What is the Need of Quantum Mechanics?

(Long Answer – Semester VI, MJC Physics)

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Introduction

Classical physics, which includes Newtonian mechanics, classical electrodynamics, and thermodynamics, successfully explains the behavior of **macroscopic bodies**. However, when applied to **atomic and sub-atomic systems**, classical theories fail to explain many experimental observations. To overcome these difficulties and to correctly describe microscopic phenomena, a new theory known as **Quantum Mechanics** was developed.

Failures of Classical Physics and Need of Quantum Mechanics

1. Black Body Radiation

According to classical theory, the energy emitted by a black body should increase indefinitely as the wavelength decreases, leading to the **ultraviolet catastrophe**. This result is not supported by experiments. Quantum Mechanics explains black body radiation by assuming that energy is emitted in **discrete packets called quanta**, thereby removing the contradiction.

2. Photoelectric Effect

Classical wave theory predicts that the kinetic energy of emitted electrons should depend on the intensity of incident light. Experimentally, it is observed that:

- Photoelectric emission occurs only above a **threshold frequency**
- Kinetic energy depends on **frequency**, not intensity

These observations cannot be explained by classical physics. Quantum Mechanics explains this effect by treating light as a stream of **photons**.

3. Compton Effect

The scattering of X-rays by electrons results in an increase in wavelength known as the **Compton shift**. Classical theory fails to explain this phenomenon. Quantum Mechanics successfully explains it by considering photons as particles having momentum.

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4. Stability of Atom

According to classical electrodynamics, an electron revolving around the nucleus should continuously radiate energy and spiral into the nucleus, making atoms unstable. In reality, atoms are stable.
Quantum Mechanics explains atomic stability by introducing **quantized energy levels** for electrons.

5. Atomic Spectra

Atoms emit and absorb radiation in the form of **discrete spectral lines**. Classical theory cannot explain the origin of these line spectra. Quantum Mechanics explains atomic spectra as a result of **transitions of electrons between fixed energy levels**.

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6. Specific Heat of Solids

Classical theory predicts constant specific heat for solids at all temperatures, which contradicts experimental results at low temperatures. Quantum Mechanics provides a correct explanation of the temperature dependence of specific heat.

7. Dual Nature of Matter and Radiation

Experiments show that light and material particles exhibit both **wave and particle nature**. Classical physics cannot explain this dual behavior. Quantum Mechanics successfully incorporates **wave–particle duality**.

Conclusion

Quantum Mechanics is essential because classical physics fails to explain several microscopic phenomena. It provides a correct and consistent explanation of atomic structure, radiation processes, and the behavior of matter at microscopic scales. Hence, Quantum Mechanics forms the **foundation of modern physics** and is indispensable for understanding the physical world at the atomic and sub-atomic level.