UNVEILED REALITY: COMMENT ON D’ESPAGNAT’S NOTE ON MEASUREMENT

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Abstract

According to d’Espagnat we must choose between non-linear breaks in quantum state evolution and weak objectivity. In this comment it is shown that this choice is forced on us by an inconsistent pseudo-realistic interpretation of quantum states. A strongly objective one-world interpretation of linear quantum mechanics is presented. It is argued that the weak objectivity favored by d’Espagnat is, in fact, inconsistent with quantum mechanics.

1 CRITIQUE

If both Alice and Bob see a teapot on the table then there is a teapot on the table. Or is there? In a recent article Bernard d’Espagnat contrasts “objectivist realism” (Option A) with an alternative theory of science (Option B) close to Putnam’s “internal realism”, which is close to Kant’s theory of science. According to Option A, the antecedent (Alice and Bob see a teapot) and the consequent (there is a teapot on the table) express two different states of affairs, such that the latter may be ontologically correlated, if not causally connected, with the former. According to Option B, the consequent is equivalent to the conditional statement “If Cecily would look to see what is on the table she would see a teapot.” This leaves no room for an ontological correlation, let alone a causal link, between the antecedent and the consequent.

According to Option A, the purpose of science is to discover how things are in themselves, rather than how they appear to us. According to Option B, science aims to describe, as concisely as possible, the common (inter-subjective or weakly objective) denominator of human experience. There are sound arguments in favor of either view. Science is driven by the desire to know how things really are. It owes its immense success in large measure to its powerful “sustaining myth” —the belief that this can be discovered. Neither the ultraviolet catastrophe nor the spectacular failure of Rutherford’s model of the atom made physicists question their faith in what they can achieve. Instead, Planck and Bohr went on to discover the quantization of energy and angular momentum, respectively. If today we seem to have reason to question our “sustaining myth”, it ought to be taken as a sign that we are once again making the wrong assumptions, and it ought to spur us on to ferret them out. A retreat from Option A to Option B should be seen for what it is—a cop-out.

Yet it takes only a millisecond’s reflection to realize the naivity of the notion that the world as it is in itself, out of relation to human minds or brains, is just like the phenomenal world—the world as we humans perceive it. The first lesson of science it that appearances are deceptive. On Option A, science peers beyond the phenomenal world at the world as it is in itself. But the notion that the world in itself is just like the world as we humans do (or eventually will) conceive it, seems just as naive. By definition, the world in itself has as little to do with human concepts and theories as it has with human perceptions. The “primary qualities” of Locke are as much products of the human mind as are the “secondary” ones.

In response to this line of reasoning one may point to “the unreasonable effectiveness of mathematics in the natural sciences” as the indicator of a kinship between the human mind and whatever is responsible for the structure of the world in itself. This again may be countered by pointing to our apparent inability to make sense of quantum mechanics (QM) as a sign that we are not all that well equipped mentally. However, these arguments are metaphysical, and of metaphysical arguments we ought to be wary, considering the “unreasonable ineffectiveness of philosophy” in the natural sciences pointed out by Weinberg.

As a matter of fact, these metaphysical arguments are beside the point. The question is not whether the world in itself (assuming there is a way of making sense of this concept) is like the world as we conceive it. The question is not even whether QM compels physicists to forswear their “sustaining myth”. As physicists we are committed to discovering such ways of thinking about what we experience as are consistent with Option A. It is not within our purview to question our “sustaining myth”. The question is not even whether unadulterated QM is...
consistent with Option A. The question is, which way of thinking about unadulterated QM is consistent with Option A? We need to discover whatever deep-seated physical (rather than metaphysical) misconceptions stand in the way of making sense of QM. It is these that we must disavow. To renounce Option A in favor of Option B is overkill.

The literature on measurement theory is so replete with mutually supportive inconsistencies that it is difficult for a critic to know where to begin. D’Espagnat rightly admonishes us to

be cautious when using the notion of ‘state’, which... has questionable metaphysical implications.

He observes that

if...we only worry about predicting what are our chances of observing this or that, and if, correlative, we impart to the word ‘state’ no other meaning than that of designating a mathematical tool allowing for such predictions, we meet with no ambiguities whatsoever.

At the very least this should make one suspect that problems arising when quantum states are taken for more than algorithms for assigning probabilities to the possible results of possible measurements, are pseudo-problems.

That a quantum state is such a probability algorithm is evident from the minimal instrumentalist interpretation of QM, which constitutes the common denominator of all possible interpretations [8]. It is equally evident from Jauch’s definition of the “state” of a quantum-physical system as a probability measure resulting from a preparation of the system and his proof [9]—based on Gleason’s theorem [10]—that every such probability measure has the well-known density-operator form, which reduces to the familiar Born probability measure if the density operator is idempotent. But if a quantum state is a probability algorithm, then it cannot also represent an actual state of affairs. How could it? A probability algorithm is one thing, an actual state of affairs belongs to an altogether different category. This immediately disposes of the “measurement problem” in its crudest form, which treats the state vector as an actual state of affairs with two modes of change, one governed by the Schrödinger equation and another governed by the projection postulate.

What changes in these two ways is a probability measure, and this for reasons that are obvious rather than mysterious. Probabilities are assigned, on the basis of relevant facts, to possible events or states of affairs (indicating possessed properties or values). They depend (i) on the time \( t \) of the events or states of affairs to which they are assigned and (ii) on the facts on which they are based. They can therefore change not only in a “deterministic” manner as functions of \( t \) but also unpredictably with every new relevant fact. The successful completion of a measurement is the relevant fact par excellence. If the outcome of the measurement is unpredictable, as it generally is, it has to be included among the relevant facts on which probability assignments must subsequently be based. The outcome being unpredictable, the basis of relevant facts changes unpredictably as a matter of course, and so do the probabilities that we assign on this basis.

It seems to me that d’Espagnat does not sufficiently heed his own advice to “be cautious when using the notion of ‘state’”. He refers to situations in which the use of ‘realistic’ sentences—invoking the verbs ‘to have’ and ‘to be’—is both harmless and convenient. This is when we know (for sure) beforehand that, if we measured an observable \( B \) on a system \( S \), we would get eigenvalue \( b_k \) of \( B \) as an outcome. In that case we may assert that system \( S \) is in a state described by one of the eigenvectors of \( B \) corresponding to eigenvalue \( b_k \).

