Novel Properties of Flat Energy Band States

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Aim : To determine an experimentally viable preparation scheme to allow a kagome Flat Band to be implemented within an optical lattice, whilst investigating novel properties along the way.

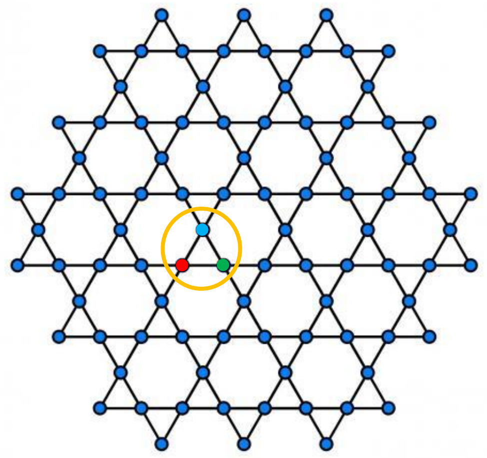

Fig. 1 : Kagome lattice

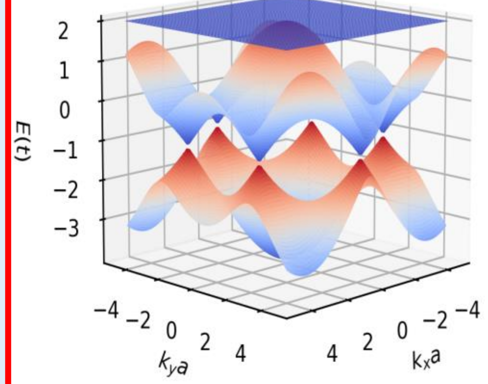

Fig. 2: Kagome Band structure

- Fig. 1 displays the Kagome Lattice. This is constructed by repeating the circled unit cell, consisting of A, B and C sites (red, green, blue)
- A tight binding model is assumed, meaning a particle can 'hop' from a particular lattice site to any of its nearest neighbours, which are connected via black lines.
- A novel property of the Kagome lattice is the production of a Flat Band within the single particle energy spectra, as shown in Fig.2
- Flat Bands signals that the particles within the lattice are strictly localised. Each particle exists with non-existent kinetic energy, creating a Flat Band.

Many researchers in the field are interested in studying Flat Band physics as individual states prepared in the Flat Band are highly degenerate. As such, the effect of particle-particle interactions is amplified, which may produce novel states of matter.

- An optical lattice is an artificial crystal created via interfering lasers.
- When Ultra-cold atoms are placed within the optical lattice, they obey similar dynamics to electrons moving through a physical solid.
- Optical lattices are used to simulate electronic motion whilst offering great control over experimental setups and parameters.

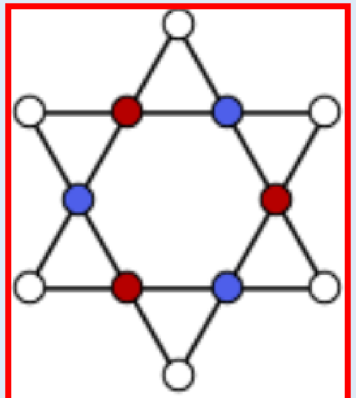

Fig. 3: Localised state

- Kagome Flat band arises when a particles wavefunction is distributed around hexagon ring as shown in Fig 3. The red and blue dots correspond to equal but opposite amplitudes
- To propagate out through the lattice, the particle must first hop to a white site.
- The particle may hop carrying a negative, or positive amplitude with equal probability.
- This results in destructive interference and as such cannot escape from this ring.

Adiabatic State Preparation

General Method

- If system parameters are changed sufficiently slowly, then the state of a particle within the system will also evolve to remain a valid solution.
- Method consists of computationally simulating an optical Kagome lattice, to evolve a particle from an initial ‘product’ state into the Kagome Flat Band
- An initial optical lattice is taken such that tunnelling is supressed (no particle hopping), with an energy offset between sites within the Lattice (Fig. 4)
- For this initial system, a single particle is projected onto all ‘A’ sites of the lattice, shown as red dots in Fig 5.

