A note on the understanding of Quantum Mechanics

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Abstract. Quantum Mechanics is understood by generalizing models for cause-effect from functions, e.g. Differential Equations, to graphs and, via linearization, to linear operators.

This also leads from classical logic to quantum logic.

1 Introduction

Quantum Mechanics is considered difficult to teach [1], as well as difficult to understand. The author's opinion is that the former is caused precisely because of the later.

The essence of this difficulty consists in us being used to *Y or N* answers to questions, which is a reduction of a complex situation to a binary model, requiring a choice, and when we expect and enforce such an answer when asking a question "Mother Nature"; otherwise Her wise reply is a more like a riddle and corresponds to a natural projection [2].

Probabilities encountered in QM are needed because our experiments are in a similar manner intrusive, destroying the delicate structures systems consist off (see collapsing the wave function below); they are the so called *strong measurements*.

Probabilities extend the range of answers from the discrete range $\{0, 1\}$, corresponding to Y/N, to the interval $[0, 1]$. In this case the "Question" (the strong measurement) is simple minded and "brutal", using a classical apparatus, twisting Mother Nature's hand for an "Answer".

Quantum Computing, on the other hand, is tested using *soft measurements*, being able to extract relative quantum phases (e.g. Quantum Optics experiments), extending the range to qubits: units of quantum information, having the geometry of a 3D ball.

Cause-effect is modeled via functions, with correlations between Input x and y in the range as being 0 or 1, if $y = f(x)$.

When several input factors contribute to a complex output via a process, networks are mandatory, or when modeling lists as vectors, to linear operators.

2 Collapse of the Wave Function

Heisenber's QM via operators and Schrodinger's Wave mechanics via densities of probabilities are equivalent.

The key debate was the significance of the wave function, representing an amplitude of probability and its probability, measuring for instance the probability of a particle to be present at a certain place q.

The collapse of the wave function was considered not as a real process. Yet in an interaction, for instance the transfer of an elementary electric charge, is a network process, with the electron being an open fermionic channel. The closed channel case is that of an orbital. The measurement is a localized interaction that will collapse the channel, a cloud orbital-like, to the corresponding point of output. Hence the collapse is real.

Modeling an electron as a fermionic channel solves also the "mistery" of the double slit experiment [3].

This way of thinking also allows to model a photon as a bosonic excitation traveling on the fermionic channel, unifying bosons and fermions; this is a realistic alternative to the just mathematical way, supersymmetry.

3 Double Slit Experiment

As an example, consider the double slit experiment for an electron. The electron viewed as a point-particle leads to a contradiction. Wave-particle duality is an early stage model for solving this paradox. Modeling the electron as a material fermionic chanel with non-trivial topology (genus $g = 1$, with two punctures: I/O) not only solves the problem, but also solves the photon double slit experiment case, and, as remarked above unifies fermions and bosons.

In addition, the measurement via a photon means a new fermionic chanel is generated from the measurement apparatus, connecting with one arm of the genus one fermionic channel of the electron, redistributing it to one side only.

4 Teaching Quantum Mechanics

First we should be aware that there is a natural progression of theories, evovled over time, which also corresponds to the audiance's background: Classical Mechanics / Physics, Quantum Mechanics / QFT and finally (!) Quantum Computing / Quantum Information Theory (or Dynamics) [7].

4.1 QC, Matrix Mechanics and Wave Mechanics

Quantum Computing benefited from our in depth understanding of Information Theory and experience, familiarity, with computers. It literally "upgrades" Quantum Mechanics in the formulation of Heisenberg, which uses complex numbers predating qubits via the paradigm of harmonic oscillator (spin $\frac{1}{2}$ systems; fundamental representation of $SU(2)$).

Schrodinger's Wave Mechanics was a "step back", with the role of a "bridge" from Heisenberg's leap forward (the New Continent of QM/QC) to the "Old Physics". While formally equivalent, they are conceptually totally distinct: states and transitions, soft measurements oriented, vs. wave-particle duality, strong measurements oriented.

4.2 What to Teach

QM is at the heart of modern electronics, chemistry and medicine, because even biological systems are Quantum Computers, processing QI. *Qi* is quantum information:

$$QI = qi.$$

For the author this "equation" completes the list of more famous equations: $E = mc^2, E = \hbar\nu$.

QM is an obtuse subject when there is a lack of background on classical computing (not the case with the young generation) and when focusing on Schrodinger's Wave Mechanics. This later approach involves PDEs and the Copenhagen interpretation (wave-particle duality); yet this may be suited for mature Physics majors, destined to take their place in the Network of Current-Traditional jobs, needed for preserving the heritage: Education System and Labs.