We may assert that the state \( \langle b_k \rangle \) is associated with \( S \), provided that all we mean by the ket \( \langle b_k \rangle \) is the Born probability measures it defines. We may not assert that \( \langle b_k \rangle \) describes the system and we may not assert that \( S \) is in a state, for these phrases make no sense when applied to probability measures. Nor can we say that \( B \) has the value \( b_k \). This phraseology may be convenient but it is not by any means harmless. It totally obfuscates the ontological import of QM.

The first thing that needs to be understood about quantum-mechanical probabilities is that they are assigned to conditional statements. If QM assigns probability 1 to \( b_k \) at a time \( t \) then we are allowed to infer that a successful measurement of \( B \) performed at the time \( t \) will or would yield the result \( b_k \). Thus, if \( B \) is or were successfully measured at \( t \) then \( b_k \) will or would be found. The transition from this conditional statement to the blunt assertion that \( B \) has the value \( b_k \) at the time \( t \) is illegitimate because the value of \( t \) is defined by the measurement, as the time at which \( B \) is measured, and is therefore undefined if the measurement is not actually made. Nothing warrants that blunt assertion except a matter of fact about the value of \( B \) at the time \( t \) (that is, an actual event or state of affairs that indicates the value of \( B \) at \( t \)). As I have explained at length in Ref. [9], the (contingent) properties of quantum systems are extrinsic in the specific sense that they cannot be attributed unless they are indicated by facts. No property is a possessed property unless it is an indicated property. A position, in particular, does not exist for \( S \) unless its possession by \( S \) is indicated by an actual event or state of affairs. And the same holds true of the time at which a property is possessed. The time \( t \) does not exist for \( S \) unless it is the indicated time of possession (by \( S \)) of an indicated property [10].
The state vector $|\psi(t)\rangle$, and the probabilities it assigns to the possible results of possible measurements, depend on a time parameter $t$. As long as probability assignments are based on the same set of relevant facts, its “evolution” is governed by the Schrödinger equation (or suchlike). What is the meaning here of “evolution”, and what is the meaning of the parameter $t$? Consider the Born probability $p(R,t)$ of finding a particle in a region $R$ at the time $t$. While few would think of this probability as something that exists inside $R$, many appear to think of it as something that exists at the time $t$. The prevalent idea is that the possibility of finding the particle inside $R$ exists at all times, so the probability associated with this possibility also exists at all times and changes as a function of time. Yet the possibility that a property-indicating event or state of affairs happens or obtains at the time $t$ is not something that exists at the time $t$, anymore than the possibility of finding the particle in $R$ is something that one can find inside $R$. And the same, obviously, holds true of the probabilities associated with these possibilities.

Neither possibilities nor probabilities are things that subsist and change. To think of possibilities or probabilities as if they persisted and changed (“evolved”) in time (continuously and deterministically, as dictated by the Schrödinger equation) is a straightforward category error. It is this logical mistake that gives rise to the somewhat gentler avatar of the “measurement problem” which asks: How is it that during a measurement one of the persisting possibilities (or worse, one of the changing probabilities associated with them) becomes a fact, while the others cease to exist? A silly question, once you come to think of it, because possibilities aren’t things that persist and probabilities aren’t things that evolve. Saying in common language that a possibility becomes a fact is the same as saying that something that is possible—something that can be a fact—actually is a fact. How can that be a problem? This non-problem becomes a pseudo-problem if one forgets that there is only one kind of actuality and misconstrues the common-language “existence” of a possibility as a second kind of actual existence that can be converted into the genuine article by means of a measurement.

Since the probability $p(R,t)$ isn’t something that exists at $t$ (anymore than it is something that exists in $R$), the parameter $t$ isn’t the time at which the probability $p(R,t)$ exists. $p(R,t)$ isn’t a thing of which we can say when it exists. A fortiori it isn’t something that can evolve. Quantum-mechanical probability assignments are conditional on the existence of a matter of fact about the value of a given observable at a given time. $p(R,t)$ isn’t associated with the possibility that all of a sudden, at the time $t$, the particle “materializes” inside $R$. It is the probability with which the particle is found in $R$, given that at the time $t$ it is found in one of a set of mutually disjoint regions (no matter which one, $R$ being one of them). The parameter $t$ on which this probability depends is the time of this actually or counterfactually performed position measurement. It refers to the time of a position-indicating event or state of affairs, without which it is utterly meaningless.

The above quotation—“if... we only worry about predicting what are our chances of observing this or that”—creates the impression that the only choice we have in this regard is between (i) thinking of quantum states exclusively as probability measures and (ii) considering them also as warranting inferences to actual states of affairs (such as the possession of a property by a system), and that if we chose the former, we have nothing else to worry about. While option (i) is, in fact, the only consistent way of thinking about quantum states, nothing could be further from the truth than the conclusion that there is nothing else to worry about. This conclusion is based on an erroneous identification of option (i) with instrumentalism—the view that QM exclusively concerns statistical correlations between measurement outcomes, and that any attempt to go beyond these “brute facts” is idle metaphysics. There remains so much to worry about that we can’t afford wasting time and effort over “solving” pseudo-problems arising from option (ii).

Back to d’Espagnat’s Note:

Similarly, when, as with the example of the stone on the path [or the teapot on the table], we know for sure that if we looked we would have the impression of seeing a certain physical system lying within a given region of space instead of outside it, we are allowed to consider this knowledge as enabling us to make some definite statements concerning the quantum mechanical description of this system. For instance, when the system in question is an electron we are allowed to infer from such a knowledge that the state vector of the electron (or, better to say, of the whole Universe including the electron) is an element of a certain set of vectors.

