International Journal of Theoretical Physics, Vol. 44, No. 7, July 2005 (© 2005)
DOI: 10.1007/s10773-005-7060-0

Energy–Information Coupling From Classical to Quantum Physics

Arcangelo Rossi[1]

Received August 14, 2004; accepted September 23, 2004

The idea of exploiting a supposedly enhanced information content of superposition states in quantum computation seems to invalidate the classical probabilistic definition of information; but this is not necessarily so.

KEY WORDS: foundations of QM; quantum information.

1. INTRODUCTION: REVOLUTIONARY ONTOLOGY

A now prevailing trend in scientific literature consists in interpreting quantum concepts and processes in ontological terms, far beyond the more cautious, instrumentalistic traditional interpretation maintained, for example, by Niels Bohr (1934). To the effect of totally overwhelming the classical physical view by radically transforming all fundamental concepts of physics in the sense of Thomas S. Kuhn's scientific revolutions. In fact, the trend was already exemplified by Kuhn himself with reference to modern physics by the transformation of the classical concept of mass in Relativity Theory (Kuhn, 1962): in Kuhn's opinion this concept was completely changed by the transition in the sense that under the same term—mass—completely different, even uncommeasurable realities were concealed. Such a radical transformation would then have taken place in Quantum Mechanics too, for, according to the now prevailing opinion, even, for example, the fundamental concept of probability would have assumed in the new theory a quite new ontological meaning. Now, in fact, it would imply a true creation out of nothing of individual properties of quantum objects in a way that would be totally discontinuous and only predictable in irreducibly probabilistical terms, which would then be interpreted in ontological sense as absolute chance, and no longer in purely epistemic sense, as mere ignorance, as in classical physics (Feynman, 1951). A true causal discontinuity would take place in a process of

---

[1] Dipartimento di Fisica, Università di Lecce, Via Arnesano, I-73100 Lecce, Italy; e-mail: rossi@le.infn.it.

0020-7748/05/0700-0821/0 © 2005 Springer Science+Business Media, Inc.

objectivation of properties which would exclude their objective preexistence. As said, it would not be referred to our mere ignorance or only partial knowledge of individual properties as in classical physics, where they were supposed in any case as pre-existent. This new ontological concept of probability in Quantum Mechanics has however been largely discussed and it is not necessary to insist on it here. On the contrary, another fundamental concept surely deserves more attention for what concerns the problematicity of its transition from classical to quantum physics, the concept of information (Shannon and Weaver, 1949; Brillouin, 1962). There is in fact a growing diffusion of a concept of quantum information, often linked even to technological applications (to be true, mainly tentative, as the so-called quantum computation), thought of as ontologically distinguished from classical information, to the point of outlining a true quantum information theory alternative to the classical one (Zeilinger, 1999). On purpose, it is mostly fit to search for which novelties Planck's quantum hypothesis surely introduced into the concept of information, even though it did not really modify the classical concept, but, on the contrary, maintained some of its essential characters. First of all, the energy–information coupling and, second, the essential link between probability and information content we will discuss later on at more length. In this sense, as we will see, the application of the notion of information content to quantum states does not imply at all a modification of the classical definition of information based on that link, but simply invalidates the claim made by the so-called quantum information to gain an information content richer than what is allowed by the classical information theory.

2. THE QUANTUM ENERGY–INFORMATION COUPLING

The transmission of information from a broadcasting system to a receiving one, that locally reduces the entropy of the receiving system, always involves the transmission of a certain amount of energy, that physically carries out that information (Wiener, 1948). Neither can information travel as an ordering of elements, nor can it be picked up as a local entropy reduction factor if at least a minimum amount of energy is not simultaneously transmitted. Therefore, a piece of information which travels and is picked up is a message carried out particularly by the energy of light. Sun light is in fact not only energy poured on our planet but also a carrier of a message that informs us on what happens in the sun: we are in front of a coupling of both energy transmission between communicating systems (as, in this case, sun and earth) and information transmission between the systems themselves. In short, they are connected not only energetically but also informationally, provided that energy is the widely more important element, as it is what literally sustains and supports the message of which information consists, that is the ordering of elements constituting it.

