**A.1.6. X-Ray Emission from $Ta^{q+}$ (q=45-49) + Ar Collisions at Low Energies—***Hiro Tawara, C. Fehrenbach, R. Schuch,* and Martin Stöckli*

Low energy (~ 1 keV/amu) collisions of highly charged, heavy ions having inner-shell vacancies are interesting [1] from two different points of view: 1) because the inner-shell vacancies can be in a controlled manner brought with projectile ions into collisions, instead of by ionization during collisions, some detailed collision mechanisms can be pursued since dominantly the inner-shell vacancies decay through X-ray emission due to transitions of the outer-shell electron captured from the target; and 2) because inner-shell vacancies can be directly brought into the quasi-molecular atom or ion tentatively formed during collisions, the transitions between the quasi-molecular orbitals result in the emission of so-called molecular orbital (MO) continuous X-rays. The observations of spectra of the MO X-rays can provide insight on the structures of the molecular orbitals of quasi-molecules formed during the collision.

In the present experiment, $Ta^{q+}$ ions (q = 45 - 49) have been produced in the KSU CRYEBIS, accelerated up to $150 \times q$ keV, and then sent into a collision chamber with an Ar gas jet, and finally detected with a multi-channel detector. Typical X-ray spectra observed with a Si(Li) detector are shown in Fig. 1 for $150 \times q$ keV $Ta^{q+}$ (q=45-49) ions. Several different types of X-rays are clearly seen and have the following features:

(1) Two dominant peaks at energies of 1.6 and 2.3 keV: These are due to the characteristic M-shell X-rays originating from the transitions (3d-4p and 3d-4f, respectively) of the highly charged Ta ion whose relative intensities sharply vary with the projectile charge, though total X-ray yields vary only mildly over the measured collision energy.

(2) Two continuous band-like X-rays: one is distributed from 2.5 to 4.5 keV and the other from 4.5 - 6.5 keV. These two continuous X-rays are understood to be due to the transitions between the molecular orbitals of a quasi-molecule formed during collisions.

(3) No M-X-rays or MO X-rays have been observed for $Ta^{45+}$ ions which have no 3d vacancy.

(4) No Ar-K X-rays are observed.

These features can be understood as follows: While our relativistic theoretical calculations show a huge increase of the radiative transition rates for 3d-4p and 3d-4f transitions for higher charge projectile ions, the ratios of these radiative transition rates are nearly constant for all $Ta^{q+}$ ions investigated. Thus, the observed enhancement of 3d-4f transitions over 3d-4p transitions in higher charge ion collisions cannot be due to the enhanced radiative transition rates but is expected to be related to the electron capture probabilities into ($n\ell$) states and the following cascade into 4f and 4p states. Though the precise calculations of the relevant parameters are not easy, the general trend in the electron capture processes at low energies indicates that an electron tends to be captured into high n-state for higher charge projectile ions and then most likely into higher $\ell$-states, agreeing with the present observation.

The observed two different MO X-rays (MOX-1 and MOX-2 in Fig. 1) can be understood to be due to the transitions involving two molecular orbitals (3d$\sigma$ and 3p$\sigma$) of the quasi-molecular ($^{78}Pt^{q+}$) atom formed in $^{73}Ta^{q+}$ + $^{18}Ar$ collisions. The first vacancy state is brought directly by the projectile ions (note (3) mentioned above), while the second is created through the vacancy transfer between 3p (having the initial vacancy) and 3d states on the incoming collision path.

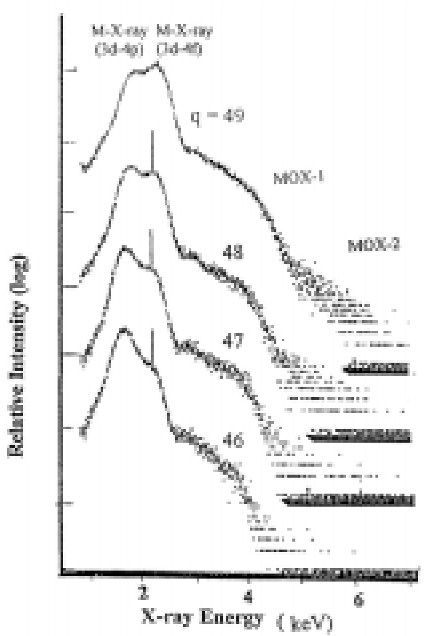


**Figure 1.** X-ray energy spectra produced in 150 kV $\times$ q $Ta^{q+}$ ions colliding with Ar gas atoms.

**Reference**


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1. M.W. Clark *et al.*, Phys. Rev. A 47, 398 (1993).