Cooling complex molecules for quantum interferometry and measurements of parity violation in chiral molecules

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Methods to cool molecules to low temperatures have so far been limited to very simple molecular species. The aim of this project is to cool vastly more complex molecules, and to use these for two applications in quantum metrology. The first application is matter-wave interferometry with large molecules, as pioneered in Vienna [1]. This work explores the boundary between quantum and classical physics, tests whether there is any fundamental limit to quantum delocalization, and explores the basic mechanisms of decoherence. It also provides a tool for exceptionally sensitive measurements of tiny forces. As the molecules get larger and heavier, it is necessary to make ever colder and slower beams so that the de Broglie wavelength and the coherence lengths remains large enough for interferometry. The second application is the study of parity violation in chiral molecules. When chiral molecules are made in the laboratory, there is no preference for one handedness over the other. This is because the electromagnetic interactions involved in their synthesis are invariant under a parity transformation and so do not distinguish left from right. Most biological molecules however come with a single handedness. This is true of all sugars and amino acids. The origin of this biological homochirality, and whether parity-violating weak interactions played a role, are open questions. Working with the group in Paris, we aim to shed light on these questions by measuring the tiny energy difference between left and right-handed versions of chiral molecule caused by the weak interaction [2, 3]. For this work, slow beams of cold chiral molecules are needed.

FIG. 1: Producing cold beams of large molecules by cryogenic buffer gas cooling.

The focus of this project will be the production and detection of suitably-prepared cold and slowly-moving beams of complex molecules including chiral molecules that can be used to measure parity violation, and large molecules that can be used for interferometry. The molecules will be injected into a buffer gas of helium cooled to about 1 K [4] in order to produce highly collimated beams with a temperature of 1 K and speeds below 100 m/s. We will develop a sensitive technique of cavity-enhanced microwave detection, where molecules collectively emit microwave radiation into a cavity. We will also use microwave techniques to resolve the handedness of chiral molecules. The apparatus and methods of beam production, manipulation, identification and detection will be developed at Imperial College, and there will be a possibility of spending time in Paris to develop the parity violation measurement.

6-month project. In the short project, you will begin to explore the production of large molecules at low temperatures. The project will focus on the production of cold methyltrioxorhenium and trioxane, which are important test molecules for parity violation measurements. You will explore the optimum production method and learn how to do vibrational spectroscopy at a wavelength of 10 microns using a quantum cascade laser.