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RESONANT EXCITATION OF MOLECULES BY LOW-ENERGY ELECTRONS

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Abstract. *Low-energy electron impact vibrational and electronic excitation cross sections of the CO, N_2 and CO_2 molecules are measured by use of a high resolution crossed-beams double trochoidal electron spectrometer. The spectrometer is designed to work in standard and time-of-flight regimes. The energy dependences of the resonant vibrational excitation of the first several vibrational levels of the N_2, CO, and CO_2 molecules, have been measured. Characteristic substructures in energy excitation spectra in the cases of N_2 and CO have been obtained and discussed for some vibrational channels for the first time. The ratio of forward-to-backward scattered electrons from the $^2\Pi$ resonance in CO is found to be equal to 1, and thus the angular distribution of scattered electrons to be symmetric relative to 90°. This conclusion supports the fact that the contribution of the $p\pi$ partial wave is dominant in the energy region of the $^2\Pi$ resonance in CO. The energy dependences of the near threshold resonant excitation of the valence and Rydberg states of the N_2 and CO molecules have been measured. The cross sections of the near threshold resonant excitation of the C $^3\Pi_u$ valence state, and the E $^3\Sigma^+_g$ and a'' $^1\Sigma^+_g$ Rydberg states of the N_2 molecule have been measured. In the case of the CO molecule, the cross sections of the near threshold resonant excitation of the a $^3\Pi$ valence state, and the b $3\Sigma^+$ and B $^1\Sigma^+$ Rydberg states have been measured. Resonant structures in excitation functions of all measured electronic states are observed and their locations are compared with resonances obtained in different decay channels.*

Key words: *Vibrational excitation; Electronic excitation; The N_2, CO and CO_2 molecules*

INTRODUCTION

Vibrational excitation of the nitrogen molecule by electron impact, via the $^2\Pi_g$ resonance, has been studied intensively in the past few decades. Moreover, it was the first experimental evidence of a resonance in electron–molecule scattering (Haas 1957, Schulz 1964). The unusual behavior of the excitation cross sections, in particular the position

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and widths of the quasi-vibrational resonant structures as a function of excitation channel, was first explained and described by the introduction of the boomerang model, by Birtwistle and Herzenberg (1971). This phenomenon has been studied experimentally in further detail by Ehrhardt and Willmann (1967), Boness and Schulz (1973), Wong and Dube (1978), Jung *et al.* (1982) and more recently by Allan (1985, 1989), Brunger *et al.* (1989) and Brennan *et al.* (1992). It has also become a touchstone for the theories of resonant coupling of the electronic and vibrational motion and it remains of current interest, as is shown by numerous studies, Schneider *et al.* (1979), Cederbaum and Domcke (1981), Berman *et al.* (1983), Domcke *et al.* (1984), Nestman and Peyerimhoff (1985), Huo *et al.* (1987). Despite such activity concerning low-energy vibrational excitation of the N_2 molecule, some discrepancy between measurements and theoretical predictions still remains. Experiments and theories do agree on the overall structure, energy positions and shifts of peaks with the final vibrational quantum number. The agreement is not so good concerning shapes and relative magnitudes of peaks corresponding to the same excitation channel, they differ somewhat even between the different measurements. Furthermore, recent theoretical predictions have introduced a fine 'substructure' occurring as a pronounced asymmetry of particular peaks and even as a weak shoulder on the first peaks in some particular vibrational level excitation functions. This has not been clearly reproduced by the experiments so far. The aim of this measurement is to obtain an additional set of relative cross sections for vibrational excitation of N_2 below and in the $^2\Pi_g$ resonance region with particular attention to the predicted substructure, and consequently to determine the shape of the resonant state potential.