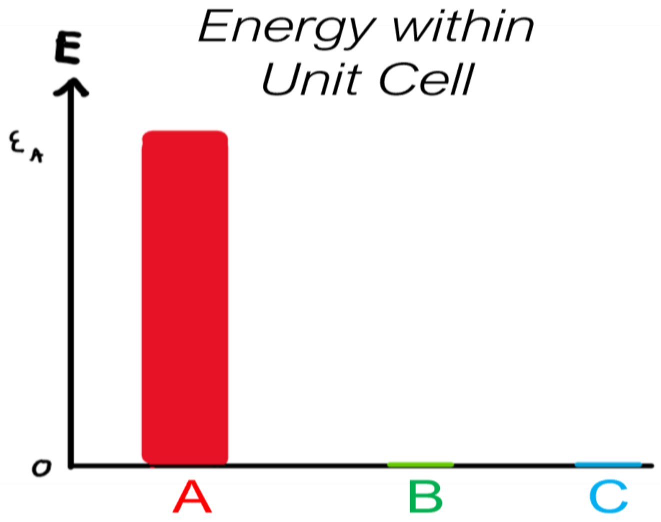

Fig. 4: Energy offset

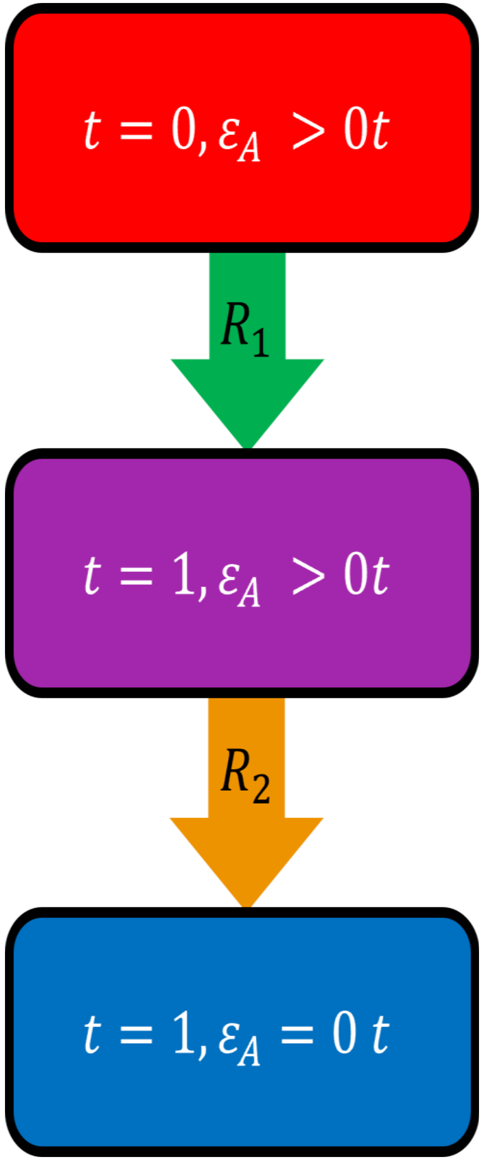

Fig. 6: Ramp schematic

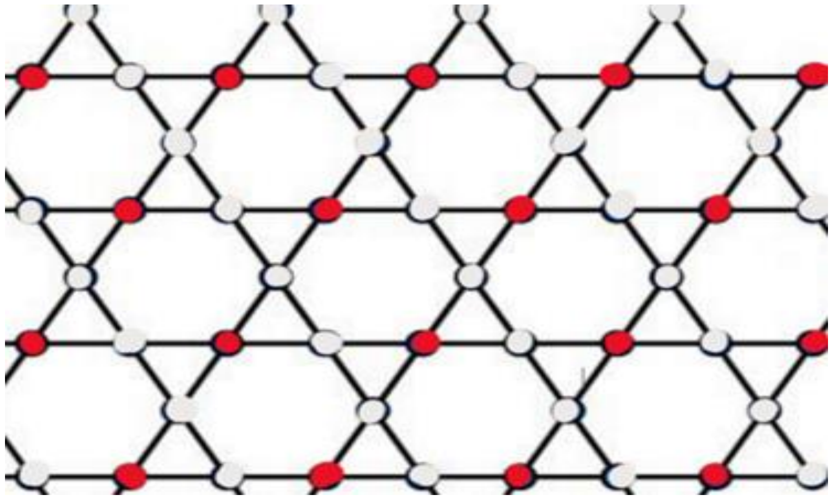
Fig. 5: Initial state

Two stage Ramps

- To load into the Flat Band, a two stage ramp process is utilised, shown schematically in Fig. 6 (t denotes the tunnelling coefficient.)
- Ramp 1 (R_1) starts in the initial system, then slowly turns on hopping, whilst maintaining an energy offset
- Ramp 2 (R_2) reduces the energy offset to zero.
- If this preparation scheme is successful, the final prepared state will then be almost exactly a Flat Band eigenstate.

