On some current misinterpretations in present physics

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"The pragmatic tendency of modern research has often obscured the difference between knowing the usage of a language and understanding the meaning of its concepts. There are many students everywhere who pass their examinations in quantum mechanics with top grades without really understanding what it all means"

(J.M. Jauch, *Foundations of Quantum Mechanics*, (Addison-Wesley, Reading, MA, 1968), p. v.

ABSTRACT. In this paper I suggest that we must discriminate between theoretical concepts and physical concepts, in order to stop the intrusion of metaphysics into our science. As an example of this invasion I would remind the reader that the **expression** "wave packet reduction" has not the phenomenological meaning which this words call to mind, that reduction is not a physical effect neither a physical necessity but only a mathematical convenience. A text by W. Heisenberg is adduced in support of my arguments. By the way, I indicate that in the same text there is another hazardous extrapolation which gives rise to many misunderstandings: the treatment of single, energetically non divisible photons (in linear electrodynamics), with (classical) infinitely divisible wave packets. I also point out that all our formulae are valid only in the domain where they have been "ratified" by measurements. As another example, I deal once again with the EPR "paradoxe" and remind the reader that a measure is a perturbation... and I explain why there is one exception. By the way, I comment on some of L. Mayants conclusions concerning Bell's fundamental formula and Aspect's experiment.

RÉSUMÉ. Dans cet article je suggère l'idée que nous devons faire une distinction entre concepts théoriques et concepts physiques, et cela pour freiner l'intrusion de la métaphysique dans notre science. Comme exemple de cette invasion je rappelle que la "réduction du paquet d'ondes" n'a pas de signification phénoménologique, qu'il s'agit d'un simple postulat. Un texte de W. Heisenberg me sert de support pour mes arguments. En passant, j'indique que dans ce même texte il y a aussi une extrapolation hasardeuse qui est à l'origine de méprises fréquentes: traiter des photons (dont l'énergie est insécable) en utilisant des paquets d'ondes classiques (indéfiniment sécables). J'attire aussi l'attention sur le fait que toutes nos formules ne sont valables que dans le domaine dans lequel elles ont été "ratifiées" par des expériences. En dehors de ce domaine il ne s'agit que de spéculations sur le comportement éventuel de la nature. Comme un autre exemple, je traite une fois de plus le "paradoxe" EPR et je rappelle qu'une mesure est une interaction et donc une perturbation ... tout en expliquant pourquoi il y a une exception. Je profite aussi pour commenter certaines conclusions de L. Mayants sur la formule fondamentale de Bell et l'expérience d'Aspect.

1. Introduction.

I think that physicists must do something to stop the present drift of physics towards metaphysics. To a certain extend there is a tendency to consider as physical descriptions what is no more than theoretical speculations or unwarranted extrapolations, such as the "many-worlds" interpretation of quantum mechanics [1] and Schrödinger's cat [2]. Some of these speculations and extrapolations, to which no physical content has been given by measurements, may be interesting, sometimes useful for further research, but have nothing to do with physics proper. They are conjectures, and conjectures may be helpful to open the mind to new physical ideas, but it must clearly be indicated that they are theoretical speculations or extrapolations that are not experimentally founded. Other extrapolations such as Schrödinger's cat are mere misinterpretations of experimentally confirmed quantum mechanical formulae.

L. Mayant's introduction of concrete and abstract objects [3] is an attempt to clarify this situation. My suggestion is simpler: let us make a clear distinction between theoretical concepts and physical concepts. By the way, Bitsakis [4] speaks of actual and potential states.

In the present paper I comment also on some of Mayant's suggestions and I criticize some of his arguments. There are two points in his paper with which I disagree totally: his explanation of Bell's failure to translate EPR's thought experiment into genuine experimental terms, and his explanation of the ins and outs of Aspect's experiment. But I agree with him when he writes, concerning Aspect's experiment (p. 183) that this result "is thus due merely to that particular conservation law, and has again nothing to do with **action-at-a-distance** or any other fabrications". In my opinion, Mayants has correctly conjectured that Bell's formulation is not **physically** valable but he has not suitably justified his intuition.

The outline of this paper runs as follows: in section 2, I suggest a differentiation between theoretical and physical concepts. Section 3 recalls that wave packet reduction is a postulate and has not the phenomenological meaning it suggests. My arguments are based on a text by W. Heisenberg.

