CONF-8604149--1

Proceedings of Eighth European Conference on Surface Science
to appear in Surface Science

CONF-8604149--1

DE86 008535

Electron Emission from the Interaction of Multiply Charged Ions with a Au (110) Surface

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Abstract

We have measured energy distributions of electrons produced during slow glancing collisions of H-like and He-like N and O projectiles with a clean Au(110) surface. For the case of the H-like incident projectiles, two peaks, at 250 and 350 eV, and 250 and 490 eV for incident N^{+6} and O^{+7}, respectively, are observed. Both peaks are associated with Auger transitions to the K-shell vacancy brought into the collision by the incident H-like multicharged ions: from the higher lying shells of the projectile in the case of the high energy peaks, and from the target inner shells in the case of the low energy peaks.

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1. Introduction

Pioneering studies[1,2] have shown that electron emission and ion neutralization during slow multicharged ion impact on metal surfaces can be understood in terms of resonance capture leading to (multiply) excited states of the projectile, followed by deexcitation via a series of Auger processes, each bridging a gap of about 15-30 eV and ejecting an electron. In this picture, the electron emission coefficient is directly proportional to the total neutralization energy of the incident ion, and the reflected ion charge state distribution becomes independent of initial ionic charge in the limit that the surface presents a sufficiently thick target for complete charge equilibration. The above interpretation is based on experiments using multicharged ions with enough remaining bound electrons that there were no energy gaps greater than about 30 eV between adjacent electronic states in the manifolds of any of the intermediate charge states traversed during the neutralization.

Recent measurements on electron emission[3] and ion neutralization[4] during multicharged ion impact on surfaces have shown significant deviations from the behavior described above for highly charged ions that had very large gaps between the ground and first excited electronic states. For these ions the electron yield as a function of increasing projectile charge state was observed to saturate, and the charge states observed in the reflected ion beams increased suddenly from +1 and +2 in the case of the lower incident charge states to +1, +2, and +3. Both observations are consistent with the hypothesis that the deep lying vacancies

carried into the collision by these projectiles survive the interaction with the surface. Eventually, the vacancy is filled by Auger deexcitation (or radiative deexcitation for ions of considerably higher Z than those considered here), resulting in, e.g., a jump to the next higher charge state of the reflected ion, and only one additional free electron. Until now, the role of projectile inner shell vacancies on secondary electron emission during ion-surface interactions could only be inferred, and has not been directly observed.

2. Experiment

In the present paper we report the first energy distribution measurements for electrons produced by H-like, and He-like multicharged N and O ions colliding with a clean Au(110) surface at grazing incidence. Beams of N^{+5}, N^{+6}, O^{+6}, and O^{+7} were produced by the ORNL ECR multicharged ion source[5] and extracted at 10 kV source potential. After charge selection and beam collimation, the ions were made incident at 5° on the (110) surface of a gold single crystal mounted in an ultrahigh vacuum chamber equipped with a 4 grid low energy electron diffraction (LEED) system. The surface of the Au crystal was etched clean by a 10 keV Ar^{+1} beam and subsequently annealed. The cleaned surface was characterized as having less than 20% of a monolayer of C contamination by the use of electron-induced Auger spectroscopy and from the visual verification of a (1x2) LEED pattern. The energy distributions of the multicharged-ion-induced electrons were

obtained by using the LEED grids in the retarding field mode to measure the transmitted electron current as a function of retarding voltage on the positively biased phosphor/collector, and then numerically differentiating the resulting spectrum. The retarding voltage was repeatedly ramped over the preselected electron energy range in order to average out short term beam fluctuations. The transmitted electron current vs. retarding voltage spectrum was accumulated using a mini-computer-based multi channel analyzer (MCA). Long term beam drifts were monitored and corrected for by simultaneously accumulating the net instantaneous Au target current (i.e. sum of incident ions and ejected electrons) in an another memory segment of the MCA and then dividing the former spectrum by the latter prior to the numerical differentiation. The electron yield for the incident ions studied was roughly estimated to be 90 ± 25 from measurements of the crystal target current at 0 V and + 50 V bias conditions. A slight spillover of the incident ions onto the grounded crystal support structure could have a significantly amplified effect on the crystal current at positive bias because of the large secondary electron yields at grazing incidence, and precluded total yield measurements more precise than about ± 30 %. From the electron collector current and the biased and unbiased crystal target currents recorded for some of the runs, an average electron collection efficiency of 17 ± 2 % was determined. The theoretical efficiency arrived at by considering the combined transmission of four 80% transmission grids, and the 120° angle subtended by the collector at the crystal target is 20 %. Typical collector electron currents were in the range

