SF_6 absolute total electron scattering cross section in the 75–4000 eV energy range

A. Zecca, G. Karwasz [1] and R.S. Brusa
Università di Trento, Dipartimento di Fisica, 38050 Povo, Italy

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Total absolute cross sections for electron SF_6 scattering have been measured in the 75–4000 eV energy range. The data have been fitted with a Born-like formula. A comparison with other experimental data and partial cross sections is presented.

1. Introduction

The SF_6 molecule has received much attention in recent years. Measurements have been performed with probably all available spectroscopies to elucidate the molecular structure, electronic, vibrational and rotational levels, and interaction mechanisms of this molecule with laser, ion and electron beams. Part of this interest has been triggered by the similarity of this molecule with the UF_6 molecule which is important for uranium isotope separation. The SF_6 has been considered an easily obtainable substitute for UF_6. And the SF_6 molecule has been used for a long time in high-voltage gas insulation and related technologies. The peculiar structure of this molecule has promoted theoretical and experimental work. In the field of electron collisions, total electron scattering cross sections exist in the energy range from less than 0.05 to 700 eV [1–5]. Differential electron SF_6 cross sections have been measured by Srivastava et al. [6] and Sakae et al. [7]. Ionization cross sections have been measured by Rapp and Englander-Golden [8] and more recently by Margreiter et al. [9]. Stański and Adamczyk [10] have measured relative ionization cross sections. Dehmer et al. [11] have performed theoretical calculations of the e^-–SF_6 total cross section in the 0–40 eV energy range.

Correspondence to: A. Zecca, Università di Trento, Dipartimento di Fisica, 38050 Povo, Italy.
[1] Permanent address: Polish Academy of Sciences, IMP-PAN, Gdańsk, Poland.

2. Experimental

The measurements were performed with a Ramsauer-type electron spectrometer [12]. At each fixed energy the electron beam attenuation caused by scattering in the collision chamber was measured by monitoring both the decrease of the current reaching the collector (I_c), and the increase of the scattered current intercepted by the scattering chamber (I_s). With this provision the Beer–Lambert attenuation law takes the form:

$$I_{c1}/(I_{c1}+I_{s1}) = [I_{c2}/(I_{c2}+I_{s2})] \times \exp[-\sigma(E)L(N_1-N_2)] ,$$

where L is the path length of electrons in the scattering chamber (140.2 mm in our spectrometer), $N_{1,2}$ is the gas density corresponding to two different pressures, and $\sigma(E)$ is the total cross section. The apparatus and the measurement procedure have been described [12] and we refer to this paper for details. Here, we only recall a few characteristics which determine the quality of the measurements. The scattering chamber is split into two parts: the first containing the gas and the second with a much lower pressure. This apparatus allows us to achieve a good angular resolution: the acceptance of the collector is 4×10^{-4} sr. This low value allows us to perform mea-

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surements up to energies of 4 keV with a negligible angular resolution error. The use of the data of Sakae et al. [7] lets us set an upper limit for our angular resolution error. This is less than 0.25% at 75 eV and less than 0.5% at 700 eV. The cathode region is differentially pumped: this reduces the ion bombardment on the cathode, improving the beam stability and avoiding discharges. The background pressure in the optics is kept constant during each measurement regardless of the pressure in the scattering chamber: this again improves the measurement stability. The capacitance manometer head tracks electronically the scattering chamber temperature within a fraction of a degree: this avoids thermal transpiration.

Each measured value reported later is the average of several runs (typically 5) performed in different electron-optical situations. The statistical uncertainty (one standard deviation of the average) is less than 3% in the entire energy range. The systematic error was evaluated to be about 3% at the lowest and highest portions of the energy range; about 2.5% elsewhere.

The SF_6 was a commercial grade gas with a stated purity of 99.5%.

3. Results

The results of the present measurements are given in a numerical form in table 1 and in graphical form in fig. 1. Fig. 1 also shows the measured values of Dababneh et al. [5] and those of Kennerly et al. [1]. The SF_6 cross section falls monotonically from a value of 27.4×10^{-20} m^2 at 80 eV to a value of 2.7×10^{-20} m^2 at 4000 eV. Our measurements are generally higher than those of Dababneh et al. (2% to 6% in the overlap range from 75 to 700 eV) and those of Kennerly et al. (3% to 5% in the overlap range from 75 to 100 eV). Although these discrepancies are within the combined error bars, it is worth noting that the discrepancy with Dababneh et al. [4] is in the same direction and same magnitude as found in previous measurements on other gases (see for instance Zecca et al. [12,13]). The data of Kennerly et al. could suffer from an angular resolution error.