Once again: There is no such thing as a quantum-mechanical description in the sense intended by d’Espagnat. All we know for sure is the statistical correlations that exist between property-indicating facts (diachronic correlations between the results of measurements performed on the same system at different times, and synchronic correlations between the results of measurements performed on different systems in spacelike separation). The task before us is to draw ontological inferences from these correlations while eschewing an inconsistent mathematical realism that interprets some or all of the mathematical symbols employed by QM as mirroring (representing, describing) the physical world, and that allows inferences from quantum states to possessed properties. If all we know for sure is that a position measurement, if one were successfully performed, would
indicate the presence of an electron in a finite region $R$, we are not allowed to infer that the electron is in $R$. Nor are we allowed to infer (from this knowledge) that a state vector (rather than an “impure” density operator) can be assigned to the electron. Nor is there a way of making sense of the state vector of the universe. The values of quantum-mechanical observables being extrinsic properties, they obviously cannot be attributed to the universe as a whole.

D’Espagnat fails to make due allowance for the difference between mathematical realism (in the sense just defined) and an “objectivistic realism” (to stick to his term) that (i) allows perceptions of teapots to be correlated with the existence of real teapots and (ii) holds that science is in the business of discovering the truth about things in themselves (including teapots). If mathematical realism were the only possible objectivistic realism then Option B would quite arguably be the only way of making sense of QM. But it isn’t.

The key issue is to find a way of thinking about quantum-mechanical correlations that is consistent with the existence of classical behavior at macroscopic scales, and a common way of dodging this issue is to implicate human consciousness or knowledge. This may have started with von Neumann’s principle of psychophysical parallelism, according to which subjective perceptions correspond to objective (neural) processes. As far as I can tell the principle is sound, but it tends to be used in the wrong direction, by arguing from the definiteness of observation reports to some sort of superselection rule. It ought to be used instead to eliminate all references to observations (qua conscious and/or intentional acts). Nothing but confusion is created by dragging the mysterious relation between things and perceptions of things into discussions of QM. This relation has nothing to do with QM, for it exists between mental representations and facts and is anything but statistical, whereas QM concerns the statistical correlations that exist between facts and facts. (The relation between things and perceptions, by its very nature, doesn’t even fall within the purview of the objectivistic paradigm, but precisely because it has nothing to do with QM, it doesn’t follow that QM is inconsistent with Option A.)

D’Espagnat accepts the common point of view according to which

the Schrödinger time evolution leads, for the overall system $S$ composed of $S$ and the pointer...to a state that is a superposition of macroscopically distinct states; a result which is incompatible with Option A.

The Schrödinger equation leads to nothing of this sort. It statistically correlates property-indicating facts (preparations not of systems but of probability measures) with property-indicating facts (measurement outcomes). It governs not the time evolution of a state (in the common-language acceptation of “state”) but the dependence of probability measures on the time span between preparation and measurement. (Note that “preparation” and “measurement” can be exchanged: Diachronic correlations can be used to retrodict as well as predict, just as synchronic correlations can be used to assign probabilities to the possible results of Bob’s measurement on the basis of the result of Alice’s measurement as well as vice versa. Our sense of a directed time “flow” is irrelevant to the interpretation of QM.)

A “superposition of states” is a probability measure expressed in a form in which the probability amplitudes associated with the possible results of a certain measurement are explicit. It entails nothing but the wholly unproblematic common-language “existence” of several possibilities. An inconsistency between “superpositions of states” and the definiteness of observation reports only arises if one commits the category mistake of thinking of possibilities or probability measures as if they were facts or as if they entailed anything factual. Then one has to do some explaining. And the first question that arises is: Are wave function collapses in the mind but not in the world, or in the mind because they are in the world, or in the mind and therefore in the world? There aren’t any wave function collapses, but if one must choose then d’Espagnat’s conclusion appears inescapable: If they are in the mind because they are in the world then “in a way or another the linear nature of the dynamics must be broken”.

I heartily agree with d’Espagnat that none of the schemes that materialize the break is as yet considered, for various reasons, as being fully convincing.

But this isn’t the fault of Option A and it doesn’t entail Option B. None of those schemes is convincing because there isn’t any “break” that needs to be “materialized.” The actualization of a possibility is not a physical process.

If adulterations of QM are rejected, the choice is between (i) only in the mind and (ii) in the mind and therefore in the world. The first option leads to the many-worlds (or many-minds) extravaganza, the latter leads, credibly enough, to Option B. If the premise is that system $S$ enters into a “state of entanglement” with apparatus $A$, then apparatus $A$ enters into a “state of entanglement” with Cecily’s brain as she takes cognizance of the measurement outcome, and then the definiteness of observation reports combined with the principle of psychophysical parallelism spells collapse. Since it would be a bit rich to claim that Cecily’s peep at the pointer causes a collapse “out there” in the real world, divorcing the subject matter of science from the real world “out there” seems the proper thing to do. If science is concerned only with the intersubjective (weakly objective) reality of the “world as we know it” (to use Kant’s phrase), mind-induced collapses make more sense.
But this doesn’t mean that they make sense. A “state of entanglement” is a probability measure just like any old quantum state, except that it gives joint probabilities for the possible results of possible measurements on more systems than one. If a probability measure changes unpredictably, it does so for reasons that are obvious rather than mysterious, as explained above. If anything gets entangled, it is possibilities, and if anything gets correlated, it is probabilities. There isn’t any way of making sense of an actual “state of entanglement”. Option B therefore is just another gratuitous solution to a pseudo-problem. There is nothing wrong with the philosophy behind Option B, except that it is irrelevant.

According to this trend of thought (considered as being the most reasonable one by, perhaps, the majority of contemporary philosophers), the fact that we perceive such “things” as macroscopic objects lying at distinct places is due, partly at least, to the structure of our sensory and intellectual equipment.

True enough but, as I said, beside the point, for the real issue is the ontological import of statistical correlations between facts and facts. The nonstatistical correlations between facts and perceptions have nothing to do with it. (I would also contest the parenthetical claim. Putnam, the erstwhile champion of internal realism, for one, now considers the same philosophy “fatally flawed”.)

