Topological Insulators

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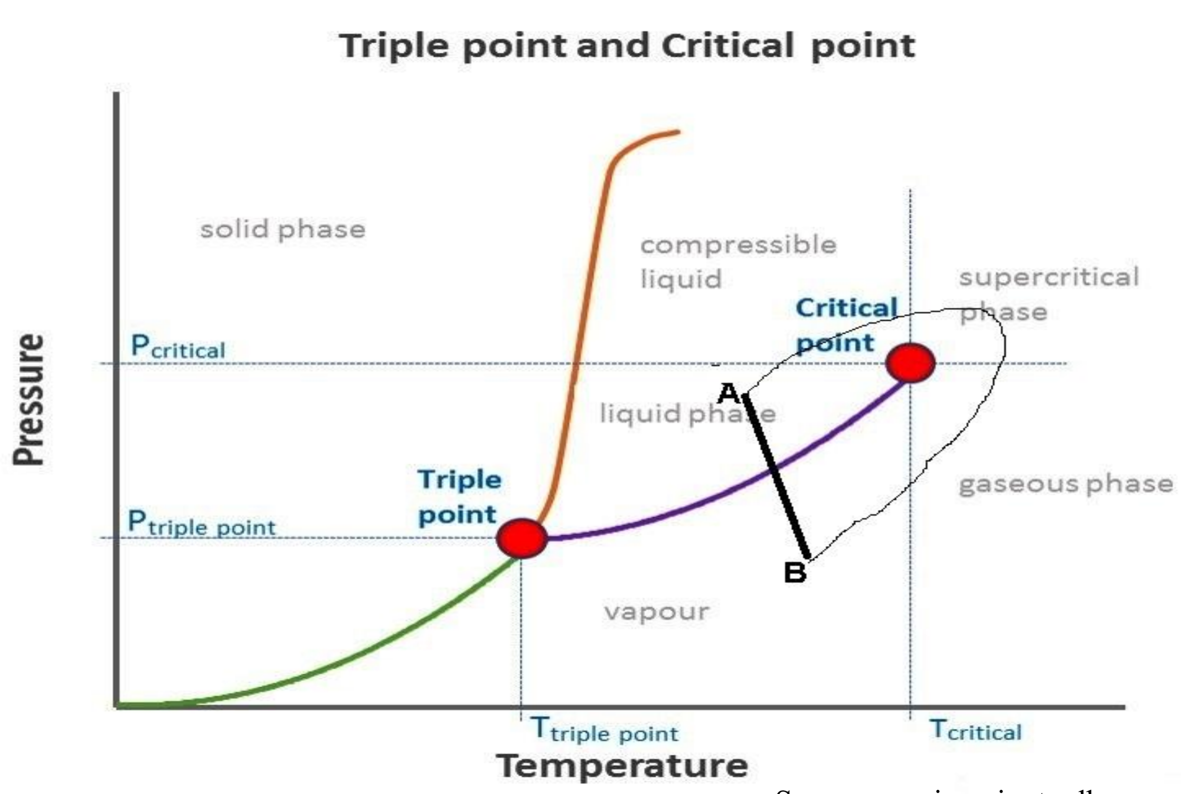
Introduction

Topological Phases of matter



Source : engineeringtoolbox

- Topological Phase are phases that are the same according to symmetry but distinct because of topology.

