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Electron scattering from CO in the $^2\Pi$ resonance region

Stephen J. Buckman and Birgit Lohmann
Atomic and Molecular Physics Laboratories, Research School of Physical Sciences, The Australian National University, P.O. Box 4, Canberra, Australian Capital Territory, Australia 2600
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The total cross section for electron scattering from CO in the energy range 0.5–5 eV has been measured with use of a time-of-flight spectrometer. This energy region encompasses the $^2\pi$ shape resonance, and a comparison is made with other experimental and theoretical results with regard to the magnitude and position of this structure.

I. INTRODUCTION

Low-energy (<10 eV) electron scattering from carbon monoxide is dominated by excitation of the $^2\Pi$ shape resonance centered at around 2 eV. This feature, when observed in the total scattering cross section, has a width of about 1 eV. There have been a number of experimental[1–5] and theoretical[6–8] investigations of the total $e^- + \mathrm{CO}$ cross section in this energy region, but there still remain significant ($\sim 30\%$) discrepancies in the magnitude of the cross section at the resonance peak between the most recent measurements[4,5] and between the most recent theory[8] and experiment.[5]

Jain and Norcross,[8] in highlighting this discrepancy, have proposed that it may be due to the failure of the experiments, which are all of a transmission nature, to adequately discriminate against forward-scattered elastic and inelastic electrons. In these experiments the total cross section σ_T is obtained by use of the Lambert-Beer law,

$$\sigma_T = \frac{1}{NL} \ln \left[\frac{I_0}{I} \right],$$

where N is the gas number density in the scattering cell of length L, and I and I_0 are the intensities of transmitted electrons with and without gas in the cell, respectively. Inadequate discrimination against forward scattering results in an increase in I and thus a decrease in the measured cross section. As pointed out by Jain and Norcross,[8] the problem may be compounded in the case of low-energy electron scattering by CO as the differential cross sections for elastic,[9] pure rotational, and rovibrational[10] excitation are all strongly forward peaked in the energy region of the resonance. A similar situation may occur in the Ramsauer minimum region in argon where recent measurements[11–13] predict a considerably larger cross section minimum than earlier results.[14,15]

Kwan *et al.*[5] conducted their recent measurements in CO with a discrimination angle against forward scattering of 6° at an energy of 5 eV (the lowest energy for which a value of the discrimination angle is provided). Their resultant cross section of 45 Å^2 at the resonance peak lies approximately midway between the value obtained in the earlier measurements (~ 35 Å^2) and the theoretical value of 60 Å^2.

II. EXPERIMENTAL APPARATUS AND PROCEDURE

The present measurements were performed with a linear, time-of-flight electron-transmission spectrometer. The apparatus is described in detail in another publication[13] and only a brief description will be given here. A pulsed, high-energy (150 eV) electron beam is retarded in energy by a number of electrostatic lenses before passing through a gas cell 255 mm in length which is at a uniform potential. Those unscattered electrons which emerge from the cell are then detected by a channel-electron multiplier. The temperature of the gas cell is monitored using platinum-resistance thermometers, and the absolute number density of the target gas is measured with a spinning-rotor viscosity gauge. The final cross section at a given energy is determined by taking the weighted mean of a number of individual cross-section measurements. These measurements were obtained over a wide range of target-gas number density and electron optical settings. No dependence of the measured cross sections on these experimental conditions was observed over the entire energy range.

The pulsed nature of the experiment allows the absolute determination of the electron energy from the measured electron flight time. The time-of-flight (TOF) analysis is used to determine the electron energy up to an energy of 1.5 eV, at which point the absolute uncertainty in the energy is 54 meV. At higher energies the error in the calculated energy begins to increase rapidly. We therefore calibrated the energy scale at 1.5 eV, using the energy obtained from the time-of-flight analysis, and used this calibrated scale at higher energies (>1.5 eV). The error involved in this procedure comprises the 54-meV uncertainty from the TOF analysis and the uncertainty due to using only the peak channel of the Gaussian timing distribution at higher energies. The calibration at 1.5 eV and above was checked and adjusted by scanning across the $^2\Pi$ resonance peak in N_2 and comparing the structure observed with that obtained by Kennerly.[16] We estimate the absolute uncertainty to be ≤ 100 meV for energies above 1.5 eV.

III. RESULTS AND DISCUSSION

The problem of inadequate discrimination against forward-scattered electrons is a vexing one, and attempts to estimate the magnitude of the effect on the measured cross section are sometimes hindered by a lack of information on the appropriate elastic and inelastic differential cross sections.

In the present apparatus the limiting aperture at the end of the field free-drift space, which is located 10 mm from the exit aperture of the gas cell, subtends a solid angle of 1.66×10^{-4} sr with respect to the center of the scattering cell. This solid angle corresponds to a forward-scattering half-angle of 0.42°. Using cross sections which are 10 times larger than the reported theoretical and experimental elastic and rovibrational differential cross sections,[8-10] an estimate of the error introduced in the measured cross section by inadequate forward-scattering discrimination indicates that the effect on the cross section at the resonance peak is still less than 0.1%. We thus expect that any error in the present results due to lack of discrimination against forward-scattered electrons will be negligible. These estimates indicate that the effect of forward scattering on the data of Kwan *et al.*[5] will also be negligible.

