

Internship / PhD Position

Quantum computing with a hybrid array of molecules and Rydberg atoms

Laboratory: Centre for Cold Matter, Imperial College London

Location: London, United Kingdom

Website: <https://www.imperial.ac.uk/centre-for-cold-matter/>

Supervisor: Chi Zhang (c.zhang@imperial.ac.uk)

PhD thesis possibility after internship: YES, subject to funding and admission

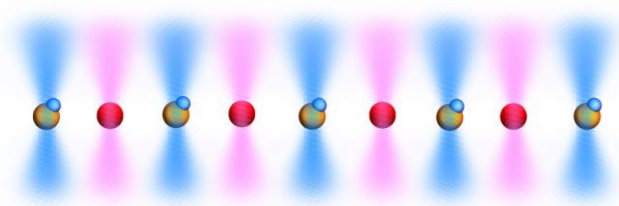
PhD funding: Subject to availability

Scientific context

Ultracold atoms and molecules are among the leading platforms for quantum information processing. Polar molecules have rich internal structures that provide long-lived quantum states for storing information, while highly excited Rydberg atoms feature strong, controllable interactions that enable fast quantum operations. Combining these complementary strengths offers exciting opportunities for scalable quantum computing.

We have proposed a new hybrid quantum computing architecture in which polar molecules are coupled through their interactions with nearby Rydberg atoms [1]. This approach promises entangling gates on microsecond timescales, several orders of magnitude faster than conventional molecular gates. The same interactions can also enable quantum-state readout and mid-circuit measurements, which are important building blocks for quantum error correction.

At Imperial College London's Centre for Cold Matter, we are developing a new experimental platform combining laser-cooled CaF molecules and Rb atoms in reconfigurable optical tweezer arrays. The experiment aims to investigate interactions between individual molecules and Rydberg atoms and use these interactions to demonstrate fast quantum gates and entanglement.



Hybrid atom-molecule optical tweezer array. Individual molecules and atoms are trapped and controlled using tightly focused laser beams. Interactions with Rydberg atoms enable fast quantum gates between molecular qubits.

Internship

The internship will contribute to the development and operation of the hybrid atom-molecule experimental platform.

The student will participate in implementing and characterising optical tweezer arrays for individual atoms and molecules. Depending on the stage of the experiment and the student's background, the project may focus on optical trapping, single-particle fluorescence imaging, coherent control of Rb atoms, or Rydberg excitation and spectroscopy. Numerical simulations of trapping potentials, atomic energy levels or interaction dynamics may complement the experimental work.

The student will work closely with a team of experimental researchers, gaining hands-on experience in modern atomic and molecular physics. The project will provide training in laser optics, quantum control, experimental automation and data analysis, while contributing to the development of a new quantum computing platform.

PhD Thesis

A possible continuation into a PhD would focus on the coherent interactions between individual molecules and Rydberg atoms. Following the initial development of the experimental platform, the research would investigate the molecular-state-dependent Rydberg excitation spectrum and demonstrate the interaction required for quantum logic gates.

The next goal would be to use these interactions to entangle atoms and molecules, and ultimately to implement fast entangling gates between pairs of molecular qubits. The research could subsequently explore mid-circuit measurements and the generation of multipartite entangled states.

This project would provide opportunities to develop expertise in experimental quantum computing, ultracold molecules, Rydberg physics and coherent quantum control. A PhD continuation may be possible, subject to the availability of funding, admission requirements and mutual agreement.

References

- [1] C. Zhang and M. R. Tarbutt, *Quantum Computation in a Hybrid Array of Molecules and Rydberg Atoms*, PRX Quantum **3**, 030340 (2022).
- [2] L. Anderegg et al., *An optical tweezer array of ultracold molecules*, Science **365**, 1156 (2019).