

Course Outline LECTURE 1 Introduction Brief Review Lattice Basics Detection Methods Hubbard models Single Atom Imaging/Control Single Atom Imaging Bosons/Fermions Probing Thermal and Quantum Fluctuations Single Spin Manipulation Topological Quantum Matter

LECTURE 3 - Many-Body Localisation

Introduction

- **1** Many-Body Localisation Phase Transition in 2D
 - Probing MBL transition using domain wall dynamics and CDW dynamics
 - Wavelength Dependence of Localization
- 1

2 2D MBL with Coupling to a Finite Bath

 ${\ensuremath{\,{\rm \triangleright}}}\xspace$ CDW Dynamics in the presence of a finite bath



3 Probing Relaxation/Transport Dynamics close to MBL

LECTURE 2 - Quantum Magnetism with UCQG Light Cone Spreading of Correlations Superexchange Interactions Single Spin Impurity Bound Magnons AFM Order in the Fermi Hubbard Model Probing Hidden AFM in 1D Hubbard Chains Direct Imaging of Spin-Charge Separation Incommensurate AFM in 1D

Imaging Polarons - Charge Impurities in an AFM



Introduction $f(x,y), \sigma(x), \sigma(x),$

see A. Georges (CdF)

Three Central Goals

New probes & analysis techniques
 new light on known phenomena -

- Quantitative predictions
 e.g. equation of state BEC-BCS crossover -
- 3 New phenomena / phases of matter in new regimes



















Experiments isolated from environment

Not connected to reservoirs!





Experiments isolated from environment

Not connected to reservoirs!











Measuring Momentum Distributions





































Single Atoms

Superfluid

J. Sherson et al. Nature 467, 68 (2010)

Mott Insulators

LMU

Mott-Insulator











Toronto (⁴⁰K)



































Gauge Fields Harper Hamiltonian and Hofstadter Butterfly

























An Aharonov Bohm Interferometer for Determining Bloch Band Topology

















































Some statements for the second law of thermodynamics become invalid!

LMU

















Single Particle in a Periodic Potential - Band Structure (2)

Use Fourier expansion

$$V(x) = \sum_{r} V_r e^{i2rkx} \quad \text{and} \quad u_q^{(n)}(x) = \sum_{l} c_l^{(n,q)} e^{i2lkx}$$

yields for the potential energy term

$$V(x)u_{q}^{(n)}(x) = \sum_{l} \sum_{r} V_{r} e^{i2(r+l)kx} c_{l}^{(n,q)}$$

and the kinetic energy term

$$\frac{(\hat{p}+q)^2}{2m}u_q^{(n)}(x) = \sum_l \frac{(2\hbar kl+q)^2}{2m}c_l^{(n,q)}e^{i2lkx}.$$

In the experiment standing wave interference pattern gives

$$V(x) = V_{lat} \sin^2(kx) = -\frac{1}{4} \left(e^{2ikx} + e^{-2ikx} \right) + \text{c.c.}$$

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IMU

$$H\phi_q^{(n)}(x) = E_q^{(n)}\phi_q^{(n)}(x)$$
 with $H = \frac{1}{2m}\hat{p}^2 + V(x)$

Solved by Bloch waves (periodic functions in lattice period)

$$\left(\phi_q^{(n)}(x) = e^{iqx} \cdot u_q^{(n)}(x) \right)$$

q = Crystal Momentum or Quasi-Momentum
n = Band index

Plugging this into Schrödinger Equation, gives:

$$H_{B}u_{q}^{(n)}(x) = E_{q}^{(n)}u_{q}^{(n)}(x) \quad \text{with} \quad H_{B} = \frac{1}{2m}(\hat{p}+q)^{2} + V_{lat}(x)$$

$$\begin{aligned} \text{Single Particle in a Periodic Potential - Band Structure (3)} \\ \text{Use Fourier expansion} \\ \sum_{l} H_{l,l'} \cdot c_{l}^{(n,q)} = E_{q}^{(n)} c_{l}^{(n,q)} \quad \text{with} \quad H_{l,l'} = \begin{cases} (2l+q/\hbar k)^2 E_r & \text{if } l = l' \\ -1/4 \cdot V_0 & \text{if } |l-l'| = 1 \\ 0 & else \end{cases} \\ \begin{pmatrix} (q/\hbar k)^2 E_r & -\frac{1}{4} V_0 & 0 & 0 & \cdots \\ 0 & -\frac{1}{4} V_0 & (4+q/\hbar k)^2 E_r & -\frac{1}{4} V_0 & 0 \\ -\frac{1}{4} V_0 & \ddots & \end{pmatrix} \\ \begin{pmatrix} c_{l,nq}^{(n,q)} \\ c_{l,n}^{(n,q)} \\ \vdots \end{pmatrix} = E_{q}^{(n)} \begin{pmatrix} c_{l,nq}^{(n,q)} \\ c_{l,nq}^{(n,q)} \\ \vdots \end{pmatrix} \\ \text{Diagonalization gives us Eigenvalues and Eigenvectors!} \end{aligned}$$





