J. Phys. B: Atom. Molec. Phys., Vol. 12, No. 18, 1979. Printed in Great Britain

LETTER TO THE EDITOR

Doubly differential cross section for K-shell ionisation of silver and gold for 300 keV electron impact

M Komma and W Nakel

Physikalisches Institut, Universität Tübingen, D-7400 Tübingen, West Germany

Received 9 July 1979

Abstract. The doubly differential K ionisation cross section of Ag and Au was measured for electron impact as a function of outgoing electron energy at a fixed scattering angle of 20°. The incident electron energy was 300 keV. Coincidences between characteristic K x-rays and outgoing electrons are used to isolate the K ionisation process. The results are compared with calculations of Das and of Das and Konar.

There are still very few experiments on multiply differential cross sections for inner-shell ionisation by electron impact. For relativistic electron energies only Quarles and Faulk (1973) have published experimental data on doubly differential cross sections for K-shell ionisation of Cu and Ag for 140 keV electrons.

We report here a measurement of the doubly differential K ionisation cross section of Ag and Au for 300 keV electron impact as a function of outgoing electron energy at a fixed scattering angle. Coincidences between characteristic K x-rays and outgoing electrons are used to isolate the K ionisation process.

In our experimental arrangement the primary electron beam strikes a thin target placed at the centre of a scattering chamber. The target consists of evaporated films of silver (self-supporting) and gold (on formvar backing) with thicknesses of 54 and 64 $\mu g\ cm^{-2}$, respectively.

The outgoing electrons are observed at a scattering angle of 20° within a solid angle of 1·36 msr defined by a circular carbon aperture. In order to suppress the elastically scattered electrons before the spectral measurements are made, a non-dispersive magnet (Komma 1978) is inserted between the defining aperture and the electron detector. The energy distributions of the electrons transmitted through the magnet (40–200 keV) are measured with a silicon detector.

Characteristic K x-rays produced at 35° with respect to the incident electron beam pass out of the scattering chamber through a thin plastic window and are detected by a Ge detector.

The pulses of the electron detector and of the photon detector are fed into a two-parameter coincidence system. The system was designed to measure simultaneously the electron–photon correlations of the processes of electron-electron bremsstrahlung, electron-nucleus bremsstrahlung, and the coincidences between the characteristic K x-rays and outgoing electrons. The details of the system employed will be published later together with the measurements of the bremsstrahlung processes. In brief, it consists of a time-to-amplitude converter for the fast coincidences, two linear amplifiers for the energy signals and a two-parameter multi-channel analyser. Both

0022-3700/79/180587+03$01.00

energy signals are gated by the fast coincidences and fed to the two ADC of the multi-channel analyser.

The differential cross section for K-shell ionisation was determined from

$$\frac{d^2\sigma}{d\Omega\, dT} = \frac{4\pi N_c}{N_0 \tau \epsilon_e \Delta\Omega_e \Delta T \epsilon_\gamma \Delta\Omega_\gamma \omega_k}$$

where N_c is the number of coincidences, N_0 the number of incident electrons, τ the target thickness, $\Delta\Omega_e$ the electron solid angle, ϵ_e the efficiency of the electron detector, ΔT the energy width, $\Delta\Omega_\gamma$ the photon detector solid angle, ϵ_γ the photon detector efficiency, and ω_k the K-shell fluorescent yield of the target atom. The beam current was measured with a Faraday cup and found to be 10^{-8} A. The target thickness was determined from measurements of the energy loss of α particles passing through the foil. The conversion factor was taken from the tables of Barkas and Berger (1964). Moreover, the product of target thickness and beam current was checked by measuring the elastically scattered electrons with a surface barrier detector. The photon detector efficiency (0·98 at 68 keV and 0·87 at 22 keV) was measured using calibrated radioactive sources. The spectra were deconvoluted with an electron detector efficiency of $\epsilon_e = 0{\cdot}85$ (cf Berger *et al* 1969). The fluorescent yields of 0·834 for Ag and 0·96 for Au were taken from the compilation of Bambynek *et al* (1972).

The results of the experiment are shown in figure 1(*a*) for Ag and in figure 1(*b*) for Au for an electron scattering angle of 20°. Each spectrum was recorded in a single run of about 100 h accumulation time. We have plotted $d^2\sigma/d\Omega\, dT$ versus the kinetic energy of the outgoing electrons.

The error bars shown are the mean square roots of statistical errors and estimated systematic errors. The statistical errors ranged from about 8% to 20%. The systematic error was estimated to be 15% for the measurement on Ag and 19% for the measurement on Au.