I grant d’Espagnat that dictionaries “define” facts in terms that reek of Option B. The Concise Oxford Dictionary (8th edition, 1990) “defines” “fact” as a thing that is known to have occurred, to exist, or to be true; a datum of experience; an item of verified information; a piece of evidence. How else could it be “defined”? “Fact”, like “existence”, like “reality”, is so fundamental a concept that it simply cannot be defined. So what is the editor of a dictionary to do? The obvious thing is to fall back on the metalanguage of epistemology. This shifts the burden of definition to such terms as “experience” or “knowledge”. Let’s look them up: Experience is an “act of experience of or practical acquaintance with facts or events”. Knowledge is “awareness or familiarity gained by experience (of a person, fact, or thing)” (italics supplied). Which shows, if anything, that such terms as “experience” or “knowledge” cannot be invoked to give meaning to the word “fact”.

If “fact” is so fundamental a term that it cannot be defined, the existence of facts—the factuality of events or states of affairs—cannot be accounted for, any more than we can explain why there is anything at all, rather than nothing. (If something can be accounted for, it can be defined in terms of whatever accounts for it.) Before the mystery of existence—the existence of facts—we are left with nothing but sheer dumbfoundment. In spite of this, measurement theorists are busy trying to explain the emergence of facts (a.k.a. “classicality”). The apparent need for this wholly gratuitous endeavor arises if one thinks of the possibilities to which QM refers, and/or of the probabilities it assigns to them, as if they constituted a self-existent matrix from which facts emerge—another category error due to taking the quantum state for more than a probability measure on the possible results of possible measurements.

Classical physics deals with nomologically possible worlds (that is, worlds consistent with physical theory). The question as to which of these worlds is real (agrees with the actual world) is of historical rather than scientific interest. Giving an answer to this question is strictly a matter of observation. Does this imply that classical physics makes sense only within a theory of science committed to Option B? Obviously not. In classical physics the actual course of events is in principle fully determined by the actual initial conditions (or the actual initial and final conditions). In quantum physics it also depends on unpredictable actual events at later (or intermediate) times. Hence picking out the actual world from all nomologically possible worlds requires observation not only of the actual initial conditions (or the actual initial and final conditions) but also of those unpredictable actual events. Does this imply that quantum physics makes sense only within a theory of science committed to Option B? If the answer is negative for classical physics, it is equally negative for quantum physics.

QM concerns statistical correlations between facts, and the correlations warrant interpreting the facts as indicative of properties. That is, they warrant the existence of a physical system or systems to which the indicated properties can be attributed. Suppose that we perform a series of position measurements, and that every position measurement yields exactly one result (that is, each time exactly one detector clicks). Then we are entitled to infer the existence of an entity that persists through time (if not for all time), to think of the clicks given off by the detectors as matters of fact about the successive positions of this entity, to think of the behavior of the detectors as position measurements, and to think of the detectors as detectors. If instead each time exactly two detectors click, we are entitled to infer the existence of two entities or, rather, of a physical system with the property of having two components. This property is as extrinsic as are the measured positions. There is a determinate number of entities only because every time the same number of detectors click. Not only the properties of things but also the number of existing things supervenes on the facts.

This ontological dependence of the properties and the number of things on facts warrants the distinction between two domains, a “classical domain” of facts and a “quantum domain” of properties that exist only because they are indicated (by facts). The impossibility of attributing to the properties of the quantum domain an intrinsic existence (or, equivalently, the necessity of attributing their existence to the classical domain) com-
bined with the apparent impossibility of understanding the relation between the two domains within the objectivist paradigm, is the reason behind the frequent invocation of consciousness in general and of Option B in particular. If (i) the real world is the quantum domain, and if (ii) the properties of the quantum domain depend on the classical domain, and if (iii) the classical domain can be neither defined nor accounted for by the quantum domain, then the conclusion that the classical domain is grounded in human experience is inescapable.

The second antecedent is certain. QM presupposes facts from beginning to end—from the preparation of a probability measure to a measurement. If the first antecedent is accepted, the third means that the classical domain isn’t part of the real world, and this leads to the conclusion that the classical domain is “in the mind”. On this view saying that the properties of the quantum domain exist only because they are indicated by what happens or is the case in the classical domain, is the same as saying that the properties of the world exist only because they are perceived—esse est percipere aut percipi. But the real world isn’t the quantum domain. The real world is the classical domain plus whatever properties of the quantum domain can be inferred from the goings-on in the classical domain. The third antecedent remains true, inasmuch as the properties of the quantum domain are defined and accounted for by the properties of the classical domain rather than vice versa. But it doesn’t mean that the classical domain isn’t part of the real world. And therefore it doesn’t follow that the classical domain is “in the mind”.

2 STRONGLY OBJECTIVE ONE-WORLD INTERPRETATION OF LINEAR QM

So much for pseudo-problems and some of their gratuitous solutions. Before addressing some real problems I would like to express my deep and abiding admiration for the work of Professor d’Espagnat, whose numerous books and articles (e.g., [18] [19] [20] [21] [22] [23] [24]) demonstrate conclusively that no interpretation of QM that takes the quantum state for more than a probability measure is consistent with Option A. It is not the intention of this Comment to belittle that outstanding achievement.

According to Feynman, the mother of all quantum effects is the two-slit experiment with electrons [25]. If nothing indicates the slit taken by an electron then the electron goes through both slits without going through a particular slit and without having parts that go through different slits. How can this be? That’s what I call a problem. To my way of thinking, the origin of the problem is a mismatch between the spatial aspect of the world and the way we all tend to think about it. Ask yourself how you think about the empty regions L and R inside the two slits. No doubt you will consider them different, separate, distinct. Yet if they were distinct then either the electron would go through a particular slit or it would be divided into parts by its passage through both slits. Hence if nothing indicates the slit taken by the electron then those regions can’t be distinct for the electron, and so they can’t be distinct per se. That’s what baffles us.

But think again. How are L and R different? You may say, well, they are in different places; they have different positions. So where are these different places? Your answers will have the following form: “L is at/inside L” and “R is at/inside R”, where L and R are shorthand notations for whatever you say the positions of L and R are. So where is L—the position of L or the region containing L? It is clear that you are poised for an infinite regress. Your answer will have the form: “L is at/inside L”, where L is short for whatever position you attribute to L, and so on.

