AN ATTEMPT TO IMAGINE PARTS OF THE REALITY OF THE MICRO-WORLD[1].

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1. ABSTRACT

Quantum mechanics is the theory used to 'describe' the processes that take place in the micro-world. From the start quantum mechanics has been a 'strange' theory, in the sense that it seemed to contradict in various ways the image of a micro-world consisting of 'objects' moving around in a three dimensional space, and interacting with each other in this three dimensional space. So from the advent of the theory a lot of disagreement existed as to the 'physical meaning' of this quantum theory, and a lot of discussions of a philosophical nature have taken place among the founding fathers. Only however during the last years experiments have been performed that, independently of the strangeness of the quantum theory, confront us directly with the strangeness of the reality of the micro-world. We have in mind the experiments on the EPR problem.

In our opinion to be able to 'understand' the reality of this micro-world, it will be necessary to introduce new concepts, and become aware of old 'classical' prejudices. Certainly in not such a radical way as proposed by what is sometimes called the 'California interpretation' of quantum mechanics, but also in not such a vague way as is proposed by what is called the 'Copenhagen interpretation' of quantum mechanics. Since we nowadays have very 'specific' results, on very refined experiments, we should start 'imagining' how this 'micro-reality' is.

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The aim of this paper is to try something in this direction, and to propose what could be called a new discipline in theoretical physics.This discipline should investigate whether different kinds of realities (world-models) can correspond with the results of the experiments that we now have, and with the theoretical descriptions given by the quantum theory. And so although we agree that the quantum-world is a very strange one, our aim will be to show that it is not so strange as it looks at the first place. Just because 'a reality' can be much more complicated than one would imagine.

2. INTRODUCTION.

A lot of revolutions of a conceptual nature have taken place in the history of mankind. Once humanity thought that the earth was flat. And that 'up' and 'down' were 'absolute' concepts. An earth of another form, for example the form of a sphere, was at that time thought to be very unlikely, since obviously everything on the down side of the sphere would fall of it. So if the earth was not flat, anyhow only on the upper side, things like animals, plants, and humans could exists. It took quite some experiencing and imagining to be able to become to know that the earth was not flat and had the form of a sphere. And that it was equally possible to live on the other side. To understand this, one had to interpret the force that pulls everything 'down' as a force directed towards the center of this earth. We want to remark that although it took humanity hundred of years to come to this insight, there are no specific difficulties for the human mind to 'understand' it.

Humanity also thought for a long time that the earth was the center of the universe, every other star and planet turning around it. As we all know, Ptolomeus had developed a very ingenious model, that could explain all the motions of the stars, and the planets turning around the earth in the center. But mankind found out that reality was different. We now know that the earth is only one of the 9 main planets turning around the sun, which is one of the more than hundred million stars of the milky way, which is one of the 20 galaxies of the the local group cluster, which is one of the 100 clusters of the Virgo super cluster. The universe is filled up with these kind of super clusters. But again, once this knowledge about the structure of the universe was acquired, there are no specific difficulties for the human mind of 'understanding' it.

Relativity theory was probably the first physical theory that introduced difficulties of 'understanding', as to how the reality of the world is. And not so much later it was followed by the quantum theory. Most of us agree with Richard Feynman, when he exclaims that 'nobody understands quantum mechanics'. Indeed in comparison with earlier scientific revolutions of which we just mentioned some, we are for the first time confronted with a situation that is the following : Quantum mechanics has a well defined mathematical formalism, and we know how to use this mathematical formalism, but we do not understand the physical meaning of the basic concepts of this mathematical formalism. We will make no attempt to enumerate all the different kinds of problems of 'understanding' that quantum mechanics has delivered to humanity, because they are too many, and there even does not exist any agreement on what they are. But the fact that after more than sixty years of existence of the theory, and successful application of it, not any kind of concensus has been reached among those physicists thinking about the physical meaning of the quantum formalism, shows that there is a real problem of 'understanding'. Can we learn something from the earlier revolutions?

What can be said is that all of them had to do with a change of 'prejudices' about the nature of reality, prejudices coming from the fact that we are human beings, living in our specific environment, and have constructed our models for reality, using the concepts of this specific human environment. Indeed, if we consider again the episodes just mentioned, we can see that :

In earlier times 'up' and 'down' were thought to be absolute concepts, because in the direct environment of us human beings, they indeed are 'absolute'. In the sense that 'up' is the direction of the sky, and 'down' is the direction of the soil, and objects are always falling down.The earth was thought to be flat, because first of all in our direct environment it looks flat, and second because the model we had in mind was the model of a 'table'. The table has an up-side, where everything can be located without falling of. It has a down-side, where everything falls of if one would try to locate it there, and it has borders. With this flat-earth-model, there was the puzzling question : "What happens if we always go in the same direction? Is there a place where we will come at the border of the earth, and if we then go further, will we fall of?" In some primitive societies, this model still is the existing model for the earth.

The fact that the earth was considered as the center of the universe was already of a more sophisticated origin than the example of the prejudice of the flat earth. This prejudice came from the observation that all other things than the earth were turning around it. Obviously the sun and the moon, but also the stars. After more refined observations of the motions of these celestial objects, a very complicated model was proposed by the Greeks, now commonly called the model of Ptolomeus. We all know about the fascinating period, and incredible resistance, during which this model was finally replaced by the model we now use.

