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Research Note

N III and N IV line emission following K–shell photoionization

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Abstract. Soft X–ray irradiation of low density cold matter K–ionizes neutral nitrogen. The full ionization process followed by Auger decay populates the excited states of N III and N IV ions. N III and N IV uv lines are therefore produced directly with comparable intensities. Some observable intensity ratios are evaluated.

Key words: atomic processes – atomic data – UV: general – X-rays: general

1. Introduction

K–photoionization contributes to the ionization balance in a more complicated way than outer shell photoionization. In fact K–photoionization when followed by Auger decay couples three or more ionization stages instead of two in the usual equations of ionization equilibrium. For low temperature and low density plasmas, the most abundant species are neutral and UV line emission of higher ionized species is weak if due to electron excitation. However there exists the possibility of producing these lines directly by the double process of K–photoionization followed by Auger decay. K–photoionization does not lead simply to the creation of 1s–hole initial target terms (single photoionization). The rapid change of the inner part of the central potential V(r) following ejection of a 1s electron and its interaction with the outer shell are responsable for two important secondary processes. Firstly, the shake up process, in which there is simultaneous excitation of an outer shell electron. Secondly, the shake off process, in which simultaneous ionization of an outer shell electron occurs. In general this second process is the most important. For example, for neon the shake up and shake off cross sections represent respectively 8 and 17% of the single K–photoionization (Krause 1971, Krause et al. 1971). Åberg has shown that these effects can be well estimated by the sudden approximation (1969). In this case the rapid change of the central field potential is completely responsible of these effects. The Z range 9–35 study indicates that for low Z these effects increase rapidly suggesting that for lower Z atoms, i.e boron, carbon, nitrogen and oxygen, strong shake off effects are expected. Unfortunately, except for beryllium (Krause and Caldwell 1987 a,b) there is a lack of experimental and theoretical investigations for these important cosmic elements with respective K–edges at 192, 283, 399, and 531 eV. For these elements, the 2p shell is open and the ΔV(r) is relatively more efficient for exciting the outer electrons. Also the 1s ejected electron excites or deexcites efficiently the residual ion outer shell. Therefore going down to low Z, a smooth increase of these secondary effects is expected. On the other hand if the target is ionized these effects are weaker (Åberg 1969).

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The 1s–hole ions will decay by Auger effect producing higher ionized species and for light ions the radiationless decay exceeds the K_α radiative decay (Bambynek et al. 1972). Auger decay in most cases creates *excited* states of the residual ion. The net effect of K–photoionization followed by radiationless transitions is to produce doubly or triply ionized targets in *excited* states. UV lines are emitted by the residual ions independently of electron density and local temperature. The line intensity ratios depend only on Auger rates, shake off probability and radiative cascades.

In this note, we consider a nitrogen target undergoing irradiation by photons with energies above 500 eV (K–edge for nitrogen: 399 eV). Note that the full shake off regime is reached when there are photons with energy in excess of 600 eV (Åberg 1969). Such situations exist for example in the outer layers of envelopes surrounding soft–X sources or in the interstellar medium (Rappaport 1994). Supersoft X–ray sources are a class that was originally discovered during a survey of the LMC. In the outer part of the envelope, neutral nitrogen exists and relative intensities of a few N III and N IV lines are dependent on the above mentioned atomic parameters. The soft–X source ionizes the dense plasma which absorbs the low energy photons. The high energy photons are only partially absorbed. Consequently

