Comments on some problems of modern physics

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RÉSUMÉ. L'auteur suggère une façon très simple pour se débarrasser des difficultés apparentes qui concernent l'interprétation de la Mécanique Quantique. Pour cela il suffit de se rappeler que la physique est une science expérimentale et que les résultats des mesures sont la « pierre de touche" de toute théorie physique. De plus, les raisons des difficultés pour comprendre la sub-microphysique sont dues au fait que nous n'avons pas les concepts indispensables pour pouvoir comprendre, pour appréhender et manier les notions globales que des descriptions phénoménologiques, parfois contradictoires, appellent dans notre cerveau. Il est clair que nous ne pouvons pas « expliquer » des choses pour lesquelles nous n'avons pas les concepts et les mots nécessaires. L'auteur suggère de créer ces concepts, en nous basant sur des descriptions phénoménologiques et d'intégrer ces concepts dans notre « panoplie » de concepts classiques courants, pour finir par nous habituer à leur signification et à leur utilisation courantes. Pour cela il faut, évidemment, les enseigner régulièrement dans les cours de physique. C'est ainsi que, en une ou deux générations, ces concepts –aujourd'hui encore pour beaucoup non-intuitifs- deviendront courants, donc intuitifs. Selon ce point de vue, l'auteur traite le cas du chat de Schrödinger, la dualité onde-particule, le concept de non-séparabilité et l'interprétation de la Mécanique Quantique..

ABSTRACT. The author suggests a very simple way to get rid of the apparent difficulties concerning the interpretation of Quantum Mechanics. One need only keep in mind that physics is an experimental science and that the results of measurements are the "touch stone" of any physical theory. In addition, the reason for our difficulties in understanding sub-microphysics is that we lack the necessary concepts, and it is clear that we cannot "explain" things for which we do not have the corresponding concepts and words. The author suggests that we create these concepts, on the basis of phenomenological descriptions and integrate them into our "panoply" of current, classical concepts…and get accustomed to their meaning and use by teaching them on a regular basis. Using these ideas, he discusses Schrödinger's cat, wave-particle duality, the concept of non-separability and the interpretation of Quantum Mechanics.

1 Some remarks concerning Schrödinger's cat.

Contrary to what one reads frequently in popular science magazines, and unfortunately, also in some manuals, there is no true problem in physics with Schrödinger's cat. And, strictly speaking, there is no real paradox, either. To understand this, one need only remember that physics is an experimental science. On the basis of the results of observations and working hypotheses, the physicist constructs theories. As in the case in mathematics, such a theory has a domain of application, or of validity, that in physics is limited to the domain in which the results of measurements agree with the predictions of the theory. In other words, the results of the experimental tests constitute the "touch stone" of the theory and therefore, strictly speaking, there can be no false physical theories. So, if a given theory and measurement agree, the theory is a genuine physical theory; if not, it is a working hypothesis or a metaphysical speculation. Naturally, any extrapolation of a physical theory to a region where it has not been confirmed experimentally cannot be considered, a priori, as being a part of a physical theory. It is the result of a measurement that will make it possible to decide if this extrapolation is, or is not, an extension of the physical theory.

Therefore, if the prediction of the probability of the decay of the excited atom does enter the quantum mechanical domain, what follows from the thought experiment conceived by Schrödinger, cannot (1). The application of quantum theory to experiments made with flasks, hammers and cats never yielded measurements that coincided with the predictions of quantum theory. Besides, Schrödinger invented his quantum fable of the cat with only one objective, to show what absurdities one arrives at if one applies quantum theory to a region outside its domain of validity. Unfortunately, frequently his hoax, as I shall call it, has been interpreted erroneously and by applying quantum theory beyond its context, one can make it say whatever one wants.