The birth of relativity theory is another example. For this revolution the proper concepts of space and time were involved. Again from our experience as a human being with our direct surrounding environment we had developed a model for space and time, where these are independent entities. Which means, there is 'space' which is three dimensional and Euclidean, and in this space time passes by, moment after moment. If this image would be correct the following statement makes sense : "At this moment it is the year 1989 after the birth of Christ, April 17, 1 hour in the afternoon, and 5 minutes, and 34 seconds, and ..." And this statement is 'real' for all places of the space of the universe. The revolution going together with relativity theory, showed us that reality is more complicated. When observers are moving in relation with each other, simultaneity becomes a paradoxical concept. Space and time get intermixed in a certain way, mathematically described by the Lorentz-Poincaré transformations.

In 1902 Henri Poincaré wrote his little booklet 'La science et l'hypothèse'[1)]. In this booklet the roots can be found for a way of thinking that finally culminated in the theories of relativity. But Poincaré goes much further in his analysis of the concept of space, than afterwards was needed for the development of the relativity theories. He analyses how the reality of three dimensional Euclidean (or non-Euclidean) space, has been constructed from our daily experiences as a human being with the objects that are most important for us (rigid bodies), and closely around. This does not mean that this three dimensional space is an 'invention' of humanity. It exists, but the way we have ordered, and later on formalized it, by means of specific mathematical models, does make part of it. In other words, what we call the three dimensional reality of space partly exists in its own and partly exists by the structures that we have constructed, relying on our specific human experience with it.

This is a very important insight, and in my opinion generally true for all 'realities'. The 'up' and 'down' that first were thought to be 'absolute' concepts, later showed themselves to be 'realitive' concepts, in an obvious sense, that we all understand nowadays. This does not mean that these concepts do not exist, and are purely inventions of the human mind. They exist, but in the construction that we have made of them, there was, and always will be, a human dimension.

We think that to be able to understand the strange aspects of the reality of the micro-world, this type of insight will have to be used explicitly. In relation with the 'strange' (but not so strange as most physicists think, as we will show in 5 and 6) effects of the 'so called' non-locality, that have been revealed meanwhile in different experiments, we think the 'human part' of the construction of the reality of three dimensional space, Euclidean or non-Euclidean, will have to be rethought. We will have to find out which part in the reality of this three dimensional space finds its origin in our organization and modeling of it, as specific human creatures, having used our specific human experiences with the macroscopical objects around us. Some physicist in the past have certainly thought about this necessity, but I think that most have felt it to be an impossible step for the human mind. "How would it be possible to still imagine a reality, if the space where this reality is in, is not the space as we imagine it." We are more optimistic as to the capacities of the human imagination. We think that in our world of today, already a lot of 'entities' are not so obviously 'present' in this three dimensional space.

Let me explain more clearly what I have in mind by means of a very concrete example. Suppose we consider as our study object a language, for example the French language. Everybody agrees on the fact that the French language exists. But where is it? One could say, in France. But certainly not all French is in France. And finally if one reflects a little bit deeper on the question, it is easy to see that it makes more sense to state that the French language is not really 'present' in space. This does not bother us, because we all know what we are talking about, and there is no mystery. Also because we can always consider the entity 'French language' as a kind of derived entity constructed by humans, that would never have existed if the humans would not have existed. In the sense of what is meant by Karl Popper [2)], when he introduces his different 'worlds'.

Could it be the case that also micro-entities are not always in a state such that they are 'present' in this part of the reality of space that is constructed following our human needs, and could this be a way for explaining the strange aspects of non-locality that are encountered in many experiments with these micro-entities? This is a question we want to take seriously. And at the end of this paper we will present some examples to show you our optimism as to the power of imagination of the human mind. We will try to show that it is possible for our human mind to imagine a manner in which things could have evolved that way!

To be able to find out more in this direction, we should start investigating "what different kinds of realities" are still possible with the experimental results that we now have, and compatible with the micro-world as it is pictured in a mathematical way by the rules of quantum mechanics.

3. WHAT IS REALITY?

Reality as described by the 'classical' physical theories, is conceived as a space-time structure of events, and the whole of this space-time structure of events is what is called the 'universe'. And all reality is 'inside' this universe, or has direct connections to it, as proposed by Karl Popper in [2]).

Quantum theory fits very difficult in such a conception of reality. There are some approaches in the foundations of physics that do try to fit quantum theory in such a structure for reality. We refer here to the approaches where the micro-entities are really considered to be (point)particles in the classical sense, and all the strangeness of behavior of these point particles is put into a 'non-local' interaction (quantum potential) scheme between the particles [3]).

Another completely different approach to the problems of quantum theory, is the approach that consists of constructing a formalism that takes for granted the fact that the world consists of a collection of entities and interactions between these entities, and then describes the world of these entities by means of their 'elements of reality'. And we remark explicitly that in this approach, the world does not mean the universe. The world is the collection of entities, and interactions between these entities, and to require that these entities are inside the universe of space-time is not of apriori necessity. Such an approach has developed itself into a study of the nature of the micro-world in Geneva under the guidance of Constantin Piron [4]), and I myself have been participating in the elaboration of this approach [5]). The approach delivers a theory that is an amelioration of the old quantum mechanics in many aspects, because all used concepts are defined in a clear, realistic, understandable way, contrary to the concepts used in ordinary quantum mechanics, and new parts of reality have been described by it, impossible to describe by the old theory (see [4,5])). A great advantage of this approach as to what we want to do in this paper, is the fact that to introduce the concepts needed to represent the 'reality' of this world of entities, one does not need macroscopical classical concepts, like for example the concept of space-time continuum. Therefore it is possible to make use of the 'insights' of this approach to proceed in the direction of our goal, namely finding out 'what is the human part (the part due to our specific human place in this world) that we have put into these classical macroscopical concepts'. Let us in short repeat the main concepts needed for the construction of the reality of a world of entities.

