Total cross sections for electron scattering from CO in the energy range 380–5200 eV

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(Received 22 March 1990)

Total cross sections for electron scattering by CO molecules in the energy range 380–5200 eV have been measured with experimental errors of 3%. The present results have been compared with available experimental cross sections. No previous data have been found in the literature for impact energies above 500 eV. The dependence of total cross sections on electron energy is in agreement with the Born-Bethe approximation.

I. INTRODUCTION

There is continuous interest in the study of total cross sections for electron scattering by atoms and molecules. The results of these studies are important for several fields of physics (e.g., astrophysics, plasma physics, atmosphere physics). Moreover, these data can be used to put differential cross-section values on an absolute scale. On the other hand, accurate total-cross-section measurements for high impact energies are required to compare with results of calculations performed in the Born approximation.[1] Nowadays new experimental methods are being developed in order to achieve more accuracy in total-cross-section measurements.[2] In the case of CO molecules, previous experiments were carried out at electron energies below 500 eV.[3–9] The results of these experiments have been summarized by several authors.[10,11] The lack of experimental total cross sections at energies above 500 eV prompted this work.

In the present experiment total cross sections for electron scattering from CO molecules have been measured in the energy range 380–5200 eV by a transmission-beam technique. Special attention was paid to avoid systematic errors arising from forward electron scattering.

II. EXPERIMENTAL SETUP

The experimental setup is based on the previously described one.[12,13] Some changes were made in order to improve the energy resolution and the sensitivity of the electron detector system. A schematic diagram of the apparatus is shown in Fig. 1. The electron gun is composed of a tungsten filament, electrostatic lenses, and deflection plates. The pressure in the gun was maintained lower than 10^{-5} Torr during the experiment. The collision chamber is limited by two apertures 1 mm in diameter separated by a variable length (L) that can be changed in the range 70 to 127 mm, according to the experimental requirements. The beam intensity in the scattering chamber was typically 10^{-14} A. The gas pressure was measured by an absolute capacitance manometer (MKS Baratron 127A). In order to discriminate the inelastically scattered electrons in the forward direction, a hemispherical electrostatic analyzer has been used. The analyzer consists basically of two concentric 180° spherical sector surfaces: an inner convex one of radius 72.6 mm and an outer concave surface of radius 91.1 mm. By using 1-mm-diam entrance and exit apertures, the energy resolution was better than 0.5% with respect to the energy inside the analyzer of transmitted electrons. Retarding the electron beam by means of an electrostatic lens at the entrance of the analyzer, a constant energy resolution of 1 eV full width at half maximum for the energy range of this experiment (380–5200 eV) has been obtained. The transmitted electrons have been detected by a channeltron electron multiplier in single-pulse operation. The corresponding signals were registered by a ratemeter and

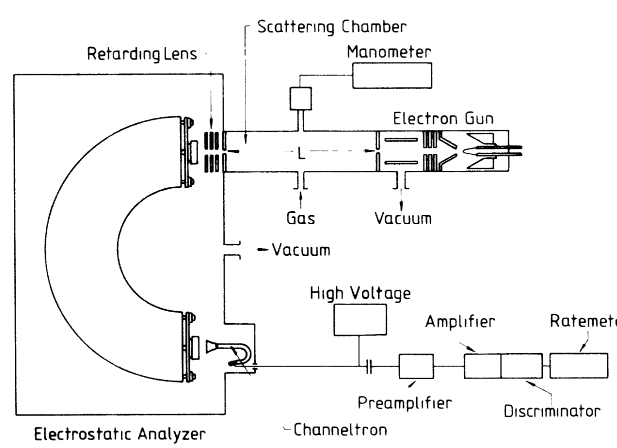

FIG. 1. Schematic diagram of the experimental setup.

a digital counter. The count rate was typically about 10^3 pulses per second with a background signal rate of 30 pulses per minute. The energy analyzer and the electron multiplier were maintained at a pressure below 10^{-5} Torr during the measurements.