ding voltage and the incident multicharged ion beam intensity. Incident ion beam currents were typically nA for the H-like and tens of nA for the He-like projectiles.

3. Results and Discussion

All the measured electron energy distributions have extremely narrow maxima at 0 eV, fall off sharply with increasing electron energy, and show long tails extending to hundreds of eV. In each case investigated, at least 94 % of all ejected electrons produced in the grazing incidence ion-surface interaction had energies less than 50 eV. Less then 4 % of the total number of electrons produced had energies greater than 100 eV. Figs. 1 and 2 show the measured electron energy distributions in the range 100 - 600 eV for the H-like N^{+6} and O^{+7} incident ions. The horizontal bar shown in the bottom left had corner of each spectrum indicates the "instrumental" width introduced by the numerical differentiation. Both spectra show two peaks superimposed on a kinetic emission[6] background having monotonic energy dependence. The higher energy peaks are observed at about 350 and 490 eV for the N^{+6} and O^{+7} incident ions, respectively, while the lower energy peaks are observed at the same energy of about 250 eV in both spectra. The identification of these peaks is facilitated by reference to Fig. 3, which shows the electron energy levels of the Au crystal target juxtaposed with those of the H-like projectile ions. The cross-hatched regions in the projectile energy level diagrams represent an estimate of the variation of the

binding energies of the K- and L-shells as a result of the stepwise neutralization of the ion during its interaction with the surface. As the projectile approaches to within a few Angstroms of the surface, resonance capture of one of more loosely bound target electrons into highly excited or autoionizing states of the projectile occurs, as indicated by the arrow labeled RC in the figure. These highly excited electronic states are rapidly deexcited in a series of Auger processes indicated by the arrow labeled AD, each lasting typically 10^{-15} - 10^{-14} s. The probability of two-center Auger transitions to the K-shell of the incident ion from outer shells of the target during the collision, which lasts on the order of 10^{-14} s, is expected to be very low due to the large energy gap involved[1]. The likelihood of two-center Auger transitions to the projectile K-shell vacancy by target inner shells, indicated by the arrow labeled TAT, depends on the proximity of target inner shell levels to the projectile K-shell energy level, and the projectile-target atom distance of closest approach during the interaction. The projectile leaves the surface almost completely neutralized, but with its inital K-shell vacancy still unfilled. Subsequent to the collision, but still within view of the electron spectrometer, this vacancy then may decay via an Auger process that only involves the projectile, an example of which is shown by the dashed arrow labeled KLL. In addition to the electrons ejected in the above Auger processes, secondary electrons are also produced at the energies investigated by kinetic emission, a mechanism involving kinetic energy transfer from projectile to metal electron and not shown in Fig. 3. Secondary electrons produced by kinetic

emission have a continuous energy spectrum that falls monotonically with increasing energy, and probably constitute a significant fraction of the background upon which the observed peaks are superposed.

