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ABSOLUTE AUGER YIELD MEASUREMENTS OF O\(^{\pm}\), N\(^{\pm}\), C\(^{\pm}\), AND B\(^{\pm}\)-PROJECTILES FOLLOWING FOIL EXCITATION

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Abstract: The K-shell excitation of 50 to 500 keV B\(^{\pm}\), C\(^{\pm}\), N\(^{\pm}\), and O\(^{\pm}\)-projectile ions emerging from thin carbon foils is examined by means of Auger-electron spectroscopy. The fraction of inner-shell vacancies in the projectile ions is determined from measurements of the absolute Auger-electron yields of the excited ions. The projectile energy dependence of the vacancy fractions is discussed.

Résumé: L'excitation de la couche K des projectiles B\(^{\pm}\), C\(^{\pm}\), N\(^{\pm}\) et O\(^{\pm}\) de 50 à 500 keV est examinée suivant le passage de feuilles minces de carbone par spectroscopie d'électrons Auger. La fraction des vacances dans les couches internes de l'ion projectile est déterminée par mesure de la production absolue Auger des ions excités. La dépendance de la fraction des vacances suivant l'énergie des ions incidents est discutée.

Only recently, the L-shell excitation of argon ions moving through thin carbon foils has been investigated by means of Auger-electron spectroscopy. It has been shown that this method is appropriate to determine absolute numbers for the average fraction of projectile ions which are ionized in the inner shell after penetrating a foil. To extend these studies on K-shell excitation absolute Auger-electron yields from 50 to 500 keV B\(^{\pm}\), C\(^{\pm}\), N\(^{\pm}\), and O\(^{\pm}\)-ions excited by thin carbon foils have been measured.

Experimental details have been given in detail previously (1,2). Therefore only a brief description will do here. The various ion beams were produced by a model AN Van de Graaff accelerator. The scattering region formed by the ion beam traversing a thin target foil (carbon foils from 8 to 10 \(\mu\)g/cm\(^2\)) was viewed by a 45°-electrostatic parallel-plate electron analyzer. The resolution of the spectrometer of 2.6% (FWHM) was found to be sufficient for the reported measurements. The basic pressure in the scattering chamber was maintained at about 3.10\(^{-3}\) Torr. Various observation angles were chosen for different systems in order to get sufficient energy separation between target and projectile Auger-electrons.

![Fig. 1: Electron emission spectra from foil-excited 300 keV N\(^{\pm}\)- and C\(^{\pm}\)-projectile ions](image-url)
In Fig. 1 typical electron emission spectra from 300 keV foil excited C⁺ and N⁺ ions are displayed. Two broad structures in each spectrum correspond to either the Auger electrons from the target (C-foil) or the projectile ions. The peaks of the projectile ions are kinematically (Doppler-) shifted in the laboratory frame plotted here. The absolute Auger-electron yields were obtained from the intensity of the structures attributed to projectiles or target, respectively. The peaks are superimposed on a continuous background of electrons as indicated in Fig. 1. The shape of the background was determined from the contributions of electrons at energies well above and below the Auger structures and by fitting the logarithm of the continuum cross section with a second order polynomial. Using the analytical expression for the background it could be subtracted from the spectrum and the remaining Auger-electron intensity could be integrated. The background subtracted spectra show a target peak, that is broadened to lower energies because of energy loss in the foil. No broadening is observed in the projectile peak which indicates that the observed projectile Auger-electrons are emitted after emerging from the foil. The angular dependence of the electron emission has been examined and the projectile Auger emission was found to be isotropic in the forward hemisphere in the projectile rest frame. Assuming the same for the backward hemisphere an integration over the total solid angle could be performed to obtain the total Auger-electron yield emitted from the excited projectile ions after emerging from the foil. For the purpose of absolute calibration measurements with respect to the spectrometer constants were performed using gas targets and well known cross sections from previous measurements with gas targets (4).

