Energy-resolved Measurements of Positron Annihilation on Large Molecules[+]

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The mystery of very large annihilation rates for positrons interacting with large molecules (e.g., containing several atoms) has remained unsolved for decades [1, 2]. In many cases, annihilation rates are orders of magnitude larger than expected from simple, uncorrelated collisions. Also, annihilation rates are often found to increase exponentially with molecular size. This phenomenon is important, not only in atomic and molecular physics, but it is also potentially relevant to annihilation in astrophysical settings and in materials such as organic solids. Theoretical models of these positron-molecule interactions have been proposed which incorporate Feshbach resonances associated with the vibrational modes of the target molecule [4], but prior to the studies described here, evidence of these resonances had remained elusive. Measurements of the normalized annihilation rate, Z_{eff}, as a function of incident positron energy will be presented for a variety of molecules, made using a cold positron beam ($\Delta\varepsilon$ ~25 meV FWHM) [3]. Incident positron energies ranged from 50 meV to the Ps threshold. The resulting energy-resolved data show large enhancements near the energies of the molecular vibrational modes. To our knowledge, these experiments provide the clearest example of a resonance phenomenon in either positron-atom or positron molecule interactions. Several features in the data lead to the conclusion that these resonances are intimately connected with the large annihilation rates observed previously using thermal distributions of positrons at 300 K. Further, the observed energies of the resonance peaks are downshifted from the vibrational mode energy. This downshift is interpreted as a measure of the positron-molecule binding energy, ranging from 40 meV in butane (C_4H_{10}) to 210 meV in dodecane ($C_{12}H_{26}$). This experiment provides the first experimental evidence that positrons can bind to neutral atoms and molecules. Recent experimental data will also be discussed, focusing on changes in the binding energy with varying molecular size and shape in alkanes, and on Z_{eff} measurements of smaller and simpler molecules than in previous work (e.g., triatomics and fluorinated methanes). The data confirm key features of a recent treatment of the vibrational Feshbach resonance model [4]. The talk will conclude with a brief discussion of a number of important questions that remain to be addressed regarding positron annihilation on molecules.

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[1] D. A. L. Paul and L. Saint-Pierre, Physical Review Letters **11**, 493 (1963).
[2] K. Iwata *et. al*., Physical Review A **61**, 022719 (2000).
[3] S. J. Gilbert *et al*., Physical Review Letters **88**, 43201 (2002).
[4] G. Gribakin, Physical Review A **61,** 022720 (2000).