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Total electron scattering cross sections of CF_4 and C_2F_6 in the energy range 100–1500 eV

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Abstract

The total electron scattering cross sections of CF_4 and C_2F_6 have been obtained for 100–1500 eV energy electrons by measuring the attenuation of the electron beam through a gas cell. These cross sections are compared to existing experimental and theoretical cross sections of these molecules. A comparison of the cross section ratio C_2F_6/CF_4 with the cross section ratio C_2H_6/CH_4 indicates a strong correlation between the cross sections and the number of electrons in these molecules.

Keywords: Electron scattering; Total cross sections; Ethane-related molecules; Flurocarbons and hydrocarbons

1. Introduction

Accurate total electron scattering cross sections of tetrafluoromethane (CF_4) and hexafluoroethane (C_6F_6) for a wide range of electron energies are required in many applied sciences and industrial applications (Hunter et al., 1985; Butterbaugh et al., 1991; Kimura and Itikawa, 2001). Also, these cross sections are indispensable tools in developing and testing the theoretical models to understand the interaction process between the energetic electrons and molecules. In general, the cross section measurements above 400 eV are scarce. For CF_4 and C_6F_6 one experimental study of the cross sections for each molecule is reported in the literature for electron energies higher than 400 eV. Zecca et al. (1992) measured the total scattering cross section of a series of chlorofluoromethane molecules including CF_4 for 75–4000 eV energy electrons. Very recently, while the present experiment was in progress, Sueoka et al. (2002) reported the experimental cross sections of C_2F_6 for 1–600 eV energy electrons. No cross sections are reported in literature for C_2F_6 above 600 eV.

The present experiment was undertaken to measure the absolute total cross section of CF_4 and C_2F_6 for 100–1500 eV electron energies. These cross sections are compared with existing experimental measurements (Zecca et al., 1992; Sueoka et al., 2002) and the theoretical predictions (Jiang et al., 1995; Baluja et al., 1992). Though the interest of this study is to measure the cross section above 400 eV, the energy range was extended down to 100 eV to compare the present measurements with those produced by Sueoka et al. (1994) for CF_4 and Szmytkowski et al. (1992, 2000) for CF_4 and C_2F_6.

2. Experimental

The experiment was designed to measure the total electron scattering cross section based on the linear transmission technique. The schematic diagram of the experimental arrangement is shown in Fig. 1. An electron gun was mounted on a vacuum chamber maintained in the low 10^{-7} Torr region. A well-collimated narrow electron beam was obtained from the gun by passing the electron beam through three well-aligned 0.76 mm (0.03 in) diameter apertures. This electron beam, typically about 10^{-10}–10^{-13} A, enters

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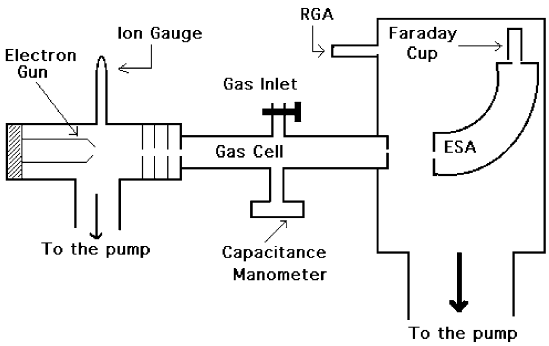

Fig. 1. The experimental arrangement.

the gas cell which was defined by two apertures, 1 mm (0.04 inch) diameter, separated by 16–32 cm variable length. The gas pressure in the gas cell was measured by a MKS Baratron 126 A capacitance manometer. Electrons emerging from the gas cell enter a Comstock AC 902 double focusing electrostatic analyzer (ESA) whose entrance is 4.5 cm away from the exit of the gas cell. The ESA was operated at 50 eV constant energy transmission mode with 1 mm diameter entrance and exit apertures. At this setting the ESA energy resolution (FWHM) is 0.75 eV or better. The ESA energy scale, measured to 0.1 eV or better, has been calibrated against the argon LMM and neon KLL Auger lines. Energetically analyzed electrons were collected on a Faraday cup and the intensity was measured by a Keithley Model 6517-A electrometer. Both the ESA and the Faraday cup were housed in a vacuum chamber maintained at 1×10^{-6} Torr or better. During the beam intensity measurement with the presence of the gas in the gas cell, the pressure in this region and the electron gun region was maintained at 1×10^{-5} Torr. The ESA, gas cell, electron gun, and the entire electron optics system were shielded from earth's magnetic field and other stray magnetic fields by 0.06 in thick mu-metal. The chamber which was housing the ESA was also equipped with a residual gas analyzer (RGA) to confirm the purity of the gases and to guarantee no air or other contaminants leak into the gas cell through the gas transport system.

