1. Brief review of Classical Physics

Results of experiments with atoms and their constituents around 1900 could not be reconciled with the known concepts of classical physics. The formulation of quantum mechanics provides the basis for our understanding of the microscopic world. It is based on new ideas and concepts, quite different from the common sense concepts regarding the nature of matter and radiation, which were implicit in classical physics.

Let us begin with a brief review of the concepts in classical mechanics and classical electrodynamics.

1.1. Concepts in Classical Physics

Classical physics is based on two fundamental concepts / models / areas

a) Classical Mechanics

In classical mechanics we deal with macroscopic objects (or particles). The state of a particle is given at any time by its

instantaneous position : x (in 1D)
or $\vec{r}$ (in 3D)

and instantaneous velocity : $v_x = \dot{x} = \frac{dx}{dt}$ (in 1D)

$$\vec{v} = \dot{\vec{r}} = \frac{d\vec{r}}{dt} \quad \text{(in 3D)}$$

Motion of the particle is <u>uniquely</u> <u>determined</u> by Newton's equation of motion (2nd Law)

$$m \frac{d^2\vec{r}}{dt^2} = \vec{F} \quad \text{or} \quad m\ddot{\vec{r}} = \vec{F} \quad \text{or} \quad m\vec{a} = \vec{F}$$

mass   external force acting on particle

Newton's three laws are <u>postulates</u>. In other words, they can<u>not</u> be derived from more fundamental concepts or equations.
(Do you remember the other two laws?)

Why do we know that Newton's laws are true?
They are tested in many experiments / real-word applications or experiences.

b) Classical Electrodynamics

The second pillar of classical physics is electrodynamics in which the phenomenon of electromagnetic waves is (one of the most) important concept. The state of an electromagnetic wave is given at any time by its

electric field $\vec{E}(\vec{r},t)$

magnetic field $\vec{B}(\vec{r},t)$

Motion (or propagation) of an electromagnetic wave is <u>uniquely</u> <u>determined</u> via the fields which are governed by the Maxwell equations (in vacuum):

charge density

$$\vec{\nabla} \cdot \vec{E} = \rho / \varepsilon_0 \qquad \vec{\nabla} \cdot \vec{B} = 0$$

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \qquad \vec{\nabla} \times \vec{B} = \mu_0 \vec{J} + \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t}$$

current density

Maxwell equations are postulates, which cannot be derived from more fundamental concepts or equations. Why do we accept them? They are tested in many experiments.

One of the most important consequences are the wave equations for electric and magnetic field

$$\vec{\nabla}^2 \vec{E} = \frac{1}{c^2} \frac{\partial^2 \vec{E}}{\partial t^2} \qquad \vec{\nabla}^2 \vec{B} = \frac{1}{c^2} \frac{\partial^2 \vec{B}}{\partial t^2}$$

speed of light

or in 1D

$$\frac{\partial^2}{\partial x^2} \vec{E} = \frac{1}{c^2} \frac{\partial^2 \vec{E}}{\partial t^2} \qquad \frac{\partial^2}{\partial x^2} \vec{B} = \frac{1}{c^2} \frac{\partial^2 \vec{B}}{\partial t^2}$$

We will review electromagnetic waves a bit more in short time.

These two fundamental concepts were well known around 1900 and Physics was considered as a complete theory — Everything is understood — Some people even considered that Physics is the most boring discipline to study.

This changed completed within the next 20-30 years and the consequences can be seen nowadays in our daily life via many techonologies.

Nowadays, we know that classical physics is limited in two respects

(i) Relativistic regime

Laws of classical physics only hold if speed of particles are small compared to c, speed of light.

(ii) Microscopic (Quantum) regime

Laws of classical physics only hold for real-world sized objects.

Here are some key concepts in quantum mechanics that show fundamental differences to concepts in classical mechanics:

- According to classical physics particles and light (electromagnetic waves) are mutually different concepts. This does not hold in QM, particles posses a wave nature and waves have a particle nature → Wave-particle dualism
- (Many) aspects of the microscopic world are probabilistic (not deterministic as in classical physics).
- In quantum mechanics we cannot ask for the instantaneous position and momentum (velocity) of a particle at the same time, which was the basics of classical mechanics.

Puzzled / confused / excited ?

Some quotes from famous scientists about QM:

"Quantum mechanics is the greatest accomplishment of human race" - Carl Wieman

"For those who are not shocked when they first come across quantum theory cannot possibly have understood it" - Niels Bohr

"I think I can safely say that nobody understands quantum mechanics" - Richard Feynman.