A pronounced resonant contribution of the $^2\Pi$ shape resonance to electron-impact excitation of the ground state vibrational levels of CO has been studied for a long time (Schulz (1973), Brunger and Buckman (2002)). It was first observed by Schulz 1964 and Ehrhardt *et al.* (1968). A notable difference exists between the $^2\Pi$ shape resonance in the isoelectronic molecules CO and N_2. The heteronuclear CO molecule has reduced symmetry and its $3d\pi$ orbital allows a *p* partial wave component to take place in a resonant scattering process (Read (1968)). Observed structure in CO has larger width than in N_2. This is a result of the resonance barrier being of a *p*-wave character (which is not as high as *d* wave barrier and has shorter lifetime) in CO, with *d* wave mixed in. In N_2, the barrier is formed predominantly by *d* wave. Relative differential cross sections (DCS) or angular distributions of inelastically scattered electrons from CO, in the energy region from 1.55 to 3 eV, have been measured by Ehrhardt *et al.* (1968) for excitation of v=1 to 6 vibrational levels. Measurements are performed in the range from 20° to 110°. Obtained results show a *p*-type behavior of the curves, with a minimum at 90°. A fairly good fit to the experimental curves was obtained by O'Malley and Taylor (1968) whose theory gives the angular distribution in the form $(1 + 7\cos^2\theta)$. The deviation of this expression from the experimental data is of the order of 10%. Read (1968) was able to improve the fit to the angular distribution using a mixture of $p\pi$ and $d\pi$ waves. The mixing of these two waves is left as a parameter which is adjusted until a good agreement with experimental angular distribution is achieved. DCS for excitation of the first vibrational level v=1 of CO have been reported by Land (1978), as a result of swarm experiments, by Chutjian and Tanaka (1980) and by Sohn *et al.* (1985). More recently, Middleton *et al.* (1992) and Gibson *et al.* (1996) have also reported DSC's for this transition at energies between 1 and 50 eV. In all cases experimental results are reported up to 130°. Theoretical calculations have been performed in Born dipole approximation (BDA) by Sohn *et al.* (1985), and *R*-matrix calculations by Morgan and Tennyson (1993) and by Gibson (1996). It has been pointed out by Brunger and Buckman (2002) that, near the resonance maximum, experimental data agree with each other fairly well but are not reproduced very well by theory. Both experimental results and theoretical predictions show a minimum of the angular distribution at 90°. The mixing of *p* and *d* partial wave contributions in this resonance allows DCS to be asymmetric relative to 90°. This asymmetry is more pronounced in theoretical results, in favor of low scattering angles. The lack of experimental results in the region between 130° and 180° does not allow one to make a definite conclusion about this asymmetry or degree of asymmetry. From this reason we have performed measurement of the ratio of DCS at forward and backward direction by use of our double trochoidal electron spectrometer with the time-of flight technique. Similar measurements have been performed by Allan (1989), Asmis (1996) in N_2 and He, and by Poparić *et al.* (2002) on $E\ {}^3\Sigma_g^+$ state in the N_2 molecule. In our previous, high resolution, experiment on vibrational excitation of the isoelectronic N_2 molecule, via the ${}^2\Pi_g$ shape resonance, a clear evidence of the fine "substructures" has been demonstrated by Vićić *et al.* (1996). These substructures were theoretically predicted by Huo *et al.* (1987) and were also reported by Allan [1985]. Similar substructures are expected to be seen also in the case of CO molecule, since it has similar electronic configuration and same mechanism of resonant excitation. The aim of this experiment is to obtain an additional set of relative cross sections for vibrational excitation of CO below and in the ${}^2\Pi$ resonance energy region, with high energy resolution and particular attention to the predicted substructures, to complete differential cross sections and to determine integral cross sections for ground state vibrational excitation of the CO molecule.

We have measured cross section for vibrational excitation of the symmetric stretch mode of the CO_2 molecule via the ${}^2\Pi$ resonance.

The energy dependences of the near threshold resonant excitation of the valence and Rydberg states of the N_2 and CO molecules have been measured. The cross sections of the near threshold resonant excitation of the C ${}^3\Pi_u$ valence state (G. Poparić *et al.* (1999)), and the E ${}^3\Sigma^+{}_g$ (Poparić *et al.* (2002)) and a" ${}^1\Sigma^+{}_g$ Rydberg states of the N_2 molecule have been measured. In the case of the CO molecule, the cross sections of the near threshold resonant excitation of the a ${}^3\Pi$ valence state, and the $b^3\Sigma^+$ (Poparić *et al.* (2001)) and B ${}^1\Sigma^+$ Rydberg states have been measured. Resonant structures in excitation functions of all measured electronic states are observed and their locations are compared with resonances obtained in different decay channels.

EXPERIMENTAL TECHNIQUE

The present measurements are performed by using a modified crossed beams double trochoidal electron spectrometer, described elsewhere Vićić *et al.* (1998). Due to the presence of a longitudinal magnetic field, needed for trochoidal electron selectors operation, in the originally designed apparatus, the detected signal consists of the sum of electrons inelastically scattered at 0° and 180°. Electrons scattered at 0° travel straight to the analyzer system and to channeltron detector. On the other side, inelastic electrons scattered at 180° move backward along the incident electron beam trajectory, are reflected on the potential barrier of the monochromator, reach again the collision region and from there follow the same path as the 0° 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 kind of measurements the incident electron beam from the monochromator needs to be pulsed in an appropriate way. A similar technique has been used earlier by Allan (1989), Asmis and Allan (1996), and Poparić *et al.* (2002). In our experiment, electron beam chopping is enabled by a square shaped asymmetric pulse signal of 1.18 MHz from a 20 MHz clock. Square pulses of 50 ns, 2 V high, are separated by 800 ns. This signal is superimposed on the voltage of the second electrode after throchoidal electron monochromator (TEM). The potential of this electrode keeps the electron beam on during 50 ns of the pulse time and off for the rest of the time. Since the collision can occur only during the pulse on time, the rising time of the pulses can be used as a trigger of the time-to-amplitude converter (TAC). In fact, this signal is used as a stop trigger of the TAC. For the start of the TAC the signal from the channeltron is used. Therefore each recorded event represents the time difference between electron detection and the next pulse coming from the generator. This inverted configuration has no influence on the results, but increases the detection efficiency of the experiment. A primary beam and elastic forward and backscattered electrons, as well as various other inelastic electrons, are separated by a magnetic field and a set of the first three electrodes of the analyzer.