An entity is a part of the world that constitutes a whole, and cannot easily be broken into different parts. Of course it is easy to see that this concept of entity is not an absolute concept. If one wants, probably all entities can be broken into parts. If one considers a play of billiards, then the balls are entities. But of course they eventually can be broken into parts. If this would happen during the play, it certainly would be considered as an accident. And indeed the classical mechanics model of the behavior of the balls on a billiard-table, considers these balls as rigid bodies, that cannot be broken. The same situation presents itself in the micro-world. A neutron is an entity, although it breaks by itself in a few minutes. So what can be considered as an entity is a 'convention' in the sense of Poincaré [1)] , and depends on what kind of model one wants to make of that part of the world.

The reality at a certain time t (time is considered at this stage just as a means of numbering the different experiences of the observer making the model) of this world of entities is constituted by the states of the entities at this time t and the interactions between the entities. Hence to be able to study this reality, we have to understand the meaning of the concept 'state of an entity'. This is a concept that has been studied in detail in the approach explained in [4,5)], and meanwhile also has been translated in the general language for physics developed at Amherst by Charles Randall and David Foulis [6)], where they call what here is meant by an entity by the name of 'realistic entity', and what here is meant by a state by the name of 'realistic state'.

The state of an entity at a certain time t is defined by the collection of all properties that this entity 'has' at this time t, or with other words, that are 'actual' for the entity at time t.

For those who want to go deep into the details of this construction we have to refer to [4)], [5)], and [7)]. In this paper, instead of staying on the abstract level, we want to make clear what this construction is by means of an example.

Let us consider the world of all human languages. So in this world, every human language is an entity. Such an entity, human language, can have different properties. For example the property of being a Germanic language, or the property of being spoken by more than 30 million people in the world, etc... Once we have agreed on the set of properties that we will consider for the different languages, we have a model for this world (we cannot consider all the 'possible' properties, this would lead to 'mathematical paradoxes' of the Russel type, we elaborate more on this problematic in [7)]). The set of all 'actual' properties at a certain moment t for a certain language, is the state of this language at that moment t, and defines the reality of that language at that moment t. For example : French is not a Germanic language, but is spoken by more than 30 million people in the world. The reality of this world of languages at a certain moment t is given by the states of these languages at that moment t, and the interactions of the different languages. It is very clear by means of this example that 'depending on the model' different realities can be found, and these realities are not part of the space-time continuum, that usually is considered to enclose all realities of all worlds, and therefore is called the universe. We must remark that when we say the phrase "the reality at a certain moment t " , the t we use does not correspond to the 'geometric' time coordinate of this space-time continuum. At the level of our formalism 'time' is just a parameter that orders the 'measurement projects' needed to define the properties, and hence the states of the entities.

We have chosen on purpose the example of the world of human languages because on one hand this is a very concrete example (no mystery at all, we all agree that languages 'exist', and have properties, that can define their states, and these states can change, etc...), and on the other hand it makes it so obviously clear that there is this prejudice of thinking that all realities of all worlds are contained in the space-time continuum, the 'universe'.

Of course, one can say that although this example gives a reality not contained in the 'universe' of space-time, it has been created out of it. Because languages are creations of human beings, and human beings are creations of energy and matter(?), and matter is indeed inside the universe. This is the way of thinking that Karl Popper proposes, to make out what reality is. There is a 'prejudice' of another nature behind this 'limitation' of possible realities, that in our opinion also stands in the way for a real understanding of the reality of the micro-world. We could perhaps call it the prejudice of 'reductionism'.

This is the prejudice that consists of thinking that if one world A is 'contained (whatever this means)' in another world B, then it must be always possible to reduce the explanation of this world B to an explanation of world A, and then world B must always be 'more complicated' than world A. There are obvious counter-examples to show the falseness of this prejudice, but still we unconsciously always believe in it if it comes to our attempts of understanding the reality of the micro-world.

Let us give such a counter-example. We consider world A which is our planet earth, with all the human beings, animals, plants, and objects on the surface of the earth, and their mutual interactions. This is a very complicated world. We consider world B, which is the solar system. Then world A is 'contained' in world B. But obviously world A is much more complicated than world B. This is because we, the humans, the animals, the plants, and all the objects on the surface of the earth, move together with the earth in a rather simple motion around the sun. And this makes that our appearance in world B is a very simple one. In the model of world B, by the laws of mechanics of Newton, we even do not have to appear at all, so simple is our participation.

This example shows us, that organization (in the case of the example the fact of moving all together attached to the surface of the earth), can lead to a bigger world that is much more simple than the parts of this bigger world.

A similar situation is encountered for the case of the micro-world (world A) and the material macro-world (world B). Quantum mechanics is a rather complex theory, describing a behavior of the entities in this micro-world that lacks any simple picture, while the material macro-world behaves in a much simpler way. We think that this must be due to the fact that the step from the micro-world to the material macro-world must entail a huge organization of all these micro-entities. It is because once together in a piece of matter, the micro-entities start to behave in a very 'organized' way, that this piece of matter finally will show this nice behavior described by the classical theories. But once destroyed, such that the micro-entities are on their own again, their behavior becomes much more complicated, because less organized, and hence strange as to our human standards, that come from our human-scale experiences with exactly this 'organized' behavior of material objects around us. This in our opinion is the reason for the fact that nobody till now has been able to find back the classical behavior of a macro-entity as a limit for a huge amount of micro-entities that behave together. Mathematically speaking, one can make millions of tensor products of Hilbert spaces, but such a huge tensor product will never deliver a classical phase space. It is not the aim in this article to enter more in detail on these kinds of reflections, because it would lead us to far. A detailed account of them can be found in [7)]. Now we want to start to give some concrete examples that fit into this way of thinking.