The root of the problem is that we keep switching between two inconsistent modes of thinking. If we say “L is at/inside L”, we treat L as a property (namely, the position of L) and we treat L as a thing that has a property (namely, the position L). If we then ask “Where is L?”, we treat L as a thing to which a position can be attributed. But we can’t have it both ways. Either L is a thing to which properties (such as a position) can be attributed, or L is a position—a property—that can be attributed to things.

Hence our problem actually has an easy solution: Stop thinking of positions and regions of space as if they were things. L and R are properties that may or may not be possessed. L—that is, the property of being inside L—is possessed just in case there is a thing T inside L—a thing that has the property L. We tend to think that saying (i) “L is inside T” is different from saying (ii) “T has the property L” because proposition (i) seems to imply that L is a thing that contains T. But this is where we are wrong. It is logically inconsistent to think of properties as if they were things. L is not a thing, and proposition (i) says exactly what proposition (ii) is saying.

Once we stop thinking of positions and regions as if they were things, we are no longer bothered by the behavior of electrons in two-slit experiments. If an electron goes (as a whole) through both slits, neither L nor R is attributable to it, nor does it have parts to which L and R are separately attributable. What is attributable to the electron is L ∪ R, and since this is not a thing that has L and R for its parts but a property, there is no reason in the world why the possession of the property L ∪ R should entail the possession of L, the possession of R, or the existence of parts possessing the respective properties L and R—no reason other than the fallacy of thinking of space as if it were a thing that has parts. The behavior of electrons in two-slit experiments forces us to acknowledge a fallacy we have previously committed with impunity because the world of classical physics
was consistent with it.

Once we commit this fallacy we end up thinking that any finite region of space has infinitely many distinct parts, and if we insist on thinking of all parts of space as self-existent and intrinsically distinct, we end up with the substantive, set-theoretic conception of space as a manifold of intrinsically distinct point individuals (usually considered in one-to-one correspondence with triplets of real numbers and denoted by \( \mathbb{R}^3 \)). I am not advocating that we should stop using \( \mathbb{R}^3 \) as a mathematical tool. But we must recognize it for what it is. We must learn to think of the elements of \( \mathbb{R}^3 \) not as things that have positions but as positions that things may have. A “coordinate point” \( \mathcal{P} \) and “its position” are the same animal. \( \mathcal{P} \) is a position and therefore it does not have a position. Only material objects have positions, and only those positions that are actually possessed exist, and only those positions that are indicated (by facts) are actually possessed. The others exist solely in our imagination. It is therefore necessary to make a clear distinction between the set \( \mathbb{R}^3 \) of all (exact) positions that a material object may have, and the spatial aspect of the world—the positions that are actually possessed by material objects. It won’t do to regard \( \mathbb{R}^3 \) itself as adequately representing the spatial aspect of the world.

Since no position is possessed unless it is indicated, and since nothing ever indicates an exact position, nothing ever has an exact position. A position measurement can never distinguish between more than a finite number of finite regions, and this is why attributable positions are always finite regions like \( L \) and \( R \). If we further take into account that in order to specify the position of an object we must say where it is in relation to another object that serves as a reference point, we arrive at the conclusion that space—the spatial aspect of the world—is the totality of relative positions (or spatial relations) that exist between material objects. This has a number of surprising consequences—surprising because they are at odds with our deep-seated misconceptions about the nature of space. For one, there is no such thing as “empty space”. If there are no objects, there are no spatial relations, and hence there is no space. A world without objects is a spaceless world. For another, there is no such thing as “the form of an electron”.

What is clear right away is that if an object without parts—a fundamental particle like the electron—had a form then this could only be the form of a point. If it had any other form, it would have parts. Now try to imagine a single pointlike object. As you imagine a pointlike object, you also imagine a spatial expanse in which this object is situated. You cannot imagine a point without imagining a space that surrounds or contains it. A point is a form, and the existence of a form implies the existence of space. But you are asked to imagine a single pointlike object—not any other thing, nor any of this object’s relations to other things. Therefore you must not imagine its external spatial relations. (The external spatial relations of an object \( O \) are those between \( O \) and objects that have no parts in common with \( O \).) And since a pointlike object lacks parts and therefore lacks internal spatial relations, your mental picture must not contain any spatial relations. And since space consists of spatial relations, your mental picture must not contain space. And since the existence of a form implies the existence of space, your mental picture must not contain any form. The upshot is that the existence of a pointlike form is inconsistent with the proper way of thinking about space—as a set of spatial relations. A fundamental particle like the electron therefore is a formless entity.

A possible way of giving QM in a nutshell is to say that there are limits to the objective reality of our conceptual distinctions. If an electron as a whole goes through both slits then the distinction we make between “The electron goes through \( L \)” and “The electron goes through \( R \)” is a distinction that Nature does not make; it corresponds to nothing in the world; it exists solely in our heads. Here we are talking about spatial distinctions, but the same is true of our substantial distinctions. What the two-slit experiment is to spatial distinctions, a two-particle collision is to substantial distinctions. Suppose that initially we have two incoming particles, one heading northward and one heading southward, and that after the collision we have two outgoing particles, one heading eastward and one heading westward. QM tells us in unmistakable terms that if the particles are of the same type (and their spins are not antiparallel) then the outgoing particle heading eastward is neither the same as nor different from either of the incoming particles. The distinction between “\( E \) is identical with \( N \)” and “\( E \) is identical with \( S \)” (where \( E \) stands for the outgoing particle heading eastward and \( N \) and \( S \) stand for the incoming particles) is another distinction that Nature does not make; it corresponds to nothing in the world; it exists solely in our heads.

If we try to think of the properties that a fundamental particle possesses “by itself”, out of relation to other things, we find that there aren’t any. The properties of a fundamental particle are either relational (like positions or momenta) or dynamical (characteristic of their interactions, like charges) or comparative (like mass ratios—the mass of a single particle has no physical significance). Can we nevertheless say that two fundamental particles, considered in themselves (and therefore out of relation to each other) are distinct? Can we say that they are two? According to the Identity of Indiscernibles, a principle of analytic ontology which says that two things cannot have exactly the same properties, the “two particles” considered in themselves are two things only if they possess the property which philosophers call “thisness” or “haecceity”. But the possession of this property implies that the two particles in our collision experiment are re-identifiable, and QM makes it abundantly clear that they are not re-identifiable. Hence if two fundamental parti-
cles are considered in themselves they cease to be two. They become identical not just in the weak sense of exact similarity but in the strong sense of **numerical identity**.

