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RESONANT SATELLITE PHOTOEMISSION OF ATOMIC Cu

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Resonant satellite photoemission of atomic Cu

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Abstract. The photoemission of atomic Cu has been obtained in the photon energy range 65 eV to 90 eV. The $3d^8\ 4s^2\ {}^1G,\ {}^3F,\ {}^1D$ satellite lines are resonantly enhanced at the energy of the $3p^6\ 3d^{10} 4s \rightarrow 3p^5\ 3d^{10} 4s^2$ transitions. The intensity of the satellites versus photon energy can be approximated by two symmetric lines separated by the spin-orbit splitting of the 3p-core. The satellites are driven by the $3p^5\ 3d^{10}\ 4s^2 \rightarrow 3p^6\ 3d^8\ 4s^2\ \varepsilon\ell$ super-Coster Kronig decay, interference effects are negligible.

At the 3p threshold of atomic Cu there are only two weak $3p^6\ 3d^{10}\ 4s \rightarrow 3p^5\ ({}^2P_{\frac{1}{2},\frac{3}{2}})\ 3d^{10}\ 4s^2$ absorption lines superimposed on a large $3d^{10}\ 4s \rightarrow 3d^9\ 4s\ \varepsilon f$ background (Bruhn et al., 1979). Recent photoemission measurements (Chandesris et al., 1981) showed a resonant enhancement of the $3p^6\ 3d^8\ 4s^2\ {}^1G,\ {}^3F$ satellite lines when tuning the photon energy to the $3p \rightarrow 4s$ absorption lines. Due to the overlap of the non-resolved $3p^5\ ({}^2P_{\frac{1}{2},\frac{3}{2}})\ 3d^{10}\ 4s^2$ spin orbit components the line shape could not be determined in these measurements (Chandesris et al., 1981). According to the calculations of Davis and Feldkamp (1981) the resonant enhancement results from the $3p^5\ 3d^{10}\ 4s^2 \rightarrow 3p^6\ 3d^8\ 4s^2\ \varepsilon\ell$ super-Coster Kronig decay. Due to the weakness of the $3p^6\ 3d^{10}\ 4s \rightarrow 3p^6\ 3d^8\ 4s^2\ \varepsilon\ell$ two electron excitation, interference effects should be negligible. Therefore the satellite intensity versus photon energy should show a symmetric line shape (Davis and Feldkamp 1981). In our experiment the synchrotron radiation emitted by the storage ring DORIS was monochromatized with a new toroidal grating monochromator. The bandwidth of 0.35 eV is sufficient to resolve the spin orbit splitting of the 3p core. This allows the determination of the line shape of the two spin orbit components. The monochromatic photon beam was focused onto the interaction zone where it crossed a beam of atomic Cu emanating from a resistively heated high temperature furnace. The kinetic energy of electrons emerging from the interaction zone was determined by a cylindrical mirror analyzer (angular acceptance 0.8% of 4π, energy resolution ΔE = 0.8% of the pass energy). Only electrons emitted at the

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magic angle of $54^\circ\ 44' \pm 1^\circ$ relative to the polarization vector of the incoming light were accepted by the analyzer. This eliminates the asymmetry of the photoelectron angular distribution (Starace 1982) and allows for a direct determination of partial cross-sections. Contrary to this Chandesris et al. (1981) had to apply corrections based on calculated asymmetry parameters. All photoemission spectra were normalized to the incoming photon flux and corrected for the energy dependent dispersion of the electron analyzer. Since the density of Cu atoms in the interaction zone was not determined only relative cross-sections are given. Details of the experimental set-up will be presented elsewhere (Bruhn et al., 1982).

