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ELECTRON IMPACT EXCITATION OF THE $a^3\Pi$ STATE OF CO: FULL RANGE DIFFERENTIAL CROSS SECTIONS

M. M. RISTIĆ[1], G. B. POPARIĆ[2] and D. S. BELIĆ[2]
[1]*Faculty of Physical Chemistry, University of Belgrade, P.O. Box 137, 11000 Belgrade, Serbia*
E-mail: ristic@ffh.bg.ac.rs
[2]*Faculty of Physics, University of Belgrade, P.O. Box 368, 11000 Belgrade,Serbia*
E-mail: goran_poparic@ff.bg.ac.rs, belicd@ff.bg.ac.rs

Abstract. Electron impact excitation from the v=0 level of the ground $X\ ^1\Sigma^+$ state to the v'=0, 1, 2, 3, 4 and 5 vibrational levels of the $a^3\Pi$ valence state of the carbon-monoxide molecule has been revisited in the energy region from threshold to 9,7 eV. A crossed beam double trochoidal electron spectrometer is used. Forward and backward scattered electrons from the v'=0 of the $a^3\Pi$ excitation channel are separated by electron beam modulation and time-of-flight detection technique. Present results are normalized and absolute values of the differential cross sections at border angles of 0^o and 180^o are determined. In this way the differential cross section measurements are completed in the full angular range from 0 to 180 degrees, in the near-threshold energy region.

1. INTRODUCTION

Investigation of electron collision processes with carbon-monoxide is important in plasma and discharge technology, chemical detectors and in laser devices (Hahn 1977, Pearson 1989). Since CO is a constituent of atmospheres of Earth, Mars and Venus, studies of electron impact excitation of CO are also important for planetary astrophysics.

Resonant phenomena in electronic excitation of CO have been reviewed by Schulz (1973). First measurements of differential cross sections (DCS) for electronic excitation of the $a^3\Pi$ electronic state of the CO molecule, with threshold energy of 6.01eV, were performed by Trajmar et al. (1971). Zobel et al. (1996) performed, by nowadays the most detailed experimental study of low energy electron impact excitation of the valence $a^3\Pi$ state. These measurements were conducted for the v'=0, 1, 2, 3, 4 and 5 vibrational levels. Excitation functions and angular dependencies have been reported in the energy range from threshold to 9.7 eV and in the angular range from 20^o to 140^o.

In the present experiment, electron-impact excitation of the $a^3\Pi$ state of CO has been revisited with the aim to determine DCSs at the critical, border angles of 0 and 180^o, in order to complete the range of DCS measurements.

2. EXPERIMENTAL SETUP

Present measurements are performed by using a crossed beams double trochoidal electron (TEM) spectrometer (Vićić et al. 1998). Monoenergetic electron beam is crossed at right angles with the gas beam. After the collision, electrons scattered in a forward (and backward) direction are analyzed by use of a double TEM device (Vićić et al. 1998) and detected by a channel electron multiplier.

In the originally designed apparatus, due to the presence of a longitudinal magnetic field, the detected signal consists of the sum of electrons inelastically scattered at 0^o and 180°, within the same solid angles, at the given residual electron energy. Electrons scattered at 0° travel straight to the analyzer system and to the detector. On the other side, inelastic electrons scattered at 180° move backward along the incident electron beam trajectory, are reflected at the potential barrier in front of the collision chamber, reach again the collision region and from there follow the same path as the forward scattered electrons. Thus they travel a longer distance and need a longer time to reach the detector. This fact is used to separate these two groups of electrons by recording their time-of-flight spectra. For this purpose, electron beam is modulated and time-of-flight technique is applied. Detailed description of this procedure is given by Poparić et al. (2004).

3. RESULTS AND DISCUSSION

Measurements are performed for the excitation of the v'=0 vibrational level of the $a^3\Pi$ state of the CO molecule, for incident electron energies of 6.5, 7, 8, 9 and 9.7 eV.

Typical time-of-flight spectrum for these measurements is shown in Fig. 1, for incident electron energy of 7 eV. As it can be seen from the figure, the spectrum consists of two distinct peaks on the time scale. The first, smaller one, with the maximum at 500 ns belongs to the electrons scattered at 0°, directly to the analyzer and detector. The second, larger peak, around 600 ns, corresponds to electrons scattered at 180°. Separation of these two contributions is performed by using standard multi-peak deconvolution procedure by means of the Gaussian functions. The result is shown by solid line in Fig. 1. The ratio of the differential cross sections at 0° and at 180° is proportional to the ratio of the areas under these two peaks. In this particular case, forward-to-backward DCS ratio is found to be 1:2.26.

Present results for the forward-to-backward scattered electrons ratio for all listed incident electron energies are summarized in Table 1. Estimated error bar is found to be of the order of ±5% (except for 9.7 eV where it is estimated to be ±10%).

