

1. Introduction to the course

1.1 Why study Quantum Mechanics?

1.2 Striking Characteristics of QM

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Quantum mechanics (QM) is a fundamental and general theory that applies on a very wide range of scale, from subatomic systems to astrophysical objects.

It is nowadays also a widely applied subject, with real-life applications (from transistors to lasers) and an active area of research. For example, it is at the basis of research in nanotechnology, in materials science, in spintronics (where the electron spin replaces the charge as the fundamental unit for storing information in a computer), etc.

Also, there has been a resurgent interest in the fundamental theory of QM, due to the interest in quantum information as well as the availability of control on single quantum systems¹. Although you might not be directly interested in quantum information per se, this discipline has shaped a new view of QM that is having impact also on practical applications. On the pedagogical side, it has pushed for a new way of presenting QM in college courses, that I will try to partially follow here, with more emphasis on discrete systems and applications instead of an historical presentation of QM theory. (You probably already have had that kind of historical introduction, both in undergrad and in 22.101).

1.2 Striking Characteristics of QM

QM is known for being *weird*, counterintuitive and difficult to understand². The vast majority of physicists do not worry about the puzzling aspects of quantum mechanics, but simply use it as a tool without asking questions of principle. Nevertheless, the theoretical and, especially, experimental progress made over the past twenty years have led to a better grasp of certain aspects of the behavior of quantum objects.

In this class we will explore these counterintuitive phenomena, in particular we will emphasize three characteristics of QM:

– Discreteness

This is the characteristic that gave the discipline its name of *quantum* mechanics³. While classical physics and the word around us seems to be continuous, in QM some quantities can only take a discrete set of values. Examples are the discrete energy levels of atoms or the amount of energy emitted in black body radiation (these are *historical* examples). In the first part of the course we will focus on discrete systems, in particular on a system that can assume only two states.

¹ This is exemplified by the work of the two Physics Nobel laureates in 2012, Dave Wineland and Serge Haroche.

² *For those who are not shocked when they first come across quantum theory cannot possibly have understood it.* Niels Bohr, quoted in Heisenberg, Werner (1971). *Physics and Beyond*. New York: Harper and Row. pp. 206. *I think I can safely say that nobody understands quantum mechanics.* Richard Feynman, in *The Character of Physical Law* (1965)

³ Etymology: Latin, neuter of *quantus* how much. Plural *quanta*. 1 a : quantity, amount. b : a certain or an allotted amount : portion (from Merriam-Webster dictionary).

– **Interference**

Interference and diffraction are characteristics of waves, in particular light. In QM it was found that interference also applied to matter and it is actually a general phenomenon. E.g. diffraction observed with large objects such as fullerenes (C₆₀). We will see how interference is linked to the possibility of finding a system in a superposition state and further explore even *weirder* phenomena such as entanglement.

– **Phase coherence**

The ability to observe interferences is linked to ability for a system to maintain a phase coherence among the different parts in a superposition state. Conversely, the loss of this phase coherence is linked to the disappearance of the QM properties of a system and the observation of classical physics behavior. This occurs e.g. when the system interacts with an environment and a good part of this course will focus on the study of these so-called *open* quantum systems.

References

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