Then what is this one and the same thing \( X \) that every fundamental particle intrinsically is? Since considered in itself, out of relation to other things, a fundamental particle has no properties, all we can say of an (existing) fundamental particle **in itself** is that it **exists**. Hence that which every fundamental particle intrinsically is, is **existence pure and simple**. Let us call it “Existence” with an upper-case \( E \).

How is Existence related to space? Space contains— in the proper, set-theoretic sense of “containment”— the forms of all things that have forms. It does not contain material objects over and above their forms; a fortiori it does not contain the formless “constituents” of matter. Space exists **between** the fundamental particles; it is spanned by their spatial relations. And since what exists at either end of each spatial relation is Existence, spatial relations are **internal** to Existence. QM tells us that the physical world is both constituted by Existence and suspended within it.

Ontologies tend to be modeled after the grammatical relation between a subject and a predicate, and matter tends to be identified with the ultimate subject—that which is the same in things with different properties, the grammatical subject by itself, bereft of predicates. But matter also tends to be thought of as that which is different in things with the same properties. We ordinarily proceed on the implicit assumption that identical things come equipped with “thisness”, and for this property only matter itself can be responsible. This way of thinking is at the roots of the Platonic-Aristotelian dualism of Matter and Form and its subsequent transformations, including the preposterous field-theoretic notion that physical properties are instantiated by the “points of space” [20].

The nonexistence of “thisness” forces us to look upon Existence, rather than upon the fundamental particles, as the ontological equivalent of the grammatical subject. The One is logically and ontologically prior to the Many, which come into being when formless Existence enters into spatial relations with itself and acquires, as a consequence, the aspect of a multiplicity of formless particles. Along with the particles, space and forms come into being, for space is the totality of existing spatial relations (between Existence and Existence) and forms are particular sets of such relations.

The relations are logically and ontologically prior to the relata—the fundamental particles. We are prone to hold the opposite view—that spatial relations are supported by a self-existent multiplicity. In reality the multiplicity is supported by relations, which are supported by Existence, which is one. QM describes a world that is created top-down, by a process of differentiation, rather than bottom-up, by a process of aggregation. (Saying that QM describes the world is very different from saying that some or all of the mathematical symbols of QM describe the world. It takes a considerable amount of thought to get from probability measures to their ontological import.)

The world is differentiated both spacewise (spatial relations warrant distinctions between “here” and “there”) and timewise (temporal relations warrant distinctions between “now” and “then”). The temporal differentiation is effected by **change**, for time and change are coinherents: A timeless world cannot change, and a changeless world is temporally undifferentiated and therefore timeless. To my way of thinking, the quintessential message of QM is that there are limits to the world’s spatial and temporal differentiation. The world is only finitely differentiated. In an infinitely differentiated world, spatial relations are indeterminate quantities; they possess definite values. In a finitely differentiated world, spatial relations are indeterminate quantities; they possess fuzzy values, and so do temporal relations [27]. The proper conceptualization of indefiniteness requires the use of statistical concepts, and this is why QM is formally a statistical theory.

The proper way of dealing with fuzzy quantities is to make counterfactual probability assignments [1]. If a quantity is said to have an “indefinite value” what is really intended is that it would possess a value if it were successfully measured, and that at least two possible values have positive probabilities of being found. (The counterfactuality cannot be eliminated but it may be shifted from measurements to fuzzy values: If a measurement of observable \( Q \) is successfully performed on an ensemble of identically prepared systems and the results have positive dispersion, the value of \( Q \) would be fuzzy for an individual system \( S \) if the measurement were not performed on \( S \).)

So how do we get from fuzzy values or counterfactual statements to unconditional statements of value-indicating facts? No property is a possessed property unless it is an indicated property. This seems to entail a vicious regress, which at first blush looks like just another version of von Neumann’s “catastrophe of infinite regression”. The positions of detectors are extrinsic, too. They are what they are only because of the facts that indicate what they are. This requires the existence of detector detectors indicating the positions of particle detectors, which requires the existence of detectors indicating the positions of detector detectors, and so on ad infinitum. Generally speaking, the (contingent) properties of things “dangle” ontologically from what happens or is the case in the rest of the world. Yet what happens or is the case there can only be described by describing material objects, and their properties too “dangle” from the goings-on in the rest of the world. This seems to send us chasing the ultimate property-indicating facts in never-ending circles. Somewhere the buck must stop if the ontological story unfolding in this section is to be a viable interpretation of QM.
To begin with, the following points should be kept in mind. First, although the teapot isn’t only there when somebody looks, it is there only because of the myriad of facts that betoken its presence. If there weren’t any actual event or state of affairs from which its position could be inferred, it wouldn’t have a position, or else its position wouldn’t have a value. (There is no need for a conscious observer to actually carry out the inference.)

Second, as it stands the problem is still ill posed, for we do not proceed from counterfactuals to unconditional statements, nor do we start with valueless positions in search of value-indicating facts. We proceed from facts and the statistical correlations obtaining among them. These correlations warrant (i) inferences to the existence of objects with kinematical properties that have fuzzy values and (ii) the interpretation of the statistically correlated facts as indicating possessed values.

Third, the “measurements” to which both the minimal instrumentalist interpretation of QM and Jauch’s definition of “state” refer, are not confined to manipulations that are intended to determine the value of a given observable or that lead to the acquisition of knowledge. The sufficient condition for a measurement is an actual event or state of affairs that warrants the assertability of a statement of the form “S has property p at time t”, irrespective of whether anyone is around to assert, or take cognizance of, that event or state of affairs, and irrespective of whether it has been anyone’s intention to learn something about S. Bohr insisted that quantum systems should not be thought of as possessing properties independently of experimental arrangements [29]. His insistence on the necessity of describing quantum phenomena in terms of experimental arrangements [30, 31] does not mean that quantum phenomena require the existence of experimental physicists. For “experimental arrangement” read: the totality of property-indicating facts. Any matter of fact that “is about” (has a bearing on) the properties of a physical system, qualifies as a measurement result.

