Quantum Materials
(UES022)

"In this field, almost everything is already discovered, and all that remains is to fill a few holes."

Nobel Prize in Physics 2024 was awarded to John J. Hopfield and Geoffrey Hinton "for foundational discoveries and inventions that enable machine learning with artificial neural networks."

Know your teacher

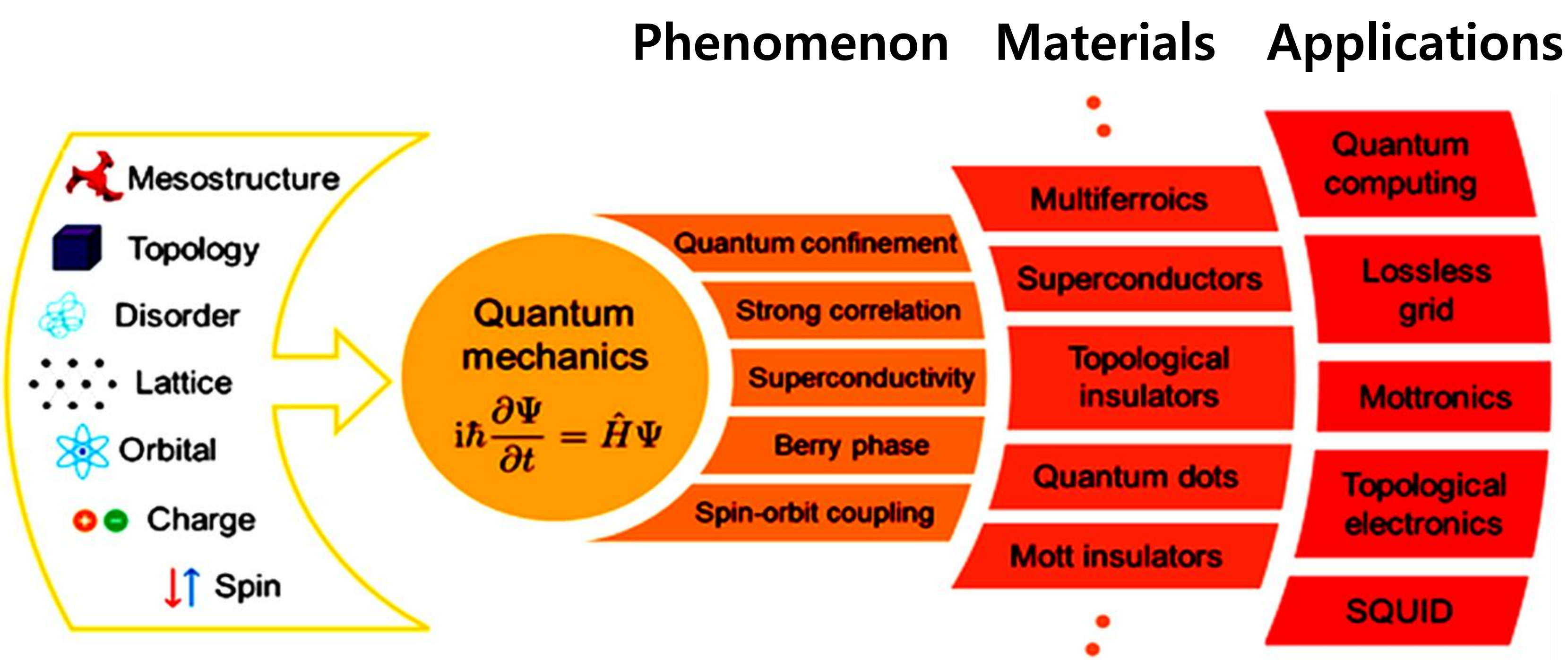
Dr. Bhaskar Chandra Mohanty
Professor,
Department of Physics & Material Science