In Fig. 1 the photoemission spectrum of atomic Cu taken at 73.2 eV, the position of the $3p^6\ 3d^{10}\ 4s \rightarrow 3p^5\ ({}^2P_{\frac{3}{2}})\ 3d^{10}\ 4s^2$ transition, is shown. There is a dominant line corresponding to the $3d^9\ 4s\ {}^1D,\ {}^3D$ states of Cu II accompanied by a series of weaker lines. The assignment taken from Chandesris et al. (1981) is summarized in Table 1. As these authors (Chandesris et al., 1981) already noticed, the $3d^9\ 4s$ line is hardly affected by the $3p^6\ 3d^{10}\ 4s \rightarrow 3p^5\ ({}^2P_{\frac{1}{2},\frac{3}{2}})\ 3d^{10}\ 4s^2$ transitions.

The explanation rests with the weakness of the $3p^5\ 3d^{10}\ 4s^2 \rightarrow 3p^6\ 3d^9\ 4s$ Auger decay (Davis and Feldkamp, 1981). In contrast to the photon energy dependence of the main $3d^9\ 4s$ line, the $3d^8\ 4s\ {}^1G,\ {}^3F,\ {}^1D$ satellite lines are strongly enhanced by the $3p^6\ 3d^{10}\ 4s \rightarrow 3p^5\ ({}^2P_{\frac{1}{2},\frac{3}{2}})\ 3d^{10}\ 4s^2$ transitions via the $3p^5\ 3d^{10}\ 4s^2 \rightarrow 3p^6\ 3d^8\ 4s^2\ \varepsilon\ell$ super-Coster-Kronig decay. Fig. 2 shows the intensity of these lines, normalized to the intensity of the $3d^9\ 4s$ line, versus photon energy. The two 3p spin-orbit components are well separated. The experimental data can be represented by the superposition of two Lorentzian curves positioned at the energies (73.15; 75.4 eV) of the $3p^6\ 3d^{10}\ 4s \rightarrow 3p^5\ ({}^2P_{\frac{1}{2},\frac{3}{2}})\ 3d^{10}\ 4s^2$ transitions. The symmetry of the line profiles corroborates the unimportance of interference effects as calculated by Davis and Feldkamp (1981). The results of their calculations are included in Fig. 2. Since the calculated line width of 3.42 eV (FWHM) is more than twice the experimental value, the spin orbit splitting is not resolved in the theoretical curves. The $3d^8\ 4s^2\ {}^3F$ is superimposed on a considerable non-resonant background ascribed to inelastic scattering into $3d^9\ 4p$ final states by Davis and Feldkamp (1981). At maximum the intensities of the $3d^8\ 4s^2\ {}^1G,\ {}^3F,\ {}^1D$ are 16%, 6%, 2% of the main line $3d^9\ 4s$. The experimental percentage of the $3d^8\ 4s^2$ emission in ^1G (63%), ^3F (27 %), ^1D (6%), $^3P + {}^1S$ (4%) compares favorably with the calculated percentage ^1G (62%), ^3F (29%) and ^1D (8%).

In summarizing we want to state that our results corroborate the predictions by Davis and Feldkamp (1981). In comparison to the results reported by Chandesris et al. (1981), there are two points we wish to stress:

i) the line shape of the two spin-orbit components is symmetric

ii) the relative intensities of the ^1G, ^3F, ^1D and $^3P + {}^1S$ photoemission lines were determined without corrections for the angular distribution of the photoelectrons.

Table 1

Experimental binding energies E_B of the states of Cu II giving rise to the photoemission lines in Fig. 1.

Line	E_B (eV)	State of Cu II
1	24.4 ± 0.2	$3d^8\ 4s^2\ {}^1S$
2	21.2 ± 0.2	$3d^8\ 4s\ 4p$
3	19.5 ± 0.2	$3d^8\ 4s^2\ {}^1G$
4	18.3 ± 0.2	$3d^8\ 4s^2\ {}^1D$
5	16.3 ± 0.2	$3d^8\ 4s^2\ {}^3F$, $3d^9\ 4p$
6	10.7 ± 0.1	$3d^9\ 4s\ {}^3D, {}^1D$
7	7.7	$3d^{10}\ {}^1S$ reference