However, because energy was conceived of as a continuous parameter in classical physics, it was maintained there that an arbitrarily small amount of energy could carry out information in any case, provided it met a receiving device able to get information, even if this was carried out by extremely small, even vanishing amounts of energy. Energy–information coupling between communicating systems was then maintained possible even through arbitrarily small energy exchanges. However, in quantum physics energy is exchanged in finite minimum amounts: line disturbances normally taking place in telephone communications are then not reducible with continuity until annihilation, beneath the discrete energy size of the electrons constituting the current: their destructive power is therefore strong up to destroying the information carried out by the current itself. The energy carrying out the signal must be then at least as strong as counterbalancing the noise energy in order not to be lost (Wiener, 1950). Even the main information carrier which is, as mentioned, light, has a quantum structure. Light of a certain frequency is radiated in indivisible curpuscules, light quanta or photons, endowed with an energy corresponding to that frequency. No energy (and then no information coupled with it) can be transmitted which is less than a single photon energy of a certain frequency, corresponding to a minimum indivisible energy for that frequency: it is really unconceivable that a piece of information can be carried out by less than a photon for a certain frequency. In any case, that very small amount of energy is enough to realize an effective information coupling between communicating systems. Even a photon can in fact allow, or better carry out a consistent transfer of information, as in the photoelectric effect. That will however depend on the physical properties of the photon itself as, in particular, position and momentum, defining its information content through reciprocal relations between their values.

3. QUANTUM INFORMATION?

Here we arrive at the crucial point related to what has to be changed, if any, in the concept of information through the transition from classical to quantum physics. In fact, we know by quantum mechanics that if we try to exactly define one of these conjugate complementary properties, the other will result no more exactly defined, and their reciprocal relation will be then liable to different possible definitions. There will be not only one but different possible definitions of the relations between the values of the conjugate complementary properties according to different possible actualizations, through following measures, of the property still undetermined compared to the previously exactly defined one (Greenstein and Zajonk, 1997). As a consequence, the information relating to the superposition state of the possible values of the second property before measurement, will have a content smaller than the one referring to the defined state after measurement; for the former is, as said before, less defined and then more compatible with different possible results of the measurement itself than the latter, if one accepts Shannon's (1949) and Wiener's (1948) classical definition of the information content of a state as the negative logarithm of the probability of that state. The quantum superposition state is in fact no doubt more *a priori* probable, as it is compatible with a larger number of possible measurement results, than the state following the measurement, which is on the contrary only one of different *a priori* possible states. The sum of squared moduli of possible values of the property in superposition state before measurement, taken as the measure of the *a priori* probability of the state itself, is in fact equal to 1 (Ghirardi, 1997) and then its negative logarithm, taken as the measure of its information content, cannot in any case be more than 0.

However, all that remarkably contrasts with the idea underlying the so-called quantum computation, according to which the information content of a superposition state is richer than that of a definite state, so allowing a parallel calculus which simultaneously utilizes the ensemble of the possible values of the undefined observable before measurement. As a consequence, a new information unit is even defined besides the traditional bit, that is the qubit, as a unit which corresponds to a plurality of possible alternative simultaneous choices, instead of a single possible choice between two alternatives (yes or not) (Deutsch, 1997; Preskill, 1999). As underlined by supporters of this view (Bruckner and Zeilinger, 1999), it corresponds to interpreting the information content of quantum measurements as the measure of real actualizations of even non-preexisting properties starting from a certain state. It has then no more to do with revelations of preexisting values (yes/not) of properties as measure of their *a priori* probability in the classical sense.

