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The Second Quantum Revolution and Its Philosophical Meaning †

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Abstract: The second quantum revolution blurs the distinction between information and matter. "It from (qu)bit or (Qu)bit from it" thus becomes a philosophical issue. According to the physicist Wen Xiaogang in MIT, quantum topological states of matter, formed by long-range entangled qubits, will show all particles, such as light and electrons, are unified by the long-range entanglement of qubits. That is, it from qubit, not bit. Quantum information unifies matter, i.e., quantum information = quantum matter. This represents a new way to view our world. However, the information-theoretical paradigm, which origins from Wheeler's "it from bit", can lead to informational immaterialism and instrumentalism. In perspective of the constructive structural realism, there exists a constructive co-dependent structural relationship between quantum information and quantum matter. Both qubit and it are fundamental structural elements for us constructing our understanding of the physical world.

Keywords: second quantum revolution; quantum information; quantum matter; long-range entanglement; it from qubit; constructive structural realism

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1. Introduction

Since ancient Greece, we have always wanted to know the origin of everything. With the development of modern science, we have achieved several great unifications of physics. From mechanical revolution to electromagnetic revolution, to relativity revolution, and to quantum revolution, the most dramatic revolution in physics, reveals the true existence in our world to be quite different from the classical notion of existence in our mind. All the matter in our world is particle-wave-like matter, particle-like matter = wave-like matter. All these have revolutionized our ideas of physical reality and given us a new understanding of the essence of physical world.

Quantum theory not only changes the notion of existence, allowing a new kind of quantum existence which is entangled and has no classical analogues, but also blurs the distinction between information and matter. It appears that we are now entering into a new stage of the second quantum revolution, where qubits emerge as the origin of everything. It is known as "it from qubit", which realizes a unification of force and matter by quantum information [1] (p. 334). It is an important conceptual revolution and arises a new philosophical discussion about the origins of everything.

2. It from Qubit, Not Bit

Traditionally, we consider that matters are the carriers of information, and information informs us of the properties, states, relations and mutative processes of matters. Observers know matter through information. However, John Wheeler has revised this traditional epistemology by changing the conventional explanatory relationship: matter → information → observers into observers → information → matter. He proposed "it from bit", where "it" refer to physical objects, such as atom, electron . . . , all elementary particles and physical entities, and "bit" refers to the information that relates to "it". Thus "it from bit" meaning the universe is at bottom an information-processing system, from which the appearance of matter or physical reality emerges [2]. Wheeler's "it from bit" represents a deep desire to unify matter and information.

However, in our world, "it" is very complicated. Most elements of "it" are fermions, while elements of "bit" are bosonic. Can fermionic "it" come from bosonic "bit"? To understand the concrete meaning of "matter from information" or "it from bit", the physicist Wen Xiaogang in MIT examines the microscopic structure of the space, which gives rise to waves that satisfy Maxwell equation, Dirac/Weyl equation, and Einstein equation. In his opinion, elementary particles described by gauge fields and anti-commuting fields in a quantum field theory can arise from qubits. Our space, as a dynamical medium, can be assumed to be an ocean of qubits or qubit ether. The empty space (the vacuum) corresponds to the ground state of the qubit ether, and the elementary particles (that form the matter) correspond to the excitations of the qubit ether. This is how "it from qubit" or "matter = information" [1] (pp. 334–335).

Our observed elementary particles can only emerge from long-range entangled qubit ether (which can be viewed as space). The requirement of quantum entanglement implies that "it cannot from bit", in fact "it from entangled qubits" [1] (p. 336). "It from qubit" implies that matter and space = information (qubits), quantum information unifies matter. That is, if we consider the relationship between frequency and energy $E = hf$ in quantum theory, and the relationship between energy and mass $m = E/c^2$, we can know that frequency, energy and mass are equivalence in description of attributes of information and matter. This also means the equivalence of information and matter in the ocean of qubits. This represents a new viewpoint of world [1] (p. 334).

Is such a qubit ether possible? According to Wen Xiaogang, the answer is "yes". The reason is that the long-range entanglement of qubits is uncovered in their discovery of fractional quantum Hall states in condensed matter physics, where highly entangled many-body systems possess a new kind of states of matter, quantum topological ordered states, in which the excitations, i.e., the waves, satisfy the Maxell equation, Yang-Mills equation or Dirac/Weyl equation. In this way, elementary particles can emerge from quantum vacuum, i.e., long-range entangled qubits sea. So, the impossible becomes possible [1] (p. 336).