This procedure has been successfully applied in our laboratory to separate forward and backward scattered electrons from the E $^3\Sigma^+_g$ state resonant excitation of the N_2 molecule (Poparić *et al.* (2002). Measurements are performed near threshold, with very low residual electron energy, of 67 meV, just at energy position of the $^2\Sigma^+_u$ resonance. In the case of slow electrons the time difference between detection of forward and backward electrons is sufficient to separate two contributions. For faster, more energetic electrons, however, backward scattered electrons reflect quickly and follow very closely forward scattered ones and the two contributions overlap in time. Thus electrons scattered backward with higher energy need to be decelerated and to travel some distance with low velocity before they get back to the collision region. In that way the time difference of their arrival to the detector can be increased. For this purpose a decelerator device has been introduced between the end of the monochromator and the collision region. It consists of two parallel plates, 20 mm long. They are kept at low negative potential below the interaction region so that backward scattered electrons travel with low velocity back and forth over this distance and spend some 80–100 ns in this device before entering again the collision region from the opposite direction. The rest of the experiment is the same as described in our previous measurements Poparić *et al.* (2002). The signal from the channeltron is processed by a fast charge amplifier, voltage amplifier, and high-voltage filter. Obtained pulses are used for the start signal of the TAC. The signal from the TAC is loaded to a pulse-height analyzer (PHA) and multichannel analyzer (MCA). Obtained time-of-flight spectra are analyzed by an on-line computer. The principal scheme of this arrangement is similar to one used earlier by Poparić *et al.* (2002, 2004).

EXPERIMENTAL RESULTS AND DISCUSSION

Vibrational Excitation of the N_2, CO and CO_2 Molecules

We have measured the excitation functions from v = 0 of the N_2 ground state to the first nine vibrationally excited states via the $^2\Pi_g$ resonance. Relative differential cross sections are obtained. The cross sections are normalized to the absolute data and normalized cross sections are presented in figure 1. As can be seen from the figure the characteristic substructures have been recorded in excitation channels v=8 and v=9.

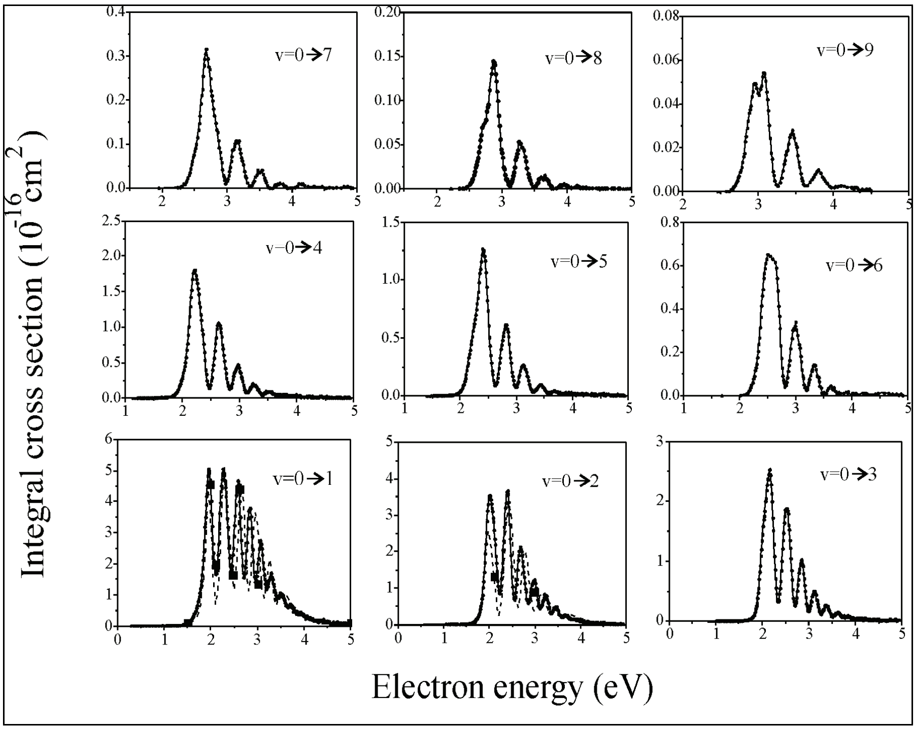

Fig. 1. Cross sections for resonant vibrational excitation of the N_2 molecule.

We have measured the excitation functions from v = 0 of the CO ground state to the first 10 vibrationally excited states via the $^2\Pi$ resonance. Relative differential cross sections are obtained (Poparić *et al.* (2006)). The cross sections are normalized to the absolute data and normalized cross sections are presented in figure 1. As can be seen from the figure the characteristic substructures have been recorded in excitation channels v=7 and v=9.