By the way, I indicate another weak point in this text: the representation of a single photon by a ("classical") wave packet. The EPR "paradox" is treated once more in section 4, by recalling that quantum mechanical predictions refer to the result of measurements, and measures perturb what we are measuring ... and in section 5, I explain why there is one exception. Section 6 shows that Mayants' criticism of Bell's formulation is not pertinent. The demonstration that Aspect's experiments are of a quantum mechanical nature and cannot be explained by Malus' law, in contradiction with Mayants' assertion (p. 184), is given in section 7. Section 8, conclusion.

2. On physics proper and theoretical speculations.

Some of our problems in present physics are false problems, e.g., Schrödinger's cat [2], EPR "paradox" [5], reduction of wave packet or *psi*-collapse [6], time reversibility [7], a.s.o. They originate in an inadequacy of the language we use for the description of physical facts: the confusion between physics proper and what we may call metaphysical speculations [8], or hypothetical considerations on the behaviour of Nature, and also in the inappropriate (physically unfounded) extrapolation of genuine physical formulae. Mayants' introduction of concrete and abstract objects is an attempt to clarify this situation. As objects can be considered, according to his suggestion, as concrete (material) or abstract (a generalized idea of a thing or a class of things), I think that this may be the cause of confusion. In particular, speaking of concrete and abstract photons poses a problem. The photon has the particularity that it is never experimentally material and we do not know of its "existence" before its annihilation or transformation. Strictly speaking, we cannot refer to photons except in the past tense. In my opinion, all photons are ... photons: I know about their past "existence" because a counter has been fired, or in an emulsion a grain has been activited [9]. And the equations we have "constructed" to describe their behaviour are mathematical idealizations. And this mathematical idealizations can be considered as physical descriptions only after measurements have given them a physical "reality"[1].

I express Mayants' basic idea in another way: I prefer to suggest that there is a vitally important distinction to be made between theoretical concepts and physical concepts[2]. As physics is an experimental science, a theoretical concept must not be considered to be a physical concept until his physical presence has been established by a measurement. Before its experimental observation through a measurement, the theoretical concept is merely a **working hypothesis**, or better yet, a **speculation** on the possible behaviour of nature[3]. In view of the above, theoretical concepts can have predictive value, it being well understood that these "predictions" are also mere **speculations** on the possible behaviour of nature. They will become physical concepts only after they have been confirmed experimentally [10].

During the last century, physicists believed that the laws of physics, i.e., the formulation in words and equations of sequences of events in

[1] Here "reality" is **not** taken in its metaphysical sense.

[2] A referee considered my distinction between theoretical concepts and physical concepts "not merely incorrect but also senseless". I think that in the context of my paper the distinction is clear: a theoretical concept is the generalized idea of a "thing", or class of "things", which does not "exist", or we have not found, in our physical world (may be could I also say a hypothetical "thing"). In 1994, the ether concept is a theoretical **concept** because we have no experimental (physical) evidence of its "existence". I think that no confusion with theoretical physics is possible: a text-book on theoretical physics describes our **physical** world in terms of the mathematical expressions we have developed to relate the different measurements of the physical facts we have observed, and insists principally on the mathematical aspects. Theoretical physics works with **physical concepts** and not with theoretical or hypothetical concepts. A physical concept is the generalized idea of a "thing", or a class of "things", which "exists" in our physical world. The concept of mass is a physical concept, also the concept of field.

[3] "Another thing that people have emphasized since quantum mechanics was developed is the idea that we should not speak about things which we cannot measure. (Actually relativity theory also said this). Unless a thing can be defined by measurement, it has no place in a theory" (Ref. 32, p. 2-8).

nature that have been observed to occur under the same experimental conditions, were universally valid, without limit. This meant that such laws were valid not only within those domains in which they had been confirmed by laboratory experiments and/or cosmological measurements, but also in every conceivable situation.

At the turn of the century, our knowledge of the physical world expanded considerably to include microphysics and very high speeds, close to that of light. The belief in the universality of physical laws was profoundly shaken and our post-classical physics methodology must now set limits to the validity of all laws, both to those of microphysics and those of macrophysics, and restrict them to those domains in which they have been confirmed by measurements. Outside of these domains, there is no physics in the true sense of the term, only speculation about the possible behavior of nature. For example, the fact that a prediction concerning the correct place in which to put the target in a particle accelerator cannot be based on classical (Newtonian) physics, does not mean that that kind of physics is false, but simply that this fact lies outside its domain of validity. A second example: early classical physics holds that the intensity of light is infinitely divisible. Thus in a classical description of an optical experiment, to say that one "is dropping one photon at a time" - an expression that has given rise to countless instances of conceptual confusion - is to make a statement that lies outside the bounds of classical physics and the consequences that may be drawn from it are necessarily fanciful. As its domain of validity is exactly that domain in which it has been confirmed by measurements, classical physics in its modern version can **never** be found in error.

