Abstract of a Keynote Speech

Physics and Astronomy World Forum

December 02-04, 2021, Frankfurt, Germany

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Experimental Observation and Mapping of Atomic and Molecular Wavefunctions: Consequences on the Fundamental Understanding of Quantum Mechanics

In 2011, with a probing tip functionalized with a CO molecule, internal details of molecular wavefunctions, the nodal structures, were experimentally observed and mapped in real space using scanning tunneling microscopy (STM) [1]. Together with the charge density contours of atomic and molecular wavefunctions directly observed and mapped by STM in the 2000s, wavefunctions are now proven to be an observable objective reality [2,3]. An important fact is, STM is a non-destructive imaging method, and the measurement process does not disturb the wavefunctions under observation.

For many decades, wavefunction has been described as a complex field, not directly observable. The new developments showed that wavefunction is similar to electrical and magnetic fields. In Maxwell's theory, a changing electrical field generates a changing magnetic field, and a changing magnetic field generates a changing electrical field. By combining the electrical field and magnetic field into a complex field, $\mathbf{F} = \mathbf{E} + i\mathbf{B}$, Maxwell's equations become similar to the complex Schrödinger's equation. On the other hand, using a pair of real wavefunctions, Schrödinger's equation becomes similar to the real Maxwell's equations. For time-independent cases, a real wavefunction and a real Schrödinger's equation suffice. Those developments enable a realistic interpretation of quantum mechanics as advocated by Einstein and Schrödinger, as well as a significant simplification in teaching and learning quantum mechanics.

[1] Gross L, Moll N, Mohn F, Curioni A, Meyer G, Hanke F, et al. *High-resolution molecular orbital imaging using a p-wave STM tip*. Phys. Rev. Lett. 2011; 1074:086101.

[2] Bartels L. Viewpoint: *Visualizing quantum mechanics*. Physics. 2011; 4:64.

[3] Chen CJ, *Introduction to Scanning Tunneling Microscop*y, Third Edition, Oxford University Press, New York, January 29, 2021, especially Chapter 8.