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Low energy positron interactions with rare gas atoms: threshold features and benchmark cross sections

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Abstract. Using a high resolution (~ 60 meV FWHM) positron beam from a Surko buffer-gas trap, we have measured grand total cross sections as well as total elastic, positronium formation and electronic excitation cross sections in the rare gases. Strong threshold (Wigner) cusps are observed in the elastic scattering channel in all the rare gases at the opening of the positronium formation channel. We present low energy elastic scattering measurements for neon which show excellent agreement with recent theory and potentially establish this system as a ‘benchmark’.

1. Introduction

The advent of high-resolution, high-flux positron beams from buffer-gas traps has the potential to unravel many new processes and features in low energy positron scattering from atoms and molecules. The past ten years, since these beams have been applied to atomic physics research, has seen the first state-resolved vibrational and electronic excitation measurements, the first absolute differential cross section measurements and insights into the long-standing challenge of explaining the anomalously high annihilation rates for positrons on some molecules.

In this paper we present recent measurements of positron interactions with rare gas atoms and focus on several new aspects of the collision process that have been revealed with the high resolution available from the buffer-gas trap beam. In measurements of the energy dependence of elastic scattering we observe prominent cusp-like features which are centred around the threshold for positronium formation, $E_i - 6.8$ eV, where E_i is the first ionization potential of the atom concerned. In other measurements of elastic scattering, we show a comparison between the measured total elastic cross section for neon and recent theoretical work.

2. Experimental aspects

Space does not permit a detailed exposition of the experimental apparatus and techniques that have been used here. They have been described previously in a number of papers [1,2] and we will only briefly discuss the relevant points here. Positrons from a radioactive ^{22}Na source are moderated, trapped and cooled in a buffer-gas trap before being released from the trap in a pulsed beam. Each

pulse is a few μs in width and contains on the order of a 1000 positrons. The energy of the pulsed beam can be readily varied between 0-60 eV, the repetition rate is typically 200 Hz, and the energy width typically 50-60 meV, full width at half maximum. The positron beam is radially confined by a strong, ~ 500 Gauss, axial magnetic field.

The positrons exit the trap and are passed through a scattering cell containing the gas under study. Those transmitted through the scattering cell are energy analysed by a retarding potential analyzer. The spectrum of transmitted positrons as a function of retarding potential can then be used to obtain the scattering cross sections in a manner which has been discussed previously [2]. In the present work we present data for two recent examples of experimental investigations with this apparatus – ‘benchmark’ total elastic scattering for neon, and structures in the elastic cross section in the energy region near the threshold for positronium formation in the rare gases. Some of this work has been recently reported [3].

3. Results and Discussion

3.1. Threshold cusps in the rare gases

Threshold (Wigner) cusps have been observed in many scattering processes involving electrons and have been predicted for positron scattering at the threshold of the Ps formation channel. The initial prediction was made by Campeanu *et al.* [4] and there have been several experimental tests and observations over the years [eg. 5-8] as well as a semi-empirical prediction for the rare gases [9].

In the present investigations elastic scattering measurements in each of the rare gases He-Xe have revealed significant features in the cross section at the threshold for the opening of the positronium (Ps) channel. Examples of these structures are shown in figures 1(a) and (b) for He and Ar, respectively.

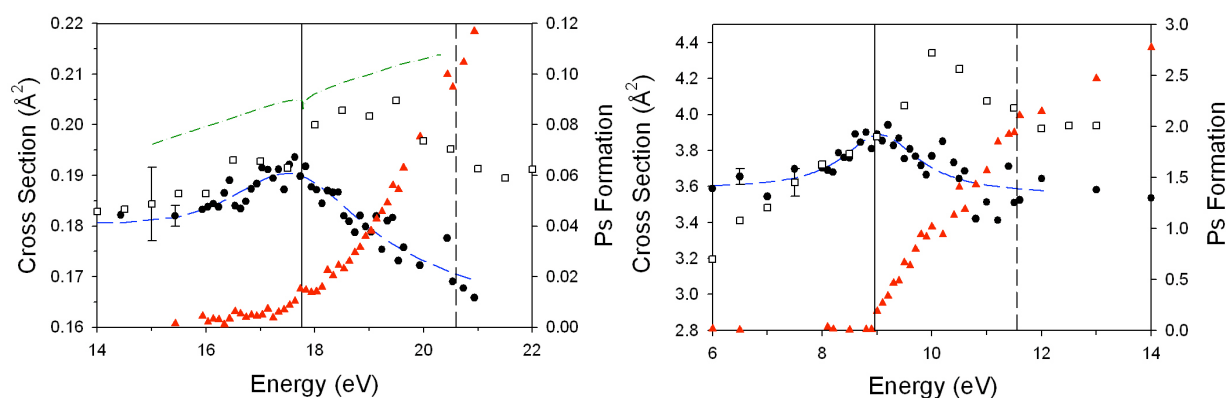


Figure 1. Total elastic and positronium formation cross sections for He (left) and Ar (right). (●) present elastic cross section, the long dashed line is a fitted curve to the data; (□) result of [7]; (---) theoretical result of [10] for He; (▲) Ps formation cross section. The vertical lines represent the Ps threshold (solid) and first excited state threshold (dashed).

Broad cusp features are observed in both He and Ar, with the elastic cross section rising just before the Ps formation threshold, and then falling off above this energy across the Ore gap – the energy gap between the Ps formation threshold and the first excited state of the atom. In He and Ar these features represent about a 10% perturbation on the elastic cross section. In the other rare gases, which we do not show due to space limitations, the magnitude of the feature varies somewhat, with the strongest presence being observed for Xe. Also shown in figure 1 are the recently published results of Coleman

et al. [6,7] and the results of a variational calculation of the elastic scattering cross section due to van Reeth and Humberston [9] for He.

