Dynamic K- and L-shell filling of Ne^{9+} projectiles interacting with an Al(111) surface

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Secondary-electron spectra of H-like Ne^{9+} ions incident with energies from 135 eV to 22.5 keV on an Al(111) surface were measured. The dependence of the K and L Auger electron yield on the energy of the projectile is studied. It is found for low impact energies that the angular distributions of the overall K Auger peak and the 740-eV component, which was formerly attributed to above-surface emission, show nearly the same anisotropy. Hence, the data provide evidence for K Auger emission from below the surface. Furthermore, for low projectile energies, it is found that, on average, two to three electrons are present in the L shell during the L and K Auger emission. For higher energies, the L shell is nearly empty during the L Auger emission, whereas five to six electrons are present in the L shell during the K Auger emission. Moreover, it is found that for higher energies the L Auger intensity is strongly reduced. These findings are attributed to the enhanced absorption of the L-shell electrons in the solid, as well as to a strong velocity dependence of the charge transfer directly into the Ne L shell.

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I. INTRODUCTION

The interaction of slow, highly charged ions with solid surfaces has obtained a great deal of attention during the last years [1–13]. In particular, hydrogenlike ions carrying a K-shell vacancy can be used to obtain information about the dynamics of the electron exchange between the ion and the solid. The emission of K Auger electrons from ions with a K vacancy has previously been analyzed [2,3,6,7,9,14–16]. From these studies it is well known that multiply charged ions capture electrons at rather large distances from the surface into high-lying Rydberg states via resonant charge transfer [17,18]. Recently, Winter [19] has shown experimentally that the capture distance can be estimated in the framework of the classical over-the-barrier model [20]. The capture process leaves the ion in a highly excited state involving various electrons in Rydberg levels (hollow atom [5,21]). The hollow atom undergoes deexcitation steps that fill lower-lying levels. To date it has been commonly agreed that the Auger cascades of the projectile are generally not terminated on entering into the solid [5,7,9,22]. Accordingly, the filling dynamics of the inner shells inside the solid is still open to study.

Recent measurements of Köhrbrück *et al.* [23], hereafter referred to as (I), indicated that the angular distribution of the K Auger yield from Ne^{9+} interacting with a solid Al(111) depends strongly on the projectile energy. They showed that the emission of K Auger electrons takes place below the surface even for projectile energies as low as 135 eV. Furthermore, in accordance with previous studies [24], they made two processes responsible for the filling of the Ne L shell during the interacting of the ion in the solid. The Ne L shell may be filled through an Auger process from the M shell as well as through a resonant charge transfer from the Al L shell. Both processes are important in understanding the filling dynamics of the Ne L shell.

In this work, we extend the studies in (I). We present spectra of secondary electrons produced by Ne^{9+} ions interacting with a solid Al(111) surface at energies from 135 eV to 22.5 keV. The measurement of the angular distribution of the K Auger emission is used to verify the emission of the electrons from below the surface. Furthermore, the analysis of the Ne^{9+} L and K Auger emission as a function of the projectile energy is used to obtain information about the charge-exchange processes occurring during the interaction of the projectile with the solid. It is found that the emission of the Auger electrons takes place below the surface and that the mean L and K Auger energy varies noticeably with the projectile energy. From this peak shift the mean number of electrons present in the L shell during the L and K Auger process is deduced. These numbers are interpreted in terms of a velocity-dependent filling of the Ne L shell via charge transfer from the Al target. It is found that the Ne L Auger electron yield is strongly reduced for higher projectile energies due to an enhanced absorption of the L Auger electrons.

