Polarisation effects in spectroscopy of the positronium n = 2 fine structure intervals

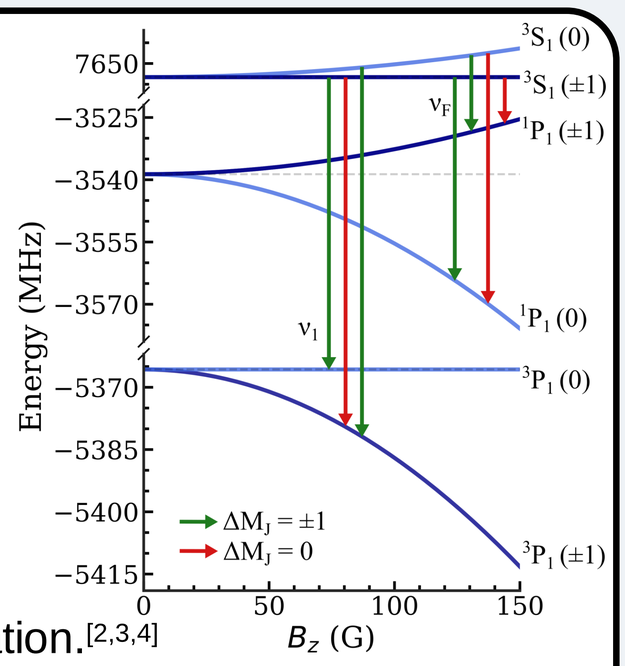
1 Ps 0.0011

Ross E. Sheldon*, Rebecca J. Daly, Krzysztof P. Habdas, and David B. Cassidy
Department of Physics and Astronomy, University College London, UK

*ross.sheldon.18@ucl.ac.uk

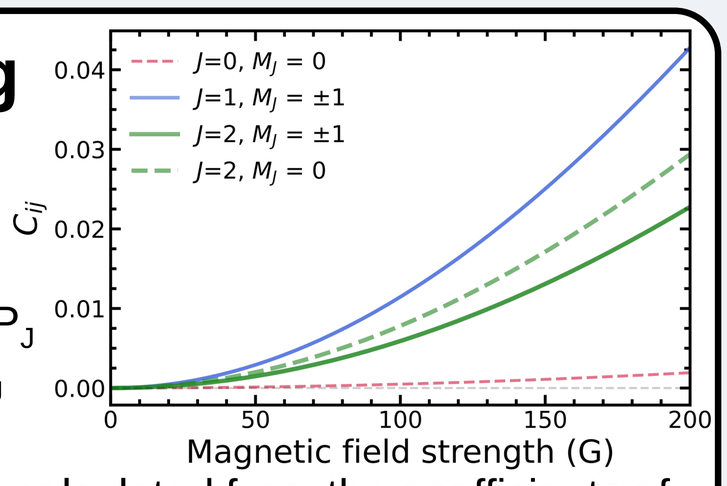
Introduction

- The n = 2 Positronium (Ps, the bound state of an electron and positron) fine structure intervals have been measured several times to test bound-state quantum electrodynamics.[1]
- All previous measurements were performed using waveguides of fixed polarisation.[2,3,4]
- Horn antennas offer a way to change the polarisation of the microwave radiation.
- We drove $2\,^3S_1 \rightarrow 2\,^{2S+1}P_1$ (S = 0, 1) transitions, known as ν_F and ν_1, using a horn antenna to evaluate the effect of polarisation in free-space Ps microwave spectroscopy.



