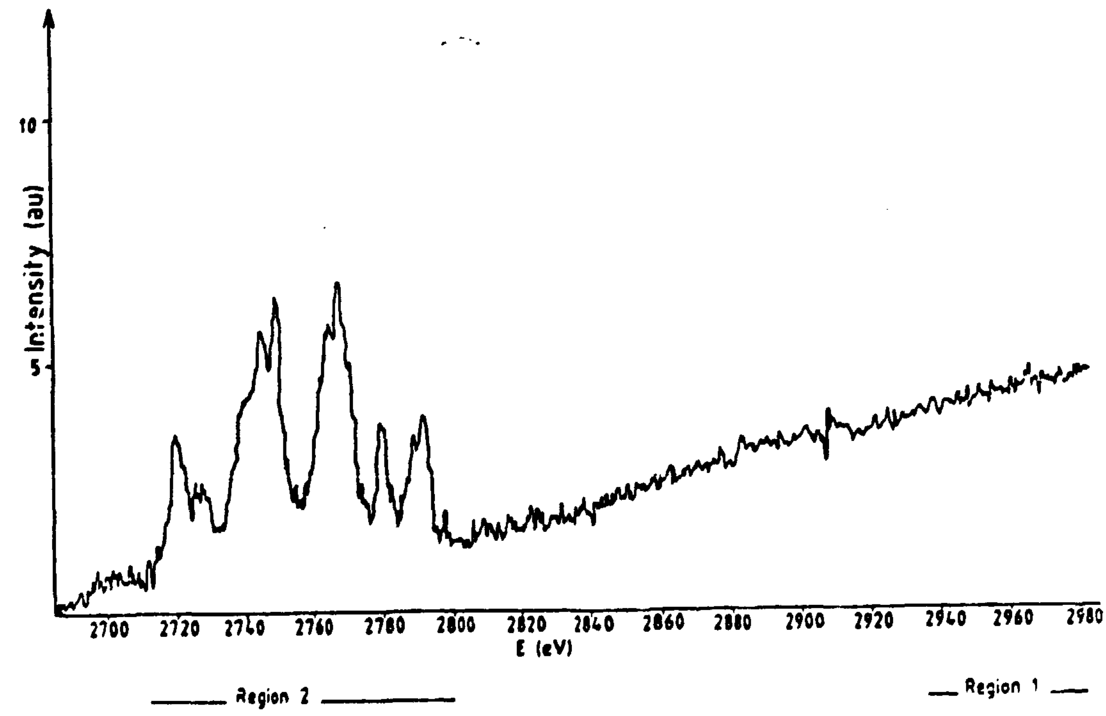

Figure 2

Kα satellite spectrum obtained after excitation of a 40 MeV Cl^{7+} beam through a 5 $\mu g \cdot cm^{-2}$ carbon foil and analyzed with a (10$\bar{1}$1) quartz crystal in the first order.

ed as :

$$R_{ij} = P_{ij} / P_i^{(tot)}$$

here P_{ij} is the $i \rightarrow j$ transition probability and $P_i^{(tot)}$ is the total decay probability of state i, including all radiative and Auger processes. These quantities have been computed with the MCDF theory [8].

The high resolution spectra obtained from these beam-foil experiments and the use of MCDF calculations to compute line energies and fluorescence yields enable us to identify many 2p → 1s satellite lines. In particular, evidence is presented of configurations with one M-shell electron. Several L-S forbidden transitions have been undoubtedly identified. The comparison between observed line intensities and theoretical fluorescence yields corroborates the assumption that the initial states are statistically populated by the large number of collisions that the ions suffer in the foil. This is verified for all states with L-and M-shell electrons. Two K-shell vacancies in the initial states are missing in the chlorine spectrum, as observed in Fig.2, compared to the sulfur spectrum (Fig.1).

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