Near Threshold Effects in Positron-O_2 Scattering

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Structure has been observed in the total ionization cross section of O_2 above 8 eV positron impact energy. A comparison with available data on the excitation to the Schumann-Runge continuum indicates that coupling effects between the positronium formation, excitation, and direct ionization channels may be responsible.

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In atomic and nuclear physics, anomalous behavior in the form of discontinuous energy derivatives of partial cross sections, at the threshold for a new scattering channel, have been interpreted in terms of flux conservation using essentially classical arguments, and quantum mechanically according to virtual transitions allowed by the uncertainty principle [1]. Such interplay between various (elastic and inelastic) scattering channels constitutes one of the current topics of major interest in positron-atom (molecule) collisions [2].

A reduction in the probability for elastic scattering just above the positronium (Ps) formation threshold has been predicted in e^+-H collisions [3]. Some experimental evidence of such a coupled-channel effect has been derived from cross sections for e^+ impact on He [4,5], Ar [5], and H_2 [5,6]. More convincingly, structure has recently been observed at intermediate energies in the differential elastic scattering cross section when plotted at a fixed angle versus the energy of positrons incident on an Ar target [7]. This structure is manifested by a decrease of a factor of 2 at 60° occurring near the energy at which the ionization cross section reaches a maximum and has been interpreted as a coupled-channel shape resonance between the elastic scattering and the Ps formation and/or single-ionization channels. Recent calculations have found further evidence of such resonances in e^+-H [8] and e^+-inert atom [9] collisions.

In this work, channel-coupling effects in e^+ scattering have been observed *directly*, for the first time, in an integral partial cross section *close to the threshold* for a new inelastic channel. This observation has resulted from the measurement of the total ion yield from e^+ impacting on molecular oxygen. This yield is directly proportional to the total ionization cross section, σ_i^t, which comprises all allowed scattering channels resulting in at least one ion in the final state and therefore may be represented by

$$\sigma_i^t = \sigma_{Ps} + \sigma_i^+ + \sum \sigma_{HO} ,$$

where σ_{Ps} is the cross section for Ps formation in all allowed quantum states, σ_i^+ is the single-ionization cross section, and $\sum\sigma_{HO}$ is the sum over higher-order processes [10]. Contributions from this latter term are expected to be negligible, however, in the energy range investigated here.

A magnetically guided beam of quasimonoenergetic positrons ($\Delta E \approx 1.0$ eV FWHM) was passed through a hemispherical gas cell [11]. Its base consisted of a set of concentric electrodes producing a dc radial field used to extract ions from all parts of the cell. The perturbation on the collision produced by the static extraction potential was investigated by varying the magnitude of the dc potential in the range 0.7–2.0 V, corresponding to maximum potentials at the beam position approximately an order of magnitude lower. Within the statistical uncertainties of the data and at the present level of energy resolution, no effect due to the static field was discerned across the whole voltage range.

The (vacuum) positron beam rate and the (gas) ion count rate versus beam energy were collected on a multichannel scalar. This was driven by an external voltage ramp generator which provided the advance pulse in synchronism to increases in the voltage of the β^+ moderator (0.5 V above ground) and of the set of $\mathbf{E}\times\mathbf{B}$ plates employed to separate the e^+ beam from the flux of fast particles originating from the β^+ source. The total ion yield, namely, the ion count rate divided by the e^+ rate, obtained from the 90 mm long cell filled with O_2 gas at a given pressure was then calculated. The signal, at all energies, was found to increase linearly with target pressure in the range 0.07–0.13 Pa. Spectra were typically collected over 1–3 day periods consisting of several hundred ramp cycles. A constant background, originating primarily from the ion detector dark counts, was determined by averaging the counts below 4 eV (i.e., in the first four channels) and subtracting it from the raw ion count rate. The validity of this procedure was checked by comparison with a spectrum collected with the e^+ beam repelled prior to the gas cell.