4. POSSIBLE REALITIES.

What has happened in the last few decades, as compared to the decennia of discussions about 'Gedanken-Experimenten' in relation with the quantum theory, is that beautiful 'real' experiments have been performed, trying to make out whether the micro-reality is indeed as strange as predicted by the mathematical formalism of quantum mechanics. This type of investigation was accelerated much by the reasonings of John Bell [8)] on the zero spin entity of David Bohm [9)] that on his turn was inspired by the situation considered in the original paper of Einstein, Podolsky and Rosen[10)]. Bell showed that, if one calculates the correlations of spin measurements in various directions at two opposite space locations, symmetrically located with respect to the place where the zero spin entity is created, and makes some 'additional assumptions', one gets contradictions with the results predicted by quantum mechanics. Most commonly these 'additional assumptions' have been identified as the assumption of 'the existence of local hidden variables' for the description of the zero spin entity. Bell had formulated his requests in the form of the now commonly called Bell inequalities. And the theoretical situation was then presented in the following way : Local hidden variable theories satisfy Bell inequalities, and quantum theory violates Bell inequalities. Experiments should then make out how the reality of the micro-world is, local (describable by local hidden variable theories) or non-local, as described by quantum mechanics. A lot of experiments have been performed [11], and they appear to confirm the predictions of quantum mechanics. Hence as the argument has been stated, this would make it necessary for us to conclude that the reality of the micro-world is non-local.

The problem with these kinds of 'theoretical' conclusions, is that usually in the reasonings that leads to the conclusion, so many 'additional assumptions' are 'unconsciously' used, that the conclusion should always be stated in a more prudent way, for example in the following way :

Statement 1 : *The reality of the micro-world is non-local (not describable by local hidden variable theories), or one of the 'additional unconsciously used assumptions (AUUA)' is wrong.*

Some physicists do in this respect believe that 'AUUA' are present in relation with the interpretation of the EPR experiments itself [12].

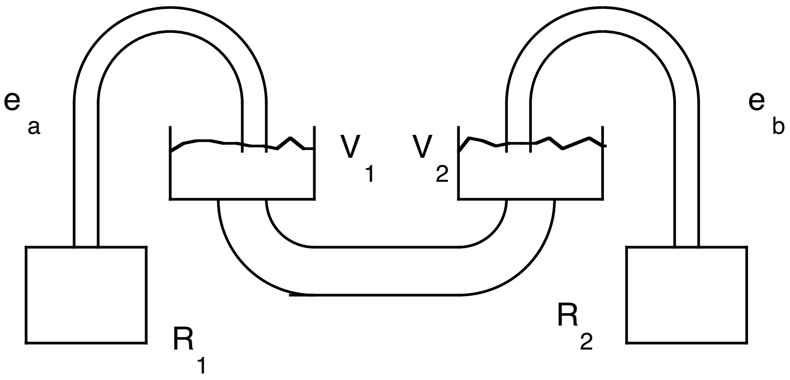
I myself have always been convinced of the presence of other 'AUUA', of conceptual nature, coming from our prejudices about how 'reality' must be, in the reasonings on the specific EPR experimental situations. These prejudices about the nature of reality are of many different types, but all come from the fact that we believe in a model of reality that comes from our daily experiences as a human being with this reality. The beautiful art of conjuring is nothing else but an exploration of the most primitive ones of these prejudices. Other prejudices are of course of a much more profound nature, and really touch on our profound believes of how reality is. In relation with the strange aspects of the quantum theory, their is a mixture of these two kinds of prejudices, the 'conjuring-like ones', and the 'profound ones'. This conviction came to me, because in the beginning it was considered as if the Bell inequalities were some kind of inequalities that 'always' were satisfied in the macroscopical world of ordinary objects, and quantum mechanics predicted them to be violated in the micro-world. Hence the Bell inequalities were presented as inequalities distinguishing between the macro-world, and the micro-world (in a similar way as do the Heisenberg inequalities). I must admit now that at that time the whole problematic was not so clear to me, but what was rather obvious to me was the fact that I could easily invent macroscopical physical entities that did violate the Bell inequalities [13] to the amazement of many physicists working in the field at that time. Now almost 10 years have passed from then, and I understand much better, what are the possible conclusions to be drawn. But for me it is by means of this example that it was possible to understand these conclusions.

Therefore we want to come now to the point announced as one of the purposes of this paper. We should, instead of staying with abstract reasonings about the nature of reality, look for examples (realizations inside the reality that we know). Because by means of these realizations, it can become clear what are the 'AUUA' that are hidden in the abstract reasonings, and which ones of these AUUA are of the 'conjuring type' and which ones are of the 'profound type', and could lead us to find those 'human' prejudices about the nature of reality, that stands in the way for an understanding of the reality of the micro-world.

5. THE VIOLATION OF BELL'S INEQUALITIES IN THE ORDINARY HUMAN REALITY.

As an example of what we mean we want to present in this section an analysis of the violation of Bell's inequalities, following strictly the realization of this ordinary classical macroscopical entity violating these inequalities, that we have been considering already at many occasions [14)], and is an improvement of the original [13)]. Because in considering this entity, we are sure that we are reasoning about a concrete physical situation inside the ordinary reality, and hence can find out concretely what is necessary inside this ordinary 'human' reality for Bell inequalities to be violated.