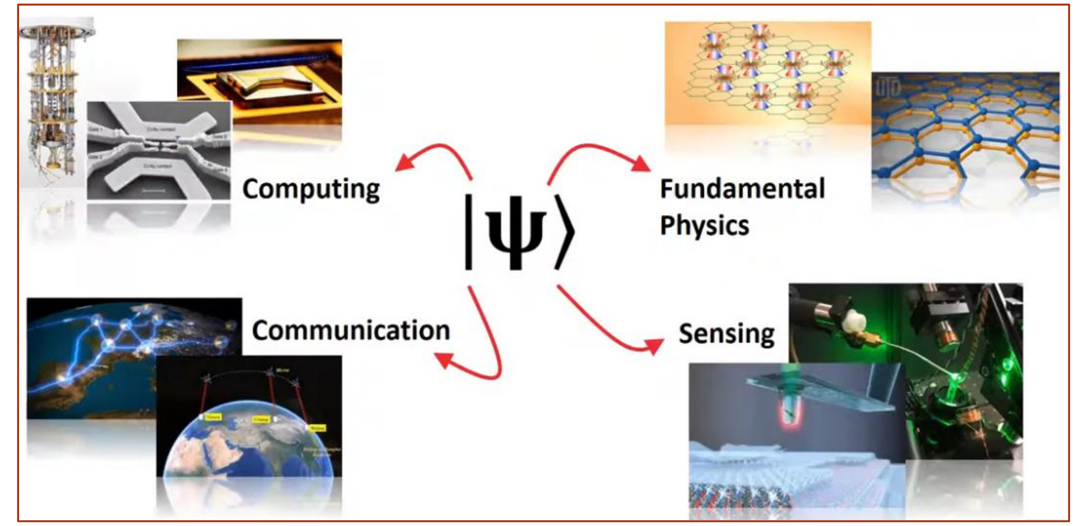
PhD, Dec. 2007 (Department of Physics, IIT Madras)
Postdoctoral research, Apr. 2008 – Aug. 2012(Yonsei University, Seoul, Korea)

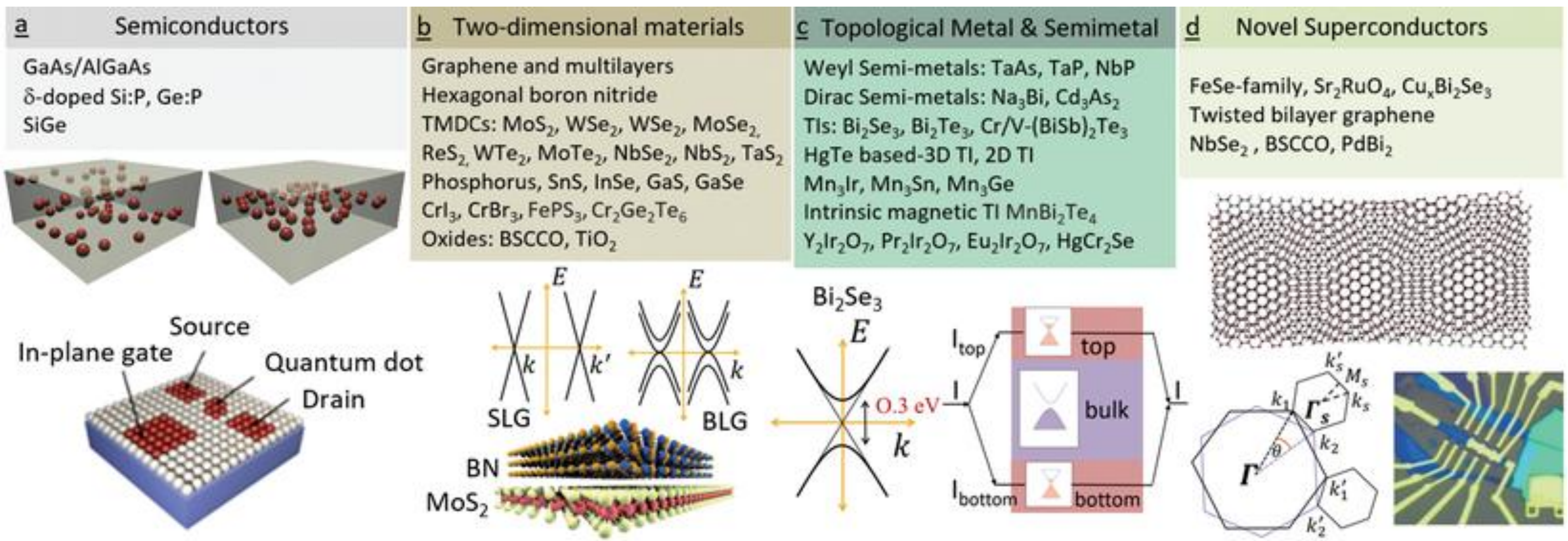
Research specialization
Thin film solar cells, Functional & Energy Materials
International Journal publications: 50

Office: G326
Email: bhaskar@thapar.edu

Quantum Materials - Material with properties not explained classically







Quantum Materials

Solid State Physics

Quantum Mechanics

Topological materials

Quantum Materials

Superconductors

Graphene

2-D Materials

What will we learn about?