There are some similarities and several significant differences between the present work and the recent measurements of Coleman and co-workers. For both He and Ne there is reasonable agreement between the two measurements with both observing cusp-like behaviour in the elastic cross section, although the result of [7] indicates a peak in the elastic cross section which is about 1 eV above the Ps threshold. For the heavier gases, Ar, Kr, Xe, Coleman and co-workers characterize their observation as an upward step in the elastic cross section which occurs above the Ps threshold and which is quite different to that observed in the present work, particularly in the case of Xe. A full description of these recent results can be found in Jones *et al.* [3] and Jay and Coleman [7].

3.2. Elastic positron-neon scattering

The other example that we provide of recent measurements is for the total elastic cross section for neon at energies up to the Ps formation threshold. One rationale for these measurements was the broad spread of absolute values that are observed in both previous experimental and theoretical investigations of this cross section. This is demonstrated in Figure 2 where we show a selection of results from previous experiment and calculation, indicating a spread in cross section values of 50% or more at some energies below the Ps formation threshold, where only the elastic scattering channel is open.

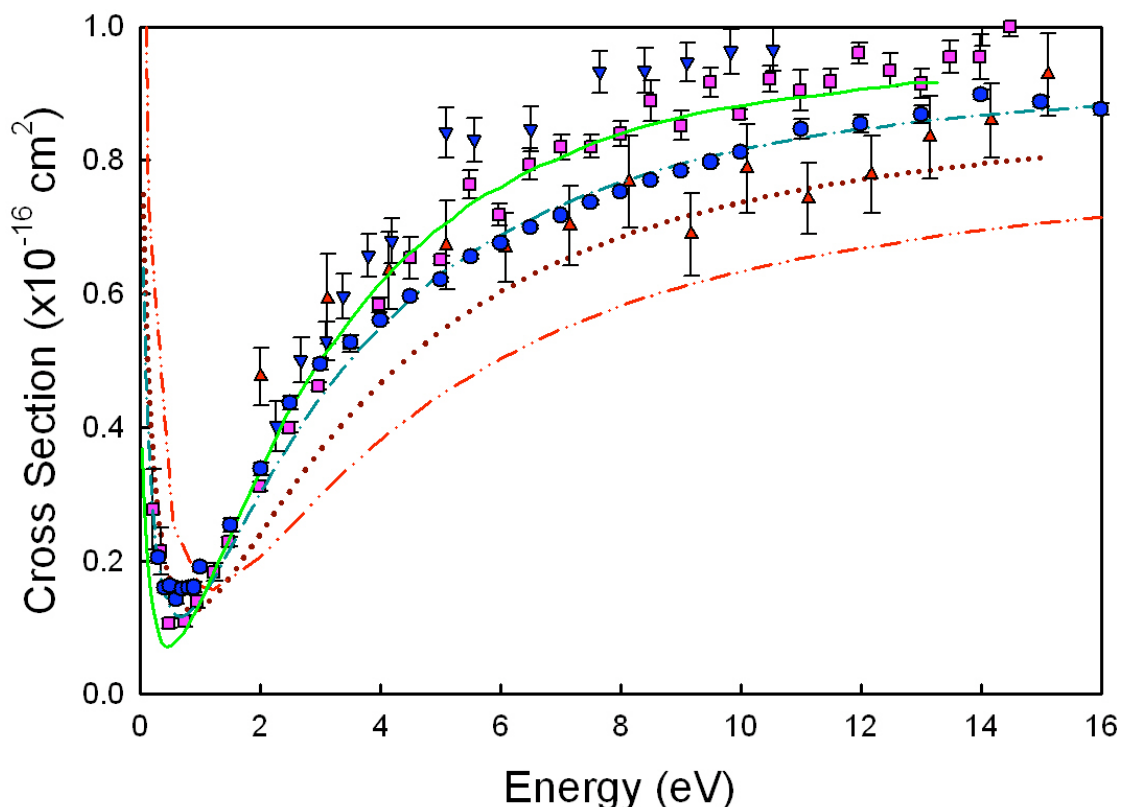


Figure 2: Total elastic cross section for positron scattering from neon. Several experimental measurements are displayed: (●) Present result, (▲) Canter *et al.* [11], (▼) Charlton *et al.* [12], (■) Stein *et al.* [13], as well as a number of theoretical calculations: (—) Dzuba *et al.* [14], (·····) McEachran *et al.* [15], (— · —) McEachran (this work), (— · · —) Nakanishi and Schraeder [16]

The present results, which have high statistical and absolute accuracy, show best agreement with the measurements of Canter *et al.* between 2-14 eV, and are in excellent agreement with the recent polarized orbital calculation of McEachran through the entire energy range. Whilst all experiments and theory show the same general features of the cross section, the present result is in essentially perfect agreement with the polarized orbital calculation in particular. Note that the present experimental results have also been corrected for forward scattering effects which, for the present experimental circumstances, result in corrections of more than 20% below 0.7 eV, but less than 1% above 9 eV.

4. Conclusions

The essential features of a trap-based positron beam – high energy resolution, high efficiency and statistical accuracy – are demonstrated with measurements of elastic scattering in the rare gases. We have identified strong channel coupling features in the elastic scattering channel, which appear as a result of the strong opening of the Ps formation channel, and manifest in the formation of Wigner cusps. The features observed in the lighter gases are similar in form to those observed by Coleman and colleagues, with some differences in energy dependence evident. In the heavier gases, however, we see quite different behaviour in the elastic cross section than is observed by Coleman *et al.* One could only speculate as to the source of these discrepancies. However it is clear that both experiments observe evidence of coupling between the positronium formation and elastic scattering channels at or near the energy of the Ps formation threshold.

Acknowledgements

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