The entity consists of two vessels V_1 and V_2 that contain each 10 liter of water and are connected by a tube. The experiment e_a consists of taking the water out of V_1 with a siphon and collecting it in a reference vessel R_1. If we collect more than 10 liters, the outcome for e_a is 'yes', and if we collect less than 10 liter the outcome for e_a is 'no'. The experiment e_b is the same as e_a but performed on V_2. The coincidence experiment e_{ab} consists of performing e_a and e_b together. This coincidence experiment creates correlations. Indeed, if we find more than 10 liters in R_1, then we find less than 10 liters in R_2, and vice verse. The correlations are detected at both sides when the water stops



The classical macroscopical system that violates the Bell-inequalities (fig 1).

flowing, this means simultaneously. Hence the events that correspond to the detection of the correlations are space-like separated events. To calculate Bell inequalities we have to introduce two other experiments. The experiment $e_{a'}$ consists of taking 1 liter of water out of V_1 and checking whether the water is transparent. If the water is transparent , then the outcome of $e_{a'}$ is 'yes', and if it is not transparent the outcome is 'no'. The experiment $e_{b'}$ is the same as $e_{a'}$ but performed on V_2. We make coincidence experiments $e_{a'b}$, $e_{ab'}$, and $e_{a'b'}$. We now define the following random variables : $E_a = +1$ if e_a gives 'yes', and $E_a = -1$ if e_a gives 'no'. In the same manner we define E_b, $E_{a'}$, and $E_{b'}$. We also define the random variables for the coincidence experiments : $E_{ab} = +1$ if e_{ab} gives 'yes,yes' or 'no,no', and $E_{ab} = -1$ if e_{ab} gives 'yes,no' or 'no,yes'. If the entity is in such a state that the two vessels of water contain 10 liter of transparent water, then $E_{ab} = -1$, $E_{a'b} = +1$, $E_{ab'} = +1$, $E_{a'b'} = +1$. Hence :

$$| E_{ab} - E_{a'b} | + | E_{ab'} + E_{a'b'} | = +4 > +2. \qquad \text{(eq 1)}$$

This shows that Bell inequalities are violated.

Bell inequalities are originally derived from a locality hypothesis formulated by John Bell in [8)]. Let us show that also this Bell Locality hypothesis is violated by our macroscopical example. This locality hypothesis was formulated for a deterministic hidden variable theory. A deterministic hidden variable theory is a theory that postulates the existence of states of the entity such that all observables have a determined outcome when the state is known. Let us denote by Γ the set of these states λ. Hence in such a theory, E_{ab} has a determined outcome $E_{ab}(\lambda)$ for every state λ. Bell introduces then the following hypothesis :

Bell locality hypothesis : *For all experiments e_a, e_b, and e_{ab} and for all λ we have* :

$$E_{ab}(\lambda) = E_a(\lambda)\cdot E_b(\lambda) \qquad \text{(eq 2)}$$

The physical meaning of this hypothesis is that the result of the experiment e_a only depends on the state λ and not on the experiment e_b. Since this Bell locality hypothesis implies Bell inequalities to be satisfied, our example must also violate the Bell locality hypothesis. Let us try to see why this is so. It is very easy to specify the deterministic hidden variables for our entity. Indeed, if we specify for example the diameters λ_1 and λ_2 of the two siphons, the outcomes of all the experiments are determined. Hence we can write:

$$E_{ab}(\lambda_1, \lambda_2) = E_a(\lambda_1, \lambda_2)\cdot E_b(\lambda_1, \lambda_2), \qquad \text{(eq 3)}$$

$$E_a(\lambda_1, \lambda_2) = +1 \text{ and } E_b(\lambda_1, \lambda_2) = -1 \text{ if } \lambda_1 > \lambda_2 \qquad \text{(eq 4)}$$

$$E_a(\lambda_1, \lambda_2) = -1 \text{ and } E_b(\lambda_1, \lambda_2) = +1 \text{ if } \lambda_1 < \lambda_2 \qquad \text{(eq 5)}$$

This is a correct factorization if one performs the coincidence experiment e_{ab}. If one wants however to use the same $E_a(\lambda_1, \lambda_2)$ to factorize the random variable $E_{ab'}$ from the coincidence experiment $e_{ab'}$, it does not work anymore. Indeed, e_a performed together with $e_{b'}$ always gives the outcome 'yes'. This means that the value of E_a does not only depends on the states λ_1, λ_2 but also on the fact that we perform experiment e_b or $e_{b'}$, and

$$E_a(\lambda_1, \lambda_2, b) \neq E_a(\lambda_1, \lambda_2, b') \qquad \text{(eq 6)}$$

since $E_a(\lambda_1, \lambda_2, b) = +1$ if $\lambda_1 > \lambda_2$ and $E_a(\lambda_1, \lambda_2, b) = -1$ if $\lambda_1 < \lambda_2$ while $E_a(\lambda_1, \lambda_2, b') = +1$ for all λ_1, λ_2.

Bell has put forward this locality hypothesis having in mind the entity consisting of two spin-1/2 particles in the singlet spin state. Why do people find this locality hypothesis 'natural' for this entity? Because they imagine the entity to be an entity consisting of two spin-1/2 particles located in different widely separated regions of space while they are flying apart. And indeed, for two entities located in widely separated regions of space, with no connection between them, the Bell locality hypothesis seems to be a natural hypothesis to be satisfied. But for two entities that actually form a whole (like the water in the two vessels) it is very easy to violate the Bell locality hypothesis, and hence also the Bell inequalities.