Fourth, the extrinsic nature of the contingent properties of physical systems follows from the fuzziness of their values, inasmuch as this requires the use of counterfactual probability assignments [14]. The use of conditionals with false antecedents would be gratuitous if the antecedents were never true, for in this case the conditionals could not be tested. But, in fact, the conditionals are abundantly tested, for they express the statistical correlations among facts that QM is concerned with, and no experiment or observation has ever given the lie to QM. This warrants the counterfactual use of the correlations (that is, it warrants the assignment of probabilities to the possible results of unperformed measurements), and this is the formal expression of indefiniteness. But if the antecedents of conditional probability assignments can be false as well as true, there has to be a criterion for when they are true, and this consists in the existence of value-indicating facts.

Value-indicating facts are actual events or states of affairs. Events are changes in the properties of objects; states of affairs concern the properties of objects. These properties are extrinsic; their possession is not factual per se. Yet facts are per definition factual per se. The task of resolving this apparent paradox is the genuine core of the “measurement problem”.

The positional indefiniteness of an object O finds expression in the unpredictability of the results of position measurements performed on O. Evidence of the indefiniteness of O’s position, or of the corresponding statistical dispersion, requires the existence of detectors with sensitive regions that are small and localized enough to probe the range of values over which O’s position is distributed. (A detector is any object capable of indicating the presence of another object in a particular region of space.) The indefiniteness of O’s position cannot evince itself through statistically distributed position-indicating events if there are no detectors with sharper positions and with sensitive regions that are smaller than the space over which O’s position is distributed. But detectors with sharper positions and sufficiently small sensitive regions cannot exist for all detectable objects. There is a finite limit to the sharpness of the positions of material objects, and there is a finite limit to the spatial resolution of actually existing detectors. Hence there are objects whose positions are the sharpest in existence. These never evince their indefiniteness through unpredictable position-indicating events. Such objects are entitled to be called “macroscopic”. We cannot be certain that a given object qualifies as macroscopic, inasmuch as not all matters of fact about its whereabouts are accessible to us, but we can be certain that macroscopic objects exist.

If the positional indefiniteness of a macroscopic object never evinces itself through unpredictable position-indicating events—the occasional unpredictability of the position of a macroscopic pointer reveals the indefiniteness of a property of another object, not the indefiniteness of the position of the pointer—then it is legitimate to ignore the positional indefiniteness of macroscopic objects. And if it is legitimate to ignore this—not only for all practical purposes but strictly—then it is legitimate to treat the positions of macroscopic objects as intrinsic.

The step from acknowledging the extrinsic nature of all contingent properties to treating the positions of macroscopic objects as intrinsic is of the same nature as the step from acknowledging the purely correlative character of classical laws of motion to the use of causal language. According to Hume [12], causality is in the eye of the beholder; it is our way of interpreting events, not a feature of the events in themselves. QM has proved him absolutely right. Macroscopic objects evolve predictably in the sense that every time the position of such an object is indicated, its value is consistent with all predictions made on the basis of (i) all past indicated properties and
(ii) the classical laws of motion. (As mentioned above, there is one exception: Whenever the position of such an object serves to indicate an unpredictable property of the quantum domain, it is itself not predictable.) This makes it possible to think of the positions of macroscopic objects as forming a self-contained system of positions that “dangle” causally from each other, and this makes it possible to disregard that in reality they “dangle” ontologically from (supervene on) position-indicating facts. The possibility of using causal concepts in the classical domain implies the possibility of treating the properties of the classical domain as intrinsic.

While correlations that are not manifestly indeterministic (like those between the successive positions of a macroscopic object) can be embellished with causal stories, in the quantum domain causal concepts are entirely out of place. Causality is a function of psychology, not of physics. It is rooted in our self-perception as agents in a successively experienced world. We can impose it on the classical domain with some measure of consistency, although this entails the use of a wrong criterion: Temporal precedence takes the place of causal independence as the criterion which distinguishes the cause from the effect. But when we deal with correlations that are manifestly indeterministic, projecting our agent causality into the physical world no longer works. Trying to causally explain these correlations is putting the cart in front of the horse. It is the statistical correlations that explain why causal explanations work to the extent they do. They work in the classical domain where statistical variations are not in evidence. In this domain we are free to use language suggestive of nomological necessity. But if we go beyond this domain, we realize that all correlations are essentially statistical, even where statistical variations are not in evidence, and that our belief in nomological necessity is just that—a belief.

By the same token, the possibility of treating the positions of macroscopic objects as intrinsic does not mean that they are intrinsic. The world is spatially differentiated to the extent that the values of spatial relations are indicated by facts, and facts never indicate numerically precise values. Even the positions of macroscopic objects are fuzzy; therefore even they are extrinsic. Yet their fuzziness exists only in relation to a backdrop that is more differentiated spatially than is the actual world, a backdrop that exists only in our imagination. Space—so we must keep reminding ourselves—isn’t an intrinsically and infinite differentiated container of objects. It is a set of more or less fuzzy relations. Some of these relations—those that obtain between macroscopic objects—are the sharpest in existence, and these are not fuzzy in any real sense; they are fuzzy only in relation to an unrealized degree of spatial differentiation. Facts that are indicative of the positions of macroscopic objects are correlated in such a way (viz., predictably) that any reference to them is superfluous: We can think of these positions as intrinsic and as evolving deterministically, and this for all quantitative purposes rather than merely for all “practical” ones. The positions of macroscopic detectors are not truly sharp, but as they are the sharpest in existence we may treat them as sharp, as intrinsic, and hence as per se available as possible properties of (things in) the quantum domain.

Recall that attributing factuality (whether to a nomologically possible world or to a measurement outcome) is beyond the scope of any theory. When the theory has done its part, we are left with the problem of attributing factuality. And this problem has exactly one consistent solution. The unaccountable factuality of facts belongs to those properties which can be treated as intrinsic because their indefiniteness exists solely in our heads.