The same holds true for quantum mechanics: if we construct it solely on physical concepts, i.e., if we banish all theoretical concepts not confirmed by measurements, quantum mechanics when applied to the domain in which has been confirmed by measurements can **never** be found in error [11]. Moreover, one must keep in mind the fact that the postulates of conventional quantum mechanics are merely postulates, i.e., statements "assumed without proof to be true, real, or necessary" (Webster's).

3 On wave packet reduction [12].

A typical example of a theoretical **concept** unconfirmed by measurements is that of wave packet reduction. This concept is just theoretical speculation, in fact, a postulate that has invaded our manuals, textbooks, our courses, and our journals and sown confusion in the minds of beginners, to whom no one has sufficiently explained that this is a mere theoretical construct: ψ-collapse is not a physical necessity but merely a mathematical convenience[4].

Allow me to restate the gist of an article published in French in 1988 [14].

During lectures given at the University of Chicago, Heisenberg said [15]: "Let us consider a thought experiment due to Einstein. We imagine a light quantum represented by a wave packet constructed with Maxwell waves, to which corresponds a certain spatial expanse and also a frequency interval in accordance with the uncertainty relations. By reflection in a half silvered mirror we can easily split the wave packet into two parts, a reflected and a transmited one. There exists now a certain probability of finding the light quantum either in one or in the other part of the wave packet. After a certain lenght of time, the two parts will be at an arbitrary distance from each other. If, with an experiment, we determine now that the light quantum is in the reflected part of the wave packet, we know at the same time that the probability of finding the light quantum in the other part is zero. By means of the experiment performed at the place of the reflected half of the packet, a kind of influence (reduction of the wave packet) is exerted on the remote part of the other half. It is easy to see that this influence must take place with a speed greater than the speed of light. At the same time we recognize that this propagation of the influence cannot be utilized to send signals with a speed greater than the speed of light. So the behaviour of the wave packet is not inconsistent with the fundamental postulate of the theory of relativity " (End of quotation).

This description of the thought experiment is the conventional description of this type of problem in quantum mechanics; it is completely unconvincing. It seems to overlook the fact that a) any probability **function** has been constructed by humans and is necessarily based on their knowledge of the phenomenon, the probability of which is described by the function; b) in physical descriptions, no concepts based on mere pre-conceived ideas should be used.

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[4] "The reduction of a pure state to a mixt state is an example of the reduction of the wave function on measurement. This has caused confusion because there is no way in which a linear Schrödinger equation can convert a pure state into a mixed state. However, we see that this reduction is not present in the treatment of the complete physical system (measured system + apparatus) and arises because we choose to direct our attention to the measured system only - it does not correspond to any physical process in nature" [13].

This latter recommendation, which is connected with the requirement that only observable magnitudes should be used as basis for equations, is what may be called our post-classical physics methodology [16]. M. Born [17] gives credit for it to W. Heisenberg [18] and indeed constitutes the methodological foundation of quantum mechanics. But Einstein [19] had already used it in 1905 to deduce relativity theory. So it lies at the base of all modern physics.

If, for example, I know that a die has been manufactured from homogeneous material and that all of its faces have the same coefficient of friction, the probability **function** that I can construct is characterized by the fact that it assigns to each face the same probability of coming up on top. If I find that one of these conditions is not met, the probability function that I could construct will not have the characteristic of the equiprobability of faces. This means that each new bit of information makes obsolete, i.e., meaningless, out-of-date, useless and erroneous, the previous probability function and makes it possible to construct, if need be, another probability function that takes into account the new information.

In view of the above, Einstein's thought experiment is easily interpreted without ambiguity. Beginning with Heisenberg's very words, we may say: If, with an experiment, we determine now that the light quantum is in the reflected part of the wave packet, this experiment withdraws the physical content of the probability function as much at the reflected as at the transmitted side. Our new information invalidates the probability function which represented our knowledge of the physical situation only **before** the measurement. This measure alters the physical situation and to describe the new state of affaires it is not necessary to write a new probability function because we know where the light quantum has been absorbed.

