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LETTER TO THE EDITOR

Total cross section measurements for positron and electron scattering on benzene molecules

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Abstract. The total cross sections (TCS) for 0.7-400 eV positrons and 1.0-400 eV electrons scattered by benzene (C_6H_6) vapour molecules obtained by a relative method are presented. The values of TCS for positrons at low energies are very high, and the positron scattering at low energies is found to be sharply forward peaked. On the other hand, the TCS values for electrons decrease with decreasing energy at low energies. The positronium (Ps) formation cross sections are rather low in comparison with the TCS.

Benzene, being one of the fundamental molecules, has been studied experimentally and theoretically in various problems. However, there has been no study of positron collisions with the benzene vapour molecule, and also no total cross section (TCS) study for electron collisions. In this letter, TCS measurements for e^+ and e^- colliding with C_6H_6 molecules have been presented using an absorption-type TOF apparatus. Part of this work has been already reported (Sueoka 1987).

The apparatus and experimental procedure are almost the same as used in previous work (Sueoka and Mori 1986). In the present TOF technique, the retarding method, in which the retarding potential is equal to the acceleration potential, is applied to eliminate the contribution from projectiles which have suffered a large energy loss by inelastic scattering and to minimise contributions from projectiles which have scattered forward elastically but, due to angular deflection, have reduced axial velocity. For the transportation of projectiles, a magnetic field provided by a solenoid is applied on the flight path including the collision cell.

As C_6H_6 vapour reacts with organic substances, the rotary pump oil was frequently exchanged. No problems with the vacuum system were encountered, although oil diffusion pumps were used. A glass reservoir was used. The sample vapour is controlled with an error of 1% using the same system as described in our previous paper (Katayama *et al* 1987). The error in the gas density $\Delta\rho$ is estimated to be almost identical to the accuracy of the pressure gauge, because the density ρ and temperature of the gas are controlled to sufficiently good accuracy. On the error estimation, $\Delta\rho$ is determined by checking the sensitivity of a Baratron pressure gauge. The check was carried out by comparing with the sensitivity of an ionisation gauge in the range of 10^{-4} Torr. It was found that the sensitivity of the Baratron in the low-pressure range was four times better than the value stated in the catalogue. The TCS measurements for e^+ were performed at pressures lower than 1×10^{-3} Torr at low energies where the TCS values are extremely high. The full scale pressure range of the Baratron used (220 BHS) was

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1 Torr, and its sensitivity is given as 1×10^{-4} Torr in the catalogue. The alteration of this estimate in the low-pressure region has a large effect on the whole experimental error.

The TCS Q_t is given as follows:

$$Q_t = (1/\rho l)\ln(I_v/I_g)$$

where ρ is the gas density in the collision cell, l is the effective length of the cell, I_v and I_g are net counts separated from the accidental coincidences in the vacuum and in the gas runs, respectively. The TCS is obtained by the relative method using the data for e^+-N_2 of Hoffman *et al* (1982) by the normalisation procedure in the energy range 25-400 eV. From the fact in the previous works (Sueoka and Mori 1984, 1986) that the TCS values for various gases with the same value of l agree with the corresponding results of other researchers, the same value of l for C_6H_6 and N_2 is assumed. The data analysis and the error estimation are performed by almost the same method as in the previous works.

The magnetic field for the beam transportation must be weak in the vicinity of the collision cell to diminish the contribution of elastic forward scattering. However, the beam intensity is fairly low in a weak magnetic field. Although the measurements are performed by TOF, the above condition is necessary because the beam energy width is fairly wide. The magnetic field dependence of the TCS gives a permissible strength of the field in the measurement. In our previous works (Sueoka *et al* 1986), the dependence for e^- only was measured. The magnetic field dependence for e^+ has been measured in this work for the first time as shown in figure 1. Values of the TCS at low energies are not saturated against the magnetic field even at the lowest field, 3.6 G. The true values at low energies are deduced to be higher. The measurements under lower magnetic field are necessary, but are not performed due to the long run times which would be involved. From the fact that the TCS at low energies depends strongly on the magnetic field, as shown in figure 1, the scattering by C_6H_6 vapour for e^+ at low energy is very sharply forward peaked. As the TCS, the values for the 3.6 G measurement are adopted in the range below 2.5 eV, those for 4.5 G in the range between 2.8-6.0 eV, the averaged values of those for 4.5 and 9 G at 6.5-7.5 eV, and those for 9 G at 8.0-400 eV.