Other derivations of Bell inequalities have been proposed than the original one [15)], that seemed to avoid this Bell locality hypothesis, and seemed to be grounded on a more general physical principle, namely the principle of Einstein locality (No signal travels faster than light). Here certainly some AUUA must be present, because nobody will believe that the example of the two vessels of water connected by a tube violates this principle. Let us try to detect the AUUA in this derivation. In this derivation one supposes that the same hidden variables describe the four coincidence experiments e_{ab}, $e_{a'b}$, $e_{ab'}$, and $e_{a'b'}$. If one considers again our example of the vessels of water connected by a tube, then one can see easily that the hidden variables are different for the experiment e_{ab} (hidden variables λ_1, λ_2) than for the experiments $e_{a'b}$, $e_{ab'}$, and $e_{a'b'}$ (no hidden variables). Hence the AUUA that the four coincidence experiments can be described by the same hidden variables is not justified from any physical principle. Mathematically it is of course possible to consider four sets of hidden variables, one set for each experiment, and then construct the Cartesian product of the four sets. In this way one can describe all four experiments by the same set of hidden variables. However something else goes wrong in the derivation of the Bell inequalities. The probability distribution $\rho(\lambda)$ of the hidden variables will depend in this case upon the experiments. And in the derivation, for example proposed [15)], the probability distribution $\rho(\lambda)$ under the integrals cannot be treated mathematically as done, since there is this dependence on the different experiments e_a, $e_{a'}$, e_b, and $e_{b'}$. Hence on should introduce four different probability distributions $\rho(\lambda,a)$, $\rho(\lambda,a')$, $\rho(\lambda,b)$, and $\rho(\lambda,b')$ in the integrals. Again Bell inequalities cannot be derived anymore.

We would now like to find out the physical reason of the violation of the Bell inequalities by our macroscopical entity. We can already understand very much if we consider the nature of the hidden variables λ_1 and λ_2. These are not hidden variables of the state of the entity 'water', before the measurement, because the state of the water (and hence the reality of the water) is completely determined by the fact that the volume is 20 liter. And λ_1 (λ_2) is a hidden variable of the experiment e_a (e_b), but not of the experiment $e_{a'}$ ($e_{b'}$). Hence if we would analyze this situation in the scheme of 'non classical probability models', as we have done in [16)], we would classify the hidden variables λ_1 and λ_2 as representing 'hidden measurements', and not 'hidden states', and as is shown in [15)], the water as in the example has a 'non classical' probability model. This explains from a probabilistic point of view why we can violate Bell inequalities with our example of the vessels of water. Indeed, the correlations that are detected by the experiment e_{ab} were not present before, but are **created** during the experiment, and therefore they can violate the Bell locality hypothesis. We propose to call correlations that were not present before the experiment and are created by and during the experiment '**correlations of**

the second kind'. Correlations that were already present before the experiment and are only detected by the experiment, we will call **'correlations of the first kind'**. Let us give an example of such correlations of the first kind. Consider a entity consisting of two material point particles moving in space and having total momentum zero. A coincidence measurement of the momenta of the individual particles gives us correlated results. These correlations were however already present before the coincidence experiment. The experiment only detects the correlations and does not create them. These kinds of correlations can never be used to violate Bell inequalities, because the result of an experiment on one of the particles will never depend on what experiment is being performed on the other particle. If we read the paper on the history of the EPR paper of Max Jammer in [17)], it becomes clear that this difference was exactly the point that puzzled Einstein, and was at the origin of the EPR article. Let us try to summarize : If we consider correlations that are created by and during the coincidence experiment e_{ab} (correlations of the second kind), then it is possible to violate Bell inequalities and the Bell locality hypothesis by means of this coincidence experiment and some other experiment, because the outcome of experiment e_a will in general depend on whether we perform e_a together with e_b or with some other experiment $e_{b'}$. If we consider correlations that were already present before the coincidence experiment, then the Bell locality hypothesis will be satisfied, and Bell inequalities cannot be violated.

Let us now try to show that the 'description' of quantum mechanics 'indicates' that this is exactly what happens in the case of the correlations coming from the coincidence spin measurements on the entity consisting of two particles in the singlet spin state. What we mean is that the description of quantum mechanics of this situation indicates that we are in a situation of correlations of the second kind. Let us analyze the form of the singlet spin state of the entity consisting of two particles. Suppose that $\Psi^1_{\theta,\phi}$ and $\Psi^2_{\alpha,\beta}$ are the wave-functions representing the state of particle 1 in the (θ,ϕ) spin direction, and the state of particle 2 in the (α,β) direction. Usually the wave function representing the singlet state S is written in the following way :

$$\Psi_S = 1/\sqrt{2}\ [\ \Psi^1(up)\cdot\Psi^2(down) - \Psi^1(down)\cdot\Psi^2(up)\ ] \qquad \text{(eq 7)}$$

where $\Psi(up) = \Psi_{0,0}$ and $\Psi(down) = \Psi_{\pi,0}$. But this wave function is mathematically equal to the wave function :

$$\Psi_S = k\cdot\ [\ \Psi^1_{\theta,\phi}\cdot\Psi^2_{\alpha,\beta} - \Psi^2_{\theta,\phi}\cdot\Psi^1_{\alpha,\beta}\ ] \qquad \text{(eq 8)}$$

for any $(\alpha, \beta) \neq (\theta, \phi)$ and some appropriate complex number k.