II. EXPERIMENTAL METHOD

The experiments were performed at the 14-GHz Electron-Cyclotron-Resonance (ECR) ion source of the Hahn-Meitner-Institut in Berlin [25]. The ion source provides ions with energies up to $20q$ keV (where q is the charge state of the extracted ions). Further, the beam line is equipped with a deceleration lens system for energies down to $5q$ eV keeping the experimental setup on ground potential. For the experiments an ultra-high-vacuum chamber was used to perform electron spectroscopy, as described in detail in Ref. [11]. The vacuum chamber includes facilities for surface preparation and examination. The base pressure during the measurements was about 1×10^{-8} Pa. Our experimental method of Auger electron spectroscopy was also used to probe

the cleanliness of the surface. After careful cleaning of the surface with a sputter gun, no contamination of the surface could be observed.

Hydrogenlike Ne^{9+} ions were used to bombard a monocrystalline Al(111) surface aligned in a random direction. The ions were accelerated to 90 keV, magnetically analyzed, and, in front the target, decelerated to energies varying from 22.5 keV to 135 eV. The beam was collimated to a diameter of about 1 mm at the target position. The beam diameter was determined by measuring the ion current on a thin wire temporally placed at the target position. To study the angular variation of the electron spectra, the data were normalized in intensity, taking into account the acceptance angle, resolution, energy dependence, transmission of the spectrometer, and the efficiency of the channeltron. In the case where the target region, viewed by the spectrometer, was smaller than the length of the target, illuminated by the beam, a calculated geometry factor was used in the determination of the absolute yield. For more details concerning the normalization of the Auger spectra see Refs. [11,13].

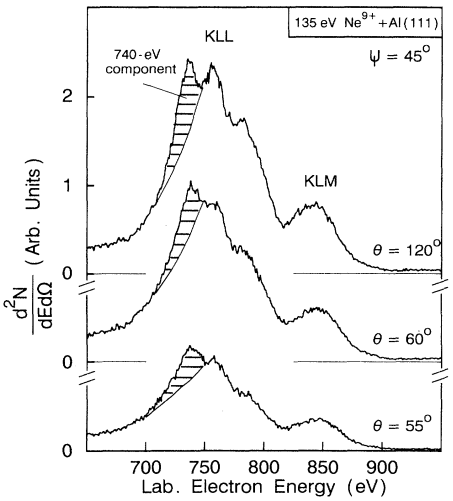

FIG. 1. K Auger emission of 135-eV Ne^{9+} ions interacting with a solid Al(111) surface at an incidence angle of 45°. The electron observation angle is 120°. The spectrum is measured with high resolution and shows a structure of four peaks. The first peak was formerly attributed to above-surface emission [14].

III. RESULTS AND DISCUSSION

A. Angular distribution of the electrons

Figure 1 shows high-resolution K Auger spectra of 135 eV Ne^{9+} interacting with an Al(111) surface at an incidence angle of 45° for the observation angles $\theta = 50°$, 60°, and 120° relative to the incident beam direction. The spectrum indicates a rather pronounced K Auger peak whose main intensity is attributed to KLL Auger transitions. One notes that the KLL Auger peak exhibits a structure of three peaks. According to Limburg *et al.* [26] the first two peaks at the low-energy side may be attributed to initial states with two electrons in the L shell ($n_L = 2$) and the M shell filled with electrons so that the atom is neutral, i.e., $1s2s^2 3s^2 3p^5$.

Using the atomic structure codes of Grant *et al.* [26] and Cowan [28], we calculated neon K Auger energies for cases in which, during the Auger transition, different numbers of electrons are present in the L shell. In the calculations, additional electrons were placed into the M shell to neutralize the ion. This was done to model the dynamic screening of the projectile of electrons in the solid [12]. The calculations show that the mean energy of the K Auger transition for a varying number of electrons in the L shell ranges from 769 to 800 eV (Table I). Therefore, it is probable that the high-energy part of the above-mentioned structures can be attributed to Auger transitions with more than two electrons in the L shell. For 90-keV Ne^{9+} on Cu this aspect of the K Auger transition was already pointed out by Köhrbrück *et al.* [9]. The shoulder at 840 eV can be attributed to KLM emission. For more details concerning the structure of the K Auger peak, see Refs. [11,13].

