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Quantum Mechanics and the Arrow of Time

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Abstract

We reformulate matrix mechanics by incrementally heating a single hydrogen atom in order to derive the complete, diagonalized Hamiltonian matrix. The spectral lines and transition probabilities cannot be generated by reversing time thereby demonstrating asymmetry. Experimental evidence in support of the theoretical model is obtained from experiments performed with the simplest quantum system, an electron cyclotron. Wave mechanics is also reformulated by altering the original Schrödinger equation describing a time symmetric, conservative system to a system of two independent equations describing a time asymmetric, non-conservative system.

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1. Introduction

Microscopic time reversal refers to the fact that the fundamental laws governing individual particles (like electrons and atoms) are symmetric with respect to time, meaning they work the same forwards or backward. The Schrödinger equation possesses time-reversal symmetry because its fundamental dynamics allow for wave function evolution both forward and backward in time. If time is reversed (t—> −t) the equation still holds and results in another valid solution. Consequently a video of a quantum process, if played backward, would look like a physically valid phenomenon. However an equivalent theory, matrix mechanics, is based on "quantum jumps" at single points in time. Thus a conflict has always existed between these two foundational, mathematically equivalent formulations of quantum mechanics concerning how quantum systems evolve in time; discretely or continuously. The first record of the dispute, which included Heisenberg, Bohr, and Schrödinger was conducted verbally and with great vigor and intensity [1]. We will now renew the debate a century later with a renewed focus on the foundations and access to experimental results that directly illustrate the topic of the discussions; that is, how the excitation and decay of an electron evolves in time.

2. Quantum Mechanics

2.1. Time's Arrow

We see evidence of the arrow of time in the second law of thermodynamics, in evolutionary theory, in Hubble's law of cosmic expansion; and also subjectively, in our own stream of consciousness. All are irreversible natural phenomena that may well be based on underlying quantum mechanical principles. They are well-known examples of time's arrow that are observable. However, time is not an observable in quantum mechanics. Observables are measured by bringing a measuring device into contact with the physical system, but time measurements do not make contact with the observed physical system. The time "measured" by clocks is just one of four coordinates, the same as in classical physics, and though clocks are used in quantum mechanics to measure the location of an event, the time of an event has no direction. Thus time asymmetry is concerned with much more than clock time and the time we experience. It is also a determining factor in how material systems evolve in time; whether in the form of a hydrogen atom, a molecule, the cosmos, or life itself.

2.2. Time Reversal Asymmetry

Wave functions describe physical variables in quantum mechanics such as position and momentum which evolve reversibly in time according to the Schrödinger equation. However, there is a mathematically equivalent theory, matrix mechanics, which describes physical variables at single points in time. It derives from the hydrogen spectrum of black body radiation and is the result of many atoms acting in unison. We are able to use it to interpret the energy of a single hydrogen atom by reformulating the Hamiltonian matrix H_{ij} describing all possible electron transitions [2]. The individual matrices H_{ij} are snapshots in time of energy states that are infinite in number, and when placed in a series from low energy to high they may be used in the same way as frames in a motion picture to depict the increase in temperature of a hydrogen atom. Increasing the temperature of a hydrogen atom is a critical, but unacknowledged initial condition for obtaining the spectral lines. The same video shown in reverse is immediately rejected since it depicts spectral lines and transition probabilities being generated in response to a lowering of temperature. Therefore a reformulation of matrix mechanics in continuous time with respect to a solitary hydrogen atom forms the basis for a hypothesis concerning the arrow of time at the most fundamental level possible, the quantization of energy.

3. Experimental Evidence

A recent experiment with single electrons provides experimental evidence to support our hypothesis concerning the quantum mechanical asymmetry of time [3]. Electrons from a high voltage discharge tube are cooled to near absolute zero and inserted in a "bottle" made of intersecting electric and magnetic fields. Single particles are trapped indefinitely by the intersection of a homogeneous magnetic field and an electrostatic quadrupole potential. The resultant motion of electrons consists of a fast circular cyclotron motion with a small radius superimposed on a much larger orbit moving slowly. The trapped electrons constitute an artificial atom or "quantum cyclotron", the simplest quantum mechanical system possible. It is so sensitive to external forces that the influence of the earth's gravitational field must be taken into account.

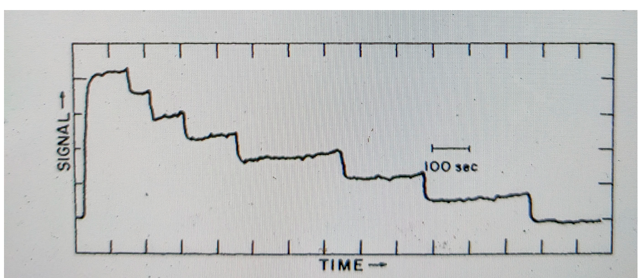

FIG. 5. Steps in the detected axial signal that appear when the axial drive is increased sufficiently to drive one electron at a time out of the trap. It is evident that there were initially seven electrons in the trap. The initial and final signal level is the noise floor (Wineland, Ekstrom, and Dehmelt, 1973).