3 REALITY VEILED AND UNVEILED

Bohr felt that our interpretational difficulties “hardly allow us to hope that we shall be able, within the world of the atom, to carry through a description in space and time that corresponds to our ordinary sensory perceptions” [34]. While this is past the shadow of a doubt, Stapp’s conclusion that “space,’ like color, lies in the mind of the beholder” [35] is a non sequitur. This would follow if a spatiotemporal description corresponding to our sensory perceptions were the only possible description. But, as the previous section has shown, an entirely different account of the spatiotemporal aspect of the world is (i) possible and (ii) consistent with both standard QM and Option A.

There is mounting evidence from neuroscience that visual perception and visual imagination share the same processing mechanisms [36, 37, 38]. Hence as long as we insist that science (which is in the business of constructing theories or conceptual models of the world) provide us with a model that can be visualized, we limit its scope by the very brain mechanisms that are instrumental in the construction of the phenomenal world—the world as we humans perceive it. This is precisely what Option B does. D’Espagnat seems to think that such a limit to the scope of scientific inquiry is unavoidable, and he tries to make a virtue of this perceived necessity.

I have here in mind a viewpoint that would be totally faithful to the...scientific ideal of keeping to what seems unquestionable within collective human experience, namely the impressions we share, without any admixture of presupposed ideas concerning the actual existence of the forms thus perceived...

The way in which the brain processes visual information guarantees that the result—the phenomenal world or “the impressions we share”—is a world of objects that
are bounded by surfaces. The phenomenal world conforms to the “cookie cutter paradigm” (CCP) according to which the world’s synchronic multiplicity rests on surfaces that carve up space in the manner of three-dimensional cookie cutters: The parts of any material object are defined by the parts of the space it “occupies”, and the parts of space are defined by delimiting and separating surfaces. This seems self-evident because this is how we perceive the world because this is how the brain analyses visual information.

As long as we take the parts of matter to be defined by the parts of space, the parts of space are logically prior to the parts of matter; hence they exist independently of matter; hence space is a thing that has parts. Another, probably similarly hard-wired misconception is that parts exist by themselves (rather than by virtue of some process of division or differentiation) or that multiplicity (rather than One Existence) is fundamental. Combining these misconceptions leads to the idea that all (conceivable) parts of space exist by themselves and to the concept of space as a manifold of intrinsically distinct point individuals.

If the world were created along the lines laid down by the CCP, the shapes of things would be bounding surfaces, and matter would be an extended stuff bounded by surfaces. A material object would have as many parts as the space it occupies, and an object without parts—a particle like the electron—would be a bit of stuff with the form of a point. Extended material objects would always occupy distinct parts of space, and the positions of pointlike objects would always be distinct. Material objects would be re-identifiable since at every time there would be a fact of the matter concerning which is which.

If we subscribe to the “scientific ideal of keeping to . . . the impressions we share”, we remain committed to the CCP, and this, clearly, leads us up the garden path. It implies the substantive conception of space as a manifold of intrinsically distinct point individuals while QM tells us that space is a set of relations between material objects. It implies that the shapes of things are points or bounding surfaces while QM tells us they are sets of spatial relations. It implies that electrons are pointlike while QM tells us they are formless. It implies that particles are re-identifiable while QM tells us they are not. It further implies that the world is infinitely differentiated spacewise and timewise while QM tells us that it is only finitely differentiated; that spatial relations are determinate quantities while QM tells us they are fuzzy; that the world is created bottom-up by aggregation while QM tells us it is created top-down by differentiation.

The upshot is that QM is inconsistent with Option B. Option B commits us to the CCP, and every one of the implications of the CCP directly contradicts what QM is trying to tell us. D’Espagnat concludes that we must either accept breaks in the linear evolution of quantum states or grant that man-independent reality . . . is something more “remote from anything ordinary human experience has access to” than most scientists were up to now prepared to believe . . .

I fully agree with this conclusion. The world according to QM, as outlined in Sec. 2, is more remote from anything ordinary human experience has access to than most scientists were up to now prepared to believe. But this does not mean that we cannot understand it. I entirely disagree with his claim that

while, through physics, Being informs us quite definitely of what it is not . . . it seems reluctant at letting us know what it truly is.

Nothing could be further from the truth. Reality does not veil itself. It is who veil it, by clinging to (i) concepts of space, time, form, and substance that are inapplicable to the physical world and (ii) pseudo-realistic ways of thinking about probability measures. Once these misconceptions are replaced by adequate ways of thinking, everything is above board. Nothing remains mysterious, except the mother of all mysteries—why there is anything at all, rather than nothing. As Wittgenstein said in the Tractatus Logico-Philosophicus: “Not how the world is, is the mystical, but that it is.” QM refers to this mystery twice: when it presupposes the unaccountable factuality of facts, and when it tells us that intrinsically each fundamental particle is existence pure and simple. These aperçu of “bare reality” play distinct ontological rôles. While the factuality of facts is the ultimate reason why there are properties, Existence is the ultimate reason why there are things that have properties.

References and Notes

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And so it isn’t something that takes (place in) time. The actualization of a possibility “during” a measurement is not a transition from a state of affairs in which the possibility “exists” as possibility to a state of affairs in which it is realized. The possibilities with which QM is concerned are of the form: “A measurement of the observable Q performed at the time t yields the result qk.” Because of its explicit reference to the time of the measurement, such a sentence cannot become true or false. If it is true, it always has been and always will be true, and if it is false, it always has been and always will be false. To say that the possibility expressed by this sentence is realized is to say nothing more than that this sentence is true. Then when did the realization take place? A meaningless question.

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In a world that is infinitely differentiated spacewise, all objects have exact positions. In such a world a moving object passes through infinitely many distinct (actual) states in any finite time span. Hence such a world is infinitely differentiated timewise. In a world that is only finitely differentiated spacewise, no object passes through infinitely many distinct actual states in a finite time span. Hence such a world is only finitely differentiated timewise.

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D’Espagnat considers it uncertain “that, independently of ourselves, macroscopic objects exist ‘out there’ as we see them (with precise locations and so
on). Does he really think that we see macroscopic objects with precise locations?

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