III. PROCEDURE

The method is based on the measurement of the electron-beam attenuation through the gas cell. The transmitted beam intensity follows the well-known law

$$I = I_0 \exp(-NL\sigma_t) ,$$

where I_0 is the intensity of the primary beam, I is the attenuated-beam intensity, L is the interaction-region length, N is the molecular density, and σ_t is the total cross section. N is obtained from the measurement of pressure and temperature in the gas cell. Each measurement was performed at gas pressures ranging from 2 to 70 mTorr. The accuracy of the pressure measurements was estimated as better than 1%, as stated by the manufacturer of the MKS Baratron 127A.

As pointed out in a recent article,[2] accurate measurement of the attenuation of an electron beam requires discrimination of the forward-scattered electrons. For this reason we have used an electrostatic analyzer to study the energy of the electrons reaching the detector. Figure 2 shows an energy-loss spectrum for 2055-eV electrons and 80-mTorr CO pressure in the collision chamber. As mentioned above, the energy resolution was the same for the whole energy range considered in this experiment. Figure 2 shows that the present energy resolution was enough to eliminate the contribution of forward inelastic scattering.

The contribution of electrons elastically scattered in the forward direction can be minimized by reducing the angular acceptance of the analyzer. In the conditions of

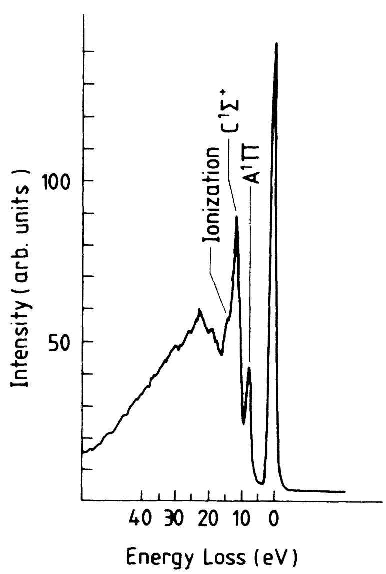

FIG. 2. Energy-loss spectrum of CO for 2055 eV incident electron energy. Positions of characteristic energy levels of CO are shown with vertical lines.

this experiment, the solid angle subtended by the entrance aperture of the analyzer as seen from the center of the gas cell was typically 10^{-5} sr. By extrapolating the elastic differential cross sections measured by Du Bois and Rudd[14] to zero angle, we have estimated a forward elastic scattering error contribution less than 0.1% at 800 eV impact energy.

Measurements were performed at electron currents ranging from 10^{-15} to 10^{-14} A. In this range no dependence of the total cross section on the electron current was found. The length of the collision chamber was changed from 70 to 127 mm. The corresponding values obtained for the total cross sections were in agreement within statistical uncertainties—namely, 2%. This result proves that our measured length corresponds, with good approximation, to the actual absorption length and that possible multiple-scattering effects are negligible in our experimental conditions, taking into account statistical uncertainties.

IV. RESULTS AND DISCUSSION

The present experimental results of total cross sections for electron scattering by CO molecules in the energy range 380–5200 eV are shown in Table I. The experimental error of these values is 3%, obtained as a combination of the aforementioned partial errors. Experimental data given in Refs. 6 and 7 are also included in this table for comparison. There is good agreement be-

TABLE I. Experimental total cross sections (in units of a_0^2) for electron scattering from CO.

	Cross sections		
E_0 (eV)	This work[a]	Ref. 7[b]	Ref. 8[c]
381	15.4		
400		14.7	13.1
500		12.7	
569	11.7		
763	9.42		
968	7.94		
1045	7.38		
1168	6.92		
1232	6.51		
1341	6.05		
1445	5.81		
1535	5.60		
1633	5.31		
1835	4.87		
2055	4.44		
2384	4.01		
2826	3.48		
3280	3.08		
3797	2.77		
4252	2.56		
4756	2.36		
5254	2.17		

[a]Experimental errors: 3%.
[b]Statistical uncertainties: 0.8%.
[c]Experimental errors: 6.5%.

