Preface

We know that light has fascinated philosophers, physicists, theologians, and engineers for a long time. The nature of light, especially, has been the subject of many controversies and discussed in detail since the seventeenth century. This is essentially due to the fact that light in itself is not visible. From simple considerations, Isaac Newton put forward the idea that light was composed of little balls. This truly innovative idea was quickly countered with the emergence of the wave theory of light. For two centuries, this theory was proven in all areas of wave frequencies. However, at the beginning of the twentieth century, this ingrained idea was challenged through the decisive contribution of Albert Einstein, who showed that the photoelectric effect could be easily explained when light was considered to be composed of small particles, or "quanta."

Then, in 1924, Louis de Broglie formulated his well-known hypothesis that waves could be associated with any massive particle. Thus was born the concept of wave-particle duality. This duality particularly manifests itself in the interference phenomenon, first discovered for light by Thomas Young in 1801. Since the de Broglie hypothesis, many interference experiments using massive particles, such as electrons, protons, and atoms, have confirmed both the wave and particle theories.

Despite experimental and theoretical efforts, the nature of light and, consequently, the nature of massive particles remain mysterious. The very issue of duality means that we do not know how to define these particles. With the advent of new technologies, we could imagine that the nature of light would be revealed. But despite these efforts, the question remains. The only thing we can characterize is the behavior of these particles or waves, depending on their action on the interacting medium. Both aspects are nevertheless mixed: when wave behavior is revealed, the particle aspect is not lost, and vice versa.

Centuries of research, heated discussions, and controversies force us to make a detailed analysis of the past and the present situation. To the best of our knowledge, no book has dealt with the interference phenomenon, including light and massive particles. Consequently, analogies between photon interferences and massive particle interferences are rare. However, over the past decade, new approaches have been developed through the detailed analysis of interference figures produced by electrons emitted during fast or slow ion collisions with molecules.

To explain these analogies, this book is divided into five parts. The first and second chapters are devoted to interferences with light and massive particles, respectively. In the third chapter, we focus our attention on electron interference experiments using macroscopic and nanoscopic interferometers, which have been carried out since 1925. Particular attention is paid to what are referred to as the Young-type double-slit experiments that were performed in the early 2000s. We shall see that this designation, which refers to the famous experiment by Young in 1807, is in fact not accurate.

Chapter 4 describes a detailed analysis of a single-electron Young-type double-slit experiment. This experiment, based on low-energy $He^{2+} + H_2$ collisions, was theoretically described in 2004. During the collision, the He^{2+} ion targets captures both target electrons onto doubly excited states. After the collision, one electron is emitted from the projectile due to the Auger effect and scatters on both of the protons acting as the double slit. The ways to obtain a single-electron condition are discussed. The angular distributions of scattered electrons, as well as their energy profiles, are analyzed. A simple model, referred to as the Path-Interference model, based on the possible trajectories taken by the electron to reach the detector, is used to give a qualitative description of the angular distributions.

Due to the limitation of the previous model, which assumes that the electron is emitted at a given distance from the slits, a more refined analysis is made in Chap. 5 using the Final-State Interaction model. This model is based on a quantum description of the Auger effect. Using a Continuum Distorted Wave approximation, the energy profiles of the emitted electrons, as well as their angular distributions, are calculated. We shall see that, contrary to predictions, this model is unable to explain the interference pattern observed experimentally.

Finally, an attempt is made to describe the experimental interferences using a semi-classical approach. The orientation of the molecule, the time at which the electron is emitted, and the orientation of the electron velocity are randomly chosen. The Hamilton equations are solved numerically and electron trajectories are calculated. Then, at a fixed detection angle, the wave aspect of the electron is taken into account to calculate the phase shift induced by the delay in the trajectories, and the angular distribution of the emitted electrons is deduced. We shall see that, surprisingly, this model is promising, challenging the way we view the electron and the associated interference.

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