More details may be given on the operations that must be performed in order to carry out the thought experiment. These operations are what is called its "preparation". One possibility is the following. On the "beam" that reaches the half-silvered mirror, there is a diaphragm. At point A, x km away on the reflected "beam", there is a photon detector; at point B, x km away on the transmitted "beam", there is another detector. It is planned to open the diaphragm for a brief instant at time t_0. At both A and B, an event is expected at time $t_0 + (x/c)$. At the point where the photon is detected, the event that constitutes new information is that very detection. So, at A or B there is a new datum.

And this new information renders physically meaningless the previous probability function both at A and B.

To say that the value of the **probability function** on the reflected side "jumps" at time of detection from the value 1/2 to the value 1, and on the transmitted side, $2x$ km away, from the value 1/2 to the value 0 is not a correct description of a physical fact either a correct probabilistic statement.

I may therefore state that wave packet reduction is not a physical concept. It is a very poor and inadequate metaphorical expression that stems from the fact that in general, the situation prior to a measurement is described by a wave function made up of a sum of terms - each of which has a coefficient and may be interpreted as a wave - and that after the measurement, the new situation may be described by another wave function, made up of a term like one of the terms of the previous sum, but with another coefficient. Clearly, the two formulas that express our knowledge of the situation before and after the measurement are independent of each other and refer to two distinct phenomenological situations: before the measurement, we had no precies data on the system, hence the sum of terms that represents all our knowledge of the system. After the measurement, we have a new bit of information that makes the previous function necessarily obsolete, i.e., physically meaningless and out-of-date. This bit of new experimental information is expressed by the single term of the new wave function. To say that the measurement is manifested by an abrupt change of one and the same wave function brings us close to magic (ψ-collapse and a kind of influence to be exerted on the remote part) and takes us away from physics.

Unfortunately for the understanding of physics, it sometimes happens that wave packet reduction is interpreted as the description of a physical phenomenon. This gives rise to countless meaningless statements, both oral and printed.

By the way, there is another weak point in Heisenberg's text. Classically, we can always split a wave packet because, in classical theory, light intensity is endlessly divisible. But a light quantum cannot be divided into light quanta of the same frequency. So Heisenberg's description of Einstein's thought experiment is merely a theoretical speculation which cannot be realized experimentally, and considering it to be a physical statement must inevitably lead to a flaw. Physically, there is no difficulty: if an average of one photon per cm^2 and second arrives at the half-silvered mirror, we find an average of one photon per cm^2 every *two* seconds in the reflected (and also in the transmitted) "beam". Obviously, an (indivisible) energy per cm^2 every *two* seconds is not the definition of a classical "intensity".

4. Revisiting the EPR paradox.

The "paradox" related to EPR's thought experiment is the consequence of - among other things - the belief that "predetermination" is a physical concept. Actually, predetermination is a theoretical (hypothetical) concept which has not been confirmed as a physical concept by any measurement: we know that Bell's attempt to give an experimental answer has totally failed and his work may be considered as the greatest misunderstanding in the history of physics. In the experiment with spin particles S_1 and S_2 in the singlet state (i.e., their spin orientations - as we know from the study of the source - were such that $\vec{s}_1 + \vec{s}_2 = 0$, and the conservation of this spin state from the source to the measuring apparatuses, followed by space quantization, is what experimenters measure as EPR correlations), only the **measurement** of the spin component s_{2x} of the "second" particle gives a physical content to the "prediction" made after the measurement of the same component s_{1x} of the "first" particle.

It must be remembered that the predictions of quantum mechanics always refer to the result of measurements. Conventional quantum mechanics has difficulties because frequently one forgets that quantum mechanics does not predict the value of the spin component but it predicts the value of the **result** of the measurement of the spin component. It predicts the **result** of the **interaction** which characterizes the measurement. In other words, without a measurement of the "second" particle, there is no interaction and there is no actual predicion. To see the **subtle** difference between a prediction (a real, physical prediction) and an "empty" or false prediction (a "prediction" not related to the corresponding measurement), we may consider once more EPR's arguments from the physical point of view.

To begin, let us use the very clear summary provided by A. Aspect in his thesis [20].

