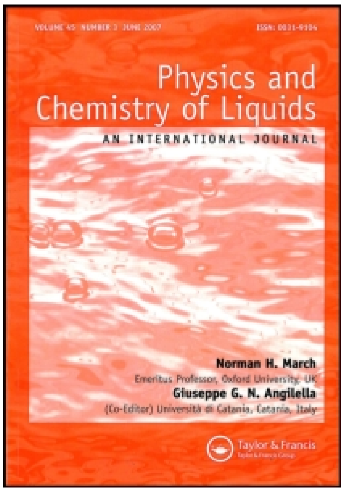

Physics and Chemistry of Liquids
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713646857

Electron Attachment Cross-Sections to Protons and Positrons Incident on the Fluids He and H_2

G. R. Freeman[a]; N. H. March[b]
[a] Chemistry Department, University of Alberta, Edmonton, AB, Canada [b] University of Oxford, Oxford, England

To cite this Article Freeman, G. R. and March, N. H.(1996) 'Electron Attachment Cross-Sections to Protons and Positrons Incident on the Fluids He and H_2', Physics and Chemistry of Liquids, 31: 3, 169 — 174
To link to this Article: DOI: 10.1080/00319109608029570
URL: http://dx.doi.org/10.1080/00319109608029570

Phys. Chem. Liq., 1996, Vol. 31, pp. 169–174
Reprints available directly from the publisher
Photocopying permitted by license only

ELECTRON ATTACHMENT CROSS-SECTIONS TO PROTONS AND POSITRONS INCIDENT ON THE FLUIDS He AND H_2

G. R. FREEMAN* and N. H. MARCH†

**Chemistry Department, University of Alberta, Edmonton, AB, Canada T6G 2G2*
†University of Oxford, South Parks Road, Oxford OX1 3QR, England

(Received 3 September 1995)

Recent experimental data by Tang and Surko on the angular and energy dependences of positronium formation in molecular H_2 has prompted us to bring them into contact with total cross-sections as a function of energy in the energy range up to 125 eV (20 aJ). Data for protons incident on H_2 are also compared and contrasted with the positron results. Two regimes are delineated: one around the maximum in the total cross-section and the second in the high energy tail. The positron data of Tang and Surko correspond to the tail regime.

Finally, contact is also made with He data, plus some brief comments on the heavier noble gases. Here, the maximum cross-sections are shown to correlate roughly quadratically with polarizability.

KEY WORDS: Positronium, polarizability, electron attachment, atomic and molecular fluids.

1 INTRODUCTION

There is current interest in the production of positronium beams. Positronium atoms are neutral and therefore can readily be fired into plasmas, and may thereby probe fusion processes. This has provided the motivation for the recent work of Tang and Surko who, for positrons of three incident energies entering H_2 gas, have measured the angular distribution of outgoing positronium atoms[1]. Their work shows the remarkable feature that the half-widths of their angular distribution curves have little dependence on incident energy, though the fraction of positrons which form positronium atoms decreases with increasing incident positron energy.

We wish to consider the relation of the data of Tang and Surko[1] to earlier total cross-section data collected by Diana *et al.* for positronium formation in molecular H_2[2]. Though there are major quantitative differences between results from different laboratories, the cross sections measured by Diana *et al.* display a well defined maximum and a relatively long tail at high energies. It is on these two features that we shall focus attention below. Our contribution is different from those described in recent reviews, which deal with different modes of ionizing the target molecules[3,4].

In the light of uncertainties in the positron data, we thought it worthwhile to go back to the much older data of Barnett and Reynolds on electron attachment to protons fired into molecular H_2 gas[5]. By considering protons and positrons of the same velocity, which means scaling the energy by the mass, these data can also be plotted with the positron results. The $H^+ + H_2 \rightarrow H + H_2{}^+$ reaction is 1.8 eV (0.29 aJ) endothermic, whereas $e^+ + H_2 \rightarrow Ps + H_2{}^+$ is 8.6 eV (1.38 aJ) endothermic, so to normalize the reaction energetics, 6.8 eV (1.09 aJ) is added to the mass-normalized proton energies to compare the electron pick-up probability at an analogous positron energy.