Energy levels of a quantum cyclotron

When a signal of alternating frequency is applied to the axial cyclotron motion it causes the electrons to be excited and seek a higher energy level. The "detected current" plotted as a function of energy versus time in the figure shows a pronounced step structure with quantization slowed to a snail's pace. Initially there are seven electrons in the cavity, each one described by a wave function and probability for decay. Emission proceeds spontaneously in discrete steps of equal energy with each one marking the exit of an electron from the cavity. The system returns to the base level when the final electron exits. The figure gives a complete record of quantization in terms of the physical

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variables energy and time; beginning at a base level, or ground state, and also ending there. The horizontal lines represent the presence of wave functions, the short vertical lines represent emissions, and the long vertical line at the left represents the input signal. The experimentally derived energy-time curve in the figure is a faithful reproduction of quantization in real time; the continuous, irreversible increase and decrease of energy by a quantum system. The input of a signal causes quantum superposition and an increased energy which then decreases as energy is released in discrete steps. The experiment reduces the complexity of quantization to its most elemental level, the increase and decrease of a potential.

The curve is a complete description of quantization since it describes the absorption of energy by a quantum system in the form of a continuous classical signal, an excited state of indeterminate time, and the discrete emission of energy in the form of a photon. It complies with the conservation of energy by beginning at the ground state, increasing to an excited state, and ending at the ground state. The wave function describes the excited state, but not excitation and decay, so it is a partial record of quantization.

4. Wave Mechanics

Once Heisenberg's theory is reformulated to describe a single atom the direction in time of a quantum system is no longer in doubt; however, the same cannot be said about wave mechanics. The equations of motion of wave mechanics for a single atom have been substantiated experimentally and it is easily verifiable that reversing the time of the Schrödinger equation (t—> −t) creates a second solution. However, the solutions are only valid for conservative systems of constant potential [4].

> "We have always postulated up till now that the potential energy V is a pure function of the coordinates and does not depend explicitly on the time. There arises, however, an urgent need for the extension of the theory for non-conservative systems, because *it is only in that way that we can study the behavior of the system under the influence of prescribed external forces*, e.g. a light wave, or a strange atom flying past." p. 103

If Schrödinger had extended his theory to include non-conservative systems of varying potential, it would be asymmetric in time. Einstein realized that something was missing from how the wave function was conceived [5].

> "The light quantum has a definite localization and a definite color. <u>Naturally one cannot do justice to this by means of a wave function</u>. Thus I incline to the opinion that the wave function does not (completely) describe what is real."

By "real" Einstein means that quantum theory should describe systems of varying potential, *a characteristic of all observable phenomena*, but not of wave functions. To define a "real quantum state" we proposed in an earlier communication to link the output of matrix mechanics to the input of wave mechanics [2]. The examples cited by Schrödinger for a non-conservative system, "light waves and atoms flying past", are classical manifestations of heat and can be expressed quantum mechanically by the Hamiltonian matrix at single points in time. They may be linked to wave mechanics and the wave function in the simplest possible way, by juxtaposition within a quantum system. Matrices supply the missing information due to a variable potential V to make the wave function complete and cause the resultant non-conservative system to be asymmetric in time *by convention*.

5. Conclusions

The quantum-classical divide exists due to a deep seated, long held misunderstanding that classical and quantum phenomena are to be defined independently of each other. The divide is not physical, as currently believed, but mathematical [6].

> "It is hardly necessary to remark how much this concept [of quanta] differs from what we imagine to be true up to this point; physical phenomena would cease to obey the laws

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expressed as differential equations and this would undoubtedly be the greatest and the most profound revolution that nature has undergone since Newton."

What the evidence actually suggests is that the classical and quantum properties of matter are bound together because continuous forms of energy cause discrete transitions. We see in the above figure that pronounced discontinuities due to the quantization of a quantum cyclotron cannot be reproduced by a single equation. The correct equations; one classical and one quantum mechanical are derived with respect to the conjugate variables energy and time; and appear in a previous communication [2]. The mathematics, classical and quantum, are distinct, but they describe a single material system.

When considering the quantum mechanical nature of time the correct question to ask is not whether the physical variable *time* is symmetric or asymmetric, but whether *time dependent* systems are conservative or non-conservative. That is because conservative systems are defined symmetrically in time and non-conservative systems are defined asymmetrically in time. However, in no case can time be conceived of as an "emergent variable" that is independent of matter and/or material systems. The reason time has been referred to as emergent is because it is inextricably tied to consciousness, which is in itself emergent.

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