In Fig. 1 we hatched the most pronounced structure at the low-energy side of the KLL Auger peak. This structure will be referred to as the 740-eV component. Following previous work by Meyer *et al.* [7], Andrä *et al.* [14], and Das and Morgenstern [15], one may attribute this component to electron emission from above the surface. In (I) it was shown that it is possible to verify whether the emission of the electrons takes place above or below the surface by studying the angular distribution of the K Auger emission. It was pointed out that an emission above the surface results in an isotropic angular distribu-

TABLE I. Mean K and L Auger energy and mean number of electrons in the Ne L shell for different Ne^{9+} projectile energies. Because of energy-loss effects in the solid, the values for the mean number of L-shell electrons derived from the L and K Auger spectra are to be considered as lower and higher limits, respectively.

Projectile energy	Mean K Auger energy (eV)	Number of L electrons	Mean L Auger energy (eV)	Number of L electrons
135 eV	769	2.5	88	2.5
1.0 keV	779	4.5	91	2
4.5 keV	783	5	97	1.5
22.5 keV	777	4	101	1

tion since the solid influences these emitted Auger electrons only slightly. Effects such as the deflection of the K Auger electrons at the Al surface were shown to be small [29]. However, an emission below the surface yields significant deviations from an isotropic emission. Hence, the angular yield distribution of the Auger electrons provides clear information concerning the study of the above or below surface emission.

Figure 2 shows the angular distribution of the K Auger electrons for the projectile energy of 135 eV. The experimental condition corresponds to that in Ref. [14] with respect to the vertical velocity of the Ne^{9+} ions. The experimental yields of the K Auger electrons (squares) were obtained by integrating the Ne^{9+} electron spectrum over an energy range from 300 to 1100 eV after subtraction of the broad continuum due to kinetic electron emission. It should be noted that the angular distributions are normalized to unity at the surface normal. The open squares give the angular distribution of the 740-eV component indicated in Fig. 1.

In (I) it was shown by means of a two-step model that the K Auger electron yield is described as

$$Y(\theta,\psi,\tau_L,\tau_K,v_p,\lambda)=\frac{\lambda^2\sin^2(\theta-\psi)}{[\tau_K v_p\sin(\psi)+\lambda\sin(\theta-\psi)][\tau_L v_p\sin(\psi)+\lambda\sin(\theta-\psi)]}\ , \tag{1}$$

where τ_L and τ_K are the time constants for the filling of the L and K shell, respectively; θ is the angle of observation relative to the incident beam direction; ψ is the incidence angle relative to the surface plane; and λ is the inelastic mean free path of the electrons. In Fig. 2 the solid and the dotted line, representing the total Auger intensity and the 740-eV component, respectively, are calculated by using Eq. (1) with adjustable fit parameters τ_K and τ_L. The results for the total Auger intensity have already been presented in (I). Here, the attention is focused on the 740-eV component.

As can be seen in Fig. 2, the angular distribution of the total K Auger peak and the 740-eV component have the same general behavior. Both distributions maximize at the angle that corresponds to the surface normal, where the loss in the solid has a minimum, and they diminish at the angle corresponding to in-surface-plane emission. However, the angular dependence is weaker for the 740-eV component than for the total K Auger line. This weaker anisotropy may be taken as an indication that some of the 740-eV electrons are ejected above the surface. To verify this possibility, we considered independent calculations [30], based on the above-surface cascade model by Burgdörfer and co-workers [20]. The calculations show that the Auger cascade in front of the surface has barely advanced to fill the N shell, indicating a negligible K Auger emission above the surface.