Results Explanations

- Results are quantified via calculation of a quantity called the fidelity (F)
- This is defined mathematically via: $F = \sum_i |\langle\phi_i|\psi(T)\rangle|^2$ where $|\phi_i\rangle$ are Flat Band eigenstates.
- In words, this quantity determines how much of the prepared state ($\psi(T)$), is constructed of Flat Band states
- $1 - F = 0$ corresponds to the state prepared exists only in the Flat Band
- $1 - F = 1$ corresponds to the prepared state not existing at all in the Flat Band

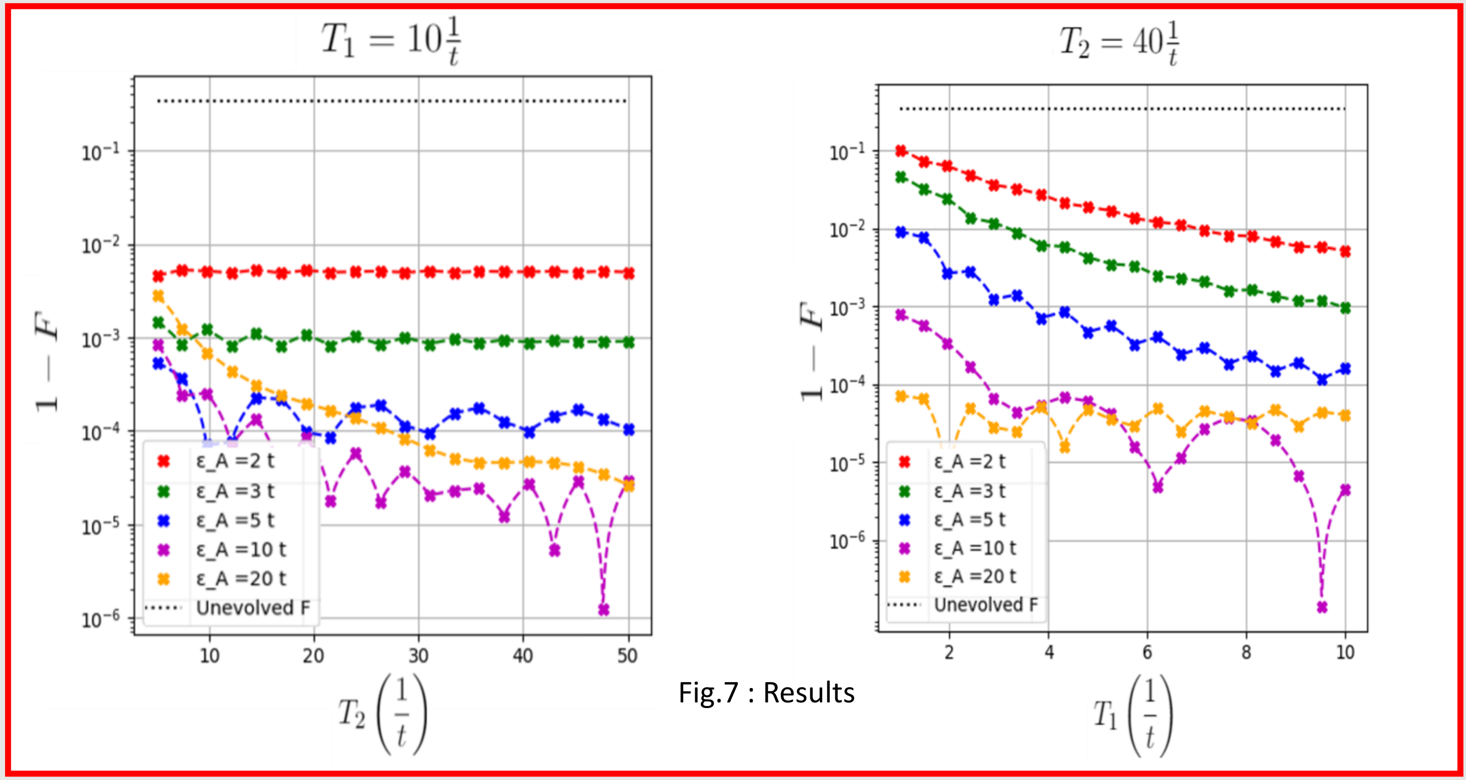

Fig.7 : Results

Results

- Fig. 7 plots fidelities against total Ramp times for Ramp 1 and Ramp 2 ($T_1$and T_2 respectively)
- As can be seen, results for $1 - F$ can drop as low as 10^{-5} or even 10^{-6}, meaning the produced state deviates only minimally from a Flat Band state.
- The optimal energy offset to use depends upon the ramp times used, but can see energy offsets > $5t$ perform best. (where t is the tunnelling coefficient)

Conclusions

This illustrates that the produced state is overwhelmingly likely to exist within the Flat Band using this preparation scheme, without the need to introduce further complexity, even for very short ramp times. This allows us to conclude that this method is a highly efficient way of preparing a system into the Kagome Flat band.

This method could thus be implemented experimentally, given an experimental set-up with the ability to adjust on-site energies.