"The total spin of the two particles 1 and 2 being zero, measurements of the spin components of the two particles along the same axis will give opposite results of module $\hbar/2$ (designated as $+1$ or -1). So an application of elementary rules of quantum mechanics leads to the

following conclusions:
a) If the measurement of the spin component s_{1x} of particle 1 along an axis $\vec{O}x$ yields the value +1, then the measurement of s_{2x} of particle 2 will certainly yield the value −1, and conversely;
b) If the measurement of s_{1y} along $\vec{O}y$ (perpendicular to $\vec{O}x$) yields the value +1, then the measurement of s_{2y} will certainly yield −1."

"The EPR line of reasoning will then use the following criterion: 'If, without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity.' "

"Let us then suppose that s_{1x} is being measured for particle 1; by using property a) above, one can predict with certainty the value one will find if one measures s_{2x}. So there is an element of physical reality corresponding to s_{2x}. However, one might have chosen to measure s_{1y}, and, by using property b), one would, in that case, have concluded that there is an element of physical reality corresponding to s_{2y}. As particles 1 and 2 are separated at the time the measurement is performed, the choice of the measurement performed on $1(s_{1x}$ or $s_{1y})$ could not disturb system 2. The spin components s_{2x} and s_{2y} are, therefore, elements of physical reality that exist simultaneously in particle 2. Now, in the singlet state, the formalism of quantum mechanics assigns no definite value either to s_{2x} or to s_{2y}; generally speaking, quantum mechanics cannot assign a precise value to s_{2x} and s_{2y} simultaneously, as the associated operators do not commute. Quantum mechanics is, therefore, a theory in which there is no counterpart to every element of the physical reality: EPR draw the conclusion that it is an incomplete theory." (End of quotation).

But Bohr [21] has shown that this criticism is not justified, because based on assumptions about the structure of nature, which implicitely contradict quantum theory from the start ... and nowadays we can add that quantum mechanics predicts always the correct experimental results.

We, for our part, consider the situation from the purely physical point of view. We have a "source" that provides us with pairs of particles S_1 and S_2 in the singlet state. This means that the directions of their spins are perfectly defined one with respect to the other ($\vec{s}_1 = -\vec{s}_2$), but are unknown to us. We set up an apparatus on the path of the particles S_1 in order to measure their spin in the direction $\vec{O}x$. We measure the spin component s_{1x} of particle S_1. According to the folklore usually associated with quantum mechanics, that would enable us to predict the **result** of the **measurement** of the spin component s_{2x} of the corresponding particle S_2. But, as luck would have it, particle S_2 has disappeared and that "prediction" is not about anything that actually exists. Moreover, this "prediction" has no physical meaning, since it is about the **result** of the measurement of S_2 and S_2 has not been measured and can no longer be. In addition, we cannot use EPR's criterion, since we do not know with certainty whether the "prediction" has been verified. Also, the criterion claims to assign an element of physical reality to a "physical quantity" (s_{2x}) which, in our case, does not exist. In order for the "physical quantity" (s_{2x}) to exist, someone must take a measurement apparatus and mesure S_2 in the $\vec{O}x$ direction. In addition, $\vec{s}_1 + \vec{s}_2 = 0$ is no longer relevant: by our action with the measurement apparatus we have acted on the spin in such a way as for force it to precess about the $\vec{O}x$ direction (fixed **arbitrarily** by our magnet) so that its x component takes on the value s_{1x}.

The upshot of all this is that it is impossible to infer the existence of an element of physical reality associated with s_{2x}, [22], contrary to what is stated in EPR's reasoning.

Next, we shift by 90° the direction in which we perform our measurements: we move from the $\vec{O}x$ direction to the $\vec{O}y$ direction. And, once again, a measurement on a particle S_1 tells us nothing valid in physical terms about the corresponding particle S_2. In other words, with our equipment, no measurement performed on S_1 enables us to draw the slightest physically meaningful conclusion about particle S_2, contrary to what is claimed by EPR and conventional quantum mechanics.