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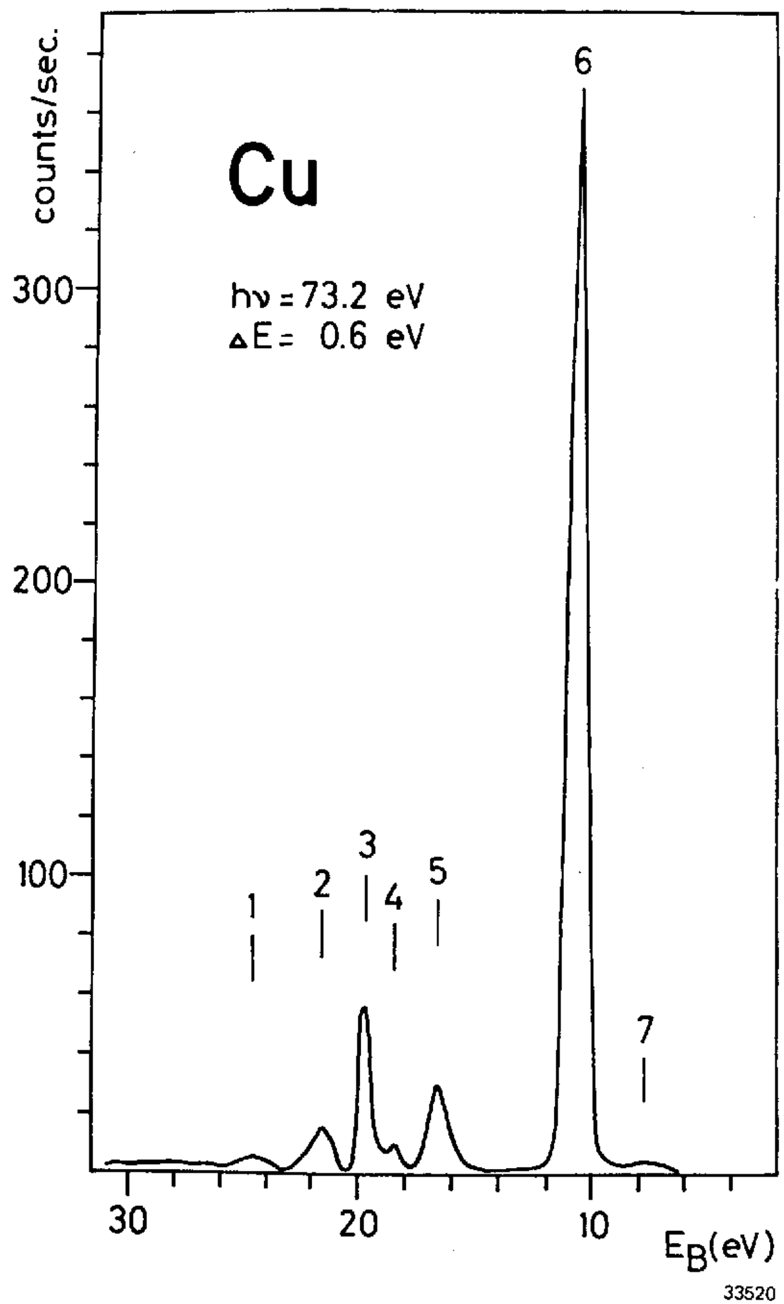
Figure Captions

