Literature Review

Matthew Gebert

February 13, 2020

Topological insulators surface states with ferroics

1 Topological Insualtors

1.1 Introduction

1.2 Spin-Orbit Coupling

Doesn't break time-reversal symmetry like magentic field for QHE, but can lead to **quantum spin hall effect**, or QSHE, where electrons differentiated by their spin move in opposite directions. No conserved spin current to test in a material.

1.3 Material Growths

2 Magnetic Materials

2.1 Classifications

2.1.1 Ferromagnetic

2.1.2 Anti-ferromagnetic

2.1.3 Paramagnetic

2.1.4 Diamagnetic

2.2 Ferromagnetic Insualtors

3 TI & FI Heterostructures

3.1 Theory

3.2 Experiments

https://www-nature-com.ezproxy.lib.monash.edu.au/articles/nature13534 https://advances.sciencemag.org/content/5/8/e
https://tms16.sciencesconf.org/data/pages/TI_lecture2.pdf https://arxiv.org/pdf/1401.0848.pdf

3.2.1 MBE Growths

4

5 Knowledge & Concepts

5.1 Symmetry

Apparently ssymmetry is very important in all physical systems. For example, the order exhibited in crystals can be described through the breaking of the continuous (rotational & translational) symmetry of space. This is due to the electrostatic interactions that cause a periodic lattice. In Magnets, spin space and time reversal symmetry are broken.

5.2 Spintronics

5.2.1 Ahrimhov Bohm Effect

5.3 Fine Structure Constant

The fine structure constant, also known as Sommerfields constant, is the coupleing constant "α" that measures the strength of the EM force interacting with light.

Two methods it has been measured by include the anomalous magnetic moment of the electron, a_e, as well as appearing in the Quantum Hall Effect (QHE).

It was originally introduced by Summerfieldas a theoretical correction to the Bohr model, explaining fine structure through elliptical orbits and relitivistic mass-velocity.

5.4 Hamiltonians of Crystal Lattices

Turns out that you can describe the hamiltonian of the electrons in a crystal lattice. For this, there exists first quantisation, second quantisation hamiltonian.

- First quantisation - The classical particles are assigned wave amplitudes. This is "semi-classical" where only the particles or objects are treated using quantum wavefunctions, but environment is classical.
- Second quantisation (Canonical Quantisation, occupation number representation) - The wave fields are "quantized" to describe the problem in terms of "quanta" or particles. This usually means referring to a wavefunction of a state, described the the vacuum state with a series of creation operators to create the current state. Fields are now treated as field operators, similar to how physical quantities (momentum, position) are thought of as operators in first quantisation.

5.4.1 Graphene

6 Review Article Notes

6.1 J. Moore - The Birth

6.1.1 Lessons from the past

- Quantum Hall Effect can occur in 2D systems (condined) in the presence of a magentic field. It is a consequence of topological properties of the electronic wavefunctions.
- Question - Can this effect arise without a large external magnetic field?

- Predicted that forces from motion through crystal lattice could provide the same hall state.
- The mechanism which this recently has occured through is **spin-orbit coupling** or SOC. Spin and orbital angular momentum degrees of freedom are coupled. This coupling causes electrons to feel a spin dependent force.
- QSHE predicted in 2003. Unclear how to measure or if realistic or not.
- Kane & Mele in 2005 produced a key theory advance, using realistic models. Showed that QSHE can survive by the use of invariants and could compute if the 2D material has an edge state or not. 2D Insulators that have 1D wires that conduct perfectly at low temps, similar to QHE.[1]
- (Hg,Cd)Te quantum wells predicted to have quantized charge conductance[2]. These were then picked up in 2007[3].

6.2 title

7 Bibliography

[1] C. L. Kane and E. J. Mele. Z 2 Topological Order and the Quantum Spin Hall Effect. *Physical Review Letters*, 95(14), September 2005. ISSN 0031-9007, 1079-7114. doi: 10.1103/PhysRevLett.95.146802. URL `https://link.aps.org/doi/10.1103/PhysRevLett.95.146802`.

[2] B. Andrei Bernevig, Taylor L. Hughes, and Shou-Cheng Zhang. Quantum Spin Hall Effect and Topological Phase Transition in HgTe Quantum Wells. *Science*, 314(5806):1757–1761, December 2006. ISSN 0036-8075, 1095-9203. doi: 10.1126/science.1133734. URL `http://science.sciencemag.org/content/314/5806/1757`.

[3] Markus König, Steffen Wiedmann, Christoph Brüne, Andreas Roth, Hartmut Buhmann, Laurens W. Molenkamp, Xiao-Liang Qi, and Shou-Cheng Zhang. Quantum Spin Hall Insulator State in HgTe Quantum Wells. *Science*, 318(5851):766–770, November 2007. ISSN 0036-8075, 1095-9203. doi: 10.1126/science.1148047. URL `http://science.sciencemag.org/content/318/5851/766`.