Exploring Quantum Magnetism and Many-Body Localisation in a Dilute Gas of Ultracold Polar Molecules

T. J. Harris[a], A. J. Groszek[a], A. Safavi-Naini[b,c] and M. J. Davis[a]

[a]*ARC Centre of Excellence for Engineered Quantum Systems, School of Mathematics and Physics, University of Queensland, Brisbane, QLD 4072, Australia.*

[b]*QuSoft, Science Park 123, 1098 XG Amsterdam, the Netherlands.*

[c]*Institute for Theoretical Physics, Institute of Physics, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, the Netherlands.*

Ultracold polar molecules pinned in optical lattices provide a flexible framework to study models of quantum magnetism due to their long-range dipolar interactions and rich internal structure. Recent advances in molecular trapping, cooling and detection techniques have allowed for increasingly sophisticated experimental control over these systems [1, 2, 3]. Despite this, lattice filling fractions in ultracold molecule experiments remain low, with reported fillings significantly below 50% [3, 4]. Although this is typically considered a limitation of the system, in our work we utilize this feature to explore non-equilibrium dynamics in the presence of quenched disorder [5]. We consider a system of diatomic polar molecules in their vibrionic ground state, with on-site disorder arising from the dilute, randomised configurations of molecules in the lattice [6]. Spin-spin couplings between molecules are introduced via the dipolar interactions, and the resulting system is effectively described by a *t-J-V-W* Hamiltonian [7, 8]. The model's microscopic parameters can be precisely controlled by altering the intensities of the lattice lasers and through application of external fields. We utilise exact diagonalisation and the discrete truncated Wigner approximation to study the relaxation of local spin observables, and the growth of bipartite entanglement entropy, in systems of molecules confined to 1D and 2D optical lattice geometries. Our results demonstrate that the model realises a transition from an ergodic to a many-body localised phase by increasing the relative strength of the spin-density interactions. This transition is also evident in the behaviour of the mean level-spacing statistics of the many-body Hamiltonian.

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