Fig. 1 reports the same data and the ionization cross sections of Rapp and Englander-Golden [8].

Table 1
e^-–SF_6 total absolute cross sections

Energy (eV)	Cross section (10^{-20} m^2)	Energy (eV)	Cross section (10^{-20} m^2)
75	27.7	550	11.9
80	27.4	600	11.0
90	26.7	650	10.8
100	26.3	700	10.1
110	25.7	750	9.72
125	24.8	800	9.46
150	22.7	900	8.97
175	21.7	1000	8.27
200	20.6	1100	7.50
225	19.6	1250	6.97
250	18.9	1500	6.22
300	17.4	1750	5.51
325	16.3	2000	4.77
350	16.0	2250	4.34
375	15.1	2500	3.89
400	15.0	2750	3.63
425	14.2	3000	3.35
450	13.9	3250	3.12
475	13.1	3500	2.91
500	12.5	4000	2.69
525	12.3		

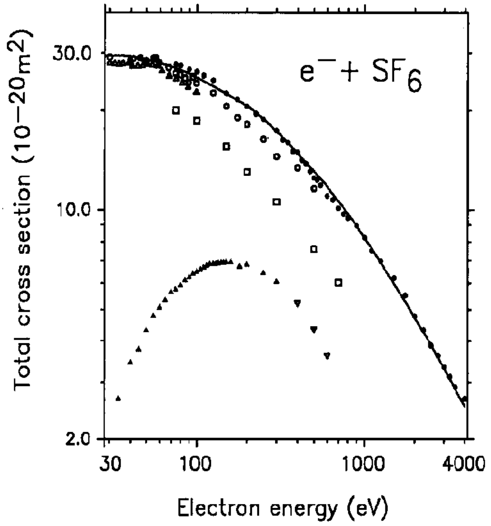

Fig. 1. Experimental total and partial cross sections for e^-–SF_6 scattering. (●) this work; (○): ref. [5]; (△): ref. [1]; (□): elastic [7]; (▲) ionization cross section [8]; (▽): ref. [10], ionization normalized to ref. [8]. (——): best fitting to cross sections (see text).

The ionization data of Margreiter et al. [9] are not reported in this figure because they are superimposed on those of Rapp and Englander-Golden in the overlap range (up to 180 eV). Three points in fig. 1 show the total ionization cross section obtained summing up the partial ionizations from Stański and Adamczyk [10] normalized to the data of Rapp and Englander-Golden. As can be seen in fig. 1, the ionization contribution to the total rises from 12% at 40 eV to 34% at 300 eV. The total elastic data [7] reported in fig. 1 show that the elastic channel contributes more than 70% at 200 eV and about 55% at 500 eV. The partitioning of the SF_6 total cross section is qualitatively similar to the scheme evidenced by Zecca et al. [14] for freons. In the considered energy range, the ionization contribution is lower than for hydrides [15], while the elastic part is larger.

No theoretical data are available in the energy range covered by our mearuements.

In previous work [15] it has been found that the total cross sections of molecular gases can be well reproduced over a large energy range (a few tens of eV up to 4000 eV) with a Born-like formula. Some gases (such as CF_4 and hydrides) show a cross section dependence on the energy which is well approximated assuming scattering on a single Yukawa potential:

$$V(r)=\frac{V_1}{r}\exp\left(-\frac{r}{a_1}\right).$$

Other gases (such as CCl_4, CCl_3F, CCl_2F_2, $CClF_3$) show a cross section which can be well approximated only by scattering on a double Yukawa potential [14]:

$$V(r)=\frac{V_1}{r}\exp\left(-\frac{r}{a_1}\right)+\frac{V_2}{r}\exp\left(-\frac{r}{a_2}\right).$$

We used the same approach to fit the SF_6 total cross section. We used our values from 75 to 4000 eV and the values given by Dababneh et al. [4] from 30 to 75 eV. It is found that the SF_6 cross section is well approximated by scattering on a single Yukawa potential. The resulting formula for the cross section is

$$\sigma(E)=\frac{1}{A+BE},$$

where

$$A=\frac{\hbar^4}{16\pi m^2 a_1^4 V_1^2},\quad B=\frac{\hbar^2}{2\pi m a_1^2 V_1^2}.$$

From the best-fit values A and B we obtain $V_1=299$ au and $a_1=0.10$ au. The continuous line in fig. 1 shows the best-fit cross section. This curve lies, almost everywhere in the range from 30 to 4000 eV, within the error bars of the measurements.

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