In light of the preceeding discussion the following interpretation of the observed electron spectra for H-like incident N and O ions is given. The high energy peaks at 350 and 490 eV are related to the normal Auger transitions in the projectiles that fill the K-shell vacany brought into the collision. The fact that the observed peak positions are consistent with previous measurements[7] of K-shell Auger spectra of simple molecules containing N and O incidates that the projectile K-shell Auger decay takes place very late in the neutralization process. Measured K-shell Auger spectra[10] observed after double electron capture by N^{+6} and O^{+7} show peaks at least 50 eV lower than the present ones. Since the low energy peak in both spectra occurs at 250 eV, it is most likely associated with target Auger processes filling, e.g., NIV and NV shell vacancies[9] produced by two-center Auger transitions to the projectile K-shell vacancy. The difference in magnitudes of the 250 eV peaks observed for N^{+6} and O^{+7} projectiles is consistent with the inverse relationship between Auger transition probability and energy level difference between initial and final states of the transferred electron[1]. It is noted that the appearance of almost equal peak heights in the case of the N^{+6} induced electron spectrum is deceptive in that the 250 eV peak sits on top of a low energy shoulder belonging to the 350 eV peak that arises from projectile Auger electrons inelastically reflected from the Au surface.

Within the ± 30 % uncertainty of the measurement of the incident ion flux to the crystal target, the area under the two peaks for both H-like incident ions corresponds to one electron per incident ion. The areas under the peaks were estimated by subtracting the measured electron energy distributions for the He-like ions from the corresponding ones of the H-like ions, since it has been shown[2] that the energy distribution for a given ion is "included" into that for the ion of next higher charge state as a result of the stepwise neutralization of the ions at the surface. The unit probability for filling the projectile K-shell vacancy suggested by the above electron yield is not surprising, since the projectile based K-shell Auger process is not constrained by the ion-surface interaction time. This feature may, however, be very useful in normalizing the probability of target inner shell processes during the collision that compete with the projectile Auger transitions in filling the projectile K-shell vacancy. From the ratio of the peak heights, we estimate that the probabilities of the 250 eV target process occuring are .32 and .19 for incident N^{+6} and O^{+7}, respectively.

4. Summary

Our conclusions are summarized as follows. Projectile K-shell vacancies carried into slow collisions with surfaces at grazing incidence are filled either by two-center Auger transition from target inner shells, or normal projectile K-shell Auger processes involving electrons captured into excited states of the projectile during the collision. The extent of competition of the former process with the latter depends on the detailed energy level structure of the target. The position of the projectile K-shell Auger peak indicates that these transitions occur very late in the collision, leaving little time for additional electron capture to compensate for the electron loss by autoionization. The area under the two observed peaks due to the above processes corresponds to one electron per incident ion. The projectile K-shell vacancy thus contributes very little to the total observed electron yield. Since the total probability of filling the vacancy is very close to unity, the probability of target inner shell processes can be estimated on an absolute scale by a simple comparison of peak heights.

Acknowledgement:

This research was sponsored by the Office of Basic Energy Sciences, U.S. Department of Energie. ~~C.C.H. was appointed through the U.S. Department of Energie, Post Graduate Research Training Program, administered by Oak Ridge Associated Universities.~~ Oak Ridge National Laboratory is operated by M&M Energy Systems, Inc., under contract No. DE-AC05-84OR21400 with the U.S. Dept. of Energy.