An estimate of the absolute total ionization cross section was obtained as follows. An average of the total cross section [12] was determined between 2–4 eV and subtracted from the values above the Ps formation threshold. The average values of four ion-yield measurements were then normalized to these differences in the range 5–7 eV. In these measurements, the maximum ion extraction potential at the beam position was ≤ 0.15 V. The results thus obtained are shown in Fig. 1 where the total ionization cross section is seen to rise, as expected,

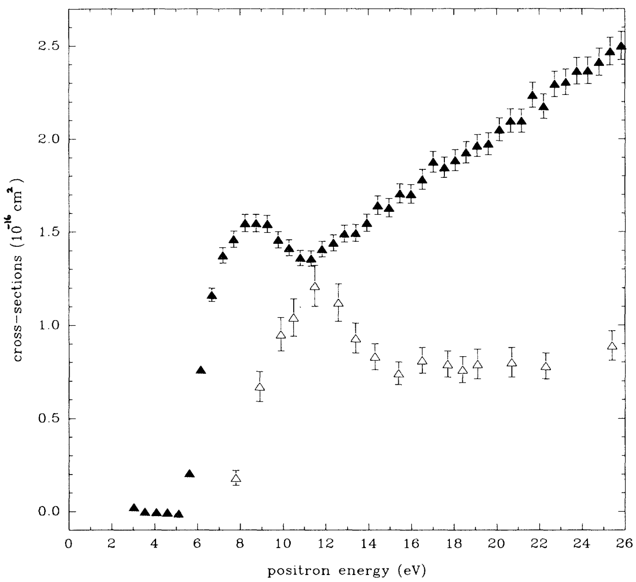

FIG. 1. Positron scattering from O_2: ▲, total ionization cross section (present results); △, cross section for excitation to the Schumann-Runge continuum [14].

near the threshold for Ps formation at 5.27 eV, before decreasing above approximately 9 eV impact energy. After reaching a minimum at around 11 eV, it is seen to rise over the remaining range of energies investigated. This energy dependence is markedly different from that observed for He, Ar, and H_2 [5,6,13] where both σ_i^t and σ_{Ps} are found to vary smoothly with projectile energy, peaking, respectively, at approximately 3–4 times and twice the first ionization potential of the target. While the uncertainty in the energy dependence of the ion yields is approximately $\pm 3\%$, the absolute scale assigned to the total ionization cross section is considerably less certain, its uncertainty (up to $\pm 50\%$) arising primarily from the unknown energy dependences, above the Ps formation threshold, of the preexisting cross sections, namely, those for elastic scattering and excitation to the $A\,^3\Sigma_u^+$ state.

Also shown in Fig. 1 are the measurements of Katayama, Sueoka, and Mori [14] for the cross section σ_{ex} for excitation, by positron impact, to the Schumann-Runge continuum, a broad photoabsorption band in the ultraviolet region. It is interesting to note that the location of the dip in σ_i^t appears to correspond with the maximum in σ_{ex}. This correspondence is evidence of coupling between the two channels. Indeed the increase of σ_i^t is arrested in the vicinity of the threshold for the excitation $X\,^3\Sigma_g^- \rightarrow B\,^3\Sigma_u^-$ at 6.2 eV while the decrease in σ_{ex} appears close to the threshold for single ionization at 12.07 eV around which energy σ_i begins to rise again. This behavior is qualitatively similar to that expected in the elastic cross section in the vicinity of the Ps formation threshold [3]. The difficulty of extracting an accurate energy dependence of a preexisting cross section across the threshold for a new scattering channel, as in the case of elastic scattering (over all space) and Ps formation [4,15], does not arise in the present study where the relevant channel is observed directly.

In conclusion, structure has been observed in the total ionization cross section in e^+-O_2 scattering which reflects coupling effects with the cross section for excitation to the Schumann-Runge continuum [14]. The energy dependence of the latter is found to complement qualitatively the present measurements. Further investigations employing a higher energy resolution system and other targets are planned.

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