Project title: Engineering Correlation Effects in Quantum Structures

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Project Summary: Controlled manipulation of electron wavefunction in nanostructures has garnered immense interest due to its implications with regard to the next generation of quantum technologies. As a consequence, semiconductor nanostructures have been exploited to investigate fundamental phenomena such as the Quantum Hall Effect, Fractional Quantum Hall Effect (FQHE), ballistic conductance quantisation, Majorana zero mode, etc. The discovery of FQHE in 1982 resulted in the first observations of the fractional charge of electrons, and since then, more than 100 fractional quantum states have been discovered in the presence of a magnetic field (B). In addition, theoretical and experimental efforts have been continued in realising the fractional states without any B. It took almost 38 years until we showed in 2019 the spatial organisation of ballistic, quasi-one-dimensional (1D) electrons, formed in GaAs-based systems, into a zig-zag chain exhibiting a variety of fractional conductance states (1/2, 2/5, etc.) in the absence of B. Finding new fractional quantum states in other high-quality electronic systems, namely a bilayer electronic system, will be a major step towards understanding self-organised fractional quantum states. A bilayer system provides an outstanding platform to investigate quantum transport as the separation between electrons can be as close as the Bohr radius; therefore, the quasi-particles, so formed, which give rise to a fractional quantisation in conductance, could be investigated in a variety of complex interacting regimes. The project will include possible investigations on 1) the emergence of self-organised fractional quantisation in novel single and bilayer electronic systems, 2) the spin and charge phases of quasi-particles, including investigations on entanglement as well as their topological effects, and 3) the relationship between the self-organised fractional quantum states to the ones observed in the fractional Quantum Hall effect [1,2]. The project will involve collaborating with experimentalists and theorists from UCL and outside.

Scientific excellence: The aim of this experimental project is to develop schemes for manipulating quantum states for the next generation of quantum devices as well as to learn about new fundamental quantum condensed matter physics. The project will bring new insight into understanding how electronic charge could be fractionalised by merely confining electrons in narrow low dimensional channels under strong electron-electron interactions, in this way, we will be able to realise new rules for ballistic fractional quantum resistors. The group has expertise in the field, therefore the chances of successfully finishing the project within the timeframe are very high.

Research training: The student will be provided with cleanroom training for the fabrication of quantum devices, and extensive training on performing low-noise quantum transport measurements at extremely low temperatures and high magnetic fields. In addition, students would have access to a variety of additional training opportunities via UCL, as well as the chance to network with interdisciplinary research teams and industry representatives. There would be many opportunities to attend national and international conferences to present work and establish networking with international researchers.

References:

1. Zero-magnetic field fractional quantum states, Kumar et al, Physical Review Letters, 22 (8), 086803 (2019).
2. Formation of a non-magnetic, odd-denominator fractional quantized conductance in a quasi-one-dimensional electron system, Kumar et al, Applied Physics Letters 115 (12), 123104 (2019);

Imaging the zigzag Wigner crystal in confinement-tunable quantum wires, Ho et al, Physical Review Letters, 121, 106801 (2018); Kumar and Pepper, Applied Physics Letters, 119 (11) (2021).