4. QUANTUM COMPUTATION OR CLASSICAL PARALLEL CALCULUS?

But if you want to maintain Shannon's and Wiener's classical definition of the information content of a state (for a different definition referring it to the *a priori* probability of the state itself in a different way is not so straightforward), you cannot avoid suspecting that the richer information utilized by the so-called quantum computation in order to develop a parallel calculus more powerful than the traditional serial one, is only due to the simultaneous carrying out of several distinguished serial computation lines. Their total information content will be then still measured, according to the classical definition, by the negative logarithm of the probability of the several distinguished corresponding states. As this probability is obtained by simply multiplying one another the probabilities of all these definite states, that are, as is known, unity fractions, it will be certainly smaller than the probability of each single state, and its negative logarithm measuring the total information content of all states will be then larger than that of each single state (Shannon and Weaver, 1949). However, all that seems to have nothing to do with quantum superposition, particularly with its "fuzzy" or "unsharp" interpretation, which underlines its absolute novelty and the unreducibility of its information content to classical physics. At least, the state ensembles defined by the so-called quantum computation are not demonstrated to be identical to the undefined superposition states described by quantum mechanics, apart from the practical consideration that in fact the coherence of superposition states cannot be maintained for longer than too short a time in order to implement a durable computation activity (Zurek, 1991). The last ones are in fact much vaguer, nonfactorizable in as much as they are characterized by interference terms you cannot find anyway in classical physics, to the effect that they cannot be reduced to simple products of composing states, as the "fuzzy" or "unsharp" interpretation particularly underlines (Zadeh, 1965). Without such demonstration, the so-called quantum parallel calculus seems to be rather interpretable as a simple product of single serial calculi simultaneously carried out, which is of course more powerful than each of them according to Wiener's and Shannon's classical definition of information, that is then not necessary to put in question. In fact, it fully suffices, as said and worth repeating, to explain in its probabilistic terms the so-called quantum computation as a simultaneous carrying out of several distinguished serial computation lines, instead of introducing a mysterious quantum computation based, as seen, on quantum superposition states, which is in any case poorer, in information content, than those simultaneous serial computations, according to Wiener's and Shannon's classical *a priori* probabilistic definition of information which is still the only viable one.

REFERENCES

Bohr, N. (1934). *Atomic Theory and the Description of Nature*, Cambridge University Press,Cambridge, London.

Brillouin, L. (1962). *Science and Information Theory*, Academic Press, New York.

Bruckner, C. and Zeilinger, A. (1999). Operationally invariant information in quantum measurements. *Physical Review Letters* **83**, 3354.

Deutsch, D. (1997). *The Fabric of Reality*, Penguin Books, London.

Feynman, R. P. (1951). The concept of probability in quantum mechanics. In *Proceedings of the Second Berkeley Simposium on Mathematical Statistics and Probability*, University of California Press, Berkeley and Los Angeles, p. 533.

Ghirardi, G. (1997). *Un'occhiata alle carte di Dio*, il Saggiatore, Milano.

Greenstein, G. and Zajonk, A. G. (1997). *The Quantum Challenge. Modern Research on the Foundations of Quantum Mechanics*, Jones and Bartlett Publishers, Boston.

Kuhn, T. S. (1962). *The Structure of Scientific Revolutions*, The University of Chicago Press, Chicago.

Preskill, J. (1999). *Quantum Information and Computation*, Springer, Berlin.

Shannon, C. and Weaver, W. (1949). *The Mathematical Theory of Communication*, University of Illinois Press, Urbana.

Wiener, N. (1948). *Cybernetics, or Control and Communication in the Animal and the Machine*, The Technology Press of MIT, Cambridge, MA.

Wiener, N. (1950). *The Human Use of Human Beings*, Houghton Mifflin Company, Boston.

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control* **8**, 338.

Zeilinger, A. (1999). A foundation principle for quantum mechanics. *Foundations of Physics* **29**, 631.

Zurek, W. H. (1991). Decoherence and the transition from quantum to classical. *Physics Today* **44**, 36.