4.3 Discreetnes and Non-classical Correlations

The Schrodinger "wave" is an amplitude of probability, and in spite of the similarity with the wave equation, the Wick rotation to imaginary time hides the discreetness via constructive and destructive interference: the presence of standing waves when there is “feedback” in closed circuits or paths.

These two aspects, discreetness and non-classical correlations, are two important aspects which can be much easier be understood from the QC point of view, which starts from acknowledging that reality is quantum, i.e. discrete, and a Network, with a selection of discrete outcomes due to “feedback” loops (when assuming the wave formalism: propagation of particles with associated “pilot waves”, a la De Broglie).

This also ensues a discrete spectrum of energies, as opposed to the classical case when particles move, have kinetic and potential energy only, and time is global in a coordinate system, with no *anti-particles* completing the propagation on closed loops against the “arrow of time” (conform Feynman and Stuckelberg interpretation).

4.4 Entanglement

This is much easier to understand when we accept that a system has “elementary parts”, i.e. which are subsystems themselves, but cannot be divided in independent parts without loosing their properties. Such subsystems have parts at different locations which are connected via vector potentials or QI channels, which are not interactions in the classical sense of resulting “Newtonian forces” that one exerts on the other.

A classical example is the EM vector potential which has quantum interpretation (Aharonov-Bohm effect). Such a subsystem is present in the double slit experiment in the presence of an ambient magnetic field with *zero force* (just a vector potential flow, or connection).

The tensorial representation of such an entangled pair of “particles” constituting such a subsystem is mathematically precise, but does not seem to be a “particle”, since it has localized “parts”.

Why would be this different from the accepted “confined quarks”, which are localized, yet inseparable? Just because they are not at the same location and when acted upon they share one property, e.g. spin?

4.5 Some Pedagogical Hints

Historically Quantum Phisics was developed via a *quantization procedure*, i.e. deforming the Classical Physics to ensue discreetness: Dirac prescription, Deformation Quantization etc.

This was understandable to be done by mature physicists, to build on what we had; but the obvious thing to do is to develop a theory from “scratch” based on the discreetness in the first place. Classical Computer Theory is such an example; it only needs an “upgrade” to become Quantum Computing: linearize the bit, to get a qubit!

This amounts to build an “entangled”, yet localized subsystem with two correlated states. The coefficients need to be 2D, i.e. complex numbers $z = Pe^i$, to allow for a probability (weight, or “dominance size” in the subsystem) and a relative phase (local “time lag”). That they form a basic “unit” is implemented as a correlation between the two coefficients.

It is impressive to realize that the 2D-projection of the qubits space ball, with a chosen base, is the Yin-Yang diagram, artistically rendered.

5 Conclusion

Evolving our understanding of reality from functions to networks as models of cause-effect phenomena leads naturally from Classical Physics to *the* Quantum Mechanics formalism. It is also obvious that an “effect”, i.e. an output of a process, may be more complex then a pointwise, localized measurement and may require an adequate model: the Network.

The use of complex numbers as coefficients is mandatory to have periodic processes, i.e. waves, localized as particles too. But this is just the shadow of $SU(2)$ as the space of qubits, i.e. the quantum units of information $q = z_1|Y > +z_2|N >$, $|z_1|^2 + |z_2|^2 = 1$, in order to have superpositions of classically disjoint alternatives: “Yes AND No” at the same “time” and “place”. Mathematically it enables products and coproducts of elementary events, i.e. classical functions and multivalued functions, to build graphs. Together we get the Hopf bundle and the Bloch sphere as a homogeneous space $U(1) \to SU(2) \to S^2$. This is the modern unit of Quantized Space-Time of General Relativity: not only a local time / “clock” (once we have an associated frequency $e^{i\omega t}$, built into the particles quantum phase: see Feynman’s QED), but also a local space-frame. Weyl’s gauge theory provides the connection between these, including the “synchronization” of clocks introduced by Einstein.

Returning to the qubit idea as a generic unit of “everything”, note that this is just the foundation of ancient Chinese Tao philosophy, considering Yin-Yang polarity as primary. Together with ancient Greek’s atom hypothesis and Zeno’s paradoxes ruling out infinitite divisibility of action, and hinting to Planck’s constant, we see how far pure thought can advance on its own, without asking “Mother Nature” with more and more sophisticated experiments.

The Network approach solves many other apparently paradoxical situations, including the collapse of the wave function and the double slit experiment. For further details, see [3, 4].

References

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