The H_2 data will then be compared with those of both positrons and protons incident on He gas. While the general features of the data are the same, the marked differences in electronic behaviour are clearly in evidence at the maxima. This point is pressed by invoking data for positrons in other noble gases. A superlinear correlation between the magnitude of the maximum cross-sections and the polarizability for the noble gases is thereby exposed.

2 ANGULAR DEPENDENCE OF FRACTION OF POSITRONS FORMING POSITRONIUM IN H_2

The data of Tang and Surko[1] have been analysed at the three energies E they consider. The maximum fraction f_{max} of positrons forming positronium in H_2 gas is such that the product Ef_{max} has the values, in units of 10^{-4} eV, of 105, 114, and 96, for $E = 50$, 80, and 100 eV, respectively. Thus, over this admittedly limited energy range we can write

$$f_{max} = C/E \tag{1}$$

with $C = (105 \pm 6)10^{-4}$ eV.

Secondly, we have plotted in Figure 1 the full width of the distribution at half maximum. This is practically constant, but with a small increase of 0.024°/eV between $E = 50$ and 100 eV.

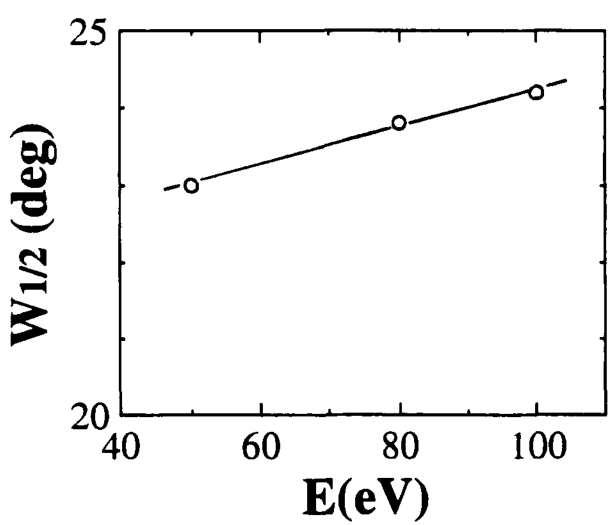

Figure 1 Width $W_{1/2}$ of the angular distribution of Ps as a function of positron energy in H_2 gas. Determined from the experimental data in ref. 1.

2.1 *Modelling of Positronium Fraction $f(\theta)$ and Total Cross-Section as Function of Energy*

Our aim below will be to bring the above, very recent, study of angular dependence into contact with earlier total cross-section measurements $\sigma(E)$ for positronium formation as a function of energy. To this end we shall adopt a Gaussian representation of $f(\theta)$ and write

$$f(\theta, E) = (C/E)\exp(-\alpha\theta^2) \tag{2}$$

No doubt a Lorenzian form of $f(\theta, E)$ would be a plausible alternative, but we are concerned here with using the $f(\theta)$ data to gain insight into the way in which to analyze the data on total cross-section $\sigma(E)$. At the present rudimentary level of knowledge about Ps formation processes, we may usefully compare the total cross-sections with the following integral cross-sections.

Integrating Eqn. (2) over solid angle increment $d\omega$ we can write the approximate form

$$\sigma(E) = A(E)\int \exp(-\alpha\theta^2)d\omega \tag{3}$$

where $\alpha^{1/2}$ is related to the half-width plotted in Figure 1, while $A(E)\ \alpha 1/E$ over the limited energy range studied by Tang and Surko. Differentiating σ in Eqn. (3) with respect to E, we find

$$\frac{d\sigma}{dE} = -\frac{\sigma}{E} - \sigma\frac{d\alpha}{d\text{E}}\frac{\int\theta^2\exp(-\alpha\theta^2)d\omega}{\int\exp(-\alpha\theta^2)d\omega} \tag{4}$$

After dividing both sides by σ to obtain

$$\frac{d\ln\sigma}{dE} = -\frac{1}{E} - \frac{d\alpha}{dE}\frac{I_2}{I_0} \tag{5}$$

where I_2 and I_0 denote the integrals in the numerator and denominator of Eqn. (4), this suggests a plot $\ln\sigma$ against E over a range of E around the Tang-Surko range from 50 to 100 eV. We turn, therefore, in section 3 immediately below, to analyze the total cross-section data as a function of energy in this way. It will prove useful to deal not only with positron data from H_2 gas, but also available data of He gas, as well as to include a brief discussion of the proton data of Barnett and Reynolds[5] for these two gases.