Again, I would like to add that the question as to where the limit between macroscopic and quantum physics lies has a very simple answer: the domain of applicability of quantum mechanics (or quantum theory), ends where the results of measurements cannot confirm its predictions. Currently, our instruments and our know-how allow us to make evident, for example, interference patterns made with electrons and atoms. Even with relatively "big atoms", in fact, with molecules formed by 60 atoms of carbon (see Zeilinger's paper in "Pour la Science", June 2000, page 43), if tomorrow we find the tricks and means to make and to record interference patterns with rolling balls, rolling balls will enter the domain of quantum theory. Let us recall merely that we can make any rolling ball in movement correspond to a de Broglie wavelength, to which we do not (yet?) have experimental access and therefore any attempts to make interferences with rolling balls do not (yet?) enter the domain of physics.

The fact that physics is an experimental science reminds us that a physicist must take care if he wants to speak of the value that a physical quantity can or could have - if this sentence is meaningful – because he works with the value that he got by observing that quantity. Nevertheless, physics is not a subjective science, because the result of an observation is considered an acceptable contribution to physics only if other physicists, with other apparatus and in other laboratories, get the same result (apart from experimental errors) while making the same observation. One can say therefore that physics is an **inter-subjective** [(2)] experimental science since it makes reference to all of humanity - in the sense that that any human can be a physicist. In the same vein, one could add that physicists must be modest and careful and not pretend to know "how Nature "really" is" because they merely describe (= tell or write about) Nature, since they work solely with the results of their observations. I think that it is better that they leave it to philosophers to see if conceptually one can go further. Therefore, physics is the science that deals with the set of physical observations made by humans and the relations that can be established among these observations. What one call "the laws of physics" is in fact the expression of human creation **strictly linked** to these observations.

2 The "problem" of wave-particle duality.

Another theme of modern physics frequently treated in manuals and popular science magazines, is the problem of wave-particle duality. But in fact it is only a pseudo-problem. Unfortunately, these expositions often make things only more confused instead of helping to clarify them. It is true that the problem is difficult to state clearly since it is very subtle. Let's try nevertheless to present a simple, physically correct, and comprehensible vision.

It has sometime happened in the history of science, that on discovering a phenomenon one has given it a name that, later, proved to be inadequate. This is the case here because, not only does "duality" (dual = having or composed of two parts or kinds, like or unlike; double, twofold (Webster's)), not pose any problem by itself, but the fact that here one considers that the two elements of different nature are, in fact, of contradictory nature, is rather shocking. However, while specifying carefully the experimental description of the phenomenon, one sees that it is not about particles that are also waves, or about waves that are also particles, but about objects that are neither particles, nor waves, in the current sense of these words. To be able to characterize these objects with their (from a classical viewpoint) strange properties, we need a new concept, one that is not represented by a name in our panoply of usual words since, in all the time that we humans have been expressing ourselves with words, we have never encountered this type of object. To describe these new objects roughly, one could say that they have some properties that make them look like what we generally call “particles”, and other properties that make them look like what we generally call “waves”.

Another way to try to explain the difficulty is the following. Towards 1897, J.J.Thomson proved the existence of a small object that had a negative charge and that behaved like a particle with a much smaller mass than that of any atom. The physicists ended up calling it an electron. In the twenties, de Broglie had had the (apparently) absurd idea of associating a wavelength $\lambda = h/p$ with any particle with impulse p. This gave rice to arduous conceptual controversies since, one said, (almost) no one could understand "how a particle could be also a wave”. The "enigma", in the beginning merely speculative, of what has been called wave-particle duality, was born. But a very short time afterwards, Davisson and Germer - and later, others - demonstrated experimentally that one can make interferences with electrons and that de Broglie’s formula expresses the phenomenon perfectly. From then on, the hypothesis of the undulatory behaviour of moving electrons ceased to be a rather speculative idea, and achieved the status of a physical fact, even though many physicists (and the "man in the street") continued to find it unlikely or incomprehensible. It is obvious that they didn't have the right anymore to say that it was illogical, that it didn't make sense, since the laboratory had confirmed it, and it was therefore a physical phenomenon. From then on, it was necessary (and for many it still is) to convince them that Nature indeed appears to us in this way.