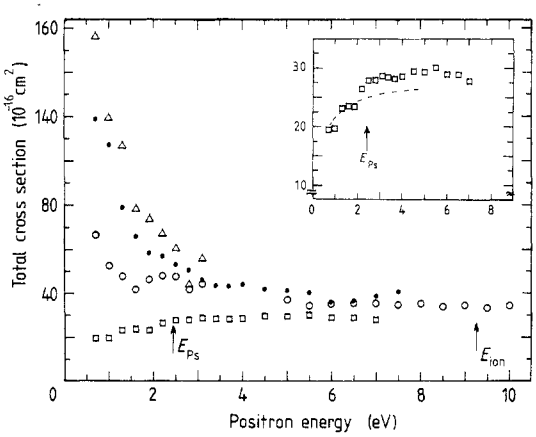

Figure 1. Magnetic field dependence of the 'total cross section' for positrons colliding with C_6H_6 molecules. The inset shows the curve for 23 G on a different scale. The broken curve is estimated as the contribution due to Ps formation. Threshold energies of Ps formation and ionisation are indicated by arrows. Δ, 3.6 G; ●, 4.5 G; ○, 9 G; □, 23 G.

The TCS curve for e^-, showing quite a different tendency from the e^+ data, is fully saturated at 3.0 or 4.5 G as depicted in figure 2. The TCS values for e^- are taken as those for the 3.0 G measurement in the range below 1.8 eV, and those for 4.5 G in the range 2.0–400 eV. The TCS curve for e^- has a very small structure at 1.5 eV, and a large broad peak at 8.5 eV. The 1.5 eV structure may be the $^2E_{2u}$ shape resonance composed of the progression of vibrational levels which is observed by electron transmission spectroscopy (Sanche and Schulz 1973). For the scattering by electrons, no large shape resonance is found.

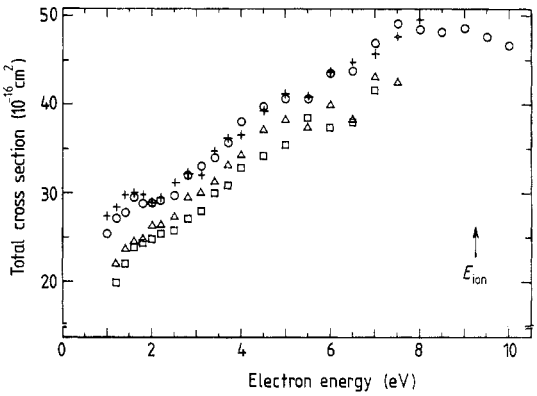

Figure 2. Magnetic field dependence of the 'total cross section' for electrons colliding with C_6H_6 molecules. +, 3.0 G; ○, 4.5 G; △, 9 G; □, 11 G.

As shown in figure 1, any increase in the TCS curves for the 3.6 or 4.5 G measurement is not present in the region above the positronium formation threshold, E_{Ps}. As discussed in the previous paper (Sueoka *et al* 1987), only the contribution of Ps formation to the absorption coefficient does not decrease the 'TCS curve' under a high magnetic field. The increase in this contribution in the region above E_{Ps} is easily seen in the 23 G measurement. We can estimate the contribution of Ps formation from the inset of figure 1 which depicts the curve which is the contribution due to positron scattering except for Ps formation. It is deduced that the value at the energy 2 eV above E_{Ps} is about 6×10^{-16} cm^2, although a very large error is included in the present case. The estimated value is not so high in comparison with the high values of the TCS. To obtain a more reliable value, a direct measurement of Ps formation (Charlton *et al* 1983, Fornari *et al* 1983) is needed.

The total cross sections for positrons and electrons in the range between 5 and 400 eV are plotted against the wavenumber k in figure 3. Although the high values near 1 eV are not shown in this figure, we can deduce from figures 1 and 2 that in the energy range below 1 eV TCS values for e^+ are more than an order of magnitude larger than those for e^-. This is the largest value of the ratio of TCS for e^+ and e^-, Q_t^+/Q_t^-, in the scattering by atoms and molecules for which TCS measurements for e^+ and e^- have been performed. The energy dependence of the ratio, Q_t^+/Q_t^-, has a similar tendency to those in other types of hydrocarbon molecules such as CH_4, C_2H_4 and C_2H_6 at intermediate energies (Sueoka 1987). The theoretical calculation of TCS for e^+-C_6H_6 is anticipated.

Values of the total cross sections at different energies are given in tables 1 and 2. The errors shown are obtained by the addition of $\Delta I/I$, $\Delta\rho/\rho$ and $\Delta l/l$ (=3%), not

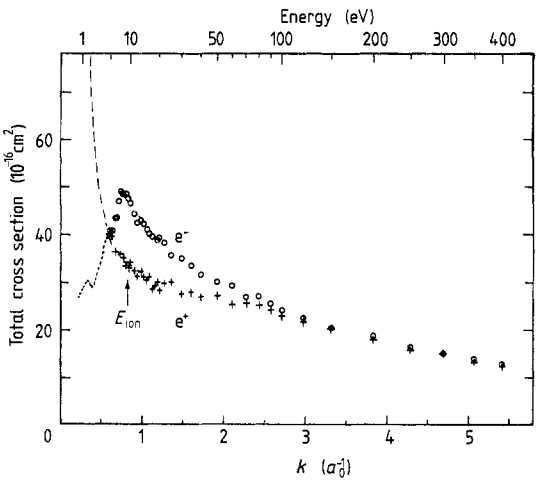

Figure 3. Total cross sections for positrons and electrons extending to intermediate energies. The values in the range below 5 eV are replaced by the dotted (for e^-) and broken (for e^+) curves showing the visual fitted curve of the present data given in figures 1 and 2. The threshold of ionisation is indicated by the arrow.