If, after the measurement of s_{1x}, we want our prediction of the result of the measurement of S_2 to be a true and physically meaningfully one, we must measure S_2 in the $\vec{O}x$ direction. This means that we must set up a measurement apparatus in the path of the S_2 particles as well. And as we must measure the two particles of one and the same system, (the two particles of a given pair that is in the singlet state) these measurements will have to be done virtually simultaneously (or else at appropriate intervals) [5]. After performing the measurements of S_1 and S_2 in the $\vec{O}x$ direction, we have the corresponding measurements results. And now,

[5] L. Mayants writes practically the same thing, p. 181: "Such kind of prediction can, thus, be verified by measurements, only if they are performed for S_1 and S_2 simultaneously, in one random test".

by looking at any single arbitrarily chosen result, we can **predict with certainty** the resulut of the other measurement. Unfortunately, what is predicted is not the value of the spin ($\vec{s}_1$ and/or $\vec{s}_2$), but the result of its measurement in an arbitrary direction (s_{1x} and/or s_{2x}) [23] and, in order to obtain our measurement results we have had to disturb S_1 as much as S_2. It is therefore impossible to apply EPR's operational criterion and we cannot infer the existence of elements of physical reality.

We see, then, that the problem connected with EPR's thought experiment has no physical meaning and reduces to mere metaphysical speculation, as was well understood from the time of Bohr's work in 1935 [21] ... until 1964, when Bell brought up the whole matter again by being unaware that only measurements results can be predicted and that if there is no measurement of the second particle, there can be no **real** prediction, contrary to what is suggested by the conventional interpretation of quantum mechanics. I believe I may suggest that the **subtle** difference between a **real** prediction that has a physical meaning and a "prediction" that is not about anything physical, is the source of a remarkable misunderstanding which caused much ink to flow.

I would like to add that if, in 1935, Einstein had applied to his thought experiment the same method of deduction that he had used in 1905 to establish the special theory of relativity, i.e., if he had reasoned on the basis of physical procedures and not prejudices, there never would have been any EPR "paradox"[6].

Moreover, we also observe that quantum mechanics is entirely right when it does not simultaneously assign precise values to the spin of S_1 in directions $\vec{O}x$ and $\vec{O}y$. And the reason for this is clear: we have no physical data on the basis of which we could assign it such values. We cannot simultaneously measure the spin of a particle in two different directions. If, one day, it became possible to measure spin in two mutually perpendicular directions simultaneously, quantum mechanics would include that in its picture of the universe.

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[6] "Einstein himself would not have formulated these ideas so bluntly, although they do express adequately his basic philosophy. Einstein wanted to be counted as a "physicist", and that automatically means an "empirisist", which he actually was up to 1915. But the dazzling light which struck him through the essentially speculative discovery of General Relativity, changed his basic scientific philosophy. From an avowed empiricist he changed to a "metaphysicist" of the Platonic type. But he did not like to talk about it, out of fear of the word "metaphysics", which has an ominous ring in the ears of most natural scientist s" (Ref. 33, p. 15).

It must be kept in mind that the equations of quantum mechanics were not handed down to N. Bohr, engraved on a tablet at the top of Yding Skowhøj, by a great arm emerging from the clouds[7]. These equations were written by humans and are necessarily based on their physical knowledge of our material universe. And the physicist requires merely that his conclusions be intersubjective [24], i.e., reproducible by, and valid for, every physicist. The question, as to whether extraterrestrials with a different mental structure from ours, arrive at the same conclusions that we do, is a question, not of physics, but of philosophy. Physics is an experimental science.

5. On an exception to the perturbation by measurements.

It should be stated that there is at least one exception to the disturbance caused by the measurement: the physical phenomenon described in terms of quantum mechanics as a measurement of a physical magnitude A performed on a system which, before the measurement, is already in a proper state of the operator associated with A [25,26].

I would now like to show why this particular measurement (which, moreover, is completely superfluous), though it does not modify what is being measured, cannot be casually invoked against the general statement that measurements disturb the thing that is measured. As an example, let us take spin 1/2 particles. Let us suppose that the spin of one of these particles is already orientated in one of the two quantum states (proper states) defined by the direction of the magnetic field of the first Stern-Gerlach. A second measurement performed with an apparatus parallel to the first will not in any way modify the result of the first measurement: the disturbance caused by the second measurement will have no detectable influence on the spin of that particle. This justifies the statement that measurements do not always disturb the thing being measured.

Yet, this phenomenon has a simple explanation: the disturbance that the second measurement was supposed to cause is not sufficient to allow the jump to the other quantum state. Let me repeat. For spin 1/2 particles, there are only two possible proper values in any given magnetic field. So, in order for the disturbance due to the second measurement

[7] See Giotto's (?) fresco "Moses receives the Table of Law on the Sinai Mount". Yding Skovhøj is the highest "mountain" in Denmark (in the Jutland), 173 m high. (Skov = forest, høj = hill).

to be able to produce a detectable effect, il would have to provoke a quantum jump to the other possible proper value. It follows that in our case it would have to cause a flip-flop. And the energy required for a flip-flop is substancially greater than that involved in the "physical interaction" that we call measurement.