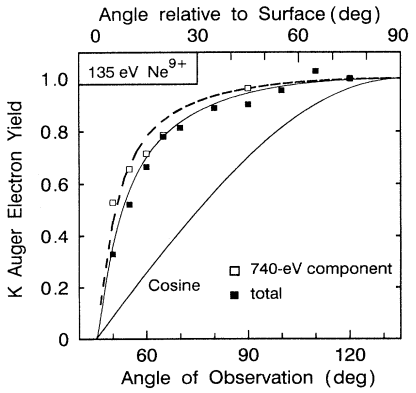

FIG. 2. Distribution of the K Auger yield of 135-eV Ne^{9+} ions interacting with a solid Al(111) surface. The filled squares are the result of the integration over the entire K Auger peak and the open squares over the so-called above-surface peak indicated in Fig. 1.

It is recalled that the 740-eV component is due to the $1s2s^23s^23p^5$ configuration, whose decay gives rise to electrons ejected at the beginning of the L-shell filling sequence. Hence, we expect that the relatively weak anisotropy of the 740-eV component is attributed to an Auger emission that takes place immediately after the ions have entered into the solid. Correspondingly, the angular distribution becomes more isotropic. Nevertheless, it can be stated that for energies as low as 135 eV the angular distribution is neither isotropic for the total K Auger peak nor for the 740-eV component. Therefore, it is concluded for the present case that the emission of the majority of the K Auger electrons takes place below the surface.

B. Filling rate of the L shell

The Ne L shell may be filled via an Auger process involving M-shell electrons as well as via a resonant charge transfer from the Al L shell. Both processes are important for understanding the filling dynamics of the Ne L shell. From the measurements of the angular distribution of the K Auger electron yield in (I), the filling rate of the L shell is deduced from $\Gamma_L=1/\tau_L$, using Eq. (1). Furthermore, in (I) it was concluded that the enhanced filling of the L shell for higher projectile energies is due to an enhancement of the resonant charge transfer. The authors provided a formula to calculate the filling rate Γ_L of the L shell:

$$\Gamma_L=\Gamma_L^A+n_t\sigma_L v_p\ , \tag{2}$$

with v_p being the projectile velocity, n_t the density of target atoms, σ_L the charge-transfer cross section in a single projectile-atom collision, and Γ_L^A the L Auger transition rate. From Eq. (2) it follows that the L-shell filling rate Γ_L is linearly dependent on the projectile velocity if the L-shell cross section σ_L is independent of the projectile

velocity. If the resonant charge transfer to the Ne L shell becomes negligible, the L-shell filling rate is expected to be constant and its value is equal to the L-shell Auger rate Γ_L^A.

In Fig. 3 the L-shell filling rate Γ_L is shown as a function of the projectile velocity v_p. The filled squares are the result of the fitting procedure of the K Auger distributions, using Eq. (1). The experimental values are taken from the work in (I). The solid line is calculated by using Eq. (2), assuming a constant cross section for the charge transfer. This straight line is obtained with the assumption that $\sigma_L=0$ at 135 eV, and hence it follows for the Auger rate that $\Gamma_L^A=\Gamma_L$ (135 eV). This is a reasonable assumption since, for the lowest projectile energy of 135 eV, the distance of closest approach is even in a head-on collision as large as 2.0 a.u. This distance is expected to be too large for a significant charge transfer between the two L shells. Furthermore, we have fixed the straight line to pass through the high-energy data point at 22.5 keV.

It is noted that the straight line was *not* drawn to achieve the best fit to the data. In principle, a straight line could be drawn through the data points, fitting the experimental results within the experimental uncertainties. However, in this case we had to make the unreasonable assumption that the L Auger yield is negligible. Rather, the present line was drawn to verify the possibility that the cross section σ_L is a constant as the projectile energy varies. It is seen for higher energies that the solid line yields good agreement with the experimental data. However, for lower energies such as 135 eV and 1.0 keV, the L-shell filling rates deviate significantly from the straight line (Fig. 3). Thus, it may be stated that the assumption of a constant cross section for the charge transfer for all projectile energies from 135 eV to 22.5 keV is not valid. Rather, the experimental data provide evidence that the cross section σ_L decreases with decreasing ion energy.