Introduction to Quantum Mechanics

Historical evolution from classical physics to quantum physics. Exploration of wave-particle duality and the concept of quantum states. Superposition and entanglement: their significance in quantum systems and potential applications. The uncertainty principle and its impact on measurement in quantum systems. Quantum wave function, Schrödinger equation (time independent). Energy quantization: Introduction to discrete energy levels in atoms and their effects on material properties.

Basics of Solid-State Physics

Introduction to Solids: Structure and bonding in solids: Overview of crystal lattices and their role in defining material properties. Classification of solids into metals, semiconductors, and insulators based on bonding and electron behavior.
Electronic Properties of Materials: Band theory explaining conduction, valence bands, and energy gaps in different material types. Detailed examination of Fermi level, density of states, and their implications for electronic behavior.
Phonons and Thermal Properties: The role of lattice vibrations (phonons) in thermal and electronic properties. Concepts like specific heat and thermal conductivity in relation to material structure and temperature.

Quantum Materials

Superconductors: Fundamentals of superconductivity: Zero resistance and expulsion of magnetic fields (Meissner effect). Differentiation between Type I and Type II superconductors. Introduction to Cooper pairs and the BCS theory. Exploration of high-temperature superconductors and their applications in fields like energy transmission.

Topological Materials: Introduction to topological phases of matter and their unique properties. Topologically protected surface states and their relevance to fault-tolerant quantum computing.

2D Materials and Graphene: Structure, properties, and significance of graphene in electronic and thermal applications. Exploration of other 2D materials, such as transition metal dichalcogenides (TMDs) and their emerging applications. Applications of 2D materials in fields like sensors, quantum computing, and renewable energy.

Scheme of Evaluation

Lecture	Tutorial	Practical	Credit
2	0	2	3

Evaluation Scheme

- Written exam: 70 marks
  - i) Mid sem Test = 30 marks
  - ii) End-sem Test = 40 marks
- Lab and Project = 20 Marks
- Sessional/Assignment = 10 marks

Study Material

Textbooks:

1. Introduction to Quantum Mechanics by David J. Griffiths and Darrell F. Schroeter
2. Introduction to Solid State Physics by Charles Kittel
3. Introduction to Superconductivity by Michael Tinkham
4. Quantum Theory of Materials by Efthimios Kaxiras and John D. Joannopoulos

Reference Books and Resources

1."Principles of Condensed Matter Physics" by P. M. Chaikin and T. C. Lubensky

A detailed resource for advanced understanding of condensed matter systems, including topological and quantum materials.

2."Quantum Materials: Experiments and Theory" edited by E. Pavarini, E. Koch, and U. Schollwöck

A collection of chapters authored by experts, focusing on the interplay between experimental observations and theoretical frameworks in quantum materials.

3."Two-Dimensional Materials: Properties and Applications" by Phaedon Avouris, Tony Heinz, and Tony Low

An in-depth exploration of 2D materials like graphene and transition metal dichalcogenides, discussing their electronic, optical, and thermal properties.