6. Mayant's interpretation of Bell's formulation.

Bell's work is based on EPR's thought experiment. We have seen that this thought experiment is physically unfounded, consequently, Bell's work is also [27]. Moreover, Bell proposed an experimental set up which, obviously, could not confirm his theoretical results: experiments are always physically founded.

We know at present that his conclusions are not necessary physical consequences of the violation of his inequalities by nature[8]. All this has been explained elsewhere [5], [28], [29]. L. Mayants [3] also says, in other words, that Bell's formulation is physically a not correctly stated problem. But his analysis of an important point in Bell's paper is not pertinent and so his criticism of Bell's formulation is questionable. In actual fact, Mayants' definition of the λ parameter is not Bell's definition.

The object of Bell's λ parameter is to specify more completely the spin state prior to measurement, because he believes that these states are predetermined: in Bell's paper λ plays the role of a hidden variable which predetermines the outcome of a couple of measurements. Mayants "replaces" Bell's probability density function $\rho(\lambda)$ of the distribution of the λ parameter, by the 4 joint probability functions of the 4 possible states $(++)^{ab}$, etc., and he calls λ each of these 4 states[9].

It is mathematically clear that with Mayants' definition of λ (only four λ values), Bell's basic formula

$$\int A(\vec{a},\lambda)B(\vec{b},\lambda)\rho(\lambda)d\lambda$$

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[8] Hundred of papers have been written drawing physical conclusions from the violation of Bell's inequality by nature. The authors of all these papers will be glad to learn that "Bell's inequality has never been tested experimentally ..." [34]. If Bell's inequality has never been tested and other similar inequalities have been violated by nature, this confirms the present author's conclusion that all available experimental i.e., physical, evidence tends to show that the problem posed by EPR's thought experiment is merely a metaphysical one.

[9] Aspect develops the same procedure to obtain the correlation coefficient, but he knows that the four possible states have nothing to do with Bell's λ. See Ref. 20, p. 20.

would be identically equal to zero, or reduce to + or -1, if $\rho(\lambda) = \delta(\lambda)$. And we must admit that with Bell's assumptions, premises and hypotheses we cannot write another equation as Bell's basic formula.

Furthermore, Mayants' treatment of this problem gives the correct quantum mechanical - and hence, experimental - result. This is further proof that Mayants' considerations are totally alien to Bell's work.

7. On Aspect's experiment and Malus' law.

The present author has shown that the result of Aspect's experiment [30] is the consequence of the conservation of the total polarization of the two photons in the singlet state. Or, as Mayants puts it in his section 5: "This fact is thus due merely to that particular conservation law, and has again nothing to do with "action-at-a-distance" or any other fabrications". Yes. But I do not agree with his interpretation of the physical foundation of Aspect's experiment. He writes (p. 183): "... where $P(b^+/a^+) = \cos^2\alpha$ is the probability for an abstract photon to have p value 1 for the b direction provided it is 1 for the a direction ..." This statement is certainly correct but I prefer the following question which has a simple physical meaning: what probability do photons polarized in direction $\vec{a}$ have of passing an analyzer whose transmision axis is the $\vec{b}$ direction ? If α is the angle between $\vec{a}$ and $\vec{b}$, this probability is $P(\vec{b}/\vec{a}) = \cos^2\alpha$, and this has the same form as Mayants' equation. As directions $\vec{a}$ and $\vec{b}$ are known, this probability is related to Malus' law because the intensity of the light beam may be interpreted as probability of finding a number of photons. But in Aspect's experiment we have two photons which have the "same" **unknown** polarization. So we cannot apply Malus' law to Aspect's experiment, contrary to Mayants' assertion (p. 184): " ... for the treatement of Aspect's experiment, in particular, it sufficies to make use of Malus' law and the polarization conservation law".

No application of Malus' law to Aspect's experiment is possible: Malus' law assumes the knowledge of two polarization directions, and in Aspect's experiment the common polarization of the two photons which have originated in the same atomic cascade, is unknown. In optics, this law is applied to a linearly polarized beam which propagates in one direction. It states, what fraction of the intensity of a linearly polarized beam striking an analyzer, is transformed into the intensity of a beam polarized in the directtion of the transmission axis of the analyzer.