The present results are plotted in Fig. 1, along with other experimental and theoretical results, and tabulated values are presented in Table I. It is immediately apparent that the magnitude of the resonance peak determined in this experiment is in poor agreement with that predicted by the calculation of Jain and Norcross,[8] with the theoretical value lying approximately 30% above the experimental result. One possible explanation for this discrepancy is the neglect of nuclear motion in the calculation.[17] The magnitude of the resonance peak in the present results is in good agreement with that measured by Kwan *et al.*,[5] the two data sets lying within the combined uncertainties in this region. There is also reasonable agreement (±100 meV) as to the position of the resonance peak in the two data sets, although there are significant differences in the magnitude of the measured cross sections below 1.9 eV. The position of the resonance peak in the present results ($E=1.95$ eV) is also in good agreement with the measurements of Szmytkowski and Zubek[4] and

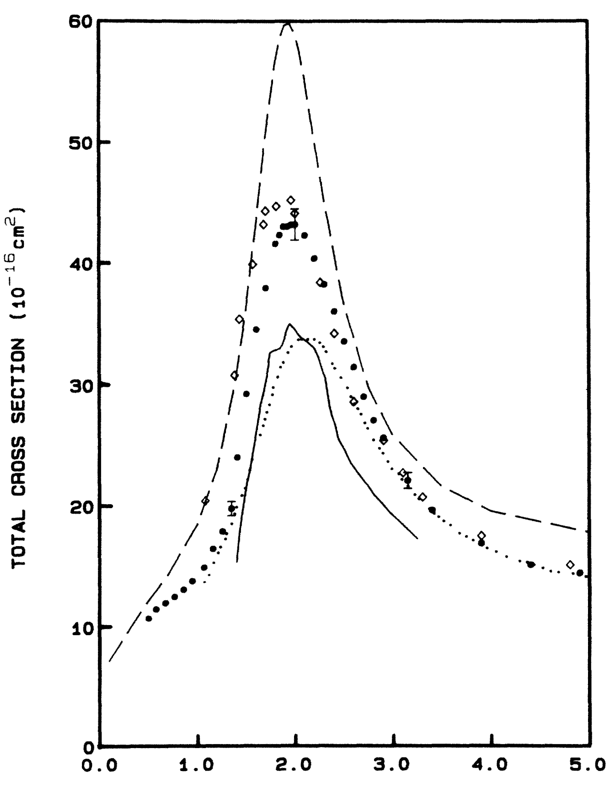

FIG. 1. Total electron scattering cross section for CO (in Å^2). ●, present results; ◇, Kwan *et al.*; ——, Szmytkowski and Zubek; · · · ·, Brüche; — — —, Jain and Norcross.

TABLE I. Total cross section measurements in CO.

Energy (eV)	σ_T (10^{-16} cm^2)[a]
0.500	10.69
0.533	11.03
0.575	11.45
0.625	11.73
0.670	11.96
0.717	12.19
0.763	12.46
0.805	12.74
0.854	13.06
0.905	13.44
0.945	13.77
0.995	14.19
1.064	14.90
1.158	16.45
1.253	17.89
1.346	19.78
1.405	24.02
1.50	29.25
1.60	34.54
1.70	37.95
1.80	41.61
1.82	41.94
1.84	42.32
1.86	42.73
1.88	43.02
1.90	43.52
1.92	43.03
1.94	43.44
1.96	43.17
1.98	43.24
2.00	43.19
2.10	42.30
2.20	40.38
2.30	38.24
2.40	36.02
2.50	33.56
2.60	31.45
2.70	29.01
2.80	27.07
2.90	25.62
3.15	22.07
3.40	19.62
3.90	16.90
4.40	15.12
4.90	14.44

[a] Errors $\pm3\%$ (1σ).

Brüche,[1] although the magnitude of the peak in both of these experiments is about 25% lower than that measured by us. As the data of Szmytkowski and Zubek have been normalized to the (2—20)-eV argon cross section measured by Golden and Bandel,[14] some, but not all, of this discrepancy can be accounted for by the fact that recent measurements[11-13] have shown that the data of Golden and Bandel may be low by as much as 10% in this energy range. We find that the data of Szmytkowski and Zubek can be brought into excellent agreement with the present results over the entire energy range of overlap by scaling by a factor of 1.25. However, the present results do not resolve any structure at the top of the resonance peak, as observed in the data of Szmytkowski and Zubek.

The measurements performed by Brüche[1] were obtained using the Ramsauer technique, and may have suffered from forward-scattering errors,[18] resulting in a smaller measured cross section in the peak. At energies above the resonance, however, the present results are in very good agreement with the measurements of Brüche.

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