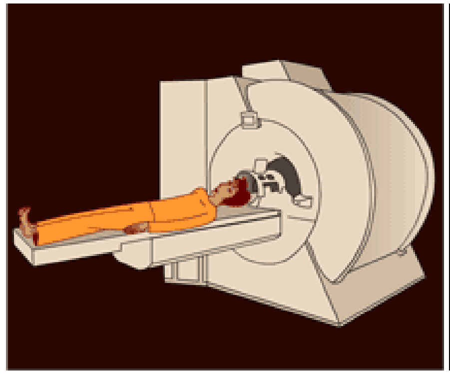
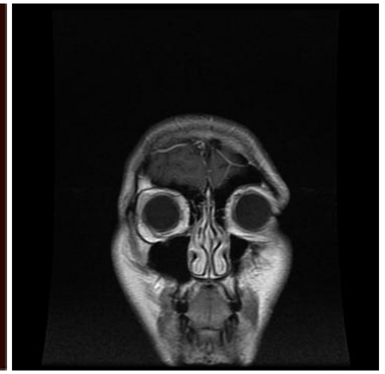
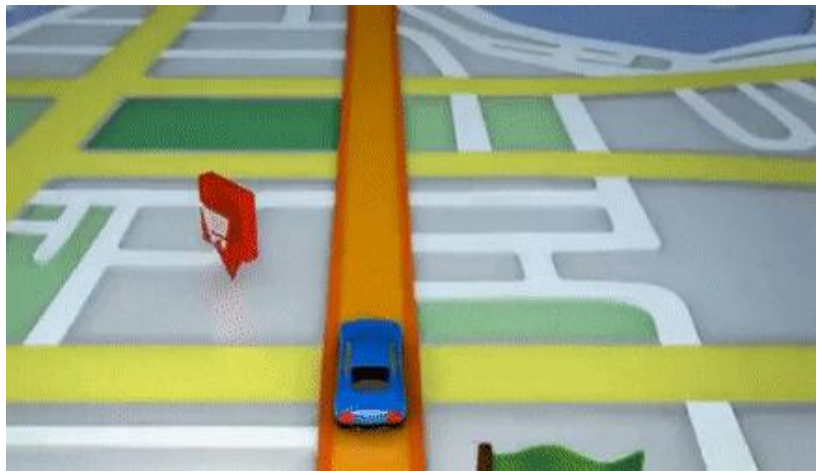
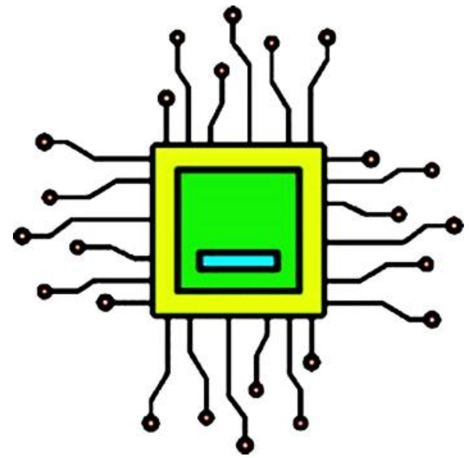
Course Learning Outcomes

By the end of this course, students will be able to:

1. Explain the fundamental principles of quantum mechanics and solid-state physics, as they apply to the behavior of quantum materials.
2. Perform experiments to analyze quantum and electronic properties of materials.
3. Differentiate between various quantum materials based on their unique properties and underlying physics.
4. Assess the potential applications of quantum materials in advanced technologies.

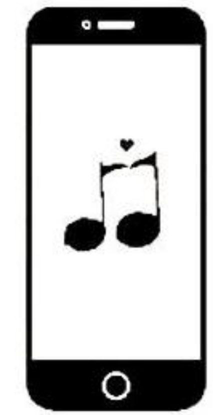
- Why was a new formalism (quantum Mechanics) required?
- Which events Quantum mechanics could explain successfully?

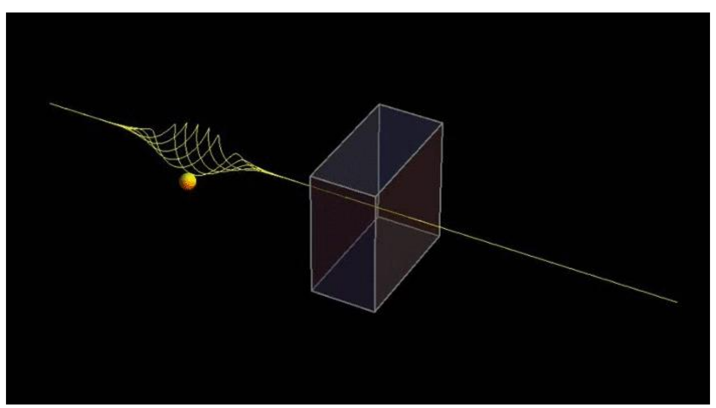
Implications of Quantum mechanics

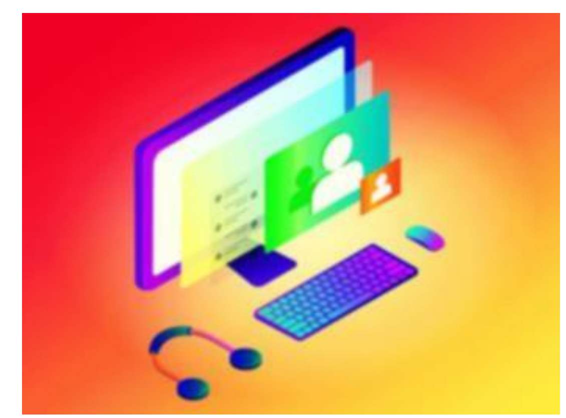






Without Quantum Mechanics, we could never have designed and built:

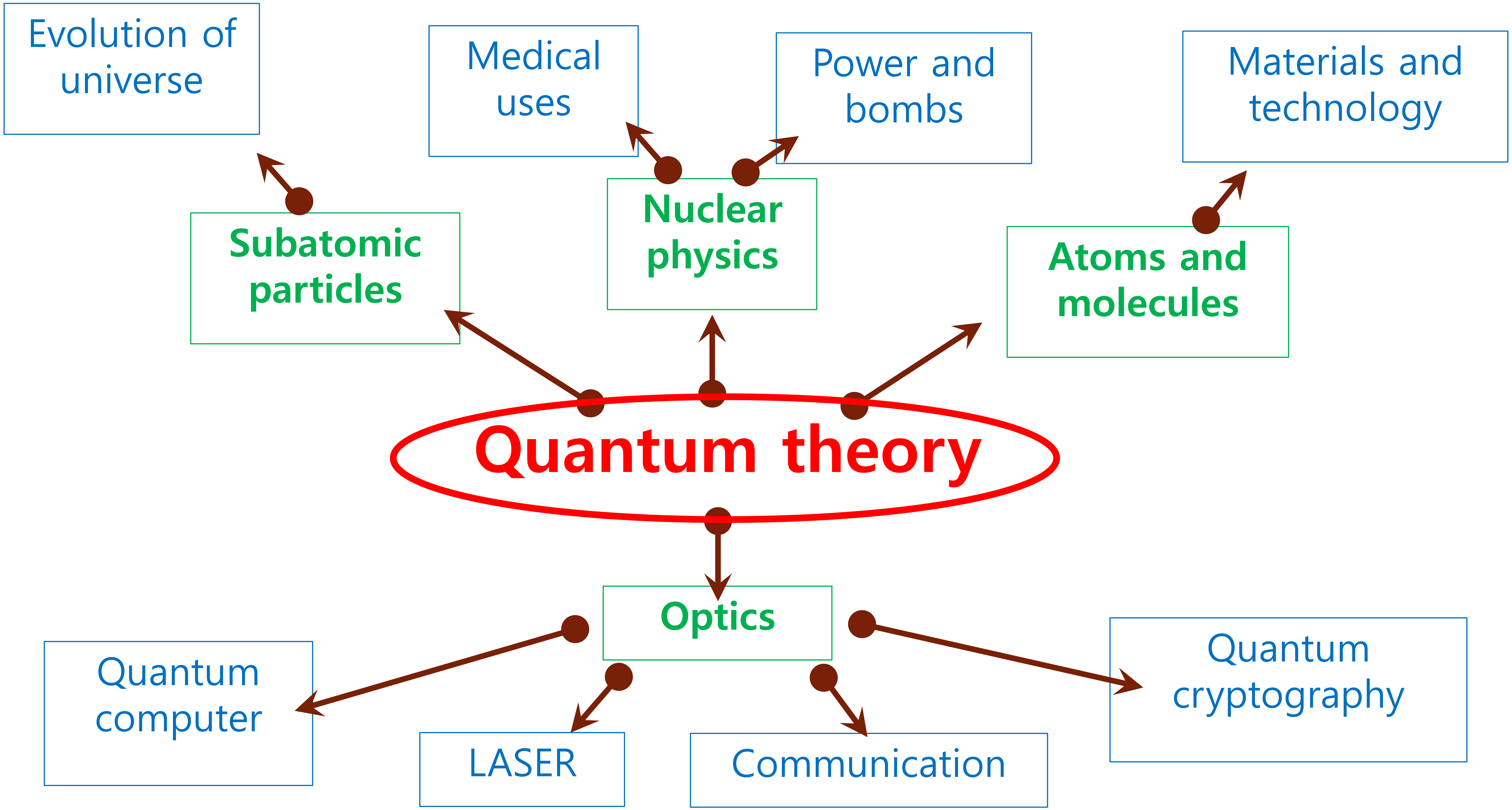
semiconductor devices
computers, cell phones, etc.
Lasers, CD/DVD players,
MRI technology,
Nuclear reactors,
Atomic clocks (GPS navigation)





Implications of Quantum mechanics



Origin of quantum mechanics

- Concepts based on the dilemma: Wave or particle?
  - Electron is a wave or electron is a particle?
  - Photon (light) is a wave or a particle?
- Observations which have no analogy in classical physics
  - Tunnelling, β-decay
- Explanation of radiation from a hot body