In Aspect's experiment we have two "beams" which propagate in opposite directions and two analyzers, followed by detectors. The photons which make up these "beams" are characterized by the fact that they stem - two by two and one of them in each beam - from one and the same atomic cascade. They have different frequencies but are "consistent in polarization". This means: as the polarization is a manifestation of the spin of the photon, the mere conservation of the total spin in the atomic cascade, must bring about a strict correlation between the spins, and so between the polarizations of the two photons. In this manner we can explain the fact that two photons of different energies and propagating in opposite directions, are in the same polarization state. This is what I have called consistent in polarization. This explanation also shows that Aspect's experiment is a quantum mechanical problem and not a classical one.

Therefore we have a very particular situation: a "beam" whose polarization state is unknown, propagates in two opposite directions from the source. If we place now - as in one of Aspect's experiments - two linear one way polarizers (or analyzers), one in the path of each beam, we find the result $1/2\cos^2\alpha$, for the probability that one photon is detected after passing the analyzer orientated in the $\vec{a}$ direction and that the corresponding photon, which propagates in the opposite direction, is detected after passing the other analyzer orientated in the $\vec{b}$ direction.

Notwithstanding the similarity between this last result and Malus' law I cannot follow Mayants in his reasoning. Moreover, there is another physical reason why Malus' law cannot be applied to this problem: the classical coherence length plays a crucial role in Aspect's experiment and none in the usual application of Malus' law. If the distance (source $\rightarrow$ counter 1) $-$ (source $\rightarrow$ counter 2) $>$ (coherence length of the light (photons)[10] used[11]) the photons detected are no longer in the singlet state and there is no correlation at all between them. To find again the correlation we must increase or decrease the time gap between measurement 1 and 2 to compensate for the different optical paths.

So we have brought to the fore two reasons why Mayants' pretention, to deduce the physics of Aspect's experiment from Malus' law, is questionable.

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[10] "Photon" is the name given to the "thing" which behaves in some situations as a very peculiar (experimentally) "massless particle" and in other situations as a finite wave. See Ref. 9, p. 579, and the very important experiments on single-photon interferences, Ref. 35.

[11] In Ref. 30, the Ca lines 551.3 and 422.7 nm.

Conclusions.

In this study, I suggest that we should make a distinction between physics proper and theoretical speculations or risky extrapolations from well-established formulae. In other words, we must clearly separate physical concepts (that correspond to physical facts) from theoretical ones (that correspond to mere mental conceptions or opinions). The latter have received no seal of approval from laboratory experiments and measurements.

An example of a theoretical concept is "wave packet reduction", which I analyze on the basis of a text by Heisenberg, by showing that there is, strictly speaking, no "reduction" at all: each new datum simply renders obsolete the previous probability function [22]. In passing, I have pointed out that, in the same text of Heisenberg, there is also an example of a risky extrapolation that has given rise to dozens of fanciful articles: the description of an (energetically non divisible) photon with a classical (infinitely divisible) wave packet.

In view of the fact that the so-called EPR "paradox" continues to appear in the columns of our journals, I return once again to the proof that this is merely a piece of subtle theoretical speculation from which no physical conclusion can be drawn, and which is based on the **belief** that nature can correctly be analyzed into elements of an objective reality [12] each of which is a counterpart of a precisely defined mathematical quantity appearing in a "complete" theory [31]. But "belief" is not a physical concept. "Belief implies mental acceptance of something as true, even though absolute certainty may be absent" (Webster's).

As Bell's work is based on EPR's thought experiment which is physically unfounded, his work is also likewise unfounded. Moreover, Bell proposed an experimental set up which, obviously, could not confirm his theoretical results: experiments are always physically founded.

And the philosophical question, as to whether there is an "objective physical reality"[12] independent of any human experimental knowledge, is one that physicists as such cannot answer, as physics is an experimental science. Physicists are observers and cannot verify if an observer-independent reality exists. Philosophy must be left to philosophers.

By the way, I also have pointed out L. Mayants' erroneous interpretation of a) Bell's basic formula and b) the physics that lies at the

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[12] Here "reality" (or "objective reality") must be taken rather in its metaphysical sense.

foundation of Aspect's experiment. In my opinion, Mayants has correctly conjectured that Bell's formulation is physically incorrect but has not suitably justified his intuition.

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