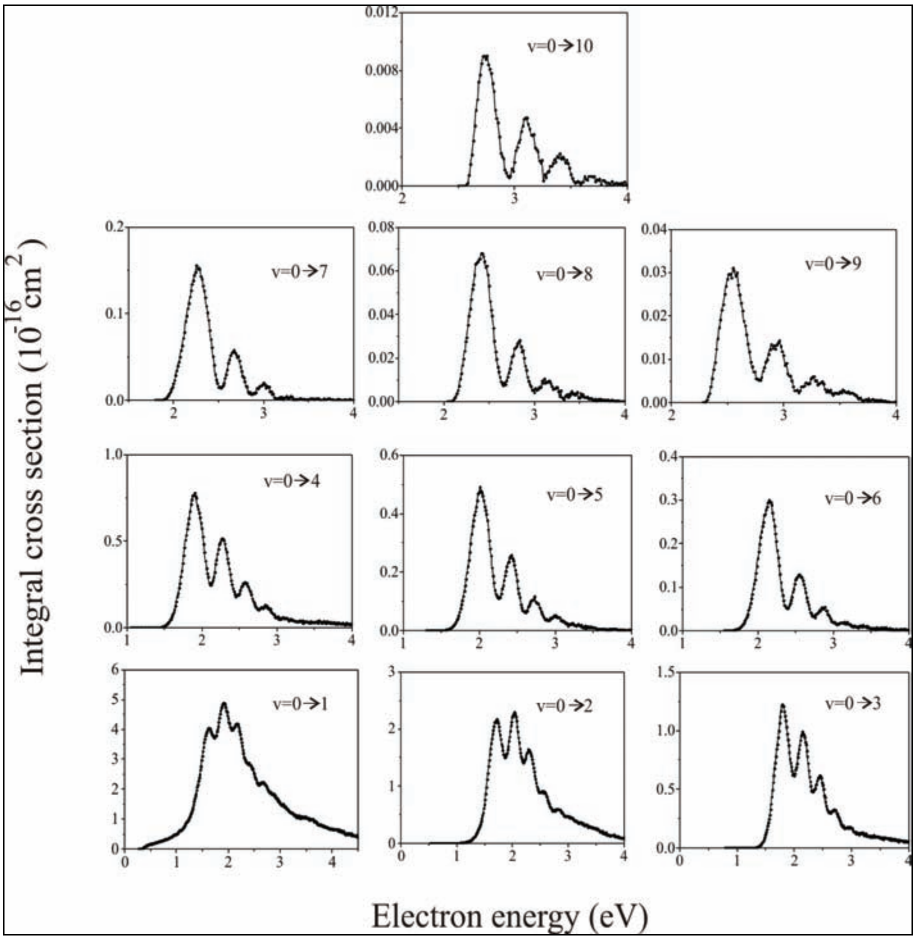

Fig. 2. Cross sections for resonant vibrational excitation of the CO molecule.

In order to resolve relative differential cross sections at 0° and 180°, we have used the procedure described in our recent measurements (Poparić *et al.* (2002, 2004)) in time-of-flight mode of spectrometer operation. The ratio of forward to backward DCS in the case of $^2\Pi$ resonant excitation of the CO molecule is found to be equal to (1.00±0.06), for all vibrational levels, and thus the angular distribution of scattered electrons to be symmetric relative to 90°. This conclusion supports the fact that the contribution of the $p\pi$ partial wave is dominant in the energy region of the $^2\Pi$ resonance in CO.