3. Procedure and errors

The experimental procedure is based on the measurement of electron beam intensity attenuation through a gas. The intensity of the primary beam and attenuated beam, respectively, are I_0 and I

$$I = I_0 e^{-\sigma n p L},$$

where n is the number density of molecules at 1 mTorr pressure, p is the pressure in the units of mTorr, L is the electron–gas interacting length, and σ is the total electron scattering cross section. According to this relationship, the variation of $\ln(I/I_0)$ with the pressure (p) is a straight line whose slope is the product of n, L and σ. An accurate determination of scattering cross section requires an accurate measurement of p, I_0, I and L.

In the present experiment, the pressure was measured by a MKS Baratron 626 A capacitance manometer. Possible errors in the pressure measurement by this device are mainly due to the temperature differences inside the capacitance manometer head and zero drifts in the scale. According to the manufacturer specifications, the combined error due to temperature differences and zero drift is estimated to be 2% or less. In beam attenuation type cross section measurements, it is important to ensure that there is no pressure gradient along the gas cell. To confirm this, the pressure in the gas cell was measured at three different points along the gas cell. All three measurements agreed to each other within the experimental error of the pressure measurement indicating no significant pressure gradient along the gas cell. Further, an estimation of the gas pressure at the ends of the gas cell was carried out by using the differential pumping speeds, area of apertures, and background pressure at the electron gun region and the ESA region. Again, no evidence of significant pressure gradient was observed.

The primary beam current (I_0) and attenuated beam current (I) were measured using the ESA, Faraday cup, and electrometer combination. Since the ESA deflects inelastically scattered forward electrons, I_0 and I could be measured accurately by passing the electron beam through the gas cell and measuring the current on the Faraday cup in the absence of the gas and in the presence of the gas. However, in this method elastically scattered electrons in the forward direction are not discriminated. In the present experiment, the solid angle subtended by the entrance of ESA and center of the gas cell is about 1.2×10^{-5} sr. Contributions from the zero degree elastic scattering to this solid angle were estimated by extrapolating the experimental elastic scattering differential cross sections (Takagi et al., 1994) for C_2F_6. It was found that the greatest error due to the contribution of zero degree elastic scattering is about 1% for C_2F_6 for the energies higher than 100 eV.

In the present experiment, the geometrical length of the gas cell is the actual gas–electron interaction length (L). This was concluded by measuring the total electron scattering cross section for three different gas cell lengths, 16; 24.5; and 32 cm, and observing the fact that these cross sections are independent of the length within the experimental uncertainties. All the cross section measurements were performed using 10^{-10}–10^{-13} A electron currents and 0.5–6 mTorr gas pressures. For these current and pressure ranges no dependence of the cross section was found either on current or on pressure. Research grade target gases of CF_4 and C_2F_6 from Matheson Co., Laporte, Texas, all within minimum purity 99.8% or better were used. An on-site RGA, attached to the vacuum system where the ESA was housed, was used to make sure there is no air leak or other gas contaminant in the gas transport system.

Errors in the electron scattering cross section measurements are as follows: (1) determination of interaction length (3%); (2) pressure measurement (2%); (3) contribution of zero degree elastic scattering (1%); (4) beam current measurement, including the possible drift in the current during the experiment (1%); (5) statistical errors in determination of the slope (1%). These random errors combine in quadrature to give an overall error assignment of 4% or less for the electron energies 200–1300 eV. At 100, 1400, and 1500 eV the beam current was not stable as at other energies. As a result, there is an additional 3% error, giving the total error 5% or less, in the measurements at these energies.

