Exploring higher-order Casimir-Polder interactions with Rydberg atoms confined in nanocells

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Highly excited (Rydberg) atoms in vapour cells have recently attracted significant attention as sensitive sensors of electromagnetic fields and as single photon sources for quantum technology applications. Rydberg atoms also present a fundamental interest for studying atom-surface interactions [1], because they expose limitations in the traditional approach of Casimir-Polder (CP) theory [2]. Indeed, when Rydberg atoms interact with surfaces in the extreme near-field, the dipole approximation breaks down and higher-order terms need to be considered. This is because the diameter of Rydberg atoms, proportional to n^{*2} (n^* is the effective quantum number), compares to the probing depth of spectroscopic experiments in nanocells filled with atomic vapours.

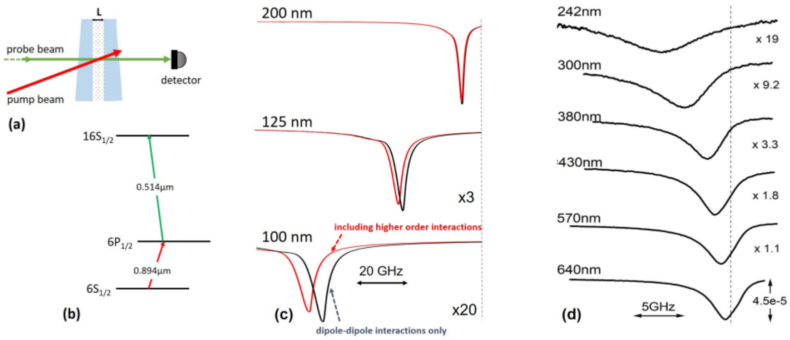

Figure 1. a) Schematic of a pump-probe experiment in a vapour nanocell. b) Relevant cesium levels for our experiment. c) Predicted thin cell transmission for different thicknesses, with (red) and without (black) higher-order interactions. d) Experimental transmission spectra for thicknesses between 640-240nm.

We present our recent calculations of the C_3 (dipole-dipole) and the C_5 (combined quadrupole-quadrupole and dipole-octupole) CP coefficients for alkali Rydberg atoms. We also examine the effects of higher-order interactions in nanocell transmission spectroscopy. In particular, we focus on a pump-probe experiment that utilises a strong laser at 894nm for exciting cesium atoms to the $6P_{1/2}$ level and subsequently deploying a green laser at 514nm to probe $Cs(16S_{1/2}$) inside the nanocell (Fig.1a,b). Our theoretical analysis shows that higher-order effects should be measurable for thicknesses below 150nm (Fig.1c). Finally, we present the results of an on-going experiment probing atoms in a nanocell whose thickness varies from 50-800nm (Fig.1d). The recorded transmission spectra, (640-240nm), show a clear shift of the atomic resonance due to strong CP interactions. We are currently measuring the C_3 coefficient of the $Cs(16S_{1/2}$

)-surface (YAG) interaction by fitting our theoretical model to the experimental curves. We are also trying to account for systematic effects due to the interactions with parasitic electric fields from charge build-up on the windows.

[1] V. Sandoghdar et al., Phys. Rev. Lett 68, 3432–3435 (1993).
[2] J. A. Crosse et al., Phys. Rev. A 82, 3010901 (2010).