Polarisation effects in microwave spectroscopy of Positronium

Krzysztof P. Habdas[1, †], **Rebecca J. Daly**[1], **Ross E. Sheldon**[1, ⋆], **David B. Cassidy** [1, ‡]

[1]Department of Physics and Astronomy, University College London, Gower Place, WC1E 6BN, London, United Kingdom
⋆ present address: Stefan Meyer Institute for Subatomic Physics, Austrian Academy of Sciences (ÖAW), Boltzmanngasse 3, 1090 Wien, Austria
†presenting author's email: k.habdas@ucl.ac.uk,
‡corresponding author's email: d.cassidy@ucl.ac.uk

Being composed only of leptons, positronium (Ps), the bound state of an electron and positron, is described almost entirely by quantum electrodynamics (QED) theory. Measurements of Ps energy intervals, decay rates, or decay modes can be used to test QED calculations, but due to various experimental challenges the measurement precision is considerably lower than the corresponding theoretical values [1, 2].

In the the Ps $n = 2$ fine structure, the precision of the calculated energy intervals is known to be 80 kHz, whereas the errors of the measured values are approximately 1 MHz [3, 4]. Recent measurements attempting to reduce this disparity have been performed using waveguides aligned perpendicularly to the beam axis, which is necessary because of the transverse velocity spread of typical Ps sources [2]. In this configuration, the direction of the electric field is such that only transitions for which $\Delta M_J = 0$ can be driven [5].

It is possible, however, to drive transitions with different microwave polarisations in free space, using a horn antenna to generate microwave radiation [6]. This approach has some limitations, such as reduced intensity of radiation and more complicated fields than are obtained in a waveguide [5], but it allows for varying of polarisation.

Here we present measurements of the $2\,^3S_1 \rightarrow 2\,^3P_1$ transition in positronium using microwave radiation generated using a horn antenna. By rotating the axis of the antenna, and hence the polarisation of the radiation, transitions were driven for which either the selection rule $\Delta M_J = 0$ or $\Delta M_J = \pm 1$ dominated. In both cases, good agreement was found with theory for the resonance frequencies and relative transition rates. We also demonstrate that previously observed frequency shifts, arising from reflections of microwave radiation within the vacuum chamber in which the measurements were performed, can be largely mitigated using a modified apparatus.

References

[1] S. G Karshenboim, *Int. J. Mod. Phys. A* **19**, 3879—3896 (2004).
[2] G.S. Adkins, D.B. Cassidy, and J. Pérez-Ríos, *Phys. Rep.* **975**, 1–61 (2022).
[3] A. Czarnecki, K. Melnikov, and A. Yelkhovsky, *Phys.* Rev. A **59**, (1999) 4316.
[4] D. Hagena, R. Ley, D. Weil *et al.*, *Phys. Rev. Lett.* **71**, 2887 (1993).
[5] L. Gurung, T. J. Babij, J. Pérez-Ríos et al., *Phys. Rev. A* **103**, (2021) 042805.
[6] R. E. Sheldon, T. J. Babij, S. H. Reeder *et al.*, *Phys. Rev. A* **107**, 042810 (2023).