Let us recall that classical physics is a part of our current life because, for example, we are accustomed as simple human beings to concepts such as distance, speed, acceleration, gravity, etc. Therefore, our vocabulary of classical physics is one that we use in our every day life and that results from our lived experiences and our relationship with macroscopic Nature. But it so happens that since the beginning of the century, physicists have discovered unexpected properties of known objects, and new objects with unknown properties. The physical behaviour of these "things" is seldom describable in our usual language without some "misinterpretations". Obviously we don't have the right to reject, or deny, this behaviour of Nature with the argument that we don't understand it. It is obvious that our “panoply” of concepts and usual words form a more restricted set than the one that is needed to describe our observations of Nature in all its manifestations, even the most recently discovered ones in the sub-microphysical domain. Not to mention all those concepts corresponding to things that we will discover in the future. Therefore, we must create and accustom ourselves to new, and consequently **non-intuitive concepts** and to the words that will designate them. For example, it is necessary to get used to the idea that the electron is not a particle, or a wave (in the current sense of these words), but an electron (a thing that has a mass, a load, a spin, an undulatory behaviour, etc.), while waiting to designate with a new general word all objects that have analogous properties.

Let me again evoke the dangers that lurk for researchers in references to “common sense" and to the expression "it is not in fact logical". A logical argument is only a tautological argument. We say that an event is logical if it is in agreement with what we already know, that is to say, with our lived experience. Therefore, a researcher who works at the border between the known and the unknown cannot reject a "classically bizarre" result just because it seems illogical to him. “Common sense", “logical" and "illogical" are concepts that the physicist must handle with great prudence, since these are, in fact, deceptive. An example: we usually say that it is logical that an object that we release falls on the floor; a child born and living in a space capsule would say that it is illogical, since his lived experience would have taught him that an object that he released remains where it is released.

In summary: the undulatory behaviour of electrons, neutrons, protons, atoms and even molecules, is a physical phenomenon; and if we want to speak about it, we must adapt our language to these manifestations of Nature. We must not pretend that our present “panoply” of concepts is, for example, absolute and complete and that Nature must restrict its behaviour to what we can understand by using only concepts from our current, everyday “panoply”.

3 What does it mean to say that physics is non-separable?

Non-separability is another theme of modern physics about which much has been written. It is one more example of a discovery to which a name has been given that misleads more than it illuminates. One can say that the notion of non-separability took flight with Bell’s [(3)] theoretical work. In it, Bell claimed to bring back Einstein, Podolsky and Rosen’s (EPR’s) 1935 metaphysical speculations [(4)] within the realm of physics. Unfortunately for Bell, his thought experiment contains a paralogism [(5)], and therefore his findings cannot be considered as anything but speculations like those of EPR. Yet the beautiful experimental work of Aspect [(6)] in 1983 (and earlier, of other researchers in the USA) on this subject, only confirmed quantum mechanical predictions. Let's recall that this theory correctly describes a physical phenomenon, which could have inspired the metaphysical speculations of EPR and Bell. This experimental test consists in setting up a quantum system formed by two distinct photons, created successively by one atom in an atomic cascade. Hence, our knowledge concerning the angular moments of these two photons reduces to the fact that, taken together, they have the value zero, so that quantum theoretically, the behaviour of this "inheritance" received by the two photons is expressed by a single wave function.

Let's recall that physicists have created the wave function and that it expresses everything they know about the physical phenomenon they are going to discuss. What is called non-separability is connected with the fact that physicists have no sufficient data to write wave functions for each of the two photons that form the system. In this type of situation, Schrödinger spoke of intricacy or intricate states. It is a fact that, in some problems where more than one quantum object appears, a physicist cannot deal with them mathematically by means of "independent wave functions", since he doesn't have sufficient physical data to do it. For example, studying the emission of the two photons from Aspect's sophisticated light source, one learns that the angular moment of the atom-source is the same before and after the emission of the two photons. From this, one concludes that the sum of the spins of the two photons is zero, i.e., that they have perpendicular states of linear polarization, and one cannot describe - for lack of data - their individual states of spin or polarization. One can only construct a single wave function, a sum or difference of products of factors corresponding to one and the other photon. And one cannot construct wave functions for every photon. One says that the two factors of every term, and the states that they represent, are intricate. Insofar as the system remains isolated, the state of intricacy doesn't depend on time; therefore, as long as nothing acts on the states of spin or polarization, the two photons will continue to be described by the same intricate function, even though the photons move away in opposite directions, and are far from one another. It may be said that there is no decoherence. Sometimes one compares the two photons to twins. But not to false twins: they are completely independent, while having some joint properties (colour of eyes, for example)