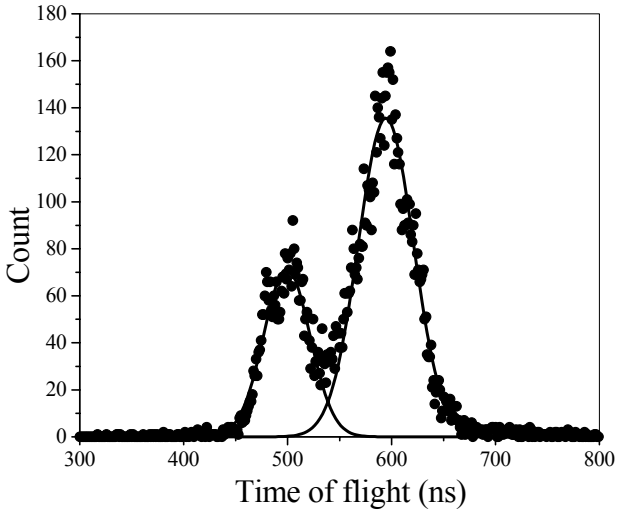

Figure 1: Time-of-flight spectrum of electrons scattered at 0° and 180° from the *v'*=0 level of the $a^3\Pi$ state of CO, at incident energy of 7 eV.

Present results are normalized to the absolute DCS values by comparison to the value for the ground level v=2 ($X^1\Sigma^+$) excitation via the $^2\Pi$ resonance, published by Poparić et al. (2006). This is performed by the constant residual energy spectrum recorded in a vide impact electron energy range for residual energy of 1.46 eV. Using for the second maximum of the v=2 peak DCS value of $3.48\text{x}10^{-17}$ cm^2sr^{-1}, at E_i = 2.03 eV, absolute value of DCS for v'=0 at 0^o is found to be $1.77\text{x}10^{-17}$ cm^2sr^{-1}. All other DCS values, listed in Table 1, are obtained by scaling corresponding relative intensities.

Table 1. DCS values (in 10^{-18} cm^2sr^{-1}) for v'=0 level of the $a^3\Pi$ state at 0^o and 180^o for listed electron energies and ICS values (in 10^{-18} cm^2).

E_i [eV]	$DCS_{0^o} : DCS_{180^o}$	DCS_{0^o}	DCS_{180^o}	ICS
6,5	1 : 1,53	1.77	2.71	16.62
7	1 : 2,26	1.32	2.99	21.36
8	1 : 4,86	0.63	3.07	30.10
9	1 : 4,60	0.58	2.71	29.05
9,7	1 : 2,19	1.01	2.22	23.61

Present results are shown together with the experimental results of Zobel et al. 1996 in Fig. 2. The angular distributions for electron energies of 6.5, 7, 8, 9 and 9.7 eV are presented. In this way the full angular range from 0 to 180 degrees is covered, The data of Zobel et al. 1996 and present results are in very good agree-

ment, both in the magnitude and in the overall shape of the angular distributions. This is in particular important having in mind that the two sets of data are completely independent. The fit of the data by the sixth order Legendre polynomials, also shown in Fig. 1, is used for determination of the ICS values listed in Table 1.

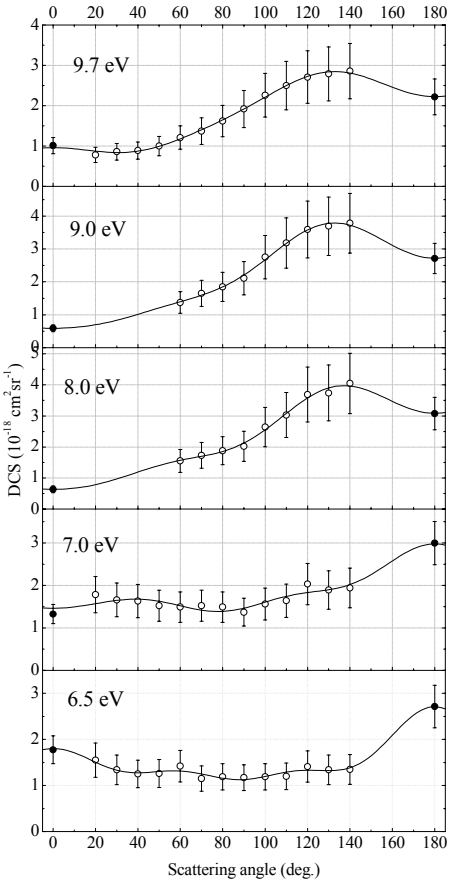

Figure 2. DCS for ν'=0 of $a^3\Pi$ state excitation at indicated electron energies: present results (solid circles); Zobel et al. 1996 (open circles); Legendre polynomial fit (full line).

4. CONCLUSIONS

Electron impact excitation of the valence $a^3\Pi$ state of CO has been investigated in energy region from threshold to 9.7 eV. The ratios of DCSs at 0^o and 180^o for ν'=0 vibrational level of $a^3\Pi$ state are measured, and their absolute values have been determined for all considered electron energies. Present results have fulfilled long standing lack of experimental DCS data for excitation of $a^3\Pi$ state of the CO molecule at border angles of 0^o and 180^o. It is expected that present results inciate further theoretical development in this field.

Acknowledgements

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