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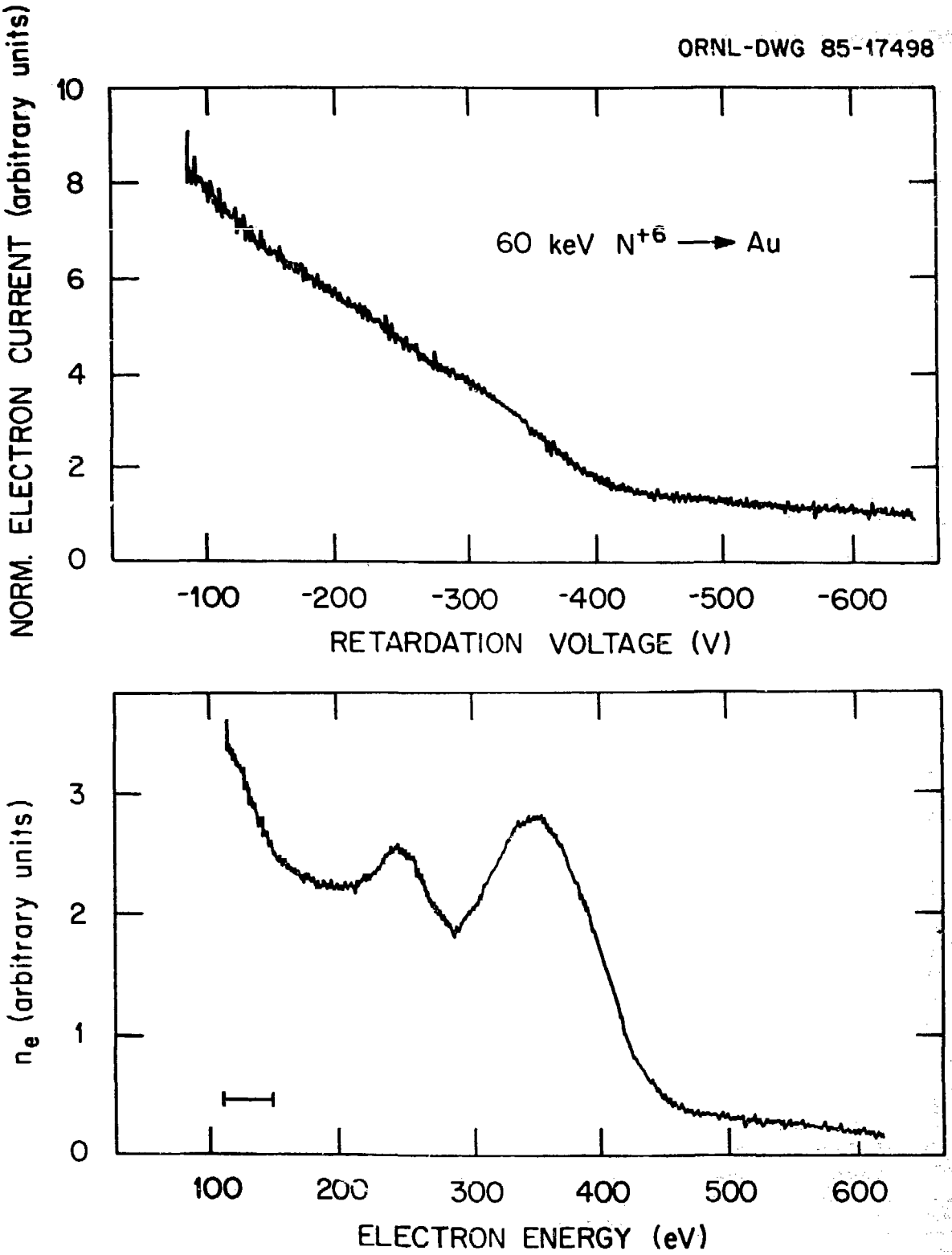
Figure Captions

Fig. 1: Secondary electron energy distributions for N^{+6} incident on Au(110) at 5°, projectile energy ∿ 4 keV/u.

Fig. 2: Secondary electron energy distributions for O^{+7} incident on Au(110) at 5°, projectile energy ∿ 4 keV/u.

Fig. 3: Electron energy level diagrams for N^{+6} and O^{+7} on Au. Arrows indicate possible neutralization and deexcitation paths:
RC-resonance capture,
TAT - two-center Auger transition,
AD and KLL-Auger deexcitation.
The dashed lines in the N^{+6} and O^{+7} schemes mark the energy levels in the neutral systems N and O.


ORNL-DWG 85-17498
NORM. ELECTRON CURRENT (arbitrary units)
10
8
6
4
2
0
60 keV N^{+6} → Au
-100
-200
-300
-400
-500
-600
RETARDATION VOLTAGE (V)
n_e (arbitrary units)
3
2
1
0
100
200
300
400
500
600
ELECTRON ENERGY (eV)