If one can isolate only one pair of these twin photons, then measuring one of them with a linear polarizer fixed by an angle ß, is equivalent to measuring the other with a polarizer fixed by the angle ß + $\pi/2$. That means that it is sufficient to measure the first with a polarizer oriented in a given direction in order to know the probability of the result of measuring the second with a perpendicularly oriented polarizer. This is due to the fact that they have been created by their atom-mother in a process that preserves the total angular moment and that they therefore have the property that, whatever the state of polarization of the first; the second has the perpendicular polarization state. Quantum mechanics shows [7] that the mathematical formulation of the amplitude of probability of our primitive wave function (the one that corresponds to the "birth" of the system of two photons), after the first photon has passed through a linear polarizer characterized by the angle ß (in relation to a fixed axis), can be expressed as the state of polarization of a vector basis | ß > and | ß+π/2 >, that forms an angle α with the first polarizer. The probability that the first photon passes through the first polarizer and the second through the second is 1/2 cos2α.

The fact that by measuring the polarization of the first photon, one can also predict the result of measuring the state of polarization of the second photon (if one knows the angle formed by the two polarizers) is at the origin of the idea, in fact exaggerated, of the non-separability of the photons. But the photons are indeed separated and independent: any physical action on one won't have any effect on the other. However, by their genesis, they share a property: they keep the joint angular moment zero received from their "mother" In other words, the sum of their spins is zero, or they have opposite circular polarizations, or their linear polarizations are respectively perpendicular. These are three ways of saying the same thing. It is clear that Aspect’s (or an analogous) test does not imply that quantum physics is non-separable. To believe it does is an error, unless we completely redefine the word "separable".

To be complete, and for the benefit of the layman, let's recall that measuring the state of polarization of a photon is a special kind of action. It is usually granted, for example, that the weight of an object is the same before and after it is measured. In Quantum Mechanics, however, the act of measuring usually influences the thing measured. But the case of polarization is a special one, because it is the polarizer that imposes its polarizing state on the light (of known, or unknown, polarization state) that falls on the polarizer. But, the quantity of light (the intensity) that crosses the polarizer depends on the polarization of the incident light. In fact, generally, we don't know the state of polarization of a photon. To measure the state of polarization of a photon is equivalent to imposing on the photon the direction of polarization of the linear polarizer with which we measure that state. This means that if the photon crosses the polarizer, it has the direction of polarization defined by the polarizer. But if it doesn't cross it, then the polarizer imposes on it - or the photon already has - the state of polarization that the polarizer cannot transmit. In summary, the polarizer imposes its state of polarization on the incident bundle of light, but the quantity of light that crosses the polarizer depends on the state of polarization of that light. Once more we see the subtlety of sub-microphysics. To use the current word "measure" to inquire about the state of polarization of the photons is more deceptive than instructive. One cannot enter a modern physics laboratory with big hooves. Again, I would like to quote J.R Oppenheimer: "The fact that the words of science are the same as those of our current life can be more misleading than illuminating".

Let me add that much has been written about the Bell affair but no one has seen the subtle paralogism hidden in his deduction. Now, even Bell's most fierce supporters admit – albeit reluctantly - that it is a metaphysical speculation. They acknowledge this while saying something as "... that they perfectly understand the inadequacy of all experimentation in relation to his theory, and that Bell had also understood this" And here we must remember the fact that: no experimental verification, no physical theory, or more strictly speaking, no physics at all.