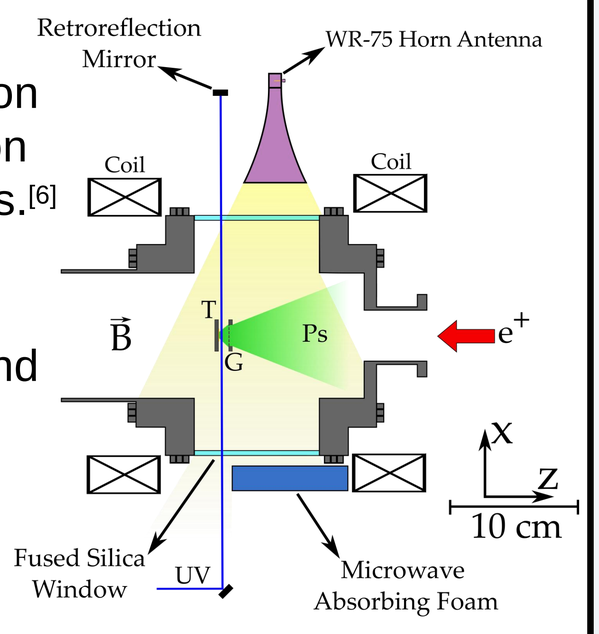
Zeeman Mixing

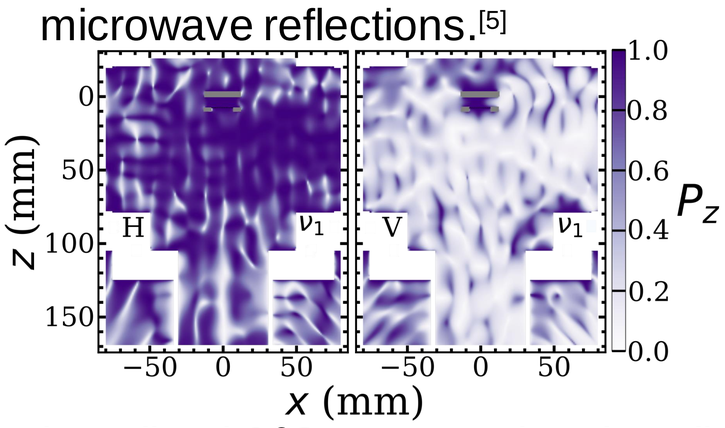
- ν_F is forbidden in zero field due to charge conjugation symmetry.
- $2\,^1P_1$ levels mix with $2\,^3P_J$ levels with the same M_J in a magnetic field.
- The degree of mixing is calculated from the coefficients of the eigenvectors of the full Hamiltonian matrix A_{mj}.



Experimental Methods

- $1\,^3S_1$ Ps was made by implanting positron pulses into a mesoporous SiO_2 film in a field of $\langle B_z \rangle$ = 131 G.[6]
- $2\,^3S_1$ Ps was made by single photon excitation in an electric field: $1\,^3S_1 \xrightarrow{\lambda_{UV} = 243\ \mathrm{nm}} 2\,^3S_1' \xrightarrow{F \approx 2 \rightarrow 0\ \mathrm{kV/cm}} 2\,^3S_1$.[7]
- Time resolved gamma-ray spectroscopy using scintillation detectors allows differentiation of long- and short-lived states.[6]
- A horn antenna emitted radiation parallel to B_z when orientated horizontally (H), and orthogonal to B_z when orientated vertically (V).
- The vacuum chamber was configured to minimise microwave reflections.[5]

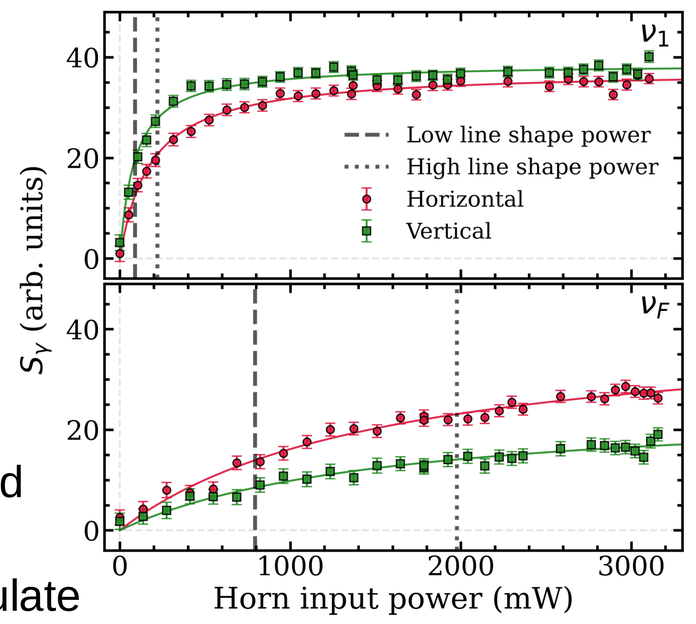




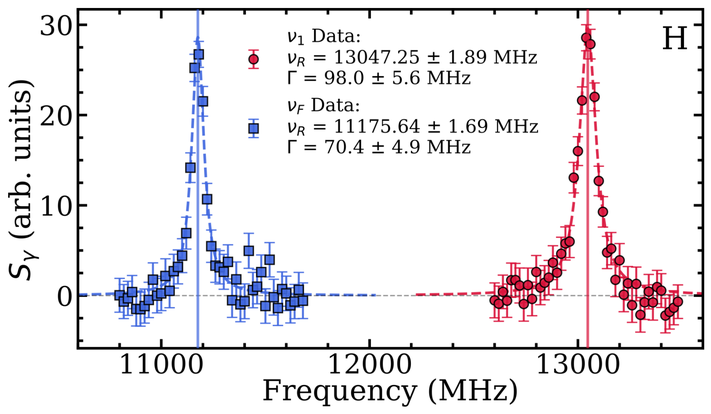
- Simulations indicate the average unpolarised fraction is 30% for both orientations.
- The population transfer from the long-lived $2\,^3S_1$ state to the short-lived $2\,^{2S+1}P_1$ state, S_γ, was measured as a function of microwave frequency and power.[4]