4. Results

The variation of the $\ln(I/I_0)$ with the pressure of C_2F_6 gas is given in Fig. 2 for several electron energies between 200 and 1400 eV. Same type of variation was observed for CF_4. The experimental points lie on the straight line whose slope is equivalent to $nL\sigma$. The slope was determined by the best linear fit to the data, and converted into the cross section. For a given electron energy, the cross sections obtained in this manner for six–eight independent experimental runs were averaged. Listed in Table 1 are the averaged cross sections as a function of energy.

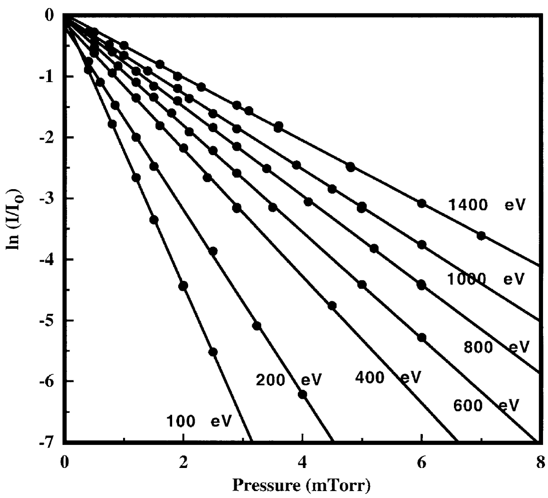

Fig. 2. Variation of the $\ln(I/I_0)$ with the pressure for C_2F_6 gas at selected energies.

Table 1
The total cross sections for electron scattering from CF_4 and C_2F_6 in $10^{-20}\,m^2$ units for intermediate electron energies

Energy (eV)	CF_4	C_2F_6
100	18.37±0.97	25.65±1.35
200	13.06±0.5	17.99±0.97
300	10.27±0.47	15.17±0.78
400	8. 86±0.42	12. 83±0.65
500	7.77±0.35	11.57±0.58
600	6.81±0.31	10.40±0.47
700	6.14±0.30	9.20±0.38
800	5.71±0.25	8.55±0.37
900	5.17±0.25	7.82±0.31
1000	4.85±0.23	7.36± 0.30
1100	4.55±0.23	6.90± 0.31
1200	4.21±0.21	6.59± 0.30
1300	3.94±0.18	6.15±0.27
1400	3.84±0.12	5.92±0.28
1500	3.73±0.12	5.72±0.28

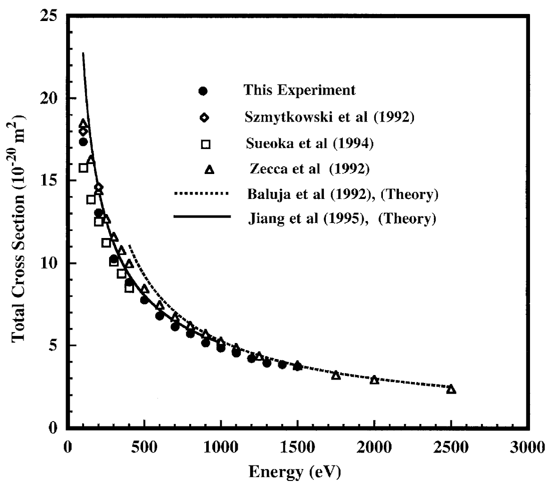

Fig. 3. The total scattering cross sections in $10^{-20}\,m^2$ for CF_4 gas.

5. Discussion

Figs. 3 and 4 display the variation of the cross section produced in the present experiment with the electron energy. In the same figures, the experimental cross sections produced in other laboratories as well as the existing theoretical predictions are given for comparison. As can be seen from Fig. 3, the experimental cross sections produced in this experiment are in agreement with those of Zecca et al. (1992) within the experimental uncertainties for the energies higher than 400 eV. At 400 eV and lower energies, the cross sections in this work are in agreement with those of Sueoka et al. (1994) while 7–8% lower than those of Zecca et al. (1992) and

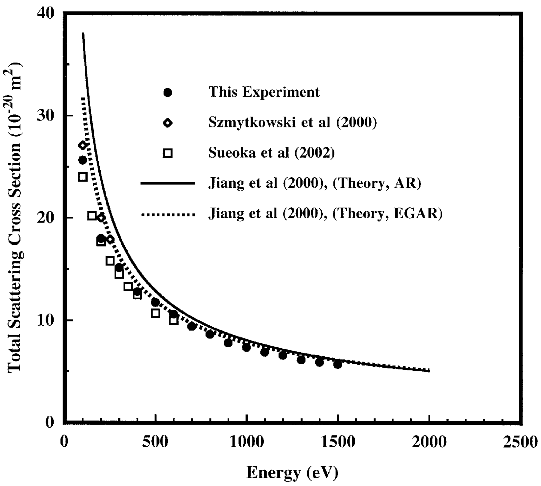

Fig. 4. The total scattering cross sections in $10^{-20}\,m^2$ for C_2F_6 gas.