The projectile energy dependence of the inner-shell vacancy fraction numbers for the various projectile ions is plotted in Fig. 2; the fraction is labelled by "f_p". The energy dependence is found to be nearly linearly increasing up to about 100 keV. From 200 keV on the f_p values seem to approach a constant value. This energy dependence is assumed to be mainly understood by two competing decay processes of the initially created inner-shell vacancies. The decay of inner-shell vacancies may either happen by spontaneous decay or in collisions with further target atoms. Obviously, the spontaneous decay is dominant at low projectile velocities where the time between successive collisions is fairly large compared with the lifetime of an inner-shell vacancy. At higher projectile energies the influence of the spontaneous decay mode vanishes. Then, the inner-shell vacancy distribution is dominated by a nearly velocity independent mechanism, that determines the vacancy decay.

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production cross section is about the same as previously deduced from gas-target measurements in the same projectile energy range. Then, we may write for the vacancy fraction present in the projectile under equilibrium conditions when passing through the foil:

$$f_p = \frac{\sigma_p}{\sigma_p + \sigma_c + \sigma_d}$$

where $\sigma_p$ represents the vacancy production cross section, $\sigma_c$ is a cross section for a recombination of the vacancies in collisions with target atoms, and $\sigma_d$ is the cross section for the spontaneous decay with

$$\sigma_d = \frac{1}{N \cdot \tau_{\text{eff}} \cdot v}$$

where $N$ is the target particle density, $\tau_{\text{eff}}$ is a mean effective lifetime of the inner-shell vacancies and $v$ the projectile velocity. It should be pointed out that $\sigma_c$ may be interpreted as a cross section that accounts for an electron capture mechanism into an inner shell. The case is somewhat exotic because there is an inner-shell vacancy present while there are some outer-shell electrons left, too.

For the limiting case $v \rightarrow 0$ it is possible to derive values for $\tau_{\text{eff}}$. This analysis has been carried out and the values deduced for $\tau_{\text{eff}}$ are given in Table I in comparison to theoretical values (5).

<table>
<thead>
<tr>
<th>Projectile</th>
<th>$\tau_{\text{eff}}$ (10^{-15}s)</th>
<th>$\tau_{\text{theor}}$ (10^{-15}s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C^+</td>
<td>0.6</td>
<td>65</td>
</tr>
<tr>
<td>N^+</td>
<td>38</td>
<td>44</td>
</tr>
<tr>
<td>O^+</td>
<td>31</td>
<td>29</td>
</tr>
</tbody>
</table>

The cross sections agree well within experimental error (20%) except for the case of O^+ on C-foil. There the cross section is much lower than one would expect. Further investigations are necessary to clarify this result.

In addition to the analysis of the Auger-electron yield from the projectile ions, it is possible to obtain informations from the target Auger-electron yield. These values were derived in the same manner as described above for the projectile. If we denote the escape depth of Auger-electrons from the foil with $\lambda$ we may write for the dependence of the target Auger yield $f_t$ according to an observation angle $\theta$:

$$f_t = \sigma_t \cdot N \cdot \lambda \cdot \cos \theta$$

where $N$ again is the target particle density and $\sigma_t$ is the production cross section for inner-shell vacancies in the target atoms. Using a value for $\sigma_t$ from previous gas target measurements (4) we obtain for the case of C^+ on C-foil a value of 172^A for the escape depth $\lambda$ which is in good agreement with a semiemperical value of 22^A (6). Using the value for $\lambda$ it was possible to deduce inner shell production cross sections $\sigma_t$ for the different projectile ions. The results are presented in Table II and compared to data from previous gas target measurements (4).

<table>
<thead>
<tr>
<th>Projectile</th>
<th>$\sigma_{\text{Foil}}$ (10^{-20} cm^2)</th>
<th>$\sigma_{\text{Gas}}$ (10^{-20} cm^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B^+</td>
<td>71</td>
<td>74</td>
</tr>
<tr>
<td>C^+</td>
<td>222</td>
<td>222</td>
</tr>
<tr>
<td>N^+</td>
<td>229</td>
<td>287</td>
</tr>
<tr>
<td>O^+</td>
<td>97</td>
<td>149</td>
</tr>
</tbody>
</table>

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References