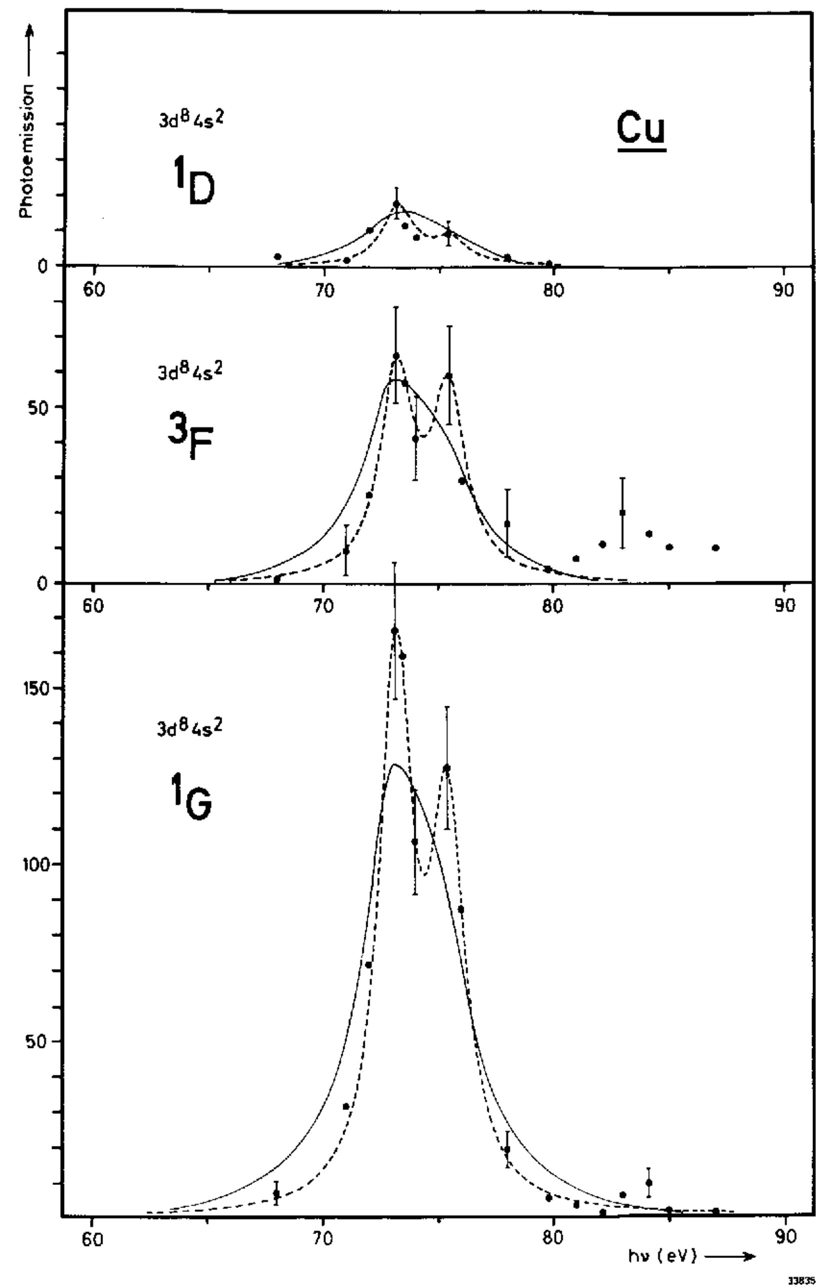
Figure 1 Photoemission spectrum of atomic Cu taken at 73,2 eV.

Figure 2 Experimentally determined intensity of the $3d^8\,4s^2\,{}^1G,\ {}^3F,\ {}^1D$ photoemission lines (·) as a function of photon energy. A nonresonant background has been subtracted (peak:background ${}^1D$ 13:1; ${}^3F$ 1.5:1; ${}^1G$ 32:1). Representation of the experimental data by a superposition of two Lorentzian curves (positioned at 73.15 eV and 75.4 eV, half width 1.75 eV) (- - -). Intensity calculated by Davis and Feldkamp (1981) (——).



counts/sec.
Cu
hν = 73.2 eV
ΔE = 0.6 eV
300
200
100
1
2
3
4
5
6
7
30
20
10
E_B(eV)
33520

Fig. 1



Photoemission
Cu
3d⁸4s²
¹D
³F
¹G
0
50
100
150
60
70
80
90
hν (eV)