THE INFLUENCE OF OUTER-SHELL EXCITATION ON THE X-RAY PRODUCTION IN ION-ATOM COLLISIONS

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Recent experimental results on X-ray production in ion-atom collisions are discussed. It is suggested that the state of the outer-shell strongly influences the X-ray emission cross sections, particularly if one applies solid targets.

It is well known that atomic inner-shells may be ionized in heavy ion-atom collisions [1]. The inner-shell vacancies decay preferentially via an Auger process resulting in the ejection of fast electrons. A radiative decay may also occur thus producing photon emission in the soft X-ray region. The use of thin window proportional counters to detect soft X-rays made it relatively easy to investigate total cross sections for characteristic X-ray emission in heavy ion-atom collisions. Such cross sections have been determined using solid targets [2-4] and gaseous targets as well [5]. The cross sections are found to be dependent upon the atomic number Z of the collision partner [2, 6, 7]. In a plot of the cross section versus the atomic number maxima occur for the symmetrical case and the quasi-symmetrical case, where the binding energy of the inner-shell under study is about equal to the binding enrergy of one of the inner-shells of the collision partners, see fig. 1.

By introducing the idea about promotion of molecular orbitals, Fano and Litchen [8] have proposed a qualitative model for the innner-shell excitation mechnism in symmetrical heavy ion-atom collisions. It is likely that this model is important also for asymmetrical collisions involving matching of electron energy levels of different inner-shells (K-L, L-M, etc.). Then the oscillating Z dependence of the cross sections may be considered as a geometrical effect of the sizes of the inner-shells involved [7]. In this letter we aim to discuss the influence of outer-shell excitations on the oscillating behaviour of the cross sections for X-ray production. We consider two links between inner- and outer-shell, firstly via the creation secondly via the decay of the inner-shell vacancy.

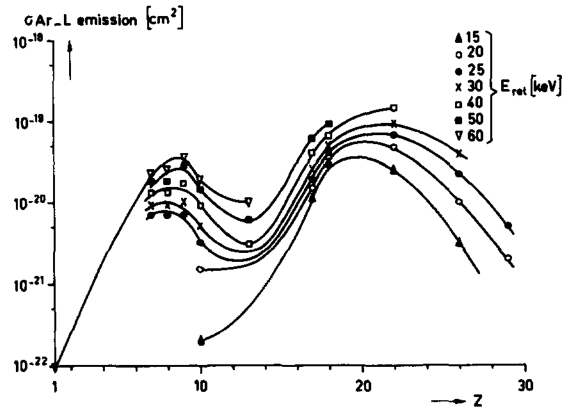

Fig. 1. Cross sections for Ar L-shell X-ray emission in $Z^+ \rightarrow$ Ar versus the atomic number of the projectile. The data are plotted for a set of impact energies (in c.m. system).

1. It is well known that the degree of excitation or ionization of the outer-shells of the collision partners affects the probability for electron promotion. For example, with the symmetric neon collision Everhart's group [9] showed that in Ne^{++} + Ne the excitation cross section for the Ne K-shell was twice that of the Ne^+ + Ne case. Similar results are reported by Ogurtsov for Ar^{++} + Ar [10]. In this respect one should also consider changes in inner-shell binding energy due to an alteration of screening.

2. The probability that a vacancy in a given inner-shell results in a radiative transition (the fluorescence yield) appears to be strongly dependent upon the impact energy and the kind of ion that created the inner-shell vacancy [5]. For proton impact on Ar the Ar-L fluorescence yield is found to be lower than for Ar^+ impact. More-

over as the impact energy of the argon projectile is doubled also the fluorescence yield becomes twice as high. These data indicate that the fluorescence yield increases as the number of electrons that can take part in the decay process decreases.

According to both arguments a larger X-ray emission cross section will be measured whenever the outer-shells are excited or ionized. It has been found recently that in small angle scattering experiments the inelastic energy lost in collisions of Ti^+ on Ar is higher than in Ar^+ on Ar [11]. If we may extrapolate these results to large angle scattering, then a higher degree of excitation of the Ar- M-shell by Ti^+ impact than Ar^+ impact is anticipated. According to argument 2 this will cause an increase of the Ar-L fluorescence yield and thus a shift of the maximum in fig. 1, which is indeed observed.

The situation is much more complicated by using solid targets in measuring X-ray emission cross sections. Apart from inherent uncertainties like the thick target absorption coefficient and the stopping power *, it is not well known in which state the outer-shell of the projectile is inside a solid. The state of the outer-shell of energetic heavy ions traversing solids is determined by various excitation, ionization, collision induced de-excitation and electron capture processes. The cross sections for these processes are strongly velocity dependent. In consequence of both points argued above it may be expected that the probability for characteristic X-ray production during collisions in solids is higher than in biparticle collisions in gases, and this probability will change as the particle is slowing down in the thick target. Kavanagh et al. [6] found that for a given ion kinetic energy the measured X-ray yields were independent of the charge state of the incident ion. Evidently the charge state of the projectile as it generates an X-ray is determined by the successive collisions in the solid target and its electron gas. This is also illustrated in ref. [6] by the lack of reciprocity in the roles of target and projectile. Experimental investigations of the transmission of ions through thin foils have shown a remarkable oscillating behaviour in the inelastic stopping power as a function of the projectile atomic number [12]. If we may assume that a large inelastic stopping inheres a high degree of outer-shell excitation then one may expect (according to arguments 1 + 2) an interference between the oscillating behaviour in inelastic stopping power and the above mentioned Z dependence of the X-ray emission cross sections. In refs. [6, 13] maxima are reported in the X-ray emission as function of projectile or target atomic number which coincide with maxima in the inelastic stopping power as measured for tungsten or gold [12].

Conclusively, there are strong indications that the state of the outer-shell largely dominates X-ray production in heavy ion-atom collisions. This is expected to be most influencial as one applies solid targets in measuring X-ray emission cross sections. More detailed spectroscopic investigations might serve as a tool to learn the state of an ion traversing a solid target.

* Sofar one has ignored the difference between projected range and real range in deducing cross sections from the thick target yield, this may introduce errors in excess of 30% [12].

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