3 ANALYSIS OF TOTAL CROSS-SECTION DATA σ(E) FROM H_2 AND HE

3.1 H_2

Figure 2 shows H_2 data for positronium formation[2,6], as in the angular distribution experiment of Tang and Surko, and for electron capture by protons[5]. The plot is, as motivated by the model Eqn. (5), of $\log\sigma$ against E. It is readily demonstrated, in qualitative accord with Eqn. (5), that $-d\ln\sigma/dE > 1/E$ for the energy range considered for

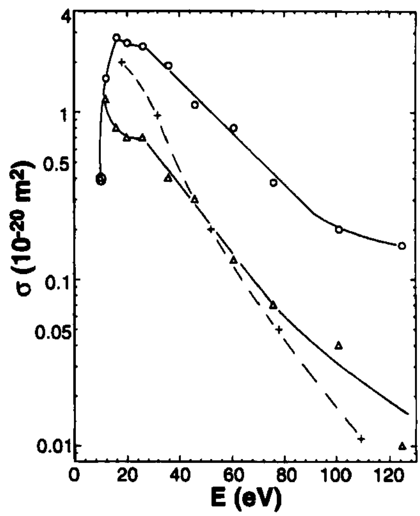

Figure 2 Cross sections for e^- pick-up from H_2 gas by e^+ (o, ref. 2; Δ, ref. 6) and H^+ (+, ref. 5). *E* refers to the positron energy, or to the mass-normalized energy of the protons ($E_{H^+}/1837$) plus 6.8 eV, the difference in endothermicities of $e^+ + H_2 \rightarrow Ps + H_2^+$ and $H^+ + H_2 \rightarrow H + H_2^+$.

positronium formation in Figure 1. In fact, for e^+ energies 30–90 eV, which are somewhat less than the Tang-Surko range, a plot of $ln\sigma$ against E would have an approximately constant slope of $-2.3 \times 0.016 = -0.036\ eV^{-1}$, which decreases at higher energies. The two sets of positron cross sections[2,6] differ by a factor of about 5, probably due to an experimental artifact, but the qualitative behaviors are the same.

The corresponding slope of the proton plot is steeper, being $-2.3 \times 0.023 = -0.053\ eV^{-1}$ between 50 and 100 eV (Fig. 2). The proton cross sections at the mass-adjusted energies cut across the two sets of positron data, and do not assist the resolution of the positron data discrepancy.

3.2 He

Turning to the data for He, Figure 3 shows similar plots for electron capture by e^+ and H^+ from this gas, which has an ionization potential of 24.5 eV, compared to 15.4 eV for H_2. If the curves in Figure 3 are shifted to the left by 9 eV to account for the greater endothermicities of electron capture from He compared to from H_2, the H^+ cross section curve becomes similar to that in Figure 2, and the high energy tails of the e^+ curves become similar in the two Figures. However, the maxima in the e^+ curves from He are only about 20% of those from H_2, and the former occur at about double the energy of the latter.

4 COMPARISON OF HE WITH HEAVIER NOBLE GASES

Having brought positron and proton data on electron capture cross-sections in H_2 gas into contact with similar data on He gas, it is of interest to seek regularities between the He data and those available on the heavier noble gases.

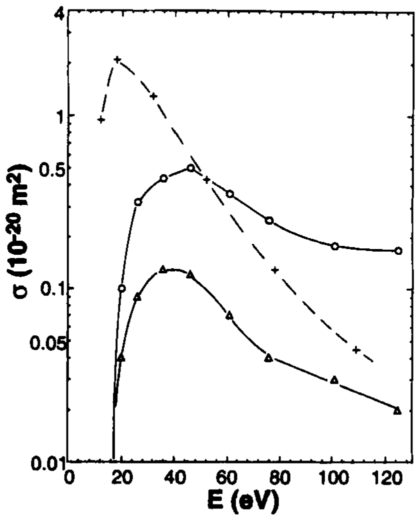

Figure 3 As Figure 2, but for He gas. Refs. 2, 5, 6.