3. Against Information-Theoretical Paradigm

Is this true? Actually, with the advent of quantum information science, some scientists and philosophers of science naturally ask the following question: Does quantum information theory indicate a new way of thinking about the world—one in which the material as research objects of physics will be replaced by the immaterial: information?

The information-theoretical paradigm by which information can be processed determine the physical theory, even the physical world, which origins from Wheeler's proposition "it from bit", for which he argued that "all things physical are information-theoretic in origin" [3] (p. 5), gives a positive answer to the problem. This means that the fundamental theory of the world could just be about information (immaterial) rather than about things (material). Just as D'Ariano says, the recovery of all physical notions, such as energy, charge, inertia, relativistic covariance and gravitation, as features of quantum information processing, would realize the dream of John Wheeler, "a physical world made of informational units" [4] (pp. 63–64).

If so, it will definitely be a huge change in ontology that a physical world is replaced by an evanescent cosmos made of pure information, in which all being, including particles and space-time, become subjective entities or "non-being", this sounds quite strange. If physics is only about information or, even more astonishingly, that the physical world itself just is information, the information-theoretical paradigm not only makes the physical world become mystical and visional, but also somewhat contradicts our common belief of physics that describes the physical structure of objective objects and laws in nature, from the very large to the very small [5] (pp. 129–130).

In the perspective of critics, the information-theoretical paradigm can lead to uninteresting philosophical consequences: informational immaterialism (information ontological view) and instrumentalism (information epistemological view) [6] (p. 209). So, some physicists, such as Christopher Fuchs, also do not believe in this program and suspect that quantum theory is mostly about information, although they maybe appreciate information's role in quantum theory. Fuchs objects to regarding being as a statement of information. In his opinion, being or quantum reality is a statement about the character of the world [7] (p. 28). This means that the further exploration of the philosophical implication of the second quantum revolution is expected.

4. Quantum Information: A New Type of Natural Kinds

Here, we present a constructive perspective of structural realism and consider quantum information as a new type of natural kinds. In the structural approach, the physical entities, or quantum matter, such as all kinds of particles, are constituted through structural relations displaying their intrinsic and essential (causally effective) features, and thus can be taken as natural kinds. That is, they have to be approved by nature, although they are conceived by scientists [8] (pp. 228–229). Similarly, quantum information can be also considered as a kind of physical entity, which is constituted through structural relations displaying its intrinsic and essential (causally effective) features, and thus can be taken as a new type of natural kinds.

In recent years, the relationship between quantum information and quantum matter has been further disclosed by quantum information theory and experiments. Quantum information and quantum matter are not irrelevant, although the relationship between them apparently seems tenuous. Just as Lloyd says, matter seems to be about energy and stability; quantum information matters a lot. First of all, information is not as immaterial as it might seem. In statistical mechanics, entropy is in fact a form of information—information about the microscopic motions of atoms and molecules. Planck's 1901 paper on black-body radiation, the very first paper about quantum matter, is also fundamentally about information and quantum mechanics, in which Planck established the constant of proportionality between information (defined statistically) and entropy [9] (p. 1209).

In the past few decades, quantum information theory actually has become an integral part of quantum matter science in all its forms. With the relationship between the theory of quantum information and the theory of quantum matter becomes more and more elaborate and intimate, some of the ongoing deep mysteries of physical world are to be unraveled by quantum information theory.

This shows that there exists a constructive co-dependent structural relationship between quantum information and quantum matter. That is, quantum information and quantum matter are mutually constituted and co-existing, and also mutually transformed under the certain conditions. This is a standpoint of constructive structural realism.

5. Conclusions

With the advent of the second quantum revolution, the intrinsic relationship between quantum information (qubit) and quantum matter (it) has become a potential philosophical issue. Moreover, the relationship of quantum information—as a new type of natural kinds—with the theory of quantum matter becomes more elaborate and more intimate. From the perspective of constructive structural realism, there exists a constructive co-dependent structural relationship between quantum information and quantum matter. Both qubits and it are fundamental structural elements for us constructing our understanding of the physical world.

Especially, unlike Wheeler's program "it from bit", Wen Xiaogang's picture "it from qubit" emphasizes the long-range entanglement of qubits, which can well explain all "it from qubit", and topological order, or more generally, quantum order and long-range entanglement give rise to new states of quantum matter. If the observed elementary particles can only emerge from long-range entangled qubit ether, then quantum information does unify matter, i.e., quantum information is quantum matter, and vice versa. This view does represent a new way to view our world.

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