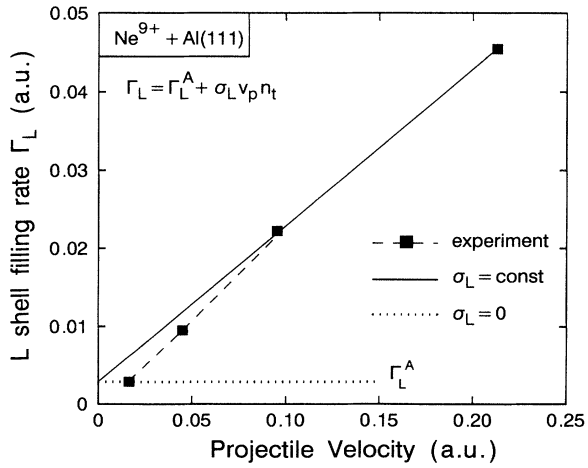

FIG. 3. L-shell filling rate of the Ne L shell as a function of the Ne^{9+} projectile velocity. The experimental data were taken from (I); the solid line was calculated by using Eq. (1) and assuming a constant charge-transfer cross section.

Up to now, no attempts have been made to study directly the influence of the projectile energy on the energy of the emitted L and K Auger electrons. From the energy distributions of the K and L Auger emission, the mean number of electrons present in the L shell can be determined. This mean number of L electrons provides deeper insight into the charge-transfer mechanisms between the Ne L shell and the Al L shell, as shown in the following section.

C. Energy distribution of the K Auger electrons

Figure 4 shows the K Auger electron spectra for 135-eV, 1.0-keV, 4.5-keV, and 22.5-keV Ne^{9+} on Al(111). The angle of incidence ψ was set to 45°. The spectra are normalized and transformed from the laboratory to the projectile rest frame. It should be noted that the spectra shown in Fig. 1 are measured with an energy resolution of 0.2%, whereas the spectra in Fig. 4 are due to a resolution of 5%. Therefore, the structures of the 135-eV spectrum are not well resolved in Fig. 4. It is seen that the spectral shape of the K Auger peak, the overall peak intensity, and the mean KLL Auger energy depend significantly on the projectile energy. For the higher energies the overall K Auger intensity is reduced, and the shoulders on the high-energy side of the main KLL Auger peak disappear. Furthermore, the intensity on the low-energy side relative to the K Auger peak is enhanced.

These findings give strong indications for below-surface emission. If the K Auger electron emission takes place in deeper layers, more electrons will suffer an energy loss in the solid on their way to the detector [31]. The energy loss is due to inelastic scattering with target electrons, as well as excitation of bulk and surface plasmons. In addition, the Auger electrons may be absorbed in the solid. Thus, it is understood that below-surface emission is ac-

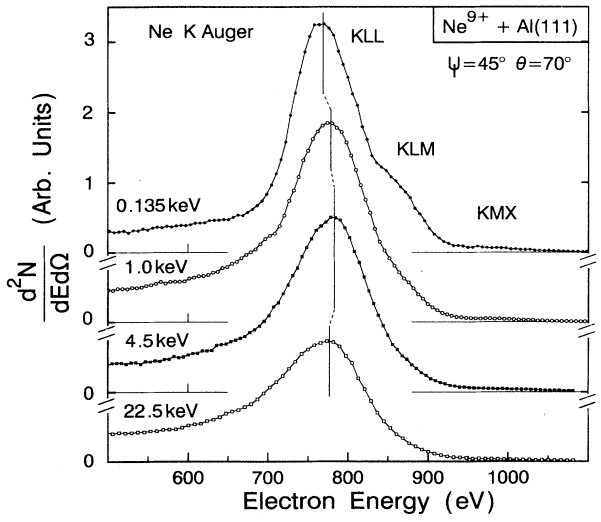

FIG. 4. K Auger emission of 135-eV, 1.0-keV, 4.5-keV, and 22.5-keV Ne^{9+} ions interacting with a solid Al(111) surface at an incidence angle of 45° and an observation angle of 70°. The spectra are normalized by taking into account the energy dependence of the spectrometer and transforming to the projectile rest frame.