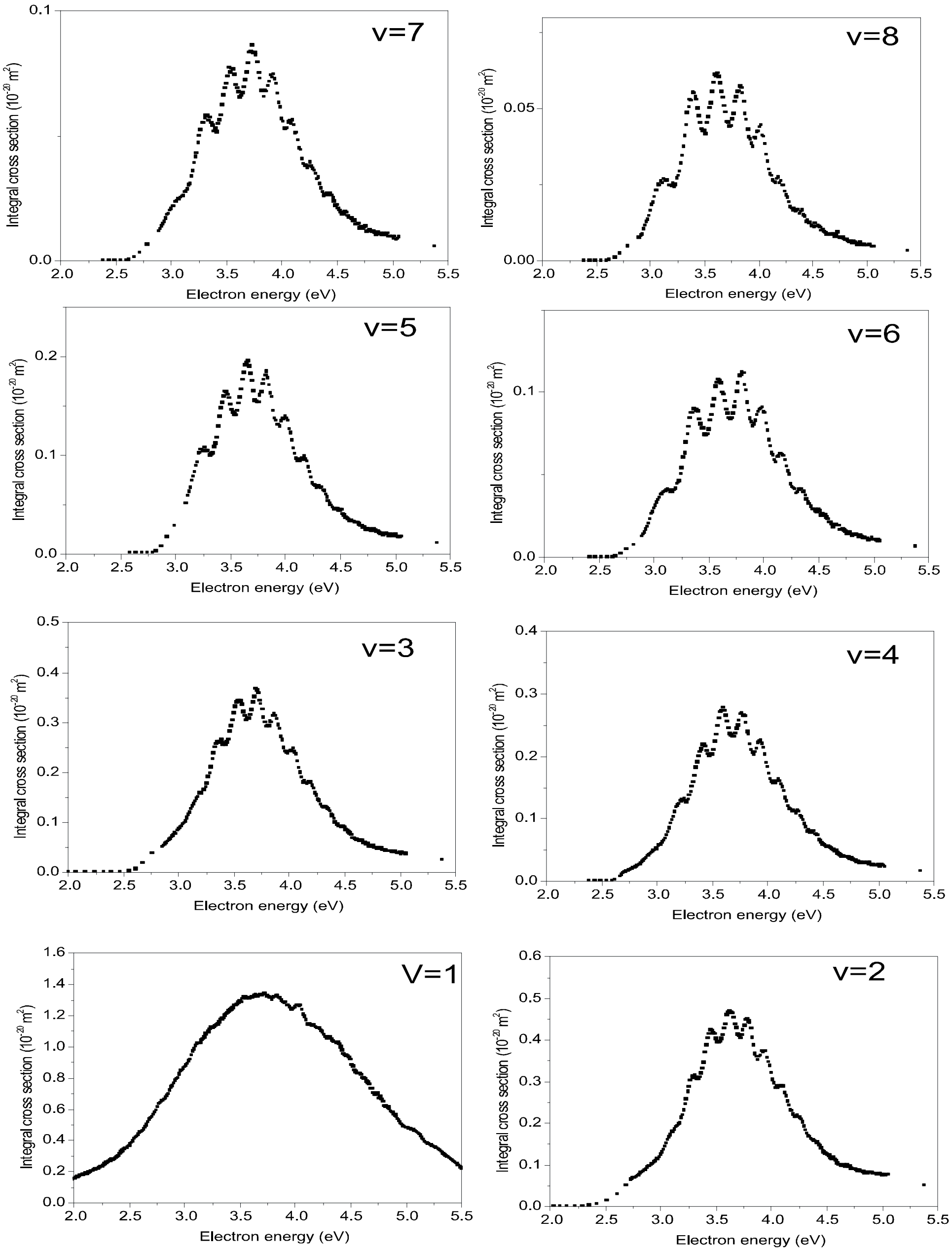

Fig. 3. Cross sections for resonant vibrational excitation of the CO_2 molecule.

We have measured the excitation functions from *v*=0 of the ground state of CO_2 to the first eight vibrationally excited states via the $^2\Pi_u$ resonance. Relative differential cross sections are obtained. The cross sections are normalized to the absolute integral cross section (ICS) value of $1.33*10^{-16}$ cm^2 at 3.8 eV in the v=1 excitation channel, obtained by the recent measurements of Kitajima *et al.* (2001). Our result for v=1 vibrational excitation is normalized, and other results are scaled relative to the v=1, by using number of counts for each particular vibrational channel under the same experimental conditions. Our normalized integral cross sections are obtained for the first time and presented in Figure 3.

ELECTRONIC EXCITATION OF THE N_2, CO MOLECULES

The cross sections of the C $^3\Pi_u$ state of N_2

The relative differential cross sections at zero degrees for excitation of the v = 0, 1 and 2 vibrational levels of the C $^3\Pi_u$ state of the nitrogen molecule have been measured (Poparić *et al.* (1999)). The obtained result is shown in fig. 4 (a). A sharp resonant peak at 11.49 eV in the v = 0 excitation channel belongs to the v= 0 level of the well known “window" type resonance $[N^+_2X^2\Sigma^+_g]$ $(3s\sigma_g)^2$ $^2\Sigma^+_g$ which has been assigned in previous measurements - in the electron transmission experiment Sanche and Shulz (1972), and in the a $^1\Pi_g$ Mazeau *et al.* (1973) and the B $^3\Pi_g$ Newmann *et al.* (1983) excitation measurements. A change of the slope, i.e. a weak bump just above 12.5 eV, in the v=0 DCS curve, can be associated to the $^2\Pi_u$ core excited resonances, seen by Mazeau *et al.* (1973) at 12.54 and 12.78 eV electron energy in the v=0 excitation channel of the C $^3\Pi_u$ state, the last one being very weak. These two energies are shown in the fig. 4 (a).

At the higher electron energies, additional structure is clearly seen in the energy region from 12.9 to 14.6 eV, in all vibrational levels. It consists of a series of peaks separated by about 230 meV from each other. These resonance structures were also seen in the electron transmission measurements, Sanche and Schulz (1972) in the differential cross section measurements of the E $^3\Sigma^+_g$, a″ $^1\Sigma^+_g$ and C $^3\Pi_u$ states, Mazeau *et al.* (1973), in the total cross section measurements of the metastable A $^3\Sigma^+_u$ production, performed by Lawton and Pichanick (1973); in a combined transmission and photon emission experiment of Golden *et al.* (1973); in a high sensitivity measurements of excitation functions of metastable states in N_2 performed by Newman *et al* (1983). Moreover, Mazeau *et al* (1973) have already seen the resonant structure, which designated as the $^2\Sigma^+_u$ resonance, in the v = 0 excitation channel of the C $^3\Pi_u$ state. Similar resonant structure was observed in other excitation channels, but we are aware of its possible artificial origin, due to the double scattering of incident electrons on the target gas (M.Allan (private communication)). The additional checks are needed. Our measurements are placed on an absolute scale by simultaneous measurements of the differential cross section for vibrational excitation of the v=1 level of the ground state of N_2, via the $^2\Pi_g$ resonance (Poparić *et al.* (1996), Ristić *et al.* (2007)), at 1.71 eV residual electron energy. The results are presented in figure 4(b).

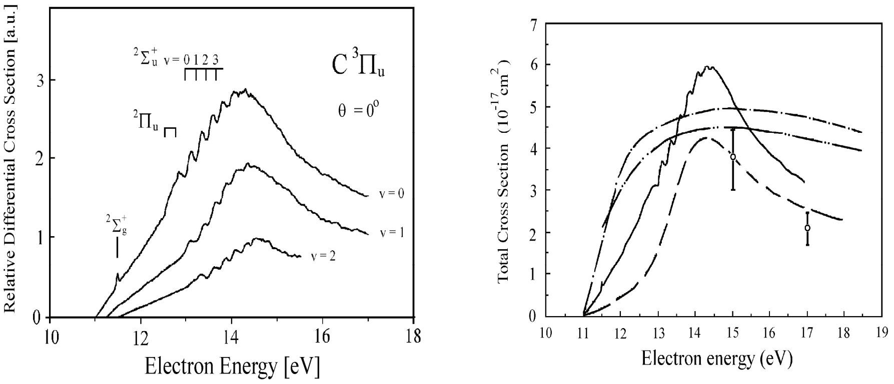

Fig. 4. (a) Differential cross sections at zero degree for excitation of the v=0, 1 and 2 vibrational levels of the C $^3\Pi_u$ state of N_2. (b) Total integral cross sections for excitation of the $C^3\Pi_u$ electronic state: — Present data; – – Zubek (1994) o Trajmar *et al.* (1983); – · – Cartwright (1970, 1972); – · · – Chung and Lin (1972).

