# IIT Mandi
# Proposal for a New Course

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| **Course number** | **: PH627** |
| **Course Name** | **: Topological Quantum Matter** |
| **Credit** | **: 3** |
| **Distribution** | **: 3-0-0-3** |
| **Intended for** | **: UG/PG/I-PhD/PhD** |
| **Prerequisite** | **: PH513, PH523** |

**Mutual Exclusion:** None

1. **Preamble:** This course dwells into the foundations of topological condensed matter physics, where topology, a branch of mathematics concerned with spatial properties, becomes a powerful tool to describe and predict the behavior of materials. The course will discuss some novel exotic materials, such as topological insulators and superconductors, where electrons cooperate in ways that defies classical intuition. The underlying theme will be the intricate connection between topology and quantum mechanics, revealing how the arrangement of electrons in solids can give rise to phenomena like protected edge states and quantized conductance.

2. **Course Modules with quantitative lecture**

**(a) The basics [4 hrs]**

Potentials in quantum mechanics, Aharanov-Bohm effect, Monopoles in physics, Berry phase.

**(b) Symmetries [6 hrs]**

Time-reversal symmetry (TRS) in classical and quantum mechanics, TRS operator, Kramer's degeneracy, Symmetries in momentum space, Inversion symmetry, particle-hole symmetry, ten-fold classification.

**(c) 1D Lattice models [6 hrs]**

Lattice models and band in momentum space, Peierl's instability, Su-Schrieffer-Heeger model, Berry phase effect on dynamics, topological index, charge fractionalization.

**(d) Quantum Hall Effect [6 hrs]**

Kubo formula and TKNN invariant, quantization of Hall conductance, QHE in 2DEG, Landau levels, QHE in graphene.

**(e) Topological insulators [6 hrs]**

Graphene, Dirac points, topological insulators, , Anomalous Hall Effect, BHZ model, edge states of BHZ model. Kane-Mele model, Z2 invariant, 3D topological insulators, strong and weak TI.

**(f) Topological metals [5 hrs]**

Accidental degeneracies, Weyl and Dirac fermions, symmetry analysis, chiral anomaly, anomalous Hall effect, Fermi arcs, Weyl semimetals, Dirac semimetals.

**(g) Majorana fermions [5 hrs]**

Topological superconductivity, Majorana fermions, Majorana modes in chiral p-wave superconductors, Majorana modes in Rashba spin-orbit coupled semiconductors, detection of Majorana fermions.

**(h) Miscellaneous Topics [4 hrs]**

Quantum Spin Liquid, RVB, Kitaev model, spin fractionalization. Materials research, experimental realization of several topological phases in TIs and topological metals. Electronic structure theory aspect of topological phases.

**Laboratory/practical/tutorial Modules:**

Not Applicable

## 3. Text books:

1.Topological Insulators and Topological Superconductors B. Andrei Bernevig, Taylor L. Hughes Princeton Univ Press 2013

2. Topological Insulators: Dirac Equation in Condensed Matter Shun-Qing Shen Spinger Berlin 2012

## 4. References:


**1. Topological Insulators- A review by R. Shankar https://arxiv.org/pdf/1804.06471.pdf**

**2.Topological Insulators M. Z. Hasan, C. L. Kane https://arxiv.org/pdf/1002.3895.pdf**

**3. Topological insulators and superconductors Xiao-Liang Qi and Shou-Cheng Zhang https://arxiv.org/pdf/1008.2026.pdf**

**4. Weyl and Dirac Semimetals in Three-Dimensional Solids N.P. Armitage, E. J. Mele, Ashvin Vishwanath https://arxiv.org/pdf/1705.01111.pdf**

**5. Berry Phases in Electronic Structure Theory David Vanderbilt Cambridge Univ Press 2018**

**5. Similarity with the existing courses:**
**(Similarity content is declared as per the number of lecture hours on similar topics)**

| S. No. | Course Code | Similarity Content | Approx. % of Content |
|---|---|---|---|
| 1. | PH613 | QM symmetries | 3% |
| 2. | PH601 | QM Hall conductance | 3% |
| 3. | PH601 | Aharonov Bohm effect | 2% |

**6. Justification of new course proposal if cumulative similarity content is >30%:**

Not Applicable.