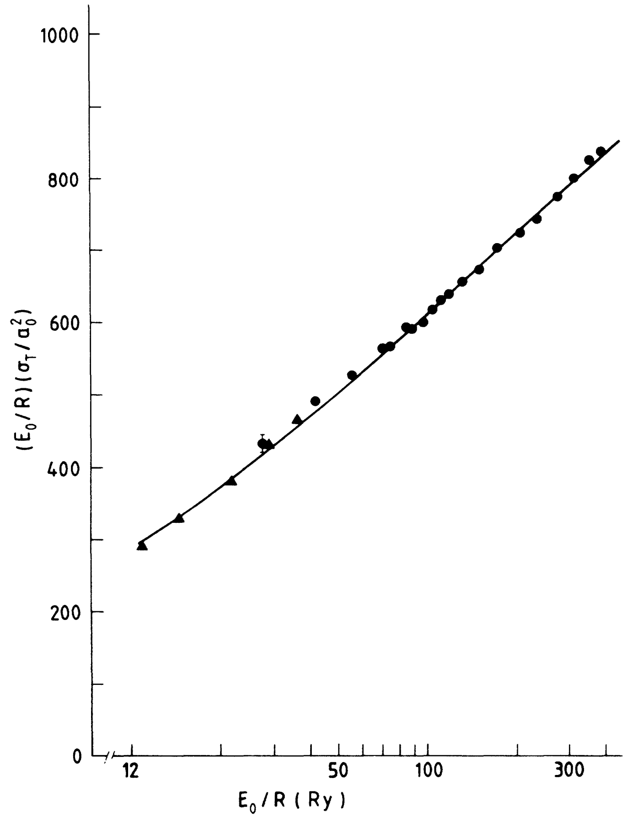

FIG. 3. $(E_0/R)(\sigma_t/a_0^2)$ plotted vs E_0/R on a logarithmic scale for CO. ●, present experimental values (experimental error for the lower energy is shown). ▲, experimental values from Ref. 7. –, values obtained fitting the expression of Born-Bethe total cross sections as a function of E_0/R to the experimental points.

tween the results of this work and those obtained by Kwan *et al.*[7] in the overlapping energy range. The value published by Sueoka and Mori,[8] for 400 eV impact energy, is about 12% lower than the present one.

In Refs. 15 and 16 the total elastic (σ_{el}) and total inelastic (σ_{inel}) cross sections are given, according to the Born approximation and the Born-Bethe theory, as

$$\frac{E_0}{R}\frac{\sigma_{el}}{a_0^2}=\pi\left[A+B\frac{R}{E_0}+\cdots\right], \tag{1}$$

$$\frac{E_0}{R}\frac{\sigma_{inel}}{a_0^2}=4\pi\left[M_{tot}^2\ln\left[4C_{tot}\frac{E_0}{R}\right]+\gamma_{tot}\frac{R}{E_0}+\cdots\right], \tag{2}$$

where E_0/R is the energy of incident electrons in rydberg units and a_0 is the Bohr radius. The constants A, B, M_{tot}, C_{tot}, and γ_{tot} are defined in Refs. 15 and 16 for electron atom scattering and have been applied for homonuclear diatomic molecules in Ref. 1. In a previous work[14] we found that the total cross sections (σ_t) evaluated from Eqs. (1) and (2) by using the A, B, M_{tot}, C_{tot}, and γ_{tot} values available in the literature for N_2 are higher than the experimental data. However, the energy dependence of calculated total cross sections was in agreement with the experiments. To our knowledge there are no calculated Bohr-Bethe parameters for the CO molecule but we consider it interesting to fit our experimental results and those of Kwan *et al.*[7] for energies above 150 eV to the expression obtained by adding Eqs. (1) and (2). In this way we obtained for the electron energy range 150–5200 eV the expression

$$\frac{E_0}{R}\frac{\sigma_t}{a_0^2}=-152+164.4\ln\left[\frac{E_0}{R}\right]+411\left[\frac{R}{E_0}\right]. \tag{3}$$

In Fig. 3, $(E_0/R)(\sigma_t/a_0^2)$ is plotted versus E_0/R on a logarithmic scale for the present experimental values and for those of Kwan *et al.*[7] at impact energies above 150 eV together with the Born-Bethe result. As can be seen from this figure, the Born-Bethe approximation gives a correct dependence of total cross sections on the electron energy. Also, the fitted parameters can be useful to compare with further calculations and to extrapolate total-cross-section values at higher energies.

ACKNOWLEDGMENTS

This work was performed under partial financial support of the Spanish Comisión Interministerial de Ciencia y Tecnología (CICYT) (Project No. PB86/0543).

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