The cross sections of the E $^3\Sigma^+_g$ state of N_2

The relative differential cross section for electron impact excitation of the v=0 vibrational level of the E $^3\Sigma^+_g$ state of the nitrogen molecule has been measured (Poparić *et al.* (1999)). A sharp resonant peak at the threshold, which is found at 11.94 eV, is in a good agreement with previous data Mazeau *et al.* (1973), Newman *et al.* (1983). It belongs to the core excited shape resonance with $^2\Sigma^+_u$ symmetry Mazeau *et al.* (1973). At incident energies of 12.14 eV and 12.38 eV, resonant contributions of the v=0 and v=1

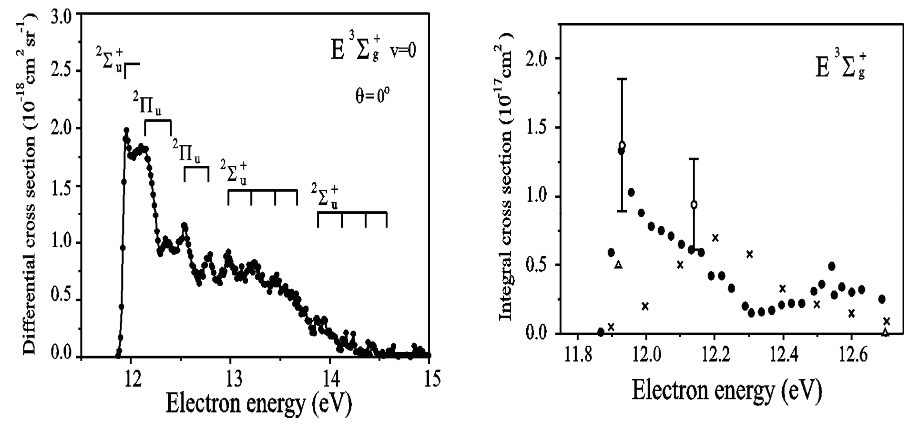

Fig. 5. (a) Differential cross sections at zero degrees for excitation of the v=0 vibrational level of the $E^3\Sigma^+_g$ state of N_2 from threshold to 15 eV. (b) Integral cross sections for excitation of the E $^3\Sigma^+_g$ state in the near- threshold region: o - present data; •- Brunger *et al.* (1990); x - Borst *et al.* (1972); Δ- Phelps and Pitchford (1985).

vibrational levels of the $^2\Pi_u$ core excited resonance Mazeau *et al.* (1973) can be seen. Two next peaks at 12.54 eV and 12.78 eV belong to the v=0 and v=1 vibrational levels of the second $^2\Pi_u$ core excited resonance Mazeau *et al.* (1973). At higher energies, starting at 12.98 eV, further resonant structure is observed, which belongs to vibrational levels of core excited resonance "band c" (Sanche and Shulz (1972), Mazeau *et al.* (1973)). At energy of 13.88 eV, another weak resonant structure can be recognized. It corresponds to the core excited resonance "band d" (Sanche and Shulz (1972), Mazeau *et al.* (1973)). All of these resonant energies are presented by vertical bars in fig. 5 (a), together with the corresponding term symbols for appropriate resonances. The results, after normalization, and correction to the transmission function, are presented in fig. 5 (a). Integral cross sections are obtained by using relative angular distributions measured by Mazeau *et al.* (1973) at 11.94 eV, and at 12.14 eV. Obtained results are presented in figure 5 (b).

The differential cross sections of vibrational levels of the a"$^1\Sigma^+_g$ state of N_2

Relative differential cross sections for excitation of the v= 0 and v=1 vibrational levels of the a"$^1\Sigma^+_g$ state of nitrogen have been measured in the region from threshold to 16 eV (Fig. 6.). At the incident energies of 12.54 eV and 12.78 eV, the resonant contributions of the v=0 and v=1 vibrational levels of the $^2\Pi_u$ core excited resonance are seen in both excitation functions. At the highest energies at 12.98 eV and 13.88 eV the next two resonant structures can be seen and they belong to the core excited resonances $^2\Sigma^+_u$ "band c" and "band d" (Sanche and Shulz (1972), Mazeau *et al.* (1973) and Newmann *et al.* (1983)). In the case of "band d" the Fano's phase shift is equal to π, and the position of the resonance is in a local minimum of diferential cross sections. All these resonant structures can be seen in Fig. 6. The results, after normalization, and correction to the transmission function, are presented in Fig. 6.