Saturation Measurements

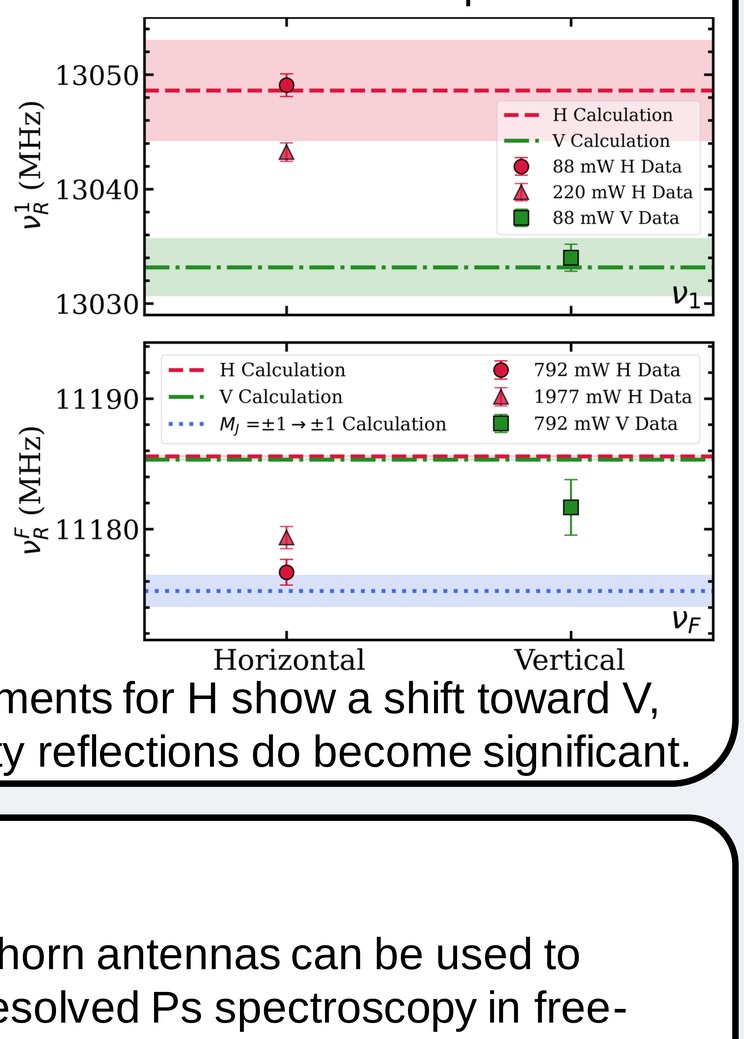
- ν_1 saturation data is consistent with all $2\,^3S_1$ states being depopulated.
- H orientation requires more power to saturate due to $2\,^3S_1$ (0) only being depopulated by low-intensity unpolarised reflections.
- ν_F does not fully depopulate the $2\,^3S_1$ state in V orientation, indicating depopulation of at least one $2\,^3S_1$ state is highly limited.



Line Shape Measurements



- Line shapes fitted with Lorentzian functions to extract the resonance frequency. Comparison made to average Zeeman shift for each polarisation.
- At low power ν_1 data are consistent with transitions driven by fully polarised radiation.
- But ν_F is shifted 4.1σ from theory in the H case. Being consistent with only $2\,^3S_1$ (±1) → $2\,^1P_1$ (±1) being driven.



- High power measurements for H show a shift toward V, indicating low-intensity reflections do become significant.

Conclusions

- We have verified that horn antennas can be used to perform polarisation resolved Ps spectroscopy in free-space. Although near the saturation regime unpolarised reflections can drive additional transitions.
- The ν_F saturation and line shape data display unexpected behaviour, likely due to an incomplete model of the Zeeman mixing.
- Ongoing waveguide measurements will further investigate the behaviour of ν_F.

[1] S. G. Karshenboim, *Phys. Reports,* **422,** 1-63 (2005)
[2] S. Hatamian et al., *PRL*, **58**, 1833 (1987)
[3] R. Ley et al., *Hyperfine interactions*, **89**, 327 (1994)
[4] R. E. Sheldon et al., *PRL*, **131**, 043001 (2023)
[5] R. E. Sheldon et al., *PRA,* **107**, 042810 (2023)
[6] B. S. Cooper et al., *Rev. Sci. Intrum.,* **86**, 103101 (2015)
[7] A. M. Alonso et al., *PRA,* **95**, 033408 (2017)

For more information check out our website: www.antimattergravity.com