

## Course Structure

- There are two parallel themes running in most weeks: (i) **theoretical and conceptual developments ( through simple experiments)** and (ii) **technological applications where these concepts are used.**

There are five main chunks of the course.

1. **Phenomena and experiment** that led us to believe that a new understanding of nature quite distinct from what we knew in classical physics is required. In this part we will collect main features and central points that need to be included in the new understanding. Emphasis is on getting to the heart of confusions, contradictions and shortcomings in our classical physics that need to be explained by new physics. The crucial issues here are to understand how physical entities exhibit both wavelike and particle like behaviour in the language of classical mechanics and get an idea of superposition principle for waves.
2. **The Meaning of Quantum Physics.** In this part we will learn how to think about the new physics of quantum mechanics and how is it different from classical physics. The emphasis will be to give a precise meaning to wave particle duality and give it a logically sound operational meaning. The central concepts are **Born's Interpretation**, **Fourier Analysis** and **Heisenberg's Uncertainty Principle**. Another important theme at the heart of Quantum Mechanics where this section will culminate is superposition principle of Quantum Mechanics in general.
3. **Dynamics of Quantum Mechanics** Once we learn how to express the nature in the new language combining waves and particles, the next step is to learn how the changes with time in this new description are expressed. This boils down to how the quantum waves evolve with time and how do we know what wave should correspond to which physics situation. The central concept here is Schrodinger's Wave equation. We will learn how the solutions of this equation look like ( which describe the nature) as well as how quantization of energy emerges from it.

4. **Advanced Application** We will apply quantum Ideas to many physics situations. One first consider some idealized situation to test the kind of predictions quantum mechanics gives and then it turns out that these idealized situations can describe many real systems. The main ideas to look for here are particle contained inside a box, Atoms, Tunneling, Bonds, Quantum Oscillations, Quantum Computation, Fermi's Exclusion Principle, Band Structure of Materials. We will discuss these ideas as application of the laws that we will learn in section 2 and 3. Applications of these ideas to many physical situations will be considered.
5. **Laws of Thermodynamics** The last part relates to studying the laws that govern the behavior of things at a collective larger scale. Most important concept here is Second Law of Thermodynamics which is central to all changes that we see around ourselves regardless of the phenomenon. We will study it as a consequence of simple counting arguments.

## Tentative Weekly Program and Goals

Each week is color coded according to above sections.

- **Week 1: Introduction** Mostly Introduction to the course and a guest lecture. We start learning basic ideas regarding light's nature as electromagnetic waves. Goal here is just to get a qualitative picture about electromagnetic phenomena and how Light is part of that phenomena as a disturbance in electric and magnetic fields.
- **Week 2: Waves and Superposition** Goal in this Week is to learn some basic properties of waves and what we mean by superposition. In recitation we learn some basic math related to waves as well as wave equations and introduce the idea of a complex wave. The key concept is how to add two waves, what is a wave equation and basic characteristics of sinusoidal waves.
- **Week 3: Light Interference and Photo-Electric Effect** Key goal this week is to learn and appreciate that light acts as a particle carrying energy and momentum when interacting with matter, especially while transferring energy.

- **Week 4: Particle Nature of Light and Relativistic Equations** This week we continue to explore various phenomena that lead to our conviction that light acts as a particle. Main issues discussed are Compton effect where light literally acts like a billiard ball and atomic spectra, where again, light's interaction with matter is not only particle like, but a consequence of this interaction is that we lose to make sense of electron's laws of motion in terms of ordinary particles as well. This is the main message of Bohr's model here. Another key concept is to understand that relativity is about how to relate Energy and Momentum of different particles. During the recitations we start developing the mathematics of Fourier analysis which is just a fancy word for how to make waves of general desired form by superposing basic sinusoidal waves and the other way around i.e., how to decompose a wave into sinusoidal components whose superposition gives us the original wave.
- **Week 5: Energy Levels, De Broglie's waves, Born's Interpretation** In this week there is a spill over from previous week and then we go on to our second theme of the course. Main task in the whole blue theme is to make a sense of what we mean when we say something is both particle and wave. This week we will learn the main bridge in this regard which is Born's Interpretation.
- **Week 6: Born's Interpretation, Fourier Analysis.** We will make precise the meaning of Born's Interpretation. The key concepts to learn are complex waves, applying Born's rule using complex waves, Probabilities for continuous variables and Fourier analysis. The main goal is to how to tell where we will find a particle and with what probability if we know what is its wave.
- **Week 7: How to Find Momentum, Uncertainty Principle** In classical physics, position and momenta are the two main quantities that we want to know about a particle ( all other properties are derived from them) . The previous week we found how to predict the position if we know the wave function, this week we will learn how to predict the momentum. The key observation would be that our predictive power for position and momentum are interrelated via Uncertainty Principle. The key concept is that how this principle comes about as a result of superposition of waves. Main goal is to be able to predict the momentum of a particle, given its wave. The Fourier math will

be the main tool in doing so. The other goal is to understand the uncertainty principle in the light of Fourier mathematics ( which is just the mathematics of superposition of waves ) and apply this principle to physical situations.

- **Week 8: Superposition in QM, Dynamical Law of QM** During this week our goal will be to generalize the wave particle duality to a fundamental feature of quantum mechanics which is that a thing can have two mutually exclusive properties at the same time. This is the main weirdness of quantum world and is called superposition ( like being dead and alive at same time). We will also learn about operators related to physical quantities and that will allow us to write the dynamical law for quantum waves which is Schroedinger equation. Therefore, our second goal is to lunderstand what is Schroedinger's equation.

**Later weeks will keep filling up two weeks in advance**