New Physics with Positron Traps and Trap-Based Beams

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The development of novel positron traps and beams has enabled new investigations of anti- matter. This talk will discuss highlights of recent successes and the critical tools that enabled them. It will conclude with a brief discussion of prospects for further technological progress and the new physics that it might enable.

Studies of antimatter are of interest for a range of scientific and technological applications, including fundamental tests of gravity and tests of symmetries predicted by field theories (e.g., CPT), understanding astrophysical processes, and the characterization of materials. Many applications benefit greatly from tailoring collections of the antiparticles to optimize them for a specific use. Unlike electrons, which are copious in our world of matter, positrons are scarce (e.g., currents of picoamps instead of amps). The need to keep positrons isolated from ordinary matter has motivated the development of methods to manipulate them in vacuum in the form of single-component gases and plasmas.

More than three decades of positron trap and beam development have enabled specially designed electromagnetic traps for long-term (e.g., weeks or more) antimatter confinement, cryogenically cooled antiparticle gases and plasmas, high-density plasmas, finely focused beams, and methods to deliver very large bursts and/or short temporal bursts of antiparticles and to create guided positronium (Ps) atom beams [1, 2].

Scientific and technological progress in several areas will be reviewed. It includes the creation and study of antihydrogen atoms and gravity tests [3, 4, 5, 6]; the formation of the positronium molecule (i.e., Ps_2, the first many-electron, many-positron state, $e^+e^-e^+e^-$) [7]; and understanding Feshbach-resonances in positron annihilation and the nature of the resulting positron-molecule bound states [8]. Outstanding goals and the challenges associated with them will be discussed. They include the opportunities that could be enabled by putting a positron trap system on an intense source such as the NEPOMUC facility in Munich, and plans to study the electron-positron system [9], namely a positronium-atom Bose-Einstein condensed gas (BEC) [10] and a classical "pair" (i.e., e^+ - e^-) plasma [11].

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[1] J. R. Danielson, *et al.,* Rev. Mod. Phys. **87**, 247 (2015).
[2] D. B. Cassidy, Euro. Phys. J. D **72**, 53 (2018).
[3] G. B. Andresen, *et al.,* Nature **468**, 673 (2010).
[4] G. Gabrielse, *et al.,* Phys. Rev. Lett. **108**, 113002 (2012).
[5] M. Ahmadi, *et al.,* Phys. Rev. Lett. **120**, (2018).
[6] M. Ahmadi, *et al., et al.,* Nature Letters **557**, 71 (2018).
[7] D. B. Cassidy and A. P. Mills, Jr., Nature **449**, 195 (2007).
[8] G. F. Gribakin, *et al.,* Rev. Mod. Phys. **82**, 2557 (2010).
[9] H. Yabu, Nuc. Instrum. Meth. B **221**, 144 (2004).
[10] A. P. Mills, Jr., Nucl. Instrum. Methods B **192**, 107 (2002).
[11] T. S. Pedersen, *et al.,* New J. Phys. **14**, 035010 (2012).

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