companied by a loss of intensity as well as by an enhancement of electrons with lower energies. Below-surface emission will also smooth out the structure of the K Auger peak. In the solid, each separate peak will be joined by a low-energy tail, which closes the gap between two peaks.

Looking at Fig. 4 in more detail, we see that the mean energy of the KLL Auger electron emission is shifted to higher energies as the projectile energy changes from 135 eV to 4.5 keV. From the atomic structure code of Cowan [28], it was calculated by Köhrbrück *et al.* [9] and by Schippers *et al.* [13] that the K Auger emission yields information about the number n_L of electrons present in the Ne L shell during the K Auger emission. Their calculations showed that a change in the mean number of L-shell electrons from two to eight results in a shift of the mean energy of the K Auger peak from 769 to 800 eV. These values were calculated under the assumption that the electrons missing in the K and L shells are placed into the M shell to keep the whole Ne ion neutral. Table I shows the mean Ne K Auger energy and the corresponding mean number of electrons n_L present in the L shell during the K Auger emission. For 135 eV to 4.5 keV Ne^{9+} the mean number of L-shell electrons varies from $n_L=2$ to $n_L=5$.

It should be noted that the present n_L values are to be considered rough estimates. They are valid only if no additional effects like energy loss in the solid influence the mean KLL peak energy. As the mean K Auger energy is reduced because of an energy loss, it would appear that fewer electrons are present in the L shell than there are actually. Hence, because of energy loss effects, the observed *(apparent)* n_L values are likely to be smaller than the corresponding number of L-shell electrons present during the Auger decay. For such low projectile energies as 135 eV or 1.0 keV, the inelastic electron scattering is not expected to play a significant role. However, for the projectile energy of 22.5 keV the inelastic contribution is important, as was shown by Hustedt *et al.* [16] for 90-keV Ne^{9+} ions interacting with an Al target. For an energy of 4.5 keV, the L shell is filled with five electrons; thus, we would expect a completely filled L shell during the Ne K Auger emission for an energy of 22.5 keV. However, the analysis yields a mean number of $n_L=4$ electrons in the L shell during the K Auger emission. In our opinion this K Auger peak shift is primarily due to an energy loss of the K Auger electrons on their way out from the solid to the detector.

As shown in the previous section, a change of the ion energy from 135 eV to 22.5 keV strongly enhances the population of the L shell before the K Auger emission takes place. This finding is in good agreement with the measurements in (I), where the angular distribution of the K Auger yield for Ne^{9+} ions interacting with an Al(111) surface was analyzed. It was shown that the L shell is filled with only two electrons during the K Auger emission for energies as low as 135 eV and becomes rapidly filled for higher projectile energies. To obtain more information about the change of the L-shell filling rate with the projectile energy, we also studied the L Auger spectra.

D. Energy distribution of the L Auger electrons

Figure 5 shows the L Auger emission of Ne^{9+} ions interacting with an Al(111) surface. The spectra are measured in the same run as the spectra depicted in Fig. 4. For a projectile energy of 135 eV the L Auger maximum exhibits two separate peaks. Using the Hartree-Fock code of Grant *et al.* [27], we calculated that the low-energy peak may be attributed to LMM Auger transitions and the high-energy peak to LMN transitions. For the incident energy of 1.0 keV the gap between these two peaks disappears. This may be caused by an emission inside the solid and hence due to an energy loss and straggling of the electrons on their way to the detector.