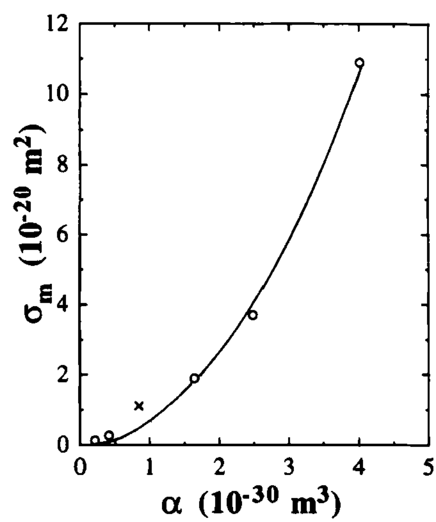

Figure 4 Cross section maximum σ_m of $e^+ + X \rightarrow Ps + X^+$ plotted against the polarizability α of the noble gas molecules X, for He to Xe (o), ref. 7. For H_2 (X) the value of σ_m (ref. 6) is plotted against $\bar{\alpha}$.

This we have done in Figure 4 by plotting the maximum cross section σ_m observed in each gas[7] against molecular polarizability α, which in turn is known to correlate strongly with size of the atomic or molecular system considered. Figure 4 can leave no doubt that, in the energy range around the maxima of the cross sections[7], the positrons are exploring the details of the electronic density distributions in the different noble gas atoms. The equation of the curve drawn in Figure 4 is

$$\sigma_m = 0.66\ \alpha^2 \tag{6}$$

where the units are $\sigma_m(10^{-20}\text{m}^2)$, $0.66\ (10^{40}\text{m}^{-4})$, and $\alpha\ (10^{-30}\text{m}^3)$. Eqn. (6) fits the data for the heavier noble gases quite well, but seriously underestimates σ_m for He, Ne, and also H_2.

5 SUMMARY AND FUTURE DIRECTIONS

There can be no doubt that angular distribution data such as those of Tang and Surko can be illuminating in enabling total cross-section data to be interpreted. Thus, if one could characterize the angular distribution by its maximum and its half-width as a function of energy, both of these quantities could be expected to affect $\sigma(E)$ in an important way. Therefore, angular distribution experiments over a wider energy range than in ref. 1 will be important in a fuller analysis of total cross-section data. It is also a matter of some moment to understand the reasons for the discrepancies between total cross-section data from different laboratories[3,4]. Finally, to extend the Tang-Surko data to electron capture by protons would also be very worthwhile.

Acknowledgements

NHM wishes to acknowledge that his contribution to this work was made during a visit to the University of Alberta, Edmonton in 1995. Thanks are due to the Chemistry Department and to the Theoretical Physics Institute for partial financial support. GRF thanks the Natural Sciences and Engineering Research Council for financial assistance of this work.

References

1. S. Tang and C. M. Surko, *Phys. Rev., A*, **47**, R743 (1995).
2. L. M. Diana, P. G. Coleman and D. L. Books, P. K. Pendleton and D. M. Norman, *Phys. Rev., A*, **34**, 2731 (1986).
3. D. R. Schultz, R. E. Olson and C. O. Reinhold, *J. Phys., B, At Mol. Opt. Phys.*, **24**, 521 (1991).
4. H. Knudson and J. F. Reading, *Phys. Rep.*, **212**, 107 (1992).
5. C. F. Barnett and H. K. Reynolds, *Phys. Rev.*, **109**, 355 (1958).
6. T. C. Griffith, in *Positron Scattering in Gases*, eds. J. W. Humberston and M. C. R. McDowell (Plenum: New York), 1984, page 53.
7. M. Charlton, G. Clark, T. C. Griffith and G. R. Heyland, *J. Phys., B*, **16**, L465 (1983).