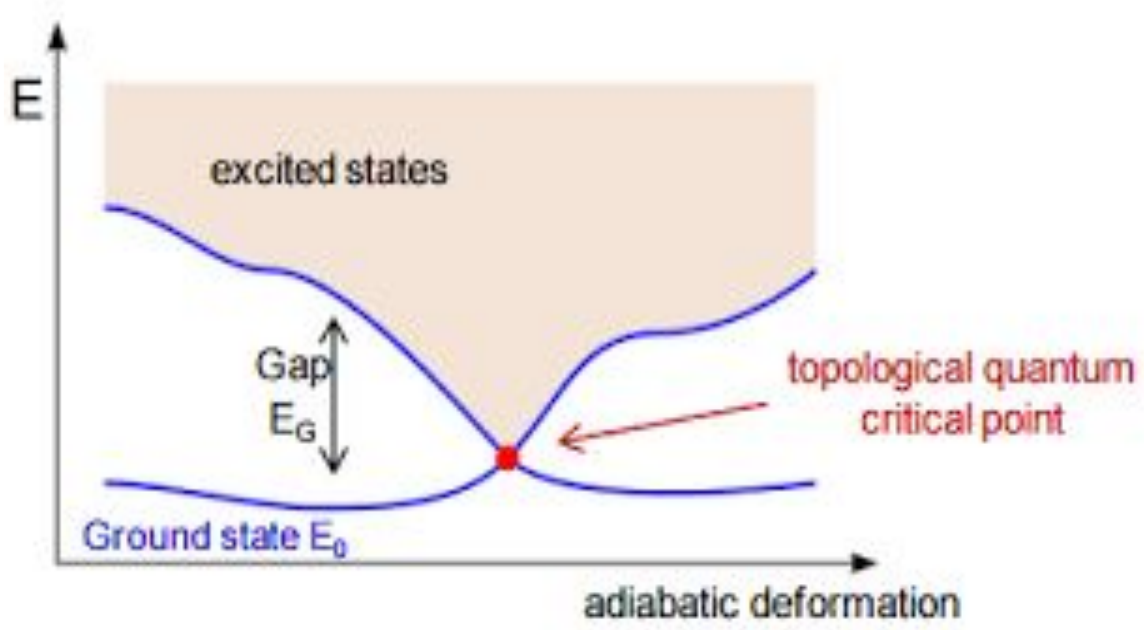
Gauss-Bonnet Theorem

$$\int_S K dA = 4\pi(1 - g)$$

Where,
K = Gaussian Curvature,
g = genus of the surface (# of holes in the surface)

g= 1 gives Torus   Source: scientificamerican

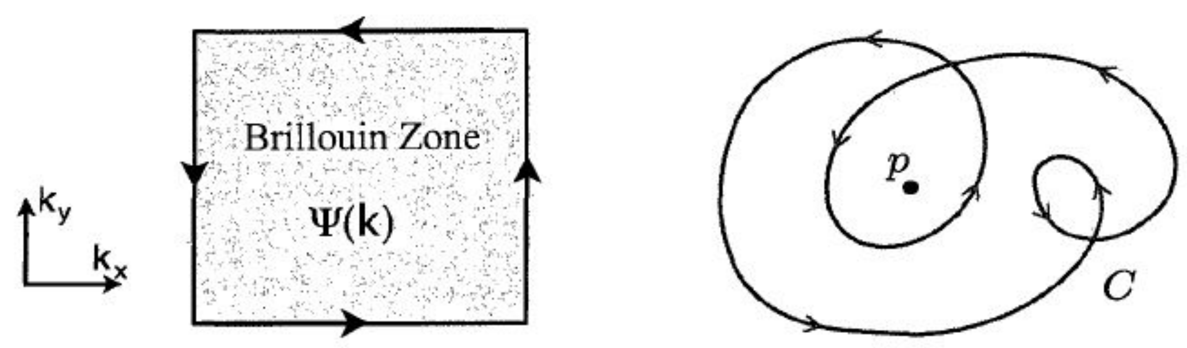
Topological equivalance arising from adiabatic continuity



- For non-trivial phase one has to go through Quantum Critical point where energy gap is zero.
- Adiabatic principle in Q.M. tells us that if we have a quantum state that is separated from all other quantum states by a finite energy then that energy difference defines a time scale over which we can smoothly change our Hamiltonian, very slowly to stay in the same state, the whole time without inducing transitions.

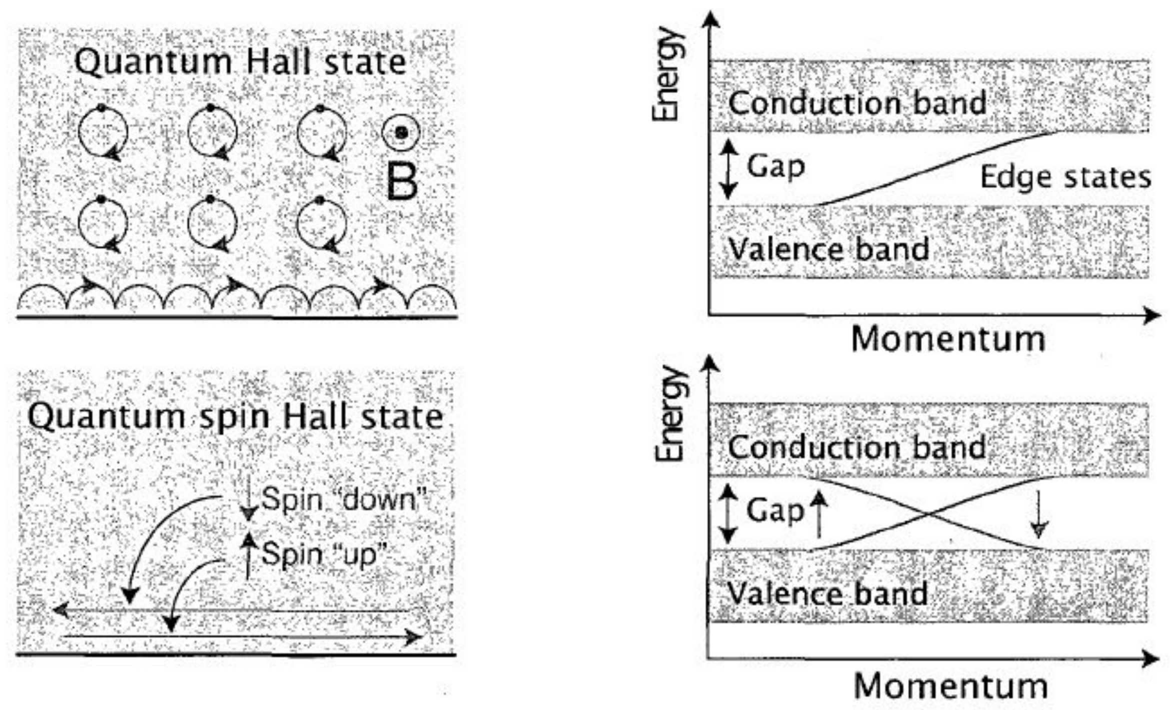
Quantum Hall Effect and Topological Insulators

- Discovery of quantum Hall effect led to study of topological properties of band structure; quantization of Hall conductance.
- Hall conductivity tensor has topological invariant expressions called Chern number. [3]
- Chern number is the winding number of the Berry phase of electron wavefunction around the Brillouin zone.