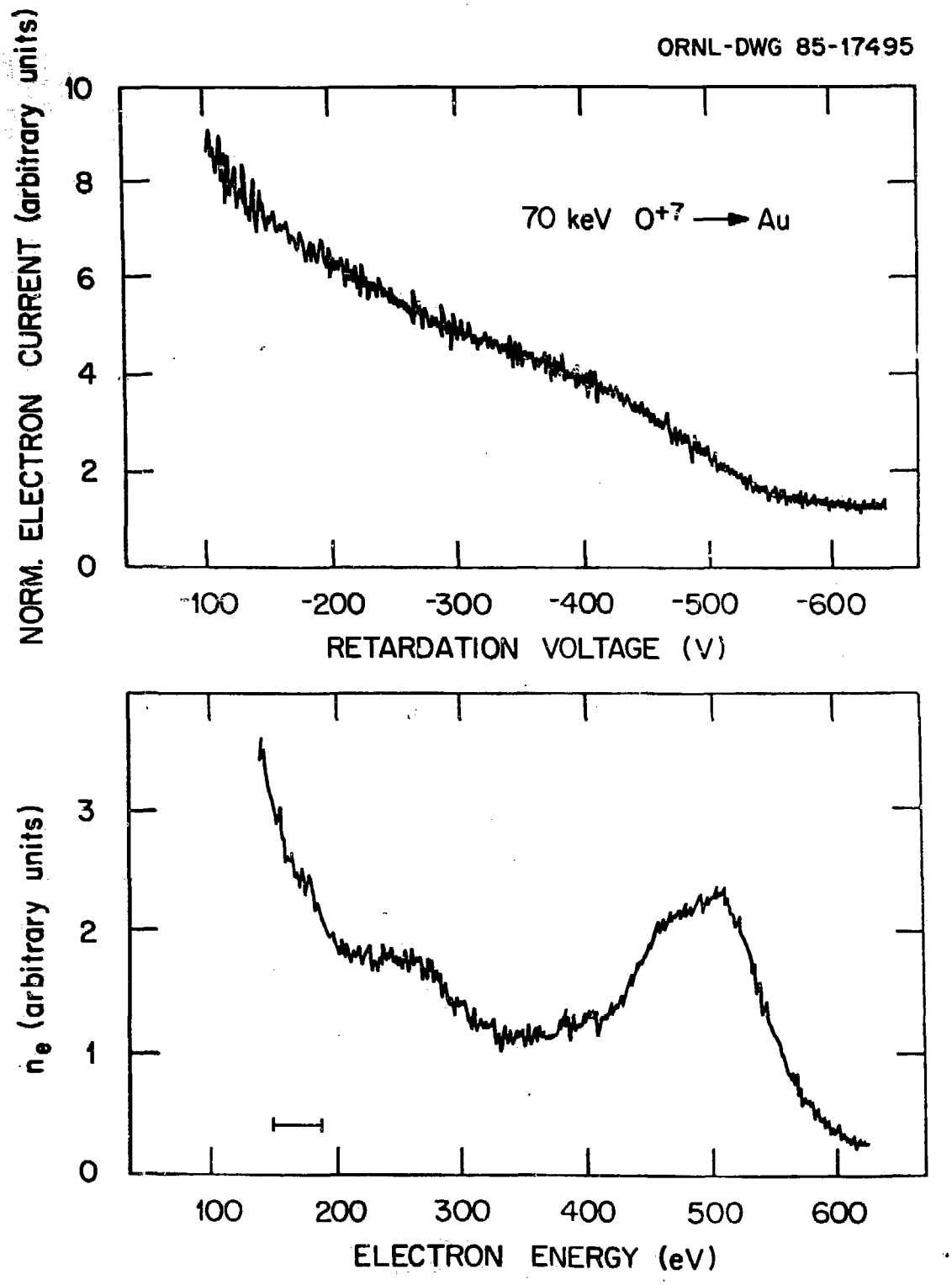

ORNL-DWG 85-17495
NORM. ELECTRON CURRENT (arbitrary units)
10
8
6
4
2
0
70 keV O^{+7} → Au
-100
-200
-300
-400
-500
-600
RETARDATION VOLTAGE (V)
n_e (arbitrary units)
3
2
1
0
100
200
300
400
500
600
ELECTRON ENERGY (eV)