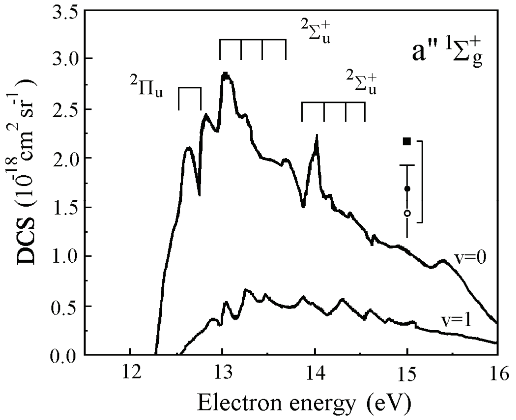

Fig. 6. Differential cross sections at zero degree for excitation of the v=0, 1 and 2 vibrational levels of the a"$^1\Sigma^+_g$ state of N_2. At 15 eV is shown sum of cross section: # , this work; !, Cartwright *et al.* (1977); +, Brunger and Teubner (1990).

Differential cross sections for the a$^3\Pi$ state of CO

The relative differential cross sections at zero degrees for excitation of the v = 0 to v=5 vibrational levels of the a $^3\Pi$ state of the carbon-monoxide molecule have been measured in the energy region from threshold to 11 eV. Our measurements are placed on an absolute scale by simultaneous measurements of the differential cross section for vibrational excitation of the v=5 level of the ground state of CO, via the $^2\Pi$ resonance, at 1.71 eV residual electron energy. This is performed by using the angular distributions of the scattered electrons measured by Zobel *et al.* (1996). The obtained results are shown in

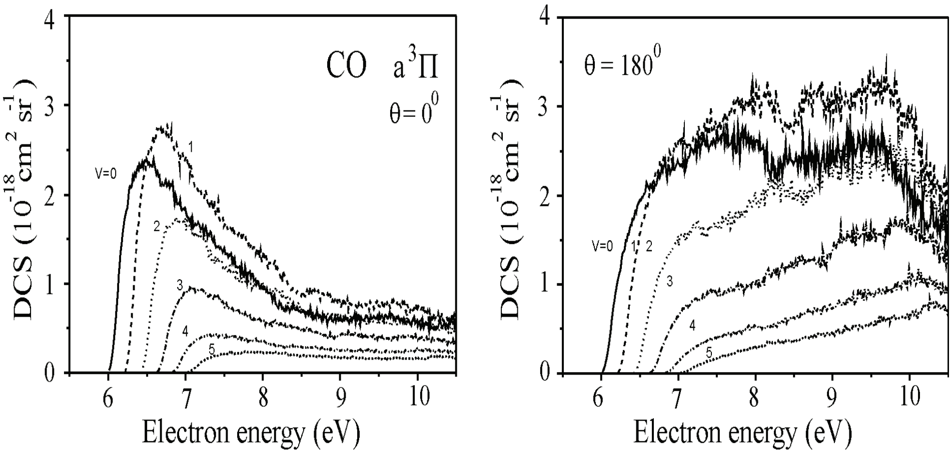

Fig. 7. Differential cross sections for excitation of v=0-5 levels of the a $^3\Pi$ state of CO.

The cross sections of the b $^3\Sigma^+$ state of CO

The relative differential cross sections for electron impact excitation of the v=0 vibrational level of the b $^3\Sigma^+$ state of the carbon monoxide molecule have been measured in the near-threshold electron energy region (Poparić *et al.* (2001)). All

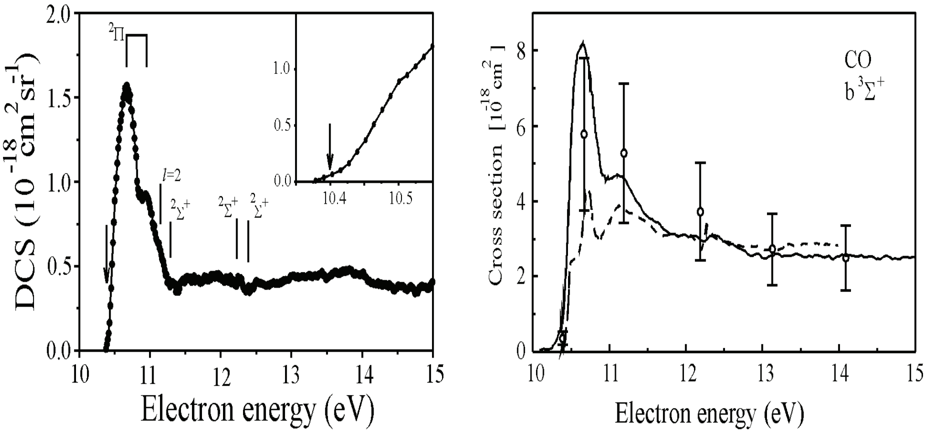

Fig. 8. (a) Differential cross sections at zero degrees for excitation of the v=0 vibrational level of the $b^3\Sigma^+$ state of carbon monoxide from threshold to 15 eV. The inset shows near-threshold region (see the text.).(b) Integral cross sections for excitation of the b $^3\Sigma^+$ state in the near-threshold region: o - present data; - - - Zobel *et al.* (1996); — Zubek *et al.* (1997).

resonant energies are presented by vertical bars in fig. 8 (a), together with the corresponding term symbols for appropriate resonances. In order to place our relative differential measurements to an absolute scale, we have performed simultaneous measurements of this process and the vibrational excitation of the ground state of the carbon monoxide molecule, via the $^2\Pi$ resonance. Integral cross sections are obtained by using relative angular distributions measured by Zobel *et al.* (1996) and by Mazeau *et al.* (1972). After integration we have obtained integral cross sections at the threshold energy of 10.40 eV, at $^2\Pi$ resonance energy of 10.70 eV, at 11.2 eV, 12.2 eV, at 13.14 eV and at 14.1 eV, respectively. Obtained results are presented in fig. 8 (b).