We compare our results with theoretical predictions of Das (1972) and of Das and Konar (1974).

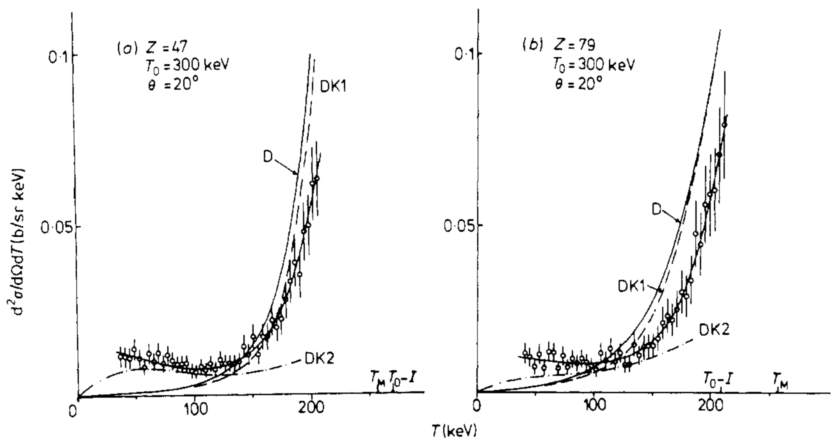

Figure 1. Doubly differential cross section for K-shell ionisation of (*a*) Ag and (*b*) Au versus the kinetic energy T of the outgoing electrons. T_0: kinetic energy of the incident electrons; θ: scattering angle; T_M: Møller energy; I: binding energy. The theoretical curves labelled D, DK1, and DK2 are discussed in the text.

First we have evaluated the cross section formula of Das (1972). The corresponding curves are labelled 'D' in figures 1(*a*) and (*b*). In his calculation Das uses the relativistic interaction Hamiltonian, a non-relativistic hydrogen wavefunction for electrons in the inner shell, a non-relativistic Coulomb wavefunction for the low-energy (ejected) electron and relativistic plane waves for the incident and high-energy (scattered) electron. The exchange was included in this calculation in the Ochkur approximation.

Recently, Das and Konar (1974) have improved this work by the use of the relativistic Sommerfeld–Maue wavefunction for the ejected electron and have published the triply differential cross section for the inner-shell ionisation process. For comparison with our measurements of the doubly differential cross section one has to integrate over the directions of one of the outgoing electrons. The integration over the direction of the ejected electrons has been done analytically by J N Das and A N Konar (private communication). From the evaluation of this formula we got the curves labelled 'DK1' in figures 1(*a*) and (*b*). This calculation gives mainly the scattered electron contribution because of the non-exact treatment of the exchange effects.

The comparison of the experimental data with the theoretical predictions shows that the use of the Sommerfeld–Maue wavefunction yields some improvement for the present parameters. However, there is no increase of the theoretical cross section for low energies. Therefore, to have an estimate for low energies we have integrated numerically the triply differential cross section over the scattered electron directions as proposed by Konar (1975).

The results are presented in figures 1(*a*) and (*b*) by the curves 'DK2'. Although the calculation still underestimates the measured cross sections, the increase for low energies is evident.

To extend the measurements to lower energies T, the time resolution has to be improved. The cut-off at high energies resulted from considerations concerning the measurements of the bremsstrahlung processes observed simultaneously.

To resolve the apparent discrepancies, more experimental and theoretical work is needed.

We would like to thank Professor H Krüger for his support of this work. We are very grateful to Dr J N Das for helpful correspondence.

References

Bambynek W, Crasemann B, Fink R W, Freund H U, Mark H, Swift C D, Price R E and Venugopala Rao P 1972 *Rev. Mod. Phys.* **44** 716

Barkas W H and Berger M J 1964 *Nat. Acad. Sci.—Nat. Res. Council Publ.* **1133** 103

Berger M J, Seltzer S M, Chappell S E, Humphreys J C and Motz J W 1969 *Nucl. Instrum. Meth.* **69** 181

Das J N 1972 *Nuovo Cim.* B **12** 197

Das J N and Konar A N 1974 *J. Phys. B: Atom. Molec. Phys.* **7** 2417

Komma M 1978 *Nucl. Instrum. Meth.* **154** 271

Konar A N 1975 *Acta Phys. Acad. Sci. Hung.* **38** 337

Quarles C A and Faulk J D 1973 *Phys. Rev. Lett.* **31** 859