Fig 2

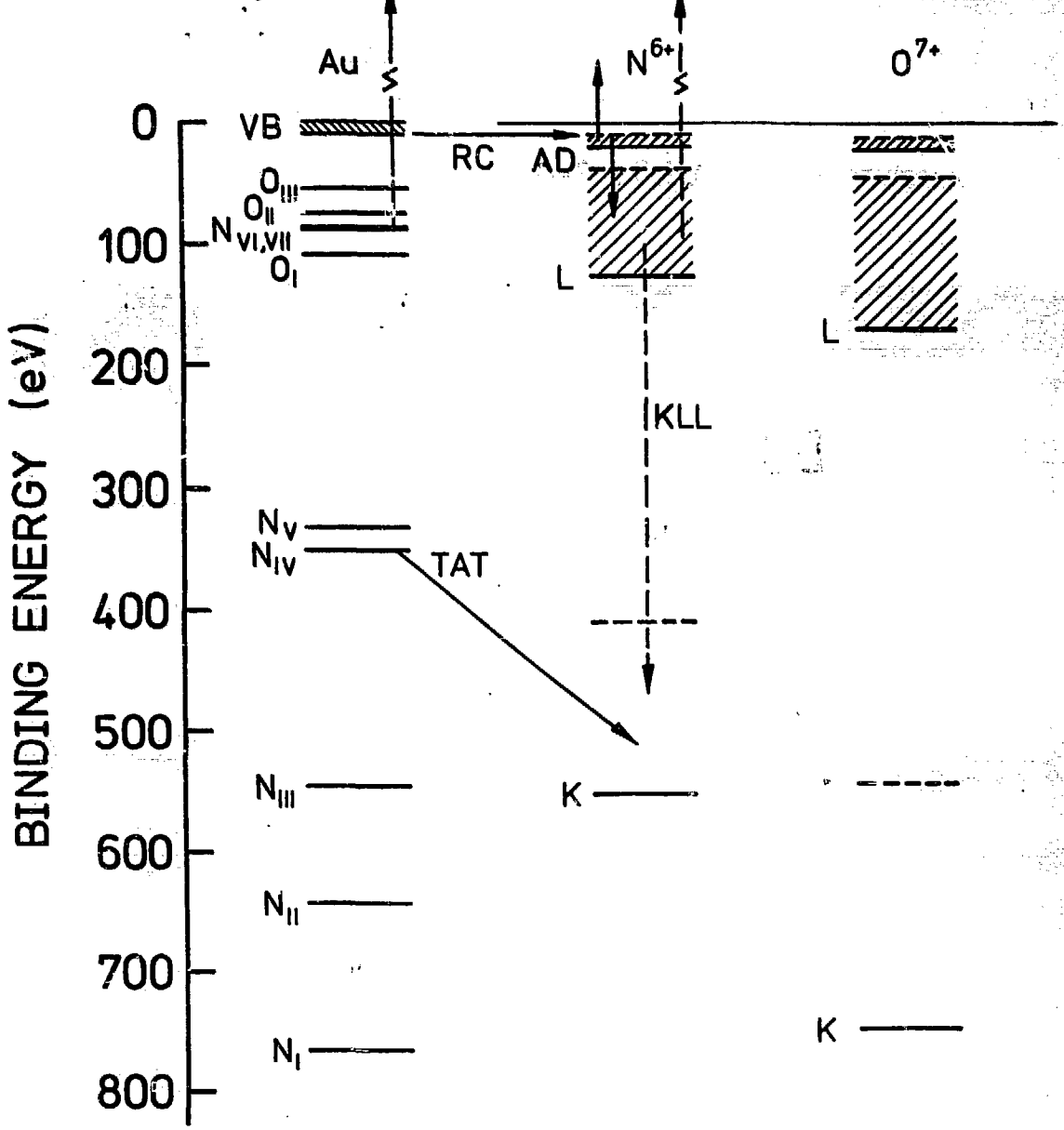


Fig 3