Clearly Ψ_S does not depend on the values of (θ,ϕ) and (α,β). This shows that Ψ_S does not represent a state of two particles which have already their spin, although mathematically it is constructed in this way. It represents a state of an entity, consisting of two particles, which do not have yet their spins. And the spins are created by the coincidence experiment, that is exactly the experiment that takes apart the one entity, and breaks it into to two 'separated' entities. Let us try to summarize all this :

Statement 2 : *The violation of Bell inequalities is not a property of micro-entities. Bell inequalities can equally well be violated by coincidence experiments on classical microscopical entity. In fact Bell inequalities can always be violated if during the coincidence experiments one breaks one entity into separated pieces, and by this act creates the correlations. In analogy with the example of the vessels of water, a lot of other macroscopical entities violating Bell inequalities can be invented. But there is of course no mystery in these violations, because we see with our own eyes, inside our own human reality what happens.*

Is this then the end of the story? Don't we have to be amazed at all by the experiments on micro-entities that violate the Bell inequalities? Certainly not.We believe there is indeed a mystery, touching upon 'profound prejudices' of our human part of the construction of reality. We will try to make clear what in our opinion is the mystery.

6. THE MYSTERY, INDICATING SOME OF OUR PREJUDICES ABOUT THE 'HUMAN' PART OF THE CONSTRUCTION OF REALITY.

From our analysis follows that we should consider the entity consisting of the two particles in the singlet spin state as being one whole, without having already two separated individual parts having their spin directions, before the coincidence measurement is made. But this would mean that this one entity is present in a part of space of a macroscopical magnitude (of the order of 12 meters of length in the case of Aspects experiments). Is it imaginable that two micro-entities can form one whole in such a huge region of space? For the water, there is no problem, because we can put a connecting tube, as long as we want, but for two micro-entities?

Moreover, for example in the Aspect experiment, the space like parts of the photons, if described by a wave-packets, seem to fly apart, because they pass through two filters of different frequencies. Hence, although it is very complicated to make a rigorous description of these space like parts, they seem to be 'separated' in a certain sense.

While all the 'non-local' aspects are due to the spin-like parts of the entities. From this follows that we should not only 'imagine' ourselves a photon-pair with the dimensions of a 'cloud' of 12 meter diameter, but with the additional fact, that there is 'nothing'(we should say 'nothing' in ordinary space) between. The particles remain 'one whole' while the space regions with probabilities of detecting one of the particles almost equal to 1 get separated at macroscopical distances. This is certainly a situation that we will not be able to imitate by means of a classical macroscopical entity.

Indeed, if we consider two space regions R_1 and R_2 that are macroscopically separated and an entity S that constitutes a whole such that in the region R_1 we have a probability almost equal to 1 to detect one part S_1 (or S_2) of the entity S, and in the region R_2 we have a probability almost equal to 1 to detect the other part S_2 (or S_1) of the entity S. And such that between the two regions we have a probability almost equal to 0, to detect the entity, then this situation can only be realized by means of a macroscopical entity when this macroscopical entity is already separated into two sub entities. Macroscopical entities seem to have one additional property, that microscopical entities not necessarily have. Let me call it the 'property of macroscopical wholeness'.

The property of macroscopical wholeness : *For macroscopical entities we have the following property : if they form a whole (hence are not two separated parts), then they hang together through space. Which means they cannot be localized in different macroscopically separated regions R_1 and R_2 of space, without also being present in the region of space 'between' these separated regions R_1 and R_2 .*

To understand clearly this property of macroscopical wholeness, think of the example of the water. If we cut of the connecting tube, the two vessels of water get localized in different separated regions of space, but then they are separated entities, and Bell inequalities cannot be violated anymore with coincidence experiments on them. Microscopical entities seem to be able to constitute a whole, without necessarily being submitted to this property of macroscopical wholeness. This is in my opinion what we have to learn from the EPR experiments as a matter of fact.

If it were only the EPR experiments that cause us troubles of understanding about the nature of reality, we could still hope to find a solution in the sense of questioning principles like 'causality, or Einstein locality etc..'. But other experiments, ever more strongly, and more clearly, indicate that micro-entities do not satisfy this property of macroscopical wholeness. This is what I am investigating at this moment together with Jean Reignier. We have been considering more specifically the situation of a typical Stern-Gerlach experiment [18]. And we are investigating the state of such 'one' particle, when it comes out of the Stern Gerlach magnet. Our aim is to work out the meaning of this state showing that this one particle (hence only one entity) effectively does not satisfy this property of macroscopical wholeness. In a certain sense it is 'present' in two separated regions R_1 and R_2 and not between. We support this interpretation by the results of the experiments with neutrons, and the neutron interferometer [19].

It is very difficult for us to imagine that one entity as a whole does not satisfy this property of macroscopical wholeness. But this difficulty probably comes exactly from the part of the reality, that we have called the human constructed part. Indeed, as we know space, and the entities that are in it, we think that only two situations are possible.

Situation 1 : *An entity forms a whole, and then breaking it into parts can make us perform experiments that violate Bell inequalities, but then this entity must 'hang' together, and hence cannot be localized in different separated regions of space.*

Situation 2 : *An entity is formed out of two separated entities, and then making experiments on the parts never will make it possible to violate Bell inequalities. In this case the separated parts can of course be localized in different separated regions of space.*

Other situations are very difficult for us to imagine. Why? Now I want to come to the main point of this paper. These other situations are very difficult for us to imagine, because we have constructed space from our human experiences with macroscopical entities, that exactly satisfy this macroscopical wholeness property. In the next section we will make by means of an example an effort to 'imagine', how local human space could have grown, although originally the entities of which the objects in it are constructed do not satisfy this macroscopical wholeness principle.