4 About the interpretation of Quantum Mechanics

Many manuals raise the problem of the interpretation of the chapter that deals with sub-microscopic physics, that is to say, Quantum Mechanics. The later deals with a domain to which we don't have direct access with our senses, and in which some new objects have experimental features that are markedly inconsistent with our current knowledge. It is no wonder, therefore, that we don't have mental representations (concepts) of these features, or words to designate them. The complication arises when we try to use our everyday concepts and our current words to describe these features. So we create paradoxes or pseudo-illogicalities and we state that Quantum Mechanics is incomprehensible.

It seems obvious to me that it is not the intrinsic behaviour of Nature that is paradoxical, but the fact that we want to adapt its behaviour to our knowledge of classical physics, instead of adapting ourselves to Nature's behaviour by creating the necessary new concepts [(8)]. The creators of the mathematical formulation of Quantum Mechanics set aside the problems resulting from the impossibility of understanding a phenomenon if one lacks the necessary concepts, and confined themselves to creating a solid algorithm which, whether comprehensible or not, is confirmed by the results of measurements. That wise decision made possible the enormous progress of quantum physics that characterizes our time. But, as the man in the street would say, it did so without explaining anything at all. Here it is necessary to recall what the word **"to explain"** means. To explain a phenomenon to someone is to try to decompose the phenomenon into partial facts for which one has the concepts and words that the person knows. If the phenomenon is very new and very - say -

bizarre, the decomposition only makes things muddier, and, as for the phenomenon one doesn't have a word in the current panoply of words, therefore one is not able to explain it… and the person is not able to understand it. So it is necessary to start by creating a new concept with the help of a phenomenological description and by assigning a name to this concept. Then it is necessary to wait for humanity to integrate this concept into the panoply of current concepts. It is only then that the phenomenon in question will cease to be considered **counter-intuitive** or illogical. This takes one or two generations... provided that all teachers play the game. In summary, and as indicated already, since our present panoplies of concepts and of words to describe our observations of the physical universe are based on our lived experience as humans, it doesn't embrace all concepts that could prove necessary to describe all future observations. That means that as we discover properties described as "bizarre" by the man in the street, we must create the necessary concepts and words and accustom ourselves to their use.

References

[1] The hoax of the cat is described in E. Schrödinger, *Die gegenwärtige Situation in der Quantenmechanik*, Naturwissenschaften **23**, 807-812, 823-828, 844-849 (1935) John Trimmer's version of Schrödinger's text says: *One can even set up quite ridiculous cases. A cat is penned up in a steel chamber, along with the following diabolic device (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, so small, that perhaps in the course of one hour one of the atoms decays, but also, with the equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for one hour, one would say that the cat still lives if meanwhile no atom has decayed. The first atom decay would have poisoned it. The •-function of the entire system would express this by having in it the living and the dead cat (pardon the expression) mixed or smeared out in equal parts.* In *Quantum Theory and Measurement*, edited by J.A. Wheeler and W.H Zurek, Princeton Series in Physics, Princeton 1983, p.157

[2] The idea to call "inter-subjective" an experimental result that any human accepts because it had been –or can be- verified by any human being –therefore by any physicist- anywhere in the world, has been taken in B. d'Espagnat's, *Une uncertaine réalité*, Gauthier Villars, Paris, p, 31. (In general, the author does not agree with d'Espagnat's theses)

[3] J.S. Bell, Physics **1**, 195 (1964)

[4] A. Einstein, B. Podolsky, N. Rosen, Phys. Rev. **47**, 777 (1935)

[5] The paralogism in Bell's deduction is clearly explained in several papers by the author, for example, D. Canals-Frau, Ann. Fond. L. de Broglie, **23**, 74 (1998), p. 75.

[6] A.Aspect's very fine experiment is very well described in his Thesis: Institut d'Optique, Orsay, France, 1983.

[7] To see the "mechanism" of the quantum mechanical calculation of the interrelationship of the two photons, see: D. Canals-Frau, Ann. Fond. L. de Broglie, **14**,1804 (1989).

[8] Concerning the problem of the interpretation of Quantum Mechanics, see: D.Canals-Frau, Physics Essays (Canada) **13**, n° 1, 85 (2000); D. Canals-Frau, Ann. Fond. L. de Broglie, **25**, 325 (2000)

Reçu le 7 mai 2002.