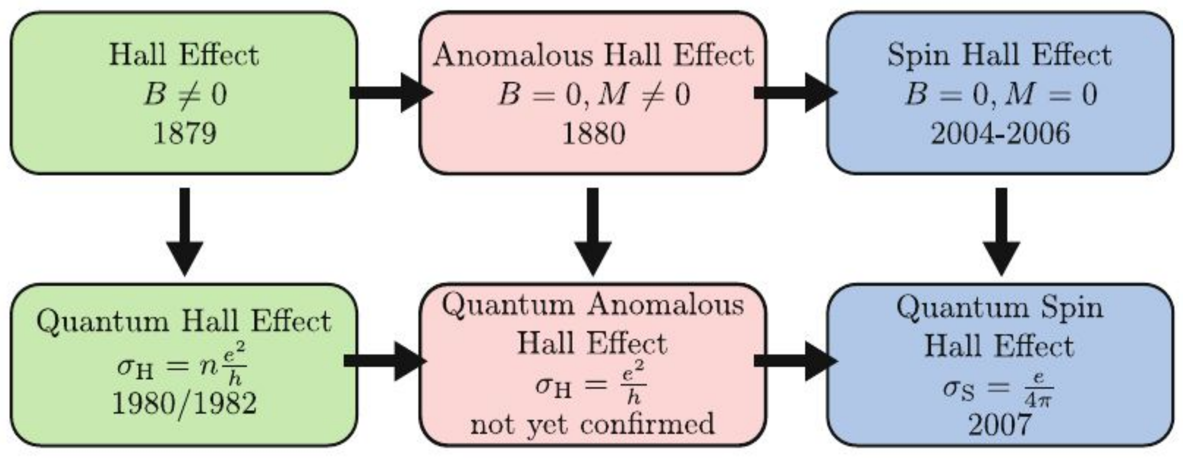
- Electron wavefunction. Number of times, a loop C winds around p.

- Classifying insulating states uses “adiabatic principle” i.e., without going through phase transition.
- In 2005, quantum spin Hall effect was proposed.
- Provided time reversal symmetry is preserved, a quantum spin Hall insulator cannot change into ordinary insulator adiabatically.



- Quantum spin Hall effect in real space vs that in momentum space

- By Kramers degeneracy, i.e., momenta invariant under k → -k. Time reversal symmetry assures level crossing at k = 0.



- Evolution of Hall effect to the quantum Hall effect

- Dirac equation enters the field of topological insulators [4], first of all there is strong spin-orbit coupling and the other is that the effective Hamiltonians for the quantum spin Hall effect and three-dimensional topological insulator have identical structure of the Dirac equation.

Growth & App.

Growth & Characterization of Topological Insulators(TI)

- Metal Organic Chemical Vapour Deposition (MOCVD)
- Solvo Thermal Synthesis
- Molecular Beam Epitaxy (MBE)

MBE is the most common technique for the growth of TI.
The growth of thin film TI is governed by weak Van der Waals interactions.
Due to weak Van der Waals bonding, the lattice matching condition is relaxed. So, TI can be grown on a wide variety of substrates, such as Si(111), Al_2O_3, GaAS(111), InP(111), CdS(0001) and $Y_3Fe_5O_{12}$. [1]

TIs has been focused on bismuth and antimony chalcogenide based materials such as Bi_2Se_3, Bi_2Te_3, Sb_2Te_3 or $Bi_{1-x}Sb_x$

Structural and Chemical probes done using XRD and EDS.
Electron transport measurement is also carried out for resistivity, Hall effect and magnetoresistance using Four Probe Measurement.

Applications:

TI has been extensively used in researches to see applications in Photodetector, magnetic devices, FET and LASER.
TI can also be used in gas sensors and in memory but less research is done till date.
The advantages of TI memory is low energy dissipation and high quality factor. The magnetically doped TI surface can be used as a memory cell. By changing the magnetization state, it is possible to write in memory, while reading out from memory depended on the quantum spin effect of TI [2].

References:

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[2] Fujita T., Jalil M.B., Tan S.G. Topological insulator cell for memory and magnetic sensor applications. Appl. Phys. Express. 2011;4:544–548. doi: 10.1143/APEX.4.094201

[3] Liang Fu. Phd Thesis, Theory of topological insulators. University of Pennsylvania. 2009.

[4] Shun-Qing Shen. Topological insulators and Dirac equation. Springer Berlin Heidelberg, 2012.