Commentary

A Complete Quantum Mechanics That Is Also Visualizable

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We hypothesize that quantum mechanics is incomplete because it does not take into consideration the absorption of energy by quantum systems as described by matrix mechanics. To be complete quantum mechanics must include both matrix and wave mechanics, and due to the conservation of energy the first (absorption) must be carried out to completion before the second one (emission) can begin. The combined model of matrix and wave mechanics integrates naturally with Einstein's use of independent coordinate systems K and K' to describe the absorption and emission of radiation. All subsequent mathematical models are versions of this physical model.

1. Introduction

When Richard Feynman initiated his lecture series on physics he anticipated the difficulties his students would encounter if they tried to visualize the mathematical models[1]. "Your experience with things you have seen before is incomplete. The behavior of things on a tiny scale is simply different. The difficulty is really psychological and exists in the perpetual torment that results from your saying to yourself, 'But how can it be like that?' which is a result of uncontrolled but utterly vain desire to see it in terms of something familiar. I will not describe it in terms of an analogy with something familiar I will simply describe it.".

Despite this rather discouraging initial advice Feynman later uses classical analogies in his lectures to describe the behavior of microscopic matter. Because he is an excellent teacher he cannot help but try to present complex subject matter in a way that is easier to understand. He will be especially helpful in our studies of the foundations of quantum mechanics for as we shall see he explores the classical roots of the "quantum revolution" more thoroughly than the original authors.

 doi.org/10.32388/PQ5JZL.2

2. Quantum mechanics

2.1. A brief history of its development

Quantum mechanics developed in order to explain the spectral properties of the black body radiation emitted by hydrogen. The first attempt, matrix mechanics, is based on the assumption that matrices describe all possible observables of a quantum system, the frequencies and intensities[2]. A year after matrix mechanics appeared Schrödinger published his wave mechanical model describing the energy eigenvalues of steady states[3]. Schrödinger claimed to show that the two models are complete with a paper showing their mathematical equivalence. However, his arguments have been strongly contested because they are not well documented and are limited in scope[4][5]. Mathematical equivalence has been demonstrated by showing that the matrix mechanically determined energy states of the Bohr atom and the eigenvalues of wave mechanics define the same physical endpoint[6]. The matrix mechanically determined steady states of the Bohr atom and the energy eigenvalues of wave mechanics describe the same thing, but every other aspect of the models; measurement procedures, physical interpretations, and mathematical formalisms; is different. As usual Feynman thinks about the problem on a different level[7]. "The two different roots were one by Schrödinger, who guessed the equations. Another by Heisenberg, who argued that you must analyze what's measurable. So it's two different philosophical methods reduced to the same discovery in the end." We wish to resolve the philosophical differences by explaining them physically.

2.2. Matrix mechanical model

Heisenberg's seminal paper on quantum mechanics is nearly incomprehensible. Its meaning was clarified mathematically by Born and Jordan who introduced the concept of matrices[8]. Dirac completed the "simplification" of matrix mechanics by expanding upon the idea of non-commutativity[9]. The mathematical derivation, performed in three distinct steps a century ago, was carried out without a careful analysis of its physical meaning. Heisenberg's philosophically oriented belief, that quantum mechanics should be "founded exclusively upon relationships between quantities which in principle are observable" was adopted[2]. No evidence, theoretical or physical, has ever been presented to substantiate his claim, consequently the Hamiltonian matrix is believed to describe the complete atom. However, there are no matrices describing single atoms. The only matrices that are

actually used in radiation processes describe spin or molecular structure, quantum mechanical variables with no thermal input. We continue our study of the Hamiltonian matrix by following Feynman[10].

"In most chemical reactions and other low-energy happenings, nothing goes on in the nuclei; they don't get excited. Furthermore, if a hydrogen atom is moving slowly and bumping quietly against other hydrogen atoms—never getting excited inside, or radiating, or anything complicated like that, but staying always in the ground state of energy for internal motion—you can use an approximation in which you talk about the hydrogen atom as one object, or particle, and not worry about the fact that it *can* do something inside. This will be a good approximation as long as the kinetic energy in any collision is well below 10 electron volts—the energy required to excite the hydrogen atom to a different internal state. We will often be making an approximation in which we do not include the possibility of inner motion, thereby decreasing the number of details that we have to put into our base states. Of course, we then omit some phenomena which would appear (usually) at some higher energy, but by making such approximations we can simplify very much the analysis of physical problems. For example, we can discuss the collision of two hydrogen atoms at low energy—or any chemical process—without worrying about the fact that the atomic nuclei could be excited. To summarize, then, when we can neglect the effects of any internal excited states of a particle we can choose a base set which are the states of definite momentum and z-component of angular momentum."

This entire passage is a discussion about the unobservable continuous motions of low energy molecules that anticipate the discrete energy exchanges of quantum mechanical emission. Although unobservable, they are nevertheless physically meaningful.