Table 1. Total cross sections (TCS) for positrons (10^{-16} cm^2). The cross section values in the energy range 0.7–2.5 eV are taken from the 3.6 G measurement, those at 2.8–6.0 eV from 4.5 G, those at 6.5–7.5 eV from 4.5 and 9 G and the others are taken from the 9 G measurement.

Energy (eV)	TCS	Energy (eV)	TCS	Energy (eV)	TCS
0.7	156 ± 59	7.5	35.8 ± 2.6	30.0	27.8 ± 1.9
1.0	120 ± 24	8.0	35.2 ± 2.5	35.0	28.1 ± 2.0
1.3	107 ± 17	8.5	33.8 ± 2.7	40.0	27.1 ± 1.7
1.6	79 ± 11	9.0	34.3 ± 2.6	50.0	27.4 ± 1.8
1.9	74 ± 9	9.5	33.3 ± 2.7	60.0	25.5 ± 1.5
2.2	67 ± 8	10.0	34.3 ± 2.7	70.0	25.8 ± 1.5
2.5	61 ± 7	11.0	32.6 ± 2.1	80.0	25.3 ± 1.4
2.8	51 ± 5	12.0	31.4 ± 2.0	90.0	24.3 ± 1.5
3.1	46 ± 5	13.0	32.4 ± 2.4	100	23.0 ± 1.4
3.4	44 ± 4	14.0	31.4 ± 2.2	120	21.9 ± 1.2
3.7	43 ± 5	15.0	30.6 ± 2.5	150	20.2 ± 1.2
4.0	44 ± 4	16.0	31.2 ± 2.3	200	18.1 ± 1.2
4.5	42 ± 4	17.0	28.9 ± 2.4	250	15.9 ± 0.9
5.0	41 ± 4	18.0	29.5 ± 2.2	300	15.3 ± 0.8
5.5	40 ± 4	19.0	30.1 ± 2.5	350	13.4 ± 0.7
6.0	36 ± 4	20.0	28.3 ± 2.3	400	12.4 ± 0.7
6.5	35.9 ± 2.7	22.0	29.8 ± 2.3		
7.0	35.8 ± 2.5	25.0	30.0 ± 2.1		

Table 2. Total cross sections (TCS) for electron collisions (10^{-16} cm^2). The cross section values in the energy range 1.0-1.8 eV are taken from the 3 G measurement, and the others are taken from the 4.5 G measurement.

Energy (eV)	TCS	Energy (eV)	TCS	Energy (eV)	TCS
1.0	27.4 ± 1.6	7.0	46.9 ± 2.6	25.0	35.7 ± 2.0
1.2	28.4 ± 1.6	7.5	49.2 ± 2.8	30.0	35.1 ± 1.9
1.4	29.9 ± 1.7	8.0	48.5 ± 2.8	35.0	33.5 ± 1.8
1.6	30.0 ± 1.8	8.5	48.2 ± 2.9	40.0	31.7 ± 1.7
1.8	29.9 ± 1.8	9.0	48.6 ± 2.8	50.0	30.1 ± 1.5
2.0	28.9 ± 1.6	9.5	47.6 ± 2.8	60.0	29.4 ± 1.4
2.2	29.2 ± 1.6	10.0	46.6 ± 2.7	70.0	26.9 ± 1.2
2.5	29.7 ± 1.6	11.0	44.4 ± 2.7	80.0	27.1 ± 1.2
2.8	32.0 ± 1.7	12.0	42.5 ± 2.9	90.0	25.5 ± 1.2
3.1	33.0 ± 1.8	13.0	43.0 ± 2.6	100	24.3 ± 1.1
3.4	34.0 ± 1.9	14.0	42.3 ± 2.5	120	22.7 ± 1.0
3.7	35.7 ± 2.1	15.0	41.2 ± 2.4	150	20.6 ± 0.9
4.0	38.1 ± 2.2	16.0	40.2 ± 2.4	200	18.9 ± 0.8
4.5	39.8 ± 2.5	17.0	39.3 ± 2.4	250	16.5 ± 0.7
5.0	40.6 ± 2.5	18.0	39.5 ± 2.3	300	15.1 ± 0.6
5.5	40.7 ± 2.5	19.0	38.8 ± 2.3	350	14.0 ± 0.6
6.0	43.5 ± 2.7	20.0	39.3 ± 2.3	400	13.0 ± 0.5
6.5	43.7 ± 2.8	22.0	38.3 ± 2.1		

including the systematic error, where I means $\ln(I_v/I_g)$, including all the statistical errors in the counting.

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