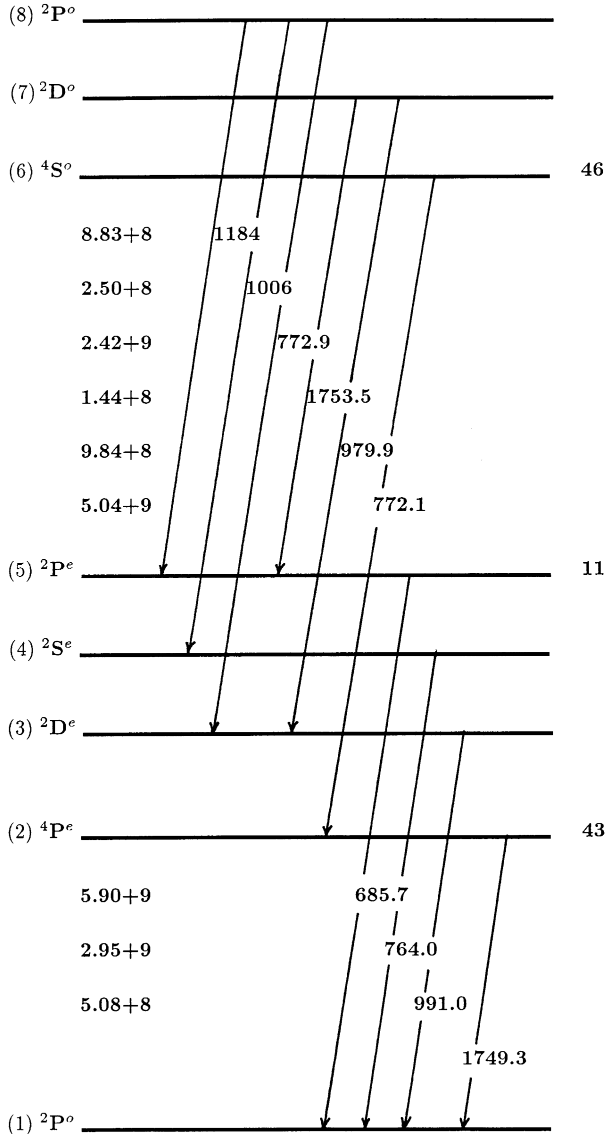

Fig. 1. Relative Auger rates to NIII terms associated with configurations $1s^22s^22p$, $1s^22s2p^2$ and $1s^22p^3$ assuming statistical weights for the NII initial 1s–hole terms are given on the right hand side. Dipole Opacity Project transition probabilities are shown (5.90+9 = 5.90 10^9 sec^{-1}).

an abundance of photons with energies of a few hundreds eV escape from the enveloppe.

2. Results

The nitrogen ground state is $1s^22s^22p^3$ $^4S^o$. After single K–photoionization the $1s2s^22p^3$ $^3S^o$ and $^1S^o$ terms are populated respecting the statistical weight (s.w.) distribution. The simultaneous 2p ejection produces mainly $1s2s^22p^2$ ^2P and ^4P terms. For these we assume a s.w. distribution. Auger rates are evaluated using the UCL codes (Petrini 1981). Figs. 1 and 2 show respectively the effective N II and N III Auger probabilities (assuming s.w. rule for the 1s–hole terms). In these figures transition probabilities are given for convenience. These data are

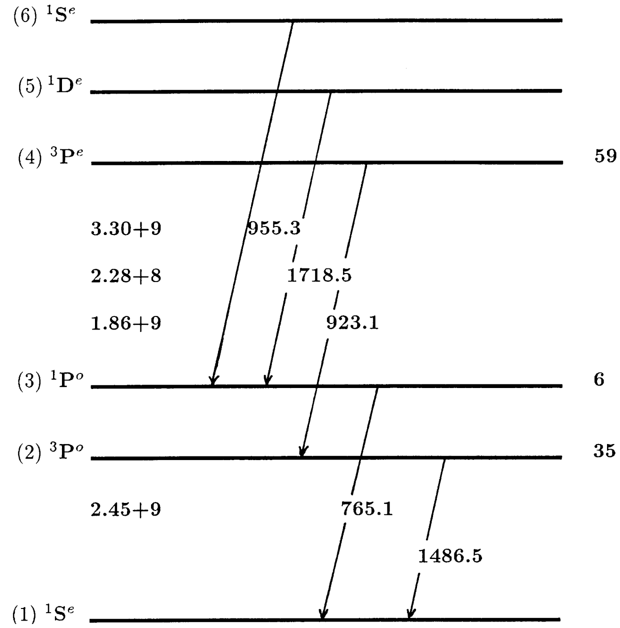

Fig. 2. Relative Auger rates to NIV terms associated with configurations $1s^22s^2$, $1s^22s2p$ and $1s^22p^2$ assuming statistical weights for the NIII initial 1s–hole terms are given on the right hand side. Dipole Opacity Project transition probabilities are shown (2.45+9 = 2.45 10^9 sec^{-1}).

from the Opacity Project data bank (Seaton et al. 1992, Cunto et al. 1993). The NII triplet and quintet S terms decay mostly to the NIII quadruplet terms. The λ772.1 Å and λ685.7 Å lines dominate (line intensity ratio λ772.1/λ685.7 is about 3.7). Due to radiative cascade, the forbidden line at 1749.3 Å is enhanced. The radiationless decay of N III produces mostly NIV triplet terms. The line 923.1 Å is enhanced. Taking into account a relative shake off effect of 30%, we obtain for the λ1486/λ1749 line intensity ratio a value of about 0.38.

Let us consider a dominant N II ion abundance instead of N I. The ground state of N II is $1s^22s^22p^2$ ^3P and the single K–photoionization leads to NIII 1s–hole doublet and quadruplet P with s.w. distribution. For ionized targets the shake off and shake up effects decrease, and here a relative shake off of 15% is a reasonable estimate. The 1s–hole terms created are then $1s2s^22p$ singlet and triplet. Auger decay of these is mostly (75%) to NV $1s^22p$ giving rise to the line λ1240 Å. Therefore the NV/NIV] line intensity is about 0.08

3. Conclusions

K–photoionization of nitrogen produces directly a few NIII and NIV UV lines. The full process K–photoionization followed by Auger decay participates to ionization balance relating finally 4 degrees of ionization. For C, N, O atoms and ions, photon energies needed are a few hundreds eV. However similar processes occur with lower photon energies when the target is Na, Mg, Si, P, S and A. In this case the 2s and 2p L edges range from 55 to 287 eV. Single 2s and 2p photoionizations, shake up and shake off (Carlson and Nestor, 1973), followed by Coster–Kronig radiationless transitions (Bambynek et al. 1972) and radiationless cascading are efficient for producing highly ionized species in excited states. For example, 2s *single* photoionization of neutral argon leads to 4.2% of A III, 93% of A IV and 2.5% of A V (Kochur et al. 1995). Higher ionized argon species are produced by shake off and double Auger processes (Carlson and Nestor 1967, Krause 1971).

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