Quantum Interference of Molecules
Probing the Wave Nature of Matter

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The double-slit interference experiment has been famously described by Richard Feynman as containing the “only mystery of quantum mechanics”. While the double-slit experiment for light is easily understood in terms of its wave nature, the very same experiment for particles like the electron is somewhat more difficult to comprehend. It has taken almost six decades after the establishment of its wave nature to carry out a ‘double-slit interference’ experiment for electrons. This has set the stage for interference experiments with atoms and molecules. In the last decade there has been a spectacular progress in matter–wave interference experiments. Today, molecules with over a hundred atoms can be made to interfere. In this article we discuss some of these exciting developments which probe new regimes of Nature, bringing us closer to the heart of quantum mechanics and its hidden mysteries.

1. Introduction: The Dual Nature of Radiation and Matter and the Birth of Quantum Mechanics

At the turn of the last century, there were several experimental observations which could not be explained in terms of the established laws of classical physics and called for a radically different way of thinking. This led to the development of quantum mechanics, which is today regarded as the fundamental theory of Nature and the most elegant tool for describing the physics of the microworld. Some key events and developments that set the stage for the coming of quantum mechan-
The birth of quantum mechanics is intimately linked with discoveries relating to the nature of light. Theories relating to the nature of light have a long and chequered history. Is light a wave or is it made up of particles? The earliest theory on the nature of light goes back to the corpuscular theory of Newton in 1704. Though Christian Huygens had proposed the wave theory of light in 1690, Newton’s corpuscular theory, according to which light is composed of tiny particles or corpuscles, was the favoured one for over a hundred years – a consequence of Newton’s towering presence and authority in the scientific community at that time. In 1801, Thomas Young performed an experiment with light where a beam of light was passed through two parallel slits in an opaque screen and formed a pattern of alternating light and dark bands on a screen beyond – this we know as interference – a phenomenon which is associated with waves. Later, other important experiments on diffraction and interference of light were also done, notably by Fresnel (1814) and others that could only be interpreted in terms of the wave theory for light. In the face of such irrefutable experimental evidence, the wave theory became the dominant and accepted theory of the nature of light in the 19th century. In 1864, James Clerk Maxwell showed that electric and magnetic fields propagated together and that the speed of these electromagnetic waves was identical to the speed of light. It became clear at that point that light is a form of electromagnetic radiation. Maxwell’s theory was confirmed experimentally with the