POSITRONIUM COLLISIONS WITH ATOMS AND MOLECULES

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Electron-Like Scattering of Positronium

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[Graphs showing total cross-sections for various gases (He, Kr, N₂, O₂, H₂, SF₆) as a function of velocity (a.u.)]
Resonant Scattering of Positronium in Collision with CO$_2$

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Ps Scattering Processes

- Elastic: \( \text{Ps}(1s) + B \rightarrow \text{Ps}(1s) + B \)
- Excitation: \( \text{Ps}(1s) + B \rightarrow \text{Ps}(nl) + B \)
- Ionization: \( \text{Ps}(1s) + B \rightarrow e^+ + e^- + B \)
- Assuming B remains in the ground state.
Thermal collisions of Rydberg atoms with ground-state atoms (E. Fermi, M. Matsuzawa)

\[ k_d = \int_{0}^{\infty} v \sigma_e(v) f(v) \, dv \]

Does this work for a ground-state Ps?
Impulse approximation

\[ f_{ba}(p_f, p_i) = 2 \int g_b^*(q) f^-(v_f^-, v_i^-) g_a(q + \Delta p/2) d^3q + 2 \int g_b^*(q) f^+(v_f^+, v_i^+) g_a(q - \Delta p/2) d^3q \]

\[ v_i^\pm = p_i/2 - \Delta p/2 \pm q, \quad v_f^\pm = p_i/2 + \Delta p/2 \pm q. \]
Proof of the principle

- Assume positron scattering small compared to electron scattering
- Ps energy is well above the ionization (break-up) threshold

Then

\[ \sigma_a(\text{Ps}) = \sigma_a(\text{e}^-). \]
Pseudopotential calculations

• Pseudopotential from $e^- - A$ and $e^+ - A$ scattering phase shifts in the static-exchange approximation

• Average pseudopotential over the Ps density distribution

• Add van der Waals interaction in the form

$$V_W(R) = -\frac{C_6}{R^6} \left\{ 1 - \exp\left[-\left(\frac{R}{R_c}\right)^8\right]\right\}$$
Ps-Kr

![Graph showing phase shifts vs. Ps velocity for different L values (L=0, L=1, L=2).]
TABLE II: Mean atomic radii $\langle r \rangle$, core radii $R_0$, and Ps-atom scattering lengths $A$ for Ar, Kr and Xe. All values are in a.u.

<table>
<thead>
<tr>
<th>System</th>
<th>$C_6$</th>
<th>$\langle r \rangle$</th>
<th>$R_0$</th>
<th>$A^a$</th>
<th>$A^b$</th>
<th>$A^c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar</td>
<td>104.5</td>
<td>1.66</td>
<td>2.67</td>
<td>1.73</td>
<td>2.14–2.33</td>
<td>1.30–1.98</td>
</tr>
<tr>
<td>Kr</td>
<td>152</td>
<td>1.95</td>
<td>3.14</td>
<td>2.35</td>
<td>2.35–2.50</td>
<td>1.22–2.26</td>
</tr>
<tr>
<td>Xe</td>
<td>234</td>
<td>2.39</td>
<td>3.85</td>
<td>3.23</td>
<td>2.45</td>
<td>1.50–2.60</td>
</tr>
</tbody>
</table>

$^a$Scattering length from Eq. (20), obtained using Eq. (21) with $\gamma = 1.61$.

$^b$Present scattering calculations.

$^c$Values obtained by Mitroy et al. [9, 15].
Low-energy electron scattering

\[ \tan \delta_0 = -Ak - \pi k^2 \alpha / 3 + O(k^3 \ln k) \]

R P McEachran and A D Stauffer

e-Ar A<0
Low-energy scattering – controlled by van der Waals interaction

A>0 – no Ramsauer-Townsend minimum
Positronium Production and Scattering below Its Breakup Threshold

S. J. Brawley, S. E. Fayer, M. Shipman, and G. Laričić

\[(Ps, e^-, e^+) + Ar\]

Positronium energy (eV)

Total cross section (10^{-20} m^2)

Cross section (10^{-20} m^2)

Inset: crossed: \(Q_{m}^Ps\), full: \(Q_{T}^Ps\)

Velocity (a.u.)
Ionization-Binary Encounter Approximation

- Assume electron and positron scatter independently and neglect interference.

\[ |\vec{u}| = |\vec{u}'| \]
Ps-Xe cross sections
Brawley et al., PRL 115, 223201 (2015)

\[(\text{Ps}, e^-, e^+) + \text{Xe}\]
Ps-H$_2$
Ps-N$_2$

![Graph showing cross section (10^{-16} cm^2) vs. Ps velocity (a.u.) with data points and curves for elastic, ionization, total cross sections.](image-url)
Conclusions

- Energy range above the Ps ionization threshold: impulse approximation (quasifree electron model) works and explains similarities between \(e^- - A\) and Ps-A scattering
- Low energies: no similarity, no Ramsauer-Townsend minimum (???)
- Approach works for Ps-H\(_2\) collisions
- New calculations: Resonance Ps-N\(_2\) scattering is confirmed theoretically