The cross sections of the B $^1\Sigma^+$ state of CO

The relative differential cross sections for electron impact excitation of the v=0 vibrational level of the B $^1\Sigma^+$ state of the carbon monoxide molecule have been measured in the near-threshold electron energy region. In order to place our relative differential measurements to an absolute scale, we have performed simultaneous measurements of this process and of the vibrational excitation of the ground state of the carbon monoxide molecule, via the $^2\Pi$ resonance. In order to resolve contributions of 0^0 and 180^0 scattered electrons, we used the angular distributions of the scattered electrons measured by Zobel *et al.* (1996). Obtained results are shown in Figure 9.

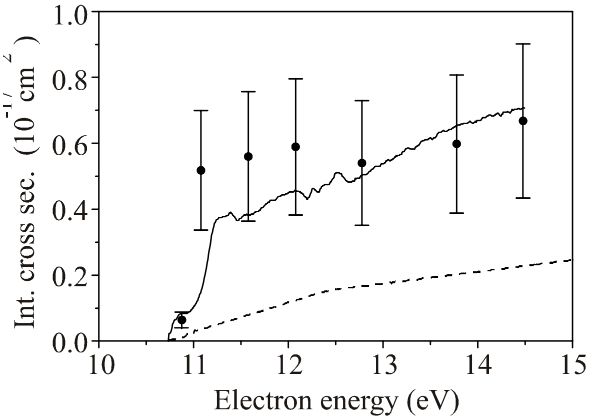

Fig. 9. Integral cross sections for excitation of the B $^1\Sigma^+$ state in the near-threshold region: ! - present data; — Zobel *et al.* (1996); - - - Skubenich (1967).

CONCLUSION

Low energy electron impact vibrational and electronic excitation cross sections of the CO, N_2 and CO_2 molecules are measured by use of a high resolution crossed-beams double trochoidal electron spectrometer. The spectrometer is designed to work in standard and time-of-flight regimes. The energy dependences of the resonant vibrational excitation of the first several vibrational levels of the N_2, CO, and CO_2 molecules, have been measured. Characteristic substructures in energy excitation spectra in the cases of N_2 and CO have been obtained and discussed for some vibrational channels for the first time. The ratio of forward-to-backward scattered electrons from the $^2\Pi$ resonance in CO is found to be equal to 1, and thus the angular distribution of scattered electrons to be symmetric relative to 90°. This conclusion supports the fact that the contribution of the p□ partial wave is dominant in the energy region of the $^2\Pi$ resonance in CO. The energy dependences of the near threshold resonant excitation of the valence and Rydberg states of the N_2 and CO molecules have been measured. The cross sections of the near threshold resonant excitation of the C $^3\Pi_u$ valence state, and the E $^3\Sigma^+_g$ and a'' $^1\Sigma^+_g$ Rydberg states of the N_2 molecule have been measured. In the case of the CO molecule, the cross sections of the near threshold resonant excitation of the a $^3\Pi$ valence state, and the b $^3\Sigma^+$ and B $^1\Sigma^+$ Rydberg states have been measured. Resonant structures in excitation functions of all measured electronic states are observed and their locations are compared with resonances obtained in different decay channels.

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REZONANTNA EKSITACIJA MOLEKULA ELEKTRONIMA NISKE ENERGIJE

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Mereni su diferencijalni preseci za ekscitaciju molekula CO, N_2 *i* CO_2*, pri čemu je korišćen dvostruki trohoidni elektronski spektrometar visoke rezolucije. Spektrometar je dizajniran za rad u standardnom režimu, i režimu merenja vremena preleta. Merena je energijska zavisnost rezonantne vibracione ekscitacije prvih nekoliko vibracionih nivoa molekula* N_2*, CO, i* CO_2*. Karakteristične podstrukture u spektru energijske zavisnosti u slučaju molekula* N_2 *i CO su snimljene i diskutovane po prvi put. Određen je odnos broja elektrona rasejanih unapred i unazad na* $^2\Pi$ *rezonanci oblika u slučaju molekula CO, pri čemu je dobijena vrednost 1, i tako je zaključeno da je ugaona raspodela rasejanih elektrona simetrična u odnosu na ugao od 90°. Ovakav rezultat odslikava činjenicu da je doprinos* $p\pi$ *parcijalnog talasa dominantan u energijskom regionu* $^2\Pi$ *resonance u slučaju molekula CO. Energijska zavisnost u blizini praga za rezonantnu ekscitaciju valentnih i Ridbergovih stanja molekula* N_2 *i CO je takođe merena. Mereni su efektivni preseci za ekscitaciju C* $^3\Pi_u$ *valentnog stanja, i E* $^3\Sigma^+_g$ *i a''* $^1\Sigma^+_g$ *Ridbergovih stanja molekula* N_2*. U slučaju molekula CO, mereni su efektivni preseci za ekscitaciju a* $^3\Pi$ *valentnog stanja, i b* $^3\Sigma^+$ *i B* $^1\Sigma^+$ *Ridbergovih stanja. Snimljene su rezonantne strukture u ekscitacionim funkcijama svih merenih elektronskih stanja i njihova lokacija je poređena sa strukturama dobijenim u različitim kanalima raspada rezonace.*