To end this section we want to make one additional remark on this classical wholeness principle, that is not really important for the aim of this paper, but gives a good example of the superiority of the Geneva formalism as to the formalism of ordinary quantum mechanics. If one wants to describe a collection of entities by the mathematical formalism of ordinary quantum mechanics, then it is easy to prove, that such entities can never be separated in the classical sense (hence situation 2 cannot be described). This is one of the great shortcomings of mathematical structural nature of the ordinary quantum formalism, that has been corrected in the Geneva formalism, and is studied in detail in [5] and [14]. As is shown in [13] [14] and more specifically in [20] is this shortcoming that is at the origin of the 'logical' content of the EPR paper (as explained by Max Jammer in [17] the part of the content of the EPR paper due to Boris Podolsky, and his contacts with Kurt Gödel).

7. IMAGINING NON LOCAL ENTITIES GIVING RIZE TO A CONSTRUCTION OF SPACE FILLED UP WITH LOCAL ENTITIES.

This section must purely be seen as an attempt of inventing a world of entities, such that these entities are in principle not submitted to this property of macroscopical wholeness, but in organizing themselves in a certain way, the organized structures of huge numbers of such entities do acquire this property. We make this attempt with the purpose of showing that such an evolution is possible. It may indicate future ways of research towards more serious, and realistic models of such an evolution, that could eventually deliver a model for the evolution from the micro-world to the material macro-world. This example must be understood in the same sense as Poincaré's example of the heated plate, to explain the possible reality of non Euclidean Geometry, or his reasonings about the conventional nature of the number of dimensions of our space (see [1]) ch 4).

In our example, the entities are human beings, and the world of entities is our human society. Everybody agrees that there are a lot of interactions of different nature between human beings, and it is the collection of all these interactions, and the states of all human beings at a certain moment t, that constitute the 'reality of our society at this moment t'. The interactions are very complicated, and therefore nobody has been able to present simple mathematical models for this world. Let us consider a typical interaction, that we call 'friendship'. This interaction is at this moment very unstructured. We all have 'close friends', and 'less close friends' and 'a set of people that are neutral', and also sometimes 'non-friends or enemies'. We can imagine that the world would evolve in a direction such that this interaction of 'friendship' gets more and more structured, such that in the long future, every human has a strictly quantitative amount of friendship for every other human. Let us suppose that humanity has only survived if 'enemies' have been eliminated from this future world, hence the amount of friendship that a certain person x feels for another person y can be represented by a positive number d(x,y). Let us suppose that for reasons of structural stability of this future world, the 'friendship' always has to be mutual, such that $d(x,y) = d(y,x)$ for all persons x, and y of this society. It is easy to imagine what kind of other 'future' suppositions one has to make about the evolution of this 'interaction' of friendship, such that the resulting structure would be more or less 'space-like', in the sense that d(x,y) would represent 'really' a kind of distance between persons x and y. Details of this part of the story can be found in [7]). What we want to mention for the purpose of this paper is the following aspect of this example. It is very well imaginable that in such a society different 'subgroups' start to emerge, all evolving towards a structuring of the interaction 'friendship'. An aspect of this kind of evolution is nowadays even already present, if we think of the different 'sects' that arise on the surface of the earth. Suppose that we consider two such subgroups A_1 and A_2. Hence A_1 is a group collecting people that are living in a very structured 'friendship space', and A_2 is a group of people living also in a very structured 'friendship space'. In the old Euclidean space of the surface of the earth, they live intermixed, as nowadays also the different sects on the earth live intermixed. But in their new 'friendship space', and hence measured with the friendship-distance function $d(A_1,A_2) = \inf \{ d(x,y), x \in A_1, \text{ and } y \in A_2\}$ the two groups will be very far from each other. Which means that $d(A_1,A_2)$ will be big, and hence A_1 and A_2 will be located in different separated regions R_1 and R_2 of the friendship space. Suppose now that we consider a person z that neither belongs to the group A_1 nor to the group A_2. This person will be considered to be far away by both groups in the friendship space, and we can for example say that he will be considered in between the two groups A_1 and A_2. Suppose that for the person z it is necessary to choose to become a member of A_1, or to become a member of A_2. If he chooses to become a member of A_1, in the friendship-space he collapses into the region R_1 and if he chooses to become a member of A_2 in the friendship space he collapses into the region R_2. His original state, before choosing or being forced to choose, was a 'superposition state'. But if we re-analyze the whole situation in the original Euclidean space of the surface of the earth, this choosing does not take any time, and does not move him in this space.

With a little bit more imagination, we could think that after a long time, the humans have forgotten about their original Euclidean space of the surface of the earth, and hence such an happening in their friendship space will confront them with a non local aspect of this friendship space.

The story tries to show that it is conceivable from a realistic point of view that micro-entities move, and behave in another space, that we in the construction of the reality of the human part of space have forgotten about. The macroscopical material entities (A_1 and A_2 if we respect the analogy) would be the super organized structures of the micro-entities (x,y,z). The macroscopical entities move around in this nice three dimensional space, and can be in two kinds of situations : 1) They are 'separated' but then consists of two separated entities, with interactions through space between these entities. 2) Or they form a whole, but then hang together through space. When now a micro-entity (z) is departed from such a macro-structure (this is exactly what humans force it to do, when making experiments with micro-entities), and flies around in its old space, it can behave following different laws. When (z) is given the chance (by means of a measurement) to become again part of one of the two macro-entities A_1 or A_2 (the measurement apparatus) it collapses out of its superposition state. Could this be a realistic explanation for the non-classical behavior of micro-entities ?

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