Furthermore, it can be seen in Fig. 5 that the L Auger intensity is strongly reduced for higher projectile energies. This reduction is due to the increased absorption of the emitted L Auger electrons caused by the deeper emission inside the solid. In addition, it is due to the higher probability for charge-transfer processes [see Eq. (2)], which reduces the overall L Auger emission. In the present analysis we are not able to decide which effect is more important for the L Auger emission. We expect that the detailed analysis of both the L and K Auger intensities will provide more information about the relevance of side feeding and absorption effects. This aspect of the L Auger emission will be studied in the future.

In Fig. 5 it is seen that for higher projectile energies, the LMM Auger peak shifts to higher energies. Again, as in the case of the K Auger emission, we determined the mean number of electrons present in the L shell during the L Auger emission from the mean LMM Auger electron energy by comparing the experimental data with Hartree-Fock calculations (Table I). It is found that a higher mean L Auger energy corresponds to fewer electrons present in the L shell during the L Auger process.

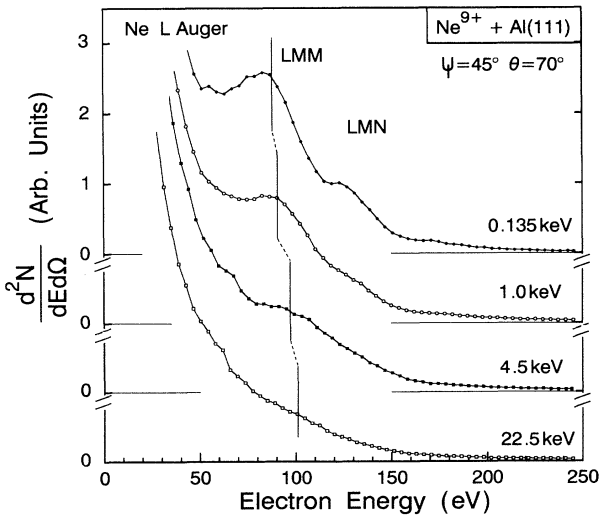

FIG. 5. L Auger emission of 135-eV, 1.0-keV, 4.5-keV, and 22.5-keV Ne^{9+} ions interacting with a solid Al(111) surface. The spectra are measured in the same run and normalized in the same way as the spectra shown in Fig. 4.

This finding is inverse to the K Auger emission, where a higher K Auger energy is due to a larger number of L electrons present in the L shell during the K Auger process. It is found that for higher projectile energies the mean number of L spectator electrons during the L Auger process is reduced. For a projectile energy of 22.5 keV the L shell is nearly empty (Table I).

In a first view, this shift of the L Auger peak is quite surprising. From the measurements of the Ne K Auger peak it was found that for higher projectile energies the L shell becomes more and more filled before the K Auger electron is emitted. It was concluded that the L shell is rapidly filled for higher projectile energies because of an enhanced resonant charge transfer (Fig. 3). This enhanced filling of the Ne L shell should also be visible in the L Auger spectra. Similar to the K Auger process it is expected that the L shell is filled with more electrons before the L Auger process takes place. However, a shift of the L Auger peak to higher energies, as seen in Fig. 5, is due to fewer spectator electrons in the L shell during the L Auger emission.

To understand these findings, other important aspects should be taken into account. First, the absorption of the L-shell electrons affects primarily Auger electrons that are emitted deeper inside the surface. This is true for Auger electrons emitted from projectiles with an increasing number of L-shell electrons. Thus, Auger electrons for high n_L values are suppressed, and the *apparent* number of L-shell electrons is decreased. In the extreme case of high incident energies, the data may give the impression that the L shell is nearly empty.

Second, at low energies, the charge-transfer process becomes very unlikely for two atomic levels that are not close in energy. With the Grant program [27], calculations of the energy levels of the Ne L shell depending on the number of electrons present in the L shell (Table II) show that the empty Ne L shell with a binding energy of 5.7 a.u. and the Al L shell with a binding energy of 4.4 a.u. are not close. Therefore, we suggest that, regardless of the energy of the ions, the filling of the Ne L shell starts with an L Auger process.