2.3. Base states

In the above passage a set of "base states" are chosen for hydrogen atoms of low energy, which are the states of definite momentum and the z-component of angular momentum. When the energy of the hydrogen atom is increased causing the electron to be excited; then a different set of base states must be chosen, a quantum mechanical set. The description is more complicated now[11]. "In a hydrogen atom which has one proton and one electron, we have many different base states to describe—up and down spins of the proton and electron and the various possible momenta of the proton and electron." and continuing: "Any state vector $|\phi\rangle$ can be represented as a linear combination with suitable coefficients of a set of base 'vectors'—or, if you prefer, as a superposition of 'unit vectors' in suitable

proportions." The need for differing base states severely limits how a complete quantum mechanical process, consisting of absorption and emission, can be described mathematically.

The mathematical description of a hydrogen atom as it transitions from low to high energy states is straightforward. One set of base states is chosen for hydrogen molecules of low energy and a different set is chosen for the hydrogen atoms of higher energy when excitations of the electron occur. Different base states are used in classical and quantum mechanical equations of motion. It is impossible to derive non-relativistic equations of motion to describe the transition continuously because time is absolute; however, it is possible with relativistic equations of motion[12]. It is also possible to visualize the transition from a classical set of base states to a quantum set by appealing to the Hamiltonian matrix. We can describe the time evolution of thermal energy to hydrogen gas by beginning with the distribution of energy among the various microscopic base states available to the system according to the Boltzmann distribution. The increases in temperature can also be expressed discretely by using the formula E=kT, where k is Boltzmann's constant. The transition energy E of a hydrogen molecule at room temperature is 0.4 electron volts. This corresponds to an electron transition far from the diagonal of the Hamiltonian matrix. Due to the infinite nature of the matrix it will always be possible to link continuous exchanges of kinetic energy to discrete electron transitions.

2.4. Visualizing quantum mechanics

The spectroscopic properties of hydrogen studied by Heisenberg are produced by heating hydrogen gas to create an emission spectrum. The transfer of heat to a gas has been extensively studied and occurs due to both classical and quantum mechanical means. It initiates with classical exchanges of energy by the temperature dependent motion

of particles, but the gradual increases may also be described by changes in state by means of the quantum electron Hamiltonian equation, $\hat{H}=-\hbar^2/2m\nabla^2 +V(r)$, which is composed of kinetic and potential energy terms. Infinitesimal thermal exchanges correspond to matrix elements that describe infinitesimal changes in state. We describe the heat absorption of a hydrogen gas molecule initially with matrix elements far from the diagonal, gradually proceeding closer to the diagonal as the temperature increases. Electron transitions can be either positive or negative so the complete matrix of an atom requires a two-fold infinite number of elements to describe all possible energy exchanges, *with energy emission occurring when electrons have net positive transition energies*. In other words, energy is first absorbed raising the electron to a higher state before decaying to create the spectroscopic

observables. No one has ever used matrix mechanics to study the function of an atomic oscillator, for if all off-diagonal matrix elements are equal to zero it would be immersed in a "thermal bath" equal to absolute zero and would not radiate at all.

The matrix and wave mechanical theories both describe the same *invariant* physical observables that characterize the steady states, but they do not explain why they follow different paths to arrive there. Einstein's unfinished theory answers that question by showing that radiation processes occur in two physically independent steps, absorption in K and emission in K'[13]. We adopt Einstein's mathematical convention describing the foundations of quantum theory in the remainder of this paper. There are two coordinate systems and two distinct mathematical formulations, matrix mechanics originating in K and ending with the eigenvalues. Wave mechanics which originates in K' and yields the eigenvalues. Both are needed for a complete quantum mechanics. A complete quantum mechanics describes the time evolution of two physical processes, and due to the conservation of energy the first (absorption) must be carried out to completion before the second one (emission) can begin.

3. Discussion

We propose to complete quantum mechanics by visualizing heat transfer to the hydrogen gas causing it to radiate. It begins with continuous particle motions described using four degrees of freedom in Einstein's coordinate system K. Four degrees of freedom are next assigned to the wave function with coordinates in K', at rest with respect to the atom. We require both mathematical formulations with a total of eight degrees of freedom to describe the transition from classical to quantum coordinates, during absorption and emission. Einstein's systems of coordinates, K and K', developed in his unfinished quantum theory, provide a means for visualizing the transition between classical and quantum mechanical coordinates in continuous time. Non-relativistic theory, formulated in absolute time, describes the transition by means of "wave function collapse", which violates special relativity theory and *cannot be visualized*.

Consider the atomic process of parametric down conversion where the impact of a photon on a non-linear crystal produces two photons with perpendicular polarization. The photons are created in the coordinate system K', at rest with respect to atomic structure. They separate and follow different trajectories in K in accordance with the conservation of energy and momentum. There is nothing unusual about the entanglement that exists between the two photons because it originated in K' and

propagated in K. Wave function "collapse", when the polarization of both photons becomes known, is the sudden recuperation of the four classical dimensions in K that were suppressed when the wave function was formulated in K'. The wave function is incomplete, not for philosophically oriented reasons concerning locality, but because the principles of matrix mechanics were not taken into consideration. Due to the conservation of energy neither model is complete without the other.

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Declarations

Funding: No specific funding was received for this work.

Potential competing interests: No potential competing interests to declare.