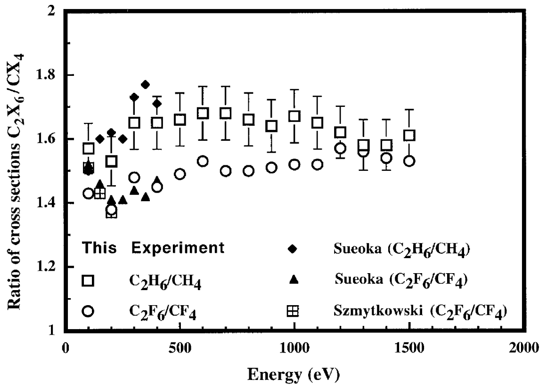

Fig. 5. Comparison of the C_2H_6 to CH_4 cross section ratio with the C_2F_6 to CF_4 cross section ratio at different electron energies.

Szmytkowski et al. (1992). In general, the cross sections produced in all four laboratories spread out about 7–15% at 400 eV and lower energies but tends to follow the same general trend. In comparison with theories, it is evident that Baluja et al. (1992) predictions at 1000 eV and higher are in good agreement with the experimental values while those at lower energies are overpredicted. In contrast, at 1000 eV and lower energies (down to about 200 eV), the theoretical predictions by Jiang et al. (1995) are in good or closer agreement with the experimental cross sections. No predictions are made by Jiang et al. (1995) for energies higher than 1000 eV.

As displayed in Fig. 4, the C_2F_6 cross sections produced in this experiment are in closer agreement with those of Sueoka et al. (2002) but about 8% lower than those of Szmytkowski et al. (2000) where the energies of three experiments overlap. In comparison of present experimental C_2F_6 cross sections with the predictions of those by Jiang et al. (2000) using two theoretical models (AR model and EGAR model), it is evident that their predictions of the EGAR model are in closer agreement with the experimental cross sections while those of AR model are consistently higher than the present experimental cross sections.

Next, the cross sections of CF_4 and C_2F_6 are compared to the cross sections of CH_4 and C_2H_6 produced in this laboratory in a recent experiment (Ariyasinghe and Powers, 2002). The molecular symmetry of CF_4 and C_2F_6, respectively, are identical to that of CH_4 and C_2H_6. However, the polarization effects in CF_4 and C_2F_6 are much larger than those in CH_4 and C_2H_6. In order to compare the cross sections of two fluorocarbons with the cross sections of two hydrocarbons by alleviating polarization effects, the C_2F_6 / CF_4 and C_2H_6 /CH_4 cross section ratios are scaled as a functions of energy in Fig. 5. It is interesting to see in this figure, the two ratios are closely equal to each other while the ratio of the fluorocarbons consistently falls below the ratio of the hydrocarbons for the entire energy range. Average ratio for the hydrocarbons and fluorocarbons, respectively, are 1.63 and 1.43. Using these average ratios, if one calculates the hydrocarbon to fluorocarbon ratio it would be 1.14 which is the ratio of the number of electrons in these molecules. In other words, the fraction $(C_2H_6/CH_4)/(C_2F_6/CF_4)$ in terms of cross section is equivalent to the same fraction in terms of the number of electrons in the molecules. This fact indicates a strong correlation between the cross sections and the number of electrons in these molecules.

6. Conclusion

Total electron scattering cross sections of CF_4 and C_2F_6 have been measured for 100–1500 eV electrons. The measured cross sections are in fair agreement with the reported cross sections in the literature. In a comparison of the cross sections of CF_4 and C_2F_6 with the cross sections of CH_4 and C_2H_6, it revels a strong correlation between the total cross section and the number of electrons in the molecule.

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