The faster the projectile, the deeper inside the solid the emission of the L and K Auger electrons will be. If the first electron is filled into the Ne L shell via an Auger process, we will observe this Auger electron for higher projectile energies coming from deeper layers inside the solid. Therefore, the overall L Auger intensity is strongly reduced, as clearly seen in Fig. 5.

After the first electron is transferred to the Ne L shell, the situation changes. For higher energies, the filling of the Ne L shell will take place within a short time in comparison to the next L Auger process because in this case the Ne and Al L levels are quite resonant. It can be stated that it depends on the number of electrons actually present in the L shell whether the $2s$ or the $2p$ level of Ne is resonant to an Al L level. Hence, for high projectile energies (i.e., 22.5 keV) the collision rate is high and the distance of closest approach is low, yielding a relatively high charge-transfer probability. Therefore, we expect to observe only the first L Auger transition in agreement with the observation depicted in Fig. 5.

However, for low projectile energies, we expect to observe more than one L Auger electron. The resonant charge-transfer probability is rather low because of a strong reduction of the projectile-target collision rate and the reduced charge-transfer probability in a single collision process. Nevertheless, the observation of the L Auger electrons is limited by the depth distribution of the emitting projectile in the solid. Thus for low projectile energies, such as 135 eV, we may understand a mean number of two to three electrons present in the L shell during the L Auger process.

IV. CONCLUSIONS

We presented electron spectra for the Ne^{9+} ion interacting with a solid Al(111) target for different energies from 135 eV to 22.5 keV. The angle of incidence was fixed to 45°. The analysis of the L and K Auger emission during the interaction of the Ne^{9+} projectile with an Al target yields information about the deexcitation of the highly charged Ne projectile and the charge-transfer processes involved.

Extending the studies of Köhrbrück *et al.* in (I), it was shown that the 740-eV component of the Ne^{9+} K Auger emission, which was formerly attributed to above-surface emission [14], is due to electron emission in shallow layers below the surface. This was verified by studying the angular distribution of the K Auger electrons. In addition, it was shown that the cross section of the resonant charge transfer filling the Ne L shell depends on the projectile velocity. For the lowest energy of 135 eV, it was found that the charge transfer cross section is negligible and that it is constant for higher projectile energies.

For the K Auger electron, the L shell was observed to be increasingly filled as the projectile energy increases. This finding is attributed to the velocity dependence of the charge transfer rate for the L shell. In contrast to the

TABLE II. L-shell binding energies for Ne with different numbers of electrons n_L in the L shell in a.u. Electrons missing in the K and L shell are assumed to belong to the M shell to keep the Ne atom neutral.

Energy		L-shell Ne							
(a.u.)	L-shell Al	$n_L=8$	$n_L=7$	$n_L=6$	$n_L=5$	$n_L=4$	$n_L=3$	$n_L=2$	$n_L=1$
$2s$	4.4	2.2	2.7	3.1	3.5	3.9	4.3	4.7	5.7
$2p$	2.7	1.2	1.7	2.2	2.8	3.3	3.9	4.3	5.2

K Auger electrons, the L Auger energies indicate a decreasing number of L shell electrons as the projectile energy increases. To interpret this unexpected finding, the enhanced absorption of L Auger electrons with higher n_L values is considered. Furthermore, it is suggested that the first electron to fill the Ne L shell is an L Auger electron independent of the ion velocity. For higher ion velocities the resonant charge-transfer probability from the Al L shell to the Ne L shell is enhanced. After the first electron fills the L shell, the charge-transfer process is expected to become quite probable. Consequently, the probability that L Auger processes will occur is reduced. Therefore, for higher projectile energies it appears that the L Auger transitions involve a nearly empty L shell.

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